



SmartSoft AES **Operator's Guide**

Part No. 700650 Rev. A

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ULVAC-PHI Safety Notices

ULVAC-PHI's (PHI's) products are designed and manufactured in compliance with accepted worldwide practices and standards to provide protection against electrical and mechanical hazards for the operator and the area surrounding the product. All ULVAC-PHI products are designed and intended for professional use only, by skilled "operators" for their intended purpose and according to all of the instructions, safety notices, and warnings provided by ULVAC-PHI.

Those instructions, notices, and warnings assume that an "operator" will not employ any tool when using ULVAC-PHI products. They further assume that all operators clearly understand that use of ULVAC-PHI products in any manner not specified by PHI may impair the protection provided by the products and expose them to hazards.

A "technician" is a qualified servicing individual who:

- Has received training to work with voltages above 50 V,
- Has read and understood the ULVAC-PHI technician's manual for the equipment,
- Observes and understands all safety notices on ULVAC-PHI equipment.

The safety symbols that PHI uses are defined on the following page.* To reduce or eliminate hazards, technicians and operators of this equipment must fully understand these symbols.

ULVAC-PHI's products are installed with international-style or ANSI†-style safety notices, according to site requirements. International notices are symbols within triangles (alerts) or circles (mandatory actions). ULVAC-PHI's ANSI-style safety notices contain:

- One of three signal words (in all capitals) preceded by the general danger symbol ();
- One of ULVAC-PHI's safety symbols along with a brief description of the hazard and the risk or injury that could occur;
- Short message that observes ANSI's Hazard Alert Trilogy Rule by identifying the hazard, the possible result of ignoring the notice, and how to avoid the hazard.

The three signal words are defined as follows:

- **DANGER**—imminently hazardous situation that, if not avoided, will result in death or serious injury;
- **WARNING**—potentially hazardous situation that, if not

avoided, could result in death or serious injury;

- **CAUTION**—potentially hazardous situation or unsafe practice that, if not avoided, may result in minor or moderate injury or damage to equipment.

SEMI‡ standards require identification of type 3, 4, and 5 electrical maintenance tasks in equipment manuals:

- **Type 3** electrical maintenance tasks involve energized equipment, exposed live circuits, and possible accidental contact; potential exposures are less than 30 V RMS, 42.2 V peak, 240 V-A, and 20 J.
- **Type 4** is the same but potential exposures are greater than 30 V RMS, 42.2 V peak, 240 V-A, and 20 J or radio frequency is present.
- **Type 5** tasks involve energized equipment and measurements and adjustment require physical entry into the equipment, or equipment configuration will not allow the use of clamp-on probes.

Only experienced, trained technicians should attempt to perform type 3, 4, or 5 electrical maintenance tasks.

* Many of ULVAC-PHI's safety symbols are provided and copyrighted by Hazard Communication Systems, Inc., Milford, PA.

* American National Standards Institute, 1430 Broadway, New York, NY 10018.

‡ Semiconductor Equipment and Materials International, 805 E. Middlefield Rd., Mountain View, CA 94043-4080.



Voltages may be present that could cause death or personal injury.



A risk of death, personal injury, and/or damage to equipment exists (and a more specific label is not available).



Pulling the plug from its power source before servicing is mandatory.



A pinching point is present that could cause personal injury.



A risk of explosion or implosion may be present that could cause personal injury.



Lifting with assistance or equipment could cause personal injury.



An overhead door is present that could cause personal injury. Do not work under door without auxiliary door supports installed.



Visible or invisible radiation may be present that could cause personal injury.



Hot surfaces may be present that could cause personal injury.



Turning off the power switch before servicing is mandatory.



Refer to the manual(s) before proceeding.



Contents are under pressure.



A harmful or irritant material may be present that could cause personal injury.



Extremely low temperatures may be present that could cause personal injury.



A risk of fire may be present that could cause personal injury.



A potentially dangerous magnetic field may be present.



An environment with depleted oxygen may be present that could cause death or personal injury. Open at least 2 doors and wait 2 minutes before entering the enclosure.



Wearing protective gloves is mandatory.



Wearing eye protection is mandatory.



Wearing foot protection is mandatory.



This is the location of the protective grounding conductor terminal.



This is the location of the fuse.



This is the location of an earth (ground) terminal.

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LIMITED WARRANTY

Basic Warranty

Except as otherwise provided herein, the Seller warrants to Buyer that the equipment sold hereunder, is new equipment and is, at the time of shipment to Buyer from Seller, free from defects in material and workmanship. As Buyer's sole exclusive remedy under this warranty Seller agrees either to repair or replace, at Sellers sole option and free of part charge to Buyer, any part or parts of such equipment which, under proper and normal conditions of use prove to be defective within twelve (12) months from the date of receipt by the Buyer. Warranty period for equipment requiring installation by Seller will commence on completion of standard installation services. If, customer delays installation beyond forty-five (45) days after delivery, the warranty period will commence to run forty-five (45) days after delivery. Seller reserves the right, at it's own discretion, to perform preventative maintenance services including but not limited to realignment, readjustment, recleaning, or recalibration during said warranty period.

Exclusions and Limitations

It is recognized that some parts by their nature (expendable items), may not function one year; therefore, excluded from the foregoing warranty are filaments, anodes, cathodes, multipliers, retard grids, special ceramics, ionizers, along with other such parts mentioned in the applicable operating manual.

The foregoing warranty excludes certain major items or accessories specifically indicated on applicable price lists or quotations, as to which Seller passes to the Buyer whatever warranty is provided to Seller by the manufacturer or the specific warranty indicated by the price list or quotation.

This warranty does not cover loss, damage, or defects resulting from transportation to the Buyer's facility, improper or inadequate maintenance by Buyer, buyer-supplied software or interfacing, unauthorized modification or misuse, operation outside of the environmental specifications for the equipment or improper site preparation and maintenance.

Limited Warranty

Product Services

All claims must be brought to attention of Seller within thirty (30) days of the failure to perform.

Seller at his option may require the product to be returned to the factory, transportation prepaid for repair.

Refund of Purchase Price

In lieu of the foregoing, Seller may at anytime elect, in its sole discretion, to discharge its warranty by accepting the return of such equipment and refunding any portion of the purchase price paid by Buyer.

Software and Firmware Products

The sole exclusive warranty applicable to software and firmware products provided by Seller for use with a processor will be as follows: Seller warrants that such software and firmware will conform to Seller's program manuals current at the time of shipment to Buyer when properly installed on that processor. Seller does not warranty that the operation of the processor software or firmware will be uninterrupted or error-free.

NO OTHER WARRANTY IS EXPRESSED OR IMPLIED. SELLER EXPRESSLY DISCLAIMS THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.

SMART-Tool™ System Safety Hazards and Precautions

This section describes the safety hazards and precautions related to the standard *SMART-Tool™ System*.* The information is presented as follows:

- Manufacturer Identification
- Hazard Alerts
- Hazards Inherent in System
- Hazards Inherent in Tasks
- Lockout Device
- Material Safety Data Sheets (MSDSs)
- Personal Protective Equipment (PPE)
- Training Requirements
- Ergonomic Adjustments
- Hardware Safety Interlocks

ATTENTION: Operators of the SMART-Tool are not to perform maintenance on the system. Installation and maintenance of the SMART-Tool system are intended to be performed by PHI Customer Service Engineers.

Manufacturer Identification

The *SMART-Tool* system is manufactured by Physical Electronics, Inc., in Chanhassen, Minnesota, USA. In case of equipment failure, contact PHI Customer Service as follows:

By mail:

Physical Electronics, Inc.
PHI Customer Service
18725 Lake Drive East
Chanhassen, MN 55317-9384 USA

By e-mail:

service@phi.com

By telephone or fax:

| Region | Telephone | Fax |
|--------------|----------------|----------------|
| U.S. | 1-800-922-4744 | 1-952-828-6325 |
| Outside U.S. | 1-952-828-5831 | 1-952-828-6325 |
| Japan | 81-46-785-6522 | 81-46-785-4411 |
| Europe | 49-89-96275-0 | 49-89-96275-50 |

* Any additional safety measures provided in the equipment that were requested by the end user are described elsewhere.

Hazard Alerts

The hazard alerts used by Physical Electronics on equipment safety labels are described in “PHI Safety Notices” at the beginning of this document. Equipment safety labels are attached to any equipment that poses a risk to personal safety.

Procedures for operating the equipment are described in the operator’s guide provided by Physical Electronics with the system to ensure safety.

Hazards Inherent in System

The primary hazards inherent in the *SMART-Tool* system are prevented by hardware and firmware interlocks, described later in this section. Any other hazards and how to prevent them are identified by label(s) on the equipment posing the hazard. The operator’s manual contains no procedures that pose hazards, as long as operators do not use a tool on the equipment. (See “PHI Safety Notices” at the beginning of this document for more information.)

Emergency Shutdown

The *SMART-Tool* has five Emergency Off buttons, the system’s primary safety device for the operator. Pressing one of these buttons provides complete, instantaneous shutdown of system power.

The Emergency Off buttons turn off power to all vacuum and electronics console components except the 24 Vdc control circuit. Pressing one of the Emergency Off buttons is effectively the same as shutting off the main power circuit breaker (CB1) on the power distribution panel of the electronics console.

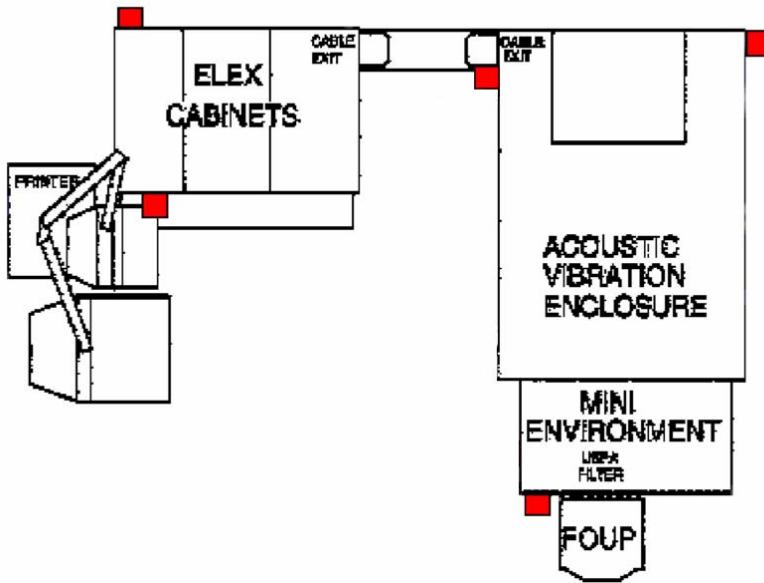
ATTENTION: Do not use the emergency off buttons as a daily power-off switch.



CAUTION: The EMERGENCY OFF buttons quickly turn off power to all portions of the system including the system computer. They are to be used only if a catastrophic system failure occurs.

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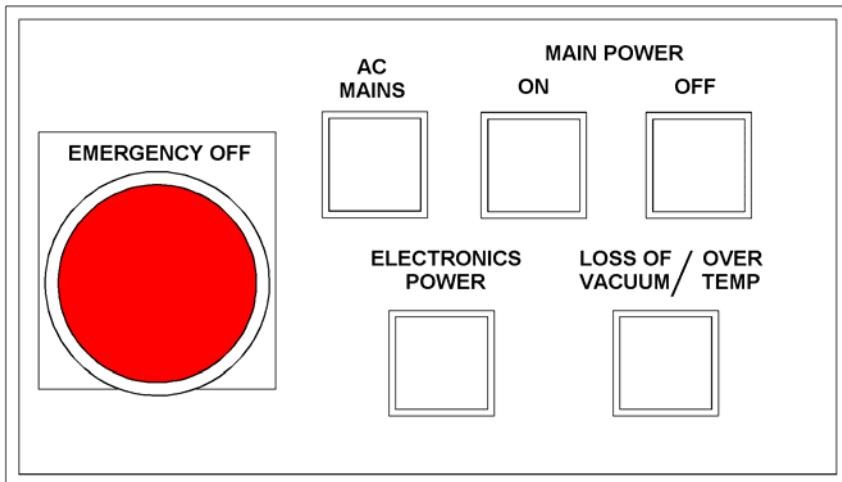
The buttons are located as illustrated below (system shown in laboratory layout):



System Power Control

All 120 and 208/230 Vac branch circuits in the instrument are fed through 24 Vdc contactors, which are controlled by the EMO circuitry. Note that all the return side of all coils and indicators are tied to the negative output of the 24 Vdc control supply. Therefore, the following explanation will only discuss the +24 Vdc lines.

The System Power Control box includes four illuminated indicators, a MAIN POWER OFF pushbutton, and one of the Emergency Off (EMO) buttons. The box is found on the front of the electronics console.



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Functions of System Power Control Box Buttons.

| | |
|----------------------------|---|
| EMERGENCY OFF | Turns off power to all vacuum and electronics console components except the 24 Vdc control circuit. Pressing this button is effectively the same as shutting off the main power circuit breaker (CB1) on the power distribution panel of the electronics console. ATTENTION: <i>Do not use this switch as a daily power-off switch.</i>  CAUTION: <i>The EMERGENCY OFF button quickly turns off power to all portions of the system including the system computer. It is to be used only if a catastrophic system failure occurs.</i> |
| MAIN POWER OFF | Turns off power to all vacuum and electronics console components and convenience outlets. Does not turn off power to the 24 V control circuit. |
| MAIN POWER ON | Turns on power to all vacuum and electronics console components and convenience outlets. Does not turn on the 24 V control circuit.    DANGER: <i>Any time input power is connected, lethal voltages are present.</i> |
| AC MAINS | This light indicates that power is applied to the main system circuit breakers. Pressing this button also checks operation of the bulbs in the buttons on the System Power Control box. |
| ELECTRONICS POWER | Turns on power to the 120V electronics and 208V/230V electronics outlets on the electronics console. This switch is intended for routine power-down of electronics components—not including the system computer and field emitter. |
| LOSS OF VACUUM / OVER TEMP | This light indicates that the vacuum chamber pressure has risen above a certain set point (i.e., the chamber has lost vacuum). |

* *NOTE: All circuit breakers on both the electronics and vacuum consoles must be on for the System Power Control box switches to function correctly.*

+24 Vdc is fed directly to the System Power Control panel to always power the green AC MAINS indicator, which is lit whenever mains power is being fed to the instrument. The AC MAINS indicator is also a momentary pushbutton: pressing it should always cause the other three indicators to light as a lamp test.

+24 Vdc is looped through connectors J9 and J12, which are used to wire in additional normally closed EMO pushbuttons both in the instrument (via J9) and remotely (via J12) if the customer's site requires them. Pressing any EMO button on the system (or any power interruption) will remove 24 Vdc from the control relays and cause all the AC contactors to drop out, completely shutting down the entire system. The system will remain powered down until an operator starts it back up after the EMO buttons are

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reclosed. The Main Power Off button is in series with the EMO buttons and works exactly the same way.

To start up the system, the MAIN POWER ON pushbutton, S2, must be closed momentarily. It feeds 24 Vdc to both of the redundant latching relays, K1 and K2. When both relays are energized, they complete their latching circuit, feeding 24 Vdc to their own coils and to the circuit feeding 24 Vdc to the MAIN POWER ON indicator light and the 24 V interposing relay K12. When K12 is energized, its contacts supply 208/230 Vac to the main contactor K11.

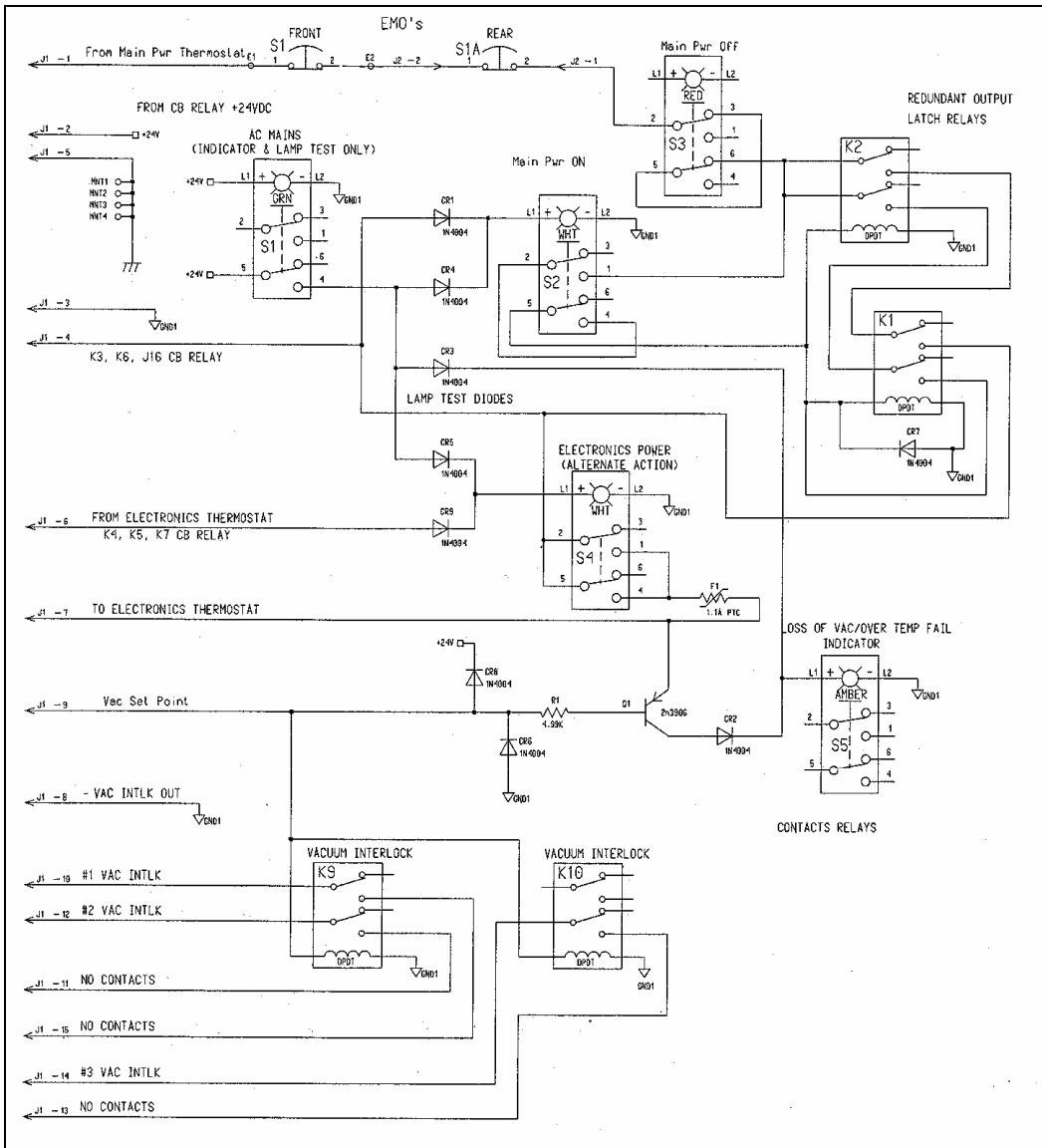
The use of redundant relays K1 and K2 Ensures that the EMO circuit will operate even if one of the relays remains closed when power is removed. Those relays also feed 24 Vdc to the Auxiliary Main Power Control jacks, J16A, J16B, and J16C. Those jacks feed EMO-controlled 24 V to the vacuum console's power distribution box, the electronics console fan, the main power contactors K3 and K6, and any other extra equipment whose operation must be controlled by the EMO circuit.

When K1 and K2 are closed, 24 Vdc is fed to the alternate action ELECTRONICS POWER switch, S4. When it is closed, 24 Vdc from it is fed through a NC over-temperature thermostat in the electronics rack. As long as it isn't too hot in the electronics console, the Electronics Power contactors K4, K5 and K7 close and 24 Vdc is fed to the vacuum interlock control circuitry.

24 Vdc from the ELECTRONICS POWER control is fed through a vacuum set point contact on one of the system ion gauge controllers via J11. Also in series with this contact is the bake control switch and a relay that is controlled based on the stage temperature. If the pressure in the system bell jar is low enough, the bake switch is set to off and the stage temperature is < 70 C, then K8, the contactor that powers the vacuum interlocked 120 Vac circuit, will be closed. In addition, relays K9 and K10 provide contact closures to control other vacuum interlocked units such as the card rack power supply, via the Vacuum Interlock control jacks, J15A, J15B, AND J15C.

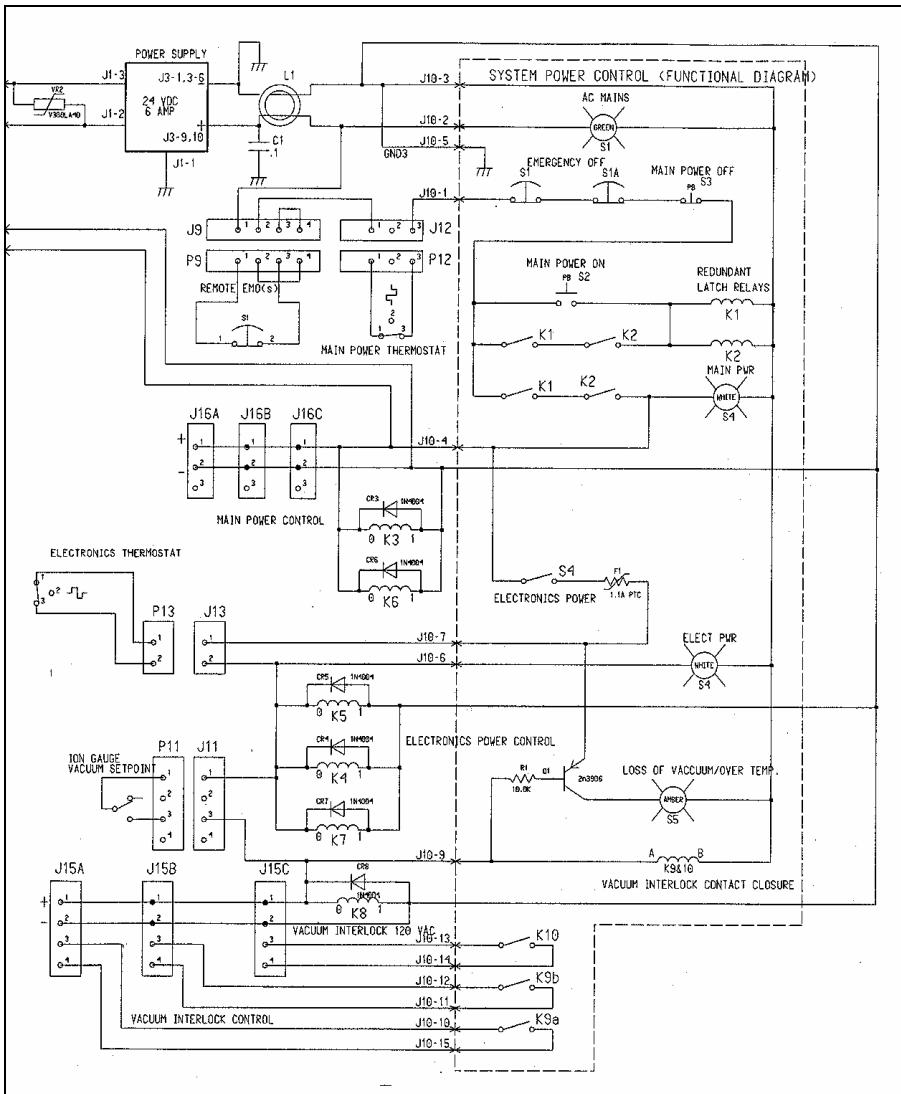
If the electronics thermostat, bake interlock, or vacuum interlock set point are open, the base of Q1 is pulled low, lighting the amber LOSS OF VACUUM indicator lamp on the System Power Control box.

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System Power Control schematic.

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Schematic showing System Power Control, remote EMOS.

Static Magnetic Fields (Non-ionizing Radiation)

Static magnetic fields can affect operation of an implanted cardioverter/defibrillator (ICD) device. The SMART-Tool has four sources of static magnetic fields:

- Two 280 l/s ion pumps,
- An 80 l/s ion pump,
- A titanium sublimator pump (TSP), commonly known as a getter pump.

Persons with an ICD device should maintain a minimum distance of 30 cm (12 inches) from these pumps.

Laser Radiation

Laser radiation can cause serious injury. Laser radiation is emitted from the two laser interferometers and the laser mounted on the vacuum chamber, which are used for stage positioning. An additional laser is used by the photoelectric laser sensor to scan wafer cassettes.

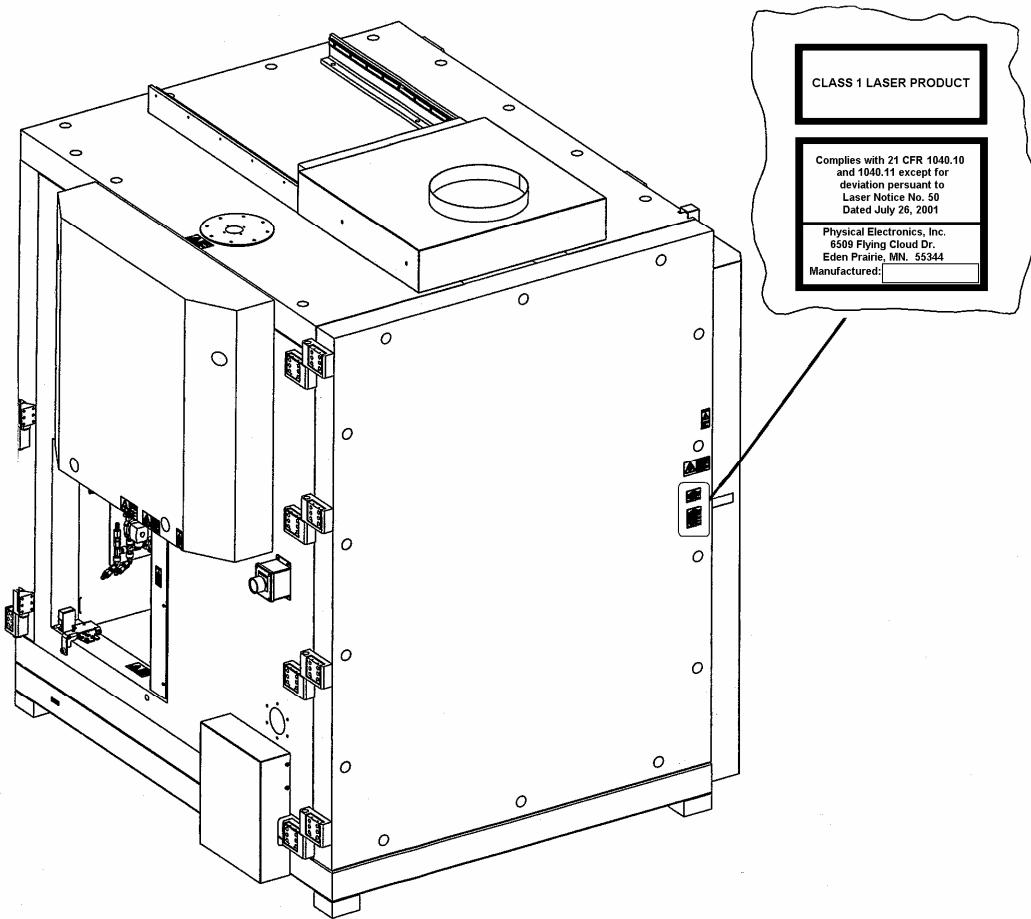


CAUTION: Use of controls or adjustments or performance of procedures other than those specified herein or within any SMART-Tool documentation may result in hazardous radiation exposure.

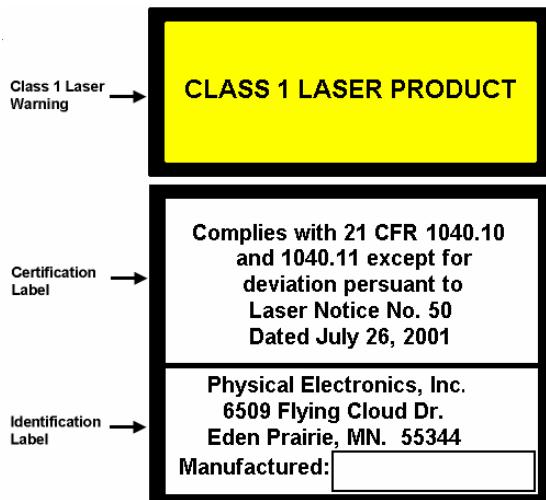
Operators of the *SMART-Tool* are not approved to perform any adjustments, maintenance or service procedures on the system's lasers. All covers, doors and access panels should be closed to prevent hazardous radiation exposure during operation. Only trained and qualified service personnel are allowed to open any covers, doors or access panels.

Below is the location of the laser certification label on the *SMART-Tool*. The label is located on the back of the acoustic enclosure, as illustrated.

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Location of Laser Certification Label on acoustic enclosure.



Components of the Laser Certification Label.

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Laser Radiation label found within the acoustic enclosure, warning service personnel that laser radiation exposure is possible if the cover is removed.

NOTE: Physical Electronics recommends that the user/organization of this system contact the applicable State Department of Radiological Health for requirements, if any, regarding registration of the system as a radiation machine.

Hazards Inherent in Tasks

In the Physical Electronics manuals, every procedure or step in a procedure that has a safety risk associated with it is preceded by a safety label, signal word (DANGER, WARNING, or CAUTION), and text that identifies the hazard and how to avoid it. “PHI Safety Notices” at the beginning of the manuals defines these signal words and task types.

System Bake

The system bake procedure is performed periodically to remove contaminants from the system so that ultra-high vacuum can be achieved. The bake is performed by a PHI field service engineer or by a site technician who has been trained in the procedure.

The *SMART-Tool* cannot be used while undergoing a bake. If the system is being baked, caution placards will be placed on doors on either side of the acoustic enclosure. The placards state:



CAUTION– Burn Hazard. Surfaces may be hot! Do not open doors or touch surfaces until bake has ended and system has cooled.

Lockout Device

The MAIN POWER circuit breaker, CB1, on the front of the electronics console can be locked in the off position, when desired, using a device such as a padlock.

Material Safety Data Sheets (MSDSs)

Links to the Material Safety Data Sheets for argon, isopropyl alcohol (IPA) and liquid nitrogen (LN₂) are included at the end of this section. These are the only chemical substances associated with the *SMART-Tool* that have MSDSs.

Personal Protective Equipment (PPE)

No PPE is required for operation of the *SMART-Tool*.

The use of isopropyl alcohol (IPA) is recommended for cleaning the exterior of the *SMART-Tool*. Cleanroom compliant safety goggles, a smock, an apron and neoprene or other solvent-resistant gloves should be worn when working with IPA. Refer to the IPA MSDS for information on safety and proper disposal of IPA-contaminated waste (click on the link at the end of this section).

NOTE: In some areas, local regulations limit the amount of volatile organic cleaning solvents that may be used per year. Other regulations require permits for the use of organic cleaning solvents. Regular wipe-down of the SMART-Tool could exceed limits imposed by such regulations, either alone or in combination with other equipment in your facility that is cleaned in a similar fashion. Check with local authorities concerning these regulatory requirements.

Liquid nitrogen (LN₂) is used in *SMART-Tool* systems that include the optional EDS subsystem. PPE is required if servicing of the LN₂ auto-fill system becomes necessary, particularly if working with parts of the system that are frosted. Loose-fitting, insulated gloves, safety shoes and safety goggles or glasses plus a faceshield (all cleanroom-compliant) should be worn. Refer to the LN₂ MSDS (click on the link at the end of this section).

Training Requirements

Training is recommended for safe operation of the system. Training is provided at installation by the PHI Customer Service Engineer.

Installation and maintenance of the *SMART-Tool* system are intended to be performed by PHI Customer Service Engineers.

Ergonomic Adjustments

The monitor arms for the PC and video monitors (see figure below) are fully adjustable. The swivel of the PC monitor bracket can be repositioned by loosening the swivel screw, adjusting the position, and then tightening the swivel screw. The height of each monitor bracket can be repositioned by loosening the height screw, adjusting the position, and then tightening the height screw.



Tightening Adjustments on the Monitor Arms.

Hardware Safety Interlocks

The table below lists the operator and equipment safety interlocks present in the *SMART-Tool* system.

| Interlock | Location | Description | Type |
|---|---|--|----------|
| Emergency Off button | Front and back of electronics console, both sides of acoustic enclosure, end of minienvironment | Complete shutdown of system power | Hardware |
| Cover interlock switch on DIGITEL MPC | Front of electronics console | Shuts off power when cover is removed | Hardware |
| SAFECCONN-style connectors on high-voltage outputs of DIGITEL MPC | Inside of electronics console | Shuts off high voltage from the DIGITEL MPC when either connector is removed | Hardware |
| Cover interlock switch on input power | Model 18-195 Electron Beam Power Supply cabinet | Shuts off power to the Model 18-195 when cover is removed | Hardware |
| Circuit breakers (CBs) | Inside the electronics console | Line power circuits protected by listed CBs | Hardware |
| NTRL-listed thermostat | Inside the electronics console | Power to the electronics rack is disabled if the internal temperature is too hot | Hardware |
| NTRL-listed thermostat | Inside the vacuum console and inside the acoustic enclosure | Baking is terminated when temperature exceeds safety threshold | Hardware |
| Airflow sensor | Exhaust air duct | Baking is terminated if the airflow is restricted | Hardware |
| Interlock switches | Top hatch, and lower acoustic enclosure doors | Prevents bakeout until the proper ventilation configuration is achieved | Hardware |
| Key switch and console interlock switches | System Bakeout Control in vacuum console | Prevents nonbakeable cables from being baked and electronics power from being applied during bakeout | Hardware |
| Redundant relief valves | Chilled water, dry nitrogen, and compressed air supplies | Relief valves open to limit pressure | Hardware |
| User-adjustable vacuum setting | Ion gauge controls on electronics console | Shutdown of ion gauge filament and high voltage upon loss of upper and/or main chamber vacuum | Firmware |
| Door interlock switches | Minienvironment | Robot disabled when a door is open | Hardware |
| Water spill detectors | Floor of acoustic enclosure | The chiller is disabled when a leak is detected | Hardware |
| UL listed GFIs | Bake Control | Interrupt power to a bake zone when a ground fault is detected | Hardware |
| FIXLOAD™ safety frame | FIXLOAD™ surrounding FOUP port | Halts and reverses loading of FOUP if an object blocks the path of the FOUP | Hardware |

MSDS Links

Section S: System Safety

Argon

Isopropyl Alcohol (IPA)

Liquid Nitrogen (LN₂)

Section 1: Introduction and Overview

This manual is published electronically to be viewed in color on the system computer's desktop using Adobe® Acrobat® Reader. Hard copies may be made in color or black and white, but black and white printouts may be harder to follow.

The sections of this manual are the following:

Section S, System Safety Hazards and Precautions—Information required for safe use of the system, including how to reach PHI Customer Service.

Section 1, Introduction and Overview—Overview of manual, system software and Auger electron spectroscopy.

Section 2, Starting and Ending a Session—Logging on and off the system computer; starting and ending a session.

Section 3, FOUP—Loading and removing 300-mm FOUPs, 200-mm cassettes, and the multi-sample platen.

Section 4, INTRO—Loading and removing PHI 700, PHI 690, PHI 680 Samples.

Section 5, Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM—Obtaining an electron beam image; adjusting stage height; optimizing the SEM image; importing defect coordinates; aligning the stage coordinates; locating the area of interest; generating SEM images.

Section 6, AES—Using the Lab Book; setting up, acquiring, analyzing and reporting AES surveys, maps, lines, and depth profiles.

Section 7, Ion—Using the sputter ion gun for sputtering; milling with the FIB(Option) focused ion beam using the liquid metal ion gun.

Section 8, EDS (Option)—Procedures detailing the interaction between the Oxford Energy-Dispersive Spectroscopy system and the *SMART-Tool*; information on when to retract the EDS detector, and on EDS calibration.

Section 9, AutoTool—Procedures for performing automated analysis in SmartSoft.

Appendix A, AES Table—AES peaks database.

The topics in Section 1 include System Hardware Overview, System Software Overview and Introduction to Auger Electron Spectroscopy (AES).

System Hardware Overview

Refer to the *SMART-Tool* System Manual, PHI Part No. 647980, for information on the system hardware. The CD containing this Operator's Guide also contains the System Manual.

System Software Overview

The *SMART-Tool or PHI 700, PHI 690, PHI 680* are operated using three software packages:

- SmartSoft, for the primary operation of the system, including wafer handling, stage navigation, SEM imaging, Auger analysis, FIB imaging and milling, and depth profile sputtering;
- MultiPak, for post-acquisition and off-line data reduction and reporting; and
- Watcher, the System Vacuum Control interface.

For systems that include the optional EDS system, the Oxford software package is also included.

The system computer uses the Windows® XP™ operating system and comes with the Microsoft Office™ suite. Microsoft Office includes Word™ for creating reports and articles, PowerPoint® for producing presentations, and Excel™ for performing statistical analyses and generating graphs and charts. Data from PHI software packages can be copied to the Microsoft Windows clipboard and pasted into any of the Microsoft software packages quickly and easily. PHI data can also be saved in standard ASCII or graphics formats and inserted into the Microsoft software packages.

The following subsections provide brief overviews of the system software:

[**Introduction to SmartSoft**](#)

[**Introduction to MultiPak**](#)

[**Introduction to Watcher**](#)

[**Reporting Software Performance Issues**](#)

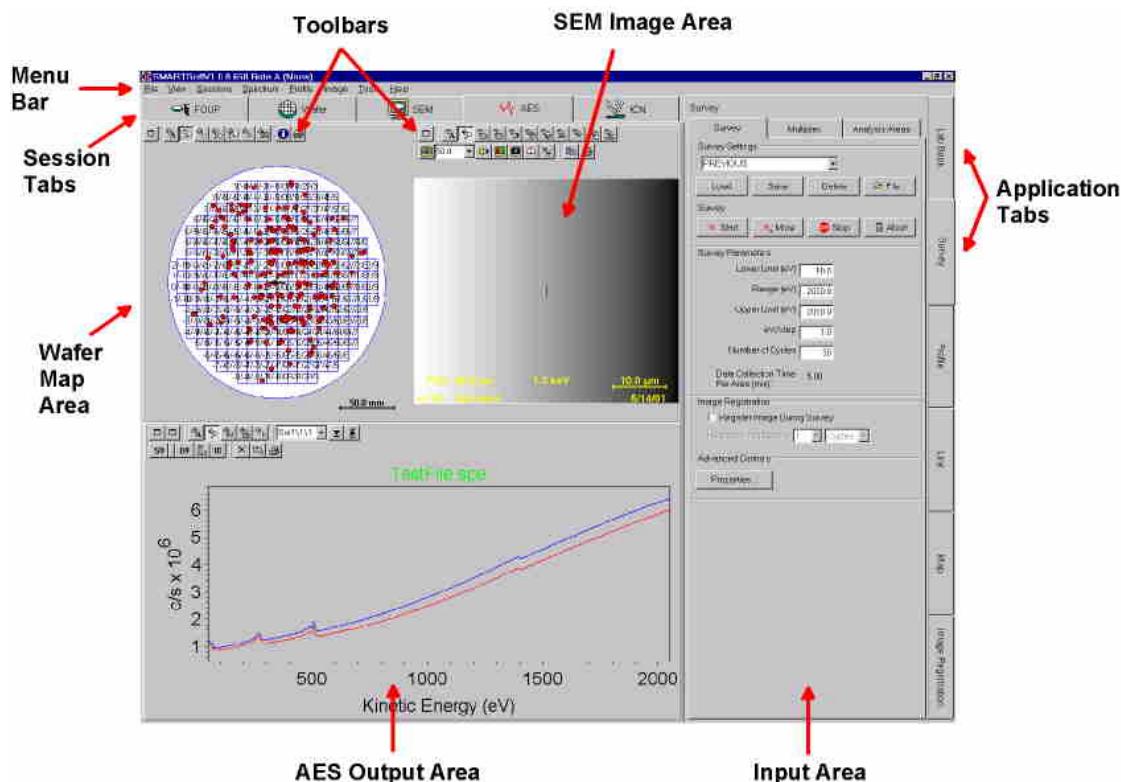
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Introduction to SmartSoft

SmartSoft is a Windows-based interface with five primary “sessions” devoted to different tasks:

- **FOUP (SMART-Tool)**, for loading and unloading wafers or the multi-sample platen;
-or-
- **INTRO (PHI 700, PHI 690, PHI 680)** for loading and unloading samples;
- **Wafer (SMART-Tool)**, for stage navigation, importing position lists, aligning the wafer and searching for defects, SEM operation;
- **Samples (PHI 700, PHI 690, PHI 680)** for stage navigation, SEM operation;
- **SEM**, for adjusting and outputting SEM images;
- **AES**, for acquiring Auger surveys, line scans, depth profiles and maps; and
- **Ion**, for depth profile sputtering and using the optional FIB (focused ion beam).

SmartSoft Operator Interface



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Within each session are application tabs; each application contains one or more procedures to be performed by the operator. Clicking a new application tab will change the appearance of the input area, as new procedures are made available.

Many of the procedures in the input area are sequences of buttons arranged in flow charts so operator actions are intuitive. Most buttons and text fields display a tool tip when the cursor is pointed at them.

The output area of the SmartSoft interface varies according to the session selected and data files opened. It can include the wafer map area, SEM image area, position list or AES output area. Toolbar buttons are available to allow the operator to interact with the image, wafer map or data files.

The menus in the menu bar include:

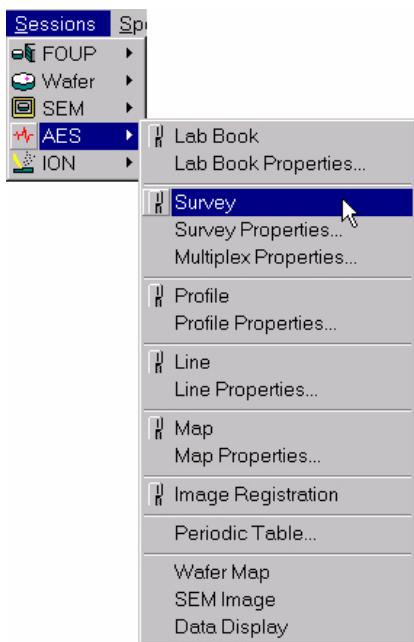
- File – Contains commands to open files and position lists. Select the desired file or position list from the box. The exit command closes the SmartSoft software.
- View – Selecting Normal shows the entire SmartSoft interface; Input Tabs displays the input area only; Output Tabs displays the output area only.

To adjust the view of the output area, select Tile, Wafer Map, SEM Image or AES Data. Tile will show all of the areas that are currently available (which varies, depending on the session). Selecting one of the other options will display only that area.

When multiple data files of different types (spectra, maps, depth profiles) are open, select Spectrum, Profile or Image Viewer to display only that type of data file. The Spectrum Viewer will display survey and multiplex spectra and line scans; the Profile Viewer will display depth profiles; and the Image Viewer will display maps.

- Sessions – This menu allows the operator to select a session and application or properties box.

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In the example above, the AES session menu shows commands that match the application tabs when the AES session is active, as well as properties boxes for each application. Clicking one of the commands will take the operator to that session and application tab or properties box.

- Spectrum – Use this menu to open the smooth/derivative setup box. Other commands allow the operator to close the currently displayed spectrum, or close all displayed spectra.
- Profile – Contains commands to close the currently displayed depth profile, or to close all depth profiles.
- Image – Contains commands to close the currently displayed map, or to close all maps.
- Tools – Opens boxes that are generally used by PHI Customer Service, including the analyzer and detector hardware properties box and the service tools box. The system log is also accessed from this menu.

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Settings



Many of the application tabs include a settings area. A setting is a group of parameter values related to the displayed application tab. The settings area allows the operator to save and retrieve parameters as settings for future use.

NOTE: Not all related parameters are stored when a setting is created. Some parameters will have the same value regardless of the setting, but can be changed individually by the operator.

The PREVIOUS setting is found in all the setting areas, and will load the setting that was active prior to the last system shutdown. The PREVIOUS setting is updated whenever the operator moves to a new session tab or exits SmartSoft.

The INITIAL setting is found in settings areas that save hardware parameters. The INITIAL setting is automatically selected when the system is first started because it sets the system hardware to safe default parameters.

To select a setting, use the text box to highlight the desired setting, then click Load.

Alternatively, you can restore a setting that was used during the acquisition of a specific data file. Data files (surveys, SEM images, maps, etc.) generated in SmartSoft include information on the settings used during their acquisition. Click the File button in the settings area, then select the desired data file. The file itself will not open, but the settings stored with it will be loaded into the active application tab.

To create a new setting, set the parameters as desired. Type a setting name in the text box and click Save.



To delete a setting, select it, then click Delete.

Introduction to MultiPak

MultiPak has four main windows: the Spectrum, Profile, and Map windows, which are very similar in appearance and layout, and the Periodic Table window.

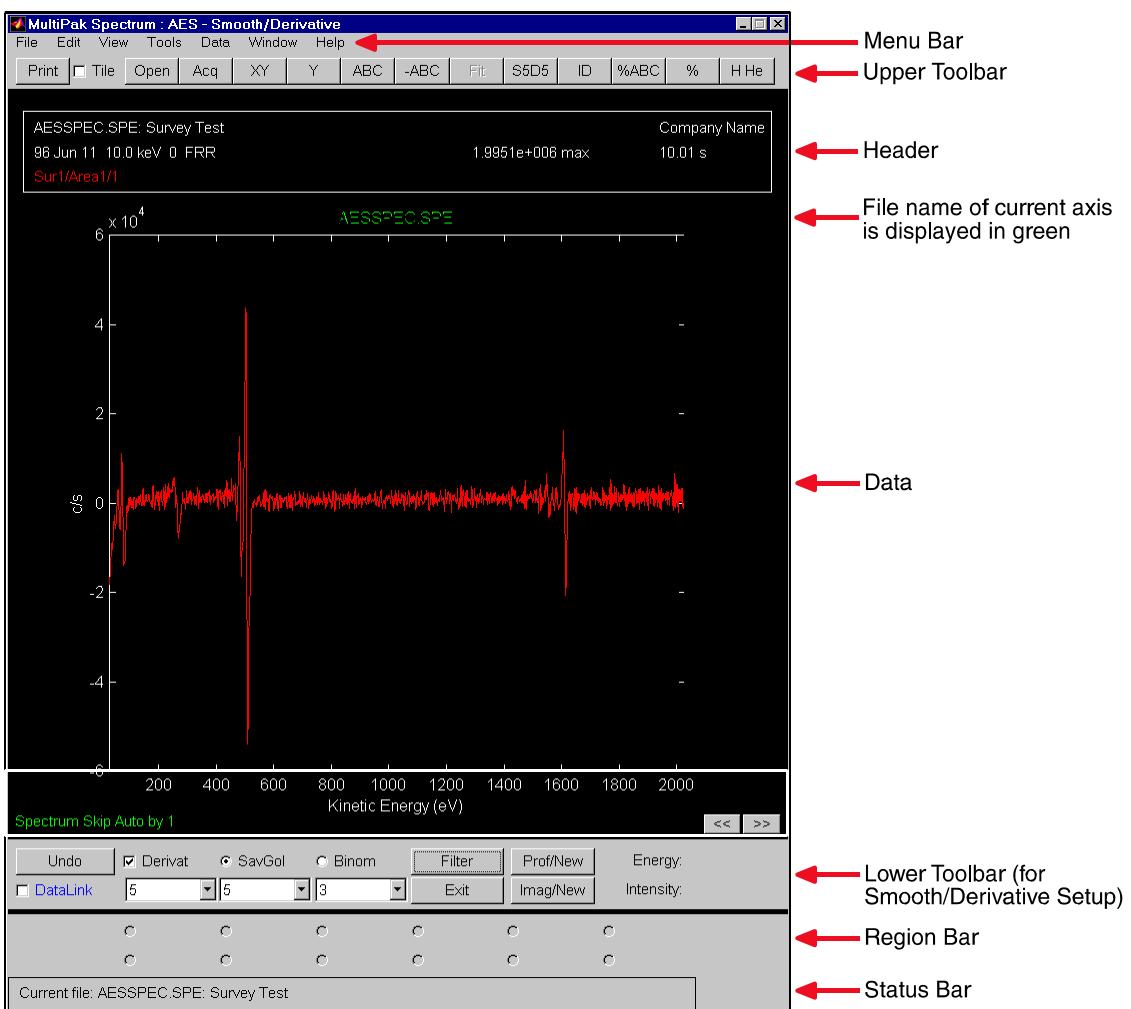
At startup, the Spectrum window is displayed on the left side of the desktop and the Periodic Table window is displayed on the right. When opened, the Profile and Map windows are displayed on the right side of the desktop screen. The Profile and Map windows will be displayed on top of the Periodic Table window. (Another MultiPak window can be moved to the foreground by selecting its name from the Window menu of any MultiPak window.)

The extension of the file name determines which window a data file will open in, as follows:

- ***Spectrum Window***—files having the SPE (spectral data) extension. SPE files contain survey and multiplex acquisitions. Surveys are scans performed over certain energy ranges to identify the primary elements present in a sample. Multiplexes are scans that contain multiple regions, each of which typically contains a single element.
- ***Profile Window***—files having the PRO (depth profiles) or LIN (line scans) extensions (plus associated spectra in the Spectrum window). Depth profiles are performed to obtain compositional data as a function of sample depth. Line profiles provide the surface distribution of an element along a straight line. A line profile is collected point by point over the defined line.

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Parts of the MultiPak Window.



- **Map Window**—files having the MAP (map images) and SEM (scanning electron micrographs), plus associated displays in the Spectrum window. MAP files provide information on the two-dimensional surface distribution of an element. Map data is collected point by point in a grid fashion over a selected area of the sample. SEM files are AES image acquisitions.

Each window has a menu bar, upper and lower toolbar, region bar, a header area, and a status bar, as described in the following subsections.

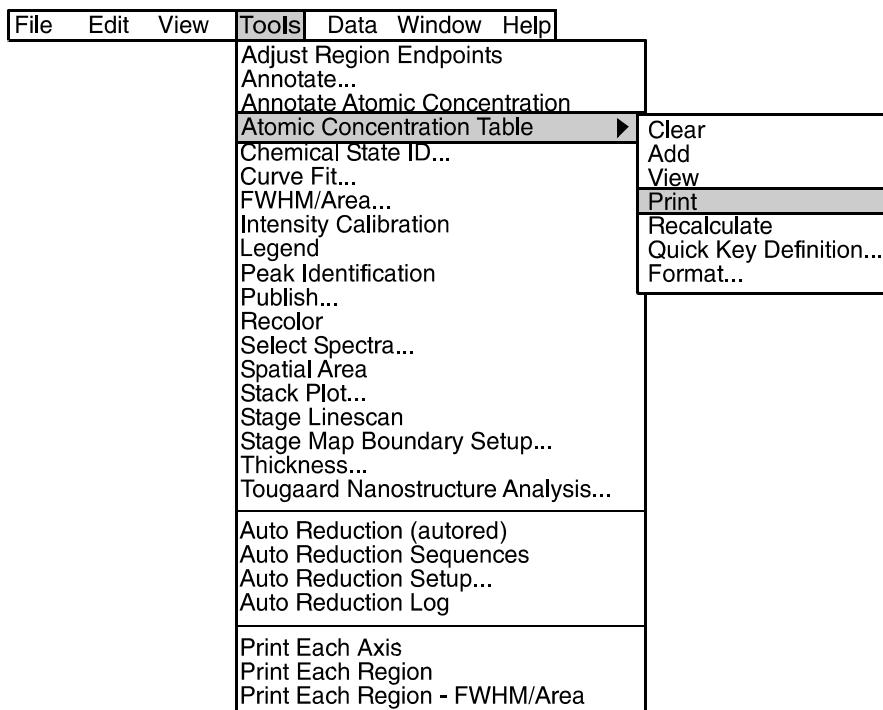
Menus, Selecting Functions, and Other Windows Terminology

MultiPak's three main windows (Spectrum, Profile, and Map) use the same seven “main menus” on their menu bars: File, Edit, View, Tools, Data, Window, and Help. A MultiPak function is started (“selected”) by finding it on a menu or an associated cascading “submenu,” then highlighting it and releasing the mouse button. Many

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functions can also be started using short-cut keys (shown on the menus) or clicking on (“pressing”) a pushbutton in the upper toolbar.

*Selecting a Function from a Cascading Menu:
“Select Tools—Atomic Concentration Table—Print.”*



Parameters for a function are set by the operator using a dialog box or the lower toolbar. Common features of these—“option menus,” buttons, and boxes—are illustrated below. Other menu items are followed by an ellipse (...), such as Print (“Print...”) on the File menu, meaning that a dialog box will open when the menu item is selected.

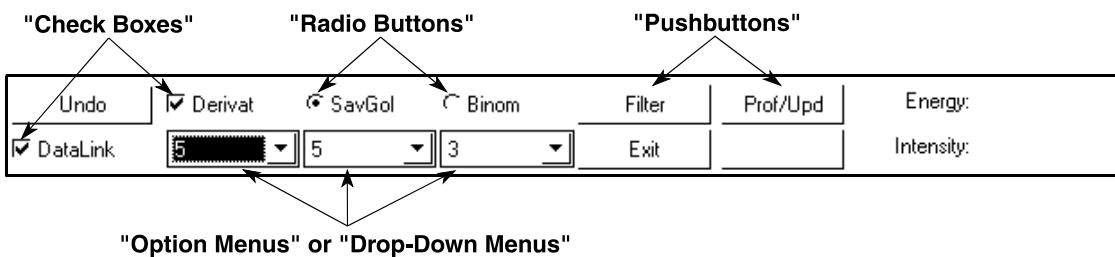
Toolbars and Region Bar

MultiPak has three toolbars: the upper toolbar, the lower toolbar, and the region bar. A toolbar is a portion of a window that contains “buttons” that can be used to perform many functions in MultiPak.

The upper toolbar is located below the window’s menu bar and above the data display area of the window. The lower toolbar is located below the data display area and above the region bar. The region bar is located below the lower toolbar and above the status bar.

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Buttons, Check Boxes, and Option/Drop-Down Menus.



Check boxes are toggle switches that are on when filled and off when not filled.

A **radio button** is one button in a set of buttons, only one of which can be on at a time. A button is on when filled and off when not filled.

A **pushbutton** activates a function. To "press" a button, click on it once with the left mouse button.

Option menus are **drop-down menus** that are displayed by clicking the arrow. An item is selected from the menu by clicking on it when the drop-down menu is displayed.

Header

The header, displayed above the data's axes, is the listing of parameters from the currently selected data file.

Status Bar

The status bar, located at the bottom of the window, is used to display operator messages, system notices, and the name of the currently selected file.

Current or Selected Data

When multiple sets of data are displayed in a window, a green title above a set of data indicates that it is the currently selected data. The file name of the selected data set is also displayed in the status bar at the bottom of the window. Data are selected using the left mouse button.

Most functions, when activated, are applied to the current spectrum or image only. Further, many functions will retain their last setting indefinitely, so that displays of newly opened spectra or images will be based on that setting.

The terms "current," "selected," and "currently selected" are all used.

Formats for Viewing Multiple Axes

Four formats are available for viewing multiple axes in a single window at the same time. Up to 36 axes (six rows and six columns) can be displayed concurrently in three of the views: *Landscape* (oriented in rows first, then columns); *Portrait* (oriented in columns first, then rows); and *Square* (landscape arrangement but all axes are equal in size). Up to 6 axes can be displayed concurrently in the *Stack* view (stacked in six rows in one column).

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Analysis Data Set

This subsection briefly describes the types of files that can comprise an AES data set and other general information about a data set that the MultiPak user should be aware of.

AES data can include some or all of the following types of files:

- Spectra, stored in files having the extension “SPE,” which will open in MultiPak in the Spectrum window. Each file contains a series of data points, in the E N(E) format, from one point (stationary electron beam was positioned on a specific point) or area (rapidly scanned or rastered over an area of the surface). Spectra are acquired either as surveys or multiplexes. A *survey* is a quick scan over a wide contiguous energy range to survey the elements present in a sample. A *Multiplex* is a high-resolution scan of several narrow energy ranges to obtain enhanced sensitivity and spectral detail.
- Maps, stored in files having the extension “MAP,” which will open in MultiPak in the Map window. Maps provide information on the two-dimensional surface distribution of an element across the analysis area.
- Line scans, stored in files having the extension “LIN,” which will open in MultiPak in the Profile window. Line scans provide information on the surface distribution of an element along a straight line through the analysis area.
- Depth profiles, stored in files having the extension “PRO,” which will open in MultiPak in the Profile window. Profiles provide information about the distribution of an element as a function of depth (after the surface has been sputtered).
- Images, which will open in MultiPak in the Map window. AES imaging capabilities generate “SEM” (scanning electron micrograph image) file types. An image is used during acquisition to define the analysis area where additional data is to be acquired. The analysis area may be the whole image area or a subset of it.

Other Important Data File Characteristics

Each data file in a set has characteristics important to the analyst using MultiPak, such as which files contain data from the same analysis area or point and whether the same hardware parameters (e.g., beam voltage, beam size, etc.) were used to acquire the data. Some of this information can be found in the file’s “header,” which MultiPak will display along with the acquired data, but some of it will have to be known by the analyst to ensure that appropriate analyses of the data files are performed.

File Types and Their Directories

MultiPak looks for different file types in certain subdirectories within the MultiPak directory, so proper file management is important. The following table shows directory paths used for data files, handbook spectra, and other files.

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Subdirectories for Different File Types

| Files | Technique | Directory on the PC** |
|--------------------------------------|------------------|---|
| Data | AES | c:\multipak\datafile\phiouser1\aes |
| Handbook data | AES | c:\multipak\datafile\handbook\aes |
| Basis spectra† | AES | c:\multipak\datafile\basic\aes |
| Data on which to perform TFA† | AES | c:\multipak\v7.3\userdata\phiouser1\tfa |
| User-defined data reduction routines | AES | c:\multipak\v7.3\userdata\phiouser1\autored |

** Creation of employee-specific and project-specific folders within the AES folder is recommended.
For example:

c:\multipak\datafile\phiouser1\aes\<NAME>\<PROJECT>\<FILENAME.*>

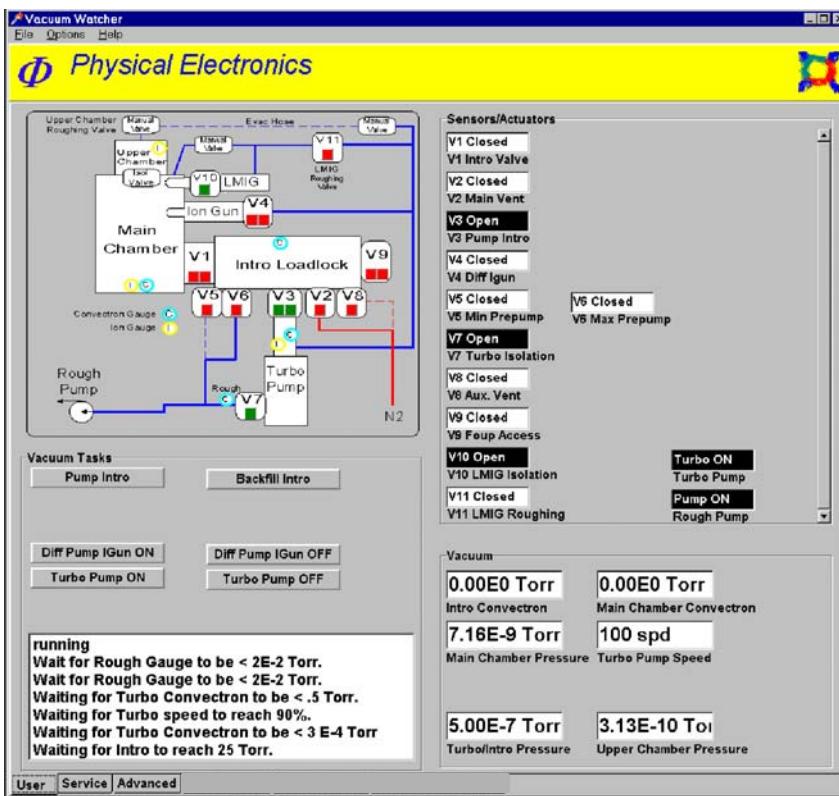
Introduction to Watcher

PHI Watcher is a stand-alone software application. The software is launched by activating the Watcher icon on the system's desktop. The system operator has access to the "User" tab only. The other tabs displayed are available only to PHI Customer Service or a site technician who has been trained on the system.

A diagram of the vacuum system in the upper left corner of the Watcher window displays the valves and pumps. The rest of the interface is divided into the Vacuum Tasks area, status/message area, Sensors/Actuators area, and Vacuum readout area.

The Vacuum Tasks area is where the operator performs tasks: Pump Intro, Backfill Intro, Diff(erentially) Pump I(on) Gun ON, Diff Pump IGun OFF, Turbo Pump ON, and Turbo Pump OFF. How the operator uses these buttons is given in the procedures in the other sections of this operator's guide. The other areas of the interface report data to the operator: task execution progress, valve and pump status, and pressure levels.

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Reporting Software Performance Issues

SmartSoft Procedure

A WRI file for reporting issues is available in the software's directory following software installation. The files include "SPR" in their names (e.g., SPR.WRI).

MultiPak Procedure

1. Open the Notepad application.
2. Open the file (e.g., \multipak\v7.3\mpspr.txt).
3. Complete the form, referring to the information in the table below. (Please feel free to use the editing capabilities. For example, the business address need not be limited to a single line.)
4. Save the document using the Save As... function of the application software. (Using the Save As option will leave the original, empty template intact for later use.)
5. Mail, fax, or e-mail the performance report to PHI Customer Service.

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Fields of the Software Performance Report

| | |
|------------------------|--|
| Company Name | Name of the business that owns the software. |
| User Name | Name of the system operator or contact person. |
| Business Address | Mailing address for mail that may come from Physical Electronics. (Include internal mail-stop information.) |
| TEL | Telephone number of User. (Include area code and country code, if applicable.) |
| FAX | Complete telephone number to which to transmitting facsimiles. |
| MultiPak Version | Version of MultiPak with which the issue came up. |
| Model Number of System | Model number of the PHI system with which MultiPak is being used. (Example: SMART Tool). |
| Analysis Techniques | Indicate "Auger" |
| Description of Issue | A detailed account of the problem or concern. The goal is to provide PHI Customer Service with enough information so that PHI can recreate the occurrence. (Many issues are intermittent or depend on the events that led up to the occurrence.) Such details help PHI address the issue in a timely fashion. <i>NOTE: A copy of the data file being used at the time of the occurrence should be sent along with the performance report.</i> |

Introduction to AES

Refer to the *Handbook of Auger Electron Spectroscopy** for a detailed review of AES theory, Auger analysis using PHI instrumentation, and reference spectra for 81 elements to assist with identification, quantification, and interpretation of AES data.

AES is a fast, nondestructive analytical technique used to determine the elemental composition of the top few atomic layers of a surface or exposed interface in a solid material. AES can detect all elements except hydrogen and helium, and it can provide semi-quantitative information with an average detectability limit of 0.1 to 1 atomic percent. Newer AES instruments with field emission electron sources provide rapid characterization of sample features less than 100 Å (10 nm) in size.

AES occurs under ultrahigh vacuum (UHV) conditions, typically by probing the sample with a 3 to 25 keV electron beam. Incident electrons collide with inner shell electrons in the material, leaving atoms in an ionized state. When the ionized atom relaxes to a lower state, an Auger electron can be emitted. Pierre Auger first described this electron emission process in 1925.

Auger electrons escape from the surface with a kinetic energy characteristic of the parent atom. The energy of these escaping electrons is analyzed, resulting in a

* K.D. Childs et al., *Handbook of Auger Electron Spectroscopy*, Third Edition, Physical Electronics, Inc., Eden Prairie, 1995.

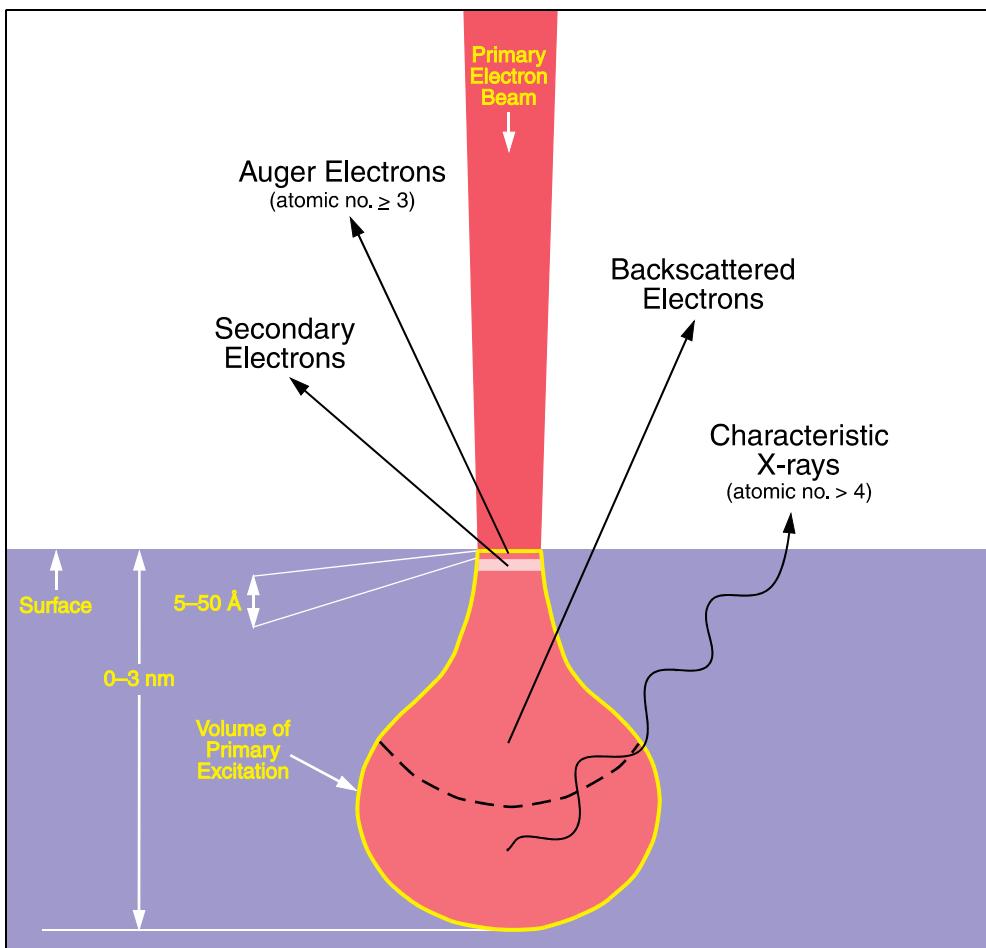
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spectrum of Auger peaks that acts as a fingerprint of the probed surface. Each element has a unique set of Auger peaks.

The kinetic energy of Auger electrons is typically between 40 and 2500 eV. In this energy regime, electrons have an escape depth of approximately 5 to 50 Å (see diagram). This shallow escape depth gives AES its surface sensitivity, enabling analysts to obtain information from the top few atomic layers of the sample. In certain instances, chemical state information for an element can be derived from shifts in energy or changes in line shape. Although AES is normally used to analyze conductive solids, the technique can also be used to analyze inorganic oxides.

Scanning auger microscopy (SAM) is accomplished by scanning an electron beam across the surface of a sample while measuring resultant electron signals. This process generates secondary electron microscope (SEM) images and Auger maps. SEM images, which provide a topographic view of the sample by detecting low-energy electrons emitted from the surface, are used to locate specific areas for more detailed study.

Cross Section of Activity



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Auger maps, obtained by measuring the emitted Auger electron intensity while scanning the electron beam, reveal the lateral distribution of an element. Acquiring a complementary set of Auger maps provides a thorough characterization of a sample's surface.

Additional information can be obtained by sputter etching the sample surface using inert gas ions. Such sputter etching erodes the sample in a controlled manner and is typically performed with argon ions. A sputter depth profile, which plots the Auger signal as a function of sputter time, shows elemental concentrations as a function of sample depth. This technique is particularly effective for thin-film analysis and for solving materials problems that require identifying such characteristics as the thickness of a thin surface layer, the composition of a thin-film deposit, the presence of interdiffusion between thin films, or the presence of contamination at an interface between two layers.

Types of AES Data

Survey

A survey is one spectrum acquired from a quick, high-sensitivity scan of a wide energy range (typically 30 to 2030 eV in 1 eV steps) to survey the elements present at a point on the sample or over an area. In *point* analysis, a stationary electron beam is positioned on a specific point. In *area* analysis, the beam is rapidly scanned, or rastered, over an area of the surface.

Multiplex

A multiplex is a set of spectra acquired from a series of high-resolution surveys of narrow energy ranges (typically 30 eV wide in 0.5 eV steps). This type of acquisition yields great sensitivity and spectral detail in a short analysis time, because only selected energy regions expected to contain Auger peaks of interest are scanned.

The more commonly used multiplex acquisition routines are the window line scan and depth profile. Up to 20 elements can be acquired in one multiplex.

Maps

A map is a set of intensity-value arrays acquired over the area of the SEM to show the surface distribution of specific elements. Each array of intensity values corresponds to an element, and each value in the array corresponds to a point in the map area. The intensity value is obtained by measuring the intensity at a specific Auger peak energy (the energy of the element's principal Auger peak), then subtracting the background intensity.

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Acquiring map data for every element identified in the survey will completely characterize the distribution of elements in the analysis area. These maps are then compared to the SEM image.

Line Scans

An Auger line scan is acquisition of data along a single line across a sample. A two- or three-point line scan acquires one spectrum that comprises the peak-minus-background values from the points along the line, and window line scans acquire a multiplex at each point along the line. Window line scan data can be used to extract chemical state information as well as atomic concentration data.

Depth Profiles

An Auger depth profile provides compositional data as a function of depth. To obtain a depth profile, the surface of the specimen is sputtered by inert gas ion bombardment, then Auger spectra are collected from the center of the etched area. Data are acquired (and acquisition parameters like the sputter rate can be adjusted, if desired) alternately with sputtering. Changes in Auger signal amplitudes after etching indicate changes in specimen composition with depth, yielding a depth vs. composition profile. Depth profile data can be used to extract chemical state information as well as atomic concentration data.

Some Analysis Considerations

- Use as much current as possible for good signal-to-noise ratio while (1) still being able to resolve the features of interest (if the beam diameter is larger than the feature of interest, you will get substantial signal from the surrounding area) and (2) not causing electron beam damage to the sample surface.

Differentiating data makes it easier to identify elements, because Auger peaks are riding on a high secondary electron background. Smoothing data will lessen the impact of noise on the spectrum, but peak resolution is lost as the smoothing function broadens.

- Survey spectra can be very noisy when rastering over an area that includes elements of drastically varying secondary electron yields or has rough surfaces with sharply changing angles.
- Longer acquisition times or multiplex spectra are usually needed to identify minor elements.
- Be aware of elemental sensitivity factors when choosing beam voltages. As a general trend, as the beam voltage is increased, the sensitivity to high-energy Auger peaks increases while the sensitivity to low-energy peaks decreases.

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- Be aware of the four types of beam damage that the current selected can do to your sample:
 - *Reduction*—Metal oxides and hydrocarbons can be reduced by the electron beam.
 - *Desorption*—Adsorbed material can be removed.
 - *Electron migration*—Mobile ionic material can be repelled or drawn toward the electron beam. For example, PSG glass contains phosphorus, which is attracted to the beam.
 - *Diffusion*—The beam’s heat can cause an intermixing of liquids, solids, and gases.

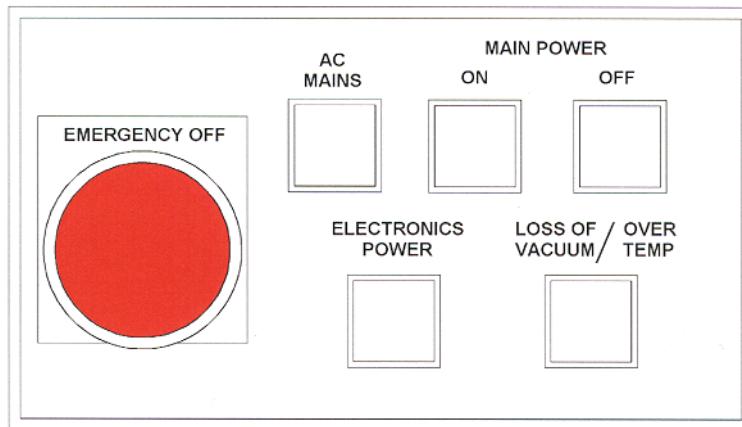
Section 2: Starting and Ending a Session

The *SMART-Tool or PHI 700, PHI 690, PHI 680* is typically left running at all times. This section describes logging on to and off from the computer, as well as information on restoring system settings.

ATTENTION: If the system was completely shut down due to an emergency, do not attempt to restart the system. Call PHI Customer Service.

Starting a Session

1. Ensure that the following buttons on the Emergency Manual Off panel are on:
 - MAIN POWER ON (white when on),
 - AC MAINS (green when on),
 - ELECTRONICS POWER (white when on).



2. Ensure that the system computer and peripherals are on:
 - Monitor on,
 - Personal computer (PC),
 - Printer.

When turned on, the system computer first performs self-diagnostics, then loads the Microsoft® Windows XP® Operating System.

3. When the prompt “Press Ctrl+Alt+Del to log on” appears, press the Ctrl, Alt, and Del keys on the keyboard simultaneously.

A box is displayed that lists the “Username” as “phiuser,” the computer’s name, and “Password.” The factory default password is the Enter key.

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4. Press Enter (or type a password if the default setting has been changed).

The system shuts off all of the voltages and resets them according to initialization parameters to ensure safety. These parameters can be changed, but the installed settings are known to be safe settings for startup of the system.

5. Double-click the SmartSoft icon, if SmartSoft is not already opened.
6. If desired, double-click the MultiPak icon to open MultiPak.
7. To restore settings to their previous state prior to the last shutdown:
 - a. In SmartSoft, click the FOUP session tab.



In the Advanced Controls area, click the Restore button to restore the previous wafer list. The wafer list must be restored if a wafer is in process (for example, on the stage), or if a FOUP or cassette is currently in place.



- b. Click the Wafer session tab.



In the Advanced Controls area, click the Restore button to restore the previous wafer map, position list and alignment points.



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- c. Click the SEM session tab.



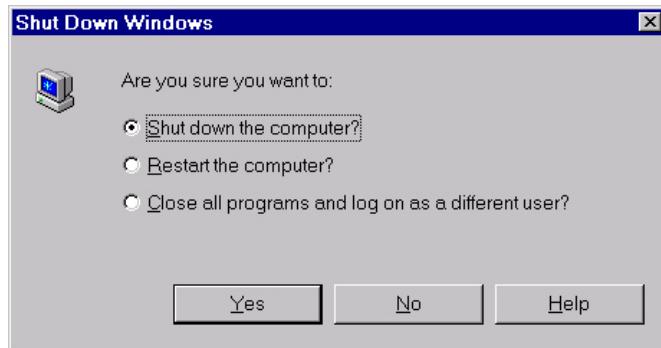
In the SEM Settings area, select PREVIOUS, then click Load. The SEM hardware settings will be restored to the settings used prior to shutdown.



Ending the Session

This procedure describes closing the system software applications and logging off from the system computer. It is not necessary to perform this procedure unless the computer needs rebooting or it is required by your site procedures.

1. In SmartSoft, click the File menu, then select Exit. Select Yes when prompted.
2. If the Watcher window is open and minimized, right-click the Watcher button in the Start task bar, and select Close. If the Watcher window is open and not minimized, select Exit from the File menu.
3. If the MultiPak window is open and minimized, right-click the MultiPak button in the Start task bar, and select Close. If the MultiPak window is open and not minimized, select Exit from the File menu.
4. Click Start in the Start task bar, then select Shut Down. Select from the options displayed to close Windows.



Section 3: FOUP

This section describes wafer and sample handling, including loading and unloading wafers from the system. The procedures in this section are:

Load and introduce 300-mm wafers

Load and introduce 200-mm wafers or platen

These procedures are to be performed after the **Starting and Ending a Session** procedure in Section 2.

Wafer handling minienvironment

The *SMART-Tool*'s integrated wafer-handling minienvironment allows for the automated transfer of wafers into the system's analytical chamber. The filtered air flow within the minienvironment maintains a class-1 or better environment when operated in a Class 1000 or better cleanroom.

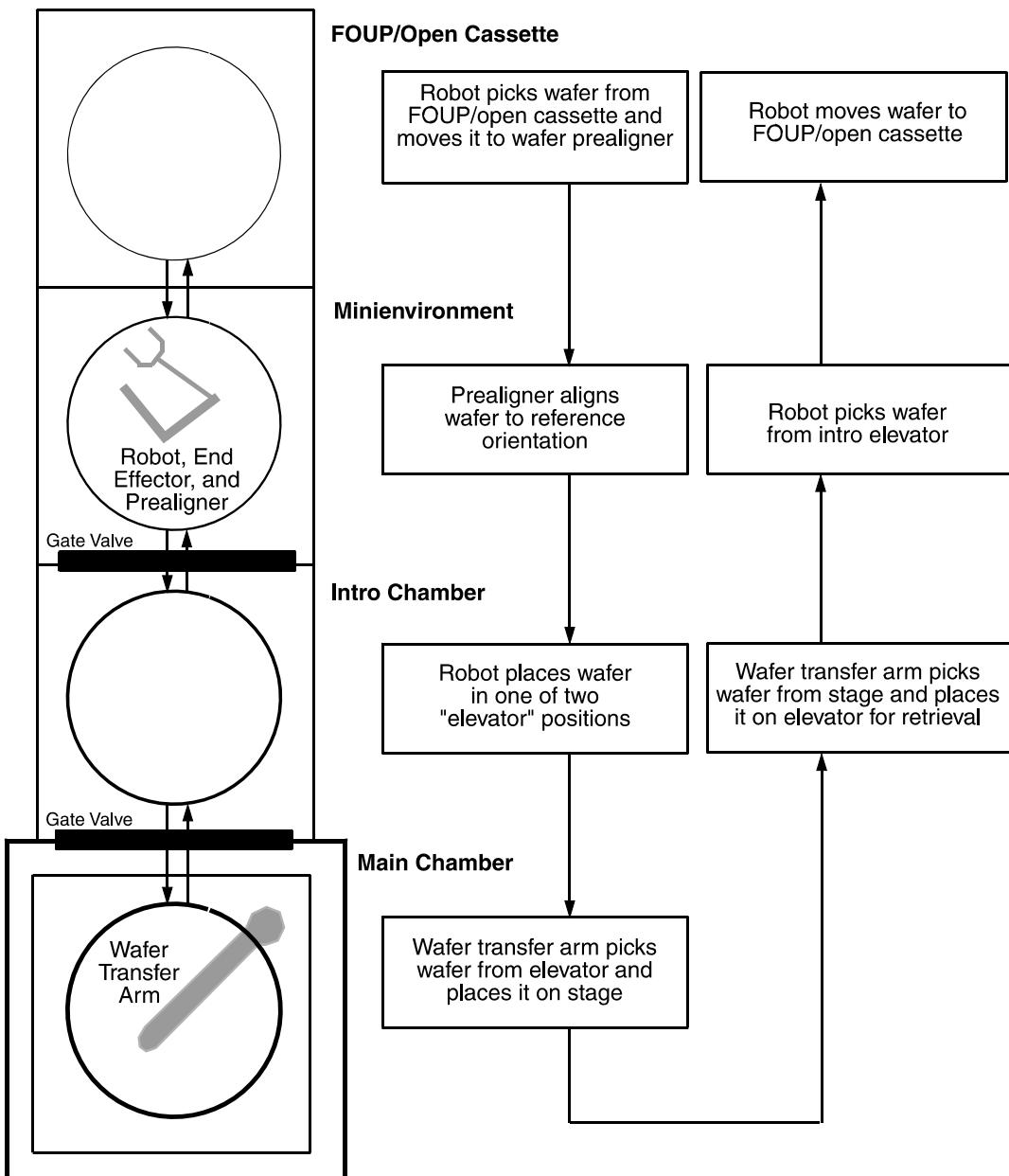
The system also accepts a special multi-sample platen for multiple small samples.

During the wafer introduction process, the wafers move from their cassette or FOUP (front-opening unified pod) into the minienvironment, where they are aligned to a reference orientation. The wafers then move into the Introduction Chamber, where they are placed on an elevator. Two wafers can be placed into the Intro Chamber at a time. This chamber acts as an airlock, pumping down to allow for safe transfer into the analytical chamber.

In the final step, the wafer transfer arm picks up the wafer from the elevator and places it on the stage for analysis.

The figure below illustrates the steps in wafer exchange for wafers in either a 300-mm FOUP or 200-mm open cassette.

Section 3: FOUP



Load and introduce 300-mm wafers

This procedure describes loading a FOUP (front-opening unified pod) with 300-mm wafers from the FIM (FOUP interface mechanism) to the wafer-handling minienvironment, then loading (introducing) the wafers into the analysis chamber.

1. Load the FOUP with 300-mm wafers onto the FIM.



2. Click the FOUP session tab along the top of the SmartSoft user interface. The Wafer Load and Unload application is displayed on the right side of the SmartSoft window.



Click the Load FOUP button.



NOTE: The tool will not access the FOUP if the pedestal for the 200-mm cassette is occupied.

Section 3: FOUP

Docking of the FOUP to the wafer-handling minienvironment is performed automatically. The FOUP is scanned to identify which slots contain wafers and which (if any) are cross-slotted (resting in slots not directly across from each other). After the scan, the slots containing wafers are displayed on the computer monitor in the wafer table, and slots containing cross-slotted wafers are flagged with an error message.

| Slot | Analyze | Order | Status |
|------|---------|-------|--------|
| 25 | Yes | 3 | FOUP |
| 24 | Yes | 2 | FOUP |
| 23 | Yes | 1 | FOUP |

3. In the wafer table, specify which wafers will be analyzed and in which order, as follows:
 - a. Each wafer displays Yes in the Analyze field. For each wafer that is *not* to be analyzed, click in that wafer's Analyze field, and the field will automatically change to No. That row in the wafer table is now gray to indicate that this wafer will be skipped when analysis of the wafers in this FOUP begins.

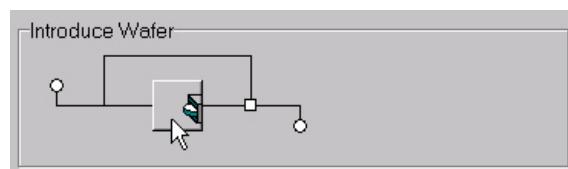
| Slot | Analyze | Order | Status |
|------|---------|-------|--------|
| 25 | Yes | 2 | FOUP |
| 24 | No | | FOUP |
| 23 | Yes | 1 | FOUP |

- b. The wafers detected are automatically assigned an order number. To change the order, click in the Order field for each wafer, and select a number to indicate the order in which this wafer is to be analyzed.

NOTE: Once another button is pressed in the Load, Unload input area, the wafer table is locked and remains locked until the wafer transfer is complete. Since loading and unloading wafers from the elevator, intro, and analysis chamber is time consuming, do not proceed until you are sure the wafer table is correct.

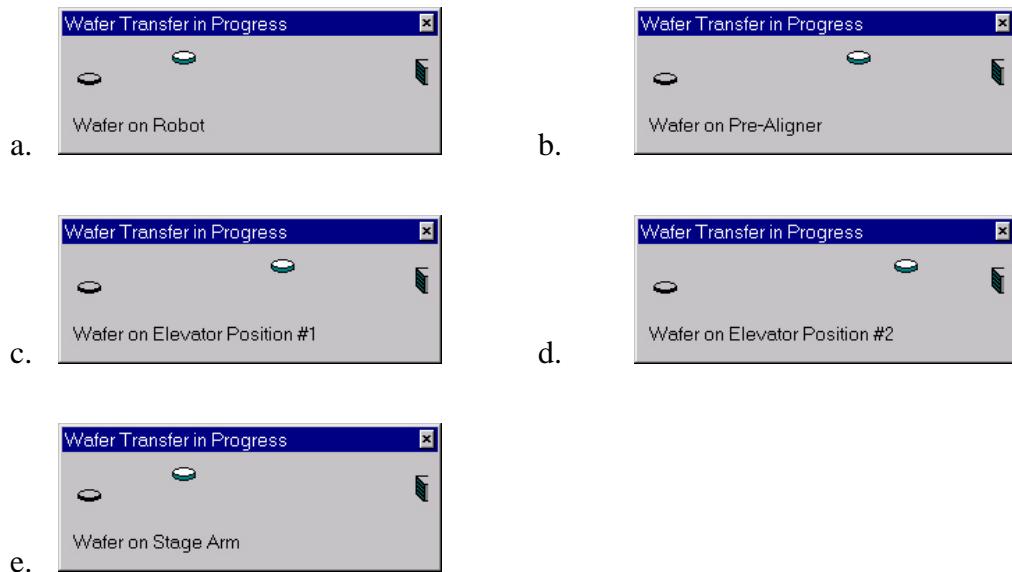
When you are sure that the wafer table is correct, go to the next step.

4. Click the Introduce Wafer button. Introduction of the first and second wafers begins.



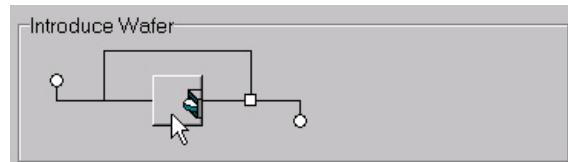
Section 3: FOUP

As the wafers are transferred, messages updating their progress will appear both in the wafer table and in “Wafer Transfer in Progress” status boxes. The following messages appear in sequence:



The final message, “Wafer staged,” appears in green in the wafer table. When the wafer is placed on the stage, the Drive to Center routine is performed automatically. The wafer is ready for analysis.

5. Perform the **Wafer/SEM, AES**, and, if desired, **Ion** and **EDS** procedures.
6. When done analyzing the current wafer, click the FOUP session tab, then click the Load Next Wafer (Introduce Wafer) button.



Section 3: FOUP

7. Repeat steps 5 and 6 until all the wafers selected for analysis from this FOUP have been analyzed.
8. Click the Unload FOUP/Cassette button. Any remaining wafers are returned to their original slots in the FOUP, and the FOUP is automatically undocked from the minienvironment for removal from the tool.



NOTE: The Restore button in the Advanced Controls area can be used to load the wafer list that was active prior to the last shutdown of SmartSoft.

Load and introduce 200-mm wafers or platen

Either an open cassette of 200-mm wafers or a special platen carrier is manually placed on the cassette pedestal inside the minienvironment. All wafer transfers from the pedestal to the vacuum system and back are fully automated.

When loading the multi-sample platen, a special platen carrier holds the platen and is placed on the pedestal. The multi-sample platen can hold multiple small samples for analysis.

Using the Multi-Sample Platen

Special care must be taken when mounting samples on the multi-sample platen so that they are positioned correctly for the analyzer.



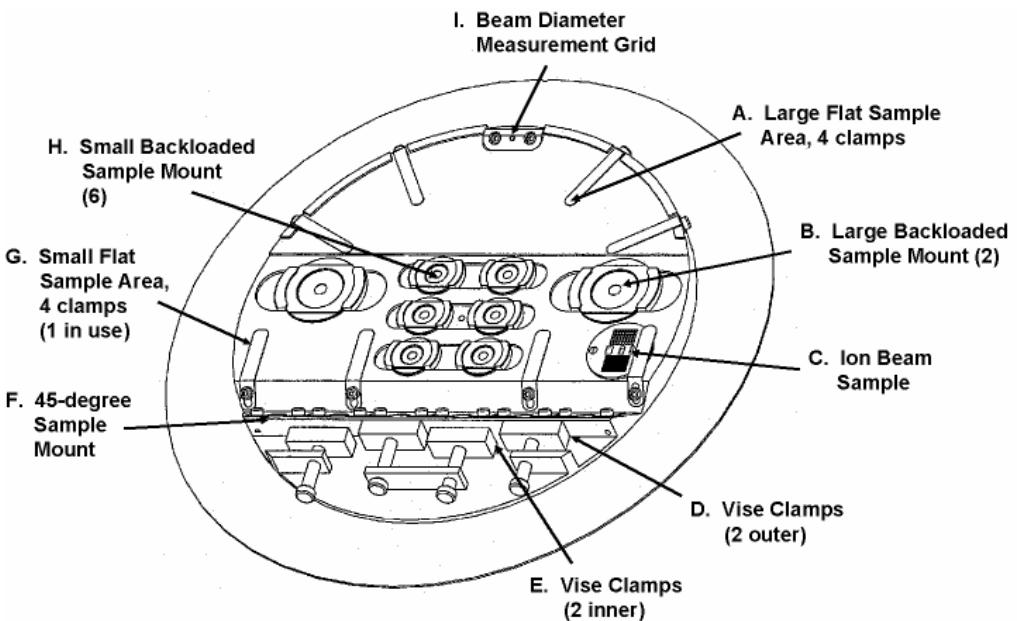
WARNING: Improper mounting of samples on the multi-sample platen can damage the analyzer. Mounting samples so that they are outside the analyzer's analysis range can result in interference with the analyzer's magnetic shield, damaging the instrument.

When mounting samples, refer to the drawing and key below, which indicate which areas of the platen can be used for various types of samples. Maximum sample size is also given.

After samples are mounted, the height gage and gage pin should be used to ensure proper mounting. Refer to the procedures given below.

Section 3: FOUP

Multi-sample platen.



Key

- Large flat sample area: This area is for small wafer pieces. Maximum thickness of the samples that can be mounted here is 0.76 mm.
- Large backloaded sample mount: Samples are loaded from the bottom of the platen using a sample backing plate and an adjustable clamping plate. A needle-nose pliers is used to pinch the clamp and move it down until it takes up all the slack between the backing plate and the sample. Samples should have a maximum diameter of 22 mm, maximum thickness of 6 mm.
- Ion beam sample: The sample mounted in this position is used for ion beam characterization.
- Outer vise clamps: Samples up to 3 mm thick and 8 mm high (maximum) can be mounted using the spring-loaded vises. The surface to be analyzed must be within 1 mm of the top of the vise.
- Inner vise clamps: Samples up to 6 mm thick and 8 mm high (maximum) can be mounted here. The surface to be analyzed must be within 1 mm of the top of the vise.
- 45-degree sample mount: This area is designed to allow samples to be mounted at a 45-degree angle. The surface to be analyzed must be within 1 mm of the top edge.

Section 3: FOUP

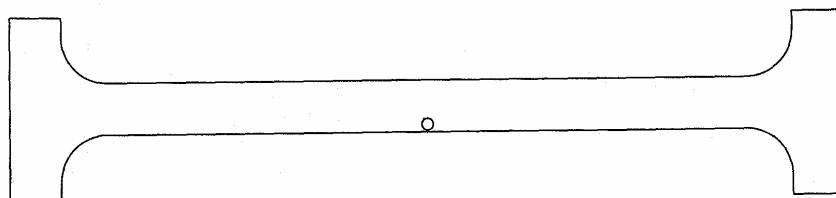
- G. Small flat sample area: This area is 1.55 mm below the top surface of the platen. Samples mounted in this area must be between 0.55 and 1.55 mm thick. If the samples are thinner, they should be shimmed up to fall into this range.
- H. Small backloaded sample mount: Samples are loaded from the bottom of the platen using a sample backing plate and an adjustable clamping plate. A needle-nose pliers is used to pinch the clamp and move it down until it takes up all the slack between the backing plate and the sample. Samples should have a maximum diameter of 12 mm, maximum thickness of 6 mm.
- I. Beam diameter measurement grid: This grid is used to characterize the electron beam of the analyzer.

After mounting the samples, use the height gage and gage pin to ensure proper mounting. The height gage will determine if samples are positioned too high, while the gage pin will determine if samples are positioned too low, below the analyzer's range.

To use the height gage:

1. Place the platen, with mounted samples, on a flat surface.
2. Drag the height gage across the top of the assembly to ensure that no part of the assembly touches the gage.

Height gage.



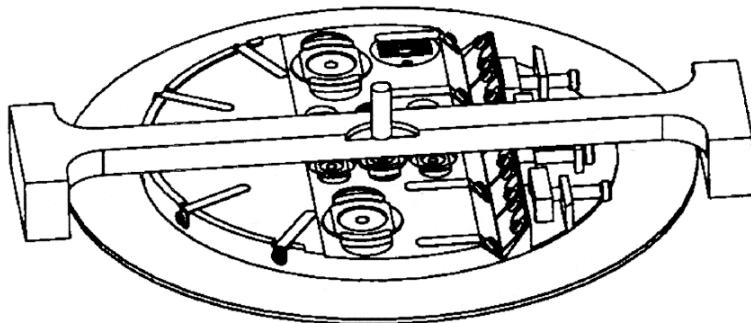
To use the gage pin:

1. Position the height gage over the platen, as pictured below, and place the pin into position.
2. Rotate and slide the height gage over the platen to check any sample. The sample surface to be analyzed should not fall below the 1 mm pin.

ATTENTION: Trying to analyze sample surfaces that fall below the 1 mm pin could result in damage to the analyzer.

Section 3: FOUP

Height gage and gage pin over platen.



Loading and Introducing 200 mm Wafers or Platen

1. Put on a clean room coat, booties, head wear, beard cap (if you have facial hair), and gloves. Tuck all hair into the head wear and beard cap. Or, follow your company's cleanroom gowning protocol.



2. Prepare an open cassette with wafers or a platen and platform.

Section 3: FOUP

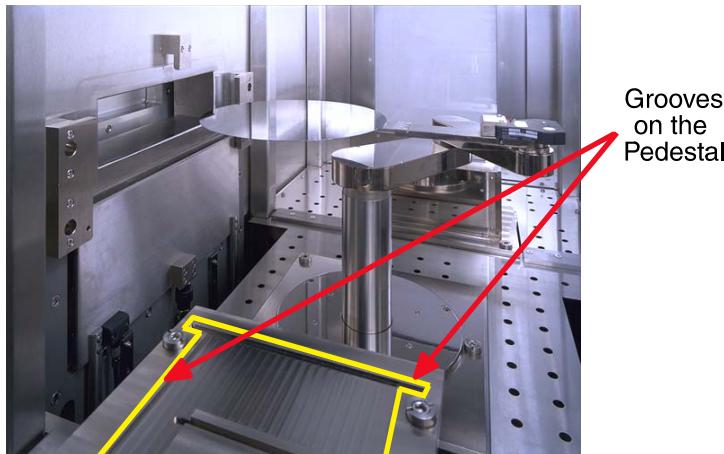
3. Open the door of the wafer-handling minienvironment as follows:

- a. Turn the “key” to unlock the first of two locks on the cassette door. Then, remove the key and insert it into the second lock. Turn it to unlock it. Then, slowly pull on the door and open it.

NOTE: Positive, nonturbulent, filtered air flow from the top to the bottom of the minienvironment maintains a class-1 or better environment when operating in a Class 1000 or better cleanroom, even when the cassette door is open.



- b. Place the cassette or platform into the grooves on the pedestal.



Section 3: FOUP



- c. Close the minienvironment door, turn the key to lock the first lock, and remove the key. Then, insert the key into the other lock, turn the key to lock it, and leave the key in the lock.



4. Click the FOUP session tab along the top of the SmartSoft user interface. The Wafer Load and Unload application is displayed on the right side of the SmartSoft window.



Section 3: FOUP

Click the Load FOUP button.



NOTE: The tool will not access the cassette/carrier if the FIM is occupied.

The cassette or platen is scanned to identify which slots contain wafers and platens. The results of the scan are displayed on the computer monitor in the wafer table. Slots that are empty or contain cross-slotted wafers (resting in slots not directly across from each other) are gray.

| Slot | Analyze | Order | Status |
|------|---------|-------|--------|
| 25 | Yes | 3 | FOUP |
| 24 | Yes | 2 | FOUP |
| 23 | Yes | 1 | FOUP |

5. In the wafer table, specify which wafers or platen will be analyzed and in which order as follows:
 - a. Each wafer displays Yes in the Analyze field. For each wafer that is *not* to be analyzed, click in that wafer's Analyze field, and the field will automatically change to No. That row in the wafer table is now gray to indicate that this wafer will be skipped when analysis of the wafers in this cassette begins.

| Slot | Analyze | Order | Status |
|------|---------|-------|--------|
| 25 | Yes | 2 | FOUP |
| 24 | No | | FOUP |
| 23 | Yes | 1 | FOUP |

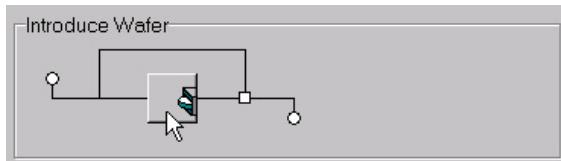
- b. The wafers/platens detected are automatically assigned an order number. To change the order, click in the Order field for each wafer, and select a number to indicate the order in which this wafer/platen is to be analyzed.

NOTE: Once another button is pressed in the Load, Unload input area, the wafer table is locked and remains locked until wafer transfer is completed. Since loading and unloading wafers from the elevator, intro, and analysis chamber is time consuming, do not click on the Introduce Wafer button (next step) until you are sure the wafer table is correct.

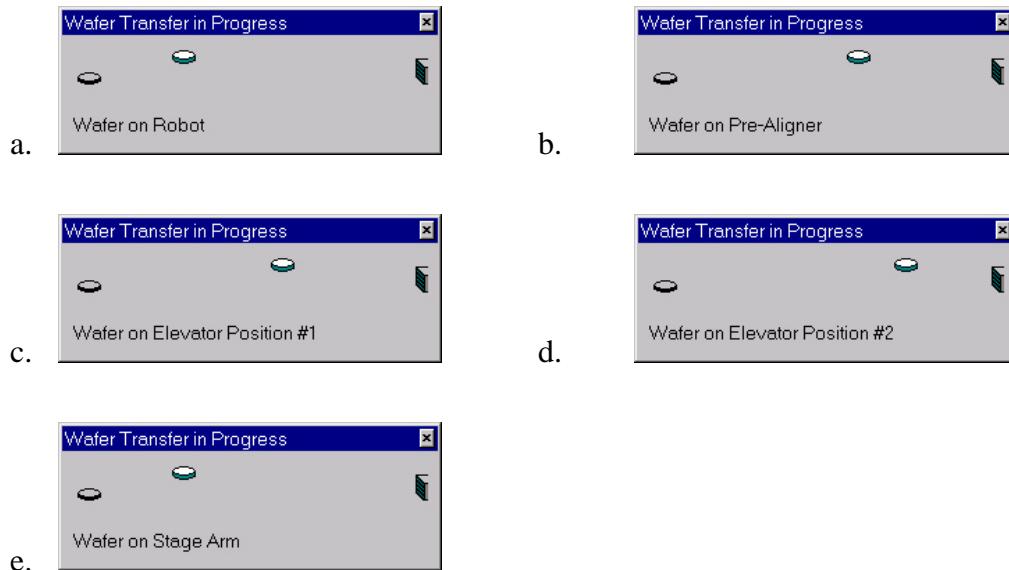
Section 3: FOUP

When you are sure that the wafer table is correct, go to the next step.

6. Click the Introduce Wafer button. Introduction of the first and second wafers or the platen begins.

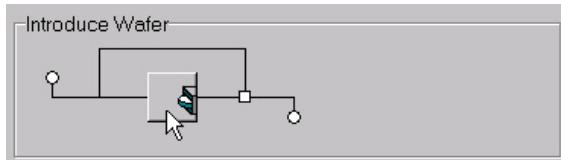


As the wafers or platen are transferred, messages updating their progress will appear both in the wafer table and in “Wafer Transfer in Progress” status boxes. The following messages appear in sequence:



The final message, “Wafer staged,” appears in green in the wafer table. When the wafer or platen is placed on the stage, the Drive to Center routine is performed automatically. The wafer or platen is ready for analysis.

7. Perform the **Wafer/SEM**, **AES**, and, if desired, **Ion** and **EDS** procedures.
8. When done analyzing the current wafer or platen, return to the FOUP session, and press the Load Next Wafer (Introduce Wafer) button.



Section 3: FOUP

9. Repeat steps 7 and 8 until all the wafers/platens selected for analysis from this cassette have been analyzed.
10. Press the Unload FOUP/Cassette button. Any remaining wafers/platens are returned to their original slots in the open cassette.



NOTE: The Restore button in the Advanced Controls area can be used to load the wafer list that was active prior to the last shutdown of SmartSoft.

11. Open the door of the wafer-handling minienvironment as follows:
 - a. Put on a cleanroom coat, booties, head wear, beard cap (if you have facial hair) and gloves. Tuck all hair into the head wear and beard cap. Or, follow your company's cleanroom gowning protocol.

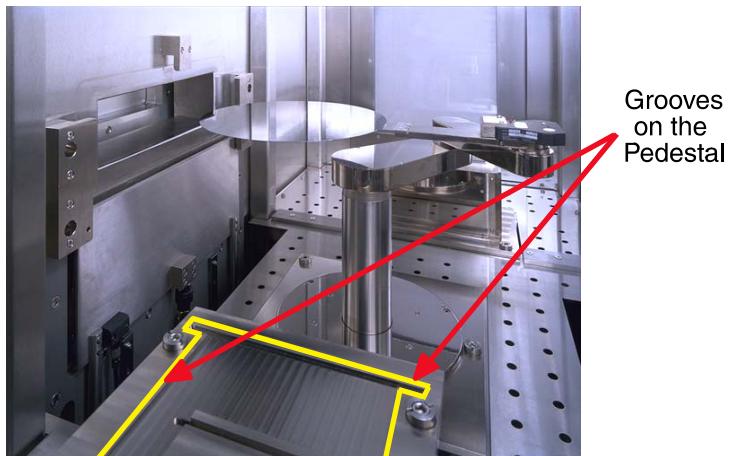


Section 3: FOUPI

- b. Turn the “key” to unlock the first of two locks on the cassette door. Then, remove the key and insert it into the second lock. Turn it to unlock it. Then, slowly pull on the door and open it.



- c. Slowly remove the cassette from the minienvironment. If needed, place the next cassette or platen carrier into the grooves on the pedestal.



Section 3: FOUPI



- d. Close the minienvironment door, turn the key to lock the first lock, and remove the key. Then, insert the key into the other lock, turn the key to lock it, and leave the key in the lock.



Section 4: INTRO

This section describes sample handling, including loading and unloading samples from the system. The procedures in this section are:

[**Initialize Stage**](#)

[**Intro Samples**](#)

[**Extract Samples**](#)

[**Park Samples**](#)

[**UnPark Samples**](#)

These procedures are to be performed after the **Starting and Ending a Session** procedure in Section 2.

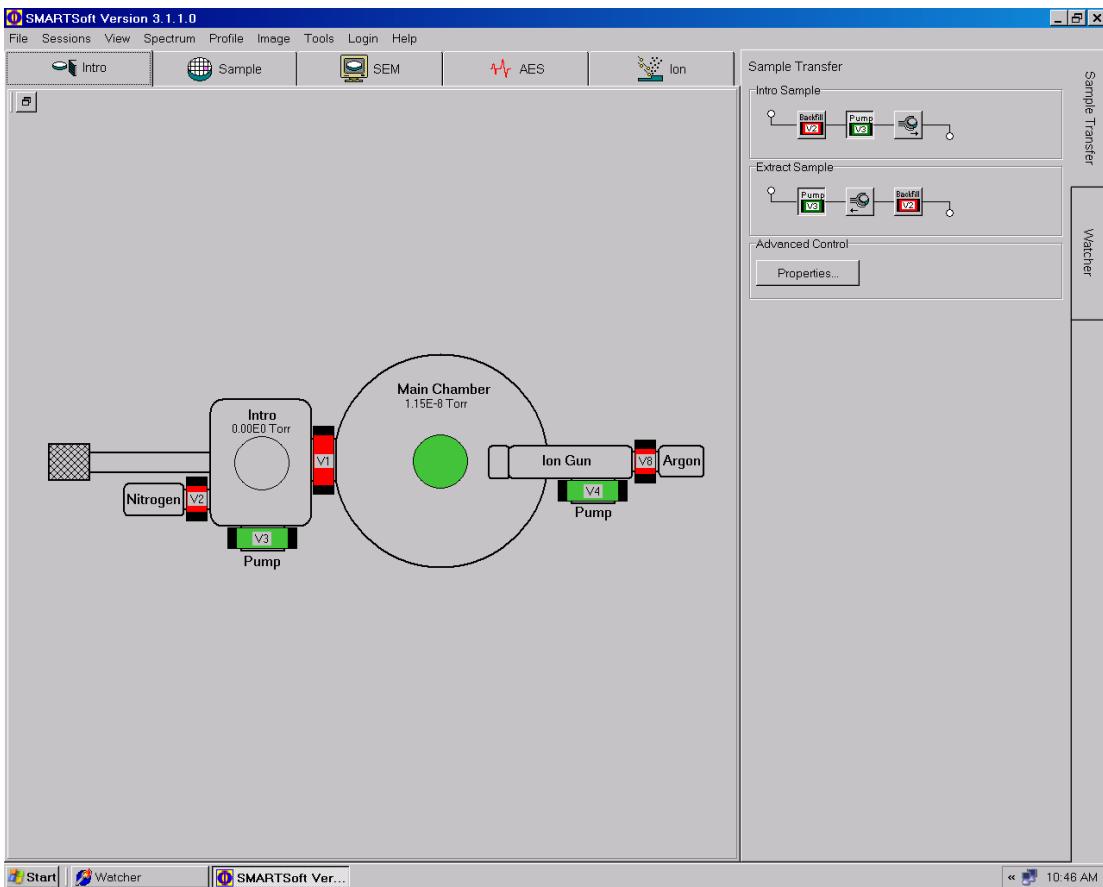
Sample Handling environment

The *PHI 700, PHI 690, PHI 680*'s integrated sample-handling environment, with SmartSoft and Watcher allows for the semi-automated transfer of sample(s) into the system's analytical chamber.

During the sample introduction process, the sample(s) are placed into the IntroChamber, where they are attached to an intro arm assembly. This chamber acts as an airlock, pumping down to allow for safe transfer into the analytical chamber.

The intro arm assembly transfers the sample(s) from the Introduction Chamber onto the stage for analysis.

Section 4:INTRO



Intro Window Display

The interactive intro display consists of the three system components [Intro, Main Chamber and Ion Gun] and their associated vacuum valves that are controlled by Watcher. Status of the valve states is indicated with the corresponding border color. Red indicates Closed. Green indicates Open.

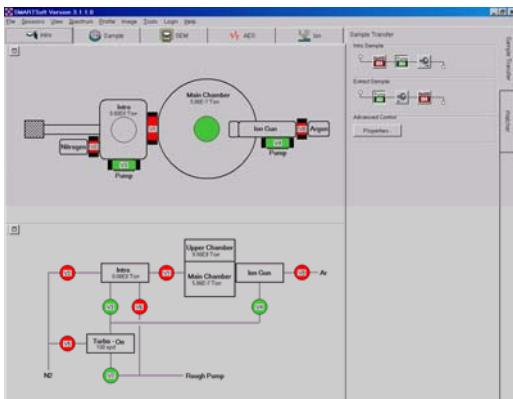
The Intro chamber circle, Main Chamber circle and Ion Gun Body each provide a “right click pull-down menu” with Watcher executable tasks.

The Main Chamber circle indicates the status of the stage. A moving stage is indicated by yellow. Green indicates that the stage is stopped and ready to be used.

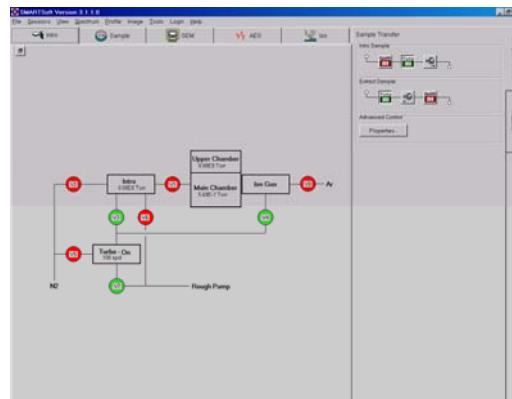
The sample end of the Ion Gun indicates the state of the Ion Gun. Clear indicates an Off state. Yellow indicates standby. Red indicates Sputter or Blank. When the ion Gun is in the sputter state, a red circle will appear on the green stage indicating that the ion beam is actually sputtering the sample.

Section 4:INTRO

Intro Display Split Screen Mode

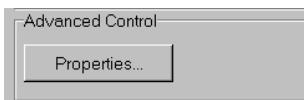


Intro Display Schematic Only



There are two other variations of available displays in the Intro window. Clicking the tile icon in the upper left corner of the display will change a full screen view to a split view. Clicking the corresponding fullscreen icon in the upper left corner of the desired view will change that view to a full screen view. The valve status in the schematic view is also updated with a “red” or “green” status.

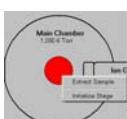
Initialize Stage



Warning: Stage needs to be initialized.

This message will appear if the stage needs to be initialized.

This will correspond with a red Main Chamber stage circle.



Right click on the Main Chamber stage circle and chose Initialize Stage.

Note: the status circle will change to yellow and the stage will perform an automated routine to drive each axis into mechanical limits to initialize each axis. When the stage has completed the rotation initialization the message will appear.



Select the Sample Tab

Section 4:INTRO

Select the Stage Tab along the right side.

Set the stage operation to relative.

Set the R delta to +2.00 or -2.00.

Drive the R axis until the index mark is aligned on the stage.



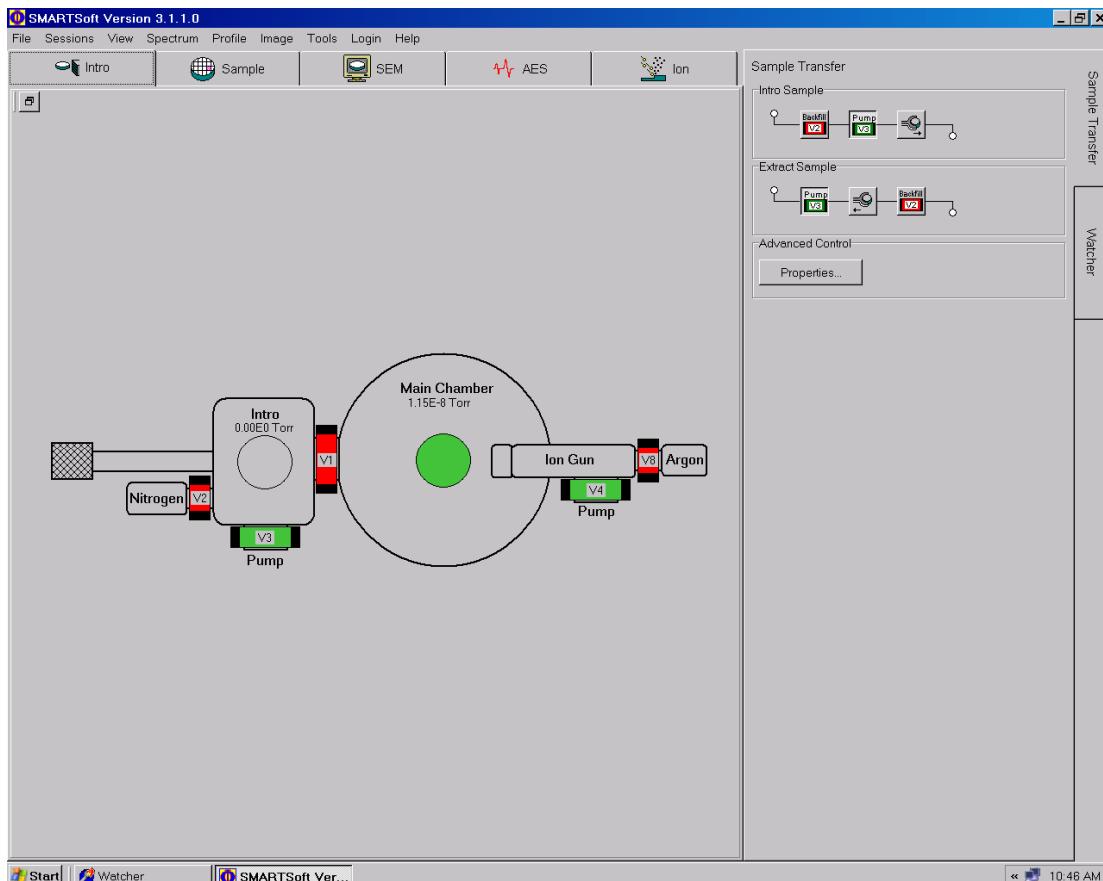
The stage is now initialized and will return to a “green status” on the Intro display.

Intro Samples

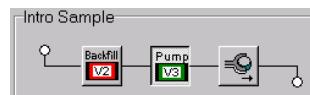
This procedure describes introducing the samples into the analysis chamber.

Load the sample to be analyzed onto a PHI sample holder

Click the INTRO session tab along the top of the SmartSoft user interface. The Sample Transfer application is displayed on the right side of the SmartSoft window.



Locate the Intro Sample flow.



Click the Backfill V2 button. V2 and V3 will toggle states.



NOTE: An hourglass will appear during the vent cycle.

When the hourglass disappears and the Intro pressure reaches 760Torr it is safe to open the introduction chamber lid.

Open the intro chamber lid and install the sample holder onto the Intro arm.

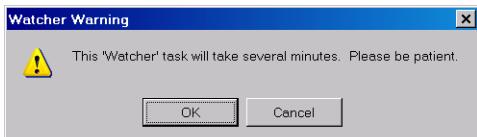
Close the intro chamber lid.

Section 4:INTRO

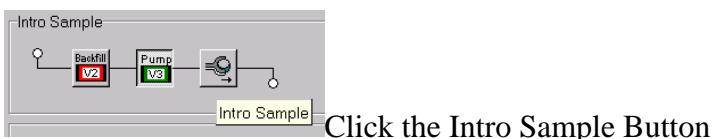


NOTE: If the Automatically Start and Stop Differential Pump button in the Ion/Sputter/SputterProperties menu is selected, then the V4 will close.

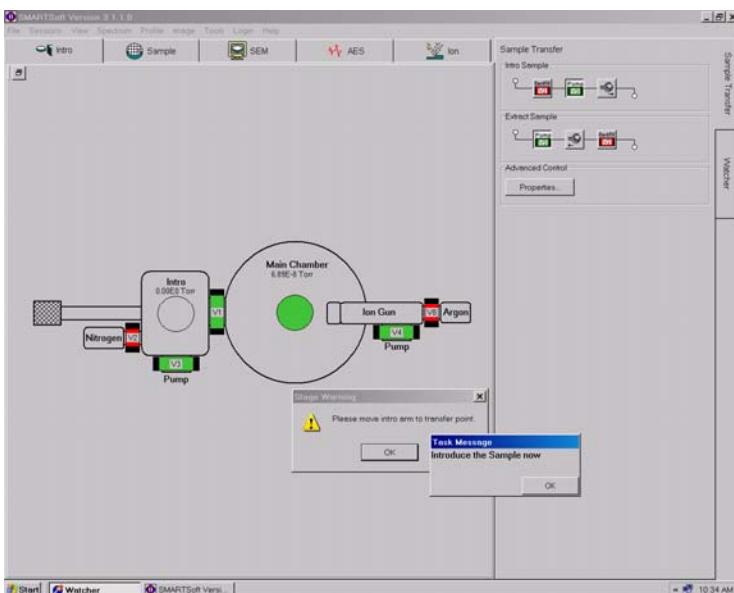
NOTE: If the turbo is not currently running, it will be automatically started by watcher.



This message will appear along with an hourglass during the pump-down cycle. When the hourglass disappears it is safe to select the next cycle.



Note: The stage will move to the Intro position. V1 will open and a message box will appear.



Slide the Introduction Rod assembly into its fully inserted position.

Click the OK button on both message boxes.

Section 4:INTRO

Note: The stage will move up to engage with the sample holder. The Main Chamber Status circle will change to yellow and back to green. A message box will appear.



Retract the Introduction Rod Assembly to its fully retracted position.

Note: When the intro arm is fully retracted, V1 will automatically close. The stage will stay in the transfer position.

Click OK.

Sample introduction is complete. The Main Chamber status is “green”. The sample is ready for positioning and analysis.

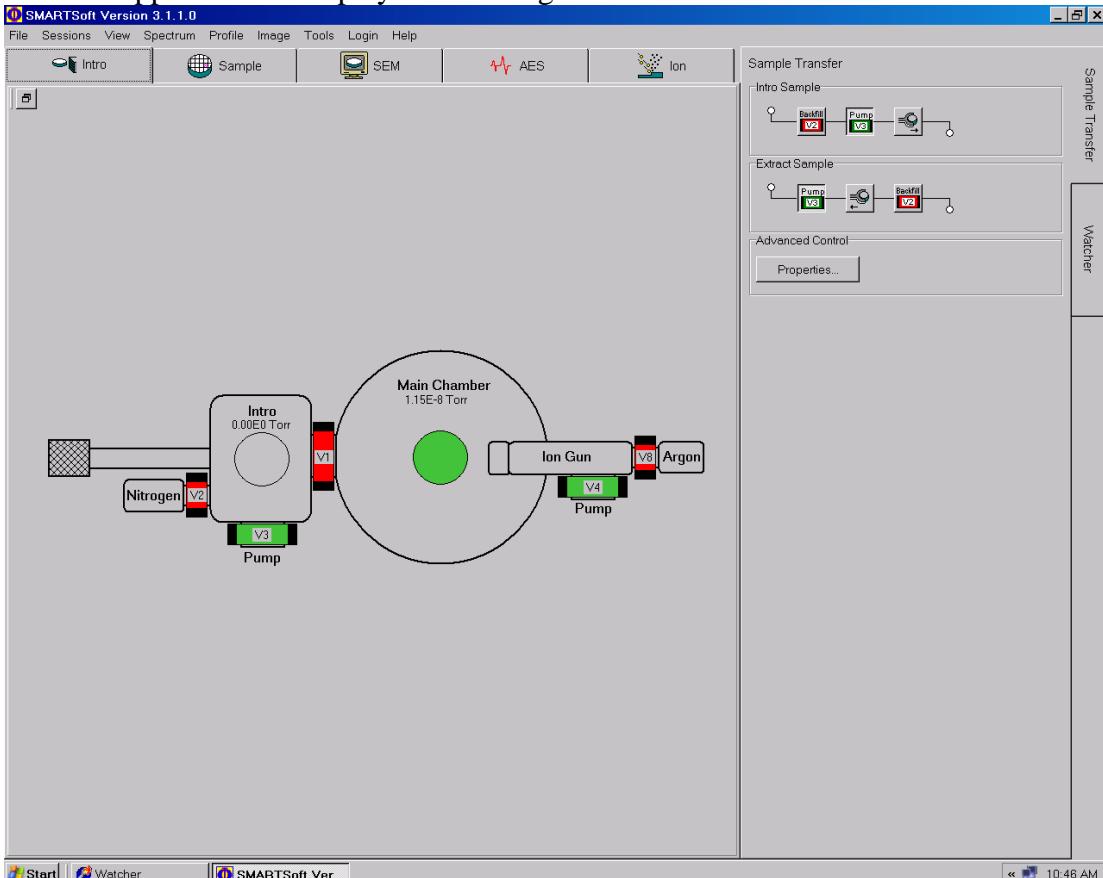
Perform the **Sample/SEM**, **AES**, and, if desired, **Ion** and **EDS** procedures.

When finished analyzing the current sample, perform the Extract Sample Routine.

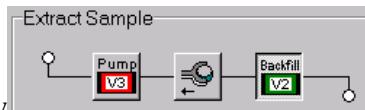
Extract Samples

This procedure describes extracting the samples from the analysis chamber.

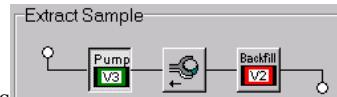
Click the INTRO session tab along the top of the SmartSoft user interface. The Sample Transfer application is displayed on the right side of the SmartSoft window.



Locate the Extract Sample flow



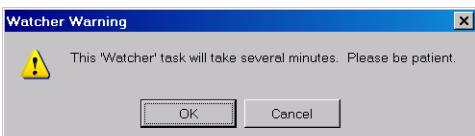
Click the Pump V3 button. V3 and V2 will toggle states



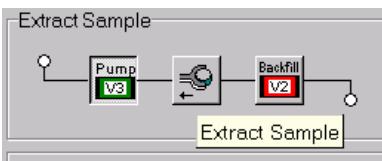
NOTE: If the Automatically Start and Stop Differential Pump button in the Ion/Sputter/SputterProperties menu is selected, then the V4 will close.

NOTE: If the turbo is not currently running, it will be automatically started by Watcher.

Section 4:INTRO

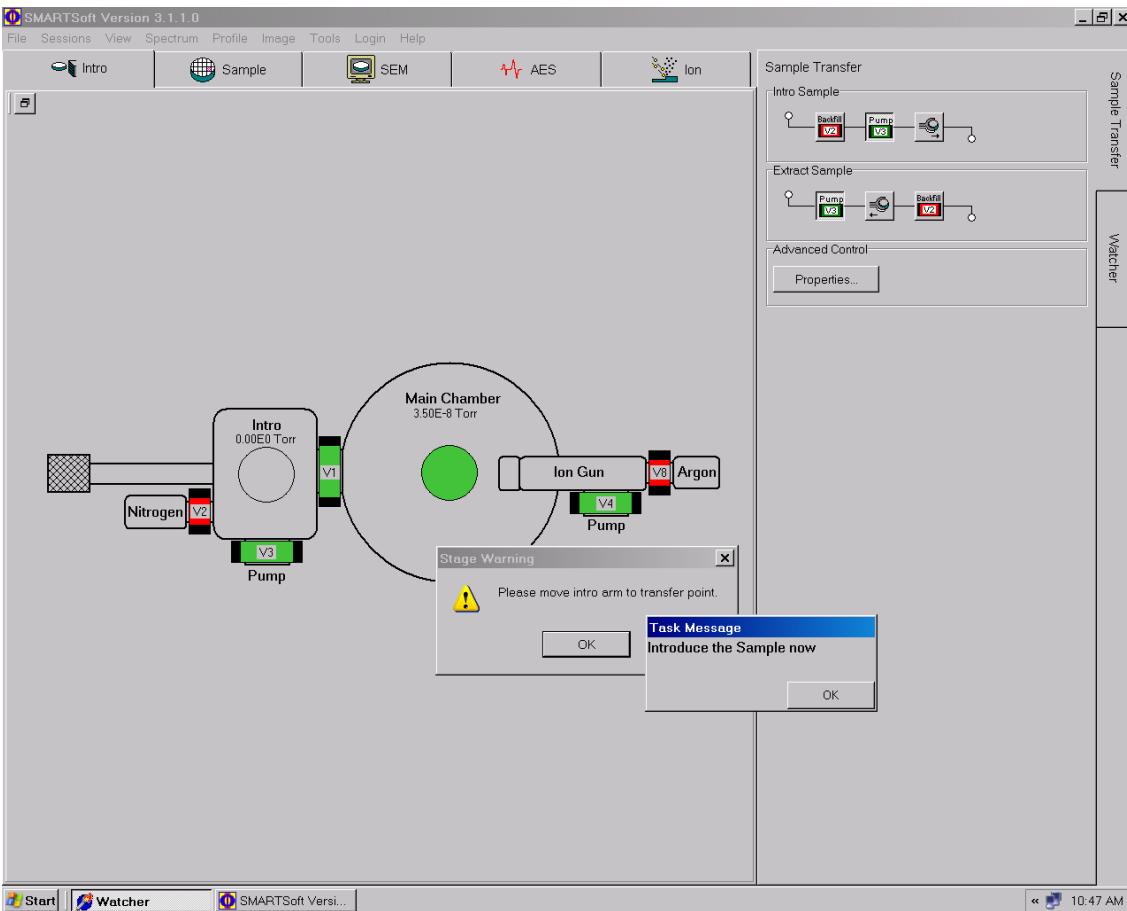


This message will appear along with an hourglass during the pump-down cycle. When the hour glass disappears it is safe to select the next cycle.



Click the Extract Sample Button.

Note: The stage will move to the Extract position. VI will open and a message box will appear.



Slide the Introduction Rod assembly into it's fully inserted position.

Click the OK button on both of the message boxes.

Note: The stage will move down to disengage with the sample holder. A message box will appear.

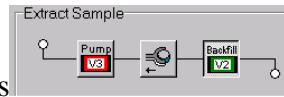
Section 4:INTRO



Retract the Intro arm to its fully retracted position.

Note: When the intro arm is fully retracted, V1 will automatically close. The stage will stay in the transfer position.

Click the Backfill V2 button. V2 and V3 will toggle states



NOTE: An hourglass will appear during the vent cycle.

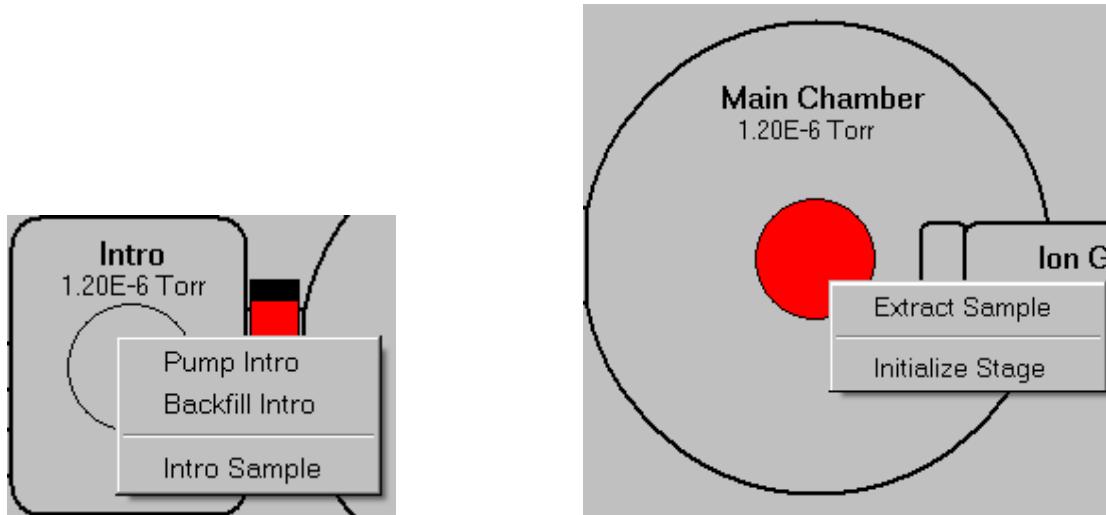
When the hourglass disappears and the Intro pressure reaches 760Torr it is safe to open the introduction chamber lid.

Open the intro chamber lid and remove the sample holder from the Intro arm.

Close the intro chamber lid.

Sample transfer is complete. The intro is ready for a new sample to be installed. If installation is not required, then the Intro Chamber can temporarily be pumped down until the next analysis.

**Additional methods of accomplishing sample transfers
and “Intro Chamber pump/vent**



Right Click the Intro area of the window display.

The pump intro and backfill intro operations can be executed from this pop-up window.
The Intro Sample operation can be executed from this pop-up window.

Right Click the Main Chamber area of the window display.

The Extract Sample operation can be executed from this pop-up window.

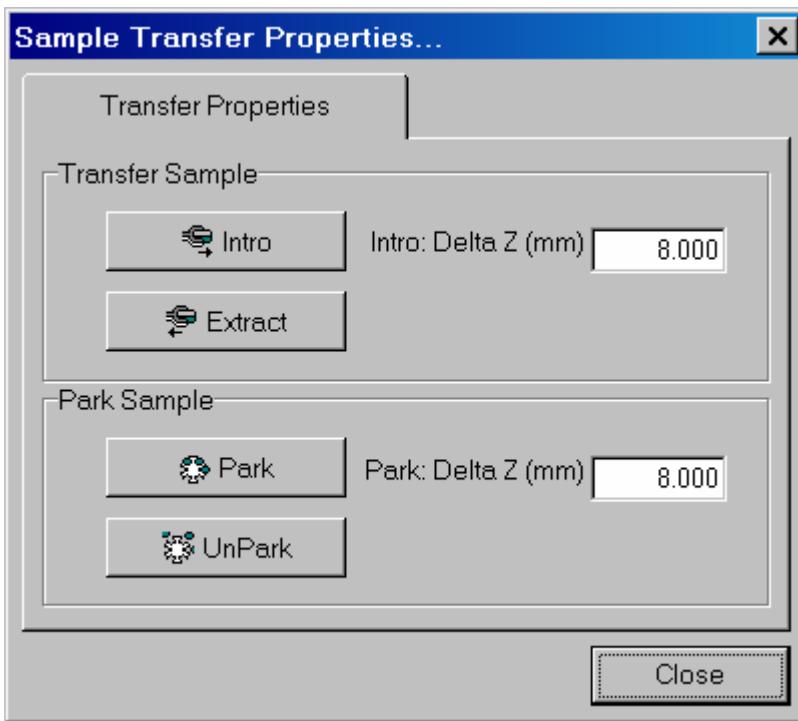
Advanced Control

Advanced Control options are located within the Sample Transfer application on the right side of the SmartSoft window.



Click the Properties... Button.

The Sample Transfer Properties... window will appear. This window will allow for calibration of the Z axis motion for the sample transfer and sample park operations. Execution of Park/UnPark Sample are located here. The Sample Transfer Intro/Extract buttons are duplicated here to facilitate the Intro:DeltaZ calibration.



Park Sample

Select the Park button.

Note: the stage will move to the Park position. The following message will appear.



Section 4:INTRO

Select the desired park station on the Specimen Parking Attachment, move to the transfer point and click OK.

Note: the stage will move down the defined Delta Z to transfer the sample from the stage onto the park station. The following message will appear.



Move the park station to the park position. The Park operation is complete. Continue with the UnPark Sample operation to retrieve another sample or return to the Intro session by choosing Close to intro a new sample.

UnPark Sample

Select the UnPark button.

Note: the stage will move to the UnPark position. The following message will appear.



Select the desired park station on the Specimen Parking Attachment, move to the transfer point and click OK

Note: the stage will move up the defined Delta Z to transfer the sample from the park station onto the stage. The following message will appear.



Move the park station to the park position. The UnPark operation is complete. Return to the Sample Tab to select the desired stage position or to the Intro session by choosing Close to extract this sample.

Section 4:INTRO

Section 5:

Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

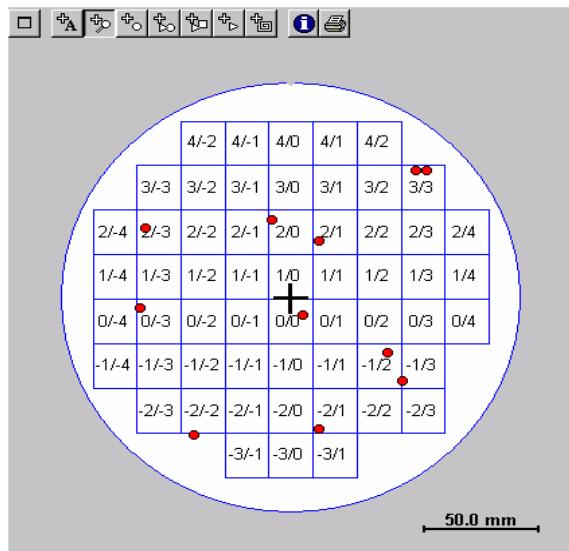
Procedures in the Wafer and SEM sessions or Sample and SEM sessions are described in this section because the two sessions are used interactively to obtain and adjust a SEM image, align a wafer and navigate to defects.

The procedures in this section include:

- A. Turn SEM imaging on
- B. Perform Manual Z Align (adjust stage height)
- C. Optimize the electron gun operating parameters
- D. Open a position list file (SMART_Tool)
- E. Align the wafer (SMART_Tool)
- F. Locate and center the area of interest (SMART_Tool)
- G. Locate and center the area of interest PHI 700, PHI 690, PHI 680)
- H. Acquire SEM images
- I. Create New SEM Settings
- J. SEM Advanced Control

Before performing these procedures, perform the Section **FOUP** or **INTRO** procedures.

Overview of Wafer Map Area

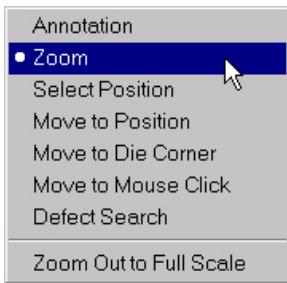


Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

The wafer map area displays a wafer map when a position list is opened. The wafer map area also includes a line scale and a crosshair over the map that shows the position of the electron beam on the sample. The crosshair is pictured here:



The operator can use the point-and-click toolbar buttons to interact with the map, or right-click over the map, which brings up a shortcut menu with additional options, as seen below.



Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

The point-and-click toolbar buttons and their actions are listed here:

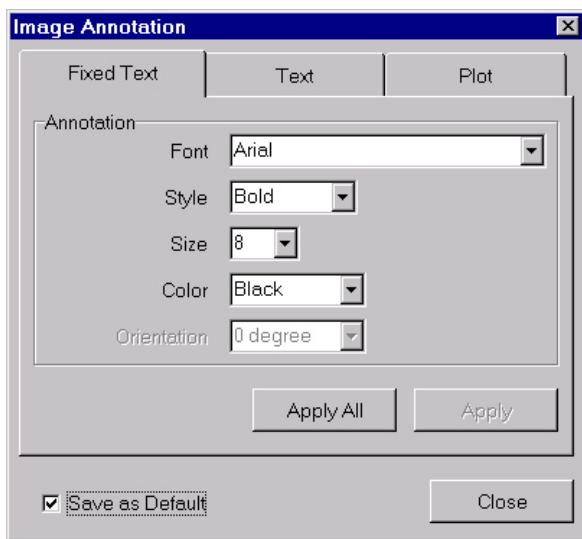
| Button | Action/Result |
|--------|---|
| or | Resizes the wafer map area; is used for a full screen view; reduces the wafer map so the position list and SEM image area can be seen. |
| | Annotation: Click this button, then double-click over the wafer map to add text to the map. A text box is created that can then be moved by clicking over the text and dragging to the desired location. Double-click twice over the box to edit text. Double-click once over the box, then right-click for more options. |
| | Zoom: Click this button, then click over the wafer map and drag to draw a box around the area you want enlarged. To view the entire map again, right-click over the map and select Zoom Out to Full Scale. <i>NOTE: The Zoom button is the default button for the wafer map area. When other buttons are clicked, then clicked again to deselect, the Zoom button becomes the active button.</i> |
| | Select Position: Use this button with the position list visible. Click the button, then click on any defect. It will be highlighted in the position list. |
| | Move to Position: Click this button, then over a defect on the wafer map. The stage will move to that defect. |
| | Move to Die Corner: Click this button, then over any die on the wafer map to move the stage to the lower left corner of that die. |
| | Move to Mouse Click: Click this button, then over any point on the wafer map. The stage will drive to that position. |
| | Defect Search: See the Defect Search subsection below for details. |
| | Display File and Wafer Information: Click to display the File Information box, which contains information on the position list file and wafer map. |
| | Print: Prints the wafer map to the default printer. |

Additional options in the shortcut menu include:

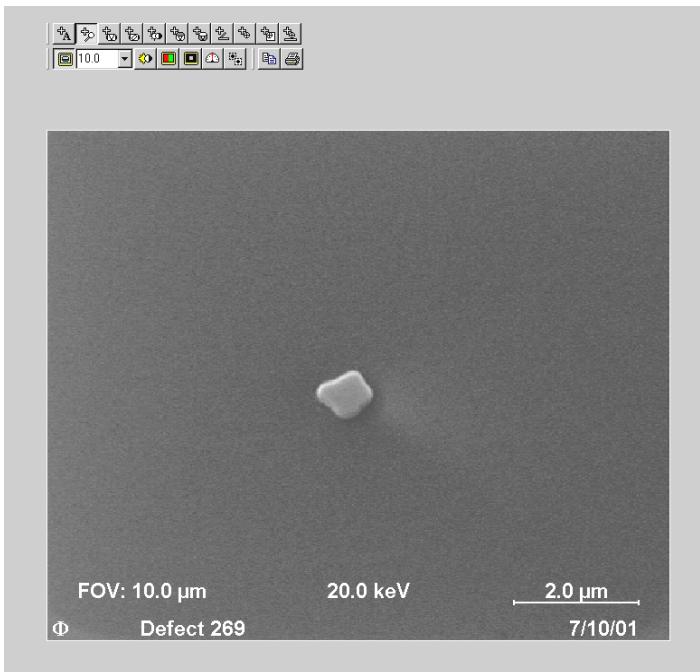
- Zoom Out to Full Scale: Returns the wafer map to full scale after Zoom is used to enlarge part of the map.

NOTE: The following options appear in the shortcut menu when the Annotation button is selected:

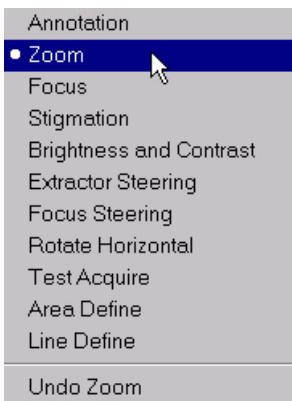
- Paste: Inserts text on the clipboard into the wafer map area as an annotation.
- Delete All Annotation: Removes all annotation from the wafer map area.
- Properties: This option brings up the Image Annotation box, which allows the operator to adjust text font, style, size, color and orientation. The Fixed Text tab adjusts the appearance of the line scale. The Text tab adjusts the appearance of annotations added to the wafer map area.



Overview of SEM Image Area



The SEM image area allows the operator to interact with the live SEM image using the point-and-click toolbar buttons. Like the wafer map area, a shortcut menu is available by right-clicking over the area:



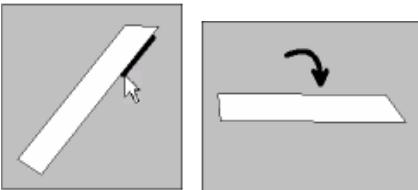
Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

The toolbar buttons listed below are used interactively — the SEM image is changed or an area defined by selecting a button, then clicking and dragging over the image:

| Button | Action/Result |
|--------|---|
| | Resizes the SEM image area; is used for a full screen view; reduces the image area so other areas can be seen. |
| | Annotation: Click this button, then double-click over the SEM image to add text to the image. A text box is created that can be moved by clicking over the text and dragging. Double-click twice over the box to edit text. Double-click once over the box, then right-click for more options. |
| | Move/Zoom: Click this button, then click over the SEM image and drag to draw a box around the area you want enlarged. You can also click over the SEM image without drawing a box; this re-centers the image so that the point that was clicked is in the center of the field of view. <i>NOTE: The Move/Zoom button is the default button for the SEM image area. When other buttons are clicked, then clicked again to deselect, the Move/Zoom button becomes the active button.</i> |
| | Focus: Click the button, then over the SEM image; drag left and right to adjust focus. This is as coarse focus adjustment. Fine focus is adjusted using the Fine Focus knob on the Model 20-625 Electron Gun Control, found on the front of the electronics console. |
| | Stigmation: Click the button, then over the SEM image; drag up, down, left and right to obtain the clearest image. |
| | Brightness/Contrast: Click the button, then over the SEM image; drag up and down to adjust brightness, left and right to adjust contrast. |
| | Extractor Steering: Click the button, then over the SEM image; drag up, down, left and right to maximize the beam current as read from the Keithley Picoammeter on the electronics console. This adjustment centers the electron beam in the objective lens aperture. |
| | Focus Steering: Click the button, then over the SEM image; drag up, down, left and right to minimize the wobble. This adjustment centers the electron beam in the objective lens. |

Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

SEM Image Point-and-Click Toolbar Buttons, concluded.

| Button | Action/Result |
|---|--|
|  | Move/Rotate Horizontal: Click the button, then click and drag to draw a line over the SEM image. The image will be rotated as seen here:  |
|  | Test Acquire: Click the button, then over the SEM image to define a point for a Test Acquire. |
|  | Area Define: Click the button, then click over the image to define a point for analysis. Click and drag over the image to define an area for analysis. Double-click over an area to change it to a point, or over a point to change it to an area. |
|  | Line Define: Click the button, then click over the SEM image to place a line for a line analysis. Double-click over the line to change its orientation from horizontal to vertical, or from vertical to horizontal. |

NOTE: Buttons marked with an asterisk () can be used in combination with the Shift key on the keyboard. Click the desired button, then press the Shift key while clicking and dragging over the image; changes to the image will be greater in magnitude than clicking and dragging alone.*

Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

The buttons below are used for adjusting the SEM image, but do not require interacting with the SEM image the way the point-and-click buttons do. These buttons set a SEM imaging parameter or activate a SEM imaging mode.

| Button | Action/Result |
|--------|---|
| | Start/Stop Imaging: Click to start or stop continuous refresh of the SEM image. |
| 50.0 | Field of View (μm): Use the drop-down box to select the field of view. The larger the value selected, the lower the magnification. Type a value into the box, which is then temporarily added to the list of FOV values. Or, use the up and down arrow keys on the keyboard to move quickly between FOV options. |
| | AutoVideo: Click this button to automatically adjust the SED multiplier voltage, gain, contrast and brightness. |
| | Video Calibrate: Click to colorize the image on the video monitor so that bright pixels are red and dark pixels are green. Then use the button to adjust the image so the red and green are balanced. |
| | Reduced Image: Click for a reduced image that can be useful when adjusting focus and stigmation. |
| | Scan Speed: A fast or medium scan speed is used during navigation. The slow scan speed yields better resolution, and is used for SEM imaging. |
| | Register Image: See the image registration subsection below for more details. |
| | Copy/Print: Click the copy button to copy the SEM image to the clipboard for insertion into MS Office applications; click the print button to print the image. |

Additional options in the shortcut menu include:

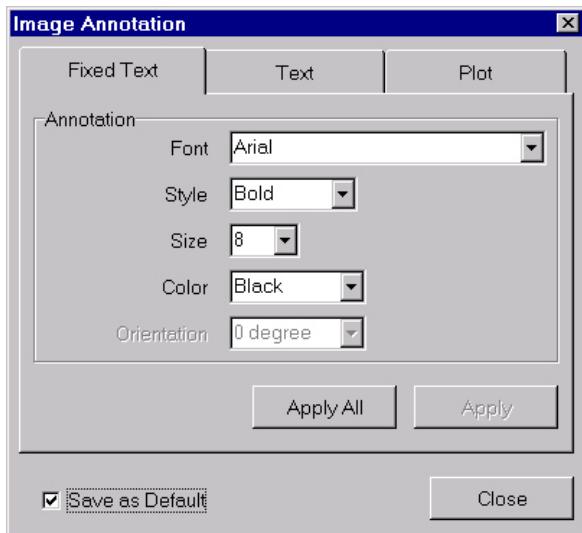
- Undo: One level of undo is offered for the last action performed.

NOTE: The following options appear in the shortcut menu when the Annotation button is selected:

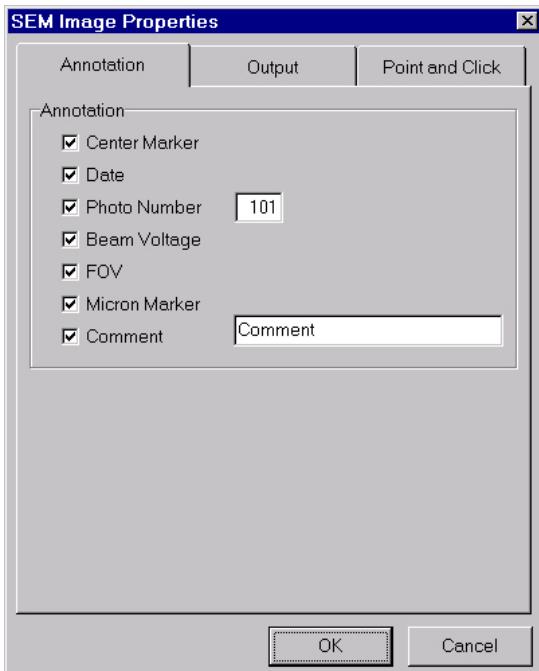
- Paste: Inserts text on the clipboard into the SEM image area as an annotation.
- Delete All Annotation: Removes all annotation from the SEM image area.
- Properties: This option brings up the Image Annotation box, which allows the operator to adjust text font, style, size, color and orientation. The Fixed Text tab

Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

adjusts the appearance of the fixed annotation fields on the SEM image (e.g., field of view, micron marker, date). The Text tab adjusts the appearance of additional annotations added to the SEM image area.

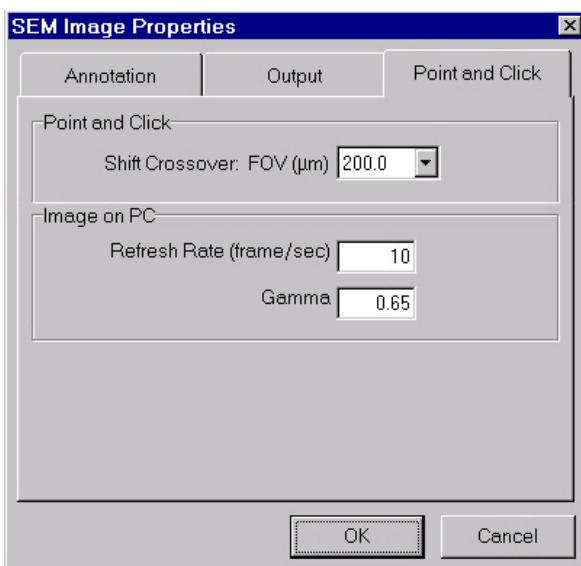


Additional adjustments can be made to the SEM image by clicking the SEM Hardware tab, then, in the Advanced Properties area, clicking the Image Properties button. This brings up the SEM Image Properties box, seen below:



Annotation tab: Select the fixed annotation fields you want to appear on the SEM image. The comment can be edited as well using this tab.

NOTE: To edit the comment without using the SEM Image Properties box, click the  button. Click once over the comment in the SEM image to select it, then double-click to edit.



Point and Click tab:

- Point and Click Shift Crossover: Typically, this parameter is not changed, but the operator may want to change it if frequent “Shift Limit” messages are displayed. The value determines whether an image shift or stage move is performed when a change of image position (e.g., zoom) is requested by the operator. When the crossover value is larger than the current field of view in the SEM image area, an image shift (optics adjustment) is performed. When the crossover parameter is smaller than the field of view, a stage move is performed to move the image.
- Image on PC: These parameters affect the appearance of the SEM image in the SmartSoft interface.
 - ◆ The refresh rate is the frequency with which the image is redrawn to maintain a constant, flicker-free image. The typical refresh rate for the image is about 10 hertz, or 10 frames per second.
 - ◆ Gamma describes the relationship between the input voltage of the cathode ray tube in the monitor and the light intensity produced. The effect of gamma is to adjust midtones relative to light and dark regions of the image. Gamma is generally adjusted to reduce excessive contrast in an image.

A. Turn SEM imaging on

When a wafer or platen reaches the stage, an SEM image or a video camera image is displayed on the video monitor. If imaging is not already on, perform the following procedure to turn imaging on:

Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

1. Click the SEM session tab.



The SEM setting will default to Initial, which sets the electron gun beam voltage and beam current parameters to safe values. The hardware values for the Initial setting are set by PHI customer service, but can be edited by the user.



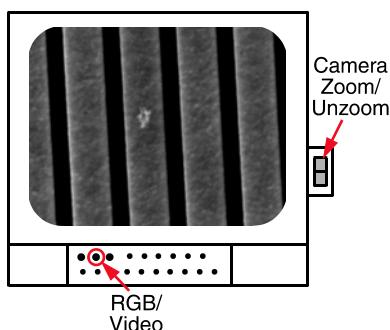
2. Select the Previous setting, which will set the electron gun beam voltage and beam current values to the values used prior to the last shutdown. Click Load.



3. Click the button in the SEM image toolbar to begin live imaging in the SmartSoft SEM area.
4. On the video monitor, the S-VIDEO light on the front of the monitor should *not* be on. If it is on, press the Video button (first monitor button) to turn it off.
5. On the video monitor, press the RGB MULTI button to toggle between the SEM (RGB MULTI light on) image or the camera image (VIDEO light on).*

NOTE: Zoom the video camera using the switch on the side of the monitor.

SMART-Tool only



* In the Ion session, when the VIDEO light is on, pressing icons in the FIB interface switches the image between an optical and an ion-induced electron image.

B. Perform Manual Z Align (adjust stage height)

When the wafer or platen is on the stage, the operator must adjust the height of the stage to place the sample's surface at the focal point of the analyzer. The focal point of the analyzer is not only where the best signal is acquired; other system parameters, like ion gun settings, magnifications, and energy scale, are calibrated for this position.

This procedure must be repeated for each new wafer/sample and may need to be repeated (depending on the flatness of the entire surface) each time the stage is moved to a new viewing or analysis position.

NOTE: Adjusting the stage height involves an elastic peak measurement performed with a 1 kV, 0.5 nA primary electron beam. In many cases, it may be sufficient to perform this procedure at or near the wafer's center. In these cases, there may be no need to locate a specific feature for the measurement.

NOTE: The Z Align hardware setting is found in the SEM settings area, and is automatically loaded when the Z Align button is selected. The parameters of the setting can be changed by the operator, but the Z Align procedure must be performed using a 1 kV, 0.5 nA electron beam to be accurate.

The procedure to perform Manual Z Align to position the surface at the focal point of the analyzer is given below.

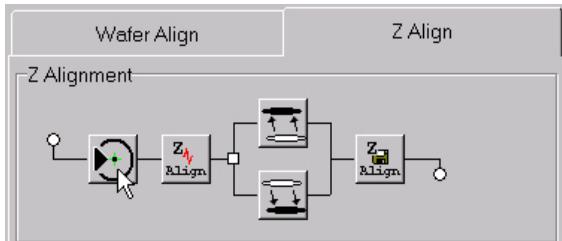
1. Click the Wafer session (SMART-Tool).



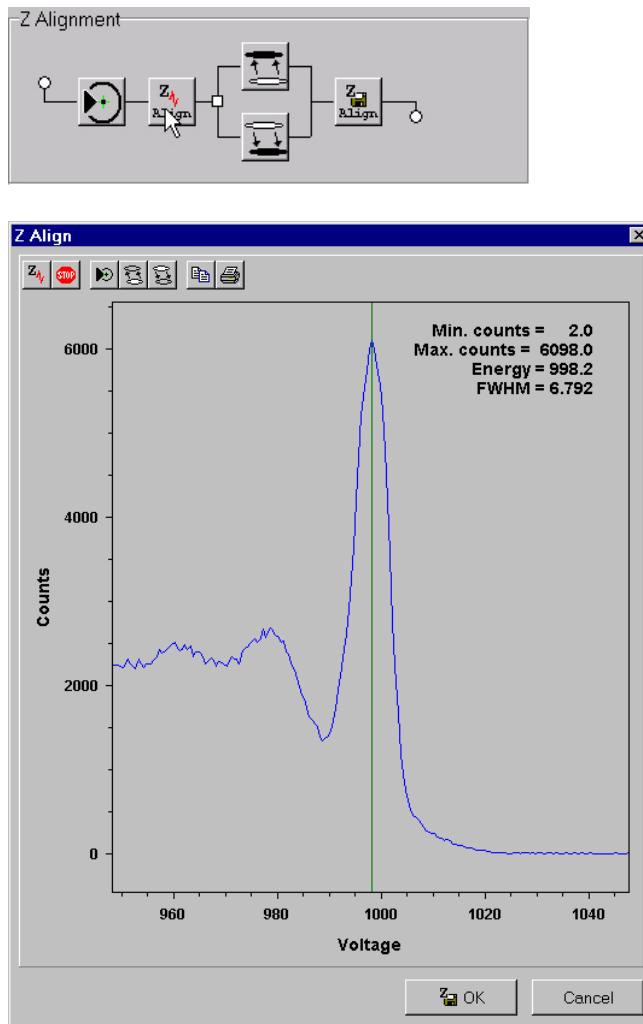
Click the Sample session (PHI 700, PHI 690, PHI 680)



2. In the Align application tab, click the Z align tab. Then click the first button in the Z Alignment flow, which will center the wafer.



3. Click the Z Align button. This opens the Z Align box, loads the Z Align electron gun parameters and starts the Z alignment.



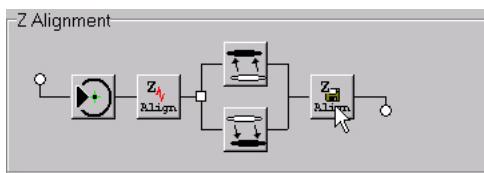
Z Align data is collected from the center of the SEM image's field of view. During Z Align, the SEM image is frozen.

Use the or button to adjust the position of the wafer so that the maximum point of the curve is centered at 1000 volts. To view a live SEM image with the Z Align 1 keV beam, click the button. Click the button to restart the Z align. When finished, click the button.

NOTE: The curve in the graph represents the elastic peak, an energy at or close to 1000 eV that is unique to each system.

(Optional) Use the  buttons to copy the Z Align graph to the clipboard or to print it.

4. (Optional) Save the current Z height as the default for this sample type (e.g., 300 mm wafer, 200 mm wafer, multi-sample platen) by clicking the Save Z Height button in the Z Alignment flow. The wafer will move automatically to the saved Z height following sample introduction if the option is selected in the Stage Properties box under Sample Introduction Defaults. See below for more information on Advanced Stage Control options.



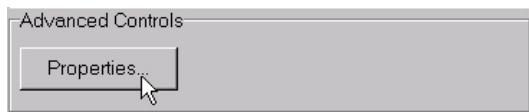
Z Align Box Properties

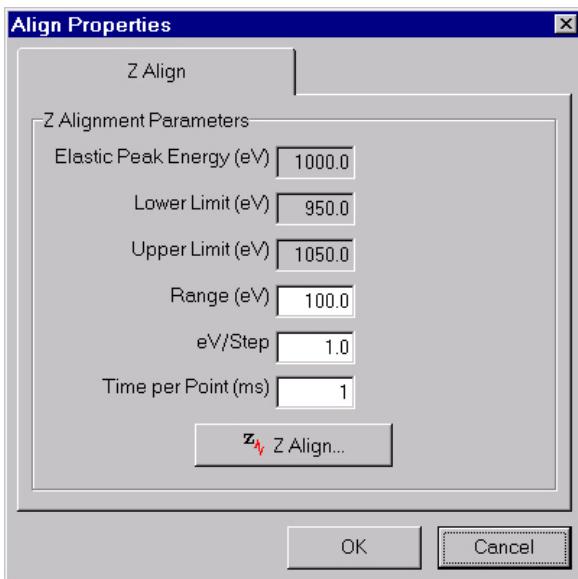
The Z Align box shows the elastic peak as a graphical representation, with the X axis indicating voltage and the Y axis, counts.

Additional information included in the graph is minimum counts, maximum counts, energy of the maximum point of the peak and FWHM (full width half maximum), which is a measure of spectral resolution.

Z Align Properties

On the Align application tab, click Advanced Properties to view the Z Align box:





The Elastic Peak Energy value is set by the PHI service engineer. The Lower and Upper Limits are the limits for the energy window in which data will be acquired. The limits are determined by the elastic peak energy value and the range value.

If desired, the Range and eV/step parameters may be changed, but the alignment must be stopped and restarted for the changes to take effect. Range is the energy range of acquisition for the alignment. (The default value is 100 eV.) The eV/step parameter specifies the energy step size for the scan (typically, 1.0). Entering a value of less than 1.0 for the eV/step parameter will result in a more precise Z alignment. This is recommended for procedures such as creating new FIB settings (see Ion Section of this manual).

C. Optimize the electron gun operating parameters

Next, the operator selects an operating beam voltage that is appropriate for the wafer/samples, then optimizes the associated operating parameters for the electron gun.

NOTE: This procedure needs to be done only once during an operation shift, unless the operating beam voltage is to be changed. In that case, perform this procedure before acquiring data at the new beam voltage.

This procedure starts with selection of a predefined “setting” that has the beam voltage and beam current desired for operation. Many settings can be defined and saved in SmartSoft. Using a predefined setting for the desired beam voltage and beam current saves countless hours, because the setting brings with it the correct electron gun parameters (e.g., Multiplier Voltage, Image Contrast, DC Offset, Extractor Wobble

Steering).* These parameters need only to be adjusted slightly to optimize them for the current analysis.

The “best” beam voltage (and associated electron gun parameters) will optimize the acquisition data for a given analysis situation. For example, a low beam voltage (3 kV) might be best for an insulating sample, but a higher beam voltage may be best for a metallic or conductive sample. Higher beam voltages yield better high-energy signal as well as better beam size at any given current.

A 10 kV beam voltage is popular for several reasons: good Auger electron yield for both high and low Auger energy peaks; good beam size; and known and published sensitivity factors.† A beam voltage of 20 kV allows for a smaller beam and is good for penetrating samples that have an insulating layer on top of a conductive layer. The high-voltage electron beam can penetrate the insulating layer and provide a conducting path to the underlying conductive layer, thereby decreasing or eliminating charging of the area during analysis. Because of the smaller beam diameter and the nature of e⁻ scattering‡, a 20 kV beam is often used for analysis of small particles on a wafer surface.

The following are general guidelines that may help the operator select an appropriate beam voltage:

| Auger Energies of Interest | Beam Voltage |
|-----------------------------------|---------------------|
| <1000 V | 5 kV |
| >1000 V | 10 kV |
| >2000 V | 20 kV |
| Magnification Used | Beam Voltage |
| > 2000 µm FOV | 5 kV |
| > 50 µm FOV | 10 kV |
| < 50 µm FOV | 20 kV |
| Bulk Insulating Material | Beam Voltage |
| Thin-Film Insulating Material | 20 kV |

ATTENTION: When the electron gun has not been at high voltages for some time, setting the electron beam voltage higher than 20 kV (>20 kV) may cause arcing, which could damage equipment. Slowly increase the voltage from a lower setting to the desired high-voltage value to condition the electron gun for the higher values.

* When a new setting is to be created, start from an existing setting, if at all possible.

† K.D. Childs et al., *Handbook of Auger Electron Spectroscopy*, Third Edition, Physical Electronics, Eden Prairie, 1995.

‡ K.D. Childs, D.H Narum, L.A. LaVanier, P.M. Lindley, B.W. Schueler, G. Mullholland, and A.C. Diebold, *Journal of Vacuum Science and Technology A*, Second Series, Vol. 14, No. 4, pp. 2392–2404, Jul/Aug 1996.

Once the beam voltage is selected, the desired beam current may need to be adjusted. The electron column is then tuned to optimize the beam size and shape by centering the electron beam in the system optics. The operator uses the SmartSoft SEM session to change the electron beam parameters incrementally while watching the SEM image. The higher the magnification used for these adjustments, the better the resulting beam shape.

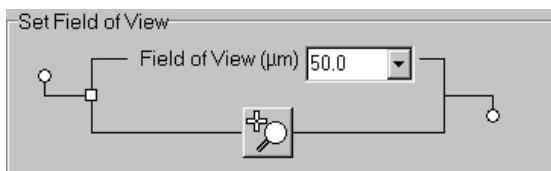
Generally, a 1 nA beam current is used for SEM imaging, and a 10 nA beam current is used for Auger analysis.

Procedure

1. In SmartSoft, click the SEM session, then the SEM application tab. Under SEM Settings, select a setting with the beam voltage and beam current desired, then click Load.



2. Click the button in the toolbar above the SEM image to start imaging if it is not already started.
3. Select a field of view in one of two ways. Click the Field of View box in the Set Field of View flow to choose a value. Or click the button in the flow, then click and drag the mouse over the SEM image to select an area. Release the mouse and the selected area will become the field of view.

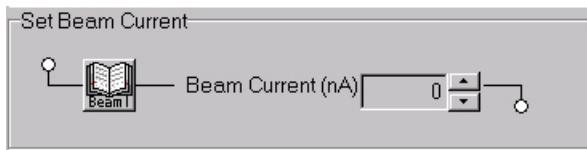


NOTE: The field of view can be also adjusted using the box or button in the SEM image toolbar.

NOTE: The beam voltage affects the size of the largest field of view that can be obtained. If the operator tries to select a field of view that is too large, the value in the Field of View box will default to the largest field of view that can be obtained.

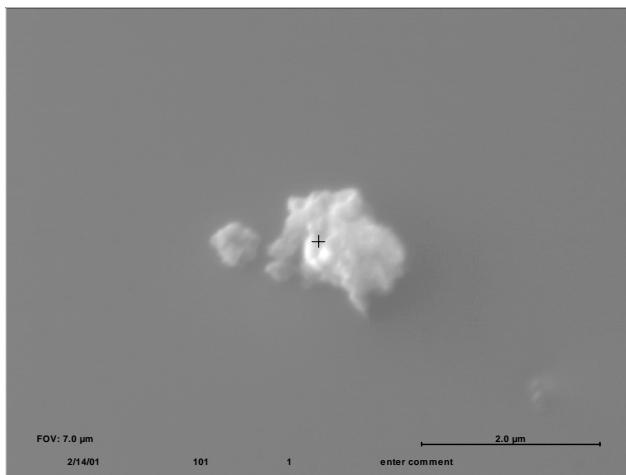
4. In the Set Beam Current flow, click the button and monitor the reading in the Beam Current box. The beam current reading is also displayed on the Keithley Picoammeter in the electronics console. Use the up and down arrows to increase or decrease the beam current until the desired value is obtained.

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NOTE: If the desired beam current is not obtained, the extractor steering must be adjusted. Refer to the “Create New SEM Settings” subsection at the end of this section for information on adjusting extractor steering.

5. Select a round, distinct feature on the sample; click the button, then click over the feature to center it in the field of view. It may be necessary to adjust focus using the button: click the button, then click and drag left or right to adjust focus.

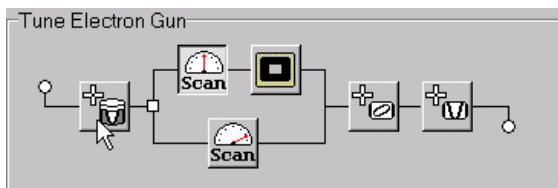


NOTE: The button is a coarse focus. For fine focus, adjust the Fine Focus knob on the Model 20-630 Electron Gun Control in the electronics console.



It also may be necessary to go to a larger field of view to find a feature (especially on an unpatterned wafer), then to a smaller field of view so that the feature is magnified. The feature will be viewed while adjustments are made to the SEM image, so it should dominate the field of view.

6. In the Tune Electron Gun flow, click the Focus Steering button, , to start the focus steering wobble.



Click and drag over the SEM image to minimize the wobble. Drag left and right, and up and down.

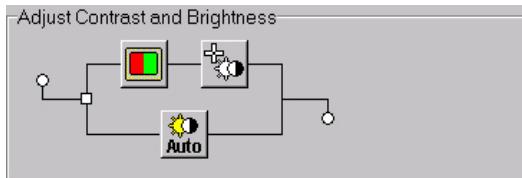
7. Select a scan speed using either the flow or the Scan Speed button in the SEM image toolbar.

NOTE: The Scan Speed button in the toolbar is variable: click it to change from slow, , to medium, , to fast, , scan rates. The buttons in the Tune Electron Gun flow are not variable because they are designed to accomplish a specific task in the flow. Clicking  will set the speed to fast. Clicking  will set the speed to medium. The faster scan speeds are used during tuning of the electron gun because a fast image response is needed to effectively tune the hardware.

8. Click  for a reduced image area. The area can be adjusted by clicking the box and clicking one of the handles on the box outline, then dragging. To move the box, click inside the box and drag.
9. Click , then click and drag over the SEM image to adjust stigmation. Stigmation is adjusted by dragging left and right, and up and down. Adjust until the image is as clear as possible. Stigmation is correctly adjusted when a feature goes out of focus uniformly in both the X and Y directions (rather than appearing to be stretched in one direction) as the Fine Focus knob is adjusted.
10. Adjust the focus using either the  button (coarse focus) or the fine focus knob on the 20-630 Electron Gun Control on the electronics console.
11. Use the stigmation and focus adjusts in tandem (one after the other) as needed until the image is sharp and clear.

NOTE: The smaller the field of view used for focus and stigmation adjustments, the better the beam shape.

12. Adjust the image's brightness and contrast in one of two ways:



- a. Click the Auto Video button (in the toolbar or in the Adjust Contrast and Brightness flow). This automatically adjusts the SED multiplier voltage, gain, contrast, and brightness to optimize the image.
- b. Click the Video Calibration button, , in either the toolbar or Adjust Contrast and Brightness flow. This colorizes the images on the video monitor (but not in the SmartSoft interface). Pixels within 20 percent of the maximum contrast range (near white) become red, and pixels within 20 percent of the minimum contrast range (near black) are set to green.

Click the button, then click and drag over the SEM image. Adjust the image so that the red and green pixels appear balanced. Click the button to stop Video Calibration.

D. Open a position list file (SMART-Tool)

This procedure describes opening a position list file. If no such file exists, go to the **Locate and center the area of interest** procedure.

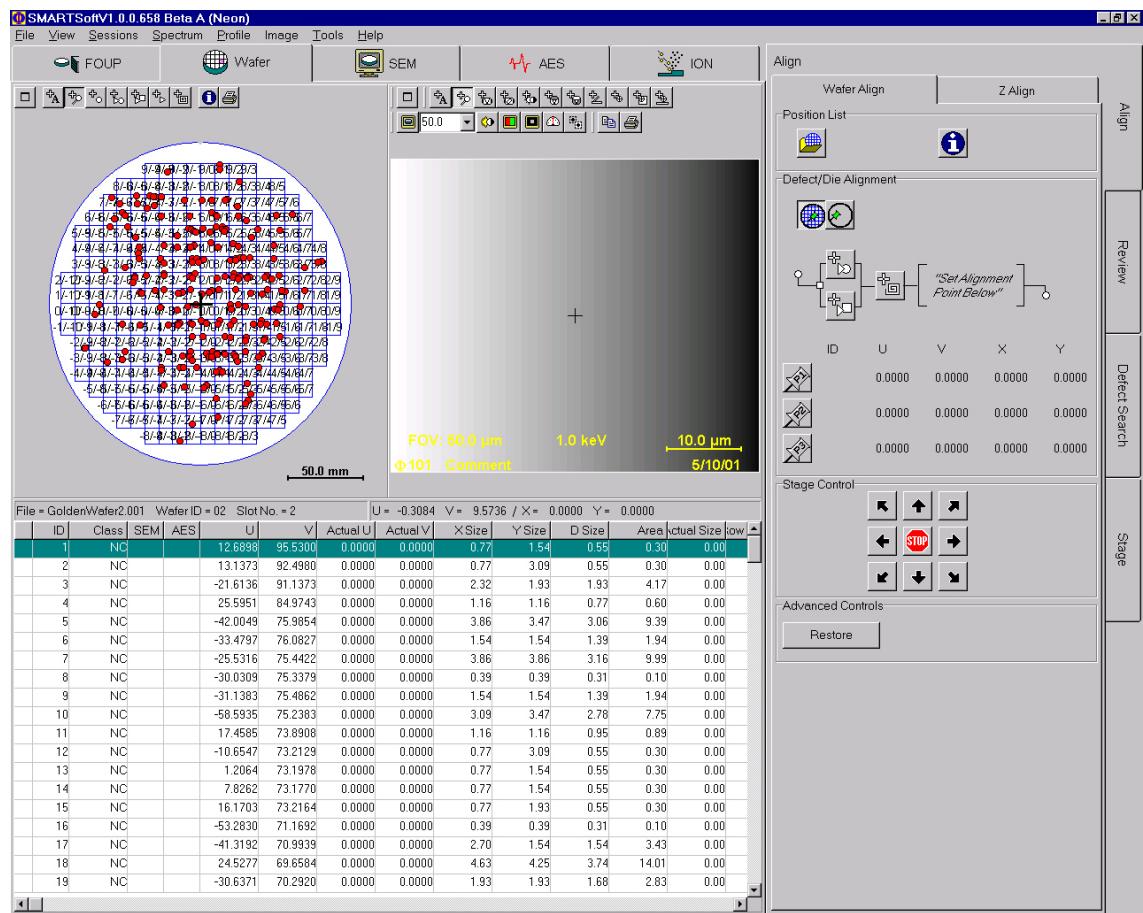
1. Click the Wafer session tab.



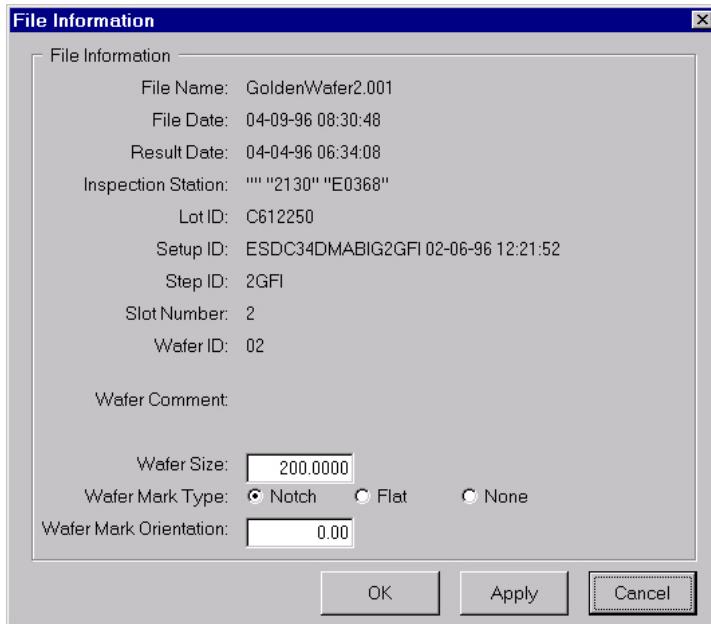
2. In the Wafer Align tab area, click the button in the Position List flow. This brings up the Open Position List box. Select the desired file and double-click to open.

When the file opens, the wafer map is displayed showing defect locations. The position list is displayed below the wafer map.

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NOTE: Clicking the icon will bring up the File Information box, which contains information on the position list file. Some of the fields can be edited, including Wafer Size, Wafer Mark Type and Wafer Mark Orientation.



E. Align the wafer (SMART-Tool)

Before starting this procedure, perform the **Open a Position List File** procedure. Three procedures are included in this subsection:

- **Align a Patterned Wafer Using Die Corners,**
- **Align a Blank or Unpatterned Wafer Using Edges,**
- **Refine the Alignment Using Defects.**

Use *either* the **Die Corners** procedure *or* the **Edges** procedure. Then, if needed, perform the **Defects** procedure.

Align a Patterned Wafer Using Die Corners

The precision of navigation on patterned wafers depends on the alignment of wafer coordinates (U,V) from the wafer's position list file with the stage's coordinates (X,Y) in SmartSoft. Alignment of patterned wafers is done by establishing alignment points at three die corners.

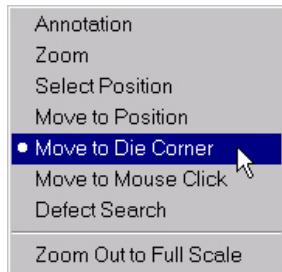
If desired, a second alignment using defects can be performed, as described in the **Defects** procedure later in this subsection.

1. In the Wafer Align tab area, click the Defect/Die Alignment Mode button, if it is not already selected.

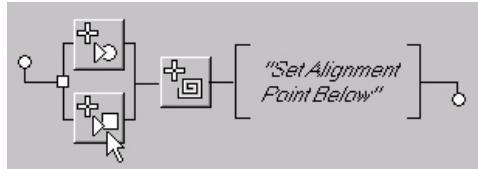


3. In the wafer map area, select Move to Die Corner mode in one of the following ways:

- Click the (Move to Die Corner) button in the wafer map toolbar, or
- Right-click over the wafer map, and select Move to Die Corner, or



- Click the button in the Defect/Die Alignment flow.



4. On the wafer map, click inside a die.

The stage moves to the lower left corner of the die that was clicked on. Wait for the stage to complete its movement. The stage position is represented by a large + on the wafer map.

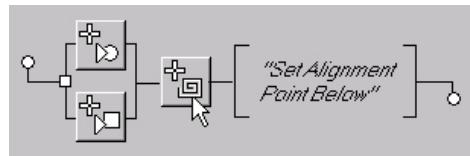
5. The die corner fiducial should be visible in the SEM image. If you *can* see it, go to step 6.

NOTE: If the SEM image is not live, click the button in the SEM image area toolbar.

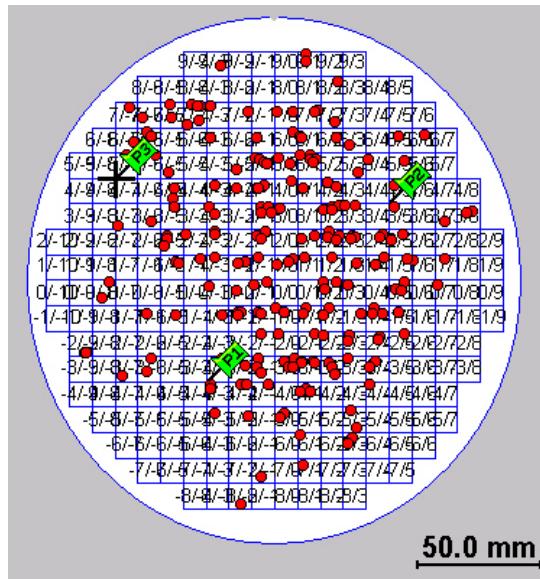
If you *cannot* see the die corner fiducial, look for the defect in one of the following ways:

- Increase the field of view of the SEM image by selecting a larger value in the box in the SEM toolbar;

- Click the  (Defect Search) button in the Defect/Die Alignment flow to define the search characteristics, then begin a spiral search. Press Done when you can see the die corner fiducial.



5. Center the die corner fiducial in the SEM image by clicking the  button in the toolbar, then clicking over the fiducial. The fiducial should be centered exactly. Using a smaller field of view (increased magnification) increases the accuracy of the alignment.
6. Press the  (P1 Set/Restore Alignment Point) button. A green pin () is placed in the wafer map at the die corner seen in the SEM image.
7. Repeat steps 3 through 7 with a second, then third die for  and  to set the next two alignment pins.



NOTE: The Restore button in the Advanced Controls area can be used to load the alignment points and position list that were active prior to the last shutdown of SmartSoft.

8. The next step is to perform the **Align the Wafer Using Defects** procedure, given later in this section. Alignment using defects, while optional, can improve the accuracy of the alignment of the stage and wafer coordinate systems.

Align a Blank or Unpatterned Wafer Using Edges

The precision of navigation on unpatterned wafers depends on the alignment of wafer coordinates (U,V) from the wafer's position list with the stage coordinates (X,Y).

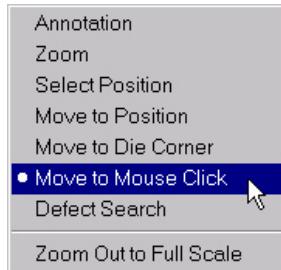
Alignment for unpatterned wafers is done by establishing five (wafer with a flat) or six (wafer with a notch) alignment points: at three positions on the edge of the wafer, and at three positions on the wafer's notch or at two positions on the wafer's flat. The alignment does not take effect until all five points (E1, E2, E3, F1, F2) or six points (E1, E2, E3, N1, N2, N3) have been defined.

After the initial edge alignment, it is often useful to perform a second alignment using defects in the position list, as described in the **Defects** procedure later in this subsection. This may improve the accuracy of the alignment of the stage and wafer coordinate systems.

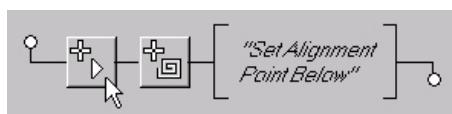
1. Perform the **Open a position list file** procedure.
2. In the Wafer session tab, click the Align application tab.
2. Click the Wafer Edge Alignment Mode button.



3. In the wafer map area, select Move to Mouse Click mode in one of the following ways:
 - Click the (Move to Mouse Click) button in the wafer map toolbar, or
 - Right-click on the wafer map, and select Move to Mouse Click.

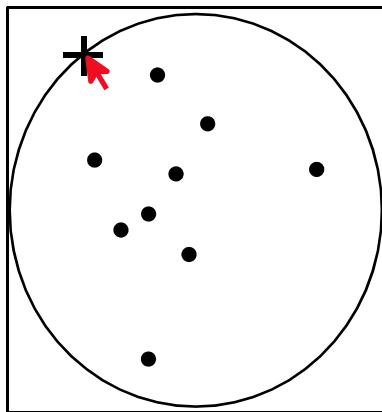


- Click the button in the Wafer Edge Alignment flow.



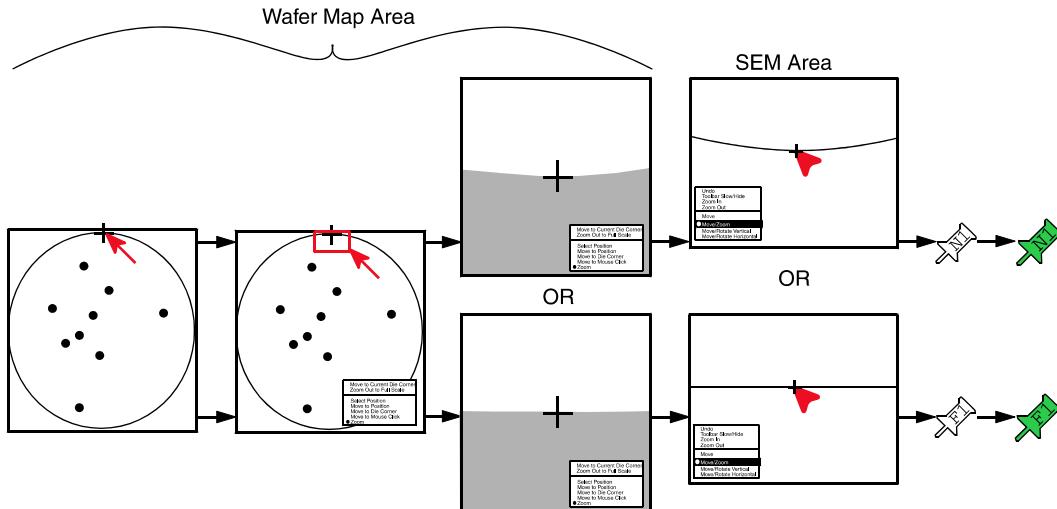
Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

5. Click over the wafer map on an edge of the wafer. Wait for the stage to complete its movement. The stage position is represented by a large + on the wafer map.

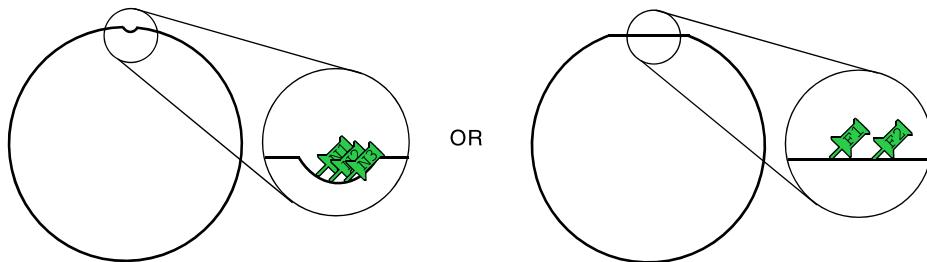
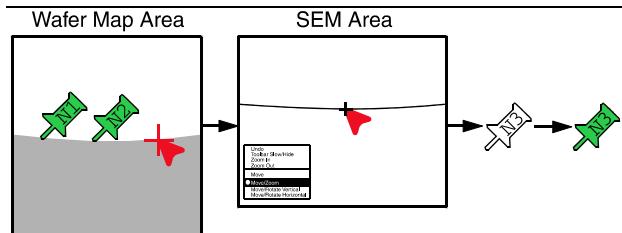
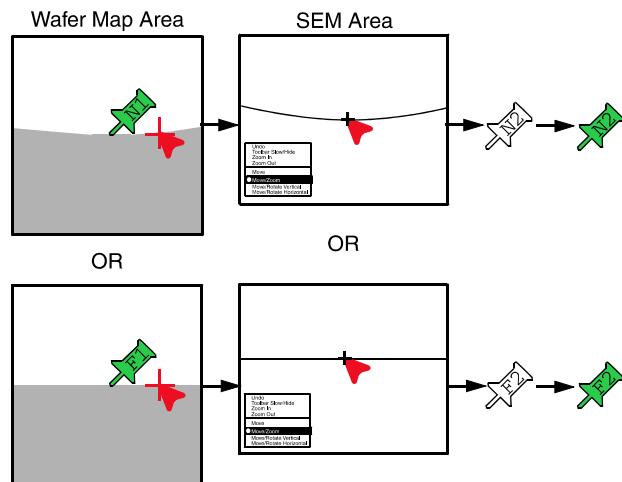


6. In the SEM image area, center the wafer edge by clicking the button in the toolbar, then clicking over the wafer edge. The exact edge of the wafer should be centered. Using a smaller field of view (increased magnification) increases the accuracy of the alignment.
7. Press the (Set/Restore Alignment Point) button.
8. Repeat steps 5 through 7 for the (second) and (third) edge points.
9. Define three alignment points on the notch or two on the flat.

NOTE: The alignment takes effect after all five (wafer with a flat) or six (wafer with a notch) alignment points are set.



Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM



NOTE: The Restore button in the Advanced Controls area can be used to load the alignment points and position list that were active prior to the last shutdown of SmartSoft.

10. The next step is to perform the **Align the Wafer Using Defects** procedure. The early part of the procedure helps the operator determine whether aligning using defects will be helpful.

Refine the Alignment Using Defects

After the alignment procedure, the ability to drive to defects will depend on:

- *Patterned Wafer*—Correct die corner being used in the alignment procedure and the accuracy of the position list file;
- *Unpatterned Wafer*—Sufficient Zoom being used to define the edge location in the alignment procedure and the accuracy of the position list file.

NOTE: This procedure is not relevant to wafers without a position list file.

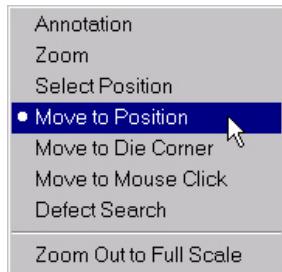
Use this procedure to, first, determine the ability to drive to defects. If this ability is good, then the rest of the procedure is performed.

1. Click the  button in the SEM image toolbar to start continuous refresh of the SEM image.
2. In the Align application tab, click the Defect/Die Alignment Mode button, if it is not already on.

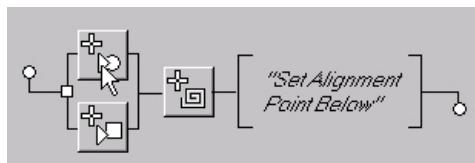


3. In the wafer map area, select the Move to Position mode in one of the following ways:

- Click the  (Move to Position) button in the wafer map toolbar, or
- Right-click on the wafer map, and select Move to Position, or



- Click the  button in the Defect/Die Alignment flow.



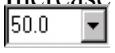
4. Click on either a defect on the wafer map or a position in the position list below the wafer map. The stage moves to the position that was clicked on.

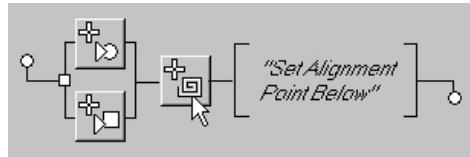
Wait for the stage to complete its movement. The stage position is represented by a large + on the wafer map.

NOTE: Initially, driving to large defects first may be easier. Large defects can be identified by clicking on the Area or Size column heading in the position list display. Clicking twice sorts them in the opposite order.

5. The defect should be visible in the SEM image. If you *can* see it, go to step 6.

If you *cannot* see the defect, look for it in one of the following ways:

- Increase the field of view of the SEM image by selecting a larger value in the  box in the SEM toolbar;
- Click the  (Defect Search) button in the Defect/Die Alignment flow to define the search characteristics, then begin a spiral search. Press Done when you can see the defect.



6. Repeat steps 3 and 4 with several (at least five) defects.
7. If defects *are* located readily and predictably at most or all of the positions looked at, continue this alignment procedure to more precisely match the stage coordinates with the position list file coordinates. Go to step 8.

If defects *are not* located at the positions, the position list file may be poor or the alignment may be poor. Do not continue this procedure. Instead, repeat the alignment procedure:

- *Patterned Wafer*—using a different die corner whose position has been verified relative to the edge of the pattern;
 - *Unpatterned Wafer*—using different edge positions.
8. In the SEM image area, center the defect by clicking the  button in the toolbar, then clicking over the defect. The defect should be centered exactly. Using a smaller field of view (increased magnification) increases the accuracy of the alignment.
 9. Press the  (P1 Set/Restore Alignment Point) button. A green pin () is placed in the wafer map.

10. Repeat steps 2 through 8 with a second, then third die for and to set the next two alignment pins (and).

NOTE: The Restore button in the Advanced Controls area can be used to load the alignment points and position list that were active prior to the last shutdown of SmartSoft.

F. Locate and center the area of interest (SMART-Tool)

Two groups of procedures are given. **Navigating on a Wafer Using a Position List File** describes navigation on a wafer with an associated position list file. If no such file exists for the sample, use the **Navigating on a Wafer without a Position List File** procedure instead.

Navigating on a Wafer with a Position List File

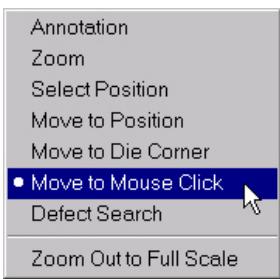
The following illustrations and procedures briefly summarize typical navigation procedures.

*NOTE: After driving to a new position, the height of the sample may be different from the last position, evidenced by an image that is out of focus. First, adjust the Fine Focus knob on the Electron Gun Control. If that does not improve the image enough, perform the **Perform Manual Z Align** and **Optimize the Operating Parameters** procedures.*

In the Wafer Map, Move to Mouse Click

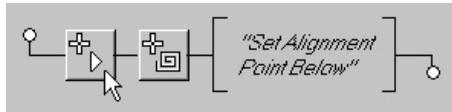
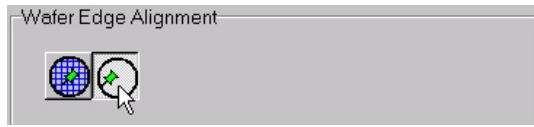
In the wafer map area, select Move to Mouse Click mode in one of the following ways:

- Click the (Move to Mouse Click) button in the wafer map toolbar, or
- Right-click on the wafer map, and select Move to Mouse Click.



- Click the button in the Wafer Edge Alignment flow.

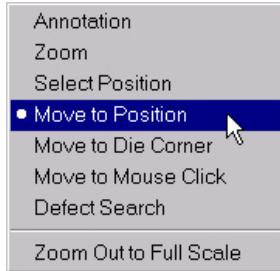
Click over the wafer map at the desired location; the stage will drive to that position.



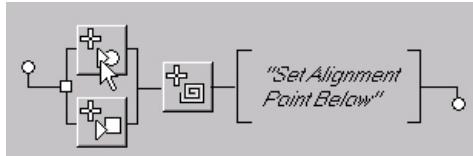
In the Wafer Map, Drive to Defect Position

In the wafer map area, select the Move to Position mode in one of the following ways:

- Click the  (Move to Position) button in the wafer map toolbar, or
- Right-click on the wafer map, and select Move to Position, or



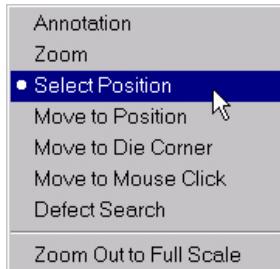
- Click the  button in the Defect/Die Alignment flow.



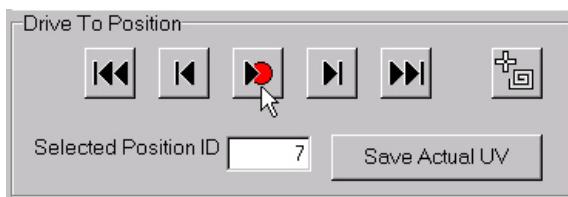
- Right-click on the position in the list below the wafer map, and select Move to Position.

| ID | Class | SEM | AES | U | V | Actual U | Actual V | XSize | YSize | D Size | Area | Actual Size | Row |
|----|-------|-----|-----|----------|---------|----------|----------|-------|-------|--------|-------|-------------|-----|
| 1 | NC | | | 12.6898 | 95.5300 | 0.0000 | 0.0000 | 0.77 | 1.54 | 0.55 | 0.30 | 0.00 | |
| 2 | NC | | | 13.1373 | 92.4980 | 0.0000 | 0.0000 | 0.77 | 3.09 | 0.55 | 0.30 | 0.00 | |
| 3 | NC | | | -21.6136 | 91.1373 | 0.0000 | 0.0000 | 2.32 | 1.93 | 1.93 | 4.17 | 0.00 | |
| 4 | NC | | | 25.5951 | 84.9743 | 0.0000 | 0.0000 | 1.16 | 1.16 | 0.77 | 0.60 | 0.00 | |
| 5 | NC | | | -42.0049 | 75.9854 | 0.0000 | 0.0000 | 3.86 | 3.47 | 3.06 | 9.39 | 0.00 | |
| 6 | NC | | | -33.4797 | 76.0827 | 0.0000 | 0.0000 | 1.54 | 1.54 | 1.39 | 1.94 | 0.00 | |
| 7 | NC | | | -25.5316 | 75.4422 | 0.0000 | 0.0000 | 3.86 | 3.86 | 3.16 | 9.99 | 0.00 | |
| 8 | NC | | | -31.1383 | 75.4862 | 0.0000 | 0.0000 | 1.54 | 1.54 | 1.39 | 1.94 | 0.00 | |
| 9 | NC | | | -58.5935 | 75.2383 | 0.0000 | 0.0000 | 3.09 | 3.47 | 2.78 | 7.75 | 0.00 | |
| 10 | NC | | | 17.4585 | 73.8908 | 0.0000 | 0.0000 | 1.16 | 1.16 | 0.95 | 0.89 | 0.00 | |
| 11 | NC | | | -10.6547 | 73.2129 | 0.0000 | 0.0000 | 0.77 | 3.09 | 0.55 | 0.30 | 0.00 | |
| 12 | NC | | | 1.2064 | 73.1978 | 0.0000 | 0.0000 | 0.77 | 1.54 | 0.55 | 0.30 | 0.00 | |
| 13 | NC | | | 7.8262 | 73.1770 | 0.0000 | 0.0000 | 0.77 | 1.54 | 0.55 | 0.30 | 0.00 | |
| 14 | NC | | | 16.1703 | 73.2164 | 0.0000 | 0.0000 | 0.77 | 1.93 | 0.55 | 0.30 | 0.00 | |
| 15 | NC | | | -53.2830 | 71.1692 | 0.0000 | 0.0000 | 0.39 | 0.39 | 0.31 | 0.10 | 0.00 | |
| 16 | NC | | | -41.3192 | 70.9939 | 0.0000 | 0.0000 | 2.70 | 1.54 | 1.54 | 3.43 | 0.00 | |
| 17 | NC | | | 24.5277 | 69.6584 | 0.0000 | 0.0000 | 4.63 | 4.25 | 3.74 | 14.01 | 0.00 | |
| 18 | NC | | | -30.6371 | 70.2920 | 0.0000 | 0.0000 | 1.93 | 1.93 | 1.68 | 2.83 | 0.00 | |
| 19 | NC | | | | | | | | | | | | |

- Alternatively, click the  (Select Position) button in the wafer map toolbar or right-click on the wafer map, and click Select Position.



Click over the wafer map on a defect; its position in the position list will be highlighted. Then click the Review application tab. Click the Move to Selected Position button (seen below). The stage will move to the defect at that position.



Other buttons in the Drive to Position area include:



Move to first position on the position list;



Move to previous position on the position list;



Move to next position on the position list;



Move to last position on the position list.

The Previous, Current, and Next buttons refer to the currently selected defect, which is the defect currently highlighted in the wafer map and in the position list below the wafer map.

In the Wafer Map, Zoom In



In the wafer map area, select Zoom mode by pressing the button in the wafer map toolbar or right-clicking on the wafer map, and selecting Zoom. Then, in the wafer map area, drag the cursor diagonally again across the area of the edge, and release the mouse button to zoom in on that area.

In the SEM Area, Zoom In

Perform the following sequence to center the defect in the SEM:

1. Right-click in the SEM image, and select the Move/Zoom mode, if it not already selected, by clicking the button in the SEM toolbar or by right-clicking and selecting Move/Zoom.
2. Click and drag diagonally over the SEM image, dragging over the area showing the defect, and release the mouse button to zoom in on it.
3. Click over the defect to center it.

In the SEM Area, Zoom Out

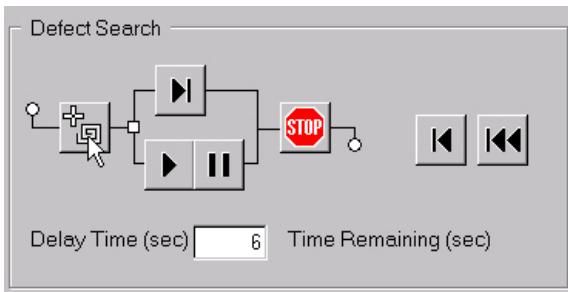
Look for the defect by zooming out, as follows:

- Increase the field of view of the SEM image using the box in the SEM toolbar.

In the Wafer Area, Defect Search



Click the Defect Search application tab. Click the button in the Defect Search flow to define the search characteristics in the box, then begin a spiral search. Click Stop when you can see the defect.

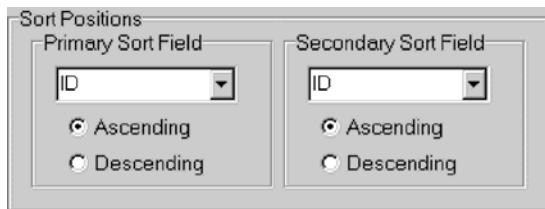


Other buttons in this flow include:

- Next Step;
- Move to Next Step Automatically;
- Pause;
- Previous Step;
- to Start Position.

In the Review Application Tab, Sort Positions

Positions can be sorted in several ways using the Sort Positions area of the Review input area or clicking on the column headers in the position list area below the wafer map.



OR

Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

| ID | Class | SEM | AES | U | V | ActualU | ActualV | XSize | YSize | DSize | Area | ActualSize | Row |
|-----|-------|-----|-----|----------|----------|---------|---------|-------|-------|-------|--------|------------|-----|
| 87 | NC | | | 68.9705 | 32.0095 | 0.0000 | 0.0000 | 24.71 | 13.90 | 13.33 | 177.70 | 0.00 | 3 |
| 18 | NC | | | 24.5277 | 69.6584 | 0.0000 | 0.0000 | 4.63 | 4.25 | 3.74 | 14.01 | 0.00 | 7 |
| 53 | NC | | | -42.7264 | 50.2891 | 0.0000 | 0.0000 | 5.02 | 2.70 | 2.70 | 11.03 | 0.00 | 5 |
| 7 | NC | | | -25.5316 | 75.4422 | 0.0000 | 0.0000 | 3.86 | 3.86 | 3.16 | 9.99 | 0.00 | 7 |
| 5 | NC | | | -42.0049 | 75.9854 | 0.0000 | 0.0000 | 3.86 | 3.47 | 3.06 | 9.39 | 0.00 | 7 |
| 31 | NC | | | -56.5726 | 61.9939 | 0.0000 | 0.0000 | 3.86 | 3.86 | 3.06 | 9.39 | 0.00 | 6 |
| 23 | NC | | | 60.7979 | 64.5795 | 0.0000 | 0.0000 | 4.63 | 2.32 | 2.32 | 8.50 | 0.00 | 6 |
| 33 | NC | | | -59.5110 | 57.1038 | 0.0000 | 0.0000 | 3.09 | 3.47 | 2.86 | 8.20 | 0.00 | 5 |
| 10 | NC | | | -50.5935 | 75.2383 | 0.0000 | 0.0000 | 3.09 | 3.47 | 2.76 | 7.75 | 0.00 | 7 |
| 52 | NC | | | 33.7437 | 50.5667 | 0.0000 | 0.0000 | 3.09 | 2.70 | 2.50 | 6.26 | 0.00 | 5 |
| 203 | NC | | | 24.4663 | -26.4214 | 0.0000 | 0.0000 | 3.47 | 3.09 | 2.50 | 6.26 | 0.00 | -3 |
| 224 | NC | | | -5.3949 | -65.4943 | 0.0000 | 0.0000 | 3.86 | 2.32 | 2.32 | 5.81 | 0.00 | -7 |
| 225 | NC | | | -13.6577 | -75.6411 | 0.0000 | 0.0000 | 2.32 | 2.70 | 2.22 | 4.92 | 0.00 | -8 |
| 181 | NC | | | -76.6066 | -17.9145 | 0.0000 | 0.0000 | 2.32 | 2.32 | 2.16 | 4.77 | 0.00 | -2 |
| 44 | NC | | | 52.9055 | 54.9339 | 0.0000 | 0.0000 | 2.70 | 2.32 | 2.11 | 4.47 | 0.00 | 5 |
| 182 | NC | | | -76.2236 | -18.0782 | 0.0000 | 0.0000 | 3.47 | 1.54 | 1.54 | 4.32 | 0.00 | -2 |
| 3 | NC | | | -21.6136 | 91.1373 | 0.0000 | 0.0000 | 2.32 | 1.93 | 1.93 | 4.17 | 0.00 | 9 |
| 81 | NC | | | 77.9806 | 35.2391 | 0.0000 | 0.0000 | 2.32 | 2.70 | 2.04 | 4.17 | 0.00 | 3 |
| 186 | NC | | | 8.1220 | -20.5179 | 0.0000 | 0.0000 | 2.70 | 2.32 | 1.93 | 3.73 | 0.00 | -3 |

In the Review Application Tab, Drive to UV Coordinates

Use the Drive to UV Coordinates area of the Review Application Tab to drive to specific U,V coordinates.

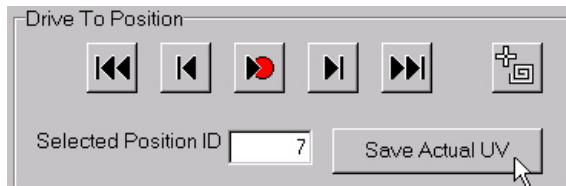
Drive To UV Coordinates

| | |
|---------|---------|
| U | 52.2359 |
| V | 27.0538 |
| Move UV | |

Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

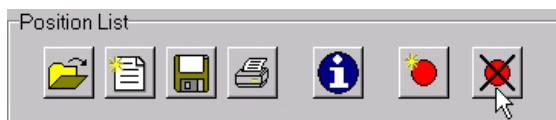
In the Review Application Tab, Update Defect Position in the Position List File

Update the position list file with exact U,V coordinates by pressing the Save Actual UV button in the Review input area. The saved position is then used for all subsequent navigation to the defect.

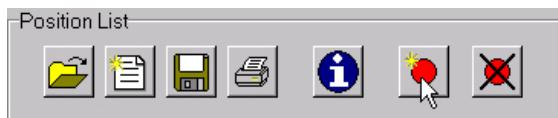


In the Review Application Tab, Delete or Create a Position in the List File

If a position is not useful and will not be looked for again, the operator may want to delete the position from the position list. Generally, this is not necessary, so it is not recommended. To delete it, select it, then click the Delete Current Position button in the Position List flow.

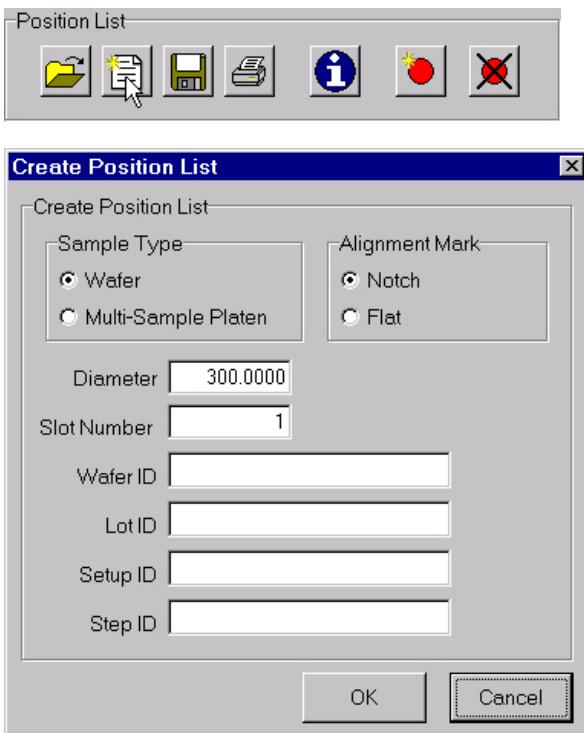


To create a new position, click the Create New Position button same flow.



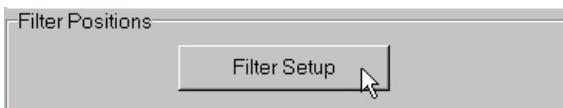
Create a Position List

Click the Create Position List button, then select Wafer and Notch or Flat, or Multi-Sample Platen. Specify other information as desired in the Diameter Slot Number, Wafer ID, Setup ID, and Step ID text fields. When ready, click Create List. Such a file allows the user to easily return to a specific position(s).



Filter Position List

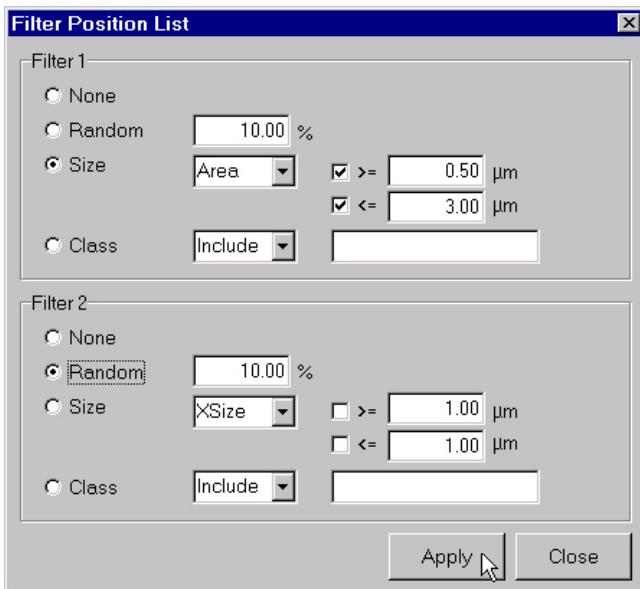
In the Review Application Tab, click Filter Setup in the Filter Positions flow.



This brings up the Filter Position List box. The position list can be filtered in three ways:

- Random: randomly filters out a certain percentage of defects. Use the box to indicate percent.
- Size: filters the defects based on a size range the operator specifies. The operator also selects which defect metric is used for this filter: Xsize, Ysize, Dsize or Area.
- Class: filters by either excluding or including a specified class of defect.

Two filters can be selected using this feature.

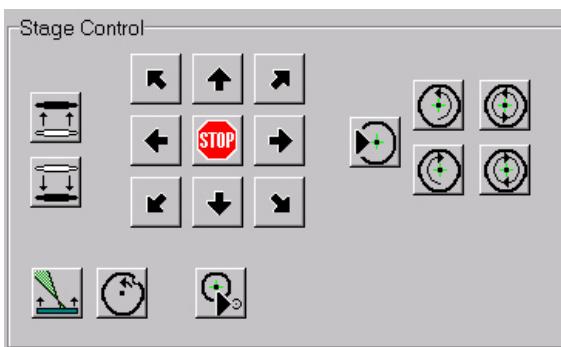


Navigating on a Wafer without a Position List File

This procedure describes navigation on a wafer without a position list file or on a sample that is mounted on a platen.

Location on the wafer or sample is determined by starting SEM imaging at a very low magnification (large field of view). In the Wafer session, click the Stage application tab. Use the arrow buttons and/or Absolute or Relative coordinates fields to move the stage in small increments to find the feature manually.

The Stage Control area, pictured below, contains the following buttons:



Move Stage Z Up;



Move Stage Z Down;



CAUTION: Use the Move Stage Z Up and Down buttons with extreme caution! Z is generally adjusted using the Z Alignment flow in the Align application tab of the Wafer session. Adjusting Z too high will result in the sample contacting the analyzer or its magnetic shield, causing damage to the sample and the instrument.



Move Stage to Default Z Height;



Rotate to Default Orientation;



Move Stage to Faraday Cup;



Move to Center of Stage;



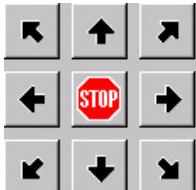
Rotate Stage Counterclockwise about the Stage Center;



Rotate Stage Clockwise about the Stage Center;



Start/Stop Continuous Rotation about the Stage Center.



The arrow buttons can be used to move the stage incrementally. Clicking an arrow key moves the stage 50 µm in the indicated direction. Clicking SHIFT + an arrow key moves the stage 500 µm (0.5 mm) in the indicated direction.

Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

Stage Parameters

Absolute Relative

Current Position Target Position Drive

| | | | |
|---------|---------|---------|---|
| X (mm) | 51.9312 | 51.9312 | X |
| Y (mm) | 17.8945 | 17.8945 | Y |
| Z (mm) | 0.3000 | 0.3000 | Z |
| R (deg) | 1.0000 | 1.0000 | R |

Drive All

The stage can also be moved using the Stage Parameters area. Indicate Absolute or Relative movement. Type a target position for the X, Y, Z or R axis, then click the X, Y, Z or R button under Drive to move to that position.

Target position values can be typed into more than one field, then the Drive All button clicked to move the stage to the new position.



CAUTION: Use the Z Target Position and Z button with extreme caution! Z is generally adjusted using the Z Alignment flow in the Align application tab of the Wafer session. Adjusting Z too high will result in the sample contacting the analyzer or its magnetic shield, causing damage to the sample and the instrument.

Another option for stage movement is to rotate the stage about the current position, as seen in the flow below:

Rotation About Current Position

Angle Drive

| | |
|---------|---|
| -1.0000 | R |
|---------|---|

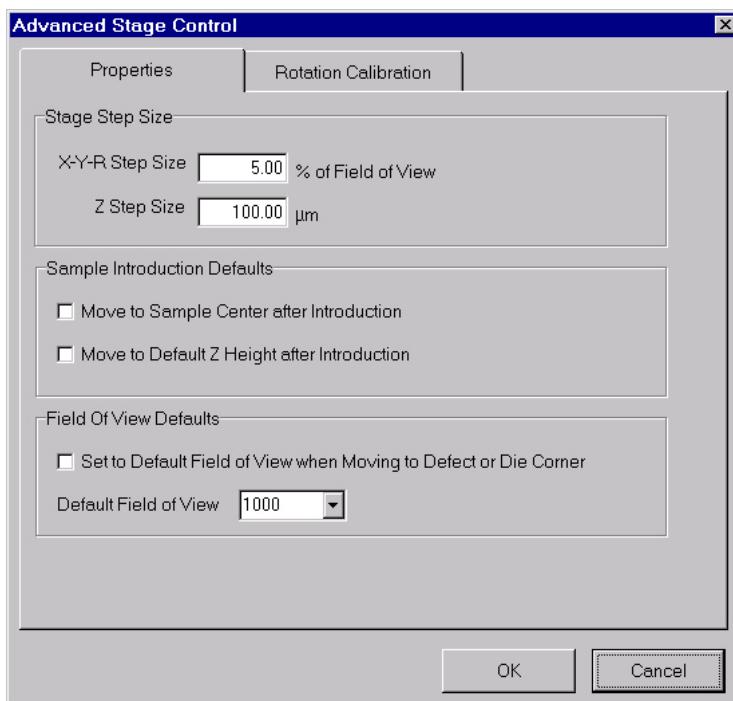
Type in an angle, the click the R button to begin the rotation.

Advanced Stage Control

Clicking Properties in the Advanced Controls area of the Stage application tab will bring up the Advanced Stage Control box. The Rotation Calibration tab of this box is used only by PHI Customer Service.

Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

The Properties tab allows the operator to set stage step sizes, sample introduction defaults and field of view defaults.



Stage Initialization

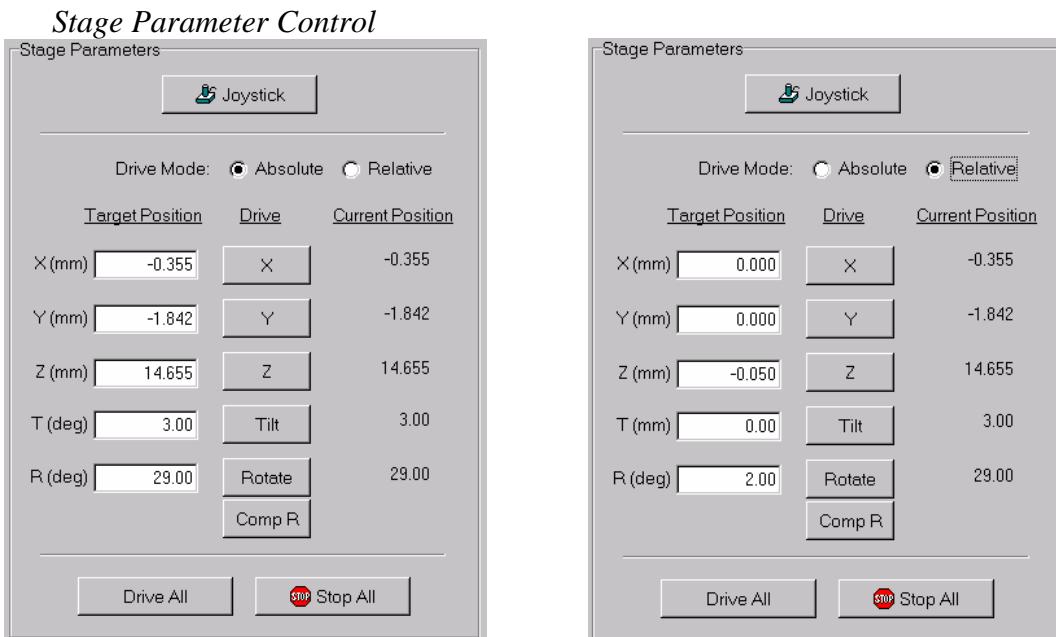
Stage initialization is a procedure that is performed by PHI Customer Service only.

G. Locate and center the area of interest

[PHI 700, PHI 690, PHI 680]

Navigating on a Sample

This procedure describes navigation on a sample using stage hardware control. Location on the sample is determined by starting with a SEM imaging at a very low magnification (large field of view).



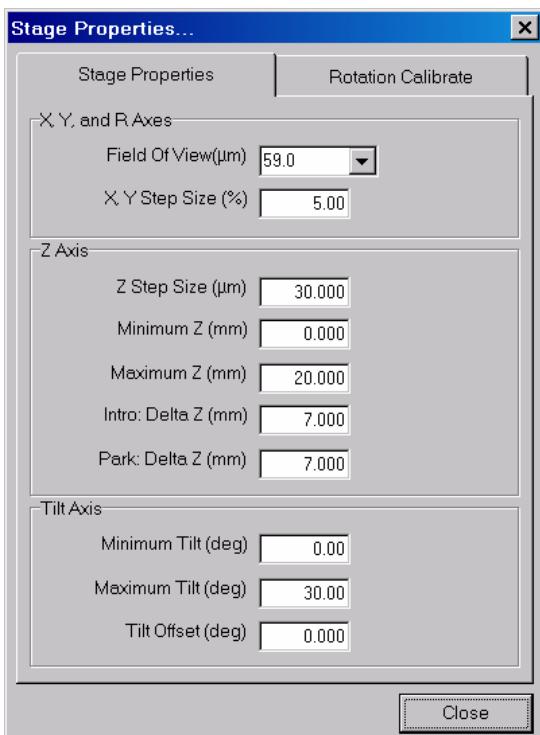
Choose the Sample session and Stage tab. The stage can be moved using the Stage Parameters area. Choose the Absolute or Relative Drive Mode. Type a target position for the X, Y, Z or R axis and click enter. Click the X, Y, Z or R Drive button to the right of that position field to move to that position. Target position values can be typed into more than one field, then click the Drive All button to move the stage to the new position. The CompR button will move the stage in a Compucentric move resulting in a rotation as defined in the R(deg) field, with an X and Y axis adjustment to return to the same point on the stage.



CAUTION: Use the Z Target Position and Z button with extreme caution! Z is generally adjusted using the Z Alignment flow in the Align application tab of the Wafer session. Adjusting Z too high will result in the sample contacting the analyzer or its magnetic shield, causing damage to the sample and the instrument.

Advanced Stage Control

Clicking Properties in the Advanced Controls area of the Stage application tab will bring up the Stage Properties box. The Rotation Calibration tab of this box is used only by PHI Customer Service to calibrate the Eucentric Rotation. The Stage Properties tab allows the operator to set stage step sizes, sample transfer defaults and Tilt axis parameters.



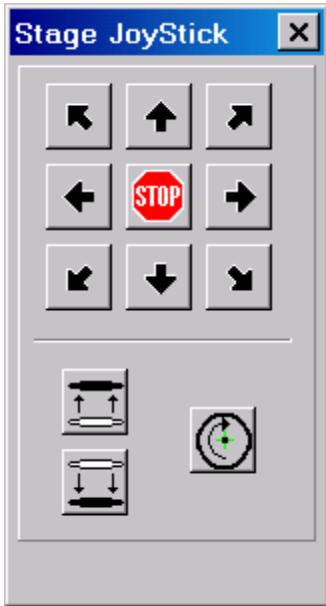
The X,Y and R Axes section defines sensitivity parameters for the Joystick arrow buttons and the keyboard arrow buttons. The arrow buttons can be used to move the stage incrementally. The Field of View(um) allows interaction with the Sample and SEM sessions raster control while in this window. The X Y Step Size (%) allows for definition of the sensitivity of an arrow key's movement of the stage as a function of the Field of View. Clicking an arrow key will then move the stage the defined % of the Field of View entered in the XY Step Size (%) field. Holding the SHIFT + an arrow key moves the stage 10x the indicated direction. Holding the ALT + an arrow key moves the stage 100x the indicated direction.

The Z Axis section defines sensitivity parameters for the Up/Down arrow buttons. The remaining four parameters are typically setup by PHI Customer Service to define safety limits for Z axis motion and calibrated Z moves for sample transfer between the intro and the park station.

The Tilt Axis section is typically setup by PHI service personal to define safety limits for Tilt axis motion and calibration of the Tilt axis

Joystick Control

In the Sample session, click the Stage application tab. In the Stage Parameters section, click the Joystick button . This will open the following window:



Use the arrow buttons to move the stage in small increments to find the feature manually. The amount of movement is proportional to the field of view and parameters set in the Properties window.



Rotate Stage Clockwise about the Stage Center;



Move Stage Z Up; proportional to parameters set in the Properties window.



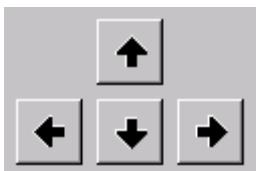
Move Stage Z Down; proportional to parameters set in the Properties window.



CAUTION: Use the Move Stage Z Up and Down buttons with extreme caution! Z is generally adjusted using the Z Alignment flow in the Align application tab of the Wafer session. Adjusting Z too high will result in the sample contacting the analyzer or its magnetic shield, causing damage to the sample and the instrument.

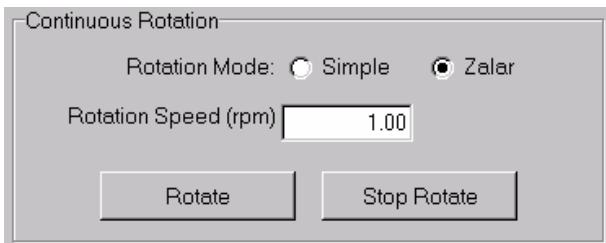
Keyboard Arrow Control

The computer keyboard arrow buttons can be used to control the X and Y axis of the stage as seen below:



In the SmartSoft Stage tab, place the cursor in the X or Y entry field. Clicking an arrow key on the keyboard will move the stage the defined % of the Field of View as entered in the Stage Parameters window. Holding the SHIFT + an arrow key moves the stage 10x the indicated direction. Holding the ALT + an arrow key moves the stage 100x the indicated direction.

Continuous Rotation Control



In the Sample session, click the Stage application tab. Choose between Simple or Zalar rotation. Simple will rotate the stage about its center. Zalar will rotate the stage with simultaneous X and Y moves to keep the current stage position at the center of rotation. Type in a rotation speed. Click the Rotate and Stop Rotate buttons to begin and stop the continuous rotation.

Stage Initialization

Stage initialization is a procedure that is performed if power or communication has been lost with the stage control electronics.

Click the Initialize button  in the Advanced Control section of the Stage tab.

Note: the stage will perform an automated routine to drive each axis into mechanical limits to initialize each axis. When the stage has completed the rotation initialization the message will appear.

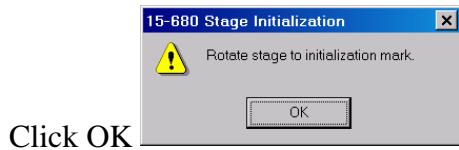


Set the stage operation to relative.

Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

Set the R delta to +2.00 or -2.00.

Drive the R axis until the index mark is aligned on the stage.

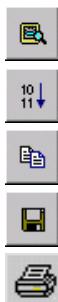


Click OK

The stage is now initialized.

H. Acquire SEM images

1. After centering the feature of interest in the SEM image area, adjust brightness and contrast as described above in **Optimize the electron gun operating parameters**.
2. In the SEM session, in the SEM application tab, use the Output Image area to save the image. Buttons in this flow include:



Preview SEM Image (Frame Average);

Increment Photo Number;

Copy to Clipboard;

Save to File;

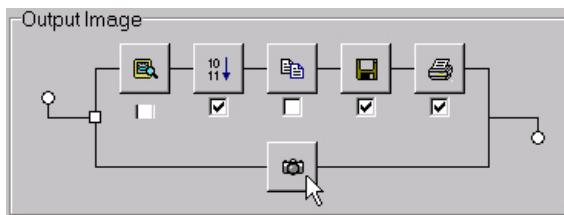
Print.

NOTE: To adjust the number of frames averaged during Preview, click the SEM Hardware tab, then, under Advanced Controls, click Image Properties. Click the Output tab and adjust the number of frames in the Average Frames box.

NOTE: When saving an image to file, use the following procedure to designate the directory in which to save the image file:

In the AES session, click the Lab Book application tab, then the Directory tab. Select the directory in which to save the image file by selecting a drive, then a folder. All image files generated will be saved to that drive and folder.

Clicking a button in the upper row will perform its action independently. The operator can also click the boxes of one or more of the five buttons, then click the button. This button will perform whichever tasks have been selected. In the case of the example seen below, clicking the button will change the photo number incrementally, save the SEM image to file and print it to the default printer.



I. Create New SEM Settings



SEM Settings allows the operator to select from defined settings. Settings that appear in all capital letters are set by PHI. These include:

- INITIAL: Sets the hardware parameters to safe default settings.
- PREVIOUS: Sets the hardware and displays to the parameters used prior to the last shutdown.
- Z ALIGN: Sets the hardware and displays to the predetermined start-up SEM parameter values used to perform the Z alignment.

In addition, other settings will have been created that have varying beam voltages and beam currents.

New settings can also be created. SmartSoft allows the operator to create hundreds of new settings. The procedure is as follows:

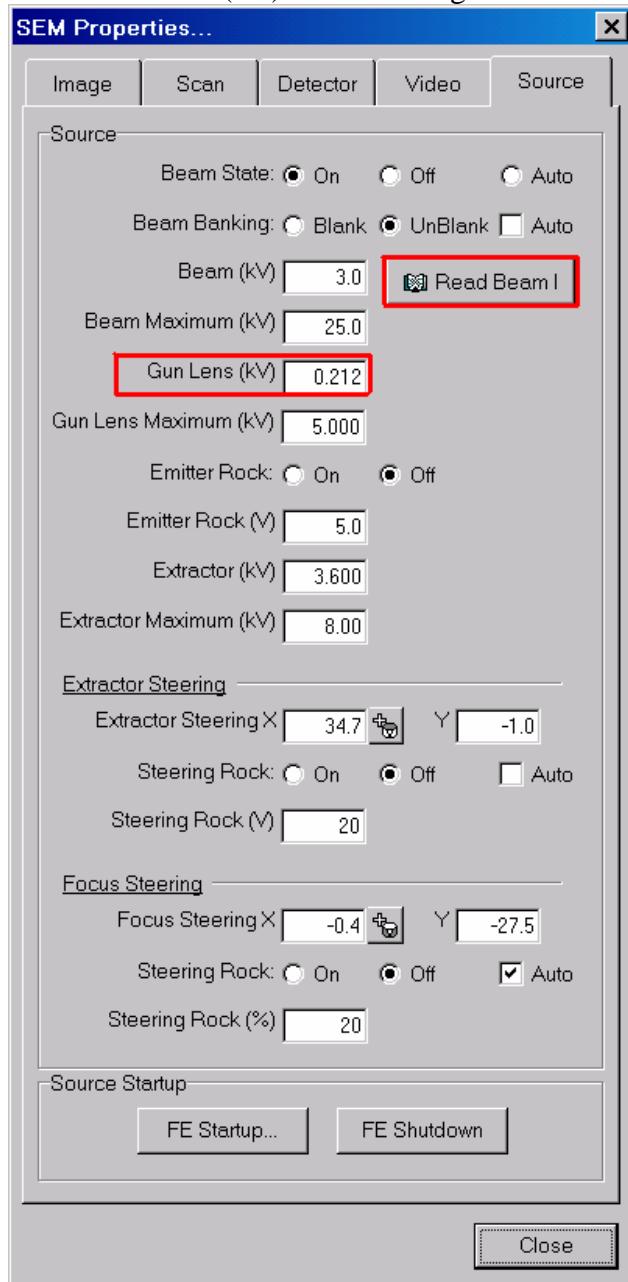
1. In the SEM session, click the SEM Hardware application tab.
2. In SEM Settings, select an existing setting that has the same beam voltage as the setting you want to create. Click Load to make that setting active.

NOTE: Starting from an existing setting with the same beam voltage saves time because several key parameters will already be in place, such as multiplier voltage, extractor steering, etc.

3. Using the existing setting, obtain and optimize a SEM image of a well-defined feature.

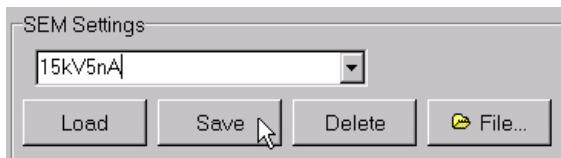
Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

4. Click the Advanced Control Properties button. Click the Source tab and monitor the beam current by clicking the Read Beam I button. The beam current is displayed on the Keithley Picoammeter on the front of the electronics console. Adjust the value in the Gun Lens (kV) field to change the beam current.



5. Click the button to adjust Extractor Steering. Click and drag over the SmartSoft SEM image (clicking and dragging left, right, up and down) or change the values in the Extractor Steering X and Y fields to maximize beam current as read on the picoammeter.

6. If necessary, adjust the Gun Lens (kV) value again to obtain the desired beam current. When the desired current is obtained, click the Stop Beam I button.
7. Click the  button to adjust Focus Steering. Click and drag over the SmartSoft SEM image, or change the values in the Focus Steering X and Y fields to minimize movement.
8. Adjust focus, stigmation, brightness and contrast.
9. Save the new setting by typing in a name for the setting in the SEM Settings box, then clicking Save. A useful convention for naming settings lists the beam voltage first, then the beam current.

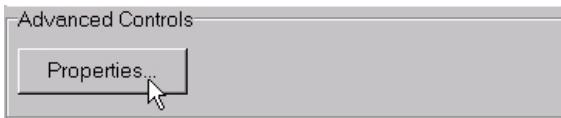


J. SEM Advanced Control

SEM Hardware tab overview

The SEM Hardware tab provides greater control over the SEM parameters than the toolbar buttons or flows. The SEM/Properties is divided into five sections: Image, Scan, Detector, Video and Source.

By clicking Properties in Advanced Controls, the SEM Properties box appears, offering more options for each of the parameters.



To adjust parameters, enter a numeric value in the field, or use the up and down arrow keys on the keyboard. Shift + an arrow key increases or decreases the value by a factor of 10. Control + an arrow key increases or decreases the value by a factor of 100.

Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

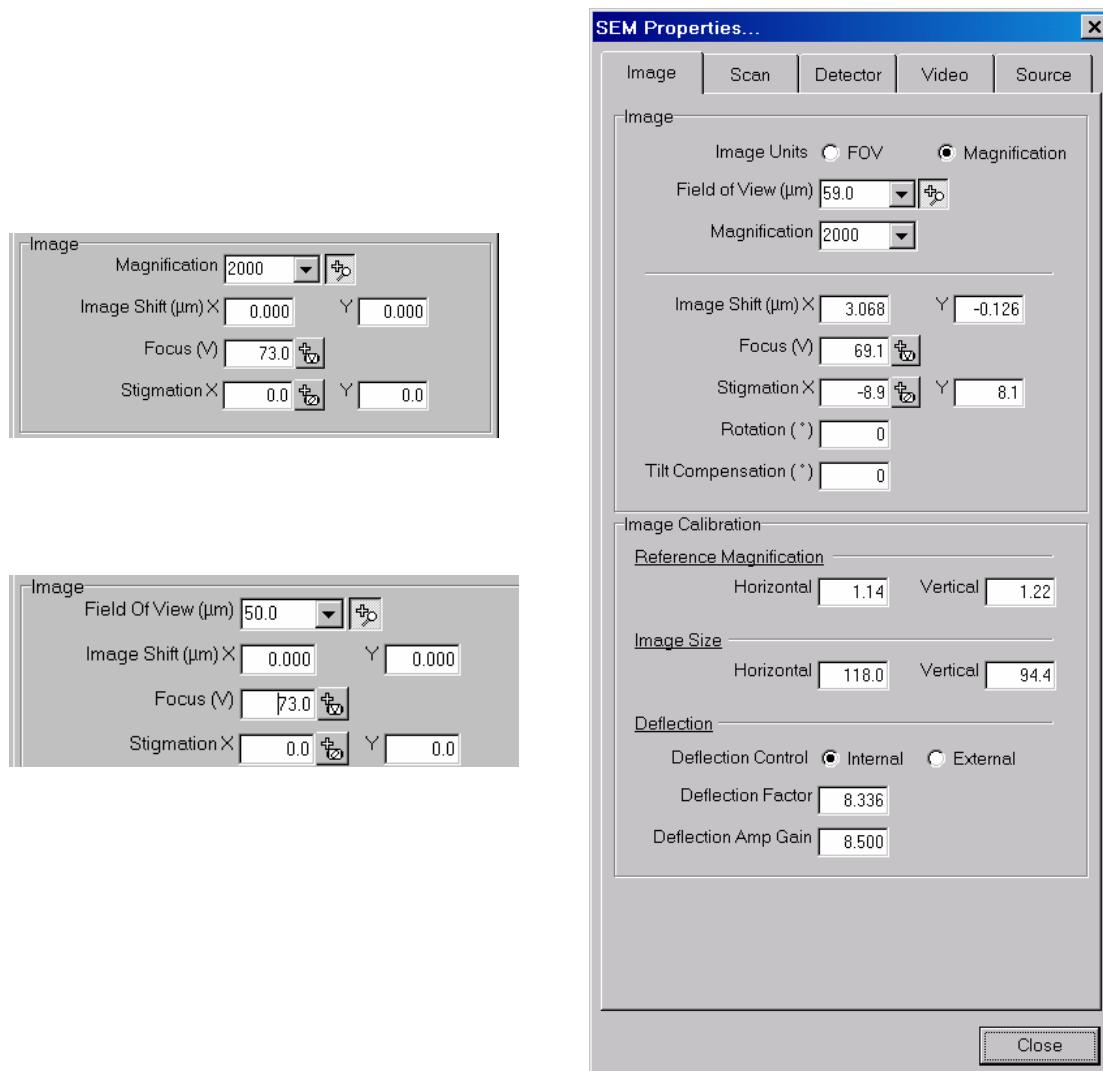
Image

The following fields appear in the Image section of the SEM Hardware tab, and in the Image tab on the SEM Hardware Advanced Properties box.

| Field | Purpose |
|---------------------------------|--|
| Image Units | Determines SEM Hardware Image units and SEM display annotation units in the SEM session window. Toggles between using FOV(field of view) or Magnification in these two locations. |
| Field of View (μm) | Determines the size of the raster that the electron beam scans on the surface of the specimen. The smaller the electron gun raster, the larger the details scanned appear on the video monitor and in the SmartSoft SEM image. The smaller the field of view, the higher the magnification. Enter a value, or use the  button to interact with the SEM image. |
| Magnification | Determines the size of the raster that the electron beam scans on the surface of the specimen. The higher the magnification, the larger the details scanned appear on the video monitor and in the SmartSoft SEM image. The higher the magnification, the smaller the field of view. Enter a value to interact with the SEM image. |
| Image Shift (μm) | Enter X and Y values to shift the portion of the sample viewed on the video monitor and in the SmartSoft SEM image. |
| Focus (V) | Sets the voltage that controls the focus (objective lens) coil current. Values can range from 0 to 100 percent of available coil current. Enter a value, or use the  button to interact with the SmartSoft SEM image. |
| Stigmation | Enter a numeric value, with X adjusting the X-axis stigmation, and Y adjusting the Y-axis stigmation. Values can range from -100 to 100. Or use the  button to interact with the SmartSoft SEM image. |
| Rotation (deg) | Provides continuous 0- to 360-degree rotation of the displayed image. This parameter is available only during scanning of the sample. Enter a numeric value to change the setting. |
| Tilt Compensation (deg) | The SMART-Tool analyzer is tilted 30 degrees in relation to the sample. Tilt compensation allows for correction of image distortion due to this geometry. The tilt compensation value should not be changed. |
| Reference Magnification | The reference magnification is a correction factor for fine adjustment of the raster size in horizontal and vertical directions on a photograph. A grid of known dimensions is used by PHI Customer Service engineers to calibrate the horizontal and vertical magnification on each Auger system. This value will be different on each system. |
| Image Size (mm) | The values are set at the factory and are specific to the system hardware. |
| Deflection Control | Toggles beam control between internal and external and should normally be set to Internal. External is used only on systems with hardware to drive the electron beam. For example, External is used during EDS analysis, because the EDS system takes control of the scan. |

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| | |
|---------------------|--|
| Deflection Factor | The distance in microns that the electron beam is deflected by a one volt potential on the deflection plates. This parameter is determined at the factory and should not be changed. |
| Deflection Amp Gain | The amount the deflection amplifier signal is multiplied from the scan process deflection digital-to-analog converters (DACs) to the deflection plates. This parameter is determined at the factory and should not be changed. |

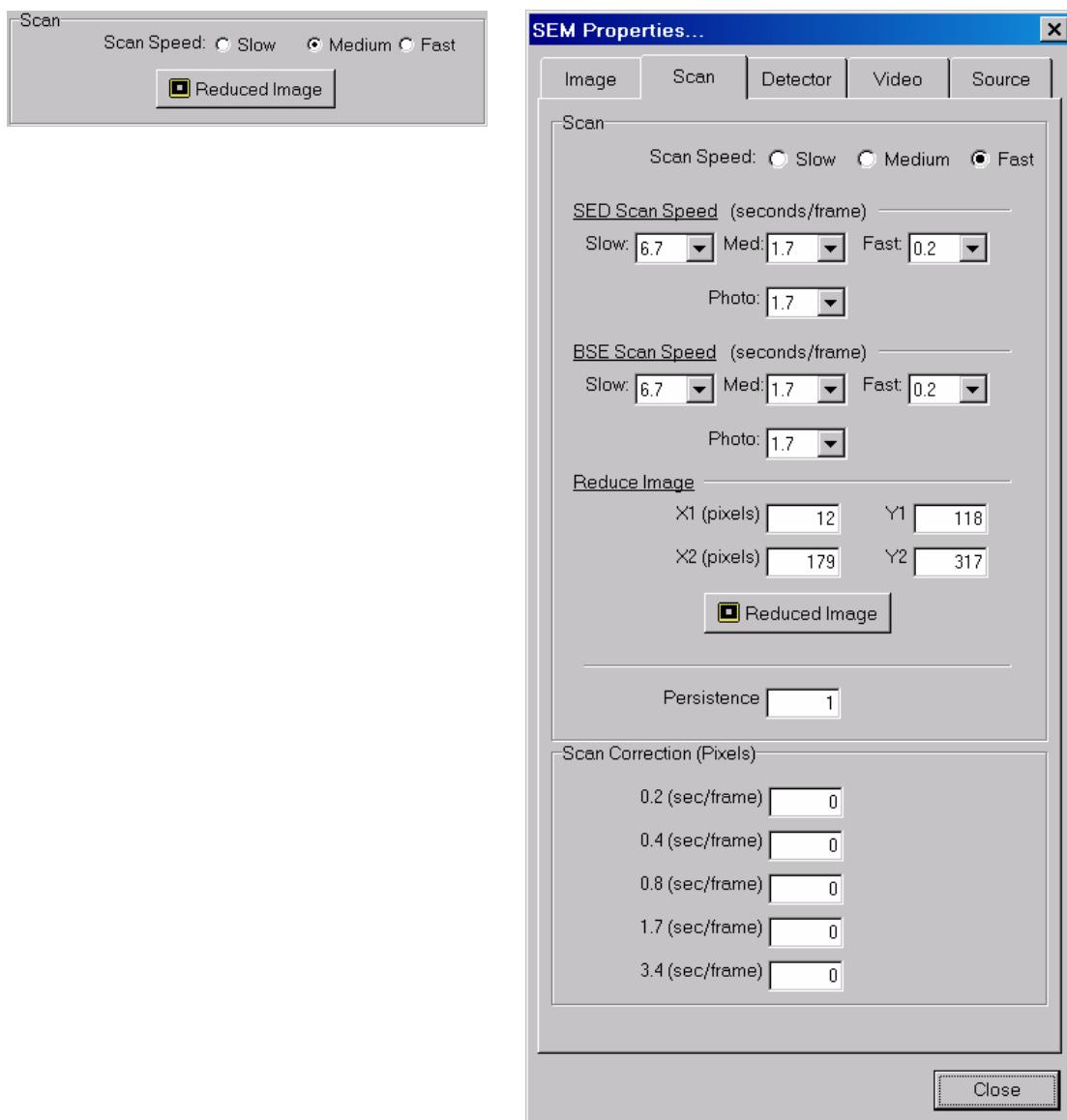


Scan

The following fields appear in the Scan section of the SEM Hardware tab, and in the Scan tab on the SEM Hardware Advanced Properties box.

| Field | Purpose |
|--------------------------|--|
| Scan Speed | Select Slow, Medium or Fast to determine the scan speed of the SmartSoft SEM image and the video monitor. A slow scan yields a higher resolution image, but can also damage beam-sensitive specimens. A slow scan is used for generating photographs and for searching for small defects. For navigation, a medium or fast scan speed should be used. |
| SED Scan Speed | Use these fields to specify exact scan speeds for the secondary electron detector (SED). Enter the desired scan speeds. Valid scan speeds are 0.2, 0.4, 0.8, 1.7, 3.4 and 6.7 sec/frame. <i>NOTE: The slow speed must be greater than (slower) or equal to the medium speed, and the medium speed must be greater than or equal to the fast speed.</i> |
| BSE Scan Speed | Use these fields to specify exact scan speeds for the backscattered electron (BSE) detector. Enter the desired scan speeds. Valid scan speeds are 3.2, 6.4, 12.8, 27.2, 54.4 and 107.2 sec/frame. <i>NOTE: The slow speed must be greater than (slower) or equal to the medium speed, and the medium speed must be greater than or equal to the fast speed.</i> |
| Reduced Image | Select Reduced Image to view a portion of the image displayed in the SmartSoft SEM image area and on the video monitor. X Position (pixels) and Y Position (pixels) are used to specify the location of the reduced image. Enter a numeric value into the fields to alter the position. <i>NOTE: The position of the Reduced Image area can also be adjusted clicking in the area and dragging. The size can be adjusted in the SEM image area by clicking on one of the box's handles and dragging to resize.</i> |
| Persistence | Sets the number of frames to be averaged when the Preview SEM Image button,  , is clicked. The SmartSoft SEM image becomes sharper when more frames are averaged, but this requires more time. |
| Scan Correction (Pixels) | Scan Correction values are set by PHI Customer Service engineers and should not require adjustment. |

Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

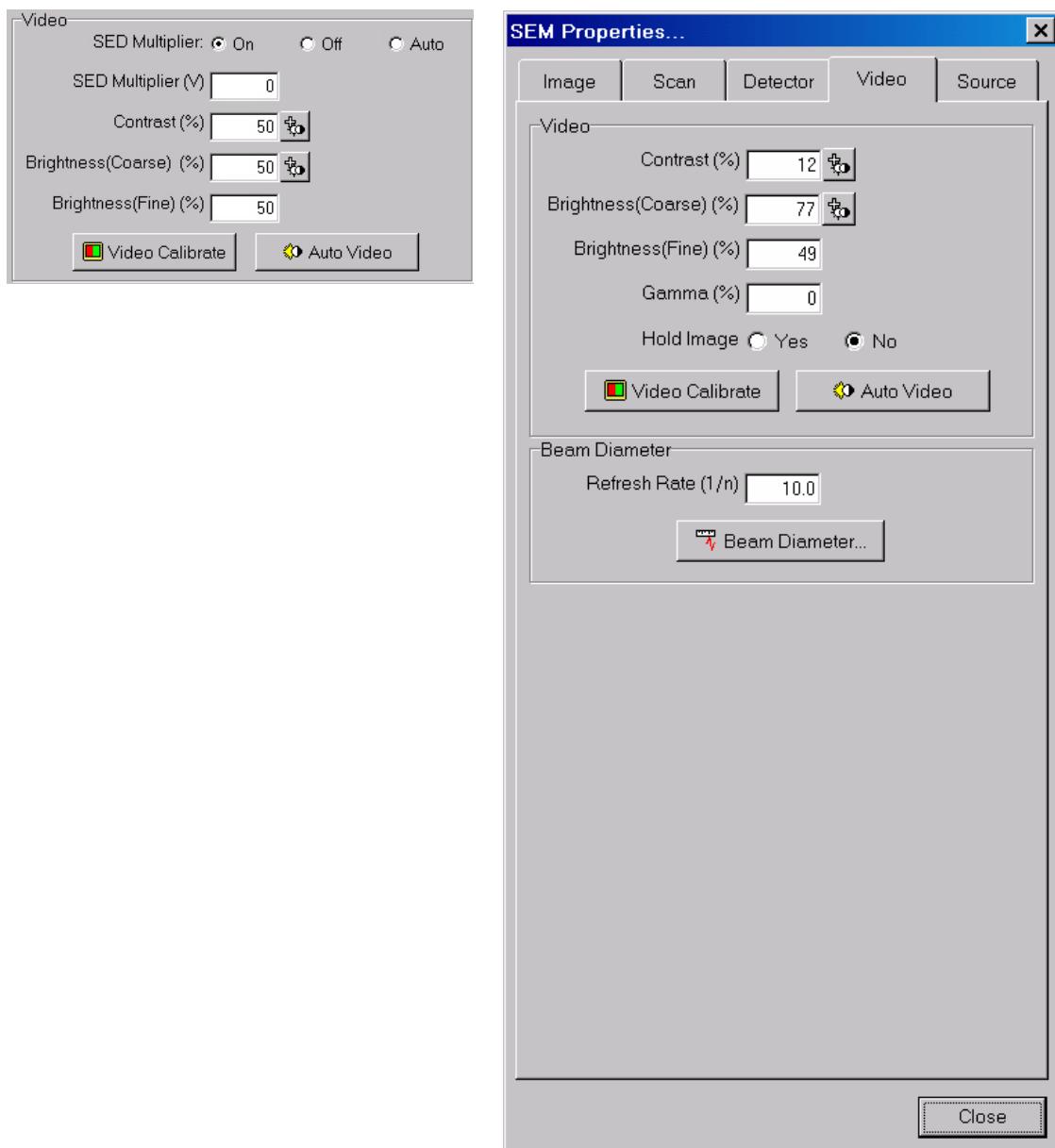


Video

The following fields appear in the Video section of the SEM Hardware tab, and in the Video tab on the SEM Hardware Advanced Properties box.

| Field | Purpose |
|----------------------------|--|
| SED Multiplier | Use this parameter to set the SED multiplier to on, off or auto. If Auto is selected, the SED multiplier will be turned on and off as specified in the hardware settings. |
| SED Multiplier (V) | Sets the electron multiplier voltage for the SED. Increasing this parameter will brighten the image up to the point where the multiplier is saturated. At saturation, a “white” image will be produced. The optimum operating point of the multiplier is just below the point of saturation. The Auto Video button adjusts this parameter automatically by ramping the multiplier voltage to the point of saturation and then reducing it slightly. This parameter is provided for manually adjusting the multiplier voltage and reducing it during periods of non-use (for example, overnight). |
| Contrast | Adjusts the contrast on the video monitor and the SmartSoft SEM image. Enter a numeric value, or use the  button to interact with the SEM image. |
| Brightness (Coarse) | Adjusts the coarse brightness on the video monitor and the SmartSoft SEM image. Enter a numeric value, or use the  button to interact with the SEM image. |
| Brightness (Fine) | Adjusts the fine brightness on the video monitor and the SmartSoft SEM image. Enter a numeric value. |
| Gamma | The effect of gamma is to darken midtones relative to light and dark regions of the image. Gamma is generally adjusted to reduce excessive contrast in an image. The gamma function mixes raw signal with gamma-modulated signal in a percentage of 0 to 100. Enter a numeric value to adjust. |
| Hold Image (Yes/No) | Freezes (stops scanning) the SEM image presently displayed on the video monitor. |
| Video Calibrate | Begins the Video Calibration routine. |
| Auto Video | Sets the SED multiplier voltage supply to the optimum value based on the amplitude of the input signal. Coarse brightness, fine brightness and contrast are adjusted for optimum viewing. |
| Beam Diameter Refresh Rate | Sets the frequency with which the beam diameter is calculated. |
| Beam Diameter | Clicking the beam diameter button opens the Beam Diameter box. Click the  button to begin the beam diameter measurement. The beam diameter is displayed graphically. |

Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM



Source

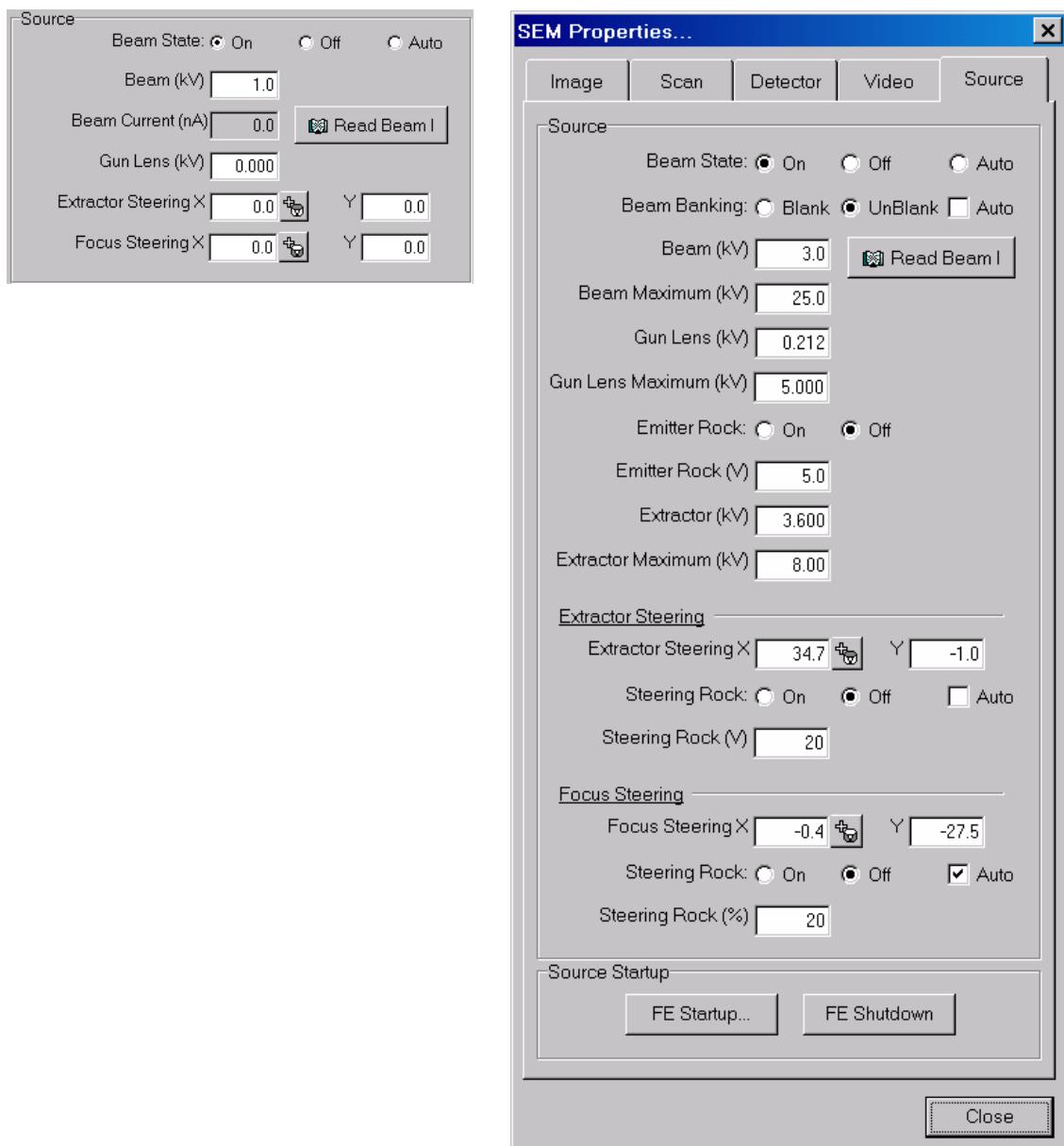
The following fields appear in the Source section of the SEM Hardware tab, and in the Source tab on the SEM Hardware Advanced Properties box.

| Field | Purpose |
|-------------------------------|--|
| Beam State | Turns the electron gun on and off. In the auto position, the electron beam is always off except during data acquisition. |
| Beam Blanking | Select on or off to enable or disable beam blanking. Checking auto will automatically enable beam blanking during a stage move. |
| Beam Voltage (kV) | Sets the electron gun beam voltage (typically, 0 to 25 kV). |
| Read Beam I | Reports the beam current. Use the Set Beam Current flow in the SEM application tab to adjust the beam current. |
| Beam Voltage Maximum (kV) | The maximum limit to which the beam voltage can be set using the Source section of the SEM Hardware tab. |
| Gun Lens Voltage (kV) | Sets base voltage for the field emission gun lens. |
| Gun Lens Voltage Maximum (kV) | The maximum limit to which the gun lens voltage can be set using the Source section of the SEM Hardware tab. |
| Emitter Rock | Used by PHI Customer Service. (Choose On to wobble the gun lens. Use the filament translation rotary feedthroughs located on top of the column to mechanically align the emitter.) |
| Emitter Rock (V) | Used by PHI Customer Service. (Sets the amount of voltage added to or subtracted from the base gun lens voltage to wobble the gun lens.) |
| Extractor Voltage (kV) | Controls emitter current by setting voltage applied to the extractor. ATTENTION: Setting the extractor voltage to zero will destroy the emitter. Use other methods to lower beam current. |
| Extractor Maximum (kV) | The maximum limit to which extractor voltage can be set using the Source section of the SEM Hardware tab. |
| Extractor Steering | Aligns the electron beam by applying voltage to the gun lens steering plates. Select this parameter to begin the rocking procedure for the gun lens steering plates (using the  button to interact with the SmartSoft SEM image to move the image in the desired direction). Or, enter numeric values in the X and Y fields. X and Y represent the percentage of available voltage to be applied to the X and Y steering plates, respectively. |
| Extractor Steering Rock | Select on, off or auto. When auto is selected, the extractor steering rock will be activated when the operator uses the  button or enters numeric values in the X and Y fields; the steering rock will then turn off when the operator selects a different mode. |
| Extractor Steering Rock (V) | Sets the amount of voltage added to or subtracted from the base extraction voltage to wobble the extractor. |

Source Fields, conc.

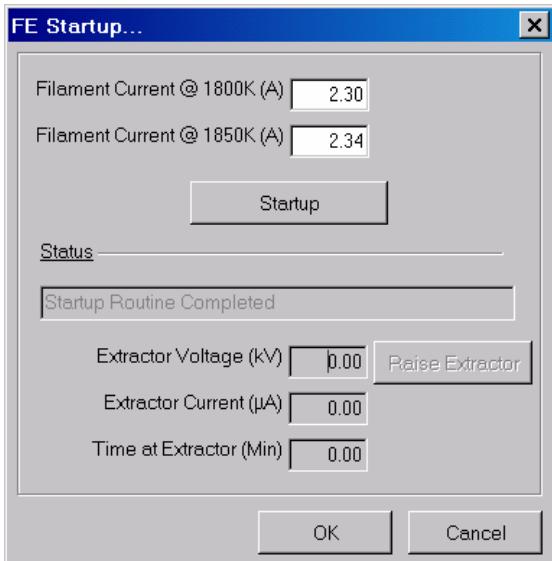
| Field | Purpose |
|-------------------------|---|
| Focus Steering | Select this parameter to begin the rocking procedure for the objective lens (using the  button to interact with the SmartSoft SEM image to move the image in the desired direction). Or, enter numeric values in the X and Y fields. X and Y represent the location of the image in the X-axis and Y-axis, respectively. |
| Focus Steering Rock | Select on, off or auto. When auto is selected, the focus steering rock will be activated when the operator uses the  button or enters numeric values in the X and Y fields; the steering rock will then turn off when the operator selects a different mode. |
| Focus Steering Rock (%) | Sets the percentage of focus (objective lens) coil current added to or subtracted from the base focus value. |
| FE Startup | Begins the field emission electron gun startup routine. Clicking the FE Startup button opens a box with additional buttons and status information. |
| FE Shutdown | Shuts down the field emission electron gun by setting the beam, extraction and gun lens voltages and filament current to zero. FE Shutdown is available only if the electron gun is running. |

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Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

Choosing FE Startup button in the Source Startup section of the SEM Properties Source tab will bring up the following window.

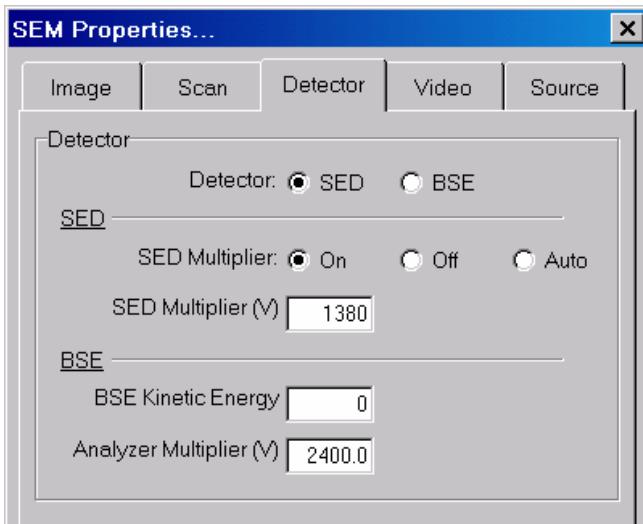


| | |
|------------------|--|
| Filament Current | The value for 1800K is the current required for normal operation of the field emission electron gun. The value for 1850K is the current used by the field emitter startup routine for outgassing the FE gun tip. Both of these values are set by PHI Customer Service engineers and should not be changed. |
| FE Startup | <p>Clicking the Startup button ramps the extractor voltage to achieve each target extraction current defined by the routine. The message, "Raising Extractor Voltage" is displayed during this time. When the last target extraction current is reached, the routine ends and the message, "Startup Routine Completed" is displayed.</p> <p>If a target extraction current is not reached within an extraction voltage limit defined by the routine, the Raise Extractor button is used. Clicking Raise Extractor increases the extractor voltage by 10 volts if the voltage is within the limits defined by the routine. If the upper limit has been reached, the voltage will not be raised.</p> |

Detector

The following fields appear in the Detector tab on the SEM Hardware Advanced Properties box.

| Field | Purpose |
|-----------------------------|--|
| Detector | Specifies whether the SED (secondary electron detector) or BSE (backscattered electron detector) will be used to obtain an image. |
| SED Multiplier | Use this parameter to set the SED multiplier to on, off or auto. If Auto is selected, the SED multiplier will be turned on and off as specified in the hardware settings. |
| SED Multiplier Voltage | Sets the electron multiplier voltage for the SED. Increasing this parameter will brighten the image up to the point where the multiplier is saturated. At saturation, a “white” image will be produced. The optimum operating point of the multiplier is just below the point of saturation. The Auto Video button adjusts this parameter automatically by ramping the multiplier voltage to the point of saturation and then reducing it slightly. This parameter is provided for manually adjusting the multiplier voltage and reducing it during periods of non-use (for example, overnight). |
| BSE Kinetic Energy | Type in the energy that matches the electron beam voltage (for example, 3000 V for a 3kV beam voltage). |
| Analyzer Multiplier Voltage | Sets the electron multiplier voltage for the AES analyzer when in the BSE mode. Increase this parameter as high as it will go to brighten the image up to the point where the multiplier is saturated. At saturation, a “white” image will be produced. Adjust brightness and contrast using the  button to interact with the SmartSoft SEM image. The optimum operating point of the multiplier is just below the point of saturation. |



Section 5: Wafer(SMART-Tool)/Sample(PHI 700, PHI 690, PHI 680)/SEM

Section 6:

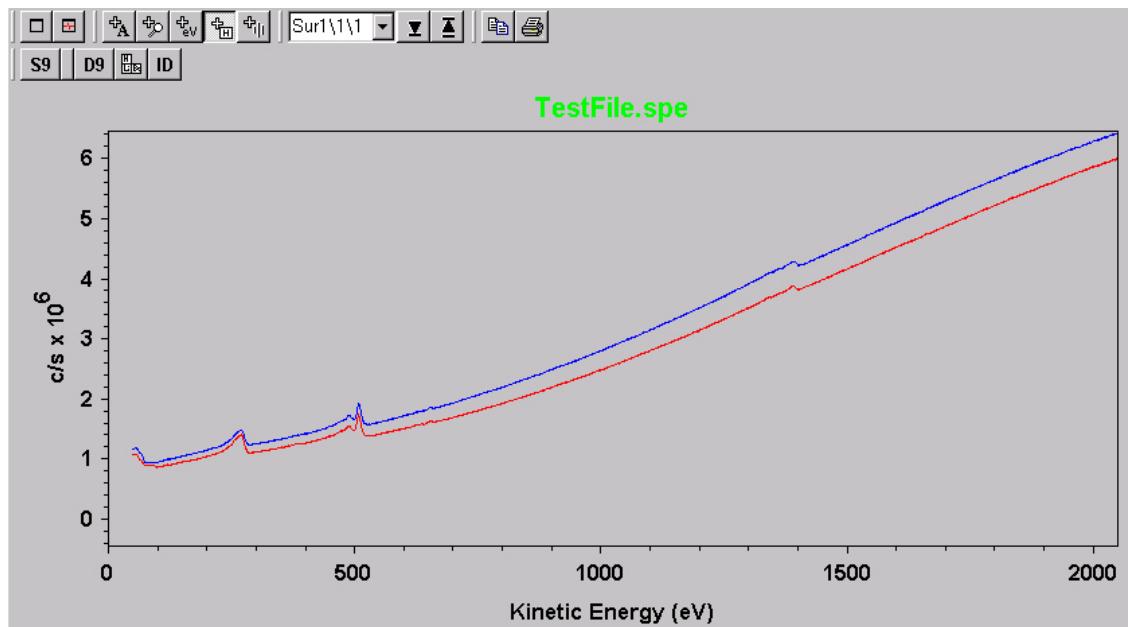
AES

Procedures in the AES session are described in this section. These include:

- A. Lab Book**
- B. Surveys**
- C. Multiplexes**
- D. Depth Profiles**
- E. Maps**
- F. Line Scans**

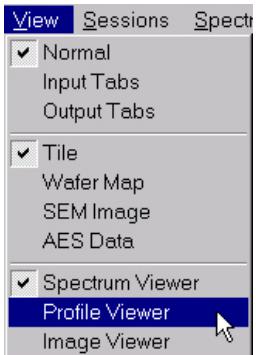
This section also contains information related to data reporting and reduction using the MultiPak software.

Overview of AES Output Area



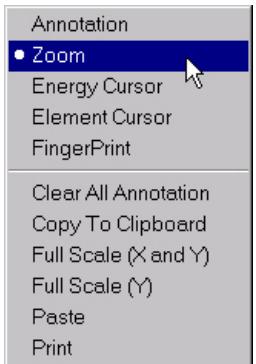
The AES output area displays Auger spectra, maps, line scans and depth profiles. Depending on the type of data being displayed, the AES output area will automatically change to display the corresponding data. The operator can manually change the layout of the AES output area by selecting between the Spectrum, Profile and Image Viewers using View in the menu bar, as seen below:

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The Spectrum Viewer will display survey and multiplex spectra and line scans; the Profile Viewer will display depth profiles; and the Image Viewer will display maps.

The operator can use the point-and-click toolbar buttons to interact with the files in the AES output area, or right-click over the area, which brings up a shortcut menu with additional options, as seen below.



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The point-and-click toolbar buttons and their actions are listed here:

| Button | Action/Result |
|------------|---|
| or | Resizes the AES output area; is used for a full screen view; reduces the area so the wafer map area and SEM image area can be seen. |
| or | Toggles between displaying all open files (spectra, maps, etc.) and displaying the selected file. |
| | Annotation: Click this button, then double-click over the AES output area to add text to the spectrum, map, profile, etc. A text box is created that can be moved. Double-click twice over the box to edit text. More options are detailed below. |
| | Zoom: Click this button, then click over the spectrum or map and drag to draw a box around the area you want enlarged. |
| | Energy Cursor: Click this button, then over the selected spectrum. The energy at the cursor's location is displayed. |
| | Element Cursor: Click this button, then over the selected spectrum. Elements with Auger peaks at the cursor's location will be displayed. |
| | Fingerprint: Click this button, then over the selected spectrum. All energies for the primary element at the cursor location are displayed. |
| Sur1\1\1 ▾ | Current Curve: On a spectrum where data were acquired for multiple points or areas, use Current Curve to designate the data curve to be displayed (using the Show One button) or to which Auto Peak ID will be applied. |
| | Show One: Shows only the data curve selected in the Current Curve box. |
| | Show All: Shows all the data curves of a spectrum. |

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The buttons below are used for data reduction, peak identification and other functions, but do not require point-and-click interaction.

| Button | Action/Result |
|--------|---|
| | Smooth/Differentiate: Use these buttons to smooth and/or differentiate the data curves. Smoothing reduces the noise evident in spectral data, improving the visual presentation and aiding with data interpretation. Differentiation is performed on AES spectra to see the relative intensities of peaks in the spectrum. See below for more information. |
| | Peak Identification: Click this button to automatically identify peaks on a spectrum. <i>NOTE: Data must be differentiated before Peak ID is performed.</i> |
| | Periodic Table: Click this button to bring up the Periodic Table box. The box consists of three tabs. Data Reduction is used to label peaks on existing spectra – click the element to label it on the selected spectrum. Data Acquisition is used to select elements for multiplexes or maps. Peak ID displays the elements used by SmartSoft for automatic peak identification. Selected elements have Auger transitions that allow for automatic identification. |
| | Copy/Print: Click the copy button to copy the active file to the clipboard for insertion into MS Office applications; click the print button to print the file to the default printer. |

Additional options in the shortcut menu include:

- Clear All Annotation: removes all annotation from the file.
- Copy to Clipboard: copies the file to the clipboard; it can then be pasted into Microsoft Office® applications.
- Full Scale (X and Y): Shows the entire spectrum or map (for use after Zoom has been used to enlarge part of the spectrum).
- Full Scale (Y): Shows the spectrum so that the entire energy range is seen.
- Paste: inserts text on the clipboard into the file as an annotation.
- Print: prints the file.

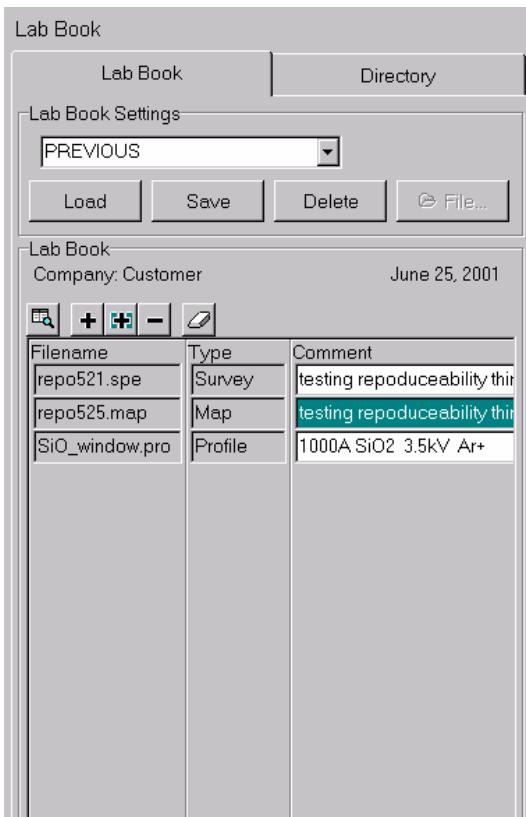
To select a data file for display when multiple data files of different types are opened,

A. Lab Book

Lab Book creates a record of all data acquired in SmartSoft. This includes all SEM images saved to file, and all surveys, multiplexes, depth profiles, line scans and maps.

Because of the record of work it generates, Lab Book can be used to review work from a previous day or shift. In addition, Lab Book records details pertaining to specific defects; for example, when a survey is acquired on a defect, Lab Book records as part of the survey data file the defect's position list, defect ID number, and X/Y and U/V positions. This makes it possible to navigate back to the defect for review or additional analysis.

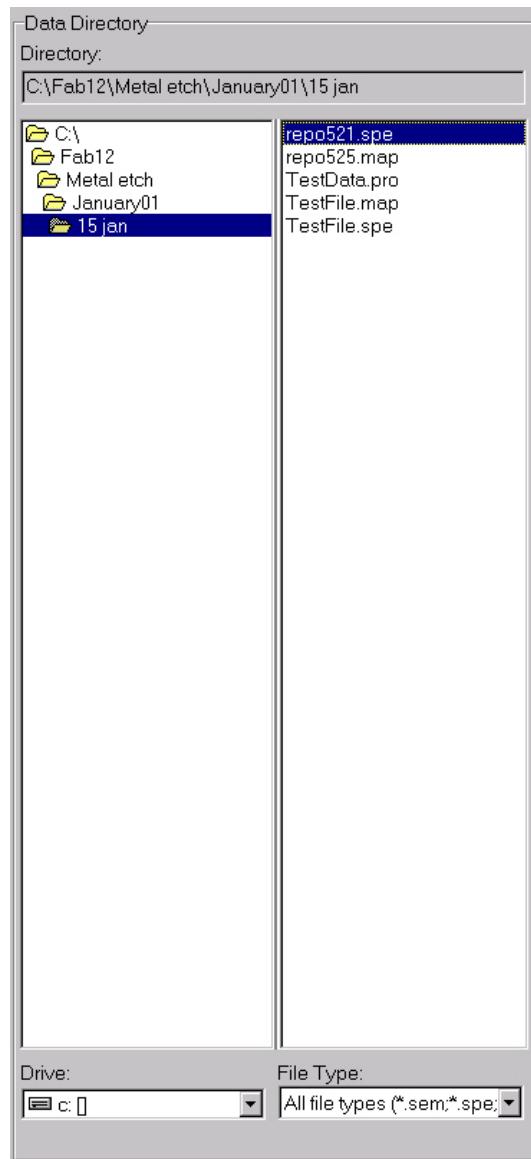
Procedures are given in this subsection to designate a directory, and set up, edit and save the Lab Book.



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1. Designate a directory in which to save data files

In the AES session, click the Lab Book application tab, then the Directory tab. Select the directory in which to save data files by selecting a drive, then a folder. All data files generated will be saved to that drive and folder.

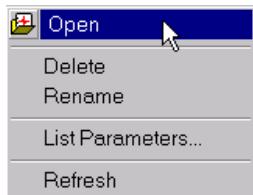


The file extensions for data files in SmartSoft are:

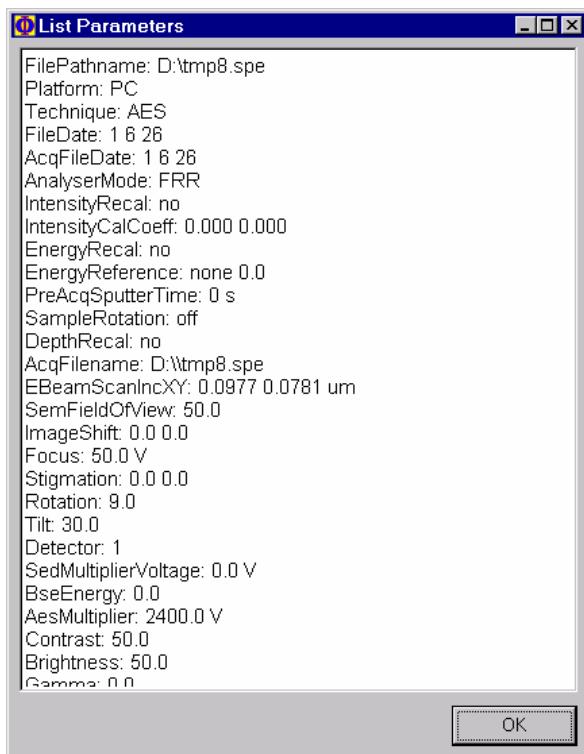
- Survey, multiplex: .spe
 - Image: .sem
 - Depth profile: .pro
 - Line scan: .lin
 - Map: .map

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NOTE: Existing data files can be opened from the Lab Book directory. Right-click over the file name to see a menu with different options:



Click Open to display the file. Other options include Delete, Rename and Refresh. The List Parameters option displays a box with information on the file:



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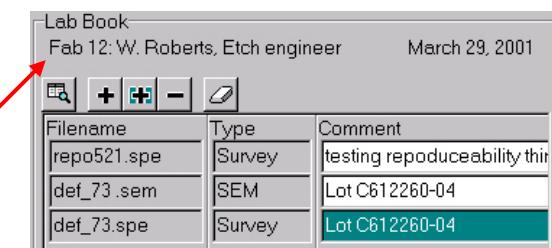
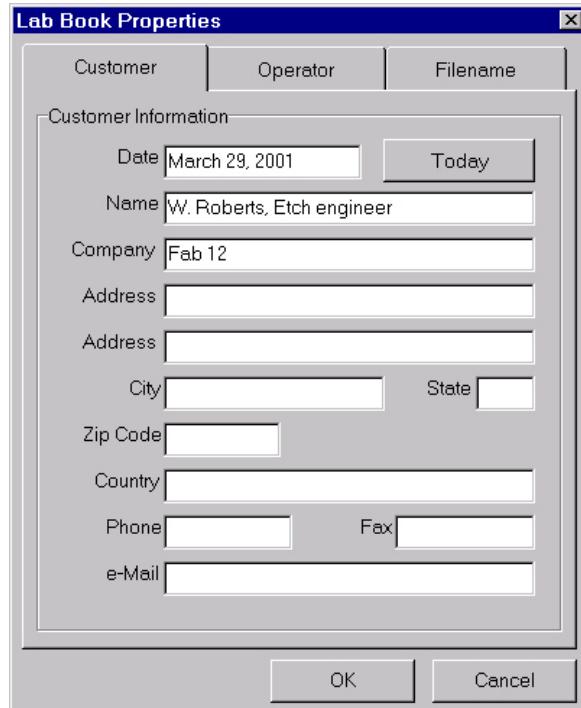
2. Set up the Lab Book

To set up the Lab Book for the current samples, click the Lab Book tab, then, under Advanced Control, click the Properties button.



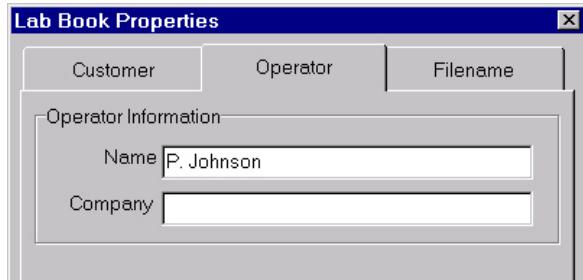
This brings up the Lab Book Properties box. The Customer and Operator tabs are used to add information that is stored with the Lab Book. The Filename tab allows the operator to designate the file name prefix for the auto filename function.

- The Customer tab includes fields for the date, name of customer, company and contact information. The first three fields, Date, Name and Customer, are displayed in the Lab Book interface, as seen below.

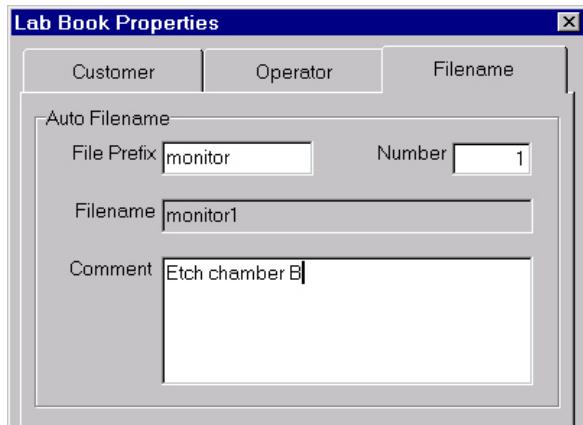


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- The Operator tab contains fields for operator name and company. The company field might also be used to indicate shift, fab, or another designation.



- The Auto Filename feature in lab book automatically assigns file names to the data files created. The Filename tab allows the operator to indicate the file prefix and starting number for the Auto Filename feature. A comment can also be added.



3. Edit the Lab Book

Once data files have been acquired, they are displayed in the lab book table. Use the buttons above the table to add or delete entries, as illustrated here:

- | | |
|--|--|
| | Add Lab Book Entry |
| | Insert Lab Book Entry (inserts a row above the selected table row) |
| | Delete Lab Book Entry |
| | Delete all Lab Book Entries |

Use the Add and Insert buttons to add comments to the lab book, independent of a data file. The file type will be listed as "Note."

The Delete Lab Book Entry button does not delete the actual data file; it only

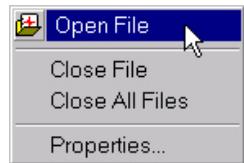
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removes the data file reference from the lab book.

Use the  button to open the Lab Book Details box. This displays additional information about each entry, including information taken from the position list. Comments can also be added or edited using this box.

Use the table to open and close data files displayed in the AES output area as follows:

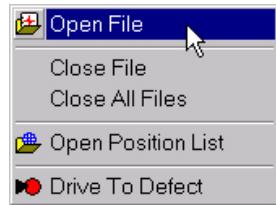
Right-click over the Comment field. This brings up the following shortcut menu:



Select Open File to open the file highlighted in the table. The data displays in the AES output area. Close File will close the file, and Close All Files will close all data files displayed in the AES output area.

Selecting Properties... opens the Lab Book Properties box, which is detailed above.

A shortcut menu is also available by first clicking the  button to open the Lab Book Details box. Right-click over the Comment field to bring up the menu:



Because the Lab Book Details box provides information from position lists, additional options are available in the menu, including Open Position List and Drive to Defect.

4. Save the Lab Book

Use the Settings area in Lab Book to save the record of the data files acquired during the analysis session or shift.

Type a name into the text box, then click Save. This saves the current lab book.

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To recall a previously saved lab book, select it in the text box, then click Load.



B. Surveys

An Auger survey is a quick, high-sensitivity acquisition of Auger data over a wide energy range. An Auger survey scan is used to identify which elements are present in the analysis area. This is typically the first step in any sample analysis, providing an overview of elements present that will guide the design of the remaining analysis session.

An Auger survey involves acquisition of one spectrum from a quick, high-sensitivity scan of a wide energy range (typically 30 to 2030 eV in 1 eV steps, at 5 milliseconds/point) to survey the elements present at a point on the sample or over an area. In *point* analysis, a stationary electron beam is positioned on a specific point. In *area* analysis, the beam is rapidly scanned, or rastered, over an area of the surface.

1. Perform earlier procedures

Perform the procedures in Section **FOUP**, and **Wafer/SEM**. Also perform the procedures in the Lab Book subsection of this section to indicate where data files should be saved.

2. Define analysis areas or points

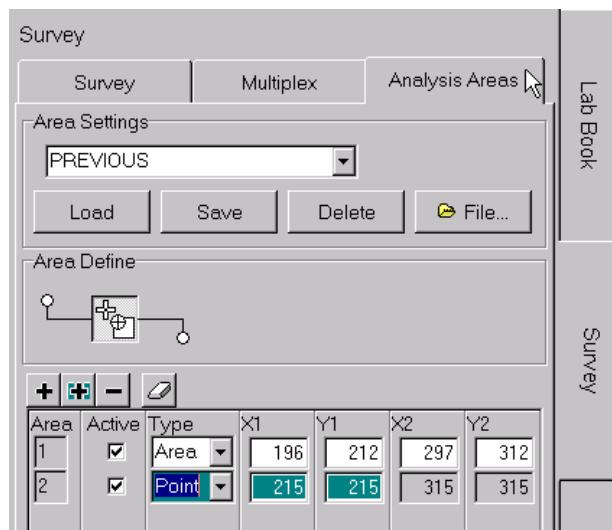
Before performing Auger analysis, the operator must specify where on the sample the analysis should occur.

Both areas and points can be defined for analysis. In area analysis, the electron beam is rapidly scanned, or rastered, over an area of the surface. In point analysis, a stationary beam is positioned on a specific point. Areas and points are defined prior to acquiring surveys, multiplexes or depth profiles.

Defining analysis areas or points

- a. In the AES session, click the Survey application tab.
- b. Click the Analysis Areas tab.

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Define an area or point in one of the following ways:

- i. Click and drag over the SEM image to define an area to be analyzed. Move the box by clicking inside the box and dragging. Resize the box by clicking and dragging on an edge of the box.

To define a point, click over the image area without dragging.

NOTE: The button is selected by default when the Analysis Areas input area is open. By selecting the button in the SEM toolbar, the operator can define areas or points in the SEM image regardless of which session tab or application tab is currently selected.

NOTE: Up to 20 points and/or areas can be defined at a time.

To change an area to a point, double-click over the area. To change a point to an area, double-click over the point.

To delete a point or area, click over it and drag it until it is beyond the boundary of the SEM image.

- ii. Use the table to establish areas or points. Click the button. In the Type field, select Area or Point.

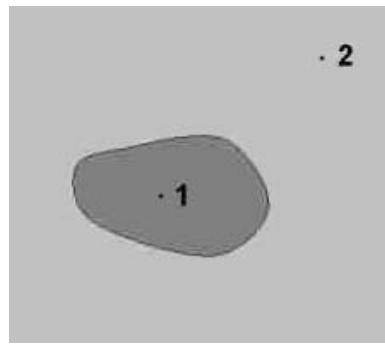
| Area | Active | Type | X1 | Y1 | X2 | Y2 |
|------|-------------------------------------|------|-----|-----|-----|-----|
| 1 | <input checked="" type="checkbox"/> | | 127 | 127 | 383 | 383 |
| 2 | <input checked="" type="checkbox"/> | | 215 | 215 | 315 | 315 |

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A box or point appears in the SEM image. To adjust the size of the area box, click in the X2 and Y2 fields; use the arrow keys to change the values, or type in new values. Using Shift + the arrow keys changes the values in larger increments. As the values are changed, the box's edges will move.

To adjust the position of an area or point, click in the X1 and Y1 fields; use the arrow keys to change the values, or type in new values. Using Shift + the arrow keys changes the values in larger increments. As the values are changed, the location of the area or point will shift.

Generally, two or more points are defined for an analysis: at least one point on the defect and one point off the defect.



Deselecting the check box in the Active field will remove the point or area from the SEM image and from any subsequent acquisition, but will not delete the area or point. The area or point can be reactivated by selecting the Active check box.

NOTE: Use the buttons above the table to add or delete areas, as illustrated here:



Add Area

Insert Area (inserts a row above the selected table row)

Delete Area

Delete All Areas

3. Set up image registration

Image registration is used to define an area on the video monitor as a reference image. This is important when doing several analyses on one analysis area, because the position of the acquisition area may move over time due to beam drift. Image registration determines if the reference image has drifted and automatically

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compensates for the beam drift, ensuring that data are acquired in the exact location intended.

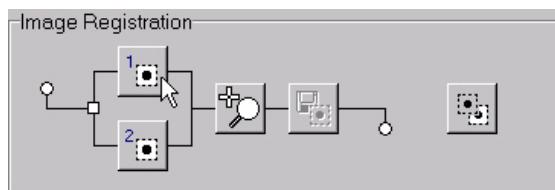
The image registration procedure involves defining a reference image around a feature with a well-defined edge. This image is stored. As the analysis proceeds, the live image is checked against the stored image and the live image is shifted electronically to correct for any drift. Set up image registration as follows:

- a. In the AES session, click the Image Registration application tab.
- b. A reference image can be defined in one of the following ways:

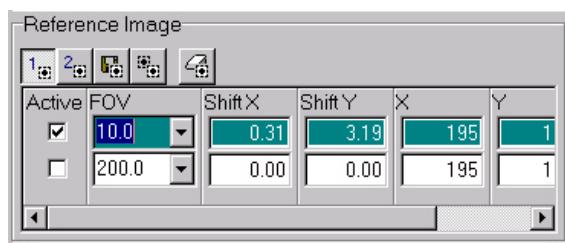
- i. Click the  button in the Image Registration flow. A box appears on the SEM image that defines the reference image. Move the box by clicking on the box and dragging; resize the box by clicking on an edge and dragging. Position the box so that it is around a distinguishable feature.

NOTE: The  button can be used to change the field of view that will be used for the image registration. However, it is only necessary to change the field of view if there is not a distinguishable feature available in the current field of view.

NOTE: In general, the smaller the reference image, the faster the registration will take place. However, it needs to be large enough to fully encompass the analysis feature and the area over which the feature may drift.



- ii. Use the table to make the reference image active. The size and position of the box can be adjusted by clicking in the Shift X, Shift Y, X, Y and Size fields. Type in new values, or use the arrow keys to adjust the values.



- c. Once satisfied with the position and size of the reference image, click the  button to save the image.

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- d. Click the  button to test the reference image. Image registration should be tested after set-up is complete to verify that the image is aligned correctly.
- e. *(optional)* A second reference area is available as part of a two-step image registration. This two-step registration is primarily used for high-magnification analysis. Reference area one, , is used to register a low magnification feature in order to give a more accurate starting point for the high magnification reference area (area two, ), and will increase the reliability of the image registration.

NOTE: The two reference images should be within 150 µm of each other and cannot exceed the distance of the electronic shift (which varies with beam voltage).

Repeat the procedure for defining reference area one  to define reference area two .

NOTE: The image registration will be performed on active areas only.

NOTE: For two-step registrations, reference area one is always registered first, followed by reference area two.

4. Set up a survey scan

The operator selects the desired survey parameters prior to the acquisition.

- a. Click the Survey application tab, then the Survey tab.
- b. Set the desired parameters in the Survey Parameters area. Each parameter is defined below.

Survey Parameters

| | |
|---|--------|
| Lower Limit (eV) | 50.0 |
| Range (eV) | 2000.0 |
| Upper Limit (eV) | 2050.0 |
| eV/Step | 1.0 |
| Number of Cycles | 30 |
| Data Collection Time 5.00 Per Area (min): | |

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| | |
|--------------------------------------|---|
| Lower Limit (eV): | Specify, in electron volts, the lower limit of the energy range for which data are to be acquired. |
| Range (eV): | Specify, in electron volts, the extent of the range of energies over which data are to be acquired. |
| Upper Limit (eV): | SmartSoft displays, in electron volts, the upper limit of the energy range for which data are to be acquired. |
| eV/Step: | Specify the energy resolution of the scan. This setting is normally 1.0. |
| Number of Cycles: | Specify the number of cycles the acquisition will last. |
| Data Collection Time Per Area (min): | The computer calculates the total time that the acquisition will last for one area based on the entered parameters. |

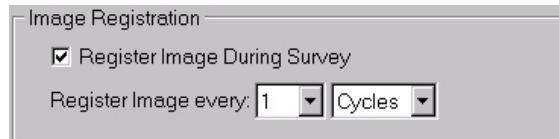
One additional survey parameter is available by clicking the Properties button in the Advanced Controls area. This opens the Survey Properties box. The Time Per Step (ms) parameter sets the number of milliseconds during which data will be acquired on each point. A typical value is 5 ms.



- c. In the Image Registration area, click the check box for Register Image During Survey if image registration is to be used during the acquisition.

Indicate whether the image should be registered so many times per cycle or per area. One cycle consists of an acquisition of all regions for all defined areas or points.

The number selected determines the frequency of image registration. For example, if one is selected, the image will be registered every cycle or area. If two is selected, the image will be registered every second cycle or area.



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Parameter Considerations

- A typical acquisition range is from 30 to 2030 eV. If the sample might contain gold, which has its major peak above 2030 eV, a wider range (30 to 2100 eV) would be required.
- With a 20 kV, 10 nA beam, spend at least 5 minutes per area when the sample contents are not known. For example, an acquisition range of 30 to 2030 eV, at 1 eV/step, at 5 ms/point, set for 30 cycles, will result in a data collection time of 5 minutes.
- When using Image Registration, try to register the image at least every minute (or even more frequently if needed).

If Image Registration is used, calculate the frequency of registration by looking at the number of areas defined and the number of minutes needed to acquire one cycle. For example, if three areas were defined and acquisition for one area takes a half minute, the image would be registered every minute and a half if the image registration is set to 1 time per cycle.

An alternative is to perform image registration 1 time per area, which would allow more frequent registrations. To choose between these options, determine how long each cycle is going to take and how frequently the image should be registered. Low magnifications require less frequent registrations.

- Under certain conditions, image registration may give unpredictable results, so it is recommended that you periodically check the position of the SEM image visually. Be especially cautious if the system was recently turned on and the system hardware has not yet stabilized, if the sample is charging (since charging will change the appearance of the image), if the image is featureless, or if sputtering has significantly altered the image.
- d. If image registration is being used and enough time has elapsed during setup, the last step before performing data acquisition should be image registration. If image registration is not being used, go to step 5.

In the SEM image area, click the  button to perform image registration.

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5. Acquire the survey scan

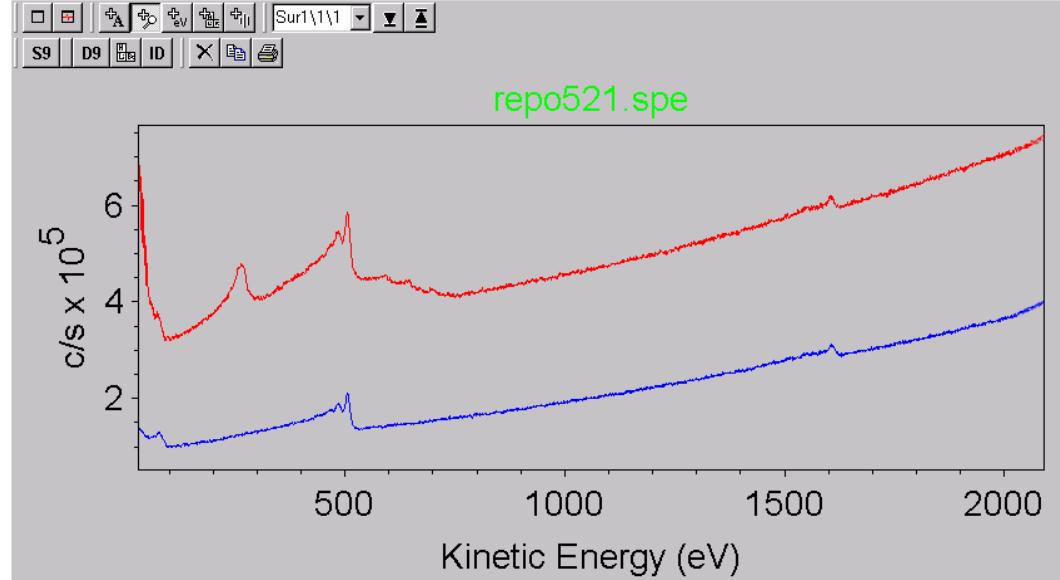
- a. Click the Start button in the Survey area.



Acquisition begins. The Acquisition Status box appears, displaying the current area and cycle numbers. The box also tracks the number of areas and cycles remaining in the acquisition.

During acquisition, the analysis areas will be displayed on the video monitor during acquisition. The image on the screen will be frozen except for the area inside the boundary being analyzed, which contains a live picture. When an acquisition begins over an area, that area will be highlighted on the screen. The image on the video monitor will toggle back and forth between areas during the acquisition.

In SmartSoft, SEM imaging is turned off and the data being acquired are displayed in the AES output area. In the example below, a spectrum is shown with data from two analysis points.



- b. To stop the acquisition before all cycles are completed, use either the Stop button or the Abort button. The Stop button terminates data acquisition at the completion of the current cycle. The Abort button terminates the acquisition immediately and eliminates the data file that was created.

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- c. Click the More button to add additional data to the completed spectrum. More will double the amount of data collected, using the parameters set when the file was first acquired.



- d. To perform a multiplex scan based on the information in the survey spectrum, go to subsection C1, Set up a multiplex scan. To reduce and report data in the survey spectrum, go to the subsection, Reduce and report the data using SmartSoft.

C. Multiplexes

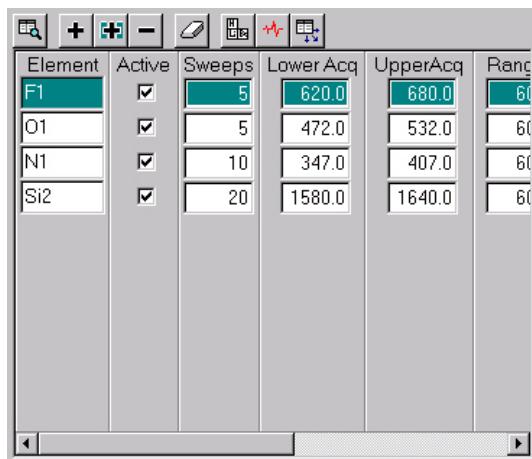
A multiplex is a set of spectra from a series of high-resolution acquisitions of narrow energy ranges (typically 30 eV in 0.5 eV steps at 20 ms/point). This type of acquisition yields great sensitivity and spectral detail in a short analysis time, because only selected energy regions expected to contain Auger peaks of interest are scanned. A multiplex acquisition is useful primarily when looking for trace elements. As many as 20 elements can be acquired in one multiplex.

The more commonly used multiplex acquisition routines are the window line scan and depth profile, which are described later in this section. This subsection describes the basic multiplex acquisition routine. The procedure below assumes that the multiplex is being acquired following an initial survey acquisition, and that analysis areas or points have been defined, and image registration set up.

1. Set up the multiplex acquisition

- a. In the AES session tab, click the Survey application tab, then the Multiplex tab.
- b. Use the table to select elements for which spectra will be acquired.

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The screenshot shows a software interface for AES setup. At the top is a toolbar with icons for search, add, delete, edit, and others. Below it is a table titled 'Element' with columns for 'Element', 'Active', 'Sweeps', 'Lower Accq', 'UpperAccq', and 'Range'. The table contains four rows: F1, O1, N1, and Si2. Each row has a checked 'Active' box and a dropdown menu for 'Sweeps' containing values 5, 10, and 20. The 'Lower Accq' and 'UpperAccq' columns show values like 620.0, 472.0, etc. The 'Range' column shows values like 60, 60, etc.

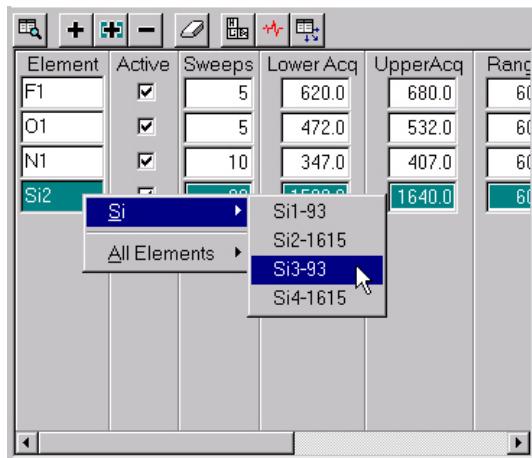
| Element | Active | Sweeps | Lower Accq | UpperAccq | Range |
|---------|-------------------------------------|--------|------------|-----------|-------|
| F1 | <input checked="" type="checkbox"/> | 5 | 620.0 | 680.0 | 60 |
| O1 | <input checked="" type="checkbox"/> | 5 | 472.0 | 532.0 | 60 |
| N1 | <input checked="" type="checkbox"/> | 10 | 347.0 | 407.0 | 60 |
| Si2 | <input checked="" type="checkbox"/> | 20 | 1580.0 | 1640.0 | 60 |

To select elements, click the  button. This brings up the Periodic Table box, Data Acquisition tab. Click the desired elements to select them.

NOTE: Always put the most volatile elements first, because they are susceptible to electron beam damage.

For elements found in the database, SmartSoft automatically enters values for those transitions in the table's fields.

To select a different transition for an element, right-click over the element in the table, then select the transition from the shortcut menu.

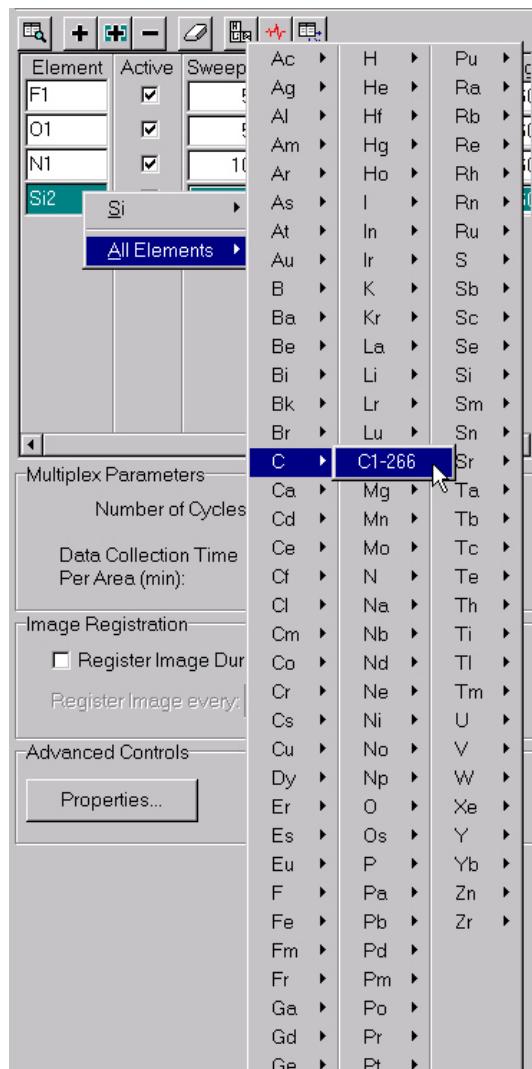


This screenshot is similar to the one above, showing the 'Element' table. However, the 'Si2' row is selected, and a context menu is open over it. The menu includes options like 'Si', 'All Elements', and several specific transition options: 'Si1-93', 'Si2-1615', 'Si3-93', and 'Si4-1615'. The 'Si3-93' option is highlighted with a blue background.

| Element | Active | Sweeps | Lower Accq | UpperAccq | Range |
|---------|-------------------------------------|--------|------------|-----------|-------|
| F1 | <input checked="" type="checkbox"/> | 5 | 620.0 | 680.0 | 60 |
| O1 | <input checked="" type="checkbox"/> | 5 | 472.0 | 532.0 | 60 |
| N1 | <input checked="" type="checkbox"/> | 10 | 347.0 | 407.0 | 60 |
| Si2 | <input checked="" type="checkbox"/> | 20 | 1580.0 | 1640.0 | 60 |

The shortcut menu can also be used to select a different element. Choose All Elements, which displays the elements alphabetically according to their periodic table abbreviation. Click the desired transition.

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To see the entire table without using the scroll bar, click the button in the table toolbar; this brings up the Multiplex Analysis Elements box. Each field is explained below.

| Multiplex Analysis Elements | | | | | | | | |
|-----------------------------|-------------------------------------|--------|-----------|-----------|-------|----------------|----------------|-------------|
| Element | Active | Sweeps | Lower Acq | Upper Acq | Range | Lower Analysis | Upper Analysis | eV Per Step |
| F1 | <input checked="" type="checkbox"/> | 5 | 620.0 | 680.0 | 60.0 | 638 | 672.0 | 1.0 |
| O1 | <input checked="" type="checkbox"/> | 5 | 472.0 | 532.0 | 60.0 | 490 | 524.0 | 1.0 |
| N1 | <input checked="" type="checkbox"/> | 10 | 347.0 | 407.0 | 60.0 | 365 | 399.0 | 1.0 |
| Si2 | <input checked="" type="checkbox"/> | 20 | 1580.0 | 1640.0 | 60.0 | 1598 | 1632.0 | 1.0 |

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| | |
|--------------------|--|
| Element: | Indicates on which element or region data will be acquired. To select a different transition or element, right-click over the element field to display the shortcut menu. |
| Active: | Click the box to remove the check only if the element is not to be acquired. |
| Sweeps: | Specifies the number of times the computer will sweep through the energy region before switching to the next region or returning to the first region. |
| Lower Acquisition: | Sets the lower limit for the acquisition window, which is the energy range over which data will be acquired. The acquisition window is represented by the blue (outer) lines in the Test Acquire box. |
| Upper Acquisition: | Sets the upper limit for the acquisition window, which is the energy range over which data will be acquired. The acquisition window is represented by the blue (outer) lines in the Test Acquire box. |
| Range (eV): | Indicates the size of the acquisition window for the element. |
| Lower Analysis: | Sets the lower limit for the analysis window, which is the range used for peak intensity measurements. The analysis window is represented by the red (inner) lines in the Test Acquire box. The analysis window range must fall inside that of the acquisition window. |
| Upper Analysis: | Sets the upper limit for the analysis window, which is the range used for peak intensity measurements. The analysis window is represented by the red (inner) lines in the Test Acquire box. The analysis window range must fall inside that of the acquisition window. |
| eV per Step: | Specifies the energy resolution of the multiplex acquisition; this value is normally set to 1.0. |

Edit the table data by clicking in a field and typing in new value, or using the arrow keys on the keyboard to change the value. Use additional buttons in the table toolbar as follows:

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Add Element



Insert Element (inserts a row above the selected table row)

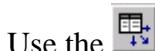


Delete Element



Delete All Elements/Erase Table

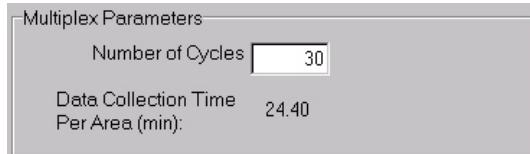
NOTE: The values for Lower/Upper Acquisition and Lower/Upper Analysis can be changed interactively in the Test Acquire box, which is discussed below.



Use the button to copy the element information to all the acquisition setup menus – the tables in the Depth Profile, Line Scan and Map application tabs. This saves time if profiles, line scans or maps are to be acquired for the same elements.

NOTE: Changes made to the table values after the element information has been copied to other setup menus will not appear in those menus unless the button is clicked again.

- c. In the Multiplex Parameters area, select the number of cycles that the acquisition will last. The Data Collection Time Per Area shows the total time the acquisition will last for one area based on the entered parameters.



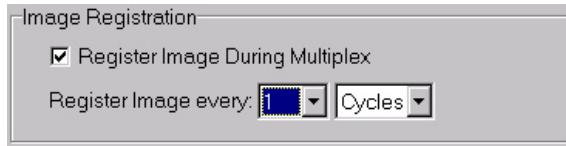
One additional multiplex parameter is available by clicking the Properties button in the Advanced Controls area. This opens the Multiplex Properties box. The Time Per Step (ms) parameter sets the number of milliseconds during which data will be acquired on each point. A typical value is 5 ms.

- d. In the Image Registration area, click the check box for Register Image During Multiplex if image registration is to be used during the acquisition.

Indicate whether the image should be registered so many times per cycle or per area. One cycle consists of an acquisition of all regions for all defined areas or points.

The number selected determines the frequency of image registration. For example, if one is selected, the image will be registered every cycle or area. If two is selected, the image will be registered every second cycle or area.

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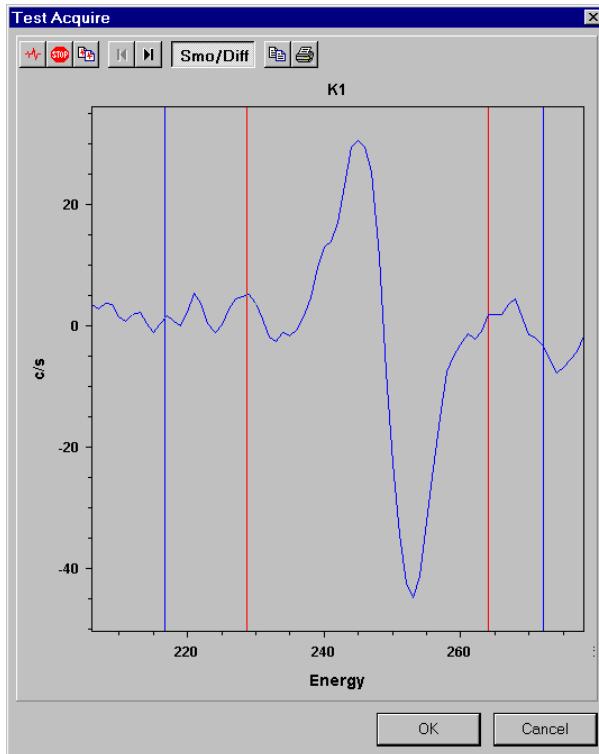
- e. If image registration is being used and enough time has elapsed during setup, image registration should be performed before Test Acquire. If image registration is not being used, go to step f.

In the SEM image area, click the button to perform image registration.

- f. Perform a Test Acquire for each selected element. Test Acquire provides an opportunity to determine whether the acquisition window set up for each element is optimized.

NOTE: It is important to make each window wide enough to include the entire Auger peak. The windows need to be wide enough so that, if the sample charges and the Auger peak shifts upward in energy, the peak will not move outside the acquisition windows.

In the table toolbar, click the button. This opens the Test Acquire box, which displays the region for the element highlighted in the element table. In addition, a Test Acquire point is displayed in the SEM image area.



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In the Test Acquire box toolbar, click the  button to begin acquisition of the selected element. Differentiated data is displayed in the graph.

Use the Test Acquire point on the SEM image to search for the element at various points on the sample, if needed. Click anywhere in the SEM image field of view to move the Test Acquire point to that location. Moving the Test Acquire point automatically stops, then restarts, the acquisition.

The test acquisition will continue until the  button is clicked.

Adjust the windows so that the full peak (both the most positive and negative excursions of the data) is contained within the analysis window (red lines). The windows are adjusted by clicking on a line with the mouse and dragging.

The area within the blue lines (acquisition window) indicates the range over which data are acquired. The area within the red lines (analysis window) is used to generate atomic concentration data and depth profiles.

NOTE: The analysis window (red lines) must fall inside the acquisition window (blue lines).

Adjust the X axis of the Test Acquire graph by clicking the axis and dragging to stretch or shrink the axis. Clicking the X axis and dragging while pressing the Shift key will offset the axis's scale.

NOTE: The Y axis scales automatically, and should not need to be adjusted.

Click the  (next element) or  (previous element) button to perform a Test Acquire on the remaining elements listed in the element table. Perform the Test Acquire procedure detailed above, until each element has had a Test Acquire performed and its parameters adjusted as needed.

Alternatively, use the  button to bring in peaks from the current survey spectrum. This loads the peaks from the spectrum and does not involve data acquisition. Adjust the windows as detailed above.

Parameter Considerations

- For extracting chemical state information, it is sometimes useful to include a relatively wide energy range below (to lower energies than) the main Auger peak, which could include some of the energy loss structure.
- Remember that the Si2 analysis window may need to accommodate both the

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Si peak in its elemental state and the Si peak in its oxide state, which is shifted to a lower energy.

- g. If image registration is being used and enough time has elapsed during setup, the last step before performing data acquisition should be image registration. If image registration is not being used, go to step 2.

In the SEM image area, click the  button to perform image registration.

2. Acquire the multiplex scan

- a. In the Multiplex area, click the Start button.

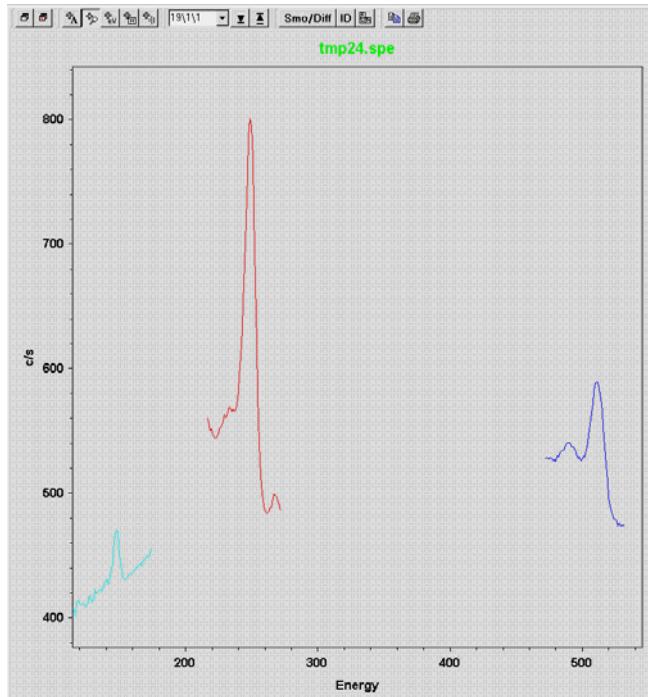


Acquisition begins. The Acquisition Status box appears, displaying the current area and cycle numbers, as well as sweeps and element information. The box also tracks the number of areas and cycles remaining in the acquisition.

During acquisition, the image on the screen will be frozen except for the area inside the boundary being analyzed, which contains a live picture. When an acquisition begins over an area, that area will be highlighted on the screen. The image on the video monitor will toggle back and forth between areas during the acquisition.

In SmartSoft, SEM imaging is turned off and the data being acquired are displayed in the AES output area. In the example below, a spectrum is shown with data for three elements.

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- b. To stop the acquisition before all cycles are completed, use either the Stop button or the Abort button. The Stop button terminates data acquisition at the completion of the current cycle. The Abort button terminates the acquisition immediately and eliminates the data file that was created.
- c. Click the More button to add additional data to the completed spectrum. More will double the amount of data collected, using the parameters set when the file was first acquired.



To reduce and report the data, proceed to the subsection, Reduce and report the data using SmartSoft.

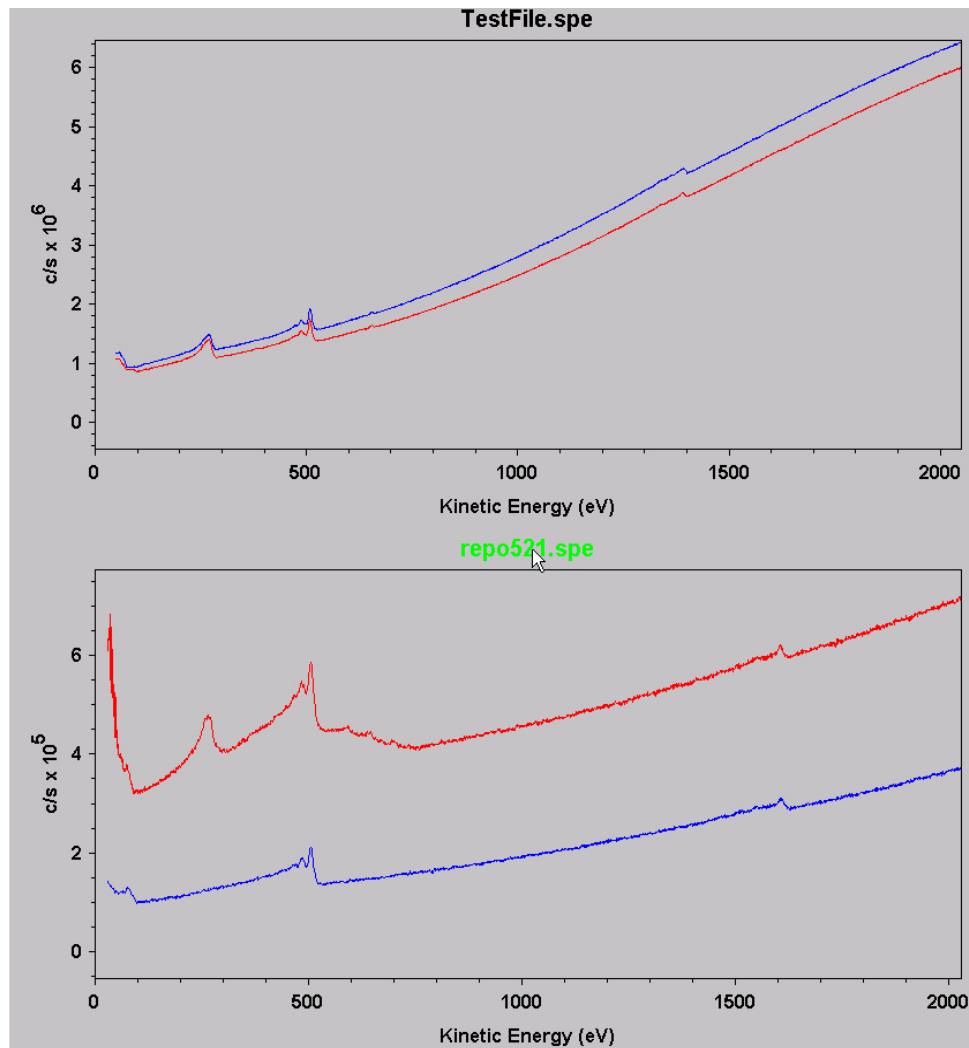
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Reduce and report the data using SmartSoft

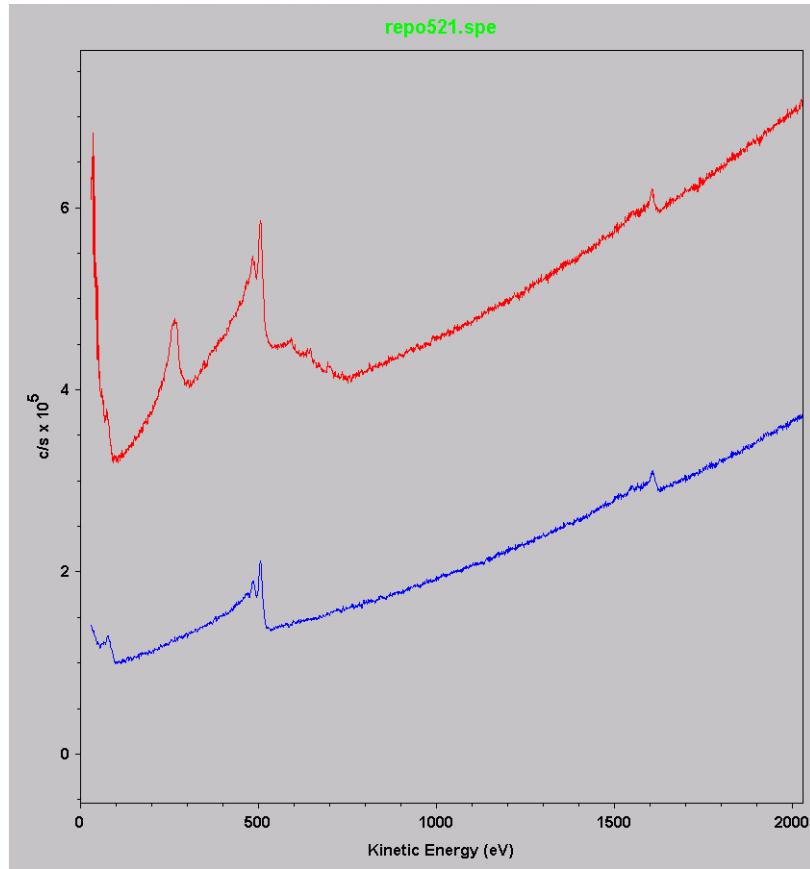
Data reduction and reporting can be performed in SmartSoft or MultiPak. MultiPak allows for more advanced data reduction; in many cases, the SmartSoft procedures will be sufficient to annotate, label and output spectra.

Display the data

- a. Click the  button for a full screen view of the AES output area.
- b. If more than one spectrum is displayed, click the file name displayed above the desired spectrum to make it the selected spectrum. The file name will turn green. Then, to display only that spectrum, click the  button.



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Smooth and differentiate the data

Smoothing reduces the noise in spectral data, improving the visual presentation and helping with data interpretation. Differentiation is performed to see the relative intensities of peaks in the spectrum. It also aids with peak identification, since Auger peaks ride on a high secondary electron background.



- To smooth the data, click the  (S9) button. A 9-point Savitzky-Golay smooth is performed on all of the spectrum's data curves.

NOTE: The Savitzky-Golay algorithm is a polynomial function that eliminates some noise from the data and tends to preserve the peak shapes of the original data.

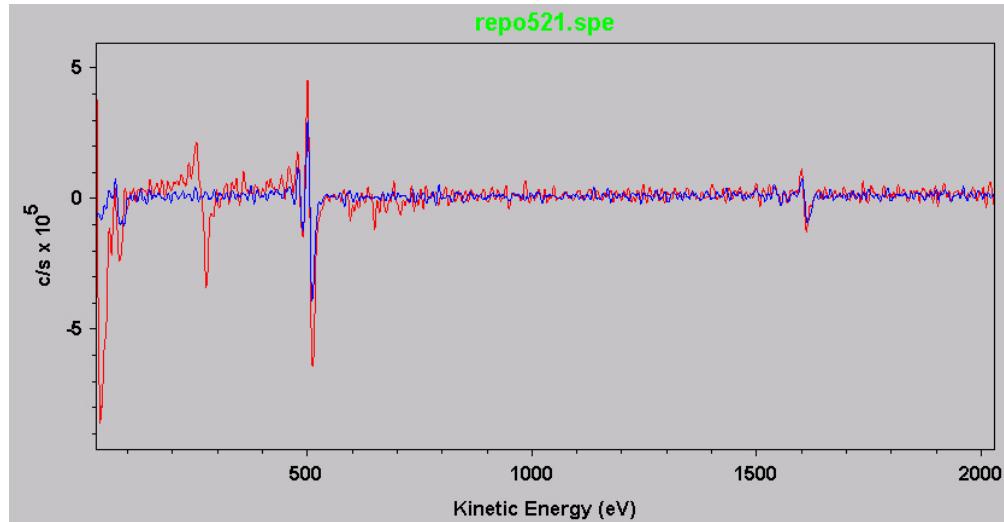


- To differentiate the data, click the  (D9) button. A 9-point differentiation is performed on all data curves.

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- c. To perform the smooth and differentiation functions at once, click the button

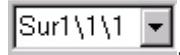
between S9 and D9:  . Following smoothing and differentiation, the data will appear similar to the spectrum seen below:

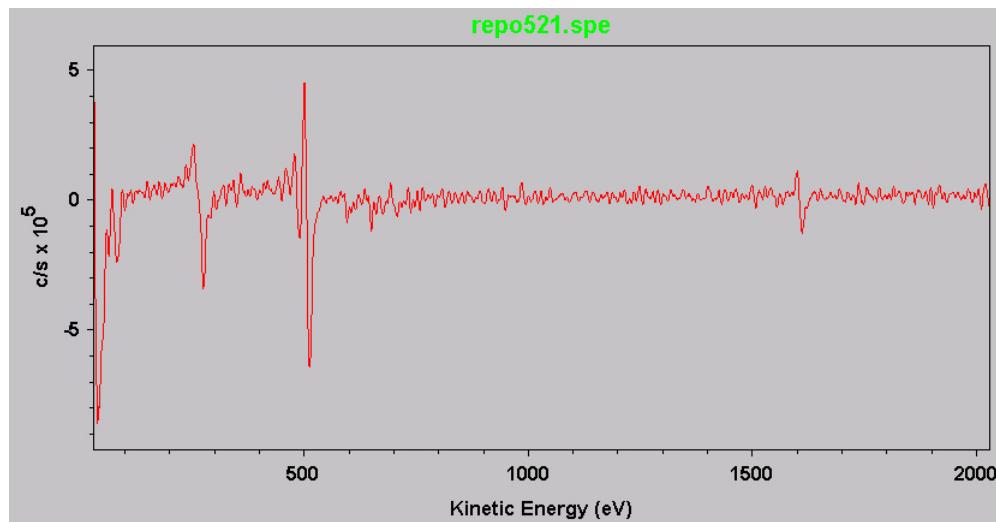


Identify element peaks manually

Manual identification of peaks is accomplished using the energy, element and fingerprint cursor buttons, along with the Zoom and Annotate buttons. Manual peak identification can also be done using the periodic table.

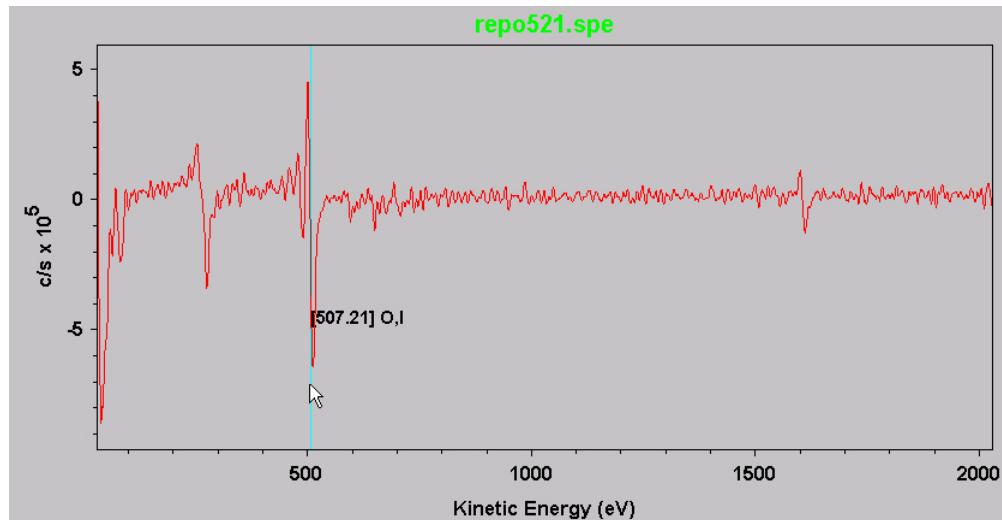
- a. It is helpful to display only one data curve while identifying and labeling peaks.

Select the desired curve in the Current Curve box:  . Then click the  button to display that curve.



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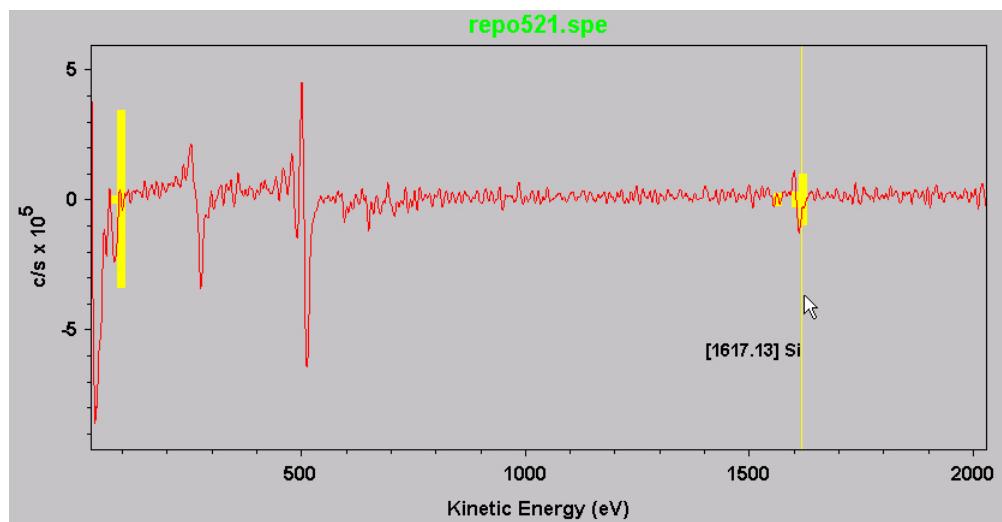
- b. Click the  button to select the element cursor. Click over the spectrum and drag until the vertical cursor is aligned with the lowest point of the largest peak on the curve. Possible elements for the peak are displayed. Use the cursor to identify possible elements for all peaks in the curve.



Additional tools for manually identifying peaks include:

Energy Cursor: Click the  button to select the energy cursor. Click over the spectrum and drag; the energy at the cursor's location is displayed.

Fingerprint Cursor: Click the  button to select the fingerprint cursor. Click over the spectrum and drag; yellow regions are displayed that represent the relative intensities and positions of the major peaks of the selected element, as seen below:



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Use the fingerprint as a quick reference to find peak energies for elements.

NOTE: The fingerprint cursor function is valid only when working with differentiated data. The energy and element cursors can be used with either differentiated or undifferentiated data.

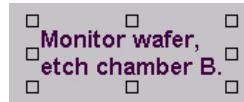
Zoom: Click the  button, then click and drag to draw a box over the spectrum area to enlarge. This can help when examining small peaks. Right-click over the spectrum and select Full Scale (X and Y) to see the entire spectrum again.

- c. Label the peaks in one of two ways:

Periodic Table: Click the  button. In the Periodic Table box, click the Data Reduction tab. Click the elements that have been identified in the spectrum; the peaks will be labeled automatically.

Annotation Button: Click the  button, then double-click anywhere over the spectrum to create a text box. Type in the desired text, then click outside the box to set the text.

To move the position of the text, click once over the text. This displays the text within a movable box. Click anywhere on the box and drag to move the box.



Right-click over this box to copy the text to the clipboard, or to delete the text. Selecting Properties... brings up the Graph Annotation box, where font characteristics and orientation can be edited.

NOTE: To rotate the letters so they are oriented vertically, select 270 degrees for the orientation.

To edit text, double-click over the text. This displays the text for editing:



Select the text in the edit box, then right-click over the edit box to display additional font options. Edit the text as desired, then click outside the box to set the text.

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Identify element peaks automatically

Click the  **ID** button to automatically identify peaks on the spectrum. The peak labels are annotations, and can be edited or deleted as described above.

Output the spectrum

 Click the  button to copy the spectrum to the clipboard. This allows the spectrum to be imported as a graphic into any Microsoft Office application (Word, PowerPoint, etc.).

 Click the  button to print the spectrum to the default printer.

NOTE: Changes made to the spectrum (smooth/differentiate, labeling peaks) are not saved as part of the data file.

The data reduction steps (smooth/differentiate, identify and label peaks, output the spectrum) should be repeated for all of the spectrum's data curves.

Reduce and report the data using MultiPak

The typical MultiPak data reduction procedures, described below, for Auger survey scan data are the following:

- Start MultiPak, and display the acquired data.
- Differentiate the data (and smooth, if needed).
- Identify the element peaks and label them.
- Print the annotated spectrum.
- Get atomic concentration data and print.

Start MultiPak and display the acquired data

Open the file with the acquired data in MultiPak for data reduction.

- a. To start MultiPak, double-click on the MultiPak icon on the desktop or select PHI-MultiPak-MultiPak from the Start menu.



- b. Open the data file in one of the following ways:

- Press the Acq button on the upper toolbar; or

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- Select File–Open Last Acquisition button; or
- Select File–Open. In the Open dialog box, select .SPE in the File Type field, find the directory your SPE (spectrum) file was saved in, and double-click on the file name.



The survey data is displayed in the Spectrum window. Notice that the file's name is displayed in green, indicating that this data is "selected." Any MultiPak functions activated will be performed on this data.

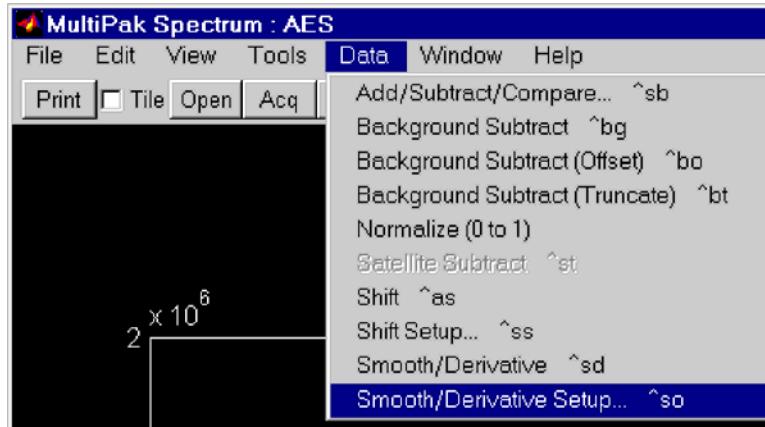
The header (displayed only when Header in the View menu is checked) lists the file's data acquisition parameters (date of acquisition, beam voltage of acquisition, etc.). The third line of the header will be updated with a processing history as data reduction routines are applied to the data.

Differentiate the data (and smooth, if needed)

NOTE: The sensitivity factors stored in the database for AC calculations are based on a 5-point differentiation.

- a. Select Data–Smooth/Derivative Setup.... The function options are displayed in the lower toolbar.

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- b. Turn the “Derivat” check box on, if it is not on already.
- c. Click on the arrow in the option menu under “Derivat,” then click on “5.”

NOTE: Differentiating data makes it easier to identify elements, because Auger peaks are riding on a high secondary electron background.

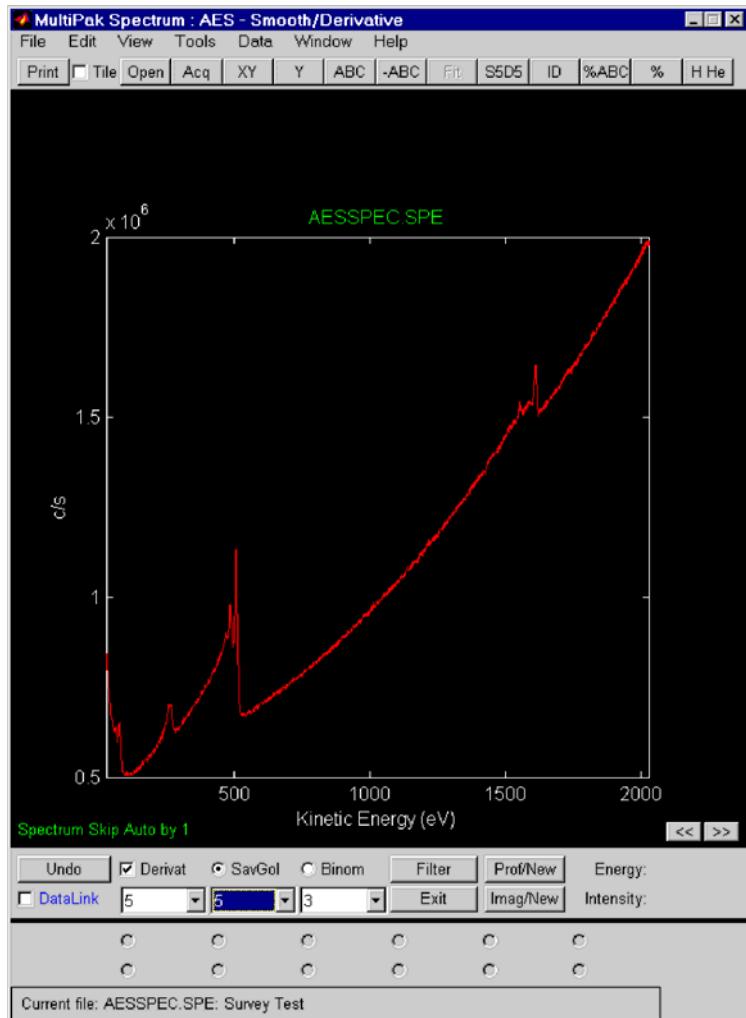
- d. Turn the “SavGol” button on. (Click on the button once if the black dot is not displayed.) This turns the Savitzky-Golay smoothing function on (and the Binomial function off).

NOTE: A Savitzky-Golay smoothing routine is recommended over the Binomial smooth, because Savitzky-Golay smoothing does an excellent job of retaining the original shape of the data curve.

- NOTE: The smoothing functions operate on the displayed data. If you press the smooth button a second time, the data will be smoothed twice.*
- e. Click on the arrow in the option menu under “SavGol,” then click on “5.” (The number displayed in the option menu under “Binom” does not matter since that function is not on.)

Notice also that the upper toolbar now has a button named “S5D5,” so that the next 5-point differentiation and 5-point smooth can be performed by simply clicking on the S5D5 button without having to open the Smooth/Derivative Setup toolbar.

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- f. Click on the Filter button in the lower toolbar. The differentiated data is displayed in the Spectrum window.



- g. Click on the Exit button in the lower toolbar. This closes the Smooth/Derivative Setup function.



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Identify the element peaks and label them

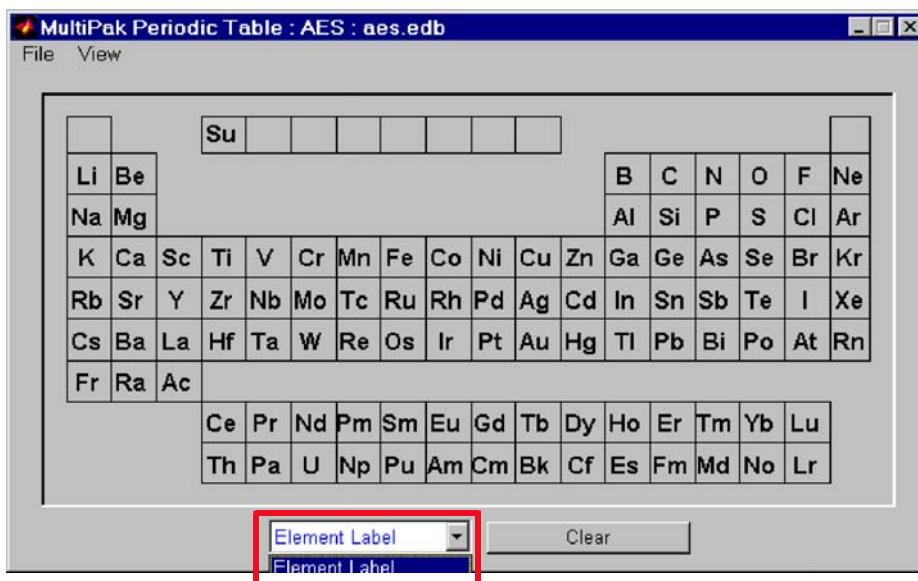
Identify the energies of significant peaks automatically using MultiPak's Peak ID function.

NOTE: The Peak Identification function does a better job of identifying peaks correctly than does Energy Cursor, because Peak Identification compares spectra, not just individual energies.

- a. Press the -ABC button (or select Edit–Clear All Annotation) to clear all existing annotation.



- b. Select Window–Periodic Table. Click on the arrow in the option menu in the lower toolbar of the Periodic Table window, then click on “Element Labels.”



- c. In the Spectrum window, press the ID button in the upper toolbar.

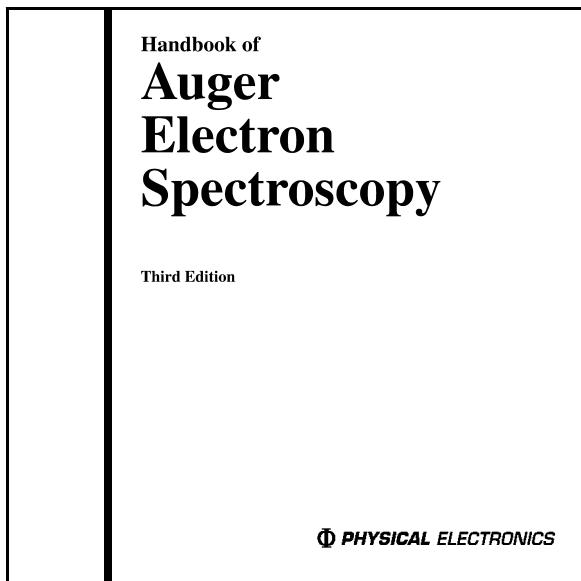


Peak labels are added to the data. The corresponding region buttons are displayed in the Spectrum window's region bar, and the corresponding buttons are turned on in the Periodic Table window. If View–Region Cursors is on, the region boundaries are also displayed.

- d. Verify the accuracy of the labels using your experience and the *Handbook of Auger Electron Spectroscopy* and make corrections, additions, or deletions as

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necessary.



Print the annotated spectrum

Print hard copies of the annotated spectra in one of the following ways.

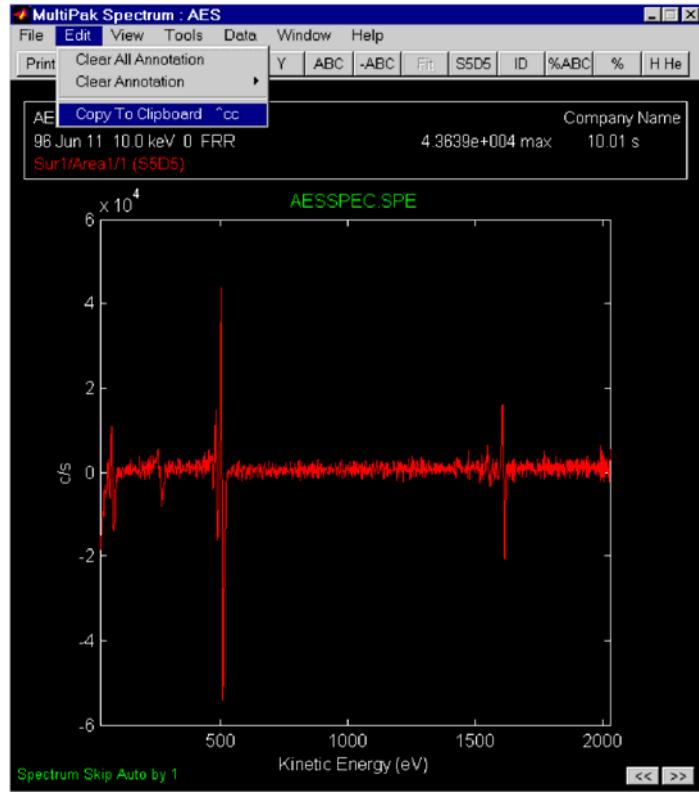
- Print directly from MultiPak by pressing Print in the upper toolbar (or selecting File–Print in B+W).



- Paste the labeled spectrum into a file in another application as follows:

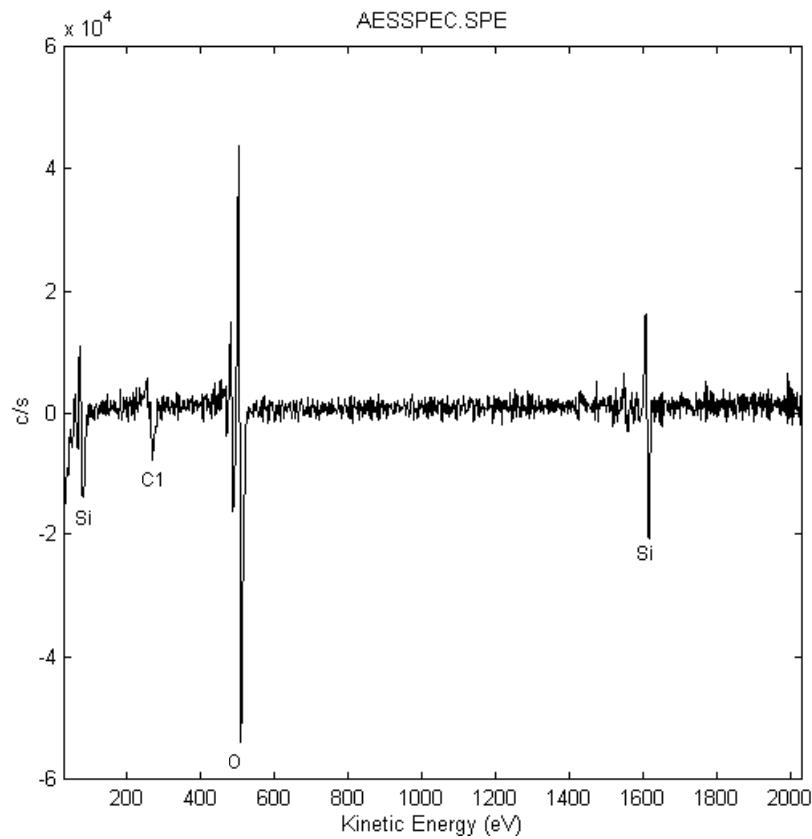
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- a. Select Edit–Copy To Clipboard.

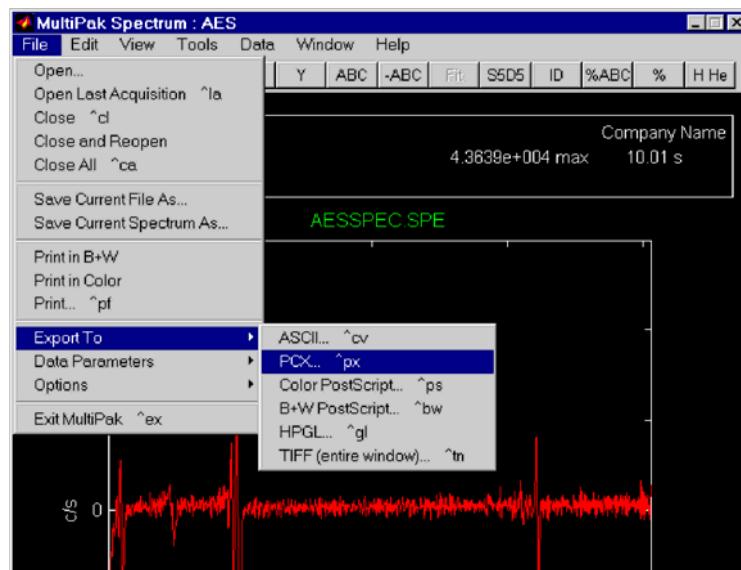


- b. In Microsoft Office applications, use the Edit–Paste Special function and select “Picture (Enhanced Metafile)” for best results. The spectrum (and header if displayed) is pasted into the document.

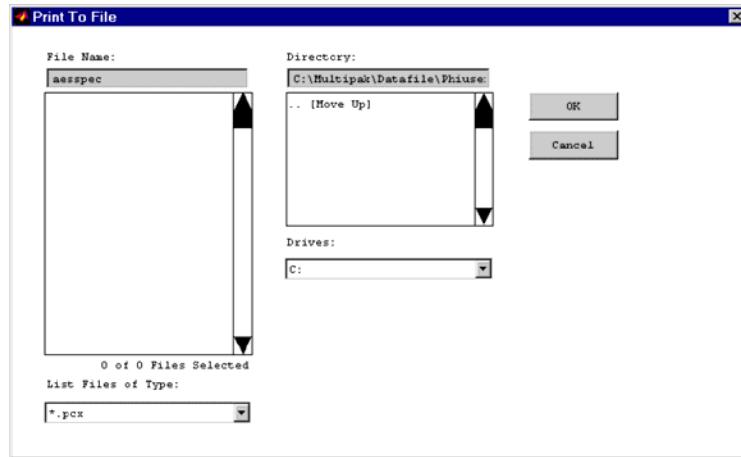
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- Write the display to a graphics file, as follows:
 - a. Select File—Export To—PCX.... A file with a PCX extension is created and placed in a MultiPak subdirectory (default is C:\MULTIPAK\DATAFILES\PHIUSER1\AES).



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- b. Open the graphics application on the desktop and load or import the graphics file.

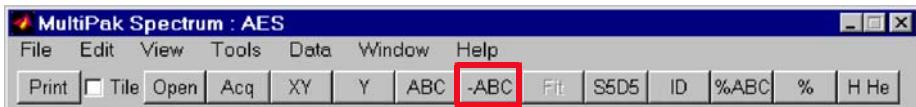
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Get atomic concentration data and print

Quantify the composition of the analysis areas/points.

NOTE: Quantification depends on peak-to-peak height between the region endpoints and above the background. Region endpoints are viewed when a region button is pressed in the Spectrum window with a spectrum displayed and with Region Cursors in the View menu set to on (checked). Placement of the region endpoint cursors and the type of background can be modified in the transition dialog box. The region cursors can also be modified temporarily simply by dragging them to a different position using the left mouse button.

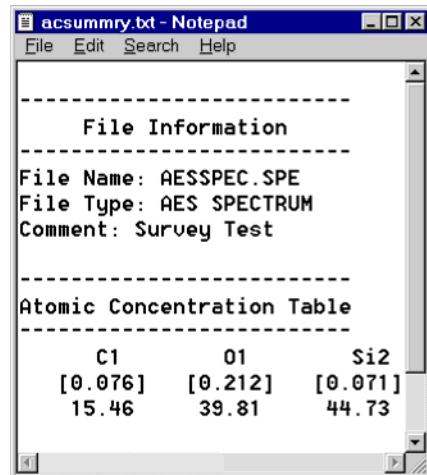
- a. Press the -ABC button in the upper toolbar to remove any AC data that may have been generated earlier in this MultiPak session.



Press the % button in the upper toolbar (or select Tools–Atomic Concentration Table–Add, then Tools–Atomic Concentration Table–View). The relative atomic concentrations are calculated for the regions present in the region bar. The Notepad application opens to show the table that was created.



- b. Output the AC table in one of the following ways, as follows:



- Print directly from Notepad: In the Notepad window, select File–Page Setup..., Printer... to designate where the table will be printed. Then, select Print in B+W.

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- Save the table as a text file: In the Notepad window, select File–Save As.... Then, enter a file name and destination directory, and press OK.
- Paste the table into another text file: In the Notepad window, select Edit–Copy. Then, open another text application on the desktop and select the Paste function (usually under the Edit menu). The table is pasted into the document.
- Paste the table as annotation onto the spectrum in MultiPak:
 - i. In Notepad, select Edit–Copy.
 - ii. In MultiPak, press the Annotate button on the upper toolbar.
 - iii. Click inside the data axes where the table is to be placed.
 - iv. Press[Ctrl][v] to paste the table onto the data.
 - v. Select Courier New in the font drop-down menu in the lower toolbar to preserve the column alignment of the AC table.
 - vi. Press Exit in the lower toolbar.

D. Depth Profiles

An Auger depth profile is made by alternating sputtering with data acquisition. Sputtering is described in the **Ion** section. This subsection describes depth profile data acquisition.

Auger depth profiles provide elemental and chemical information as a function of depth. A depth profile consists of a series of multiplex-type spectra acquired at different depths. Acquisition alternates with sputter removal of material from the surface.

A depth profile is typically used to determine what layers are present, how thick they are, and what contaminants may be present at layer interfaces. Before setting up for the depth profile, it is important to obtain as much information as possible about the thickness and composition of the layers to be monitored in the profile.

1. Perform earlier procedures

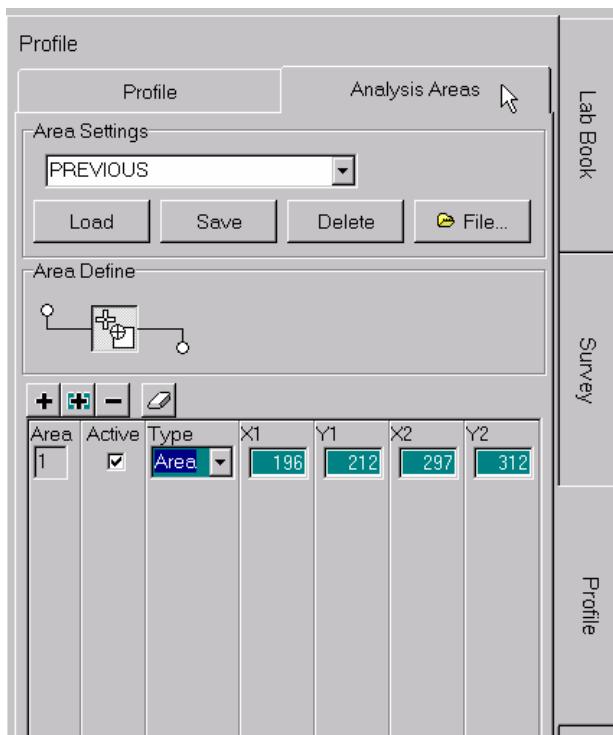
Before performing the procedures in this subsection, perform the other applicable procedures presented earlier. This subsection's procedures assume that the area of interest is centered under the electron gun optics and the optics have been optimized at that location, as described in the **Wafer/SEM** section. This places the area at the focal point of the analyzer, which is where the ion gun has been aligned.

Also perform the procedures in the Lab Book subsection to indicate where data files should be saved, and set up image registration, if not already, according to the procedure in the Surveys subsection of this section.

2. Define analysis areas or points

Click the Profile application tab, then the Analysis Areas tab.

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Refer to the procedure in the Surveys subsection of this section to define analysis areas or points.

3. Set up the depth profile

The following steps describe defining the depth profile acquisition parameters, including some sputtering parameters. (The ion gun operating parameters are defined using the procedures in the **Ion** section.)

Before setting up the depth profile acquisition parameters, it is important to obtain as much information as possible about the thickness and composition of the layers to be monitored in the profile so the depth profile can be set up to include them.

Three kinds of depth profile are available: 2-point, 3-point, and Window. Two- and three-point depth profiles store peak and background energies at every point of the profile, whereas a window depth profile stores a spectrum at every point.

A 2-point profile saves a single background energy (specified in the Background 2 parameter) at each point, whereas a 3-point depth profile saves two background energies: one is extrapolated from a high-energy background energy and the other is a low-energy background energy. Acquiring a 2-point profile is common. The 3-point profile is usually used to measure a small peak intensity on a sloping background, primarily when only a small amount of the element is present.

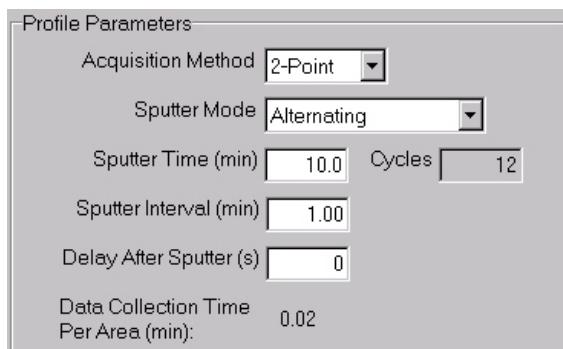
Having a peak-shape spectrum, which is acquired with the window depth profile, makes extraction of chemical state information possible. If the Auger peak energy

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shifts or the peak changes shape because of chemical state changes or sample charging effects, a 2-point depth profile will simply show a change in intensity, whereas such changes will be readily evident in a window depth profile.

One benefit of the window depth profile is that atomic concentration data can be generated, but, since a window depth profile collects much more data, acquisition requires much more time than does a 2- or 3-point depth profile.

- a. Click the Profile tab. In the Profile Parameters area, set the desired parameters. Each parameter is defined below.



- | | |
|-------------------------|---|
| Acquisition Method: | The options are 2-point, 3-point and window. |
| Sputter Mode: | Options are alternating and continuous. In the alternating mode, data acquisition and sputtering are performed in alternating time intervals. In the continuous mode, data acquisition and sputtering occur simultaneously. |
| Sputter Time (min): | Specifies the total time the ion gun will sputter. This does not include the time needed to acquire the data in an alternating sputter profile. |
| Cycles: | This value is calculated based on other parameter values. The cycle value includes two pre-sputter cycles. |
| Sputter Internal (min): | The length of time the ion gun will sputter between data acquisition cycles. This parameter appears only when the alternating sputter mode is selected. |

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| | |
|--------------------------------------|---|
| Delay After Sputter (s): | Specify a delay time, in seconds, after sputtering is completed and before data acquisition or image registration is performed. A time delay may be required for some insulating samples in order for all surface potentials to reach a new steady state condition following sputtering. This parameter appears only when the alternating sputter mode is selected. |
| Data Collection Time Per Area (min): | The computer calculates the total time that the acquisition will last for one area based on the entered parameters. |

One additional parameter is available by clicking the Properties button in the Advanced Controls area. This brings up the Profile Properties box. The Time Per Step (ms) parameter sets the number of milliseconds during which data will be acquired on each point. A typical value is 5 ms.

- b. Use the table to select elements for which data will be acquired during the profile.

| Element | Active | Sweeps | Lower Acq | Upper Acq | Range |
|---------|-------------------------------------|--------|-----------|-----------|-------|
| O1 | <input checked="" type="checkbox"/> | 5 | 472.0 | 532.0 | 60 |
| Si2 | <input checked="" type="checkbox"/> | 20 | 1580.0 | 1640.0 | 60 |

To select elements, click the button in the table toolbar. This brings up the Periodic Table box, Data Acquisition tab. Click the desired elements to select them.

NOTE: Always put the most volatile elements first, because they are susceptible to electron beam damage.

For elements found in the database, SmartSoft automatically enters values for those transitions in the table's fields.

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To select a different transition for an element, right-click over the element in the table, then select the transition from the shortcut menu. The shortcut menu can also be used to select a different element.

To see the entire table without using the scroll bar, click the  button in the table toolbar. This brings up the Profile Analysis Elements box.

The fields in the table vary according to whether a 2-point, 3-point or window acquisition is specified. Fields for a Window acquisition are the same as fields for a standard multiplex acquisition. Refer to the Multiplexes subsection for definitions of the fields.

The fields for 2-point and 3-point acquisitions are defined below. The fields for a 3-point acquisition are shown here:

| Profile Analysis Elements | | | | | | | |
|---------------------------|-------------------------------------|--------|--------------|-------------|--------------|-------------|--|
| Element | Active | Sweeps | Background 1 | Peak Energy | Background 2 | Channels On | |
| O1 | <input checked="" type="checkbox"/> | 5 | 496.0 | 507.0 | 525.0 | 1 thru 8 | |
| Si2 | <input checked="" type="checkbox"/> | 20 | 1609.0 | 1615.0 | 1628.0 | 1 thru 8 | |

- Element: Indicates on which element or region data will be acquired.
- Active: Click the box to remove the check only if the element is not to be acquired.
- Sweeps: Specifies the number of times the computer will sweep through the energy region before switching to the next region or returning to the first region.
- Peak Energy: This value is the energy of an EN(E) peak from the standard AES Element Table and can be changed in this menu.
- Background 1 and 2: For a 2-point acquisition, two energies are used to create the depth profile: peak energy and background 2. The background 2 energy value must be greater than the peak energy value.
For a 3-point acquisition, background 1, peak energy and background 2 are used. The background 1 value must be less than the peak energy value, and the background 2 value must be greater than the peak energy value.

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Channels On: Used in conjunction with Test Acquire to narrow peak energy and/or background energy windows for higher-energy peaks. See below for more information.

Navigate through the table by clicking in the fields. Edit the table data by clicking in a field and typing in a new value, or using the arrow keys on the keyboard to change the value. Use additional buttons in the table toolbar as follows:



Add Element



Insert Element (inserts a row above the selected table row)

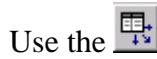


Delete Element



Delete All Elements/Erase Table

NOTE: Some of the energy values can be changed interactively in the Test Acquire box, which is discussed below.



Use the button to copy the element information to other acquisition setup menus, such as the tables in the Line Scan and Map application tabs. This saves time if line scans or maps are to be acquired on the same area.

NOTE: Changes made to the table values after the element information has been copied to other setup menus will not appear in those menus unless the button is clicked again.

- c. In the Image Registration area, click the check box for Register Image if image registration is to be used during the depth profile.

Indicate whether the image should be registered so many times per cycle or per area. One cycle consists of an acquisition of all regions for all defined areas or points.

The number selected determines the frequency of image registration. For example, if one is selected, the image will be registered every cycle or area. If two is selected, the image will be registered every second cycle or area.

Select Original or Last to indicate which image to use for registration. Original will use the image saved prior to any sputtering. Last will use the image from the last image registration performed, which may have a different appearance from the Original image because sputtering will have occurred.

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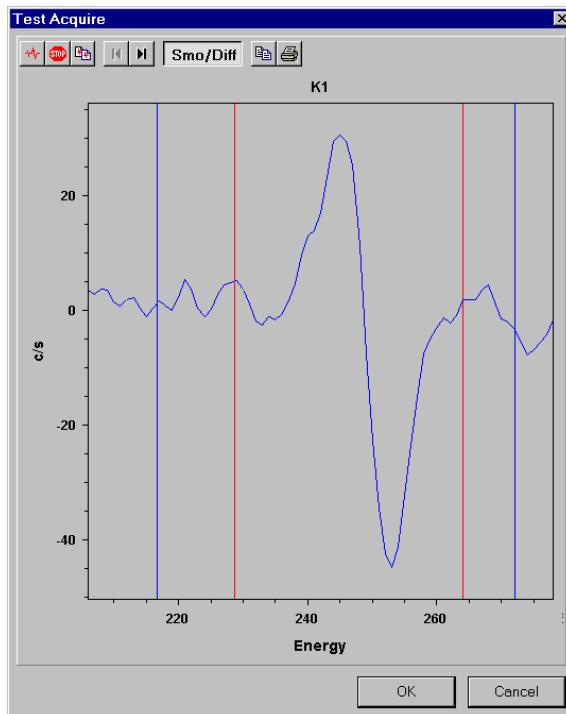
- d. If image registration is being used and enough time has elapsed during setup, image registration should be performed before Test Acquire. If image registration is not being used, go to step e.

In the SEM image area, click the button to perform image registration.

- e. Perform a Test Acquire for each selected element. Test Acquire provides an opportunity to determine whether the acquisition window set up for each element is optimized.

NOTE: It is important to make each window wide enough to include the entire Auger peak. Since Test Acquires can be performed only for the elements on the surface, the operator needs to consider the windows of the buried elements, especially on samples where there may be charging layers below the surface. The windows need to be wide enough so that, if the sample charges and the Auger peaks shift upward in energy, the peaks will not move outside the acquisition windows.

In the table toolbar, click the button. This opens the Test Acquire box, which displays the region for the element highlighted in the element table. In addition, a Test Acquire point is displayed in the SEM image area.



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In the Test Acquire box toolbar, click the  button to begin acquisition of the selected element. Differentiated data is displayed in the graph.

Use the Test Acquire point on the SEM image to search for the element at various points on the sample, if needed. Click anywhere in the SEM image field of view to move the Test Acquire point to that location. Moving the Test Acquire point automatically stops, then restarts, the acquisition.

The test acquisition will continue until the  button is clicked.

For a window depth profile test acquire (pictured above), ensure that the full peak (both the most positive and negative excursions of the data) is contained within the analysis window (red lines). If the window is too wide, or to reduce analysis time, reduce the window width, while ensuring that the positive and negative excursions remain within the window, by clicking on the lines with the mouse and dragging.

The area within the blue lines (acquisition window) indicates the range over which data are acquired. The area within the red lines (analysis window) is used to generate atomic concentration data and the depth profiles.

NOTE: The analysis window (red lines) must fall inside the acquisition window (blue lines).

For a 2-point or 3-point depth profile test acquire, click on the peak energy window (red lines) and move them so that the majority of the signal from the most positive excursion of the peak lies within the three lines. Then click on the background energy window (blue lines) so that the signal at the most negative excursion of the peak is within those lines.

Adjust the X axis of the Test Acquire graph by clicking the axis and dragging to stretch or shrink the axis. Clicking the X axis and dragging while pressing the Shift key will offset the axis's scale.

NOTE: The Y axis scales automatically, and should not need to be adjusted.

Click the  (next element) or  (previous element) button to perform a Test Acquire on the remaining elements listed in the element table. Perform the Test Acquire procedure detailed above, until each element has had a Test Acquire performed and its parameters adjusted as needed.

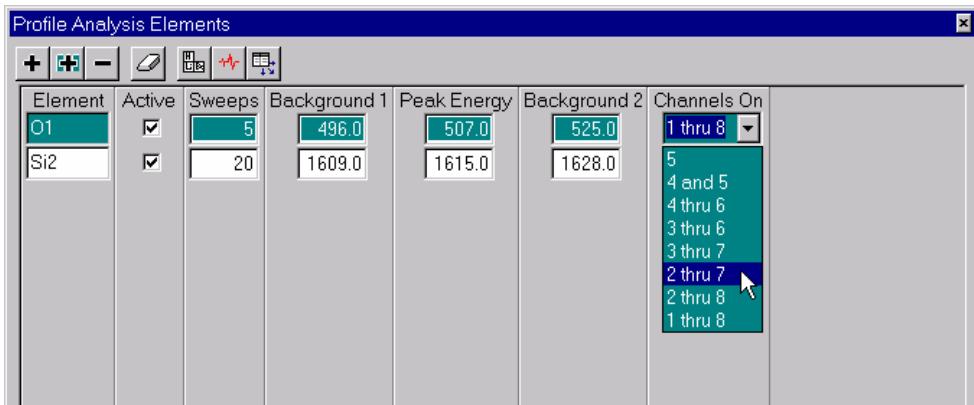
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Alternatively, use the  button to bring in peaks from the current survey spectrum. This loads the peaks from the spectrum and does not involve data acquisition. Adjust the windows as detailed above.

Parameter Considerations

- During a test acquire for a 2- or 3-point profile, it may be useful to narrow the peak energy and/or background energy windows for higher-energy peaks. This can be done by turning off some of the channels associated with the multichannel detector. Note that turning off channels will reduce total signal strength.

With the Test Acquire box opened, click the  button to display the entire element table. In the Channels On field, select the desired range of channels. Observe the windows in the Test Acquire box as various channels are selected until the desired window widths are achieved.



- Window profile: For extracting chemical state information, it is sometimes useful to include a relatively wide energy range below (to lower energies than) the main Auger peak, which could include some of the energy loss structure.
 - Window profile: Remember that the Si2 analysis window may need to accommodate both the Si peak in its elemental state and the Si peak in its oxide state, which is shifted to a lower energy.
- f. If image registration is being used and enough time has elapsed during setup, the last step before performing data acquisition should be image registration. If image registration is not being used, go to step 4.

In the SEM image area, click the  button to perform image registration.

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4. Acquire the depth profile

- In the Profile area, click the Start button.

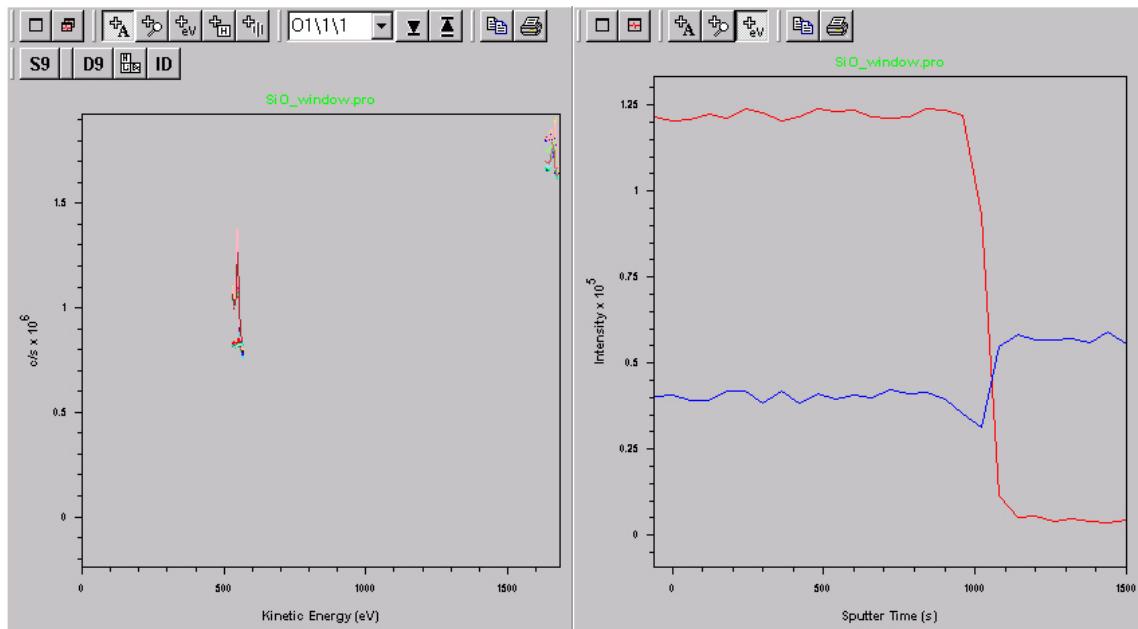


Acquisition begins. The Acquisition Status box appears, displaying the current area and cycle numbers, as well as element information. The box also tracks the number of areas and cycles remaining in the acquisition.

During acquisition, the image on the screen will be frozen except for the area inside the boundary being analyzed, which contains a live picture. When an acquisition begins over an area, that area will be highlighted on the screen. The image on the video monitor will toggle back and forth between areas during the acquisition.

In SmartSoft, SEM imaging will be turned off. The data being acquired are displayed in the AES output area. Note that a multiplex spectrum and a depth profile are both displayed if a window acquisition is taking place.

To determine a base level for each of the elements being monitored, two presputter data cycles are acquired before sputtering begins. The data curves for the elements will appear on the depth profile graph after the second cycle. The y axis on the depth profile graph is an arbitrary peak-to-peak height intensity scale; the x axis is sputter time in minutes.



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- b. To stop the acquisition before all cycles are completed, use either the Stop button or the Abort button. The Stop button terminates data acquisition at the completion of the current cycle. The Abort button terminates the acquisition immediately and eliminates the data file that was created.
- c. Click the More button to add additional data to the completed profile. More will double the amount of data collected, using the parameters set when the profile was first acquired.



- d. If no more sputtering is planned for the work shift, the ion beam filament should be turned off to extend its lifetime and the argon leak valve should be closed so that any residual argon will be pumped out of the main chamber during the non-use period. Perform the procedure given in the **Ion** section.

5. Reduce and report the data using SmartSoft

Refer to the Multiplexes subsection above for information on displaying data, smoothing and differentiating data, identifying peaks, annotating peaks and copying/printing the depth profile using the toolbar buttons in the AES output area.

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6. Reduce and report the data using MultiPak

Auger depth profiles provide compositional data as a function of depth. The following sequence examines the acquired data for peak shape changes as a function of depth and uses linear least squares (LLS) fitting to extract different chemical states of the elements found.

- a. Turn on the Data Link check boxes in both the Spectrum window's and Profile window's lower toolbar, if they are not on already.
- b. Open the AES profile data file, as follows:
 - i. Select File–Options–AES (only if “ESCA” is displayed in the MultiPak window title bar).
 - ii. Select File–Open. The Open dialog box is displayed.
 - iii. Select .PRO or *.* in the File Type field, then double-click on the file name (or click on the file name so it becomes highlighted, then click on OK).

The file opens in the Profile window, and the Spectrum window displays all the spectra used to create the profile.

- c. Perform a 5-point differentiation on the spectral data, as follows:

NOTE: When selecting whether and how much to differentiate and/or smooth the data, the intention is to keep as much of the data's structure as possible while removing only as much as noise as will interfere with data reduction.

- i. In the Spectrum window, select Data–Smooth/Derivative Setup....
- ii. In the lower toolbar, turn the Deriv check box on, and turn the SavGol and Binom buttons off.
- iii. Select 5 from the option menu below “Deriv.”
- iv. Press Filter, then Exit. The differentiated data is displayed.
- d. In the Spectrum window, ensure the correctness of the database for each region (“transition”), as follows:
 - i. In the upper toolbar, press the H He... button to bring the Periodic Table window to the foreground.
 - ii. Holding down the [Shift] key, click on N in the Periodic Table. The Transition dialog box is displayed. Ensure that this transition has the correct definitions stored (in case the original values have been changed):
 1. In the option menu at the top of the dialog box, ensure that the transition name matches exactly the name shown in the region bar of the Spectrum

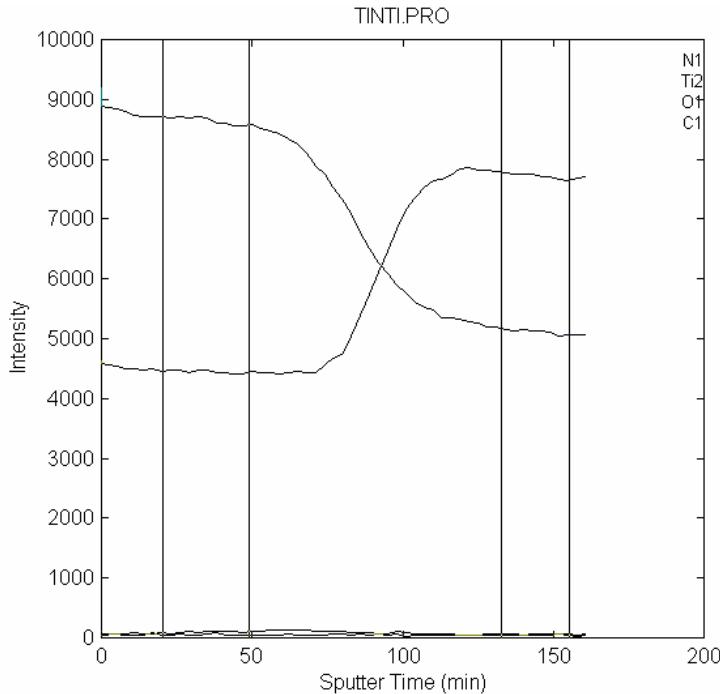
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- window (e.g., N1). If it does not, click on the down arrow in the option menu, then click on the correct name.
2. In the field labeled Background Type, ensure that None is shown. If it is not, click on the down arrow in the option menu, then click on None.
 3. In the field labeled Intensity Type, ensure that Peak to Peak is selected. If it is not, click on the down arrow in the option menu, then click on Peak to Peak.
 4. If the Background Type or Intensity Type fields were changed, press the UpdDbase button in the Periodic Table window. These (original) values have now been permanently *restored* to the database.
- iii. Repeat step ii for the Ti2, O1, and C1 regions.
- e. In the region bar, turn on the N1 check box. The display changes to show only the data within the acquisition region boundaries of the N1 transition.
 - f. Drag the left, then right analysis region boundary (vertical cursor) toward the middle somewhat to remove possible end effects in the differentiated data.
- Because LLS will be applied, only the edge effects should be taken out of the analysis region, retaining as much of the *structure* of the data inside the boundaries as possible. (If only peak-to-peak height were to be measured, the analysis region boundaries could be moved very close to the most positive and most negative excursions of the curve.)
- g. In the Spectrum window, examine the spectra for the region, as follows:
 - i. Select the Select Spectra... function from the Tools menu of the Spectrum window. A selection bar with two horizontal lines within it is displayed to the right of the axes.
 - ii. Press the Show One button in the lower toolbar. The two horizontal lines appear as one line in the center of the selection bar.
 - iii. Using the left mouse button, drag the horizontal lines in the selection slider all the way to the bottom of the selection slider (where the data begins), then all the way to the top (where the data ends) to observe how the peak shape changes with depth.
 - iv. Press Show All in the lower toolbar.
 - v. Press Exit.
 - h. Repeat steps e through g for the regions Ti2, O1, and C1. Since examination of the C1 region shows carbon at a low level in a single chemical state throughout the profile, an LLS fit on C is not performed.

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- i. In the Profile window, perform an LLS fit on nitrogen and titanium, as follows:
 - i. Press the LLS button in the upper toolbar.
 - ii. Click, drag, and release the left mouse button in the data to create a subregion like the one shown on the left side of the illustration below. Then, repeat to create a subregion like the one shown on the right side of the figure.

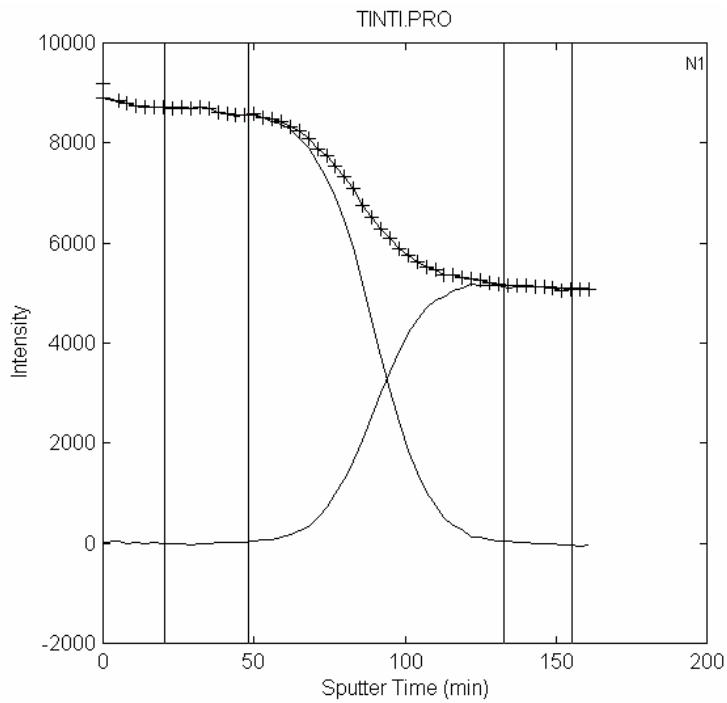
Two Analysis Subregions in the LLS Routine



- iii. Click on the N1 label in the upper right corner of the axes (or click on the curve displayed in the same color as the N1 label) to select the N1 curve.
- iv. Press the Fit button in the lower toolbar. The next illustration shows the result in the Profile window.

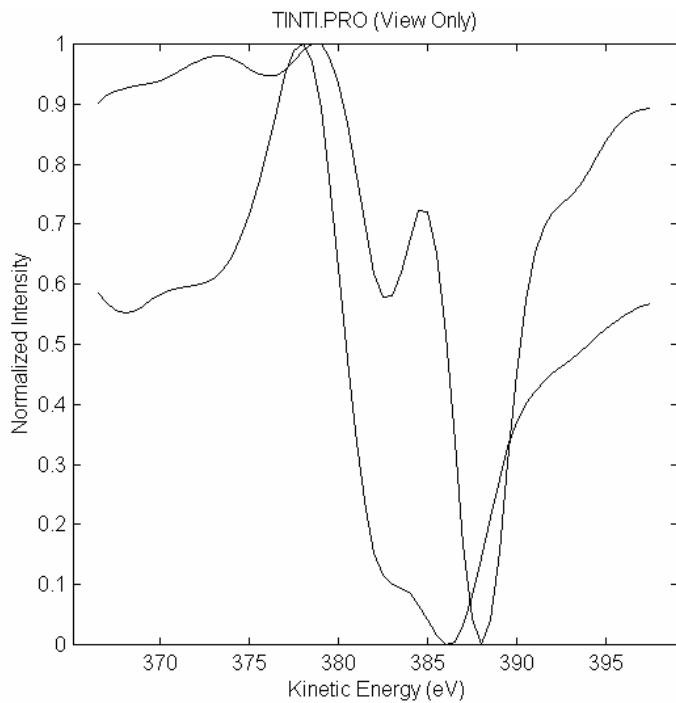
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Result of the N1 Fit in the Profile Window



- v. Press the Spec/New button in the lower toolbar, then turn on the Data Link check box, if it is not on already. The result in the Spectrum window is shown below.

Result of the N1 Fit in the Spectrum Window



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The left analysis subregion corresponds to TiN in the profile. Its associated curve in the Spectrum window is displayed in the same color as the subregion boundaries are shown in the Profile window. This curve in the Spectrum window shows the overlapping peaks of the low-energy Ti LMM transition and the N KLL transition.

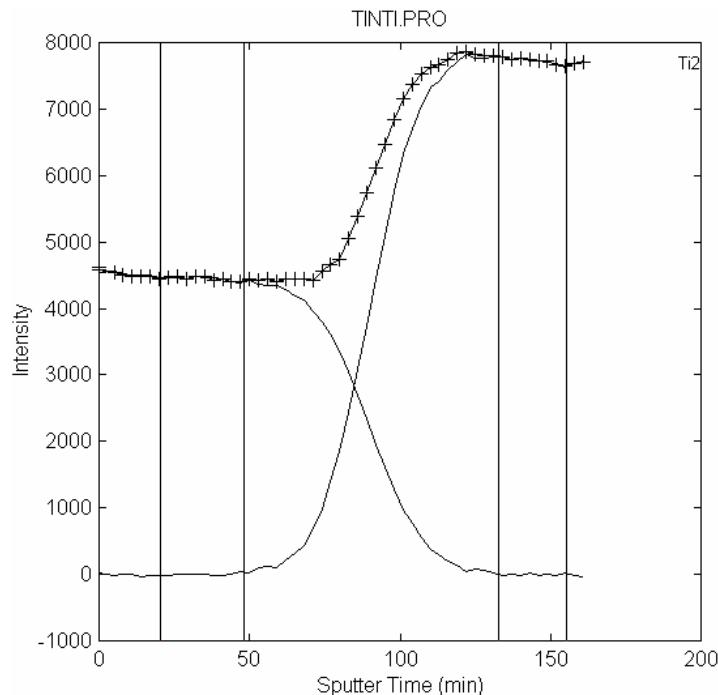
The right analysis subregion corresponds to Ti in the profile. This curve in the Spectrum window (in the same color as the right analysis subregion boundaries) shows the low-energy Ti LMM transition in elemental titanium.

- vi. Press the DispAll button in the lower toolbar to restore all the profiles to the Profile window.
- vii. Click on the Ti2 label in the upper right corner of the axes (or click on the curve displayed in the same color as the Ti2 label) to select the Ti2 curve.
- viii. Press the Fit button in the lower toolbar.

The illustration below shows the result in the Profile window, and the illustration on the next page shows the result in the Spectrum window.

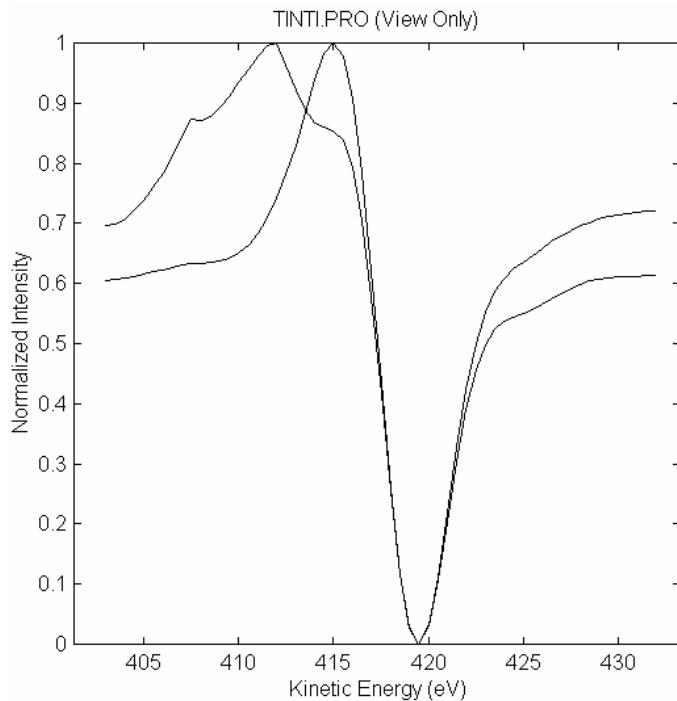
The left analysis subregion curve in the Spectrum window shows the high-energy Ti LMM transition in TiN, and the right analysis curve shows the high-energy Ti LMM transition in elemental titanium.

Result of the Ti2 Fit in the Profile Window



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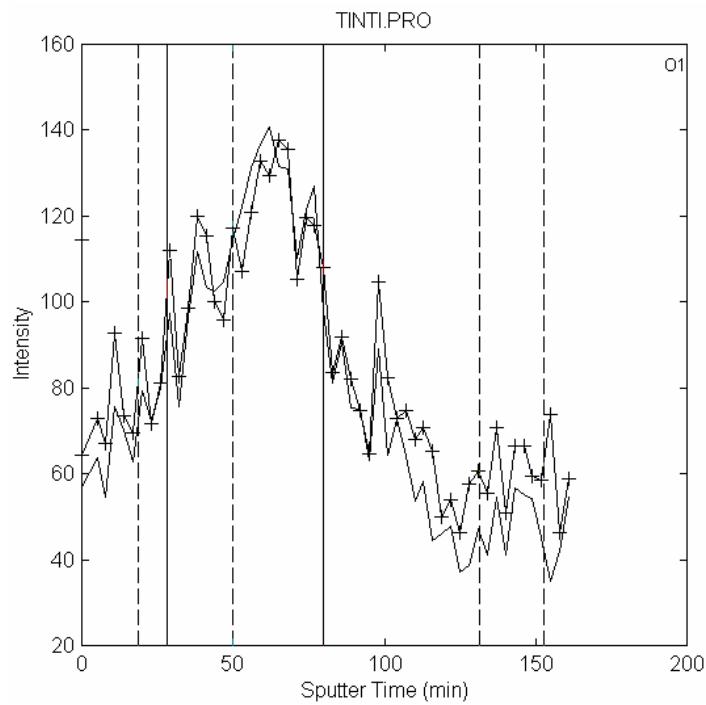
Result of the Ti2 Fit in the Spectrum Window



- j. Select the oxygen profile, turn off the two subregions, and create a third subregion for oxygen:
 - i. Press the DispAll button in the lower toolbar, then click on the O1 label (or the curve displayed in the same color as the O1 label).
 - ii. Click with the right mouse button on one of the subregion boundaries. The boundaries change from solid lines to dashed lines, indicating the subregion is currently not selected (active). Repeat this for the second subregion.
 - iii. Click, drag, and release the left mouse button to create one wide subregion that includes much of the data (next illustration).
 - iv. Press the Fit button.
 - v. The resulting LLS Fit gives a more reliable oxygen profile than does the original peak-to-peak data.

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O1 Analysis Region during LLS Fit in the Profile Window

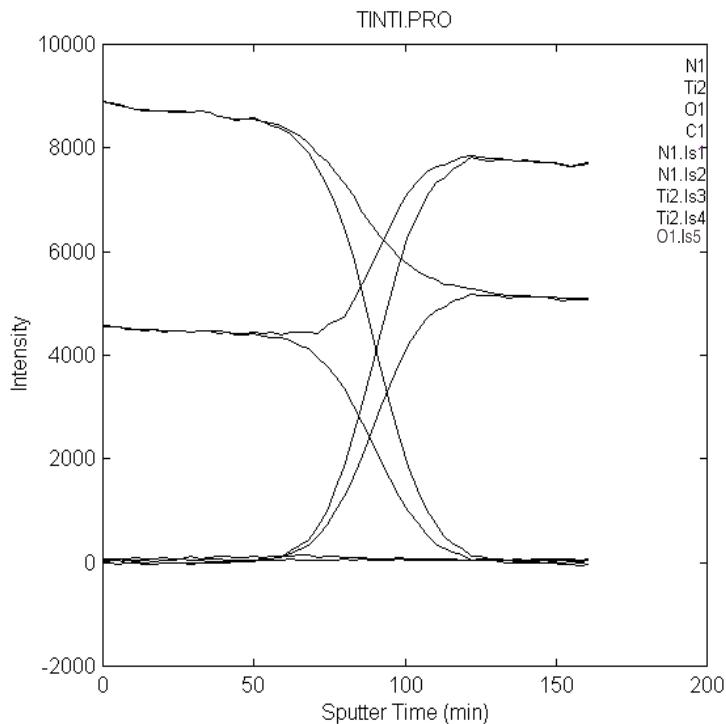


- k. Press the Exit button in the LLS toolbar in the Profile window.

Five new “regions”—N1.ls1, N1.ls2, Ti2.ls3, Ti2.ls4, and O1.ls5—are added, as shown in the illustration below.

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TINTI.PRO with the Five New Curves Created Using LLS



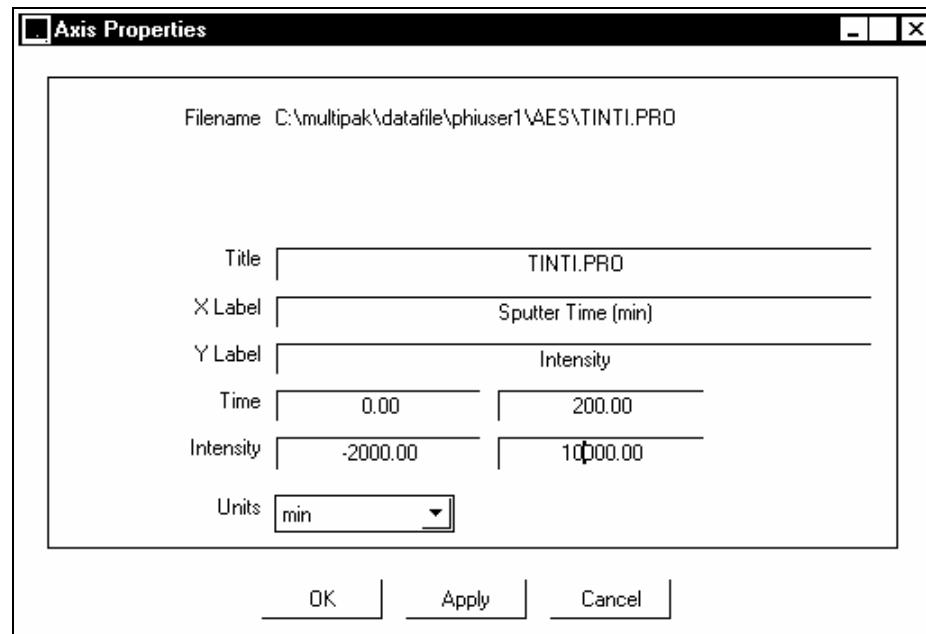
- l. Turn off the following check boxes in the region bar to remove those curves from the display: Ti2, O1, C1, Ti2.ls3, Ti2.ls4, and O1.ls5.
- m. If any of the three curves is displayed in the same color as another curve, [Shift]-left on that curve to display the Data Properties dialog box. Select another color from the color option menu, and press OK.
- n. [Shift]-left on the x or y axis to display the Axis Properties dialog box. Change the Intensity minimum to zero to eliminate negative values from the display, and change the Time maximum to 170. Press Apply, then Exit.

The next two illustrations show the Axis Properties dialog box before and after eliminating the negative values from the display.

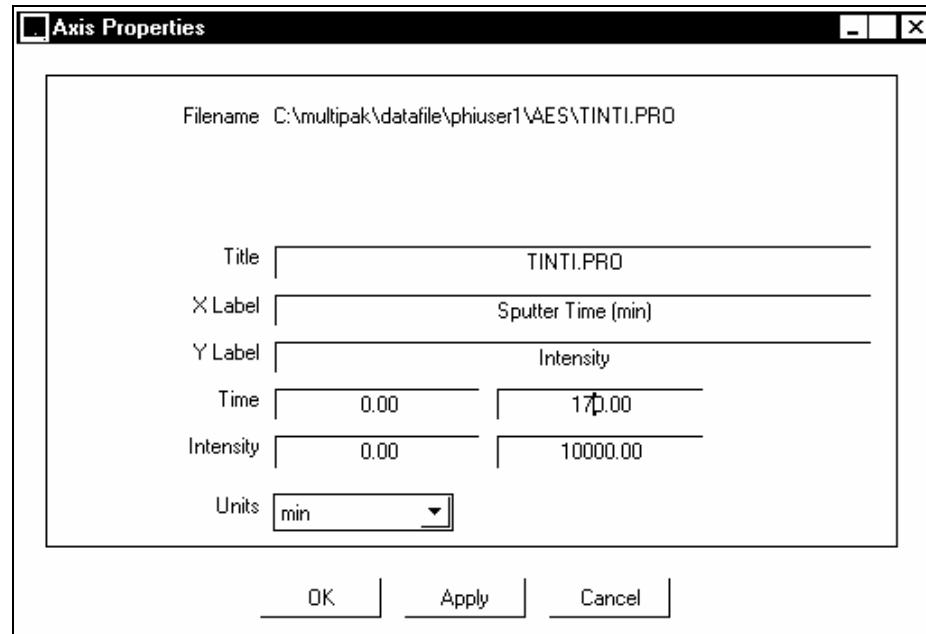
NOTE: Selecting the No Negatives function from the Data menu instead removes all negative values from the data set until a Close and ReOpen is performed. It is often preferable to simply eliminate them from the display.

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Axis Properties Dialog Box before Changing the Ranges of the X and Y Axes



Axis Properties Dialog Box after Changing the Ranges of the X and Y Axes



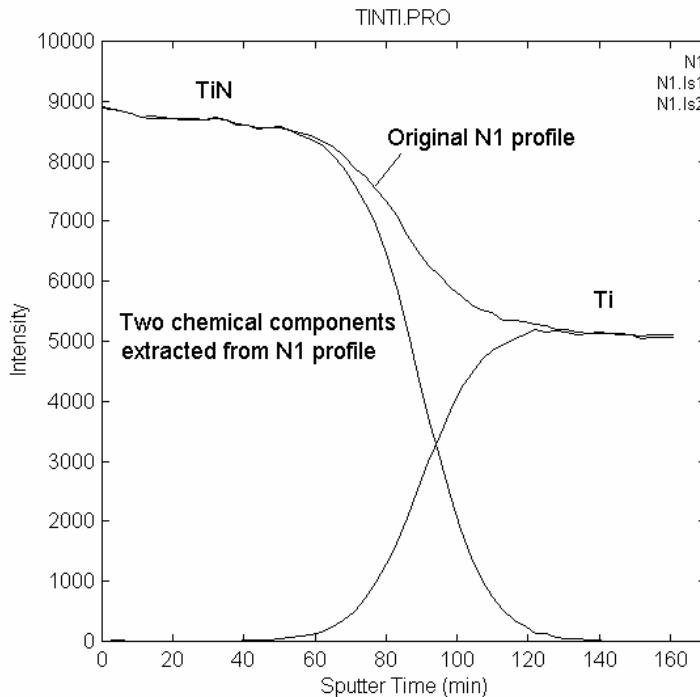
- o. Annotate the data displayed, as follows:
 - i. Press the ABC button in the upper toolbar.

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NOTE: The user may also add text by clicking on a blank area within the axes and typing, without starting the Annotate function. This “free-form” annotation capability is also available during most MultiPak functions.

- ii. Select Text as the annotation type in the lower toolbar.
- iii. In the color option menu in the Annotate toolbar, select the color of the TiN curve. Set rotation to 0, if it is not already. Select 11 in the font size option menu, click inside the axes, and type “TiN.”
- iv. In the color option menu in the Annotate toolbar, select the color of the Ti curve, click inside the axes, and type “Ti.”
- v. In the color option menu in the Annotate toolbar, select the color of the original Ni curve, click inside the axes, and type “Original Ni Curve.”
- vi. In the color option menu in the Annotate toolbar, select white, click inside the axes, and type “Two chemical components extracted from Ni profile,” as shown in the next illustration.
- vii. Press Exit in the lower toolbar to close the annotation function.

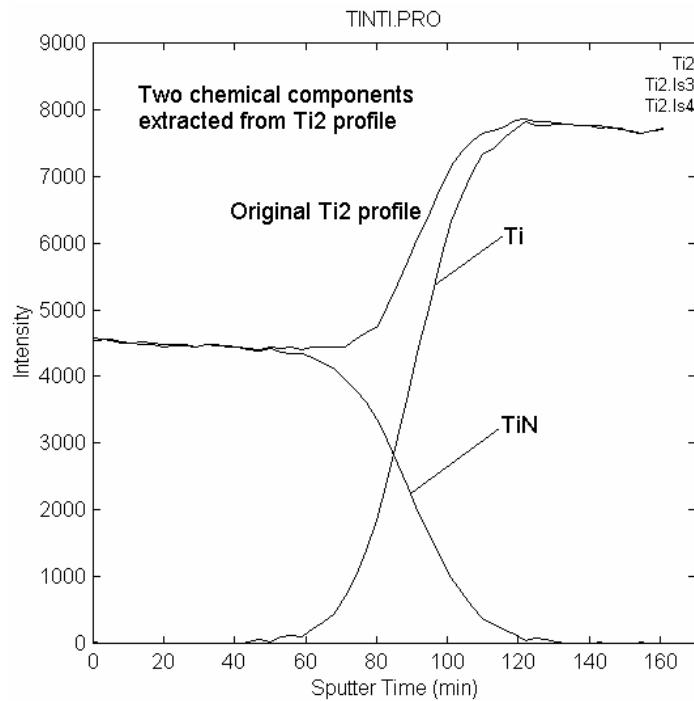
Annotated Nitrogen Curves



- p. Turn on the following check boxes in the region bar and turn off the other region buttons: Ti2, Ti2.ls3, and Ti2.ls4. Perform steps 13 and 14. Annotate the data displayed as shown in the next illustration.

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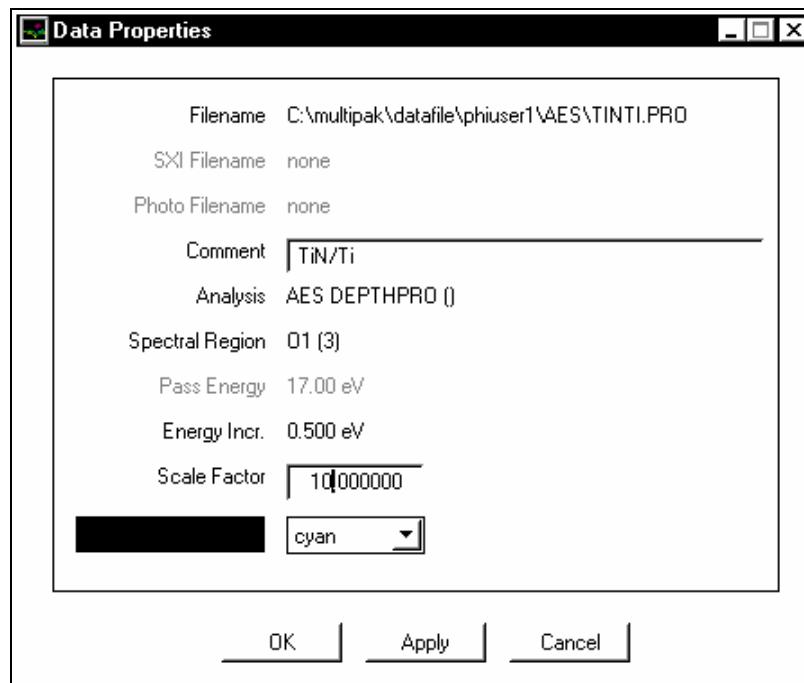
Annotated Titanium Curves



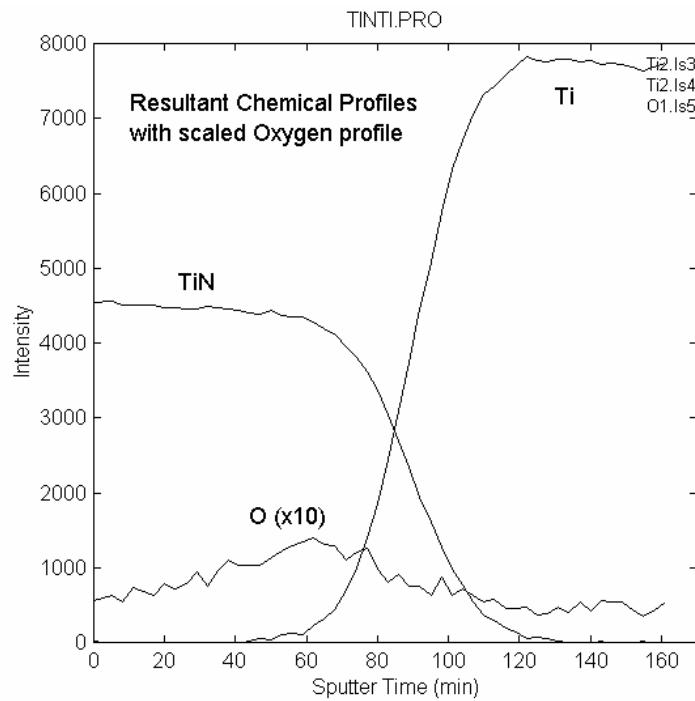
- q. Turn on the following check boxes in the region bar and turn off the other region buttons: Ti2.ls3, Ti2.ls4, and O1.ls5. Perform steps 13 and 14. Then, [Shift]-left on the O1.ls5 curve to display the Data Properties dialog box, type “10” in the Scale Factor field, and press OK. Annotate the data displayed as shown below.

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Scaling the Oxygen Curve Using the Data Properties Dialog Box



Annotated Titanium Curves with a Scaled Oxygen Curve



E. Maps

Because low concentrations of highly localized elements can be easily overlooked, complete surface characterization requires careful observation. Acquiring Auger elemental maps, then superimposing them upon each other reveals any unidentified areas on the surface. Point spectra acquired from these areas quickly identify one or more new elements, which are then mapped and added to the overlay. This overlay of Auger maps provides a picture of the two-dimensional distribution of surface elements. Superimposing maps upon each other also can reveal any unidentified areas on the surface.

The map is a set of intensity-value arrays acquired over the area of the SEM. Each array of intensity values corresponds to an element, and each value in the array corresponds to a point in the map area. An Auger map is obtained by setting the spectrometer to a specific Auger peak energy and digitally stepping the electron beam point by point over the selected specimen area. At each point, the peak intensity above the adjacent background is measured and then digitally stored for later processing. The intensity value is obtained by measuring the intensity at a specific Auger peak energy (the energy of the element's principal Auger peak), then subtracting the background intensity.

This subsection describes mapping the elements and analyzing and reporting the results. A 2-point map, described here, is the most common map acquisition. A 3-point map acquisition is usually used when the signal is small and is riding on a steep background.

Two-point acquisitions subtract the measured intensity at the background energy from the measured intensity at the peak energy. Three-point acquisitions subtract the measured intensity at the background energy (determined from a line drawn between two specified background energies) from the measured intensity at the peak energy.

1. Perform earlier procedures

Before performing the procedures in this subsection, perform the other applicable procedures presented earlier. This subsection's procedures assume that the area of interest is centered under the electron gun optics and the optics have been optimized at that location, as described in the **Wafer/SEM** section.

Also perform the procedures in the Lab Book subsection to indicated where data files should be saved, and set up image registration, if not already, according to the procedure in the **Survey** subsection of this section.

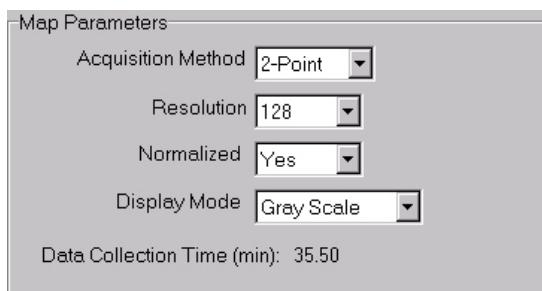
2. Define analysis areas or points

Analysis areas and/or points should be defined and data acquired to identify the elements present. This is necessary prior to the acquisition of maps, which are acquired for detected elements to determine whether all the elements on the surface at that location have been accounted for or if another element is present.

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3. Set up the map

- a. Click the Map application tab. In the Map Parameters area, set the desired parameters. Each parameter is defined below.



Acquisition Method: Options are 2-point or 3-point. See description of these methods above.

Resolution: Options are 32, 64, 128, 256 or 512. This determines the pixel resolution of the images generated. The resolution selected directly affects the time needed to acquire a map. For example, when 256 is chosen, the time increases by a factor of 4 over the time needed when 128 is chosen.

Normalized: Select Yes to normalize the map data.

Display Mode: Select Gray Scale or Pseudocolor.

Data Collection Time: The computer calculates the total time that the acquisition will last based on the entered parameters.

One additional parameter is available by clicking the Properties button in the Advanced Controls area. This opens the Map Properties box. The Time Per Step (ms) parameter sets the number of milliseconds during which data will be acquired on each point. A typical value is 5 ms.

- b. Use the table to select elements for which maps will be acquired.

| Element | Active | Frames | Peak Energy | Background 2 |
|---------|-------------------------------------|--------|-------------|--------------|
| O1 | <input checked="" type="checkbox"/> | 5 | 507.0 | 525.0 |
| F1 | <input checked="" type="checkbox"/> | 5 | 655.0 | 675.0 |
| Al2 | <input checked="" type="checkbox"/> | 15 | 1391.0 | 1402.0 |
| C1 | <input checked="" type="checkbox"/> | 20 | 266.0 | 287.0 |
| Si2 | <input checked="" type="checkbox"/> | 20 | 1615.0 | 1628.0 |

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To select elements, click the  button in the table toolbar. This brings up the Periodic Table box, Data Acquisition tab. Click the desired elements to select them.

NOTE: Always put the most volatile elements first, because they are susceptible to electron beam damage.

For elements found in the database, SmartSoft automatically enters values for those transitions in the table's fields. To select a different transition for an element, right-click over the element in the map input area table, then select the transition from the shortcut menu.

The shortcut menu can also be used to select a different element. Choose All Elements, which displays the elements alphabetically according to their periodic table abbreviation. Click the desired transition.

To see the entire table without using the scroll bar, click the  button in the table toolbar. This brings up the Map Analysis Elements box.

The fields in the table vary according to whether a 2-point or 3-point acquisition is specified. The fields are defined below. The fields for a 3-point acquisition are shown here:

| Map Analysis Elements | | | | | | |
|-----------------------|-------------------------------------|--------|--------------|-------------|--------------|--|
| Element | Active | Sweeps | Background 1 | Peak Energy | Background 2 | |
| O1 | <input checked="" type="checkbox"/> | 5 | 496.0 | 507.0 | 525.0 | |
| F1 | <input checked="" type="checkbox"/> | 5 | 642.0 | 655.0 | 675.0 | |
| Al2 | <input checked="" type="checkbox"/> | 15 | 1385.0 | 1391.0 | 1402.0 | |
| C1 | <input checked="" type="checkbox"/> | 20 | 243.0 | 266.0 | 287.0 | |
| Si2 | <input checked="" type="checkbox"/> | 20 | 1609.0 | 1615.0 | 1628.0 | |

- Element: Indicates on which element or region data will be acquired.
- Active: Click the box to remove the check only if the element is not to be acquired.
- Sweeps: Specifies the number of times the computer will sweep through the energy region before switching to the next region or returning to the first region.
- Peak Energy: This value is the energy of an EN(E) peak from the standard AES Element Table and can be changed in this menu.

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Background 1 and 2: For a 2-point acquisition, two energies are used: peak energy and background 2. The background 2 energy value must be greater than the peak energy value.

For a 3-point acquisition, background 1, peak energy and background 2 are used. The background 1 value must be less than the peak energy value, and the background 2 value must be greater than the peak energy value.

Navigate through the table by clicking in the fields. Edit the table data by clicking in a field and typing in a new value, or using the arrow keys on the keyboard to change the value. Use additional buttons in the table toolbar as follows:



Add Element



Insert Element (inserts a row above the selected table row)

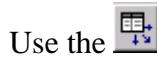


Delete Element



Delete All Elements/Erase Table

NOTE: Some of the energy values can be changed interactively in the Test Acquire box, which is discussed below.



Use the button to copy the element information to other acquisition setup menus, such as the tables in the Line Scan and Depth Profile application tabs. This saves time if line scans or depth profiles are to be acquired on the same area.

NOTE: Changes made to the table values after the element information has been copied to other setup menus will not appear in those menus unless the button is clicked again.

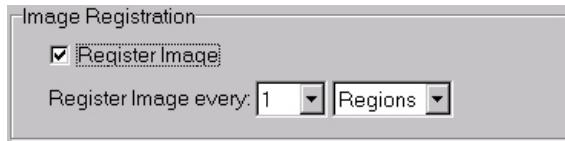
- c. In the Image Registration area, click the check box for Register Image if image registration is to be used during mapping.

Indicate whether the image should be registered so many times per line, frame or region. During acquisition, the electron beam moves along a series of lines to acquire data. A frame is one complete series of lines. Once the specified number of frames is completed (defined as Sweeps in the element table), acquisition begins for the next region, or element.

The number selected determines the frequency of image registration. For example, if one is selected, the image will be registered every frame, region or

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line. If two is selected, the image will be registered every second frame, region or line.

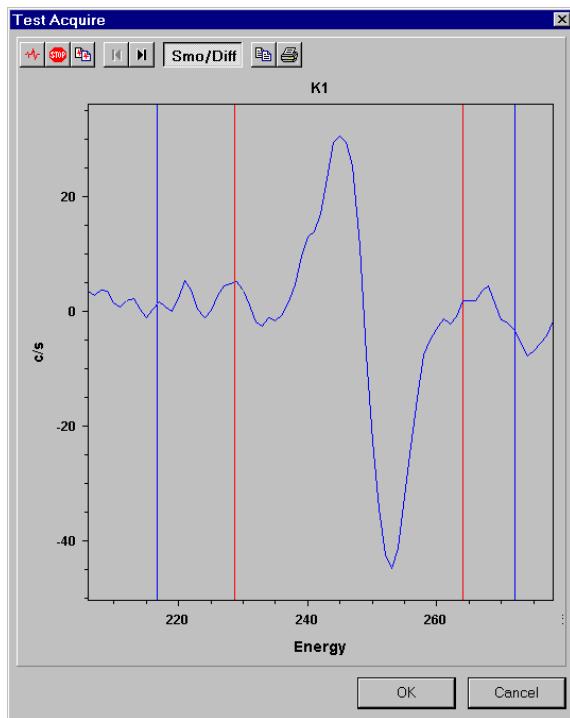


- d. If image registration is being used and enough time has elapsed during setup, image registration should be performed before Test Acquire. If image registration is not being used, go to step e.

In the SEM image area, click the  button to perform image registration.

- e. Perform a Test Acquire for each selected element. Test Acquire provides an opportunity to determine whether the acquisition window set up for each element is optimized.

In the table toolbar, click the  button. This opens the Test Acquire box, which displays the region for the element highlighted in the element table. In addition, a Test Acquire point is displayed in the SEM image area.



In the Test Acquire box toolbar, click the  button to begin acquisition of the selected element. Differentiated data is displayed in the graph.

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Use the Test Acquire point on the SEM image to search for the element at various points on the sample, if needed. Click anywhere in the SEM image field of view to move the Test Acquire point to that location. Moving the Test Acquire point automatically stops, then restarts, the acquisition.

The test acquisition will continue until the  button is clicked.

Adjust the windows so that the full peak (both the most positive and negative excursions of the data) is contained within the analysis window (red lines). The windows are adjusted by clicking on a line with the mouse and dragging.

The area within the blue lines (acquisition window) indicates the range over which data are acquired. The area within the red lines (analysis window) is used to generate atomic concentration data.

NOTE: The analysis window (red lines) must fall inside the acquisition window (blue lines).

Adjust the X axis of the Test Acquire graph by clicking the X axis and dragging to stretch or shrink the axis. Clicking the X axis and dragging while pressing the Shift key will offset the axis's scale.

NOTE: The Y axis scales automatically, and should not need to be adjusted.

Click the  (next element) or  (previous element) button to perform a Test Acquire on the remaining elements listed in the element table. Perform the Test Acquire procedure detailed above, until each element has had a Test Acquire performed and its parameters adjusted as needed.

Alternatively, use the  button to bring in peaks from the current survey spectrum. This loads the peaks from the spectrum and does not involve data acquisition. Adjust the windows as detailed above.

Parameter Considerations

During a test acquire, it may be useful to narrow the peak energy and/or background energy windows for higher-energy peaks. This can be done by turning off some of the channels associated with the multichannel detector. Note that turning off channels will reduce total signal strength.

With the Test Acquire box opened, click the  button to display the entire element table. In the Channels On field, select the desired range of channels. Observe the windows in the Test Acquire box as various channels are selected until the desired window widths are achieved.

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| Profile Analysis Elements | | | | | | |
|---------------------------|-------------------------------------|--------|--------------|-------------|--------------|--|
| Element | Active | Sweeps | Background 1 | Peak Energy | Background 2 | Channels On |
| O1 | <input checked="" type="checkbox"/> | 5 | 496.0 | 507.0 | 525.0 | <input type="button" value="1 thru 8"/> |
| Si2 | <input checked="" type="checkbox"/> | 20 | 1609.0 | 1615.0 | 1628.0 | <input type="button" value="5"/> <input type="button" value="4 and 5"/> <input type="button" value="4 thru 6"/> <input type="button" value="3 thru 6"/> <input type="button" value="3 thru 7"/> <input type="button" value="2 thru 7"/> <input type="button" value="2 thru 8"/> <input type="button" value="1 thru 8"/> |

- f. If image registration is being used and enough time has elapsed during setup, the last step before performing data acquisition should be image registration. If image registration is not being used, go to step 4.

In the SEM image area, click the  button to perform image registration.

4. Acquire the maps

In the Map area, click the Start button.



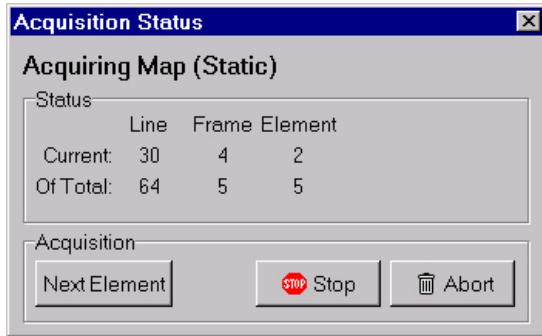
Map acquisition begins. The incident electron beam steps point by point along a line while peak intensity is measured at each point. The beam repeats the motion on the same line to measure background intensity, at each point subtracting the background intensity from the peak intensity and saving only the value of the difference.

This is then repeated for the next line, and so on until all the lines have been acquired. This is one “frame.” This is then repeated for the next frame, at each point calculating and saving only the average of [peak-minus-background intensity at this point on this sweep] and [the value stored at this point during the preceding sweep]. When the specified number of frames is completed (defined as Sweeps in the element table), the acquisition for the next region (element) begins.

When the acquisition begins, the AES output area is divided, with the maps appearing in the right side of the area. Each map is displayed as the data is acquired. By monitoring the map, the operator can decide if the signal-to-noise ratio is such that the map has adequate information and end the acquisition for that element before it has completed. This saves time.

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To end the current map's acquisition and move on to the next element, click the Next Element button in the Acquisition Status box (pictured below). Acquisition of the next element will begin when the current frame is completed.



To stop the acquisition before all elements have been mapped, click the Stop button. The Stop button terminates data acquisition at the completion of the current frame. Use the Abort button to terminate the acquisition immediately; no data file will be saved.

In the Map area, click the More button to add additional data to the completed map. More will double the amount of data collected, using the parameter values previously set in the Map Parameters area.



When acquisition of all the regions (elements) to be mapped is complete, all the region maps are saved to a single map file.

At the end of every acquisition, the beam current is automatically read and stored with the file. Once the acquisition is complete and the beam current has been read, the video monitor will return to a live image.

NOTE: Once the maps have been acquired, it is recommended that surveys be taken of various regions to confirm the data.

5. **Reduce and report the data using SmartSoft**

Display the maps

Click the button for a full screen view of the map output area.

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The maps acquired for all elements will be displayed. To view only one map, click the file name displayed above the desired map to make it the selected map. The file name will turn green. Then, to display only that map, click the  button.

Alternatively, use the Current Image box, , to select a map, then use the  button.

Annotate the maps

Double-click over a map and type in text to annotate. Click outside the text box to set the text.

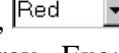
To move the text, click and drag the text to the desired location.

To edit text, double-click over the text box, then edit. Right-click over the text for more options (cut, copy, paste, delete, etc.).

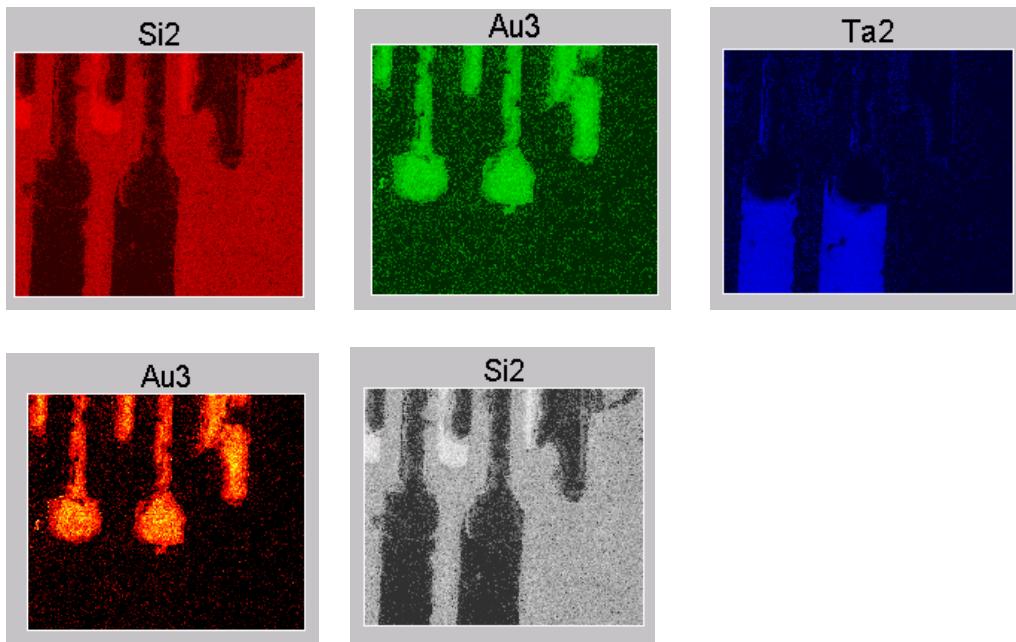
Right-click over the map for additional options, including delete all annotation. Click the Properties option to open the Image Annotation box. Use this box to select the text font, size, color, etc.

Add color to maps

Color can be added to maps as a first step in creating a color overlay, or to distinguish maps from each other in reports. In addition, adding color to maps can enhance analysis of the data in the maps.

Select a map as indicated above, then use the Color Map box, , to add color to the map. Options are red, green, blue, thermal and gray. Examples are shown below.

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The thermal option assigns red to dark pixels, and yellow to light pixels, using a gradient that includes red on the dark end, through orange, to yellow. This option can better highlight information in some maps.

Red, blue and green are selected as a first step toward creating a color overlay.

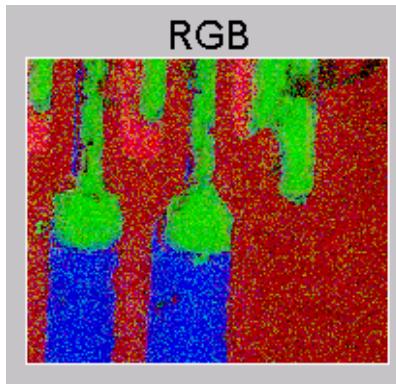
Create a color overlay

Overlays are used to determine whether there are areas of the sample that might require further analysis. For example, areas showing little or no color might contain previously unidentified elements. Overlays can also be used to better understand which elements are present in certain areas, such as an area of contamination.

Select the three maps to be used to create the overlay, then assign the colors red, blue and green to those maps as indicated above.

NOTE: A maximum of three maps can be used to create an overlay.

Click the  button to create the overlay.



In the example above, the maps for silicon, tantalum and gold were overlaid to better understand the distribution of elements on the sample. The overlay can be annotated to indicate which elements were assigned to each color.

Examine the overlay for areas that show little or no color. Acquire surveys of these areas, since they may contain previously unidentified elements.

Output the maps

Click the button to copy the selected map to the clipboard. This allows the map to be imported as a graphic into any Microsoft Office application (Word, PowerPoint, etc.).

Click the button to print the selected map to the default printer.

NOTE: Changes made to the map (annotation, adding color) are not saved as part of the data file.

6. Reduce and report the data using MultiPak

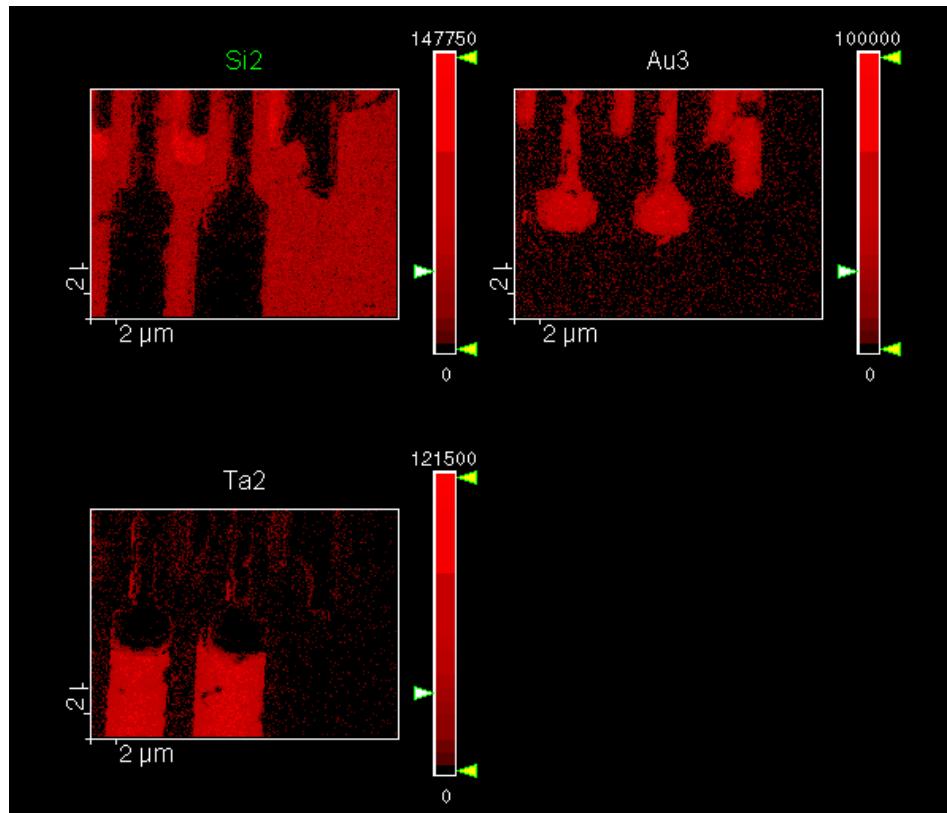
MultiPak is the recommended software for map data reduction. The typical MultiPak data reduction procedure is described below for the tutorial file named AUGERMAP.MAP that was included on the MultiPak CD.

- a. To start MultiPak, double-click on the MultiPak icon on the desktop or select PHI–MultiPak–MultiPak from the Start menu.
- b. In MultiPak, select File–Options–AES (only if “ESCA” is displayed in the MultiPak window title bar).
- c. Open the data file in one of the following ways:
 - Press the Acq button on the upper toolbar; or
 - Select File–Open Last Acquisition button; or

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- Select File–Open. In the Open dialog box, select .MAP in the File Type field, find the directory your MAP file was saved in, and double-click on the file name.

To the right of the map of each region is the “color bar,” which has three sliding handles in the shape of arrowheads. The one on the left can be dragged with the mouse to change the *brightness* of the displayed image. The two right handles can be dragged up and down, then “resolved” to adjust the *contrast*. The following illustration shows the MultiPak Map window when the file AUGERMAP.MAP is opened in MultiPak.

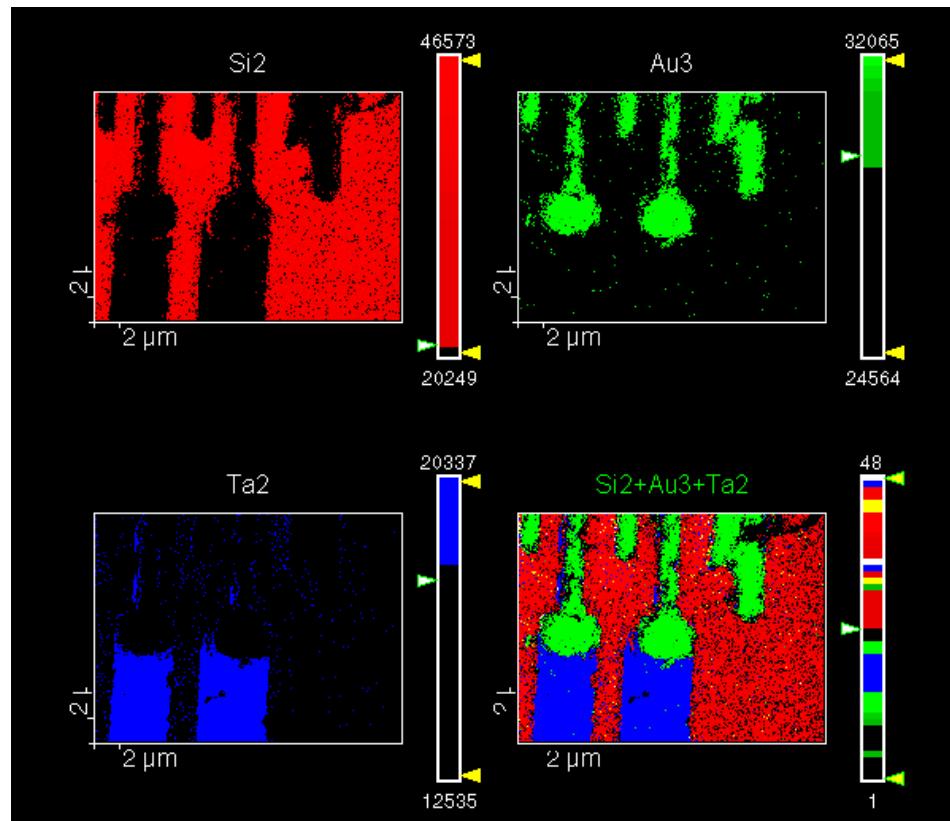


- d. Assign red, green, and blue to each region, as follows:
 - i. Click on the map so the title above it (e.g., Si2) is green. The green title indicates that it is selected.
 - ii. Click on the arrow in the color option menu on the left side of the lower toolbar. The drop-down menu is displayed.
 - iii. Click on the color to be assigned to the selected region (e.g., red for the Si2 region, green for the Au3 region, and blue for the Ta2 region).
 - iv. Repeat steps i, ii, and iii until the three colors have been assigned.

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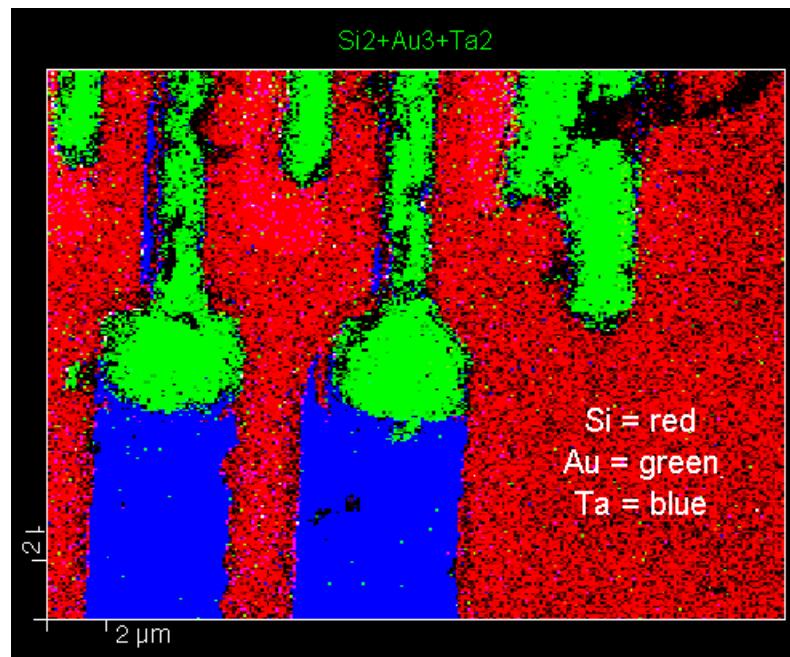
- e. Adjust the image contrast and brightness on each map, as follows:
 - i. Click and drag the *upper* arrow on the *right* side of the color bar down and release the mouse button. Click and drag the arrow again and again until the areas where the element is present are all or mostly white, and the areas where the element is absent show no or almost no white. When the contrast threshold is “resolved” (in step ii), white will be displayed in 100% of the color of the region (red, blue, or green).
 - ii. Click once with the right mouse button on that arrow to resolve that operation. (The map can be restored to its original state after resolving the operation by selecting Edit–Undo when the map is selected (its title is green)).
 - iii. Click and drag the *lower* handle on the *right* side of the color bar up and release the mouse button. Click and drag the arrow again and again until the areas where the element is absent are all or mostly black.
 - iv. Click once with the right mouse button on that arrow to resolve that operation.
 - v. Click and drag the arrow on the *left* side of the color bar and release the mouse button. Click and drag the arrow again and again until the optimal brightness is achieved.
 - vi. Repeat steps i through v for each of the three maps. The result should look very similar to the first three maps shown in the following illustration.

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- f. Select Tools–RGB Overlay. Allow time for the display to be refreshed with a fourth image, which is the red-green-blue overlay of the three regions, titled “Si2+Au3+Ta2,” as shown on the following page.
- g. Add text to the overlay to indicate which element is in what color, as follows:
 - i. Select (click on) the RGB overlay, if it is not already selected. (When it is selected, its title will be displayed in green.)
 - ii. Turn off the Tile check box in the upper toolbar. This causes the RGB overlay to use the maximum space possible in the Map window.
 - iii. Click on the ABC button in the upper toolbar. The annotation toolbar will be displayed.
 - iv. In the lower toolbar, make the desired selections from the option menus (e.g., 0, 12, normal, white, and Arial).
 - v. Click in the overlay area and type the first annotation desired (e.g., Si = red). Click again below that and type the next annotation (e.g., Au = green). Repeat until done. If desired, text can be repositioned by clicking on it and dragging it to the desired location.

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F. Line Scans

Auger line scans can provide important additional information beyond maps, especially for small features. An Auger line scan is a series of data points (in the case of 2- and 3-point line scans) or spectra (in the case of window line scans) collected along a horizontal or vertical line across a sample. The scans are collected by stepping the electron beam, point by point, along a selected line.

Line scan acquisitions yield a better signal-to-noise ratio from the sample than does a map acquisition, and in a shorter time. Up to 6 lines can be scanned, and up to 20 regions can be acquired for each line.

Three kinds of line scans are available: 2-point, 3-point, and Window. Two- and three-point line scans store peak and background energies at every point across the line, whereas a window line scan stores a spectrum at every point along the line.

Acquiring a 2-point scan is common. The 3-point scan is usually used to measure a small peak intensity on a sloping background, primarily when only a small amount of the element is present.

Having a peak-shape spectrum, which is acquired with the window line scan, makes extraction of chemical state information possible. If the Auger peak energy shifts or the peak changes shape because of chemical state changes or sample charging effects, a 2-point line scan will simply show a change in intensity, whereas such changes will be readily evident in a window line scan.

One benefit of the window line scan is that atomic concentration data can be generated, but, since a window line scan collects much more data, acquisition requires much more time than a 2- or 3-point line scan.

1. *Perform earlier procedures*

Before performing the procedures in this subsection, perform the other applicable procedures presented earlier. This subsection's procedures assume that the area of interest is centered under the electron gun optics and the optics have been optimized at that location, as described in the **Wafer/SEM** section.

Also perform the procedures in the Lab Book subsection to indicated where data files should be saved, and set up image registration, if not already, according to the procedure in the **Survey** subsection of this section.

2. *Define and select lines*

- a. In the AES session, click the Line application tab.
- b. Click the Analysis Lines tab. Define a line in one of the following ways:

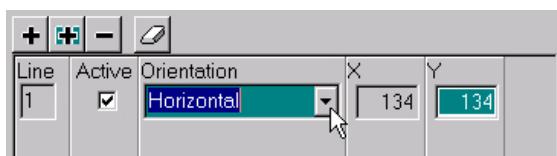
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- i. Click over the SEM image to define a line to be analyzed. Move the line by clicking on the line and dragging.

To change the orientation of the line, double-click over the line.

NOTE: The  button is selected by default when the Analysis Lines area is open. By selecting the  button in the SEM toolbar, the operator can define lines in the SEM image regardless of which session tab or application tab is currently selected.

- ii. Use the table to establish lines. Click the  button. In the Orientation field, select Horizontal or Vertical.



A line appears in the SEM image. To adjust the position of the line, click in the X field for a vertical line or the Y field for a horizontal line; use the arrow keys to change the values, or type in new values. Using Shift + the arrow keys changes the values in larger increments. As the values are changed, the line will move.

Click the checkbox in the active field to make the line active during the analysis.

NOTE: Use the buttons above the table to add or delete lines, as illustrated here:

| | |
|---|--|
|  | Add Line |
|  | Insert Line (inserts a row above the selected table row) |
|  | Delete Line |
|  | Delete All Lines |

Parameter Considerations

Up to 6 lines can be defined, and up to 20 regions can be acquired for each line.

3. Set up the line scan

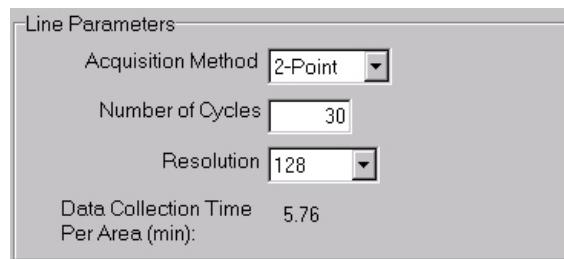
Three kinds of line scan are available: 2-point, 3-point, and Window. A 2-point scan saves a single background energy (specified in the Background 2 parameter) at each point, whereas a 3-point scan saves two background energies: one is

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extrapolated from a high-energy background energy (specified in the Background 2 parameter) and the other is a low-energy background energy (specified in the Background 1 parameter). Acquiring a 2-point scan is common. The 3-point scan is usually used to measure a small peak intensity on a sloping background, primarily when only a small amount of the element is present.

Having a peak-shape spectrum, which is acquired with the window line scan, makes extraction of chemical state information possible. However, a window line scan takes more time to acquire.

- a. Click the Line tab. In the Line Parameters area, set the desired parameters. Each parameter is defined below.



| | |
|--------------------------------------|--|
| Acquisition Method: | The options are 2-point, 3-point and window. |
| Number of Cycles: | Indicate the number of cycles the acquisition will last. |
| Resolution: | Options are 32, 64, 128, 256 or 512. This determines the pixel resolution of the scan generated. The resolution selected directly affects the time needed to acquire the scan. For example, when 256 is chosen, the time increases by a factor of 4 over the time needed when 128 is chosen. |
| Data Collection Time Per Area (min): | The computer calculates the total time that the acquisition will last for one area based on the entered parameters. |

One additional parameter is available by clicking the Properties button in the Advanced Controls area. This opens the Line Properties box. The Time Per Step (ms) parameter sets the number of milliseconds during which data will be acquired on each point.

Parameter considerations

A typical Time Per Step setting for a 2-point line scan is 20 ms. For a window line scan, it is best to specify a short time, for example, 1 ms per step.

- b. Use the table to select elements for which data will be acquired during the line scan.

| Element | Active | Sweeps | Background 1 | Peak Energy |
|---------|-------------------------------------|--------|--------------|-------------|
| O1 | <input checked="" type="checkbox"/> | 5 | 496.0 | 507.0 |
| Ta2 | <input checked="" type="checkbox"/> | 15 | 1573.0 | 1674.0 |
| C1 | <input checked="" type="checkbox"/> | 20 | 243.0 | 266.0 |
| Si2 | <input checked="" type="checkbox"/> | 20 | 1609.0 | 1615.0 |
| Au3 | <input checked="" type="checkbox"/> | 25 | 1957.0 | 2015.0 |

To select elements, click the button in the table toolbar. This brings up the Periodic Table box, Data Acquisition tab. Click the desired elements to select them.

NOTE: Always put the most volatile elements first, because they are susceptible to electron beam damage.

For elements found in the database, SmartSoft automatically enters values for those transitions in the table's fields. To select a different transition for an element, right-click over the element in the element table, then select the transition from the shortcut menu.

The shortcut menu can also be used to select a different element. Choose All Elements, which displays the elements alphabetically according to their periodic table abbreviation. Click the desired transition.

To see the entire table without using the scroll bar, click the button in the table toolbar. This brings up the Line Analysis Elements box.

The fields in the table vary according to whether a 2-point, 3-point or window acquisition is specified. Fields for a Window acquisition are the same as fields for a standard multiplex acquisition. Refer to the Multiplexes subsection for definitions of the fields.

The fields for 2-point and 3-point acquisitions are defined below. The fields for a 3-point acquisition are shown here:

| Line Analysis Elements | | | | | |
|------------------------|-------------------------------------|--------|--------------|-------------|--------------|
| Element | Active | Sweeps | Background 1 | Peak Energy | Background 2 |
| O1 | <input checked="" type="checkbox"/> | 5 | 496.0 | 507.0 | 525.0 |
| Ta2 | <input checked="" type="checkbox"/> | 15 | 1573.0 | 1674.0 | 1750.0 |
| C1 | <input checked="" type="checkbox"/> | 20 | 243.0 | 266.0 | 287.0 |
| Si2 | <input checked="" type="checkbox"/> | 20 | 1609.0 | 1615.0 | 1628.0 |
| Au3 | <input checked="" type="checkbox"/> | 25 | 1957.0 | 2015.0 | 2038.0 |

- Element: Indicates on which element or region data will be acquired.
- Active: Click the box to remove the check only if the element is not to be acquired.
- Sweeps: Specifies the number of times the computer will sweep through the energy region before switching to the next region or returning to the first region.
- Peak Energy: This value is the energy of an EN(E) peak from the standard AES Element Table and can be changed in this menu.
- Background 1 and 2: For a 2-point acquisition, two energies are used to create the line scan: peak energy and background 2. The background 2 energy value must be greater than the peak energy value.
- For a 3-point acquisition, background 1, peak energy and background 2 are used. The background 1 value must be less than the peak energy value, and the background 2 value must be greater than the peak energy value.

Navigate through the table by clicking in the fields. Edit the table data by clicking in a field and typing in a new value, or using the arrow keys on the keyboard to change the value. Use additional buttons in the table toolbar as follows:



Add Element



Insert Element (inserts a row above the selected table row)



Delete Element



Delete All Elements/Erase Table

NOTE: Some of the energy values can be changed interactively in the Test

Acquire box, which is discussed below.

Use the  button to copy the element information to other acquisition setup menus, such as the tables in the Depth Profile and Map application tabs. This saves time if profiles or maps are to be acquired on the same area.

NOTE: Changes made to the table values after the element information has been copied to other setup menus will not appear in those menus unless the  button is clicked again.

Parameter considerations

The Sweeps parameter depends on the intensity of each element and the desired signal-to-noise ratio. In the Sweeps parameter, when an element's content is expected to be low relative to the other elements, 10 sweeps might be specified. On the same sample, 5 sweeps might be specified for an element like oxygen if it is relatively abundant. If the sample also has tantalum and gold, whose signals are relatively strong, 2 sweeps might be specified for each.

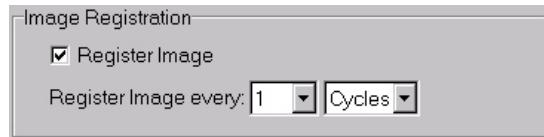
On a sample with both silicon dioxide and silicon, specify the same number of sweeps for silicon as for oxygen.

When setting up a window acquisition, it is best to specify a minimum number of sweeps for each region, because of the time involved with such an acquisition.

- c. In the Image Registration area, click the check box for Register Image if image registration is to be used during the line scan.

Indicate whether the image should be registered so many times per cycle, line or area. One cycle consists of an acquisition of all regions for all defined lines, areas or points.

The number selected determines the frequency of image registration. For example, if one is selected, the image will be registered every cycle, line or area. If two is selected, the image will be registered every second cycle, line or area.



- d. If image registration is being used and enough time has elapsed during setup, image registration should be performed before Test Acquire. If image registration is not being used, go to step e.

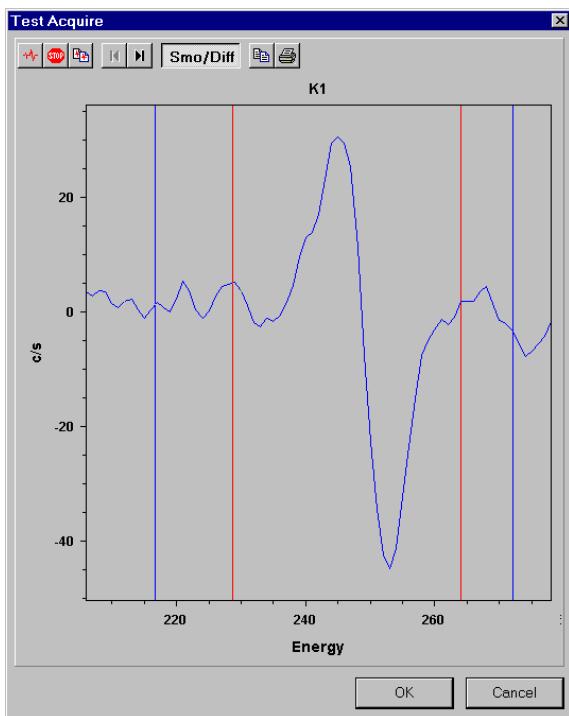
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In the SEM image area, click the  button to perform image registration.

- e. Perform a Test Acquire for each selected element. Test Acquire provides an opportunity to determine whether the acquisition window set up for each element is optimized.

NOTE: It is important to make each window wide enough to include the entire Auger peak. Since Test Acquires can be performed only for the elements on the surface, the operator needs to consider the windows of the buried elements, especially on samples where there may be charging layers below the surface. The windows need to be wide enough so that, if the sample charges and the Auger peaks shift upward in energy, the peaks will not move outside the acquisition windows.

In the table toolbar, click the  button. This opens the Test Acquire box, which displays the region for the element highlighted in the element table. In addition, a Test Acquire point is displayed in the SEM image area.



In the Test Acquire box toolbar, click the  button to begin acquisition of the selected element. Differentiated data is displayed in the graph.

Use the Test Acquire point on the SEM image to search for the element at various points on the sample, if needed. Click anywhere in the SEM image field

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of view to move the Test Acquire point to that location. Moving the Test Acquire point automatically stops, then restarts, the acquisition.

The test acquisition will continue until the  button is clicked.

For a window line scan test acquire (pictured above), ensure that the full peak (both the most positive and negative excursions of the data) is contained within the analysis window (red lines). If the window is too wide, or to reduce analysis time, reduce the window width, while ensuring that the positive and negative excursions remain within the window, by clicking on the lines with the mouse and dragging.

NOTE: The analysis window (red lines) must fall inside the acquisition window (blue lines).

For a 2-point or 3-point line scan test acquire, click on the peak energy window (red lines) and move them so that the majority of the signal from the most positive excursion of the peak lies within the lines. Then click on the background energy window (blue lines) so that the signal at the most negative excursion of the peak is within those lines.

If desired, adjust the X axis of the Test Acquire graph by clicking the X axis and dragging to stretch or shrink the axis. Clicking the X axis and dragging while pressing the Shift key will offset the axis's scale.

NOTE: The Y axis scales automatically, and should not need to be adjusted.

Click the  (next element) or  (previous element) button to perform a Test Acquire on the remaining elements in the element table. Perform the Test Acquire procedure detailed above, until each element has had a Test Acquire performed and its parameters adjusted as needed.

Alternatively, use the  button to bring in peaks from the current survey spectrum. This loads the peaks from the spectrum and does not involve data acquisition. Adjust the windows as detailed above.

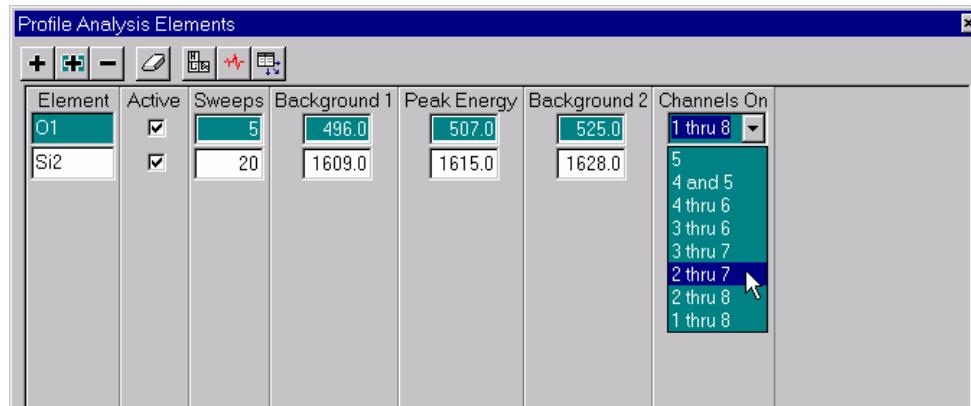
Parameter Considerations

During a test acquire for a 2- or 3-point scan, it may be useful to narrow the peak energy and/or background energy windows for higher-energy peaks. This can be done by turning off some of the channels associated with the multichannel detector. Note that turning off channels will reduce total signal strength.

With the Test Acquire box opened, click the  button to display the entire element table. In the Channels On field, select the desired range of channels.

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Observe the windows in the Test Acquire box as various channels are selected until the desired window widths are achieved.



Window scan: For extracting chemical state information, it is sometimes useful to include a relatively wide energy range below (to lower energies than) the main Auger peak, which could include some of the energy loss structure.

Window scan: Remember that the Si2 analysis window may need to accommodate both the Si peak in its elemental state and the Si peak in its oxide state, which is shifted to a lower energy.

- f. If image registration is being used and enough time has elapsed during setup, the last step before performing data acquisition should be image registration. If image registration is not being used, go to step 4.

In the SEM image area, click the button to perform image registration.

4. Acquire the line scan

In the Line area, click the Start button.

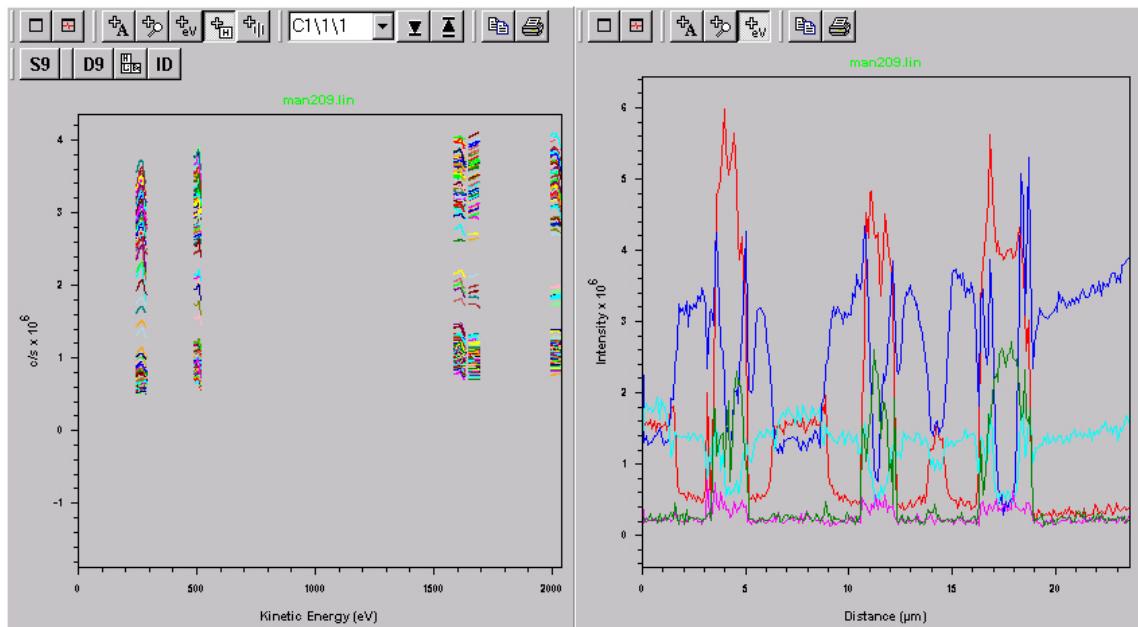


Acquisition begins. The Acquisition Status box appears, displaying the current line and cycle numbers, as well as element information. The box also tracks the number of lines and cycles remaining in the acquisition.

When an acquisition begins over a line, that line will be highlighted on the screen. The image on the video monitor will toggle back and forth between lines during the acquisition.

6: AES

In SmartSoft, SEM imaging is turned off and the data being acquired are displayed in the AES output area. For a window acquisition, both the line scan and a multiplex spectrum are displayed (pictured below).



- a. To stop the acquisition before all cycles are completed, use either the Stop button or the Abort button. The Stop button terminates data acquisition at the completion of the current cycle. The Abort button terminates the acquisition immediately and eliminates the data file that was created.
- b. Click the More button to add additional data to the completed scan. More will double the amount of data collected, using the parameters set when the file was first acquired.



5. Reduce and report the data using SmartSoft

Refer to the Multiplexes subsection above for information on displaying data, smoothing and differentiating data, annotating peaks and copying/printing the line scan using the toolbar buttons in the AES output area.

Section 7: Ion

This section describes the use of the *AES* two ion guns: the focused ion beam's liquid metal ion gun¹, used to cross section defects, and the sputtering ion gun, used to clean samples and perform depth profiles.

A. The subsections in this section related to the FIB(Option) include:

1. [Select the FIB settings](#)
2. [Tune the LMIG](#)
3. [View with the FIB](#)
4. [Mill with the FIB](#)
5. [Polish with the FIB](#)
6. [FIB Hardware Tab](#)
7. [Advanced FIB Controls](#)
8. [Mill Area Tab](#)
9. [Create New Settings](#)
10. [FIB Maintenance](#)

B. The subsections in this section related to sputtering include:

1. [Warm up the Ion Gun and Filament](#)
2. [Sputter](#)
3. [Shut Down the Ion Gun and Filament](#)
4. [Operating Parameters](#)
5. [Determining the Sputter Rate](#)
6. [Advanced Control](#)

A. Using the FIB(Option)

The focused ion beam (FIB) uses a liquid metal ion gun (LMIG) with a gallium liquid metal ion source (LMIS). The FIB can be used to cross section defects to determine at which process step a defect originated. It can also be used on multilayered structures. Auger analysis can be done on the cross section following FIB without moving or reorienting the sample.

¹ The FIB subsystem is an option on the SMART system.

1. Select the FIB Settings

The first step in using the FIB is to establish which LMIG parameters will be used for viewing, milling, and/or polishing. Typically, the operator will simply select from the predefined settings to establish the parameters.

The parameters include those displayed on the FIB Hardware application tab and those displayed in the Advanced FIB Controls box (described in **Advanced FIB Controls** later in this section).

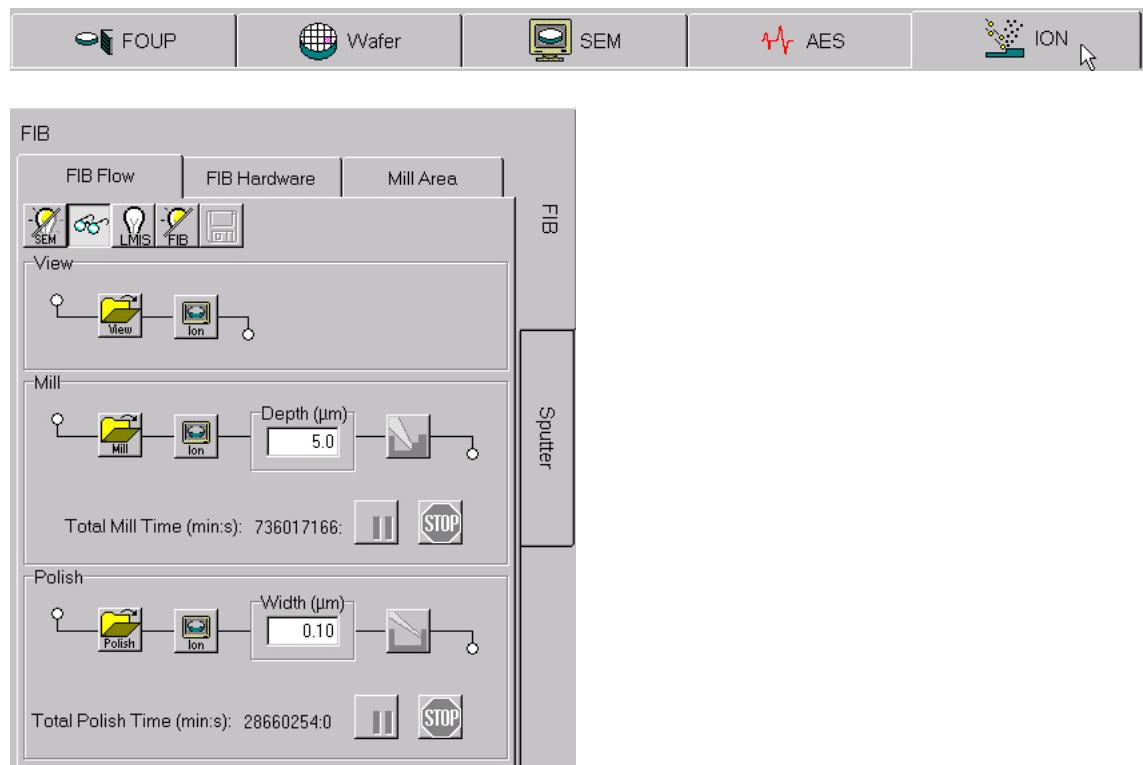
NOTE: The EDS detector must be retracted before the FIB is used. If your system is equipped with an EDS detector, go to Section 7. EDS for information on retracting the detector.

1. Center the area of interest at the appropriate magnification, and output the image to an SEM file, as described in Section 4. **Wafer/SEM**.

NOTE: If both the ion image and the secondary electron image will be used to document the mill, it is important to display the actual area to be milled at the desired magnification in the SEM, so the view in the SEM aligns with the view in the ion image.

Section 7: Ion

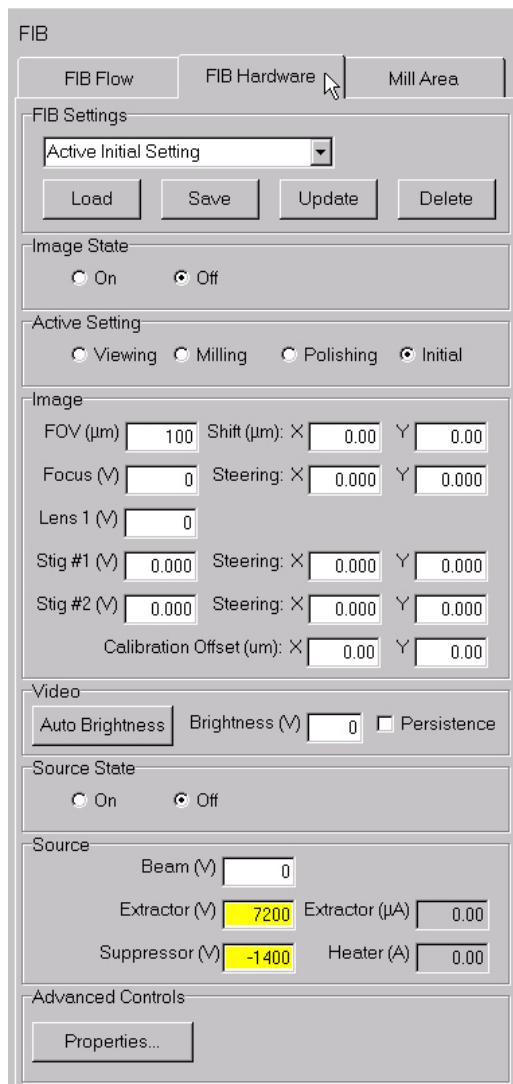
2. Click the Ion session tab. If this is the first time the Ion session has been opened since SmartSoft was started, the FIB application tab will be displayed in the input area.



The live SEM image is still displayed on the video monitor (if the monitor is in RGB mode), and nothing is displayed in the output area of the SmartSoft FIB interface.

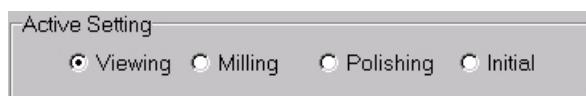
Section 7: Ion

3. Click the FIB Hardware tab.



If this is the first time the FIB session has been opened since SmartSoft was started, the Initial setting is selected, which sets the LMIG to safe default parameters.

Under Active Setting, click the Viewing button. The LMIG is set to the previously used Viewing parameters.

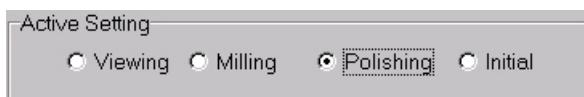


Section 7: Ion

4. If desired, change the parameters assigned to the Viewing Setting in one or both of the following ways:
 - Select a different setting from the drop-down list, and, with the Viewing button still selected, click Load to change the Viewing setting to the new setting's values.
 - Change values in parameter fields (on the FIB Hardware and/or in the Advanced FIB Controls box). For more information on creating new settings, go to the subsection **Create New Settings** below.
5. Click the Milling button. The LMIG is set to the previously used Milling parameters.



6. If desired, change the parameters assigned to the Milling Setting in one or both of the following ways:
 - Select a different setting from the drop-down list, and, with the Milling button still selected, click Load to change the Milling setting to the new setting's values.
 - Change values in parameter fields (on the FIB Hardware tab and/or in the Advanced FIB Controls box). For more information on creating new settings, go to the subsection **Create New Settings** below.
7. Press the Polishing button. The LMIG is set to the previously used Polishing parameters.



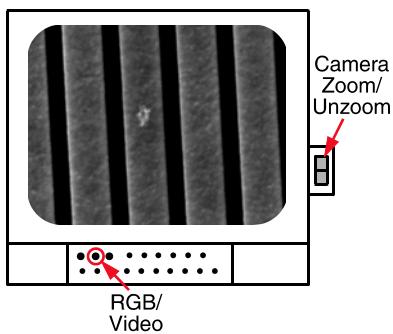
8. If desired, change the parameters assigned to the Polishing Setting in one or both of the following ways:
 - Select a different setting from the drop-down list, and, with the Polishing button still selected, click Load to change the Polishing setting to the new setting's values.
 - Change values in parameter fields (on the FIB Hardware tab and/or in the Advanced FIB Controls box). For more information on creating new settings, go to the subsection **Create New Settings** below.

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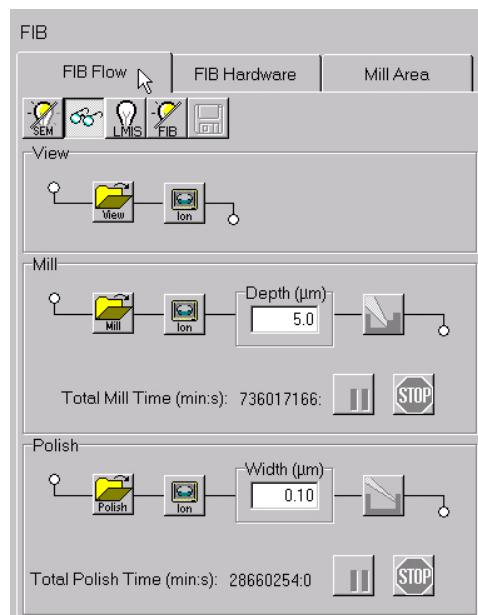
Imaging Modes

Two FIB imaging modes are available. Frame Rate Imaging is used for routine FIB work. SmartSoft will automatically use this mode when the routine FIB procedures (Viewing, Milling and Polishing) are used. Fast Refresh Rate Imaging is a faster scan used during tuning of the LMIG. The image is displayed only on the video monitor. Below is the procedure for Fast Refresh Rate Imaging.

1. Choose the desired “Selected Setting,” as indicated above.
2. Use the RGB MULTI/VIDEO button on the video monitor to select the VIDEO mode, indicated by the VIDEO light coming on. (The RGB MULTI/VIDEO button allows the operator to select between the video and RGB modes. The corresponding light turns on to indicate the selected mode. When the monitor is in the RGB mode, the SEM image is displayed.)



In VIDEO mode, you have the choice of viewing the video camera image or the FIB (ion-induced) image. To switch between the two, click the FIB Flow tab.



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On the toolbar in the input area, , toggle between the  and  icons to determine which image is displayed:  for a FIB (ion-induced) image or  for an optical (video camera) image. The default is to the video camera image, unless the ion beam is on. Select the  icon.

NOTE: At this point in the procedure, the FIB image will not yet be visible.

3. In the same toolbar, confirm that the LMIS icon is off:



4. Then click the FIB icon:



The gallium source is started if it is not already on, the focused ion beam is unblanked, and a live ion-induced image is displayed on the video monitor. The image is **not** displayed in the SmartSoft interface. Proceed to the **Tune the LMIG** subsection below.

*NOTE: If the source fails to start, go to the **Source Ignition** procedure given here.*

Source Ignition

If the FIB is not used on a regular basis, the source may fail to start after the FIB has been idle for some time. If this happens, use the “Automated Source Ignition” procedure below. If the source still does not start, use the “Manual Source Ignition” procedure, also given below.

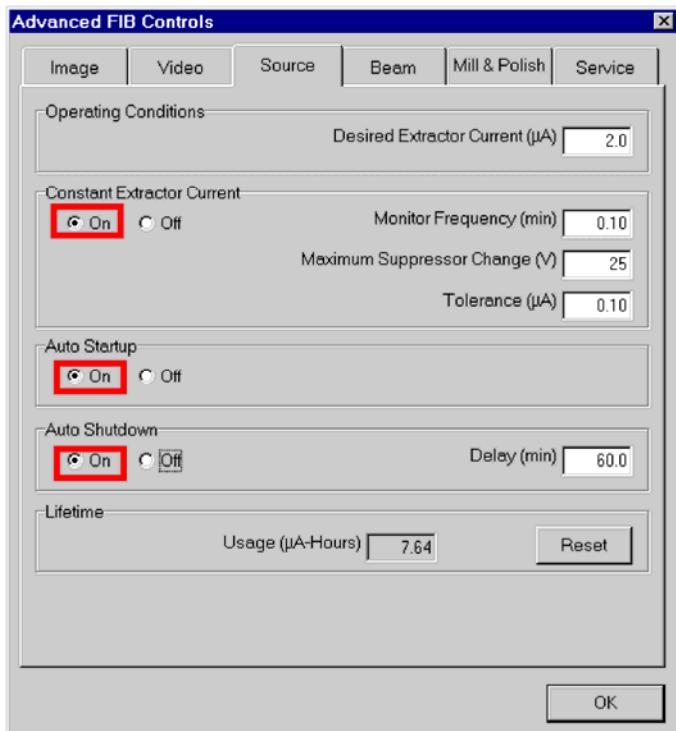
Automated Source Ignition

1. Click the FIB Hardware tab.
2. Click Properties in the Advanced Controls area.

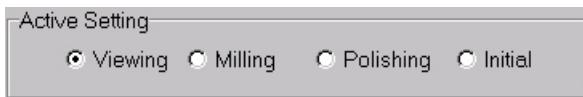


3. Click the Source tab. Click the On buttons for Constant Extractor Current, Auto Startup and Auto Shutdown.

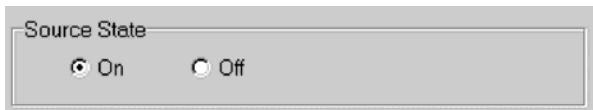
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- Click the Viewing button in the Active Setting area.



- In the Source State area, click On.



Repeat this procedure two to three times. If the source still does not start, go to the next procedure, "Manual Source Ignition."

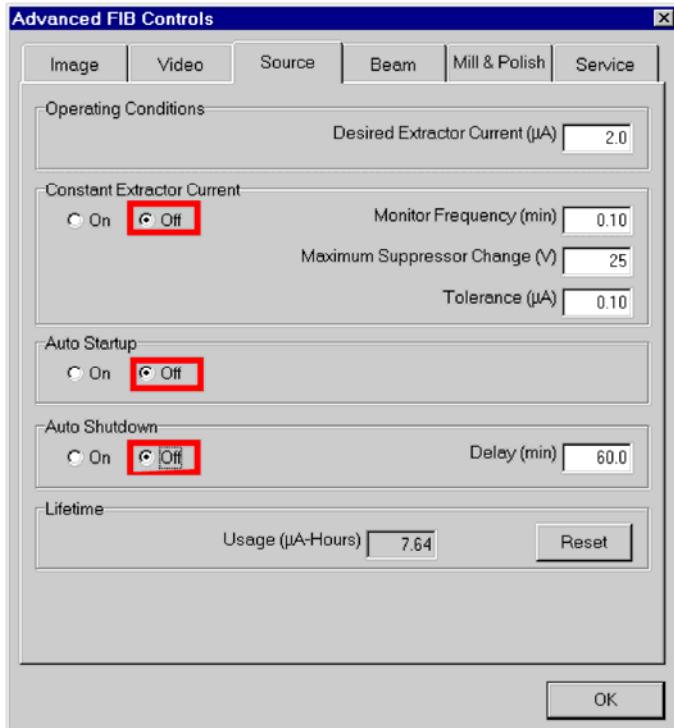
Manual Source Ignition

- Click the FIB Hardware tab.
- Click Properties in the Advanced Controls area.



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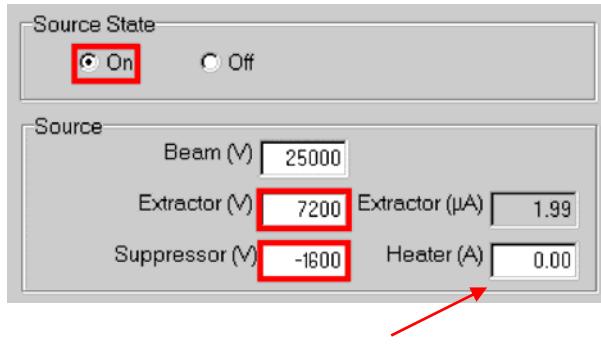
- Click the Source tab. Click the Off buttons for Constant Extractor Current, Auto Startup and Auto Shutdown.



- In the Source area, type in the specific values for the following parameters:

Extractor (V) to 7,200
Suppressor (V) to -1,600

In addition, click On for Source State.



- Increase the Extractor (V) value in 1 kV (1,000 V) steps to 10,200 V or until the source ignites (signified by the appearance of a value in the Extractor (µA) field).
- If the source does not ignite following Step 5, increase the Heater (A) value to the lowest setting needed to ignite the source, as follows:

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- a. Increase Heater (A) value to 2.5 A for no longer than 40 seconds;
 - b. Increase Heater (A) value to 2.7 A for no longer than 40 seconds;
 - c. Increase Heater (A) value to 2.9 A for no longer than 40 seconds;
 - d. Increase Heater (A) value to 3.1 A for no longer than 20 seconds.
7. Once the source has ignited, wait 10 seconds, then set the Heater (A) value to 0. Then decrease the Extractor (V) in 1 kV (1,000 V) steps back down to 7,200 V.

NOTE: With the Suppressor (V) set at -1600 V, a properly conditioned source will operate as follows:

With Extractor (V) at 10,200 V, Extractor (μ A) should be >100 μ A

With Extractor (V) at 9,200 V, Extractor (μ A) should be > 80 μ A

With Extractor (V) at 8,200 V, Extractor (μ A) should be > 50 μ A

With Extractor (V) at 7,200 V, Extractor (μ A) should be > 20 μ A

8. Once the Extractor (V) is at 7,200 V, adjust the Suppressor (V) so that the Extractor (μ A) value is 2 μ A.

NOTE: Increasing the Suppressor (V) value will reduce the Extractor (μ A) value, and decreasing the Suppressor (V) value will increase the Extractor (μ A) value.

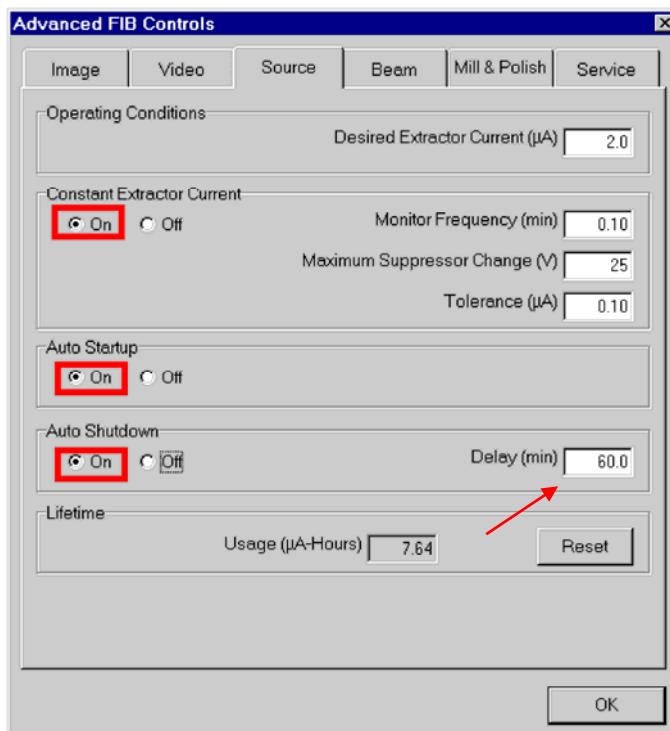
NOTE: Increasing the Suppressor (V) value in 500 V steps will reduce the Extractor (μ A) value 10 to 20 μ A. Increasing the Suppressor (V) value in 25 V steps will reduce the Extractor (μ A) value 0.1 to 2 μ A.

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- When the source is stable at 2 μA , click Properties.



- Click the Source tab. Click On for Constant Extractor Current, Auto Startup and Auto Shutdown. In addition, set the Auto Shutdown Delay value to 60.



- Proceed with the Fast Refresh Rate Imaging mode procedure described earlier in this section in preparation for tuning the liquid metal ion gun (LMIG).

2. Tune the LMIG

The operator next needs to perform optimizing, or “tuning,” of the LMIG optics at the column current that will be used for imaging, milling, or polishing. The operator observes the video monitor image for this procedure.

*NOTE: This procedure assumes that the Advanced FIB Controls parameters (e.g., Synchronize Ion and Electron Imaging = Auto) are set to the recommended values, which are shown in the **Advanced FIB Controls** subsection.*

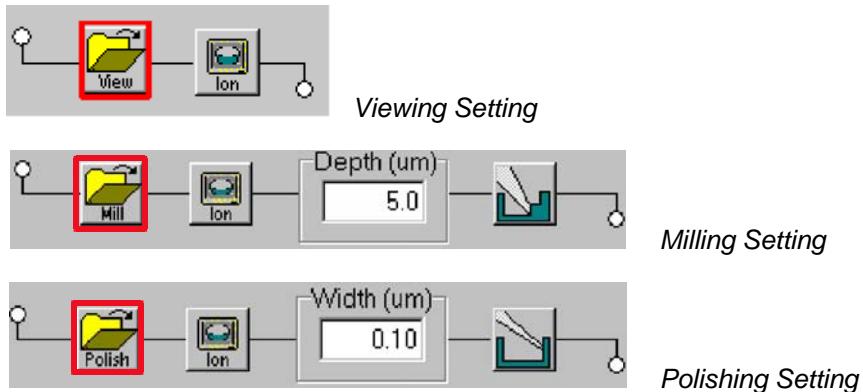
*NOTE: Tuning the LMIG should be performed only after a Z alignment of the wafer/sample. See Section **Wafer/SEM**, Subsection **Perform Manual Z Align (adjust stage height)**. It is recommended that the eV/step parameter be set at 0.1 or 0.2 eV for the Z align prior to tuning the LMIG to allow for a more precise alignment.*

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1. Center the area of interest at the appropriate magnification, and output the image to an SEM file, as described in Section **Wafer/SEM**.

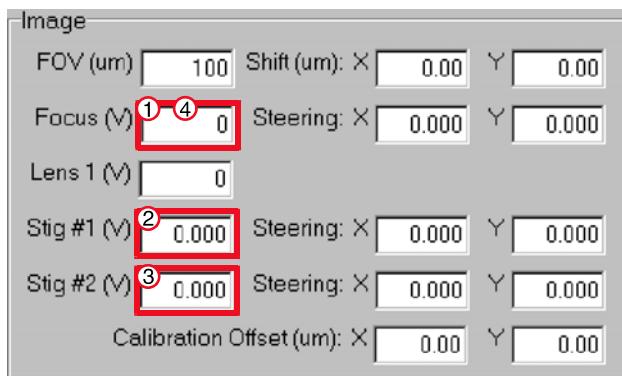
NOTE: If both the ion image and the secondary electron image will be used to document the mill, it is important to display the actual area to be milled at the desired magnification in the SEM, so the view in the SEM aligns with the view in the ion image.

2. Perform the **Select FIB Settings** procedure earlier in this section so the Viewing/Milling/Polishing Settings to be used are properly set up.
3. Perform the **Fast Refresh Rate Imaging** procedure earlier in this section.
4. Click the FIB Flow tab, if the FIB Flow area is not displayed.
5. Click the Setting button in the View, Mill, or Polish flow to set the LMIG to the Viewing/Milling/Polishing setting, so this procedure will be performed with the column current to be used.

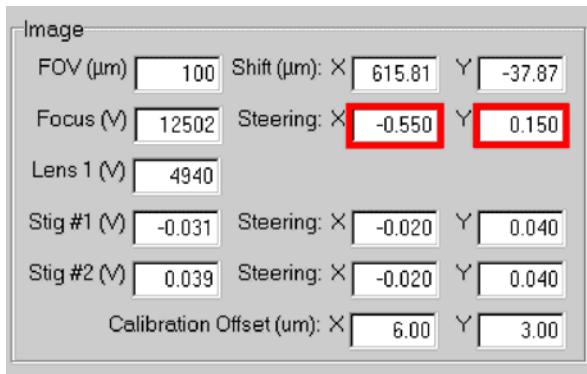


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6. Click the FIB Hardware tab.
7. In the Image area, adjust the Focus voltage (Focus (V)) until the best ion-induced image is displayed. The Focus voltage parameter is changed by clicking in the text field and typing a new value or using the arrow keys ($\uparrow \downarrow$) on the keyboard.
8. Adjust the Stig #1 and Stig #2 values by typing values or clicking in each field and pressing the arrow keys ($\uparrow \downarrow$).

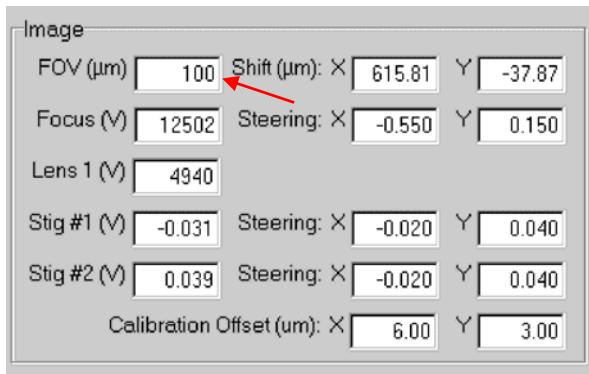


9. Readjust the focus, if needed, after the stigmators are optimized.
10. To further tune the gun, use the Focus, Stig #1 and Stig #2 wobbles. To adjust the Focus wobble, click in the Focus Steering X or Steering Y field. This will begin the wobble. Adjust the values in both the Focus Steering X and Y fields to minimize the wobble by pressing the arrow keys ($\uparrow \downarrow$), or by typing in new values.

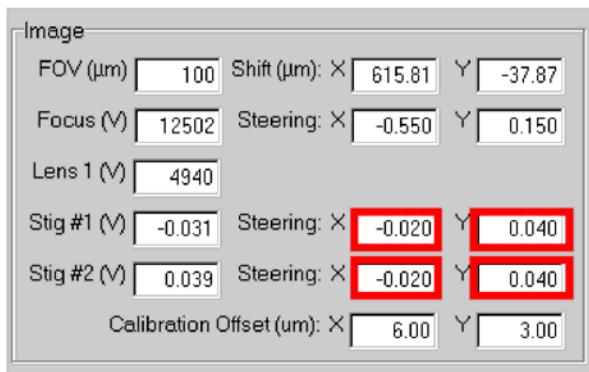


NOTE: The Focus wobble does not have an adjustment for the intensity of the wobble. It may be necessary to use a larger field of view (FOV) to see the wobble, such as 100 or 50 μm . Finish adjusting the wobble using a 20 μm field of view.

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11. Perform the wobble adjust for Stig #1 and Stig #2. The Stig #1 wobble will begin when you click in the Stig #1 Steering X or Y field; the Stig #2 wobble begins by clicking in the Stig #2 Steering X or Y field. Adjust the values in the four fields to minimize the wobble by pressing the arrow keys ($\uparrow \downarrow$), or by typing in new values.



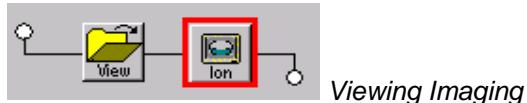
Finish the Stig #1 and Stig #2 wobble adjustments using a 20 μm field of view.

12. Repeat the wobble adjusts as needed using a 20 μm field of view. Then make further adjustments to Stig #1 (V), Stig #2 (V) and Focus (V) using a 20 μm field of view to obtain the sharpest image.
13. Below is an optional technique for optimizing stigmation:
 - a. Defocus Focus (V) slightly to see an elongation of the feature.
 - b. Adjust Stig #1 (V) to reshape the feature.
 - c. Adjust Stig #2 (V) to reshape the feature.
 - d. Adjust Focus (V) for the sharpest image.
 - e. Repeat the four steps to obtain the sharpest image in a 20 μm field of view.
14. Click the FIB Flow tab.
15. In the toolbar, click on the FIB icon to stop tuning.



3. View with the FIB

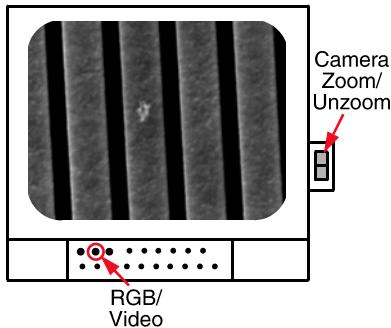
1. In the View area, click the FIB Imaging button in the View flow to start ion imaging of the area of interest using the Viewing Setting.



The gallium source for the LMIG is started automatically (if it is not already on),

indicated by turning on the (LMIS) icon. A live ion-induced image is displayed in SmartSoft when the source starts.

View the SEM image on the video monitor by using the RGB MULTI/VIDEO button on the video monitor to select the RGB mode, indicated by the VIDEO light turning off.



NOTE: If the ion-induced image does not show the same area as the electron-induced image, certain hardware parameters have been changed and must be reset. This procedure must be performed by a PHI Customer Service representative or a site technician who has been trained on the system.

2. Adjust the ion-induced SmartSoft image for brightness, persistence, focus, and stigmatism, as follows:
 - a. Click the (Auto Video) toolbar button to automatically adjust the brightness and contrast, or click the (Brightness) button, then drag the mouse across the image to increase (or decrease () the brightness.
 - b. Click the (persistence) button to turn on persistence, which improves the image using frame averaging. When persistence is on, the image quality is better; when off, the image is continuously refreshed. The Persistence button is usually left on except during navigation.
 - c. Click the (focus) button, then drag the mouse across the image to increase (or decrease () the focus.

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- d. Click the  (stigmation) button, then drag the mouse across the image to increase or decrease Stig#1 (\curvearrowright or \curvearrowleft) stigmation along the x axis and Stig#2 (\curvearrowup or \curvearrowdown) stigmation along the y axis.

4. Mill with the FIB

This procedure describes routine milling using the LMIG. This procedure is typically performed after the **View with the FIB** procedure, and assumes that the desired hardware parameters for the LMIG have been loaded into the Milling Setting.

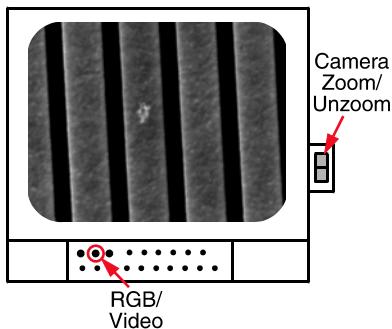
*NOTE: This procedure assumes that the Advanced FIB Controls parameters (e.g., Synchronize Ion and Electron Imaging = Auto) are set to the recommended values, which are shown in the **Advanced FIB Controls** subsection.*

1. Perform the **Tune the LMIG** procedure earlier in this section.
2. In the Mill area, click the FIB Imaging button in the Mill flow to start ion imaging of the area of interest using the Milling setting.



The gallium source for the LMIG is started automatically (if it is not already on), indicated by turning on the  (LMIS) icon. A live ion-induced image is displayed in SmartSoft when the source starts.

View the SEM image on the video monitor by using the RGB MULTI/VIDEO button on the video monitor to select the RGB mode, indicated by the VIDEO light turning off.

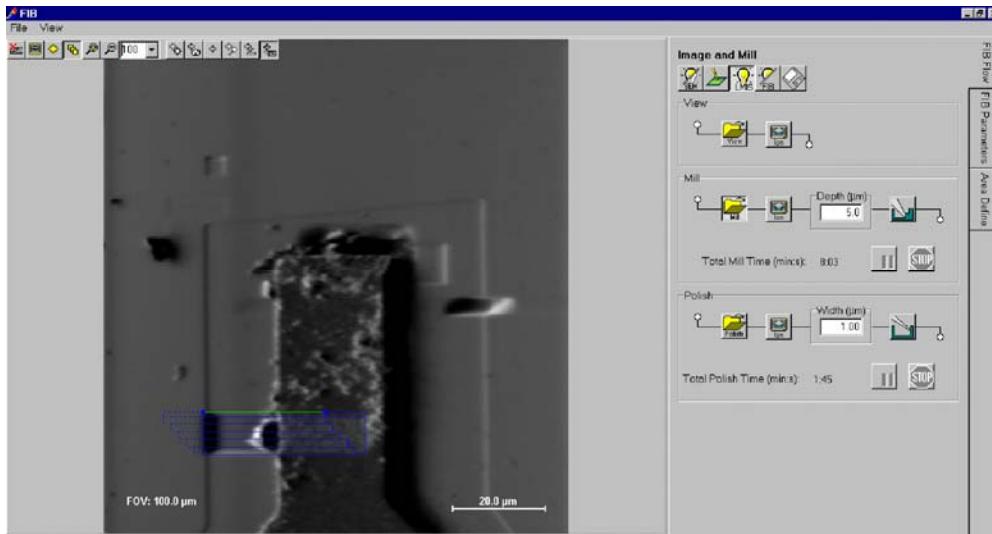


Adjust the ion-induced SmartSoft image for brightness, persistence, focus, and stigmation as described in Step #2 in the **View with the FIB** subsection above.

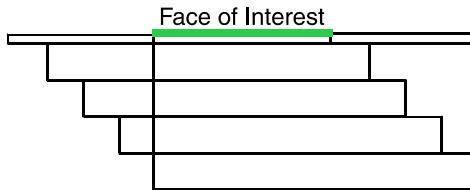
3. When the ion-induced image is optimized, click the  (FIB Imaging) button again to turn ion imaging off. The live ion-induced image is frozen, and the Area Define

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cursor is displayed. The cursor appears in the same position and at the same shape and size as the last time a mill area was defined.



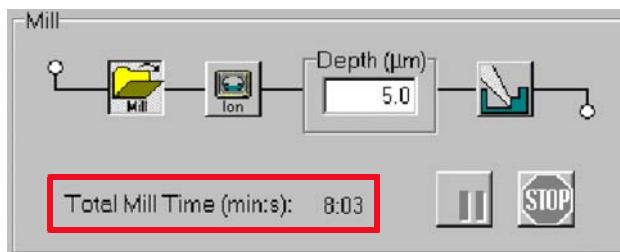
4. Drag the area cursor to the desired mill position. Adjust the face of interest endpoints as needed by first clicking on the green area, then dragging the endpoints.



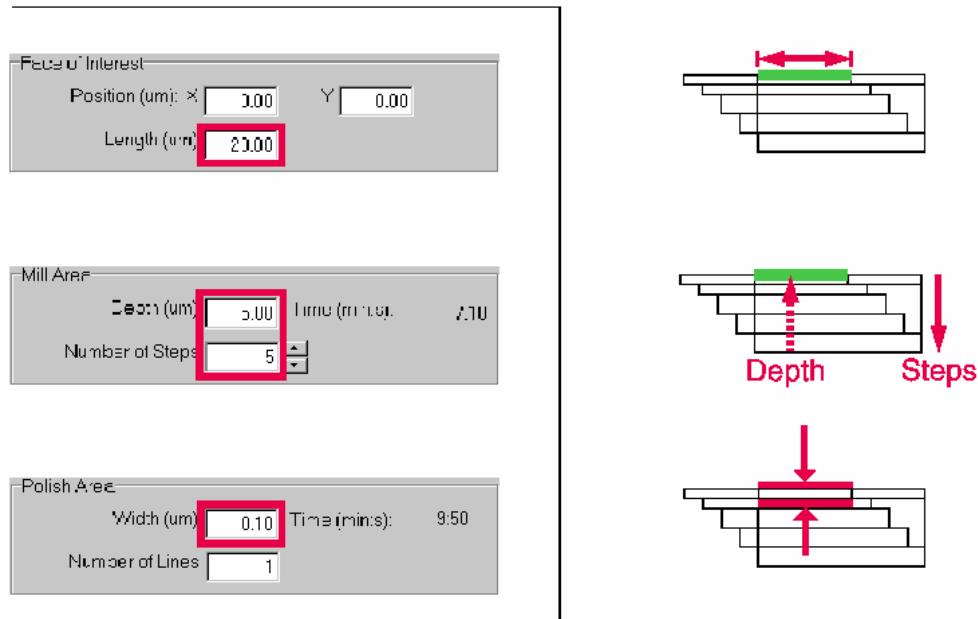
5. Specify the depth to be milled by clicking in the Depth field and typing a value or pressing the arrow keys ($\uparrow \downarrow$).



6. Observe the milling time displayed (in minutes and seconds), and adjust the milling parameters as desired to optimize your analysis time using the Mill Area tab.



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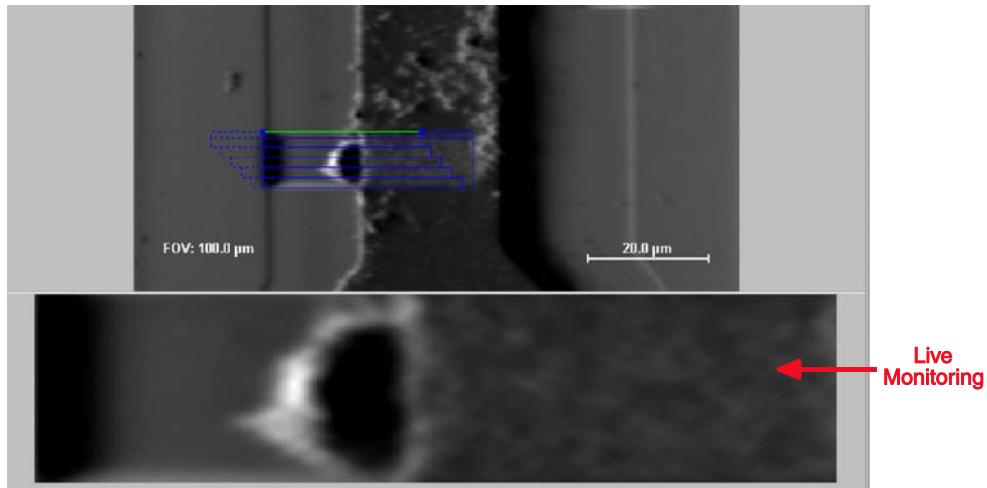


NOTE: The LMIG Current also affects the milling time. If, however, a new milling setting with a different current is loaded, repeat this entire procedure.

7. Click the Start Mill button to start milling.



During milling, the ion-induced image is frozen with the mill-area box displayed below it, a milling progress bar is displayed, and a live, ion-induced monitoring view is displayed below the frozen image.

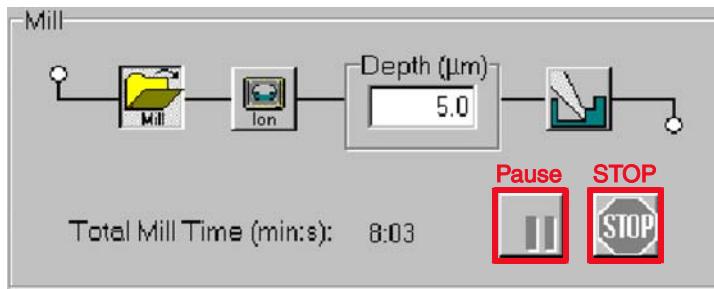


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During live monitoring, the FIB toolbar buttons may be used to adjust brightness (), focus (), and/or stigmatation () as needed and to turn persistence () on or off.

8. During milling, click Pause/Continue to suspend milling, if desired. If Pause is clicked, clicking Pause/Continue again resumes milling. Clicking Pause allows a new ion-induced image to be obtained or allows the operator to open the SEM tab to view a live SEM image.

The operator may, instead, click the STOP button to end the mill.

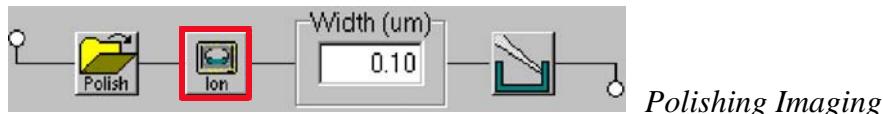


5. Polish with the FIB

The basic procedure for polishing using the LMIG is described. This procedure is typically performed after the **View with the FIB** and **Mill with the FIB** procedures. This procedure assumes that the desired hardware parameters for the LMIG have been loaded into the Polishing Setting.

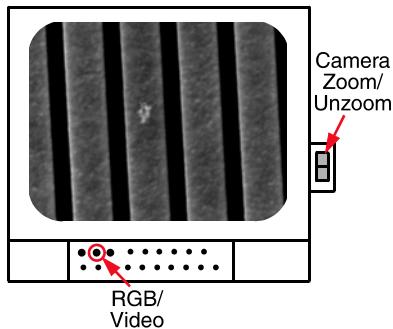
*NOTE: This procedure assumes that the Advanced FIB Controls parameters (e.g., Synchronize Ion and Electron Imaging = Auto) are set to the recommended values, which are shown in the **Advanced FIB Controls** subsection.*

1. Perform the **Tune the LMIG** procedure earlier in this section.
2. In the Polish area, click the FIB Imaging button in the Polish flow to start ion imaging of the area of interest using the Polish setting.



The gallium source for the LMIG is started automatically (if it is not already on), indicated by turning on the  (LMIS) icon. A live ion-induced image is displayed in SmartSoft when the source starts.

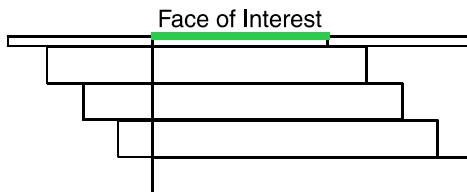
View the SEM image on the video monitor by using the RGB MULTI/VIDEO button on the video monitor to select the RGB mode, indicated by the VIDEO light turning off.



Adjust the ion-induced SmartSoft image for brightness, persistence, focus, and stigmation as described in Step #2 in the **View with the FIB** subsection above.

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3. When the ion-induced image is optimized, click the  (FIB Imaging) button again to turn ion imaging *off*. The live ion-induced image is frozen, and the Area Define cursor is displayed. The cursor appears in the same position and at the same shape and size as the last time an area was defined.
4. Adjust the face of interest endpoints as needed by first clicking on the green area, then dragging the endpoints. In addition, specify the width to be polished by clicking in the Width field and typing a value or pressing the arrow keys ($\uparrow \downarrow$).



and/or

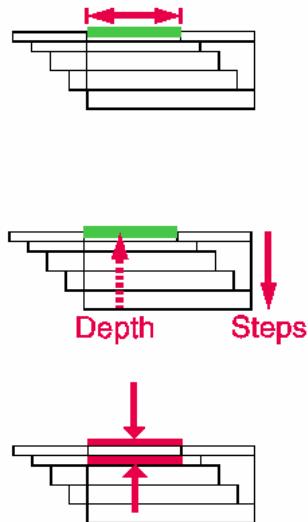


5. Observe the polishing time displayed (in minutes and seconds), and adjust the polishing parameters as desired to optimize your analysis time using the Mill Area tab.



Section 7: Ion

| |
|--|
| Focus Interest |
| Position (um): X <input type="text" value="0.00"/> Y <input type="text" value="0.00"/> |
| Length (um) <input style="outline: 2px solid red;" type="text" value="20.00"/> |
| |
| Mill Area |
| Depth (um) <input style="outline: 2px solid red;" type="text" value="5.00"/> |
| Time (min:s) <input type="text" value="2.10"/> |
| Number of Steps <input type="text" value="5"/> |
| |
| Polish Area |
| Width (um) <input style="outline: 2px solid red;" type="text" value="0.10"/> |
| Time (mins) <input type="text" value="9:50"/> |
| Number of Lines <input type="text" value="1"/> |



NOTE: The LMIG Beam Current affects the polishing time. If, however, a new polishing setting with a different beam current is loaded, repeat this entire procedure.

6. Click the Start Polish button to start polishing.



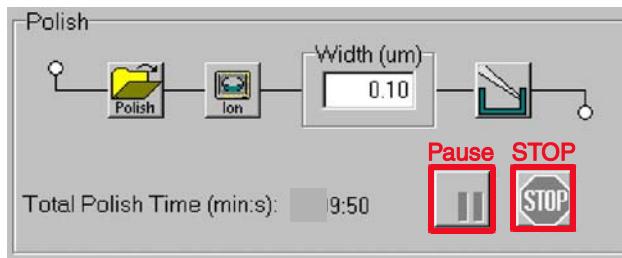
During polishing, the ion-induced image is frozen with the polish area displayed over it, a progress bar is displayed, and a live, ion-induced monitoring view of the current line of the polish is displayed below the frozen image.

During live monitoring, the FIB toolbar buttons may be used to adjust brightness (), focus () and/or stigmation () as needed and to turn persistence () on or off.

7. During polishing, click Pause/Continue to suspend polishing, if desired. If Pause is clicked, clicking Pause/Continue again resumes polishing. Clicking Pause allows a new ion-induced image to be obtained or allows the operator to open the SEM tab to view a live SEM image.

The operator may, instead, click the STOP button to end the polish.

Section 7: Ion



6. FIB Hardware Tab

The FIB Hardware tab is used for defining, changing, and selecting LMIG settings and optimizing the ion-induced image. Additional LMIG parameters are also accessed from this tab by clicking the Properties button in the Advanced Controls area, which opens the Advanced FIB Controls box.

Settings

Typical procedures for using the FIB Settings and Active Setting areas of this tab are given in the **Select FIB Settings** procedure earlier in this section. Procedures for changing settings, deleting a setting, and creating a setting are given here and below, in the **Create New Settings** subsection.

A setting is a group of parameter values from the FIB Hardware tab and the Advanced FIB Controls box. Beam voltage is included in these parameters, but FOV and Shift are not.



To change the parameters for the Viewing/Milling/Polishing Setting:

- Select a different predefined setting from the drop-down list, and, with the appropriate (Viewing/Milling/Polishing) button selected, click the Load button to change the Viewing/Milling/Polishing Setting to the new setting's values.
- Change values in parameter fields (in the FIB Hardware tab and/or in the Advanced FIB Controls box). See the **Create New Settings** subsection below.

Section 7: Ion

To change the selected predefined setting, click the Update button. The parameter values that are current when Update is clicked become the parameters of the setting selected in the FIB Settings area.

To delete a predefined setting (not Active Viewing Setting, Active Milling Setting, Active Polishing Setting, or Active Initial Setting):

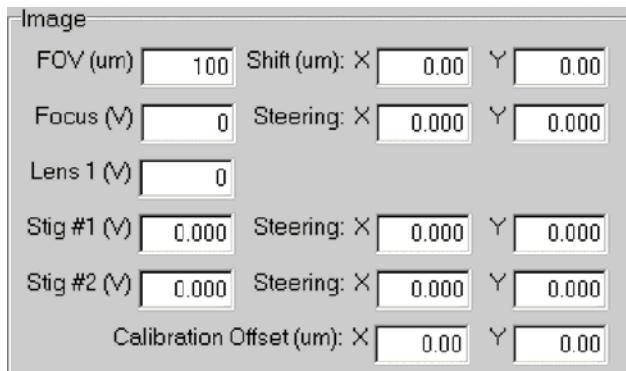
1. Select the setting from the drop-down list in the FIB Settings area.
2. Click the Delete button.

Image State

Clicking the *Image State On* or *Off* button has the same result as clicking the  icon: When *On* is clicked, the gallium source for the LMIG is started, if not already on. Once the source has started, a live ion-induced image is displayed in SmartSoft, and the  icon is lit up. When *Off* is clicked, the ion-induced image is no longer displayed, but the  icon is still on.

Image

The Image parameters here are used to optimize the ion-induced image by refining the hardware settings of the LMIG—specifically, the focus voltage, focus steering, stigmators' voltages, and the steering for the two sets of stigmation plates. Using the *Focus*, *Stig #1*, *Stig #2*, and *Steering* parameters to optimize the image as described in the **Tune the LMIG** procedure earlier in this section.



The screenshot shows the 'Image' tab of the SmartSoft software interface. It contains several input fields for tuning the LMIG:

| | | | | | |
|---------------------------------------|-------|---------------|-------|---|-------|
| FOV (um) | 100 | Shift (um): X | 0.00 | Y | 0.00 |
| Focus (V) | 0 | Steering: X | 0.000 | Y | 0.000 |
| Lens 1 (V) | 0 | | | | |
| Stig #1 (V) | 0.000 | Steering: X | 0.000 | Y | 0.000 |
| Stig #2 (V) | 0.000 | Steering: X | 0.000 | Y | 0.000 |
| Calibration Offset(um): X 0.00 Y 0.00 | | | | | |

The *FOV* (field of view), *Shift X*, and *Shift Y* parameters display the current settings selected by the operator in the image area. These are not saved with any settings.

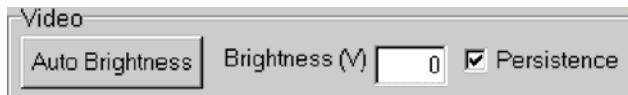
Other Image parameter values are adjusted when creating new FIB settings.

Additional hardware information about imaging resides in the Image tab in Advanced FIB Controls.

Section 7: Ion

Video

The Auto Brightness button in the Video area adjusts the output of the secondary-electron detector (SED) to automatically optimize the brightness of the ion-induced image.



The *Brightness* text field provides the operator with a different way of manually adjusting the image brightness than is available using the  (Brightness) button on the toolbar. When the  (Brightness) toolbar button is clicked, the operator drags the mouse across the image to increase ( or decrease ( ) or by typing in values and pressing Enter on the keyboard.

The *Persistence* option is used to turn persistence on or off. When persistence is on, the image quality is better; when off, the image is continuously refreshed. The *Persistence* button is usually left on except during navigation.

When the Persistence Refresh is set to Auto, the image will automatically refresh whenever necessary. Refer to the Video tab of the Advanced FIB Controls box.

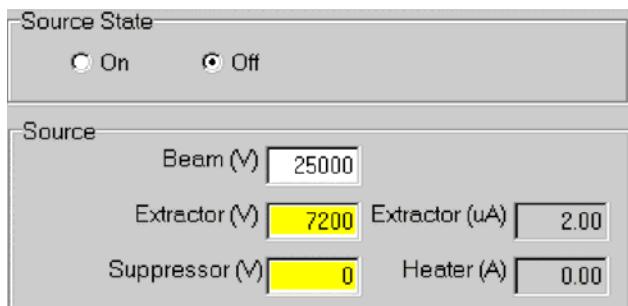
Changing the Video parameters affects any live ion-induced image displayed in SmartSoft. It does not adjust the display of frozen images.

Additional hardware information about video resides in the Video tab in Advanced FIB Controls.

Source State and Source

Clicking the *Source State On* or *Off* button has the same result as clicking the  (Liquid Metal Ion Source) icon: When *On* is clicked, the gallium source for the LMIG is started, and the  icon is lit up. When *Off* is clicked, the gallium source is turned off, and the  icon is no longer lit up.

Section 7: Ion



The source parameters set the operating values for the gallium source. Typical values are shown in the illustration. These values are adjusted during the **Manual Source Ignition** procedure described earlier in this section.

NOTE: The heater heats to 2.4 A, then automatically goes off after no more than 40 seconds of operation to maximize the lifetime of the source.

Additional hardware information about the source resides in the Source tab of the Advanced FIB Controls box.

Advanced Controls

Clicking the Properties button in the Advanced Controls area opens the Advanced FIB Controls box, which is described in the next subsection, **Advanced FIB Controls**.

7. Advanced FIB Controls

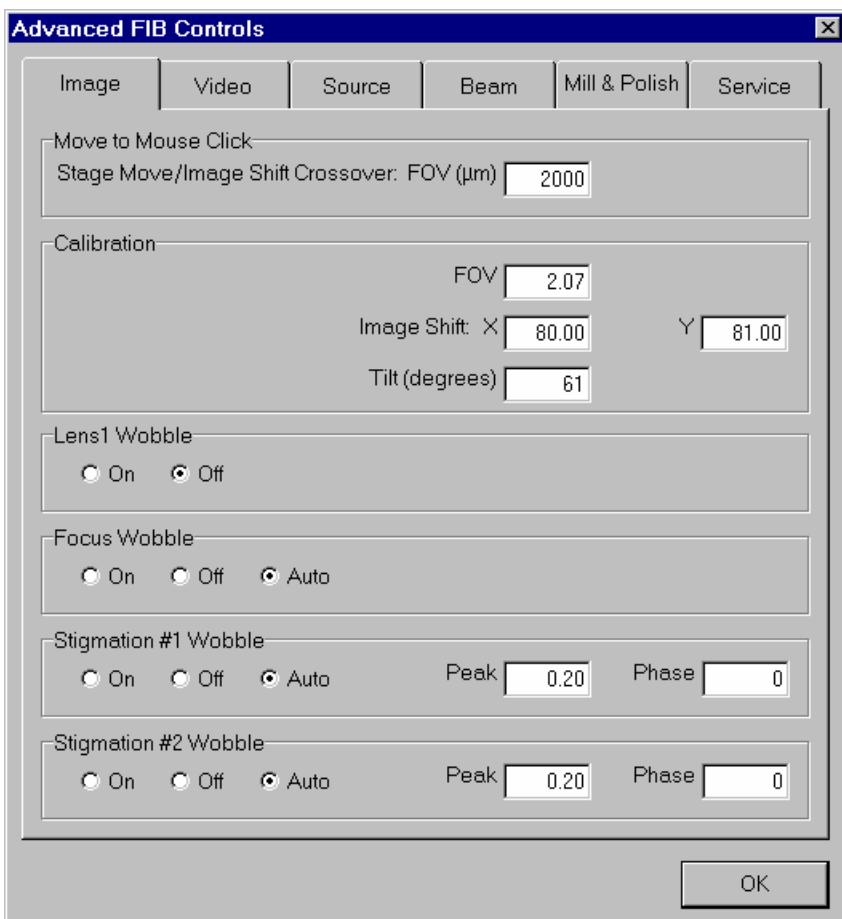
A box with six tabs used for tuning and calibration is available when the Properties button is clicked in the FIB Hardware tab: Image, Video, Source, Beam, Mill & Polish, and Service. Default settings are shown here.

Image—Advanced Controls

The typical settings for the Advanced FIB Controls Image tab, except Calibration, are shown below.

The values in the *Calibration* fields are set by the PHI Customer Service Engineer or site technician who has been trained on the system. These values should not need to be changed after installation. For example, the value in *Tilt* reflects the measured actual tilt from vertical of the LMIG and should be very close to 60°.

Section 7: Ion



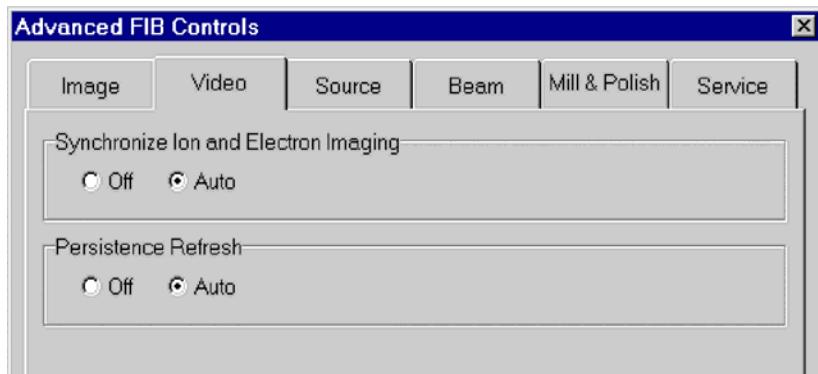
The Move and Move/Zoom toolbar buttons will do a stage move or an image shift as needed, according to the *Stage Move/Image Shift Crossover* value entered by the operator. That is, if the field of view (FOV) is greater than or equal to this value (e.g., 2000 μm), a stage move will be performed instead of an image shift (an optics adjustment).

When the *Focus*, *Wobble*, *Stigmation #1 Wobble*, and *Stigmation #2 Wobble* are set to *Auto*, wobbling starts when the operator clicks in the corresponding steering fields in the FIB Hardware tab. Changing the *Peak* parameters changes the magnitude of the wobble. The use of wobble for image optimization is described in the **Tune the LMIG** procedure described earlier in this section.

Video—Advanced Controls

The default settings for the Advanced FIB Controls Video tab are shown in the following illustration.

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The suggested settings in the Video box are *Auto* for both choices.

When *Synchronize Ion and Electron Imaging* is set to *Auto*, the electron beam is blanked when the (FIB Imaging) button or the (FIB Tuning Enable) button is turned on and unblanked when the or button are turned off.

Regardless of the selection in this box, clicking the (Electron-Induced Imaging) icon in the FIB Flow tab turns on or blanks off the electron beam.

NOTE: To get a live electron-induced image, open the SEM session and click the SEM button in the toolbar.

Persistence Refresh should be set to *Auto*, so the image will be refreshed whenever the *FOV*, *Shift*, *Focus*, *Stigmator*, or *Brightness* parameters are changed.

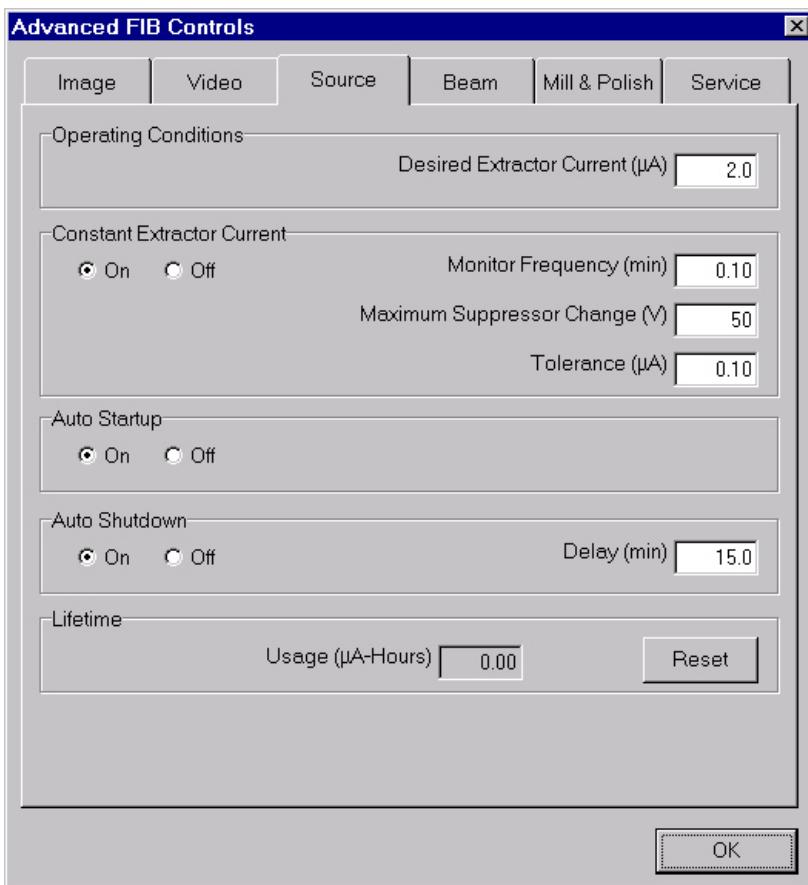
Source—Advanced Controls

The typical settings for the Advanced FIB Controls Source tab (except Lifetime) are shown below.

When *Constant Extractor Current* is set to *On*, the suppressor voltage is varied in increments (up to the value in the *Maximum Suppressor Change* parameter) at intervals determined by the given *Monitoring Frequency* to maintain the *Desired Extractor Current* within the *Tolerance* allowed.

When *Constant Extractor Current* is set to *Off*, the operator manually adjusts the *Suppressor* value in the Source area of the FIB Hardware tab to maintain the extractor current at or near the desired level. A more negative suppressor voltage raises the extractor current.

Section 7: Ion



When *Auto Startup* is *On*, source startup is performed by an algorithm that optimizes the startup routine. When *Auto Startup* is *Off*, the operator presses the *Source State On* button in the Source State area and adjusts the values of the *Extractor Voltage*, *Suppressor*, and *Heater* fields in the Source area of the FIB Hardware tab to turn the gallium source on. This procedure, **Manual Source Ignition**, is described earlier in this section.

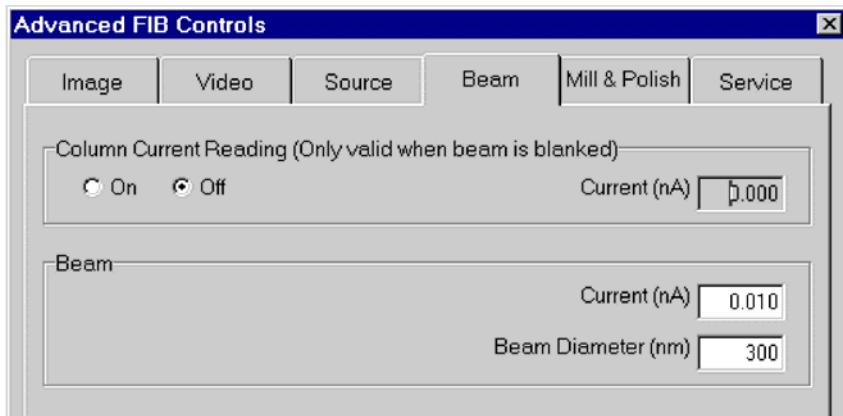
When *Auto Shutdown* is *On*, the source turns off automatically after the entered delay time (e.g., 15 minutes) of non-use. When this parameter is set to *Off*, the operator clicks the *Source State Off* button to turn off the source when done using it. To maximize its lifetime, the source should be off when not using it for an extended period of time.

The Source Usage field shows the elapsed operating time in microamperes-hours. When this value reaches 1500 μA-hr, the source should be changed. When the source is changed, press the Reset button here to zero the usage time. This field is updated every 10 seconds during operation of the source.

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Beam—Advanced Controls

The Advanced FIB Controls Beam tab is shown in the following illustration.



The value displayed in the Beam *Current* field can be set by the operator. First, turn the *Column Current Reading* to *On*. The beam current will appear in the Current (nA) box under *Column Current Reading*. Input that value into the Current (nA) field under *Beam*. This procedure is necessary to establish the proper milling time.

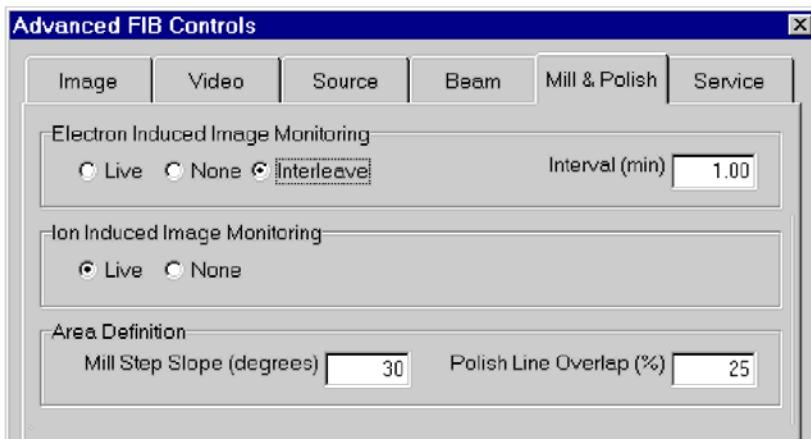
The *Beam Diameter* field is typically used by the PHI Customer Service Engineer or the trained site technician only. The beam diameter is calculated using MultiPak with an SEM file of an ion-induced image of the beam diameter standard for the SMART LMIG. To calculate the diameter:

1. In MultiPak, open the .SEM file.
2. From the Map window, select Tools—Extract Lines. In the lower toolbar, press Free Line.
3. Click and drag a small vertical line across a horizontal feature.
4. Press the Line/New (or Line/Upd) button. In the Profile window, select Tools—Beam Size.
5. Drag the two green horizontal lines, one each to the minimum and maximum y values of the curve.
6. Drag the left and right vertical lines to the nearest intersection of the data curve and horizontal lines.
7. Record the value displayed in the Beam Size field in the lower toolbar, noting the units (which are the units of the x axis).
8. In SmartSoft, type the beam diameter into the *Beam Diameter* field.

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Mill & Polish—Advanced Controls

The recommended settings for the Advanced FIB Controls Mill & Polish tab are shown in the following illustration.



When *Interleaved* is selected for *Electron Induced Image Monitoring*, milling is periodically paused at the interval specified to refresh the electron-induced image (which can be seen on the SEM tab or on the video monitor if the RGB mode is selected). When *Live* is selected, the electron beam is on and stays on. When set to *None*, the electron beam is blanked and left blanked.

When *None* is selected for *Ion Induced Image Monitoring*, the live monitoring image below the frozen image during milling or polishing will not be displayed.

The *Mill Step Slope* parameter set the pitch of the “stair steps” created during milling.

The *Polish Line Overlap* parameter specifies the percentage overlap between successive “lines” of the polish. A polish line is one beam diameter. More information can be found in the **Mill Area** tab subsection.

Service—Advanced Controls

The Advanced FIB Controls Service tab is for use by the PHI Customer Service Engineer or a site technician who has been trained on the FIB subsystem.

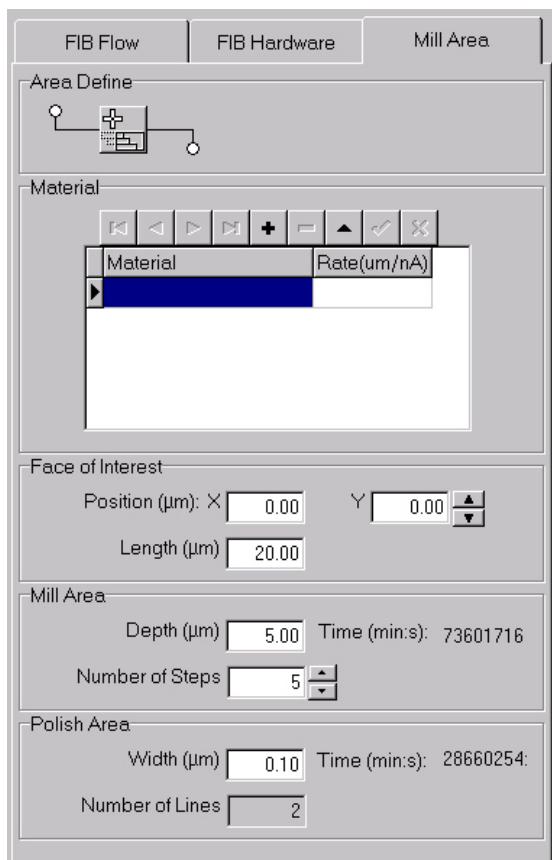
8. Mill Area Tab

Clicking the Mill Area tab opens the Mill Area interface. This tab is used primarily for specifying the rate of mill, but can be used to define or refine mill and polish area parameters instead of using the click-and-drag graphic available in the FIB tab (as described in the procedures earlier in this section).

These parameters, together with the other setting parameters (displayed in the FIB Hardware tab), are used to calculate the time to complete the mill or polish. The time, in minutes and seconds, is displayed here and on the FIB tab.

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Additional hardware information about milling and polishing resides in the Mill & Polish tab in Advanced FIB Controls box in the FIB Hardware tab.



The *Material* parameter specifies the milling or polishing rate to be used and is expressed in microns per nanoamperes ($\mu\text{m}/\text{nA}$). Typically, a single rate is used for the entire mill and for the polish. One of the predefined rates can be used, or different rates can be defined using experimentation on representative materials and saved using a descriptive name.

The toolbar with the *Material* list can be used to scroll through available options of rates or to add (+) or delete (-) list items. Use the predominate material when defining a sputter rate, or determine a sputter rate for the combination of materials to be milled.

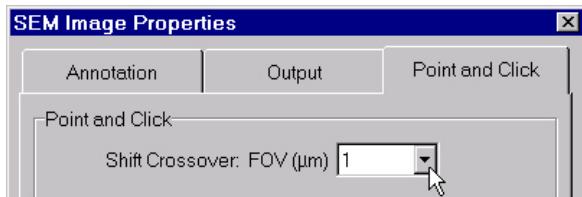
The green line in the area cursor is the face of interest. The length and endpoints of the face of interest may be defined and/or refined here by modifying the text values in the parameters, if desired.

A polish “line” is one beam diameter. The number of polish lines needed to fill the polish area, including the defined overlap, is computed automatically and is based on the Polish Line Overlap parameter in the Advanced FIB Controls Mill & Polish tab.

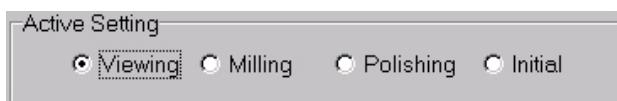
9. Create New Settings

To create a new FIB setting:

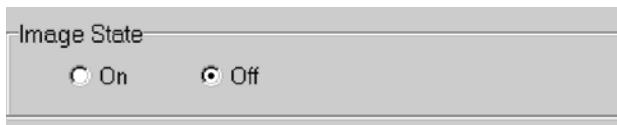
1. Perform a Z alignment of the sample. See Section **Wafer/SEM**, Subsection **Perform Manual Z Align (adjust stage height)** of this manual. It is recommended that the eV/step parameter be set at 0.1 eV for the Z align done prior to creating new FIB settings. This allows for a more precise alignment.
2. Set the electron gun beam voltage to 10 kV. See Section **Wafer/SEM**, Subsection **Optimize the Electron Gun Operating Parameters** of this manual.
3. Bring a recognizable feature into the field of view. Do not use an area that is part of a repeating pattern.
4. In the SEM session tab, click the SEM Hardware tab, then click Image Props in the Advanced Control area to bring up the SEM Image Properties box.



5. Click the Point and Click tab. Set the “Image Shift/Stage Move Crossover” FOV to 1 μm.
6. Click the Ion session tab. Then click the FIB Hardware tab.
7. In the Active Setting area, choose Viewing.

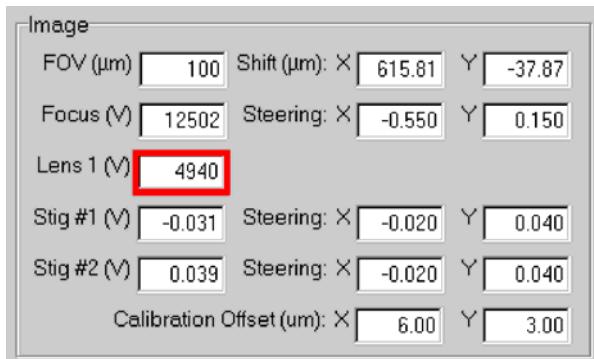


8. In the Image State area, click Off.



9. Adjust the Lens 1 (V) value to obtain the desired beam current.

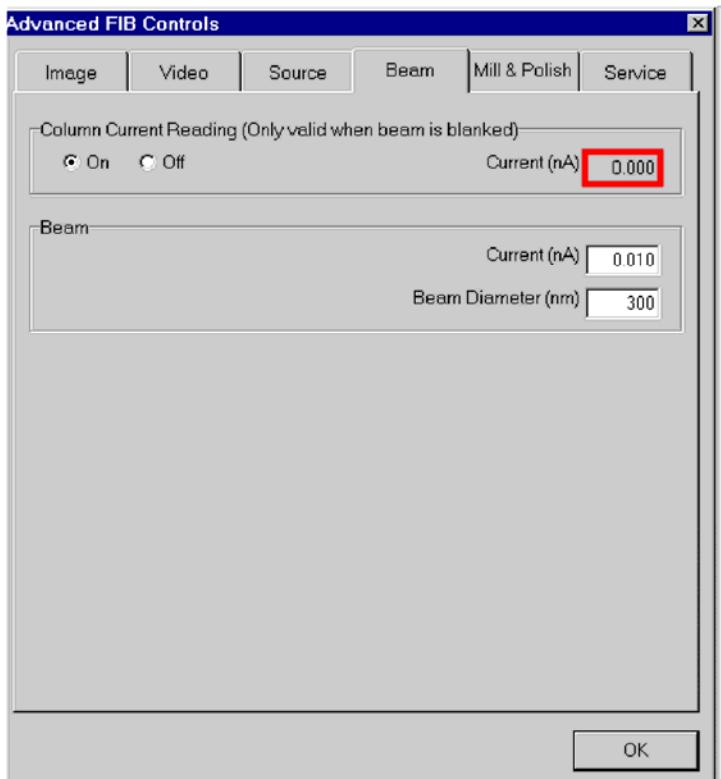
Section 7: Ion



10. Observe the beam current by first clicking Properties.



Then click the Beam tab.



In the Column Current Reading area, click On. Keep this box open and return to the FIB Hardware area to change the value for Lens 1 (V). As you change the value, you will be able to observe the Current (nA) reading in the box change.

To help determine the value for Lens 1 (V), refer to the table below. The table shows settings that are already loaded into the system, but can be used for reference when creating new settings.

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| Input this Lens 1 (V) value ... | ... to get this beam current |
|--|---|
| ~ 2700 V | ~ 5 picoAmps |
| ~ 3200 V | ~ 10 picoAmps |
| ~ 3700 V | ~ 20 picoAmps |
| ~ 4180 V | ~ 50 picoAmps |
| ~ 4430 V | ~ 100 picoAmps |
| ~ 4610 V | ~ 200 picoAmps |
| ~ 4780 V | ~ 500 picoAmps |
| ~ 4870 V | ~ 1000 picoAmps |
| ~ 4930 V | ~ 2000 picoAmps |
| ~ 5010 V | ~ 5000 picoAmps |

11. Adjust Focus (V) for the best image. Approximate values for Focus (V) are given in the table below.

| Input this Lens 1 (V) value ... | ... to get this beam current | Focus (V) will then be: |
|--|---|------------------------------------|
| ~ 2700 V | ~ 5 picoAmps | ~ 11,750 |
| ~ 3200 V | ~ 10 picoAmps | ~ 11,800 |
| ~ 3700 V | ~ 20 picoAmps | ~ 11,900 |
| ~ 4180 V | ~ 50 picoAmps | ~ 12,000 |
| ~ 4430 V | ~ 100 picoAmps | ~ 12,150 |
| ~ 4610 V | ~ 200 picoAmps | ~ 12,250 |
| ~ 4780 V | ~ 500 picoAmps | ~ 12,400 |
| ~ 4870 V | ~ 1000 picoAmps | ~ 12,600 |
| ~ 4930 V | ~ 2000 picoAmps | ~ 12,750 |
| ~ 5010 V | ~ 5000 picoAmps | ~ 12,900 |

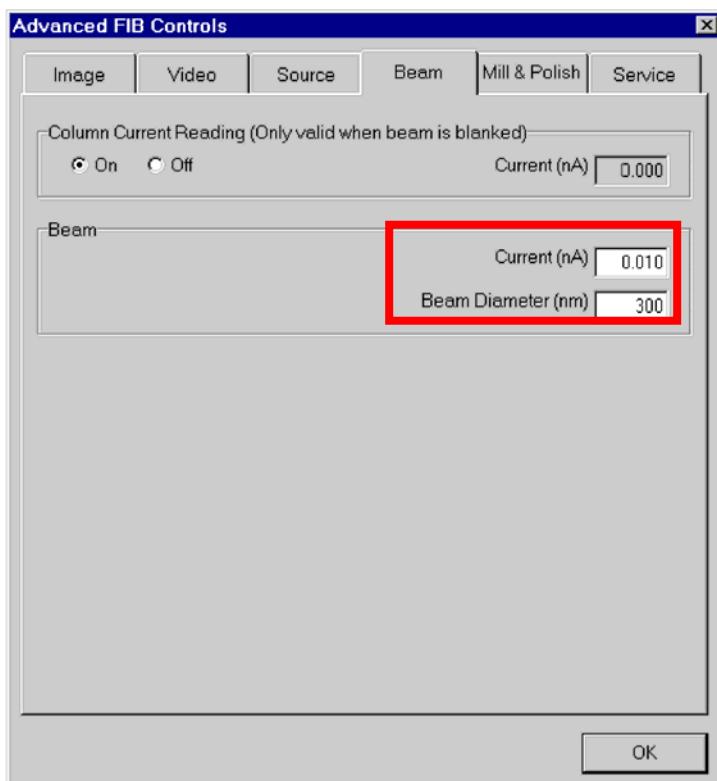
12. Set Shift (μm) X and Shift (μm) Y to 0.

Image

| | | | | | |
|---|--------|----------------------------|--------|---|-------|
| FOV (μm) | 100 | Shift (μm): X | 0 | Y | 0 |
| Focus (V) | 12502 | Steering: X | -0.550 | Y | 0.150 |
| Lens 1 (V) | 4940 | | | | |
| Stig #1 (V) | -0.031 | Steering: X | -0.020 | Y | 0.040 |
| Stig #2 (V) | 0.039 | Steering: X | -0.020 | Y | 0.040 |
| Calibration Offset (μm): X 6.00 Y 3.00 | | | | | |

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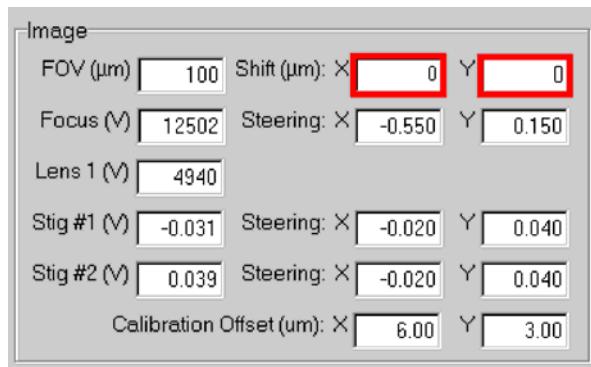
13. Check and adjust Focus, Stig #1 and Stig #2 wobbles, using the procedure detailed in the subsection **Tune the LMIG**.
14. In the Advanced FIB Controls box, input the Beam Current value in nanoAmps (multiply picoAmps by 0.001 to convert to nanoAmps). In addition, input the beam diameter. See the table below to determine the beam diameter value to use, or use the procedure above (see the **Beam – Advanced Controls** subsection) to measure the beam diameter.



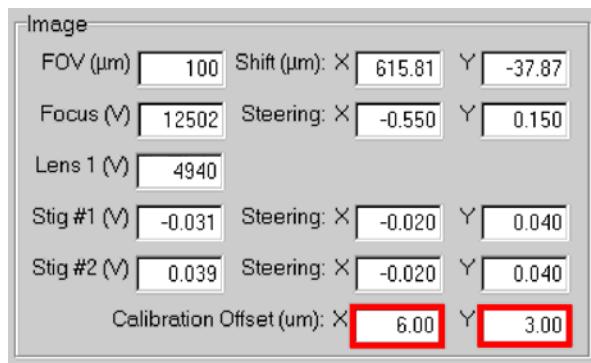
| Input this Lens 1 (V) value ... | ... to get this beam current | Beam diameter will then be: |
|------------------------------------|---------------------------------|--------------------------------|
| ~ 2700 V | ~ 5 picoAmps | < 100 nm |
| ~ 3200 V | ~ 10 picoAmps | < 100 nm |
| ~ 3700 V | ~ 20 picoAmps | < 110 nm |
| ~ 4180 V | ~ 50 picoAmps | < 125 nm |
| ~ 4430 V | ~ 100 picoAmps | < 200 nm |
| ~ 4610 V | ~ 200 picoAmps | < 250 nm |
| ~ 4780 V | ~ 500 picoAmps | < 300 nm |
| ~ 4870 V | ~ 1000 picoAmps | < 350 nm |
| ~ 4930 V | ~ 2000 picoAmps | < 500 nm |
| ~ 5010 V | ~ 5000 picoAmps | < 700 nm |

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15. Verify that Shift (μm) X and Shift (μm) Y values are at 0.



16. Adjust Calibration Offset (μm) X and Y values to align the ion-induced FIB image with the electron-induced SEM image.

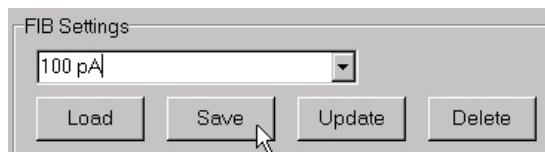


To see the SEM and FIB images simultaneously, use the RGB/MULTI button on the video monitor to put the monitor into RGB mode. The SEM image will be displayed on the monitor, and the FIB image will be displayed in the SmartSoft interface.

NOTE: The images will not align precisely – there will be differences in the rotation and possibly in the topography of the feature. The aim is to center the feature in the FIB image around the same point that the feature is centered on in the SEM image.

NOTE: Perform this Adjust Calibration Offset procedure using a 20 μm field of view.

17. In the FIB Settings window, type in the file name (usually the beam current, in picoAmps), then click Save.

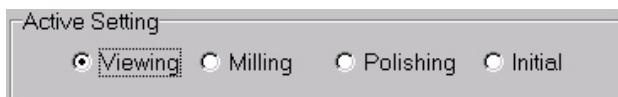


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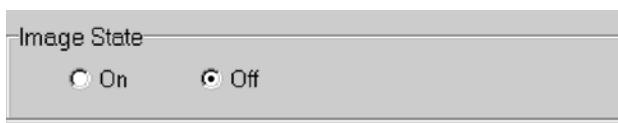
Measuring Beam Current

After creating new settings, you can confirm the beam current with the following procedure:

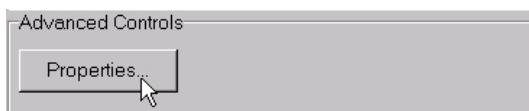
1. In the FIB Hardware tab's Active Settings area, choose the desired setting.



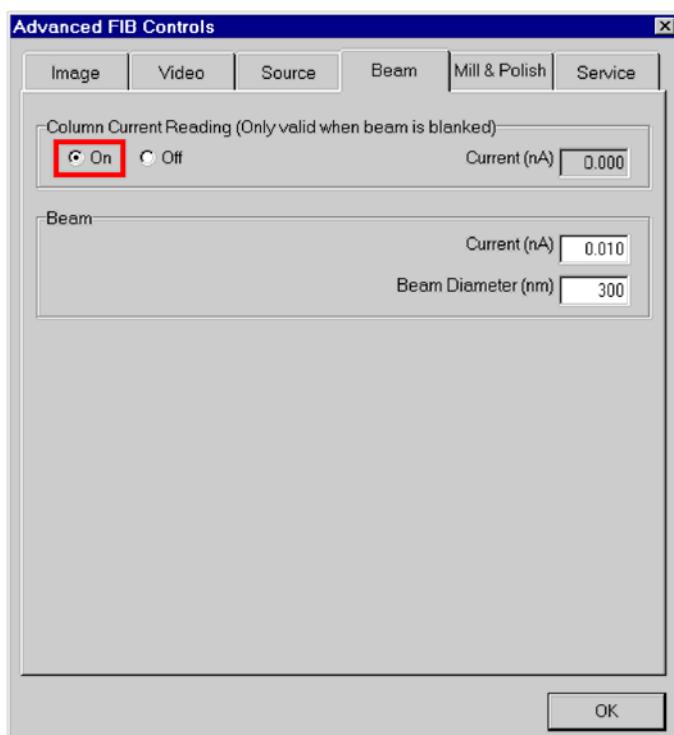
2. In the Image State area, click Off.



3. Click Properties in the Advanced Controls area.



4. Click on the Beam tab. Under Column Current Reading, click On.



The beam remains blanked as SmartSoft begins to acquire a reading from the Faraday Cup located in the ion gun column. (This is a different and separate Faraday Cup from the one located on the stage.) The beam current reading is displayed in the Current (nA) field.

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NOTE: The high gain and low gain modes for this measurement will “crossover” as the measured current gets too high or too low. This may occasionally result in a 0 nA reading if the current being measured is less than 0.04 nA. If this happens, increase the value of Lens 1 (V) to greater than 4500 V to momentarily get a reading; then gradually change the Lens 1 (V) value back to its desired setting. The electronics will automatically switch to the high gain mode as the current is reduced.

5. To turn off the beam current reading, click Off in the Column Current Reading area.

10. FIB Maintenance

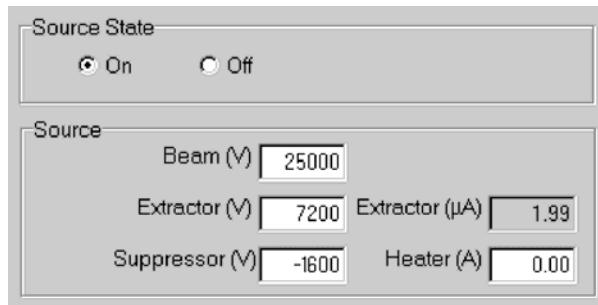
Reviving the Source

The FIB source needs to be revived periodically. If the FIB is used on a regular basis, it will be necessary to revive the source approximately twice a month.

This procedure should be performed when the Suppressor Voltage approaches –1600 V (its lower limit) in order to maintain an Extractor Current of 2 μ A.

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1. Click the FIB Hardware tab.
2. With the source running, increase the Heater (A) value to the lowest setting needed to revive the source. As you increase the Heater (A) value, watch the Extractor (μ A) reading until it begins to rise above 20 μ A. Increase the Heater (A) value as follows:
 - a. Increase Heater (A) value to 2.5 A for no longer than 40 seconds;
 - b. Increase Heater (A) value to 2.7 A for no longer than 40 seconds;
 - c. Increase Heater (A) value to 2.9 A for no longer than 40 seconds;
 - d. Increase Heater (A) value to 3.1 A for no longer than 20 seconds.



3. Once the Extractor (μ A) value is 20 μ A, wait 5 seconds, then set the Heater (A) value to 0.

NOTE: With the Suppressor (V) set at -1600 V, a properly conditioned source will operate as follows:

With Extractor (V) at 10,200 V, Extractor (μ A) should be >100 μ A

With Extractor (V) at 9,200 V, Extractor (μ A) should be > 80 μ A

With Extractor (V) at 8,200 V, Extractor (μ A) should be > 50 μ A

With Extractor (V) at 7,200 V, Extractor (μ A) should be > 20 μ A

4. With the Extractor (V) value at 7,200 V, adjust the Suppressor (V) so that the Extractor (μ A) value is 2 μ A.

NOTE: Increasing the Suppressor (V) value will reduce the Extractor (μ A) value, and decreasing the Suppressor (V) value will increase the Extractor (μ A) value.

NOTE: Increasing the Suppressor (V) value in 500 V steps will reduce the Extractor (μ A) value 10 to 20 μ A. Increasing the Suppressor (V) value in 25 V steps will reduce the Extractor (μ A) value 0.1 to 2 μ A.

The newly revived source will typically operate with a Suppressor (V) of 0 to +1000 V to maintain an Extractor (μ A) reading of 2 μ A.

B. Sputtering

This section describes the use of the sputtering ion gun, used to clean samples and perform depth profiles. The subsections in this section include:

- 1. Warm up the Ion Gun and Filament**
- 2. Sputter**
- 3. Shut Down the Ion Gun and Filament**
- 4. Ion Gun Operating Parameters**
- 5. Determining the Sputter Rate I**
- 6. Advanced Control**

Sputtering

This section describes how to establish sputtering “settings” and how to properly warm up, use, and shut down the sputtering ion gun.* The first three subsections present the typical operating procedures for sputtering. These involve tasks that the operator needs to know to prolong the lifetime of the ion gun filament and to operate the ion gun efficiently for best results.

The remainder of this section provides the *details* about ion gun operating parameters. This information is intended for the operator who *defines* “settings.” A complete set of ion gun operating parameters is called a “setting.” Settings are stored and recalled for later use in order to achieve specific sputter conditions (e.g., a certain sputter rate on a certain material at a particular ion energy).

1. Warm up the ion gun and filament

This procedure describes warming up the ion gun in preparation for sputtering. Using this warmup procedure will maximize the lifetime of the filament and prevent sudden, excessive outgassing when the ion gun is turned on.

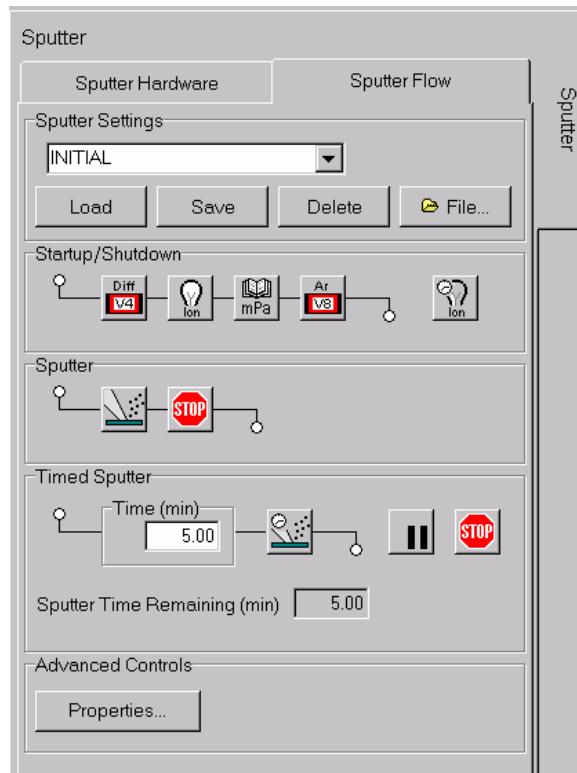
NOTE: After the ion gun has been warmed up, the Ion Gun State is Standby. In the Standby mode, voltages are set to minimal levels that do not adversely affect the sample but ensure proper flow of inert gas from the automated leak valve.

- a. Click the Ion session tab, then the sputter application tab.



* Refer to the **Depth Profiles** subsection of the AES section for details about setting up depth profile *data acquisition*.

Section 7: Ion

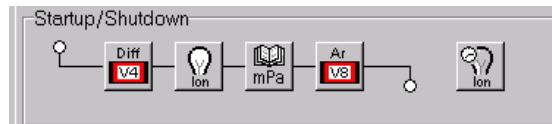


Click the Sputter Flow tab. In the Sputter Settings area, select the desired sputter setting, and click Load.

NOTE: Subsections later in this section provide details about settings.



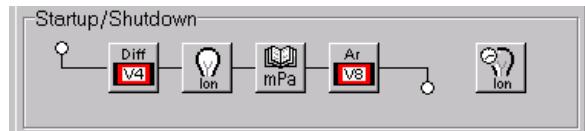
- b. In the Startup area, click the **Diff V4** button in the Startup/Shutdown area. This starts the differential pumping of the ion gun.



*NOTE: If the turbo pump is not already running, clicking the **Diff V4** button starts the turbo pump. This operation may take a few minutes as the turbo pump gets up to speed.*

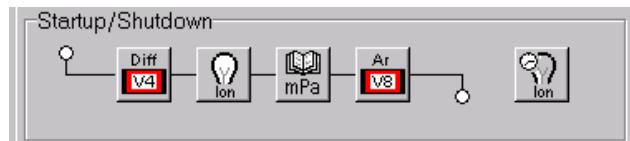
Section 7: Ion

Click the Ion Gun On  button in the Startup/Shutdown area. This changes the Ion Gun State to standby.

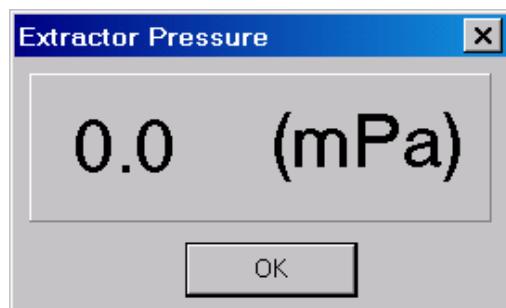


Once the  button is clicked, a warning message may appear to retract the EDS detector. Refer to the EDS section of this manual for the procedure to retract the detector.

The filament startup status box then appears, which shows the progress of the startup.



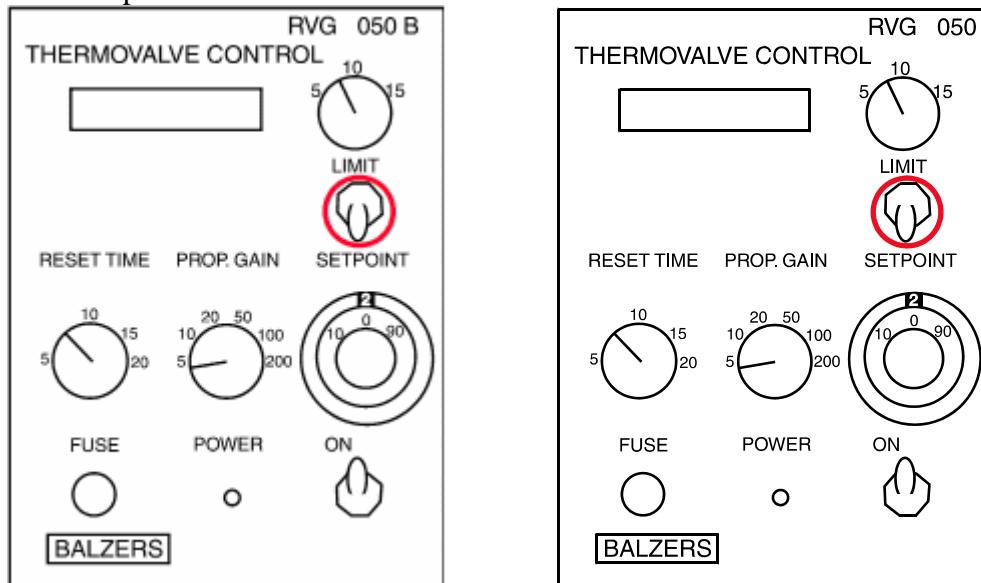
Click the Read Extractor Pressure  button in the Startup/Shutdown area. This will display the Extractor Pressure box. The Extractor Pressure is read periodically and updated in the box.



If the system is equipped with an auto leak valve, click the Open Argon Valve  button in the Startup/Shutdown area. This will open V8 and start the flow of gas into the source.

Section 7: Ion

If the system is equipped with a RVG 050B or RVG 050 Thermovalve Control, set the top switch on the Thermovalve Control to SETPOINT.



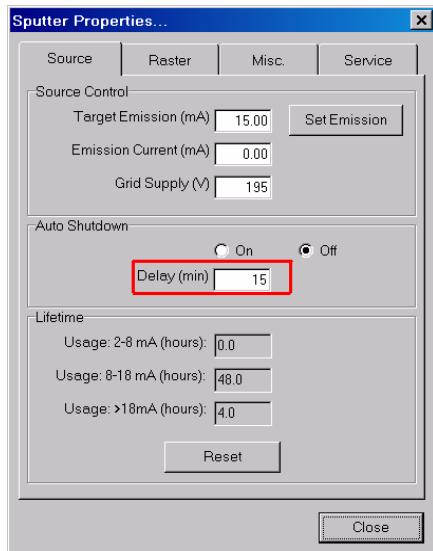
- c. When the reading in the Extractor Pressure window stabilizes, typically at about 15 mPa, click OK to close the Extractor Pressure window. The ion gun is now ready to operate at the parameters in the specified setting.

Section 7: Ion

Automated Shutdown Mode

Note: To extend the lifetime of the filament, the ion beam filament should be turned off when no more sputtering is planned for an hour or longer. Clicking the Timed

Ion Gun Shutdown  button in the Startup/Shutdown flow will place the ion gun in a mode that will automatically turn off the ion gun if there is a span of more than "Delay" time of inactivity. This delay time can be set in the Sputter Properties Source tab.



Note: This Timed Ion Gun Shutdown feature can be used with systems equipped with either the V8 gas flow regulation or the RVG 050B.

Units with a RVG 050 should not use this Timed Ion Gun Shutdown feature.

2. Sputter

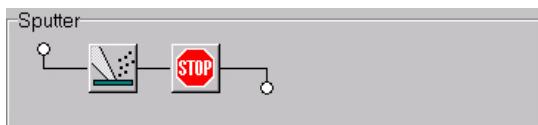
Sputtering can be done “automatically,” as part of a depth profile acquisition where sputtering alternates with data acquisition, or “manually,” where sputtering is done prior to an acquisition, but is not part of the acquisition. Both procedures are given.

Sputtering Automatically During Depth Profile Data Acquisition

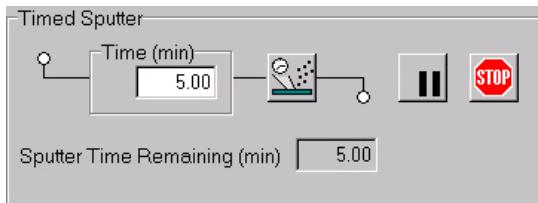
Set the acquisition parameters for the depth profile data acquisition in the Depth Profile application tab area (AES session tab). See the Depth Profile subsection of the AES section of this manual for more details. Parameters that can be adjusted in the Depth Profile area include sputter mode, sputter time and sputter interval. The ion gun will be started and stopped as needed for the sputtering requested in the acquisition menu.

Sputtering Manually

The operator may sputter the surface without acquiring data. To do this, use the Sputter or Timed Sputter areas in the Sputter Flow tab.



OR

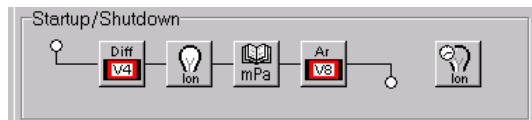


To change sputtering parameters during a timed sputter, click the Pause Timed Sputter button in the Timed Sputter area. Then, in the Sputter Hardware tab area, select a different setting or change individual parameters, as desired.

Section 7: Ion

3. Shut down the ion gun and filament

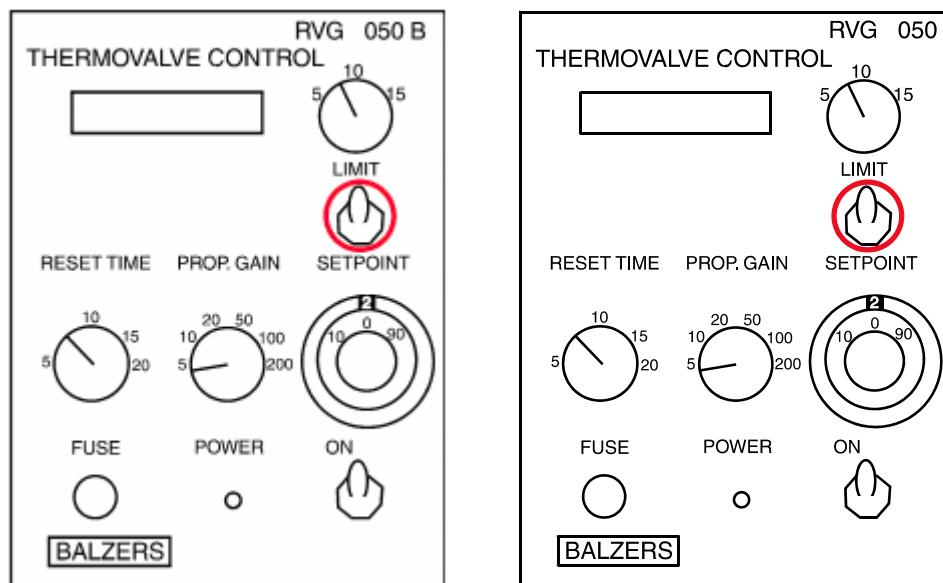
To extend the lifetime of the filament, the ion beam filament should be turned off when no more sputtering is planned for an hour or longer.



Manual shutdown

- If the system is equipped with an auto leak valve, click the Close Argon Valve button in the Startup/Shutdown area. This will close V8 and stop the flow of gas into the source.

If the system is equipped with a RVG 050B or RVG 050 Thermovalve Control, set the top switch on the Thermovalve Control to LIMIT.



- Click the button in the Startup/Shutdown flow to turn off the ion beam filament. Then, stop differential pumping of the chamber by clicking the .

4. Ion Gun Operating Parameters

This subsection describes defining, loading and saving ion gun operating parameters. The ion gun operating parameters include those displayed in the Sputter Hardware tab area, and those found in the Sputter Properties box.

Typically, the operator will simply select from the predefined settings to establish the ion gun operating parameters to be used for sputtering. A predefined setting is established by selecting the setting from the Settings option menu, releasing the mouse button so that setting name is displayed in the Sputter Hardware Settings field, and clicking the Load button. The operator may highlight and change any of the values to change the operating parameters. The values that are displayed when the Ion Gun State changes to Sputter or Blanked are the values used, and comprise the “setting” that dictates the ion gun’s operating parameters.—

A saved setting can be changed by entering one or more new parameter values and clicking the Save button. A new setting can be saved by typing a new setting name in the Settings field and clicking the Save button.

Sputter Hardware Settings

A saved setting is selected, or “loaded,” by clicking the Settings option menu, dragging the mouse to highlight the desired setting, and clicking the Load button. A saved setting can also be loaded by typing the setting name in the Settings field and clicking the Load button.



In Sputter Hardware Settings, either select an existing setting and click Load, or type the name of the new setting to be created and saved in SmartSoft and click Save. Clicking the Delete button removes the currently displayed setting from the Settings list.

Ion Gun State

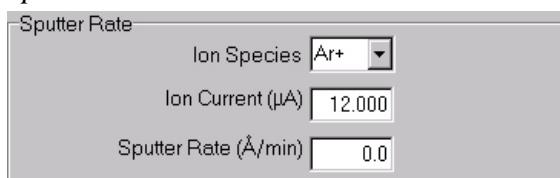
The buttons in the Ion Gun State area show the current mode of the ion gun. The state is changed automatically when the operator uses the flows on the Sputter tab, but can be changed here “manually” by clicking one of the buttons.



Section 7: Ion

For example, after the startup flow has been completed, the Ion Gun State will be Standby, indicating that the gun is ready for sputtering. Clicking Sputter in Ion Gun State starts sputtering.

Sputter Rate

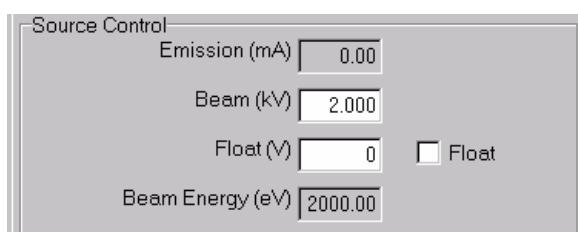


The Sputter Rate panel contains three input fields:

- Ion Species: A dropdown menu set to Ar+.
- Ion Current (μA): A text input field containing 12.000.
- Sputter Rate (Å/min): A text input field containing 0.0.

In the Sputter Rate area, select Ar (or the name of the gas being used in the ion gun) from the option menu. In Ion Current, type the current incident upon a positively biased sample as measured using the Keithley picoammeter. In Sputter Rate, enter the experimentally determined sputter rate. (See **Determining Sputter Rates** later in this section.) These fields are used for record-keeping only; they do not affect the system hardware in any way.

Source Control



The Source Control panel contains four input fields:

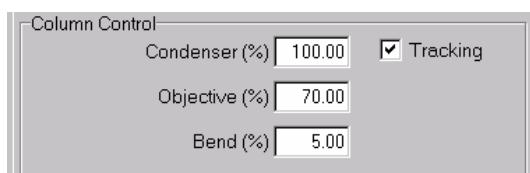
- Emission (mA): A text input field containing 0.00.
- Beam (kV): A text input field containing 2.000.
- Float (V): A text input field containing 0, with a checkbox labeled "Float" next to it.
- Beam Energy (eV): A text input field containing 2000.00.

In the Source Control area, the measured emission current and the sample beam energy are displayed. The sample beam energy is the difference between the Beam voltage and the Float voltage. Type in the desired values for Beam and Float. The float voltage can be enabled/disabled using the Float check box.

Beam voltages up to 5 kV may be specified. Typically, higher beam voltages can result in higher beam densities and, therefore, higher sputter rates. Note also that atomic intermixing in the sample tends to be more severe at the higher beam voltages, resulting in a reduced depth or interfacial resolution. A float voltage, up to 1000 V, is used to achieve high currents and small beam size for low sample beam energy.

NOTE: A change in the Beam parameter value does not change the raster size; the software adjusts the deflection voltages to maintain the specified raster size when the Beam value is changed.

Column Control



The Column Control panel contains three input fields:

- Condenser (%): A text input field containing 100.00, with a checked checkbox labeled "Tracking" next to it.
- Objective (%): A text input field containing 70.00.
- Bend (%): A text input field containing 5.00.

Section 7: Ion

The condenser lens is used to vary the ion current. The objective lens is used to focus the ion beam. In the Column Control area, check Tracking so the Condenser and Objective values adjust as the beam voltage is adjusted. When Tracking is checked, the parameter values are shown as percentages of the beam voltage.

When Tracking is not checked, the condenser and objective lens voltages are displayed. In this mode, these values will not automatically be adjusted if the beam voltage is changed. The operator can change the Column Control parameters by typing values and pressing Enter or clicking in the field and pressing the arrow keys ($\uparrow \downarrow$) on the keyboard. Bend is typically set to 5% and should not be changed except by a service technician who has been trained on the system.

Raster Control

| | |
|---------------|------|
| X Size (mm) | 5.0 |
| Y Size (mm) | 5.0 |
| X Offset (mm) | 0.00 |
| Y Offset (mm) | 0.00 |

In the Raster Control area, specify the raster beam size in millimeters in the x and y axes. Raster sizes of 1 to 5 mm are typical. A larger raster size sputters a larger area on the sample and results in a lower sputter rate. The X Offset and Y Offset parameters, which specify the beam offset in millimeters, are used to position the ion raster pattern to the desired location—which is coincident with the electron beam (SEM image) when the sample is at the elastic peak position.

5. Determining the Sputter Rate

Sputter rate varies according to the sample material(s) and the ion gun operating parameters. Sputtering can be experimentally determined in one of the following ways:

- Eroding a crater in the material of interest over a measured period time, and measuring the crater depth with a surface profilometer;
- Eroding a crater in the material of interest that has an interface at some known depth, and measuring the time to reach that depth.

The following is one procedure for determining sputter rate.

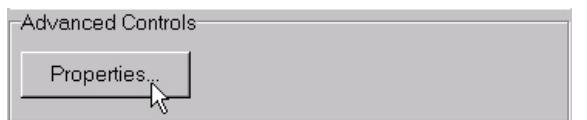
1. In the Sputter Hardware tab, be sure that Tracking option in the Column Control area is selected. This feature allows the objective and condenser lens voltages parameters to scale automatically with changes in the beam voltage, which allows the ion beam to remain in focus.
2. Define the Source Control, Column Control, and Raster Control parameters to match the acquisition scenario for which the sputter rates need to be calculated (described in **Operating Parameters**).
3. Acquire a depth profile through a layer of a sample that has an accurately known thickness. (A sample of tantalum oxide or silicon dioxide is recommended because of the stability of the materials. A thin film of material typically used in your application may also be used.)
4. Use the thickness of the layer and the time to sputter through the layer to compute the sputter rate (in angstroms, nanometers, or microns per minute).
5. Define and save a setting in the Sputter Hardware tab based on the demonstration so that the parameters may be used for sputtering in the future. In this way, maximum advantage is made of the hardware's repeatability, and depth profile data can be compared and understood with reliability. When defining the setting, select a descriptive name such as 5kV1uA or 5 kV10nm.

Assuming that new parameters have not been entered since the depth profile just completed, those profile parameters (which should be currently displayed) are saved under the new setting name.

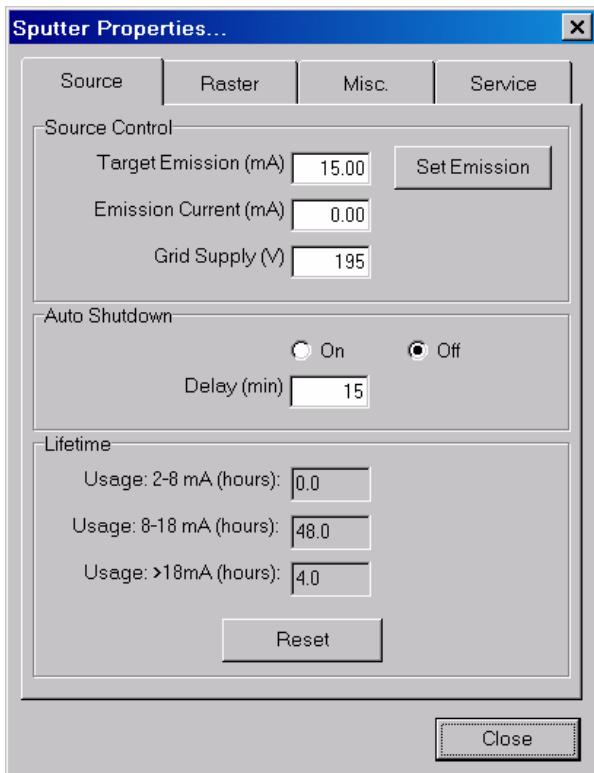
Section 7: Ion

6. Advanced Controls

The Properties... button opens the Sputter Properties box, which has four tabs: Source, Raster, Misc., and Service.



Source



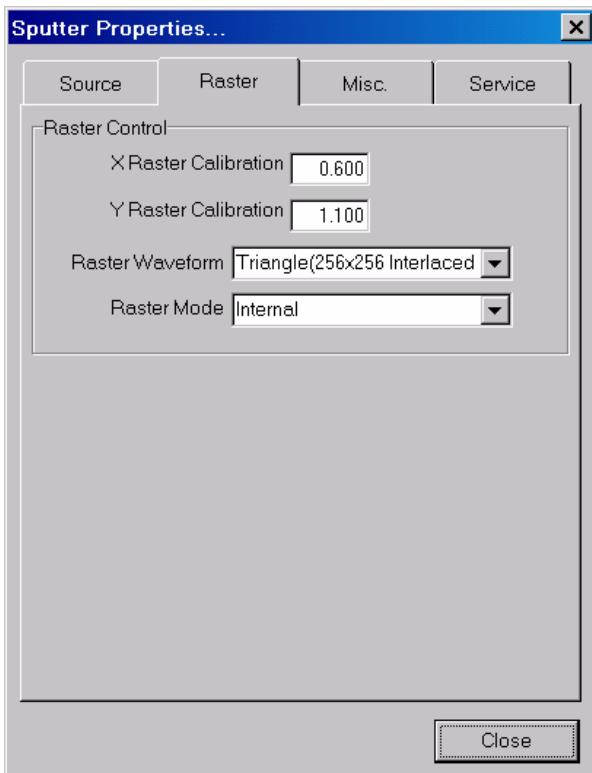
The value entered by the operator for Target Emission Current (in milliamperes) is used by the startup routine and determines the operating emission current. The emission current is typically set to 15 mA. (Values up to 25 mA may be used, but will reduce the lifetime of the ion gun filament.) In the Grid Supply field, specify the voltage that is expected to achieve the maximum ion beam current (typically in the range 140 to 190 V). Emission current can be set manually using this box. This is typically done when burning in a new filament.

The automatic shutdown feature can be turned on or off from this box, and the length of time before shutdown can also be changed here. When this is set to On, the ion gun will be shutdown after the ion gun has remained in Standby for the specified time. Setting Auto Shutdown to On in this menu also presses (enables) the Auto Shutdown button in the Shutdown flow. The amount entered in this Delay field determines the length of the delay before shutdown occurs.

Section 7: Ion

Usage displays the time, in hours that the ion gun state has been operating (including warming in Standby mode) *and* the emission current has been greater than 5.5 mA. When a new ionizer assembly is installed in the ion gun, the Reset button in the box should be pressed to reset the timer to 0.

Raster



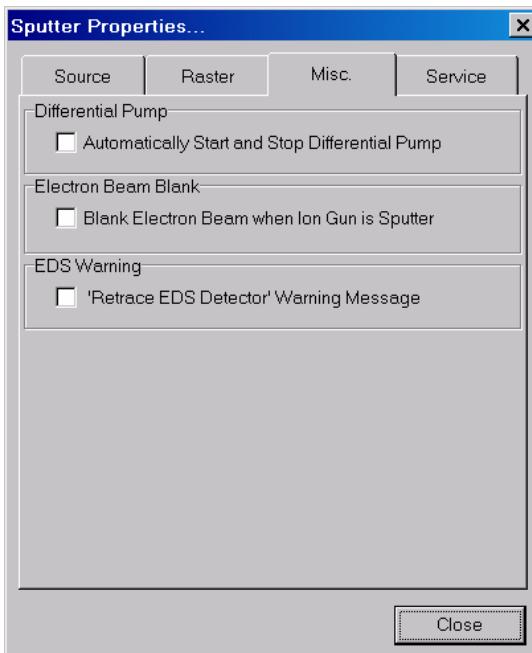
The Calibration parameters should not be changed unless maintenance is performed on the ion gun control's deflection control circuits. The values compensate for the difference between this system's flange-to-target distance and that of the system on which the predefined settings were defined, so that the size of the raster area is correct. Calibration is performed by a PHI Customer Service Engineer.

Raster Mode may be set to Internal, External, or Off. When Internal (default) is selected, the ion beam sputters a sample while moving in a certain pattern across the sample's surface. That pattern is displayed in the Raster Waveform field; a triangle interlaced pattern (256 × 256) is the default along with the options of sawtooth(256x256) and triangle(256x256).

The External selection allows for ion-induced imaging. Off means that the ion beam remains stationary during sputtering (no rastering of the beam occurs).

Section 7: Ion

Misc.



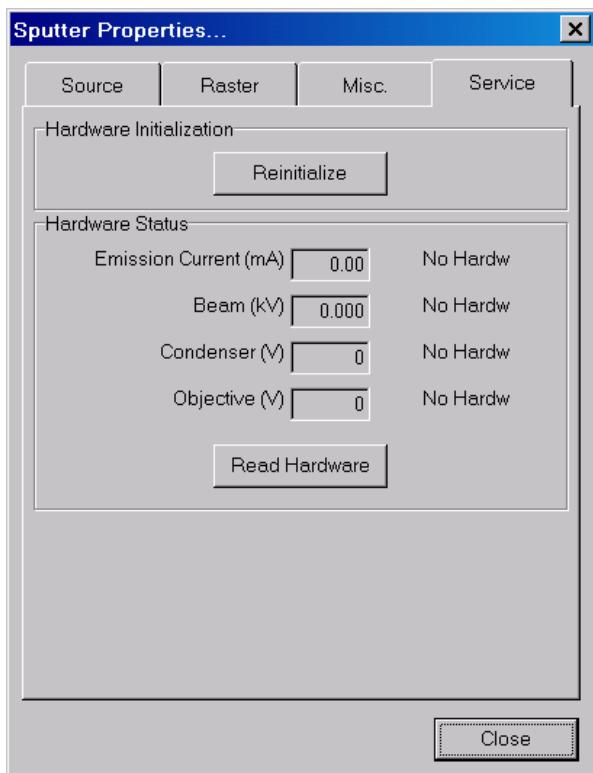
When “Automatically Start and Stop Differential Pump” is checked, differential pumping of the ion gun is being performed any time the ion gun is set to Sputter, Blank, or Standby.

Electron Beam Blank is used to automatically blank the electron beam when the ion gun is in a specific mode. Typically, the electron beam is not blanked during “Sputter”.

When ‘Retract EDS ...’ is checked, an EDS warning message is displayed when the ion gun is set to Standby for warming. Systems that do not have the EDS option should not have this field checked. This field should be checked on systems that have the EDS option, so the operator is reminded to retract the EDS detector to prolong its lifetime.

Section 7: Ion

Service



The Service box is used by service personnel to verify the operation of the ion gun.

Section 7: Ion

Section 8:

EDS (Option)

This section describes the procedure for performing energy-dispersive x-ray spectroscopy (EDS).* Also included is information on retracting the EDS detector and calibrating the EDS system.

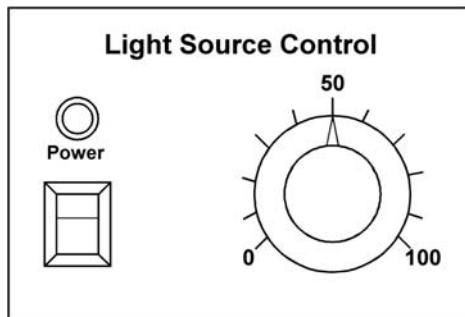
Perform EDS

Most of the information on using the Oxford Scientific Instruments system to perform EDS is found in the Oxford multi-media tool, *The Principles and Practice of Microanalysis*, or in the Oxford printed manuals. The procedures here detail the interaction between the Oxford system and the *SMART-Tool*.

The EDS detector is mounted on a motorized slide. The operator controls when to insert the detector into the analytical chamber, and when to retract it.

*NOTE: For certain procedures, such as system bake, the EDS detector **must** be retracted. See “When to Retract the Detector” later in this section for more information.*

1. Before beginning an EDS analysis and inserting the detector, make sure that:
 - a. The microscope light source within the analytical chamber is turned off. The light is controlled by the Light Source Control, found on the front of the electronics console.



- b. The sputtering ion gun is turned off (refer to the “Sputtering” subsection in Section **Ion** of this manual).

* The EDS subsystem is an option on the SMART system.

Section 8: EDS

- c. The FIB liquid metal ion gun is turned off (refer to Section **Ion** of this manual).
- d. Beam voltage and beam current are set to values that optimize the EDS collection (refer to Section **Wafer/SEM** of this manual for procedures to set these parameters). Perform EDS at a lower beam current than AES to avoid excessive dead time. Recommended beam currents are 0.5 or 1 nA. Set the beam voltage according to the type of analysis to be performed. For example, for light element detection, use a lower beam voltage, such as 5 keV. If you wish to detect a specific element, use a voltage 2 to 2.5 times the energy of the x-ray you want to excite (e.g., titanium's K α line has an energy of 4.508 keV, so using a beam voltage of 10 keV would work well).
- e. The liquid nitrogen (LN₂) auto-fill controller is used to fill the LN₂ dewar before the analysis. This prevents the analysis from being disturbed by a fill. The controller is located on the front of the electronics console. Press the “Fill Start/Stop” button, seen below:



The unit will fill until the Level 2 setpoint is reached, then shut off. Wait for the fill to finish before proceeding.

2. To start the EDS software, check the lower right corner of the *SMART-Tool* desktop for a “TL” icon:



If the “TL” is there, proceed to Step 3. If not, double-click the “EDX Init” icon on the desktop:



This will launch Isis Translink, and the “TL” will appear.

Section 8: EDS

NOTE: If the “EDX Init” icon is not on the desktop, go to the “Start” button in the lower left corner of the desktop, then to “Programs,” then “Startup,” then click “ISIS Startup.” This will launch Translink.

3. Double-click the “Link Isis” icon to open the Oxford Link Isis software, used for EDS analysis:

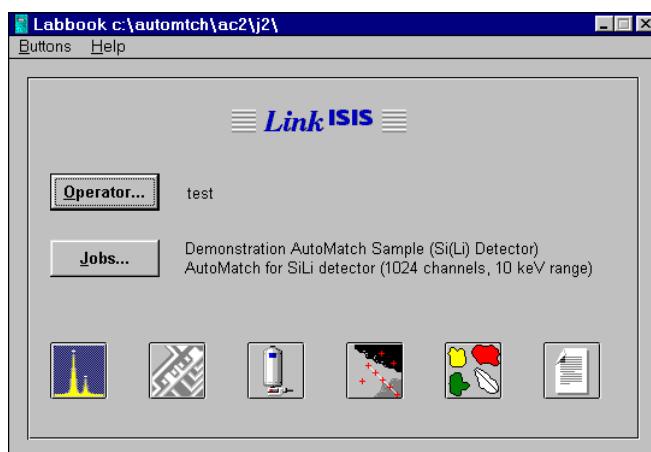


NOTE: If the “Link Isis” icon is not on the desktop, go to the “Start” button in the lower left corner of the desktop, then to “Programs,” then “Oxford Instruments,” then click “Link Isis.” This will launch the Isis software.

4. On the Welcome page that appears, select your user name (“test” in the case of the screen below) and click the Labbook icon.

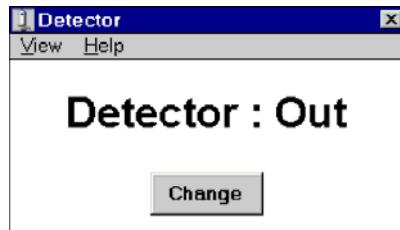


5. The Labbook screen appears.



Section 8: EDS

In addition, the Detector position box appears. This box will always open when Labbook is started.



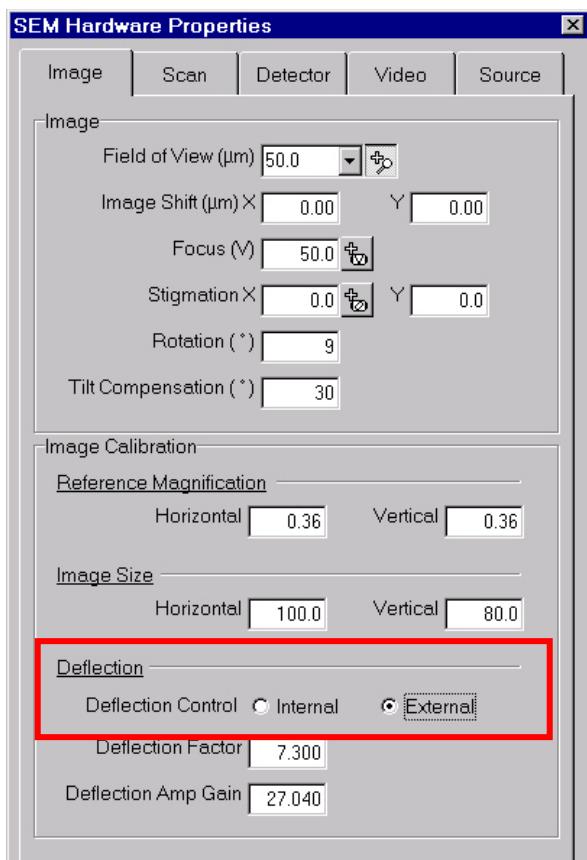
Clicking the "Change" button will open a box with "In" and "Out" buttons. Use this box to indicate "In" to insert the detector into the chamber. Wait for the detector to insert fully before proceeding.

NOTE: If the detector starts to go into the chamber, then retracts, make sure the light source, sputtering ion gun and FIB ion gun are off, and that the electron gun beam current is not too high. Any of these conditions will cause the EDS detector to overload and automatically retract.

6. In the SEM session of SmartSoft, click the SEM Hardware tab. Then click the Properties button under Advanced Control. The SEM Hardware Properties box will open.

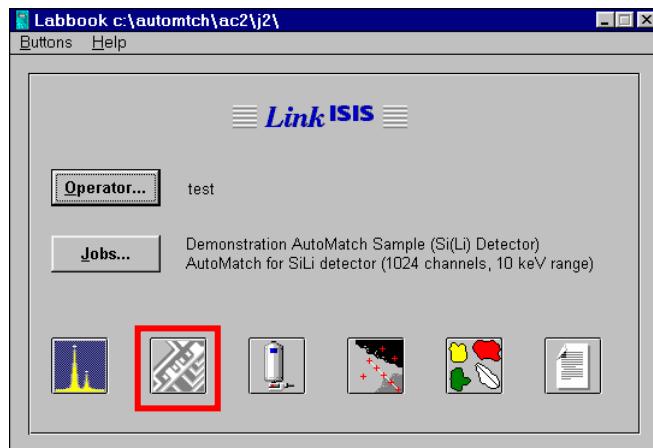


Section 8: EDS



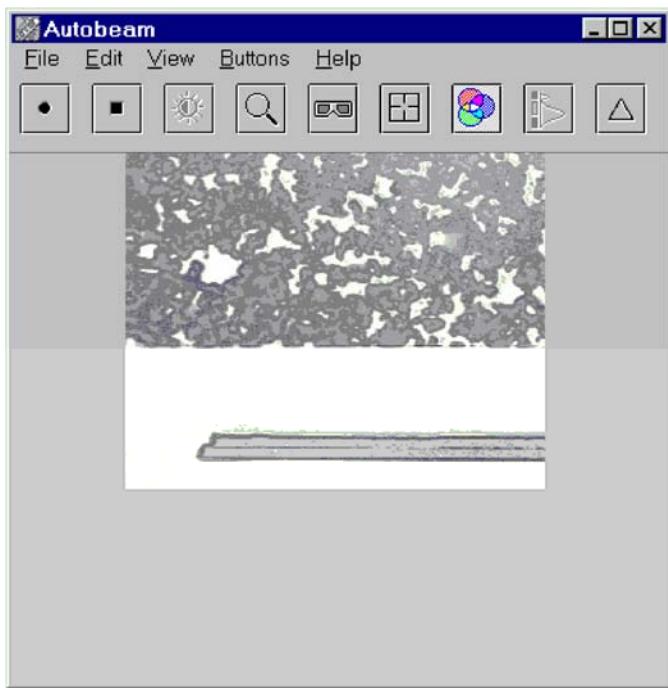
Click the Image tab; under Deflection, change Deflection Control from Internal to External. This gives control of the scan to the EDS system.

7. Return to the Labbook screen and click the imaging button, second from the left:



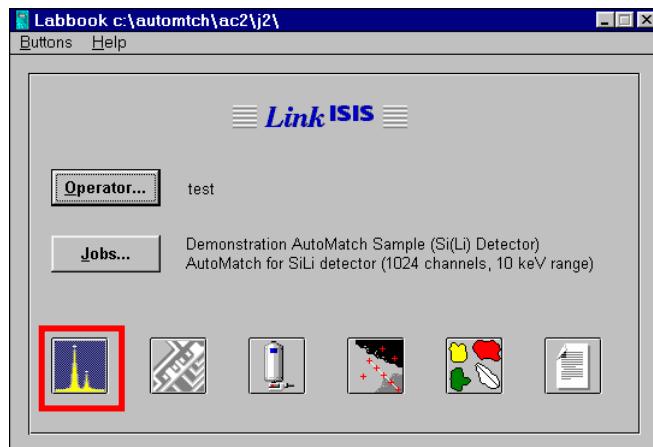
Section 8: EDS

The Autobeam screen will appear:



To capture a SEM image using Autobeam, click the button. To stop the image acquisition, click the button.

- Once you have acquired an image and stopped the acquisition, click the point in the image where you want to perform EDS. Then return to Labbook and click the EDS button to acquire a spectrum:



For further details on EDS, refer to the Oxford multi-media tool, *The Principles and Practice of Microanalysis*, or to the Oxford printed manuals.

Section 8: EDS

NOTE: Running EDS and AES simultaneously is not recommended.

NOTE: When finished with EDS analysis, remember to return to the SEM Hardware Properties box to return Deflection Control to “Internal.”

When to Retract the Detector

The EDS detector **must** be retracted:

- Before and during a system bake;
- During sputtering with the ion gun;
- While the FIB is in use;
- When venting or pumping the main chamber.

In addition, cooling water must be flowing to the detector during a system bake, and LN₂ must be available. Hardware interlocks prevent the bake from proceeding if the cooling water is not flowing to the detector, or if the detector has not been retracted.

(For more information on the bake procedure, refer to the *SMART-Tool Bakeout Manual*, PN 647398, available from PHI Customer Service.)

EDS Calibration

A Geller™ sample is provided with the EDS subsystem for calibration. It includes 37 elements and/or compounds. The sample is located near the Faraday Cup within the chamber, and, like the Faraday Cup, remains in the chamber.



WARNING: Do not attempt to move to the Geller sample if the multi-sample platen is on the stage. A difference in heights between the platen and sample could result in damage to the chamber or analytical probes. Remove the multi-sample platen before navigating to the Geller sample.

To move to the Geller sample, use the predefined position list (refer to Section **Wafer/SEM**, subsection Open a Position List File, of this manual for information on accessing position list files). See below for a map of the standard Geller sample included with the EDS subsystem.

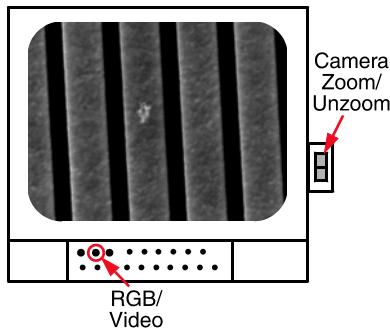
If there is no predefined position list, use the following procedure:

1. Use the video camera for low-magnification viewing.

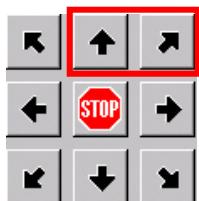
Section 8: EDS

*NOTE: Use of the video camera requires turning on the microscope light source to illuminate the analytical chamber. Make sure the EDS detector is **retracted** before turning on the light source. The Light Source Control is found on the front of the electronics console.*

On the video monitor, press the RGB MULTI button to toggle between a SEM image and a video camera image.

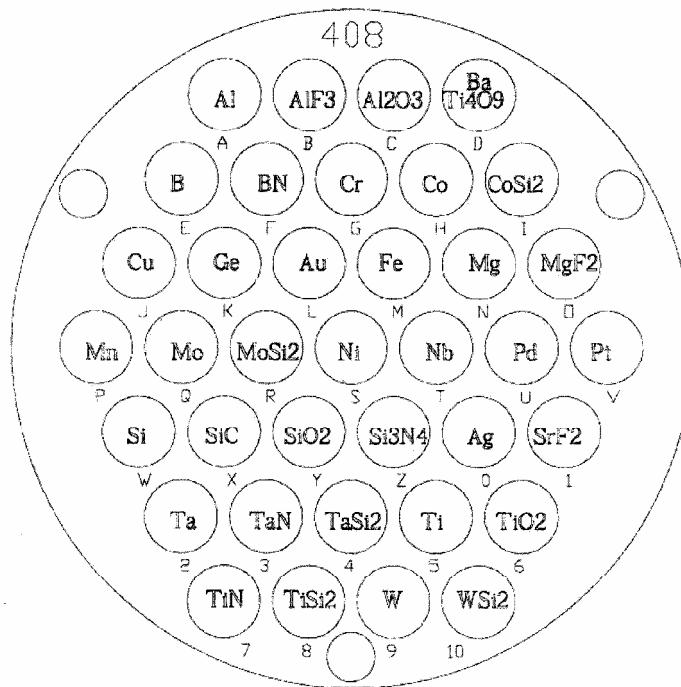


2. In SmartSoft, click the Wafer session tab.
3. Click the Stage application tab. Under Stage Control, click the button to bring the Faraday Cup into view.
4. Use the arrow keys in the Stage Control area to move to the Geller sample, as indicated below:



Section 8: EDS

The Geller sample, which is immediately adjacent to the Faraday Cup, will begin to appear in the lower left corner of the video monitor.



Use the map above as a guide to move to the different elements/compounds on the sample. The map is of the standard Geller sample shipped with the EDS subsystem.

5. To perform EDS calibration, refer to the Oxford multi-media tool, *The Principles and Practice of Microanalysis*, or to the printed Oxford manuals. Be sure to turn off the microscope light source before inserting the EDS detector.

NOTE: The Geller sample is provided for calibration of the EDS system only. It is not recommended for Auger calibration.

*NOTE: Sputtering of the Geller sample is **not** recommended, since the sputtered material can re-deposit onto other areas of the sample, causing contamination.*

Section 8: EDS

Section 9: AutoTool

The AutoTool feature in SmartSoft allows for routine or lengthy data acquisition without an operator present.

AutoTool uses the position list to move to each defect and perform the specified analysis. Data files are automatically named and stored for later review.

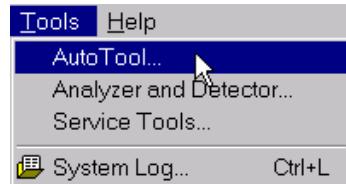
NOTE: AutoTool can be used for thin film characterization by creating a position list of various positions on a wafer, then performing a depth profile at each location.

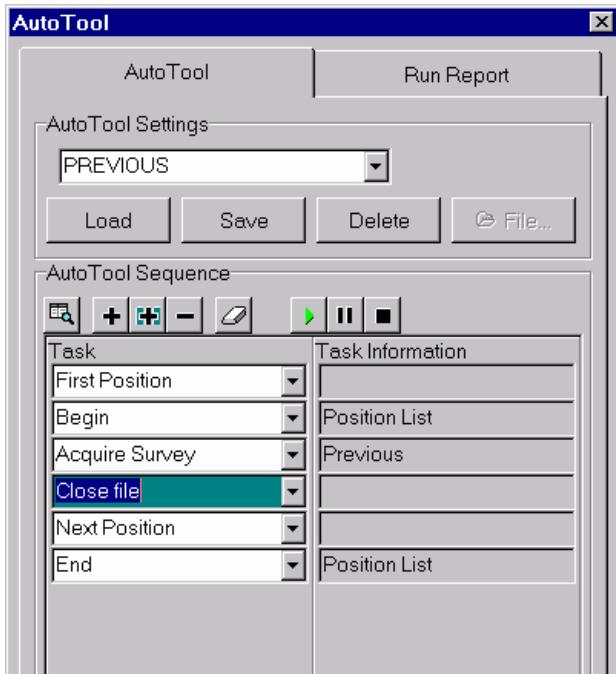
1. Before performing the procedures in this section, perform the other applicable procedures presented earlier. This section's procedures assume that electron gun optics have been optimized, as described in the **Wafer/SEM** section. The desired position list should be opened in the Wafer session.

In addition, perform the procedures in the **AES** section to indicate where data files should be saved and to define analysis areas or points.

Parameters for the type of analysis desired should be selected as well. Refer to the **AES** section for details.

2. Click Tools in the main toolbar, then click AutoTool to open the AutoTool box.





3. Use the AutoTool Sequence area to establish a sequence for analysis. Available commands include:

| | |
|-------------------------------|---|
| First Position | Moves the stage to the first defect listed in the position list. |
| Next Position | Moves the stage to the next defect listed in the position list. |
| Begin | Designates the beginning of a loop. |
| End | Designates the end of a loop. |
| Close File | Closes the last data file acquired. |
| Auto Video | Performs the Auto Video function, which automatically adjusts brightness and contrast. |
| Photo | Captures and stores a SEM photo. |
| Acquire Survey, Multiplex ... | Acquires data and generates a data file. Options include survey, multiplex, profile, line and map. |
| More Survey, Multiplex ... | Doubles the amount of data in the existing data file. Options include survey, multiplex, profile, line and map. |
| Print | Prints the data file or image. |
| Timed Sputter | Performs sputtering of the sample. |

Section 9: AutoTool

Use the following sequence to analyze all defects on a position list:

- a. First Position
- b. Begin
- c. Acquire Survey (or other type of desired data file)
- d. Print
- e. Close File
- f. Next Position
- g. End

NOTE: Close File is used to keep the AES output area from displaying an excessive number of data files.

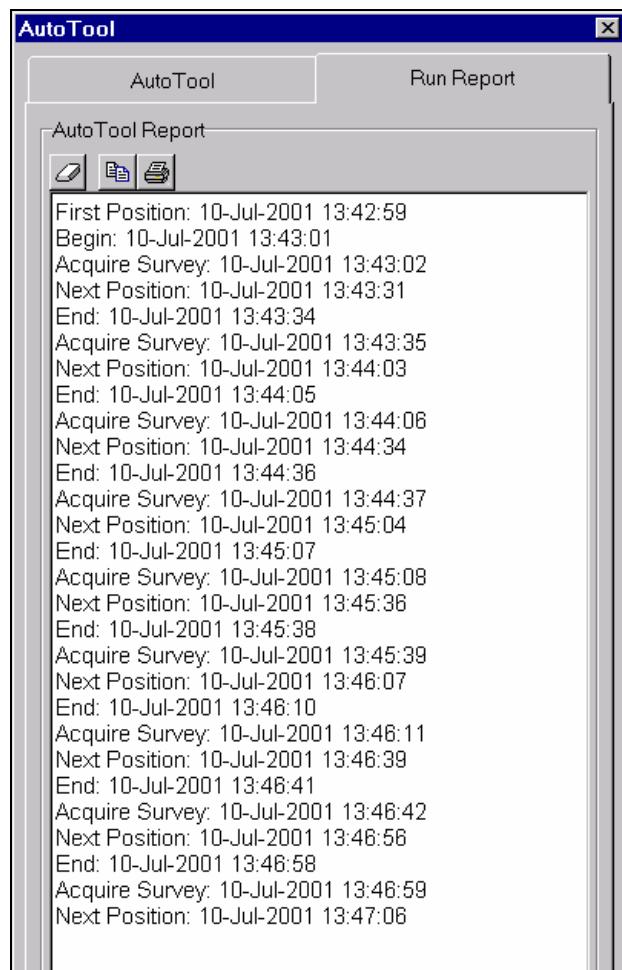
Use the  buttons to edit the sequence, if needed. The buttons can be used to generate a full view of the table, to add, insert or delete commands, or to delete all commands.

4. Click the  button in the AutoTool Sequence toolbar to run the automated analysis. The sequence will begin with the command that is highlighted in the table. This allows the entire sequence to be run, or only a portion of the sequence.

To pause the sequence, click the  button. To stop the sequence, click the  button.

5. Click the Run Report tab in the AutoTool box to view a report generated during automated acquisition.

Section 9: AutoTool



Appendix A: AES Element Table

Physical Electronics' (PHI's) SmartSoft software contains a database called "AES Transitions." The original settings of the relevant fields of this database are presented here for the user's reference. The computer enters values from this database into the appropriate fields of a menu when the user enters (in the Analysis Elements Table) one of the names of the elemental transitions from this database. The contents of the columns are defined as follows:

- **Name**—abbreviation representing the elemental transition. The asterisk (*) indicates the transition the computer enters (e.g., Au3) when the user types only the element's abbreviation (e.g., Au).
- **At.#**—atomic number of the elemental transition (not included in the database).
- **N(E) Peak**—The energy of the element's identifying peak in an undifferentiated spectrum.
- **dN(E) Peak**—The energy of the element's identifying peak in a differentiated spectrum (not included in the database).
- **S_x3/5/10**—The approximate elemental sensitivity factors, relative to that used to obtain the silver spectrum, when the electron voltage is at 3 (top value), 5 (middle value), and 10 kV (bottom value).
- **Acquisition: Lower/Upper**—The energies entered into the Lower Limit (left value) and Upper Limit (right value) menu fields for the *Acquisition* Window parameter in the Analysis Elements Table.
- **Analysis: Lower/Upper**—The energies entered into the Lower Limit (left value) and Upper Limit (right value) menu fields for the *Analysis* Window parameter in the Analysis Elements Table.
- **B1 and B2**—B1 and B2 are energies that are used in background calculations during 2- and 3-point acquisitions of lines, maps, and profiles. B2 is a value greater than the peak energy. It is entered in the Background 2 field for 2-point acquisitions and 3-point acquisitions. B1 is a value less than the peak energy. It is entered in the Background 1 field for 3-point acquisitions.
- **Test Width**—The value in the Test Width column is the width of the acquisition window during 2- and 3-point Test Acquire acquisitions. The midpoint of the acquisition window is the N(E) Peak energy.
- **Swps**—The value in this column is entered in the Number of Sweeps field in the Analysis Elements Table.

Appendix A: AES Element Table

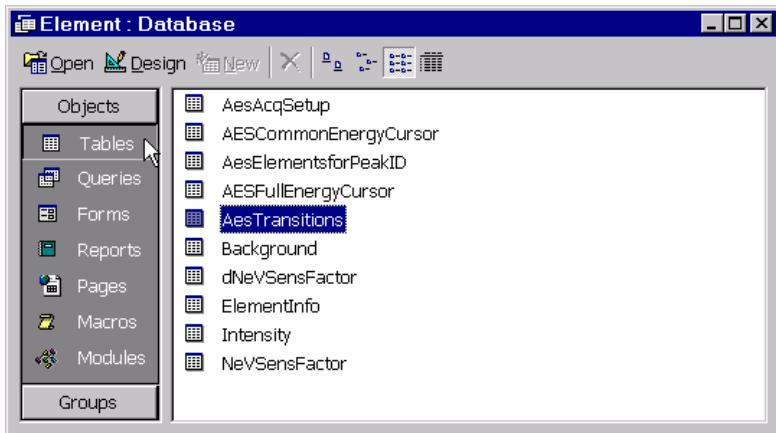
Editing the SmartSoft Database

The SmartSoft database can be edited using Microsoft Access.TM Below are guidelines for editing the database. For more complete information on using Access, refer to the Access Help files or the written documentation.

NOTE: Prior to editing the database, make a copy of the database so that the original values are saved.

NOTE: The element database in SmartSoft is separate and distinct from the element database in MultiPak. Changes to the SmartSoft database will not affect the MultiPak database. When making changes, both databases must be edited.

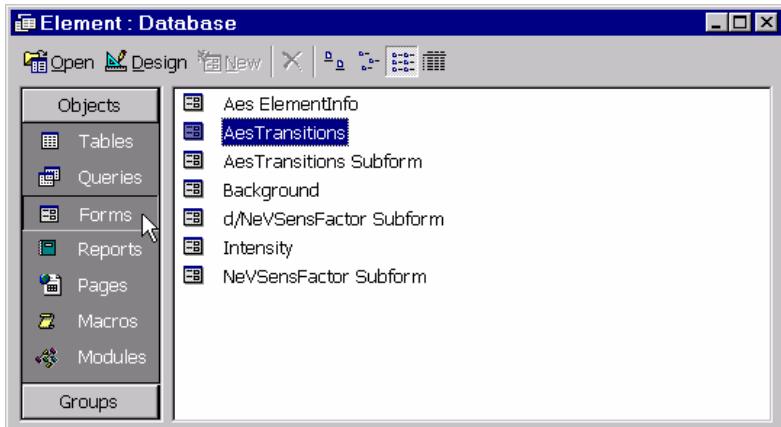
1. Exit SmartSoft.
2. Open Access by clicking Start in the desktop toolbar, then Programs, then Microsoft Access.
3. Open the database “element.mdb,” which is found in the C:\SmartSoft\Configuration folder.
4. To edit the AES Transitions table, click the Tables button, then double-click AES Transitions.



This opens the table for editing. Select the desired transition and edit the fields as needed.

5. To create a new setting, such as a new sensitivity factor for a transition, click the Forms button, then double-click AES Transitions.

Appendix A: AES Element Table



This opens a forms box that allows new table entries to be created.

The screenshot shows the 'AES Transitions' form dialog box. It contains several input fields and dropdown menus:

- Transition** section:
 - Transition Name:
 - d/NeV:
 - Atomic No:
 - eV:
- Base Energies** section:
 - Low:
 - High:
- Region** section:

| | Lower | Upper |
|-------------------------|--------------------------------|--------------------------------|
| Narrow Acquisition (eV) | <input type="text"/> | <input type="text"/> |
| Wide Acquisition (eV) | <input type="text" value="0"/> | <input type="text" value="0"/> |
| Analysis (eV) | <input type="text" value="0"/> | <input type="text" value="0"/> |
- Peak ID** section:
 - Select:
 - Label:
- Acquisition** section:
 - No Of Sweeps:
 - No Of Diff Points:
 - eV/Step:
 - Test Acq. Width:
 - Default Acq:
- Spectrum Background/Intensity** section:
 - Background:
 - Intensity:
- Sensitivity Factors** section:

| d/NeV | NeV | | | | | | | | | | | | | | |
|--|--------------------|--------------------|---|---|---|---|----|---|---|--|---|--------------|--------------------|--|--|
| <table border="1"> <thead> <tr> <th>Beam Voltage</th> <th>Sensitivity Factor</th> </tr> </thead> <tbody> <tr> <td>3</td> <td>0</td> </tr> <tr> <td>5</td> <td>0</td> </tr> <tr> <td>10</td> <td>1</td> </tr> <tr> <td>*</td> <td></td> </tr> </tbody> </table> | Beam Voltage | Sensitivity Factor | 3 | 0 | 5 | 0 | 10 | 1 | * | | <table border="1"> <thead> <tr> <th>Beam Voltage</th> <th>Sensitivity Factor</th> </tr> </thead> <tbody> <tr> <td></td> <td></td> </tr> </tbody> </table> | Beam Voltage | Sensitivity Factor | | |
| Beam Voltage | Sensitivity Factor | | | | | | | | | | | | | | |
| 3 | 0 | | | | | | | | | | | | | | |
| 5 | 0 | | | | | | | | | | | | | | |
| 10 | 1 | | | | | | | | | | | | | | |
| * | | | | | | | | | | | | | | | |
| Beam Voltage | Sensitivity Factor | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |

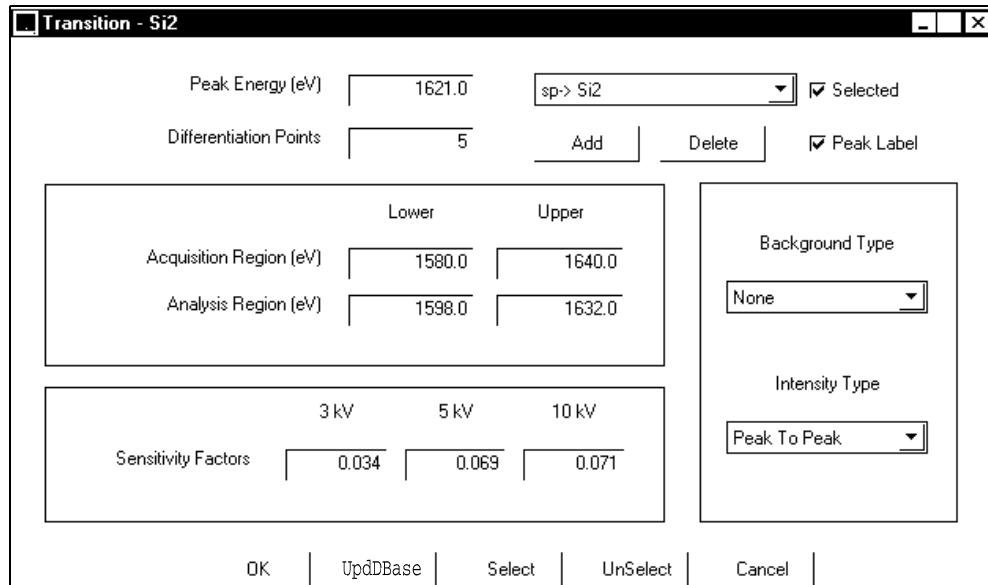
Record: [navigation buttons] 1 of 304

- When the desired changes have been made, exit Access and reopen SmartSoft. Once SmartSoft is reopened, the changes will take effect.

MultiPak Transition Dialog Box

In MultiPak, the Transition dialog box is displayed by clicking on an element in the Periodic Table window with the [Shift]-left mouse button. The following illustration shows the AES transition Si2. This dialog box shows the values stored in database.

MultiPak Transition Dialog Box for the AES Transition Si2.



Silicon, like the majority of elements in the database, has more than one transition. The Selected and Peak Label options for each transition determine the results in the Spectrum window (1) when an element is turned on in the Periodic table window (adding options to the region bar), and (2) when selecting Tools–Peak Identification, as follows:

- *Selected*—The transition is added to the region bar, and the transition label is placed on the spectrum when one of the label options is selected in the Labels Option Menu. Usually, only the major transitions of an element are specified as Selected.
- *Peak Label*—The transition is not added to the region bar, but transition label is placed on the spectrum when one of the label options is selected in the Labels Option Menu.

NOTE: Three additional factors also affect the result of the Peak ID function:

- *No transitions for an element are included when that element's button is turned off in the Peak ID Setup function.*
- *Region cursors will not be displayed if the Region Cursor function is off.*
- *No transition labels will be added to an AES spectrum if the Labels Option Menu is set to No Labels.*

Appendix A: AES Element Table

One, both or neither of these switches (Selected and Peak Label) can be on or off for each transition. When Selected is turned on, the transition label (for example, Si2p) will have the prefix “s.” When Peak Label is on, the prefix “p” will be added. When both switches are on, the prefix “sp” will be added. The prefixes are followed by a dash and greater-than sign (->).

All values in the dialog box may be changed by the user. The user also has the ability to define new transitions or delete existing transitions. Once the **UpdDbase** (update database) button is pressed, the changes entered will be saved permanently to the database (until changed again). When UpdDbase is not pressed, the changes entered will be in effect only for the current MultiPak session.

Pressing the **Select/Unselect** buttons in the dialog box toggles the element button in the Periodic Table.

NOTE: The element database in MultiPak is separate and distinct from the element database in SmartSoft. Changes to the MultiPak database will not affect the SmartSoft database. When making changes, both databases must be edited.

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _x 3/5/10 | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|--------|--------------------------|--------|------|------|---------------|------|
| Ag1* | 47 | 351.5 | 359 | 1.000 0.878 0.634 | 331.5 | 371.5 | 334.5 | 368.5 | 336 | 380 | 80 | 5 |
| Ag2 | 47 | 2573 | 2583 | – 0.008 0.015 | 2553 | 2593 | 2556 | 2590 | 2525 | 2600 | 244 | 50 |
| Ag3 | 47 | 2746 | 2755 | – 0.003 0.007 | 2726 | 2766 | 2729 | 2763 | 2720 | 2762 | 222 | 50 |
| Ag4 | 47 | 2374 | 2381 | – 0.003 0.005 | 2354 | 2394 | 2357 | 2391 | 2352 | 2411 | 216 | 50 |
| Al1 | 13 | 67 | 70 | 0.317 0.295 0.176 | 47 | 87 | 50 | 84 | 54 | 73 | 38 | 10 |
| Al2* | 13 | 1391 | 1396 | 0.075 0.121 0.105 | 1371 | 1411 | 1374 | 1408 | 1385 | 1402 | 115 | 15 |
| Ar1* | 18 | 216.5 | 219 | – – – | 196.5 | 236.5 | 199.5 | 233.5 | 209 | 226 | 45 | 20 |
| As1* | 33 | 1225 | 1229 | 0.111 0.124 0.110 | 1205 | 1245 | 1208 | 1242 | 1198 | 1237 | 128 | 10 |
| As2 | 33 | 1260 | 1264 | 0.052 0.059 0.053 | 1240 | 1280 | 1243 | 1277 | 1253 | 1272 | 110 | 25 |
| As3 | 33 | 1114.5 | 1118 | 0.062 0.067 0.029 | 1094.5 | 1134.5 | 1097.5 | 1131.5 | 1068 | 1140 | 154 | 45 |
| As4 | 33 | 92.5 | 97 | 0.039 0.028 0.017 | 72.5 | 112.5 | 75.5 | 109.5 | 87 | 103 | 37 | 50 |
| Au1 | 79 | 71 | 74 | 0.629 0.532 0.381 | 51 | 91 | 54 | 88 | 64 | 113 | 68 | 5 |
| Au2 | 79 | 239.5 | 243 | 0.048 0.044 0.033 | 219.5 | 259.5 | 222.5 | 256.5 | 210 | 270 | 89 | 40 |
| Au3* | 79 | 2015 | 2022 | 0.020 0.041 0.049 | 1995 | 2035 | 1998 | 2032 | 1957 | 2038 | 217 | 25 |
| Au4 | 79 | 2100 | 2107 | 0.011 0.030 0.038 | 2080 | 2120 | 2083 | 2117 | 2070 | 2128 | 199 | 35 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|--------|--------------------------|--------|------|------|---------------|------|
| Au5 | 79 | 1764 | 1771 | 0.006 0.013 0.015 | 1744 | 1784 | 1747 | 1781 | 1700 | 1782 | 203 | 50 |
| Au6 | 79 | 1499 | 1522 | 0.003 0.007 0.008 | 1479 | 1519 | 1482 | 1516 | 1469 | 1531 | 167 | 50 |
| B1* | 5 | 178 | 185 | 0.239 0.171 0.105 | 158 | 198 | 161 | 195 | 156 | 193 | 63 | 15 |
| Ba1 | 56 | 54 | 58 | 0.128 0.109 0.076 | 34 | 74 | 37 | 71 | 27 | 107 | 98 | 20 |
| Ba2 | 56 | 72 | 76 | 0.124 0.097 0.065 | 52 | 92 | 55 | 89 | 27 | 107 | 99 | 20 |
| Ba3* | 56 | 585.5 | 603 | 0.080 0.084 0.071 | 565.5 | 605.5 | 568.5 | 602.5 | 519 | 620 | 151 | 20 |
| Ba4 | 56 | 669 | 674 | 0.013 0.015 0.012 | 649 | 689 | 652 | 686 | 620 | 715 | 150 | 50 |
| Be1* | 4 | 103 | 108 | 0.270 0.188 0.108 | 83 | 123 | 86 | 120 | 85 | 114 | 50 | 10 |
| Bi1* | 83 | 102 | 105 | 0.348 0.304 0.212 | 82 | 122 | 85 | 119 | 72 | 136 | 85 | 5 |
| Bi2 | 83 | 247 | 253 | 0.023 0.022 0.017 | 227 | 267 | 230 | 264 | 215 | 279 | 94 | 50 |
| Bi3 | 83 | 2231 | 2243 | 0.004 0.014 0.017 | 2211 | 2251 | 2214 | 2248 | 2120 | 2260 | 289 | 50 |
| Bi4 | 83 | 2340 | 2350 | — 0.011 0.012 | 2320 | 2360 | 2323 | 2357 | 2307 | 2360 | 208 | 50 |
| Bi5 | 83 | 1932 | 1960 | — 0.006 0.007 | 1912 | 1952 | 1915 | 1949 | 1886 | 1973 | 218 | 50 |
| Br1* | 35 | 1388.5 | 1393 | 0.073 0.095 0.103 | 1368.5 | 1408.5 | 1371.5 | 1405.5 | 1334 | 1405 | 169 | 15 |
| Br2 | 35 | 1434.5 | 1439 | 0.045 0.051 0.057 | 1414.5 | 1454.5 | 1417.5 | 1451.5 | 1424 | 1448 | 125 | 25 |
| Br3 | 35 | 1263 | 1267 | 0.025 0.030 0.030 | 1243 | 1283 | 1246 | 1280 | 1216 | 1288 | 163 | 45 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|-------|--------------------------|-------|------|------|---------------|------|
| Br4 | 35 | 101 | 102 | 0.070 0.055 0.041 | 81 | 121 | 84 | 118 | 96 | 104 | 29 | 35 |
| Br5 | 35 | 53 | 55 | 0.138 0.098 0.074 | 33 | 73 | 36 | 70 | 47 | 57 | 28 | 20 |
| C1* | 6 | 266 | 275 | 0.165 0.128 0.076 | 246 | 286 | 249 | 283 | 243 | 287 | 75 | 20 |
| Ca1* | 20 | 289 | 297 | 0.249 0.199 0.132 | 269 | 309 | 272 | 306 | 258 | 304 | 78 | 10 |
| Cd1* | 48 | 377 | 379 | 1.042 0.934 0.701 | 357 | 397 | 360 | 394 | 340 | 410 | 108 | 5 |
| Cd2 | 48 | 2683 | 2694 | — 0.006 0.011 | 2663 | 2703 | 2666 | 2700 | 2641 | 2711 | 246 | 50 |
| Ce1 | 58 | 84.5 | 87 | 0.441 0.316 0.196 | 64.5 | 104.5 | 67.5 | 101.5 | 37 | 133 | 116 | 5 |
| Ce2* | 58 | 654 | 671 | 0.061 0.058 0.043 | 634 | 674 | 637 | 671 | 582 | 694 | 166 | 30 |
| Ce3 | 58 | 753 | 774 | 0.028 0.027 0.019 | 733 | 773 | 736 | 770 | 694 | 803 | 169 | 50 |
| Cl1* | 17 | 181.5 | 184 | 3.199 2.182 1.724 | 161.5 | 201.5 | 164.5 | 198.5 | 174 | 193 | 45 | 5 |
| Co1* | 27 | 773 | 777 | 0.300 0.299 0.226 | 753 | 793 | 756 | 790 | 751 | 798 | 108 | 5 |
| Co2 | 27 | 710 | 718 | 0.141 0.142 0.109 | 690 | 730 | 693 | 727 | 678 | 735 | 115 | 10 |
| Co3 | 27 | 648 | 658 | 0.109 0.109 0.084 | 628 | 668 | 631 | 665 | 623 | 678 | 109 | 15 |
| Co4 | 27 | 53 | 57 | 0.459 0.351 0.217 | 33 | 73 | 36 | 70 | 41 | 69 | 46 | 5 |
| Cr1 | 24 | 489 | 491 | 0.344 0.308 0.226 | 469 | 509 | 472 | 506 | 463 | 502 | 83 | 5 |
| Cr2* | 24 | 527 | 531 | 0.404 0.359 0.265 | 507 | 547 | 510 | 544 | 510 | 542 | 79 | 5 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|-------|--------------------------|-------|------|------|---------------|------|
| Cs1* | 55 | 554 | 572 | 0.084 0.083 0.066 | 534 | 574 | 537 | 571 | 492 | 583 | 139 | 20 |
| Cs2 | 55 | 628 | 632 | 0.012 0.012 0.009 | 608 | 648 | 611 | 645 | 583 | 663 | 133 | 50 |
| Cu1* | 29 | 918.5 | 922 | 0.260 0.307 0.269 | 898.5 | 938.5 | 901.5 | 935.5 | 901 | 932 | 101 | 5 |
| Cu2 | 29 | 839.5 | 842 | 0.080 0.093 0.081 | 819.5 | 859.5 | 822.5 | 856.5 | 804 | 873 | 134 | 15 |
| Cu3 | 29 | 768 | 778 | 0.044 0.051 0.045 | 748 | 788 | 751 | 785 | 736 | 787 | 112 | 30 |
| Cu4 | 29 | 62 | 66 | 0.361 0.297 0.197 | 42 | 82 | 45 | 79 | 49 | 79 | 49 | 5 |
| Dy1 | 66 | 143.5 | 154 | 0.125 0.072 0.043 | 123.5 | 163.5 | 126.5 | 160.5 | 36 | 178 | 166 | 30 |
| Dy2* | 66 | 1113 | 1127 | 0.025 0.023 0.020 | 1093 | 1133 | 1096 | 1130 | 1043 | 1175 | 214 | 50 |
| Dy3 | 66 | 954 | 978 | 0.019 0.018 0.015 | 934 | 974 | 937 | 971 | 877 | 1016 | 211 | 50 |
| Dy4 | 66 | 1274 | 1284 | 0.012 0.011 0.009 | 1254 | 1294 | 1257 | 1291 | 1200 | 1292 | 183 | 50 |
| Er1 | 68 | 149 | 168 | 0.089 0.067 0.043 | 129 | 169 | 132 | 166 | 30 | 186 | 180 | 30 |
| Er2* | 68 | 1211 | 1228 | 0.018 0.023 0.021 | 1191 | 1231 | 1194 | 1228 | 1129 | 1278 | 237 | 50 |
| Er3 | 68 | 1040 | 1060 | 0.012 0.015 0.014 | 1020 | 1060 | 1023 | 1057 | 954 | 1104 | 227 | 50 |
| Er4 | 68 | 1386 | 1395 | 0.017 0.022 0.021 | 1366 | 1406 | 1369 | 1403 | 1306 | 1447 | 239 | 50 |
| Eu1 | 63 | 105 | 107 | 0.250 0.169 0.109 | 85 | 125 | 88 | 122 | 25 | 165 | 161 | 10 |
| Eu2* | 63 | 844 | 860 | 0.037 0.036 0.032 | 824 | 864 | 827 | 861 | 765 | 892 | 193 | 40 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|--------|--------------------------|--------|------|------|---------------|------|
| Eu3 | 63 | 137 | 140 | 0.145 0.098 0.063 | 117 | 157 | 120 | 154 | 117 | 165 | 71 | 20 |
| Eu4 | 63 | 974 | 988 | 0.037 0.036 0.032 | 954 | 994 | 957 | 991 | 916 | 1025 | 182 | 45 |
| F1* | 9 | 655 | 659 | 0.499 0.717 0.514 | 635 | 675 | 638 | 672 | 642 | 675 | 87 | 5 |
| Fe1* | 26 | 591 | 600 | 0.144 0.139 0.103 | 571 | 611 | 574 | 608 | 568 | 616 | 98 | 15 |
| Fe2 | 26 | 647.5 | 654 | 0.212 0.205 0.151 | 627.5 | 667.5 | 630.5 | 664.5 | 616 | 669 | 107 | 10 |
| Fe3 | 26 | 702.5 | 705 | 0.255 0.246 0.178 | 682.5 | 722.5 | 685.5 | 719.5 | 685 | 725 | 97 | 10 |
| Fe4 | 26 | 48 | 50 | 0.670 0.515 0.317 | 28 | 68 | 31 | 65 | 35 | 60 | 43 | 5 |
| Ga1* | 31 | 1066 | 1069 | 0.246 0.274 0.225 | 1046 | 1086 | 1049 | 1083 | 1055 | 1080 | 104 | 5 |
| Ga2 | 31 | 1093 | 1096 | 0.130 0.137 0.115 | 1073 | 1113 | 1076 | 1110 | 1083 | 1105 | 103 | 10 |
| Ga3 | 31 | 971 | 974 | 0.063 0.073 0.060 | 951 | 991 | 954 | 988 | 931 | 991 | 133 | 25 |
| Ga4 | 31 | 55 | 58 | 0.171 0.130 0.077 | 35 | 75 | 38 | 72 | 45 | 63 | 36 | 15 |
| Gd1 | 64 | 109 | 112 | 0.157 0.131 0.077 | 89 | 129 | 92 | 126 | 32 | 170 | 160 | 15 |
| Gd2* | 64 | 1019 | 1030 | 0.025 0.031 0.026 | 999 | 1039 | 1002 | 1036 | 950 | 1078 | 204 | 50 |
| Gd3 | 64 | 139.5 | 143 | 0.190 0.153 0.088 | 119.5 | 159.5 | 122.5 | 156.5 | 120 | 170 | 73 | 15 |
| Gd4 | 64 | 882 | 896 | 0.023 0.029 0.024 | 862 | 902 | 865 | 899 | 800 | 933 | 201 | 50 |
| Ge1* | 32 | 1146.5 | 1150 | 0.140 0.172 0.149 | 1126.5 | 1166.5 | 1129.5 | 1163.5 | 1118 | 1157 | 123 | 10 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|--------|--------------------------|--------|------|------|---------------|------|
| Ge2 | 32 | 1177 | 1181 | 0.063 0.080 0.070 | 1157 | 1197 | 1160 | 1194 | 1171 | 1190 | 105 | 20 |
| Ge3 | 32 | 1043.5 | 1047 | 0.038 0.046 0.040 | 1023.5 | 1063.5 | 1026.5 | 1060.5 | 1000 | 1068 | 146 | 35 |
| Ge4 | 32 | 53 | 55 | 0.077 0.063 0.040 | 33 | 73 | 36 | 70 | 45 | 60 | 33 | 35 |
| Hf1 | 72 | 170 | 184 | 0.135 0.117 0.072 | 150 | 190 | 153 | 187 | 48.5 | 200 | 177 | 20 |
| Hf2* | 72 | 1619 | 1625 | 0.047 0.075 0.070 | 1599 | 1639 | 1602 | 1636 | 1517 | 1691 | 286 | 20 |
| Hf3 | 72 | 1408 | 1427 | 0.015 0.024 0.023 | 1388 | 1428 | 1391 | 1425 | 1315 | 1484 | 268 | 50 |
| Hf4 | 72 | 1216 | 1231 | 0.007 0.012 0.012 | 1196 | 1236 | 1199 | 1233 | 1115 | 1286 | 259 | 50 |
| Hg1* | 80 | 78 | 81 | 0.518 0.427 0.287 | 58 | 98 | 61 | 95 | 73.5 | 95 | 41 | 5 |
| Hg2 | 80 | 243 | 246 | 0.037 0.032 0.023 | 223 | 263 | 226 | 260 | 236 | 249 | 43 | 50 |
| Hg3 | 80 | 2068 | 2078 | 0.018 0.028 0.032 | 2048 | 2088 | 2051 | 2085 | 2028 | 2090 | 201 | 40 |
| Hg4 | 80 | 2159 | 2166 | 0.013 0.019 0.024 | 2139 | 2179 | 2142 | 2176 | 2133 | 2175 | 187 | 50 |
| Hg5 | 80 | 1811 | 1818 | 0.006 0.011 0.012 | 1791 | 1831 | 1794 | 1828 | 1760 | 1825 | 189 | 50 |
| Ho1 | 67 | 150 | 162 | 0.098 0.077 0.046 | 130 | 170 | 133 | 167 | 33 | 183 | 174 | 30 |
| Ho2* | 67 | 1161 | 1177 | 0.025 0.031 0.026 | 1141 | 1181 | 1144 | 1178 | 1085 | 1227 | 227 | 50 |
| Ho3 | 67 | 995 | 1016 | 0.015 0.019 0.016 | 975 | 1015 | 978 | 1012 | 913 | 1061 | 223 | 50 |
| Ho4 | 67 | 1329 | 1339 | 0.015 0.018 0.015 | 1309 | 1349 | 1312 | 1346 | 1254 | 1386 | 227 | 50 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|-------|--------------------------|-------|------|------|---------------|------|
| I1* | 53 | 506 | 510 | 0.269 0.256 0.287 | 486 | 526 | 489 | 523 | 448 | 530 | 127 | 5 |
| I2 | 53 | 516 | 519 | 0.269 0.242 0.256 | 496 | 536 | 499 | 533 | 448 | 530 | 128 | 5 |
| I3 | 53 | 559.5 | 562 | 0.033 0.037 0.037 | 539.5 | 579.5 | 542.5 | 576.5 | 535 | 579 | 93 | 35 |
| In1* | 49 | 403 | 405 | 0.715 0.586 0.432 | 383 | 423 | 386 | 420 | 360 | 443 | 122 | 5 |
| In2 | 49 | 2793 | 2806 | — 0.004 0.007 | 2773 | 2813 | 2776 | 2810 | 2757 | 2824 | 250 | 50 |
| Ir1 | 77 | 163 | 175 | 0.082 0.069 0.045 | 143 | 183 | 146 | 180 | 100 | 205 | 130 | 30 |
| Ir2* | 77 | 1901 | 1909 | 0.028 0.053 0.055 | 1881 | 1921 | 1884 | 1918 | 1798 | 1923 | 254 | 25 |
| Ir3 | 77 | 1975 | 1982 | 0.018 0.040 0.043 | 1955 | 1995 | 1958 | 1992 | 1963 | 2000 | 171 | 30 |
| Ir4 | 77 | 229 | 233 | 0.051 0.044 0.028 | 209 | 249 | 212 | 246 | 210 | 257 | 76 | 50 |
| Ir5 | 77 | 1665 | 1672 | 0.010 0.016 0.016 | 1645 | 1685 | 1648 | 1682 | 1542 | 1760 | 333 | 50 |
| Ir6 | 77 | 1418 | 1439 | 0.004 0.009 0.009 | 1398 | 1438 | 1401 | 1435 | 1360 | 1509 | 249 | 50 |
| K1* | 19 | 247 | 252 | 0.300 0.255 0.192 | 227 | 267 | 230 | 264 | 224 | 261 | 67 | 5 |
| Kr1* | 36 | 1474 | 1478 | — — — — | 1454 | 1494 | 1457 | 1491 | 1463 | 1480 | 120 | 20 |
| Kr2 | 36 | 1528 | 1531 | — — — | 1508 | 1548 | 1511 | 1545 | 1515 | 1535 | 127 | 20 |
| Kr3 | 36 | 1340 | 1343 | — — — | 1320 | 1360 | 1323 | 1357 | 1333 | 1360 | 122 | 20 |
| La1 | 57 | 80 | 83 | 0.389 0.271 0.168 | 60 | 100 | 63 | 97 | 35 | 119 | 104 | 10 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|-------|--------------------------|-------|------|------|---------------|------|
| La2* | 57 | 619 | 634 | 0.081 0.076 0.059 | 599 | 639 | 602 | 636 | 550 | 656 | 158 | 25 |
| La3 | 57 | 711.5 | 732 | 0.027 0.025 0.019 | 691.5 | 731.5 | 694.5 | 728.5 | 656 | 759 | 161 | 50 |
| Li1* | 3 | 47 | 57 | 0.120 0.070 0.024 | 27 | 67 | 30 | 64 | 43 | 53 | 28 | 50 |
| Lu1 | 71 | 169 | 182 | 0.107 0.086 0.052 | 149 | 189 | 152 | 186 | 36 | 193 | 182 | 25 |
| Lu2* | 71 | 1561 | 1568 | 0.040 0.057 0.050 | 1541 | 1581 | 1544 | 1578 | 1465 | 1632 | 276 | 25 |
| Lu3 | 71 | 1359 | 1378 | 0.014 0.020 0.017 | 1339 | 1379 | 1342 | 1376 | 1268 | 1434 | 263 | 50 |
| Lu4 | 71 | 1173 | 1188 | 0.009 0.012 0.010 | 1153 | 1193 | 1156 | 1190 | 1080 | 1240 | 245 | 50 |
| Mg1 | 12 | 46 | 48 | 0.381 0.283 0.174 | 26 | 66 | 29 | 63 | 25 | 50 | 43 | 10 |
| Mg2* | 12 | 1174 | 1188 | 0.098 0.121 0.109 | 1154 | 1194 | 1157 | 1191 | 1147 | 1194 | 132 | 10 |
| Mn1* | 25 | 536 | 545 | 0.189 0.173 0.122 | 516 | 556 | 519 | 553 | 514 | 558 | 91 | 10 |
| Mn2 | 25 | 586 | 592 | 0.246 0.222 0.161 | 566 | 606 | 569 | 603 | 558 | 605 | 97 | 10 |
| Mn3 | 25 | 635 | 638 | 0.189 0.169 0.123 | 615 | 655 | 618 | 652 | 620 | 655 | 88 | 10 |
| Mn4 | 25 | 42 | 45 | 0.508 0.369 0.226 | 22 | 62 | 25 | 59 | 30 | 53 | 41 | 5 |
| Mo1* | 42 | 187 | 190 | 0.343 0.271 0.170 | 167 | 207 | 170 | 204 | 171 | 197 | 52 | 10 |
| Mo2 | 42 | 2037 | 2044 | 0.008 0.028 0.031 | 2017 | 2057 | 2020 | 2054 | 2000 | 2058 | 195 | 45 |
| Mo3 | 42 | 222 | 225 | 0.302 0.241 0.149 | 202 | 242 | 205 | 239 | 214 | 232 | 46 | 10 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|-------|--------------------------|-------|------|------|---------------|------|
| Mo4 | 42 | 2142 | 2149 | 0.003 0.013 0.015 | 2122 | 2162 | 2125 | 2159 | 2103 | 2160 | 201 | 50 |
| Mo5 | 42 | 1874 | 1881 | 0.003 0.009 0.010 | 1854 | 1894 | 1857 | 1891 | 1810 | 1892 | 209 | 50 |
| N1* | 7 | 382 | 389 | 0.327 0.246 0.161 | 362 | 402 | 365 | 399 | 376 | 398 | 60 | 10 |
| Na1* | 11 | 986 | 996 | 0.081 0.087 0.076 | 966 | 1006 | 969 | 1003 | 959 | 1005 | 120 | 20 |
| Nb1* | 41 | 167.5 | 170 | 0.357 0.290 0.190 | 147.5 | 187.5 | 150.5 | 184.5 | 158 | 176 | 43 | 5 |
| Nb2 | 41 | 1937 | 1944 | 0.011 0.026 0.031 | 1917 | 1957 | 1920 | 1954 | 1871 | 1960 | 220 | 45 |
| Nb3 | 41 | 198.5 | 201 | 0.191 0.153 0.100 | 178.5 | 218.5 | 181.5 | 215.5 | 186 | 207 | 48 | 15 |
| Nb4 | 41 | 2031 | 2039 | 0.007 0.012 0.015 | 2011 | 2051 | 2014 | 2048 | 1997 | 2048 | 188 | 50 |
| Nb5 | 41 | 1762 | 1787 | 0.004 0.010 0.011 | 1742 | 1782 | 1745 | 1779 | 1711 | 1799 | 209 | 50 |
| Nd1 | 60 | 93 | 96 | 0.357 0.257 0.166 | 73 | 113 | 76 | 110 | 39 | 159 | 141 | 10 |
| Nd2* | 60 | 726 | 734 | 0.057 0.056 0.048 | 706 | 746 | 709 | 743 | 652 | 770 | 177 | 30 |
| Nd3 | 60 | 838 | 861 | 0.022 0.022 0.018 | 818 | 858 | 821 | 855 | 787 | 891 | 169 | 50 |
| Ne1* | 10 | 818 | 821 | — — — | 798 | 838 | 801 | 835 | 803 | 824 | 85 | 20 |
| Ni1* | 28 | 846 | 849 | 0.269 0.281 0.227 | 826 | 866 | 829 | 863 | 827 | 873 | 112 | 5 |
| Ni2 | 28 | 774 | 785 | 0.103 0.107 0.086 | 754 | 794 | 757 | 791 | 742 | 803 | 122 | 15 |
| Ni3 | 28 | 708 | 718 | 0.063 0.066 0.053 | 688 | 728 | 691 | 725 | 680 | 730 | 107 | 25 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|--------|--------------------------|--------|------|------|---------------|------|
| Ni4 | 28 | 59 | 64 | 0.410 0.321 0.208 | 39 | 79 | 42 | 76 | 43 | 74 | 50 | 5 |
| O1* | 8 | 507 | 510 | 0.338 0.296 0.212 | 487 | 527 | 490 | 524 | 496 | 525 | 74 | 5 |
| Os1 | 76 | 166 | 180 | 0.102 0.071 0.046 | 146 | 186 | 149 | 183 | 92 | 201 | 134 | 30 |
| Os2* | 76 | 1844 | 1850 | 0.037 0.054 0.055 | 1824 | 1864 | 1827 | 1861 | 1741 | 1866 | 251 | 25 |
| Os3 | 76 | 1913 | 1920 | 0.024 0.037 0.038 | 1893 | 1933 | 1896 | 1930 | 1904 | 1935 | 161 | 35 |
| Os4 | 76 | 222 | 226 | 0.045 0.031 0.020 | 202 | 242 | 205 | 239 | 202 | 250 | 76 | 50 |
| Os5 | 76 | 1615 | 1622 | 0.010 0.014 0.014 | 1595 | 1635 | 1598 | 1632 | 1494 | 1704 | 322 | 50 |
| Os6 | 76 | 1377 | 1396 | 0.006 0.008 0.008 | 1357 | 1397 | 1360 | 1394 | 1269 | 1462 | 291 | 50 |
| P1* | 15 | 120.5 | 123 | 0.828 0.613 0.371 | 100.5 | 140.5 | 103.5 | 137.5 | 112 | 128 | 38 | 5 |
| P2 | 15 | 1855 | 1862 | 0.026 0.046 0.049 | 1835 | 1875 | 1838 | 1872 | 1848 | 1867 | 145 | 25 |
| Pb1* | 82 | 94 | 97 | 0.551 0.473 0.311 | 74 | 114 | 77 | 111 | 70 | 124 | 75 | 5 |
| Pb2 | 82 | 247 | 251 | 0.033 0.032 0.022 | 227 | 267 | 230 | 264 | 211 | 276 | 95 | 50 |
| Pb3 | 82 | 2176 | 2188 | 0.005 0.020 0.023 | 2156 | 2196 | 2159 | 2193 | 2057 | 2205 | 294 | 50 |
| Pb4 | 82 | 2278.5 | 2228 | — 0.001 0.016 | 2258.5 | 2298.5 | 2261.5 | 2295.5 | 2250 | 2299 | 201 | 50 |
| Pb5 | 82 | 1885 | 1914 | 0.003 0.008 0.009 | 1865 | 1905 | 1868 | 1902 | 1850 | 1925 | 203 | 50 |
| Pb6 | 82 | 1613 | 1641 | — 0.003 0.004 | 1593 | 1633 | 1596 | 1630 | 1569 | 1650 | 193 | 50 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|-------|--------------------------|-------|------|------|---------------|------|
| Pd1* | 46 | 327.5 | 333 | 0.882 0.768 0.547 | 307.5 | 347.5 | 310.5 | 344.5 | 310 | 343 | 68 | 5 |
| Pd2 | 46 | 275 | 283 | 0.152 0.132 0.094 | 255 | 295 | 258 | 292 | 254 | 296 | 74 | 15 |
| Pd3 | 46 | 2467 | 2476 | — 0.012 0.017 | 2447 | 2487 | 2450 | 2484 | 2415 | 2550 | 298 | 50 |
| Pd4 | 46 | 2625 | 2633 | — 0.005 0.008 | 2605 | 2645 | 2608 | 2642 | 2590 | 2645 | 228 | 50 |
| Pd5 | 46 | 2275 | 2282 | — 0.004 0.005 | 2255 | 2295 | 2258 | 2292 | 2226 | 2303 | 229 | 50 |
| Pr1 | 59 | 88.5 | 91 | 0.361 0.266 0.165 | 68.5 | 108.5 | 71.5 | 105.5 | 38 | 148 | 130 | 10 |
| Pr2* | 59 | 689 | 696 | 0.049 0.049 0.038 | 669 | 709 | 672 | 706 | 615 | 730 | 171 | 35 |
| Pr3 | 59 | 795 | 817 | 0.021 0.020 0.015 | 775 | 815 | 778 | 812 | 730 | 845 | 178 | 50 |
| Pt1* | 78 | 64 | 70 | 0.513 0.393 0.296 | 44 | 84 | 47 | 81 | 56 | 107 | 70 | 5 |
| Pt2 | 78 | 170 | 173 | 0.043 0.035 0.028 | 150 | 190 | 153 | 187 | 107 | 209 | 127 | 50 |
| Pt3 | 78 | 236.5 | 241 | 0.042 0.034 0.026 | 216.5 | 256.5 | 219.5 | 253.5 | 214 | 266 | 81 | 50 |
| Pt4* | 78 | 1962 | 1969 | 0.022 0.042 0.051 | 1942 | 1982 | 1945 | 1979 | 1859 | 1984 | 258 | 25 |
| Pt5 | 78 | 2042 | 2048 | 0.017 0.035 0.043 | 2022 | 2062 | 2025 | 2059 | 2025 | 2060 | 173 | 30 |
| Pt6 | 78 | 1718 | 1725 | 0.008 0.012 0.015 | 1698 | 1738 | 1701 | 1735 | 1615 | 1820 | 323 | 50 |
| Pt7 | 78 | 1462 | 1484 | 0.003 0.007 0.008 | 1442 | 1482 | 1445 | 1479 | 1433 | 1492 | 162 | 50 |
| Rb1* | 37 | 1554 | 1561 | 0.012 0.017 0.022 | 1534 | 1574 | 1537 | 1571 | 1495 | 1574 | 187 | 50 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|-------|--------------------------|-------|------|------|---------------|------|
| Rb2 | 37 | 1614 | 1620 | 0.006 0.008 0.011 | 1594 | 1634 | 1597 | 1631 | 1598 | 1630 | 144 | 50 |
| Rb3 | 37 | 1413 | 1433 | 0.003 0.005 0.006 | 1393 | 1433 | 1396 | 1430 | 1366 | 1442 | 176 | 50 |
| Rb4 | 37 | 103.5 | 107 | 0.025 0.018 0.013 | 83.5 | 123.5 | 86.5 | 120.5 | 82 | 118 | 57 | 50 |
| Rb5 | 37 | 73.5 | 78 | 0.053 0.040 0.029 | 53.5 | 93.5 | 56.5 | 90.5 | 64 | 82 | 37 | 45 |
| Re1 | 75 | 163 | 179 | 0.156 0.126 0.080 | 143 | 183 | 146 | 180 | 81 | 198 | 142 | 15 |
| Re2* | 75 | 1787 | 1793 | 0.042 0.072 0.070 | 1767 | 1807 | 1770 | 1804 | 1686 | 1806 | 242 | 20 |
| Re3 | 75 | 1852 | 1858 | 0.025 0.045 0.044 | 1832 | 1872 | 1835 | 1869 | 1843 | 1874 | 157 | 30 |
| Re4 | 75 | 215 | 218 | 0.058 0.046 0.029 | 195 | 235 | 198 | 232 | 198 | 243 | 73 | 45 |
| Re5 | 75 | 1565 | 1572 | 0.012 0.019 0.019 | 1545 | 1585 | 1548 | 1582 | 1448 | 1650 | 311 | 50 |
| Re6 | 75 | 1336 | 1354 | 0.007 0.012 0.011 | 1316 | 1356 | 1319 | 1353 | 1228 | 1417 | 284 | 50 |
| Rh1* | 45 | 301 | 305 | 0.848 0.725 0.530 | 281 | 321 | 284 | 318 | 284 | 314 | 63 | 5 |
| Rh2 | 45 | 253 | 259 | 0.222 0.191 0.140 | 233 | 273 | 236 | 270 | 233 | 268 | 65 | 10 |
| Rh3 | 45 | 2356 | 2366 | — 0.011 0.019 | 2336 | 2376 | 2339 | 2373 | 2303 | 2383 | 236 | 50 |
| Rh4 | 45 | 2500 | 2507 | — 0.005 0.010 | 2480 | 2520 | 2483 | 2517 | 2471 | 2520 | 214 | 50 |
| Rh5 | 45 | 2172 | 2180 | — 0.004 0.006 | 2152 | 2192 | 2155 | 2189 | 2120 | 2191 | 216 | 50 |
| Ru1* | 44 | 274 | 277 | 0.574 0.495 0.302 | 254 | 294 | 257 | 291 | 256 | 287 | 62 | 5 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|-------|--------------------------|-------|------|------|---------------|------|
| Ru2 | 44 | 230 | 235 | 0.216 0.186 0.114 | 210 | 250 | 213 | 247 | 211 | 245 | 63 | 10 |
| Ru3 | 44 | 2248 | 2256 | – 0.019 0.023 | 2228 | 2268 | 2231 | 2265 | 2191 | 2272 | 231 | 50 |
| Ru4 | 44 | 2376 | 2385 | – 0.009 0.011 | 2356 | 2396 | 2359 | 2393 | 2356 | 2395 | 197 | 50 |
| Ru5 | 44 | 2038 | 2078 | – 0.006 0.006 | 2018 | 2058 | 2021 | 2055 | 2024 | 2088 | 201 | 50 |
| S1* | 16 | 149.5 | 153 | 1.277 1.042 0.652 | 129.5 | 169.5 | 132.5 | 166.5 | 145 | 158 | 37 | 5 |
| S2 | 16 | 2111 | 2119 | 0.013 0.023 0.030 | 2091 | 2131 | 2094 | 2128 | 2082 | 2125 | 185 | 45 |
| Sb1* | 51 | 455 | 458 | 0.738 0.704 0.525 | 435 | 475 | 438 | 472 | 405 | 513 | 150 | 5 |
| Sb2 | 51 | 3022 | 3035 | – 0.003 0.007 | 3002 | 3042 | 3005 | 3039 | 2968 | 3054 | 282 | 50 |
| Sc1* | 21 | 337 | 343 | 0.305 0.250 0.168 | 317 | 357 | 320 | 354 | 300 | 349 | 84 | 10 |
| Sc2 | 21 | 368 | 370 | 0.322 0.264 0.176 | 348 | 388 | 351 | 385 | 359 | 380 | 58 | 10 |
| Se1* | 34 | 1306 | 1311 | 0.074 0.097 0.032 | 1286 | 1326 | 1289 | 1323 | 1272 | 1320 | 141 | 40 |
| Se2 | 34 | 1347 | 1352 | 0.038 0.045 0.016 | 1327 | 1367 | 1330 | 1364 | 1338 | 1360 | 118 | 50 |
| Se3 | 34 | 1188 | 1192 | 0.020 0.027 0.008 | 1168 | 1208 | 1171 | 1205 | 1140 | 1213 | 159 | 50 |
| Se4 | 34 | 97 | 104 | 0.031 0.024 0.010 | 77 | 117 | 80 | 114 | 88 | 110 | 43 | 50 |
| Se5 | 34 | 44 | 47 | 0.027 0.022 0.024 | 24 | 64 | 27 | 61 | 38 | 56 | 36 | 50 |
| Si1 | 14 | 93 | 96 | 0.414 0.403 0.393 | 73 | 113 | 76 | 110 | 77 | 101 | 45 | 5 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|-------|--------------------------|-------|------|------|---------------|------|
| Si2* | 14 | 1615 | 1621 | 0.034 0.069 0.071 | 1595 | 1635 | 1598 | 1632 | 1609 | 1628 | 131 | 20 |
| Sm1 | 62 | 100.5 | 103 | 0.214 0.160 0.104 | 80.5 | 120.5 | 83.5 | 117.5 | 25 | 164 | 160 | 15 |
| Sm2* | 62 | 801 | 814 | 0.037 0.038 0.031 | 781 | 821 | 784 | 818 | 724 | 848 | 187 | 45 |
| Sm3 | 62 | 120.5 | 135 | 0.109 0.078 0.047 | 100.5 | 140.5 | 103.5 | 137.5 | 110 | 164 | 76 | 30 |
| Sm4 | 62 | 927 | 940 | 0.026 0.028 0.022 | 907 | 947 | 910 | 944 | 864 | 984 | 191 | 50 |
| Sn1* | 50 | 429 | 432 | 0.688 0.643 0.465 | 409 | 449 | 412 | 446 | 382 | 474 | 133 | 5 |
| Sn2 | 50 | 2908 | 2919 | – 0.003 0.006 | 2888 | 2928 | 2891 | 2925 | 2860 | 2939 | 268 | 50 |
| Sr1* | 38 | 1640 | 1651 | 0.016 0.023 0.027 | 1620 | 1660 | 1623 | 1657 | 1579 | 1663 | 197 | 50 |
| Sr2 | 38 | 1706 | 1718 | 0.007 0.009 0.011 | 1686 | 1726 | 1689 | 1723 | 1665 | 1728 | 180 | 50 |
| Sr3 | 38 | 1495 | 1516 | 0.005 0.006 0.007 | 1475 | 1515 | 1478 | 1512 | 1440 | 1523 | 188 | 50 |
| Sr4 | 38 | 110 | 114 | 0.057 0.040 0.029 | 90 | 130 | 93 | 127 | 95 | 122 | 49 | 45 |
| Ta1 | 73 | 168 | 183 | 0.175 0.145 0.100 | 148 | 188 | 151 | 185 | 56 | 193 | 162 | 15 |
| Ta2* | 73 | 1674 | 1680 | 0.046 0.075 0.080 | 1654 | 1694 | 1657 | 1691 | 1573 | 1750 | 292 | 15 |
| Ta3 | 73 | 1454 | 1475 | 0.015 0.024 0.026 | 1434 | 1474 | 1437 | 1471 | 1361 | 1539 | 280 | 50 |
| Ta4 | 73 | 1255 | 1271 | 0.008 0.012 0.013 | 1235 | 1275 | 1238 | 1272 | 1152 | 1331 | 269 | 50 |
| Tb1 | 65 | 114 | 116 | 0.120 0.067 0.040 | 94 | 134 | 97 | 131 | 31 | 175 | 166 | 35 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|-------|--------------------------|-------|------|------|---------------|------|
| Tb2* | 65 | 1066 | 1078 | 0.030 0.027 0.021 | 1046 | 1086 | 1049 | 1083 | 992 | 1125 | 212 | 50 |
| Tb3 | 65 | 142 | 150 | 0.147 0.079 0.045 | 122 | 162 | 125 | 159 | 31 | 175 | 168 | 30 |
| Tb4 | 65 | 918 | 937 | 0.028 0.023 0.018 | 898 | 938 | 901 | 935 | 836 | 974 | 208 | 50 |
| Tb5 | 65 | 1222 | 1230 | 0.012 0.009 0.007 | 1202 | 1242 | 1205 | 1239 | 1150 | 1273 | 211 | 50 |
| Te1* | 52 | 482 | 486 | 0.477 0.437 0.337 | 462 | 502 | 465 | 499 | 429 | 503 | 118 | 5 |
| Th1* | 90 | 66.5 | 69 | 0.537 0.435 0.286 | 46.5 | 86.5 | 49.5 | 83.5 | 53 | 107 | 73 | 5 |
| Th2 | 90 | 246.5 | 249 | 0.069 0.066 0.049 | 226.5 | 266.5 | 229.5 | 263.5 | 242 | 258 | 46 | 25 |
| Th3 | 90 | 2620 | 2634 | – 0.005 0.007 | 2600 | 2640 | 2603 | 2637 | 2542 | 2654 | 284 | 50 |
| Th4 | 90 | 2778 | 2789 | – 0.003 0.005 | 2758 | 2798 | 2761 | 2795 | 2710 | 2800 | 272 | 50 |
| Th5 | 90 | 2286 | 2296 | – 0.002 0.003 | 2266 | 2306 | 2269 | 2303 | 2210 | 2307 | 249 | 50 |
| Ti1 | 22 | 383 | 390 | 0.326 0.274 0.188 | 363 | 403 | 366 | 400 | 358 | 397 | 77 | 5 |
| Ti2* | 22 | 419 | 421 | 0.518 0.438 0.296 | 399 | 439 | 402 | 436 | 410 | 430 | 60 | 5 |
| Ti1* | 81 | 86.5 | 90 | 0.584 0.531 0.332 | 66.5 | 106.5 | 69.5 | 103.5 | 70 | 110 | 60 | 5 |
| Ti2 | 81 | 245 | 250 | 0.032 0.031 0.020 | 225 | 265 | 228 | 262 | 211 | 273 | 92 | 50 |
| Ti3 | 81 | 2122 | 2132 | 0.009 0.024 0.026 | 2102 | 2142 | 2105 | 2139 | 2000 | 2148 | 290 | 50 |
| Ti4 | 81 | 2218 | 2227 | 0.006 0.017 0.018 | 2198 | 2238 | 2201 | 2235 | 2193 | 2260 | 215 | 50 |

Appendix A: AES Element Table

| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|------|--------------------------|------|-------|------|---------------|------|
| TI5 | 81 | 1838 | 1865 | 0.005 0.009 0.009 | 1818 | 1858 | 1821 | 1855 | 1721 | 1877 | 281 | 50 |
| TI6 | 81 | 1575 | 1601 | – 0.004 0.004 | 1555 | 1595 | 1558 | 1592 | 1508 | 1611 | 213 | 50 |
| Tm1* | 69 | 154 | 170 | 0.119 0.085 0.057 | 134 | 174 | 137 | 171 | 35 | 192 | 181 | 25 |
| Tm2* | 69 | 1444 | 1452 | 0.033 0.040 0.038 | 1424 | 1464 | 1427 | 1461 | 1360 | 1508 | 250 | 35 |
| Tm3 | 69 | 1260 | 1278 | 0.022 0.024 0.024 | 1240 | 1280 | 1243 | 1277 | 1175 | 1331 | 247 | 50 |
| Tm4 | 69 | 1083 | 1100 | 0.015 0.017 0.016 | 1063 | 1103 | 1066 | 1100 | 995 | 1149 | 234 | 50 |
| U1* | 92 | 74.5 | 77 | 0.888 0.654 0.452 | 54.5 | 94.5 | 57.5 | 91.5 | 61 | 130 | 88 | 5 |
| U2 | 92 | 282 | 284 | 0.191 0.166 0.132 | 262 | 302 | 265 | 299 | 275.5 | 300 | 56 | 10 |
| U3 | 92 | 2755 | 2764 | – 0.004 0.008 | 2735 | 2775 | 2738 | 2772 | 2685 | 2789 | 284 | 50 |
| U4 | 92 | 2930 | 2940 | – 0.004 0.007 | 2910 | 2950 | 2913 | 2947 | 2952 | 2952 | 191 | 50 |
| U5 | 92 | 2404 | 2414 | – 0.003 0.004 | 2384 | 2424 | 2387 | 2421 | 2378 | 2426 | 207 | 50 |
| V1 | 23 | 432 | 440 | 0.281 0.247 0.177 | 412 | 452 | 415 | 449 | 404 | 449 | 86 | 10 |
| V2* | 23 | 472 | 475 | 0.445 0.387 0.272 | 452 | 492 | 455 | 489 | 459 | 486 | 70 | 5 |
| W1 | 74 | 168 | 182 | 0.175 0.142 0.091 | 148 | 188 | 151 | 185 | 74 | 195 | 146 | 15 |
| W2* | 74 | 1730 | 1737 | 0.050 0.081 0.080 | 1710 | 1750 | 1713 | 1747 | 1628 | 1810 | 301 | 15 |
| W3 | 74 | 1502 | 1524 | 0.017 0.024 0.023 | 1482 | 1522 | 1485 | 1519 | 1403 | 1593 | 295 | 50 |

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| Name | At.# | N(E) Peak | dN(E) Peak | S _{x3/5/10} | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|-------|--------------------------|-------|------|------|---------------|------|
| W4 | 74 | 1295 | 1312 | 0.010 0.014 0.014 | 1275 | 1315 | 1278 | 1312 | 1190 | 1373 | 276 | 50 |
| W5 | 74 | 207 | 210 | 0.036 0.028 0.019 | 187 | 227 | 190 | 224 | 196 | 235 | 66 | 50 |
| Xe1* | 54 | 534 | 537 | — — — | 514 | 554 | 517 | 551 | 518 | 552 | 81 | 20 |
| Y1 | 39 | 130.5 | 132 | 0.157 0.127 0.075 | 110.5 | 150.5 | 113.5 | 147.5 | 120 | 136 | 39 | 20 |
| Y2* | 39 | 1739 | 1748 | 0.014 0.029 0.029 | 1719 | 1759 | 1722 | 1756 | 1676 | 1762 | 205 | 45 |
| Y3 | 39 | 1815 | 1823 | 0.007 0.013 0.013 | 1795 | 1835 | 1798 | 1832 | 1790 | 1833 | 167 | 50 |
| Y4 | 39 | 1583 | 1606 | 0.004 0.008 0.008 | 1563 | 1603 | 1566 | 1600 | 1535 | 1616 | 191 | 50 |
| Yb1 | 70 | 162 | 174 | 0.094 0.068 0.052 | 142 | 182 | 145 | 179 | 28.5 | 190 | 186 | 25 |
| Yb2* | 70 | 1501 | 1511 | 0.033 0.042 0.046 | 1481 | 1521 | 1484 | 1518 | 1411 | 1570 | 264 | 30 |
| Yb3 | 70 | 1309 | 1329 | 0.013 0.016 0.018 | 1289 | 1329 | 1292 | 1326 | 1224 | 1381 | 251 | 50 |
| Yb4 | 70 | 1130 | 1141 | 0.009 0.011 0.012 | 1110 | 1150 | 1113 | 1147 | 1038 | 1197 | 242 | 50 |
| Zn1* | 30 | 993 | 997 | 0.257 0.296 0.278 | 973 | 1013 | 976 | 1010 | 945 | 1008 | 138 | 5 |
| Zn2 | 30 | 905.5 | 908 | 0.078 0.088 0.083 | 885.5 | 925.5 | 888.5 | 922.5 | 868 | 943 | 144 | 15 |
| Zn3 | 30 | 828 | 839 | 0.037 0.042 0.038 | 808 | 848 | 811 | 845 | 793 | 845 | 117 | 35 |
| Zn4 | 30 | 61 | 64 | 0.328 0.261 0.183 | 41 | 81 | 44 | 78 | 55 | 70 | 34 | 5 |
| Zr1* | 40 | 148.5 | 151 | 0.369 0.298 0.204 | 128.5 | 168.5 | 131.5 | 165.5 | 136 | 155 | 43 | 5 |

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| Name | At.# | N(E) Peak | dN(E) Peak | S _x 3/5/10 | Acquisition: Lower/Upper | | Analysis: Lower/Upper | | B1 | B2 | Test Width | Swps |
|------|------|--------------|---------------|-------------------------|-----------------------------|------|--------------------------|------|------|------|---------------|------|
| Zr2 | 40 | 1836 | 1844 | 0.018 0.036 0.043 | 1816 | 1856 | 1819 | 1853 | 1809 | 1857 | 173 | 30 |
| Zr3 | 40 | 1921 | 1929 | 0.006 0.016 0.020 | 1901 | 1941 | 1904 | 1938 | 1897 | 1940 | 173 | 50 |
| Zr4 | 40 | 1672 | 1695 | 0.007 0.012 0.015 | 1652 | 1692 | 1655 | 1689 | 1621 | 1706 | 200 | 50 |