Impedans
PLASMA MEASUREMENT

Semion Single / Multi System

Installation & User Guide

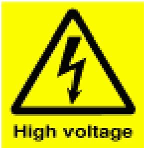
Unit 8 Woodford Court,
Woodford Business Park,
Santry, Dublin 17,
Ireland.

Phone: +353 - 1 - 8428826
Email: support@impedans.com
Web Site: www.impedans.com

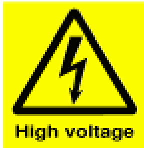
Revision: 1.0	Date: 20-11-13
Author: KON	Approved: DG

Safety Information

The following safety precautions should be observed before using this product and any related sensors and accessories.



Caution! High Voltages Present



Voltages of up to 1600V can be generated on the output terminals of this device. Due care and attention must be given to the installation and operation of the equipment.

This electronic equipment must be installed and operated in accordance with the guidelines in this user manual.

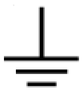
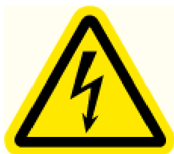
Personnel who operate this equipment must be properly trained in electrical safety and related procedures.

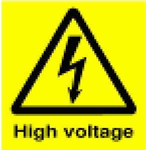
Before use, carefully check all cables including mains, USB, and HV BNC cables to identify damage. Replace any damaged cables immediately. Ensure that the mains lead is connected to a properly earthed supply.

Do not touch any cables during operation of the equipment. Ensure that all equipment is powered off before installation.

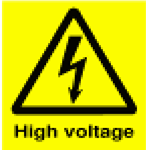
Replace blown fuses with an equivalent part. Any other replacement parts should be ordered directly from Impedans Ltd.

Symbols

			
Alternating Current	Earth Terminal	CAUTION! Risk of electric shock	CAUTION! Important Safety Information



Caution! High Voltages Present



High RF and DC voltages may be present inside the main feedthrough enclosure. A typical enclosure is pictured above.

NB: Never detach the feedthrough from the reactor while the RF bias is being applied to the electrode on which the Semion Multi sensor is mounted.

Technical Information
Semion Multi Control Unit

Electrical Requirements:	100 – 240 V~ 1.6 A 47-63 Hz

Environmental conditions

Environment:	Indoor use only.
Maximum Relative Humidity:	95% (RH), non-condensing
Operating Temperature:	0ºC to 50ºC

Technical Information
Semion Multi Sensor and Feedthrough

Maximum Continuous Operating Temperature:	150^0 C
*Maximum RF Voltage applied to the RFEA	1 kV peak-to-peak
*Maximum DC Bias Voltage applied to the RFEA	-1500 V

***The DC Bias Voltage and peak-to-peak RF Voltage limits arise for different reasons and one does not have to be de-rated based on the other i.e. the sensor will continue to operate with 1 kV peak-to-peak RF Voltage and -1500 V DC Bias applied simultaneously.**

Technical Specifications

Control Unit Output Voltages	
GRID 1	0 to -1600V
GRID 2	-1500 to +1500V
GRID 3	-1500 to +1500V
COLLECTOR	0 to -1600V
RFEA Specifications	
Maximum Energy Range	2500 eV
Ion Energy Resolution	1 eV
Sensor Operating Conditions	
Maximum RF Bias Voltage	1 kV peak-to-peak
Maximum DC Bias	-1500V
Operating Temperature Range	0 to +150^0 C
Time Averaged Frequency Range	100 kHz to 80 MHz
Time Resolved Frequency Range	DC to 100kHz
Time Resolution	5us
SYNC signal specification	TTL (0-5V Square Wave)

Table of Contents

Table of Figures

1 Introduction

This document provides an overview of the Semion Multi system, including instructions for the installation and operation of the system hardware and software.

1.1 Revision History

Table 1-1: Installation and User Guide revision history.

Version	**Description**	Date
1.0	Released Document V1.0	20-11-13
1.1	Reformatting Document V1.1	23-06-14

1.2 Purpose and Scope

The purpose of this document is to provide the user with a complete overview of the Semion Multi system hardware and software. Instructions for hardware and software installation are included, as well as a detailed user guide to enable the user to carry out ion energy, ion flux and deposition rate analysis in plasma reactors.

1.3 Glossary of Terms

Retarding Field Energy Analyser (RFEA)
Semion Multi Control Unit (SCU)
Ion Energy Distribution (IED)
Radio-Frequency (RF)

1.4 Points of Contact

General:
Impedans Ltd.
Unit 8 Woodford Court,
Santry,
Dublin 17,
Ireland.
Phone: +353 (0)1 8428826
Web Site: www.impedans.com

2 Semion Multi System Overview

This section will give an overview of the Semion Multi™ RFEA system features and applications.

2.1 Ion Energy and Ion Flux Measurements

The Semion Multi system includes a retarding field energy analyser (RFEA) for ion energy and ion flux measurements at grounded, direct current (DC) biased and radio-frequency (RF) biased surfaces in contact with a plasma discharge. Energy resolution of better than 1eV is available. The ion angular distribution is also determined with a resolution of 3 degrees.

Low pass filters with high input impedance enable the RFEA to float at the bias potential and prevent disturbance of the electrode bias. The filters also have high attenuation at the output to protect the Semion Multi Control Unit (SCU) electronic circuitry from exposure to the applied bias potential.

2.2 Installation Environment

The Semion Multi system is designed for installation in a research laboratory or industrial environment. The RFEA is installed in the plasma chamber and is connected to the SCU data acquisition system through the air-to-vacuum feedthrough. The user configures the SCU using the application software to carry out data collection and analysis.

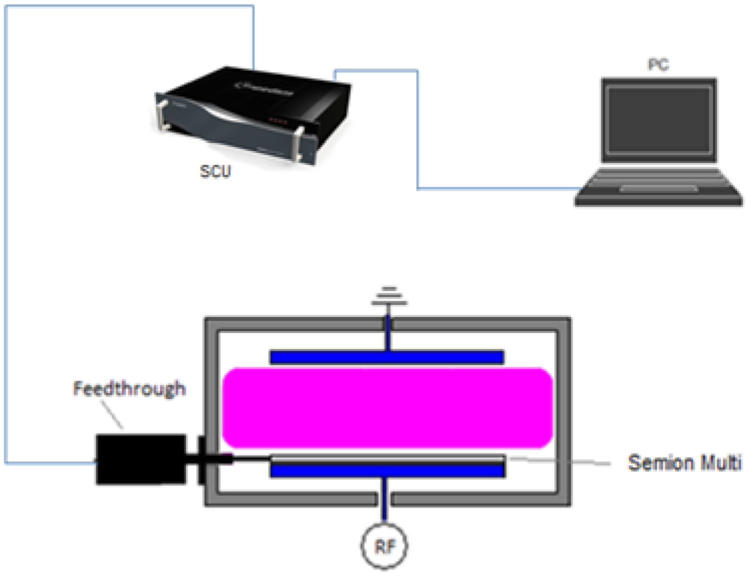


Figure 2-1: Schematic of a typical Semion Multi system installation

3 Semion Multi Hardware Components

The Semion Multi system is comprised of the following main hardware components – each of which is discussed in more detail in this section:

- Replaceable Button Probe kit
- Button Probe holder with 650mm cable as standard
- Vacuum feedthrough
- Semion Multi Control Unit
- USB, mains lead and four HV BNC cables for connecting the device

3.1 Replaceable Button Probe Kit

The Semion Multi replaceable Button Probe sensing elements contain the main retarding field energy analyser components. The standard system contains 13 individual Button Probes. The Button Probe contains 4 independently biased grids and a collector electrode. The housing material may be aluminium, stainless steel, hard-anodised aluminium or ceramic coated aluminium/stainless steel. To complete the sensor, the Button Probes mate directly into the Button Probe holder.

Figure 3-1: Semion Multi replaceable Button Probes

3.2 Button Probe Holder

The standard holder for the Button Probes is 300mm in diameter; other sizes are available on request. The holder material may be aluminium, stainless steel, hard-anodised aluminium or ceramic coated aluminium/stainless steel for use in a wide range of applications and suitable for installation in etch and deposition reactors. The holder is fitted with a signal cable covered with a protective ceramic layer. The standard cable length is 650mm; custom lengths are available on request. Figure 3.2-1 shows an example of a 300mm Button Probe holder.

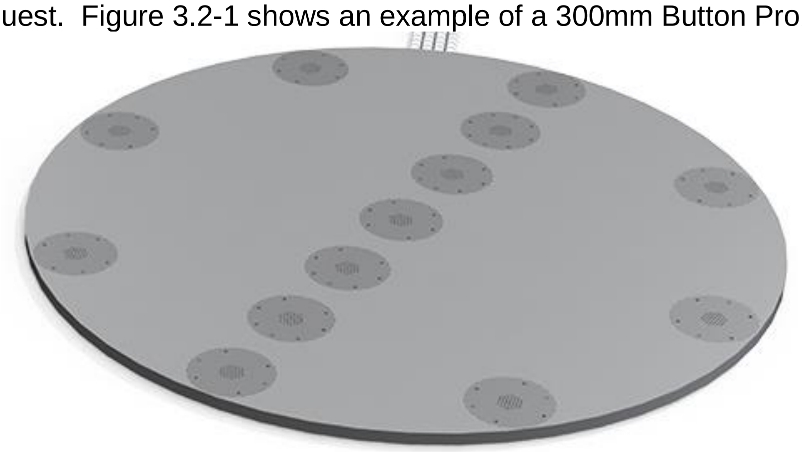


Figure 3-2: Standard 300mm Button Probe holder.

3.3 Semion Multi Vacuum Feedthrough

The sensor is installed inside the vacuum chamber. Electrical signals are passed to and from the sensor through the multi-core cable assembly. The cable assembly comprises high temperature wiring protected in a high temperature sleeve, all of which is insulated from the plasma with a flexible ceramic shield. The vacuum feedthrough makes the interface between the vacuum and the air side of the reactor. The sensor cable is terminated with a 17 pin plug which mates to the socket in the feedthrough on the vacuum side.

Figure 3-3: Semion Multi feedthrough.

3.4 Semion Multi - RF Filter Specification

The Semion Multi feedthrough enclosure houses the low pass filter elements which enable the sensor to float at the bias potential applied to the surface on which it is mounted. The filter is located in the feed-through in order to provide high impedance to the bias frequency.

Low pass Filters with high input impedance at the frequencies of interest, placed between each grid/collector and the RFEA electronics, ensure that the grid/collector maintain the electrode RF potential. These high input impedance filters prevent loading of the RF electrode impedance. Critically, these filters also have high attenuation at the output preventing any RF voltage drop across the RFEA electronics. The Semion Multi feedthrough enclosure incorporates the terminals for connecting the RFEA sensor to the SCU data acquisition unit.

Figure 3.4-1 shows the typical low pass filter impedance versus frequency characteristic. Figure 3.4-2 gives the attenuation at the filter output as a function of frequency.

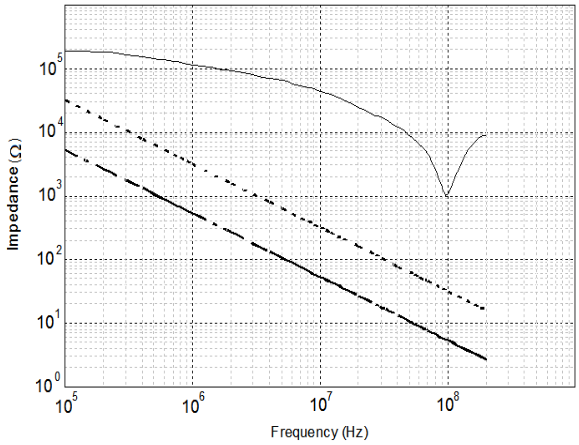


Figure 3-4: Filter input impedance as a function of frequency.

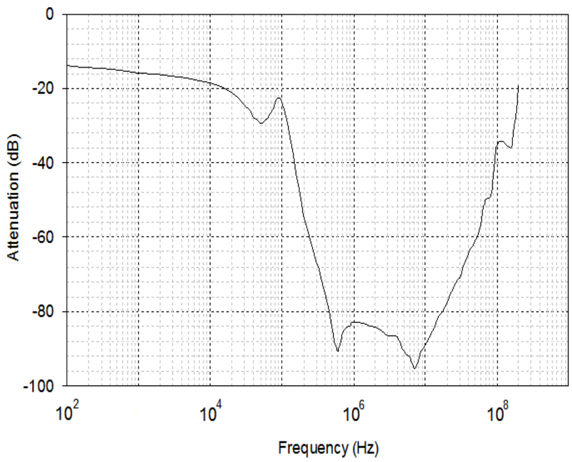


Figure 3-5: Filter output attenuation as a function of frequency.

3.5 Semion Multi Control Unit

The Semion Multi control unit is a versatile scientific instrument which provides a controlled high-voltage source and high-precision low-current measurement system in a single self-contained unit.

Figure 3-6: SCU rear panel connections.

Table 3-1: SCU rear panel connection details.

1	MAINS	Mains supply. See technical information section.
2	USB	Connects the SCU to a host PC. Semion Multi host PC software controls the SCU and displays data.
3	SYNC	Sync input port. Time-resolved mode requires a synchronisation signal. TTL (0 to 5V Square Wave).
4	EARTH	Provides access to SCU electrical earth point.
5	COMMS	Provides a digital communication bus between the feedthrough and the SCU
6	G2	Provides the voltage sweep to G2 to discriminate ions based on their energy.
7	COLLECTOR	Provides the voltage to the collector electrode and returns the ion current for detection.
8	G1	Not used
9	G3	Provides the secondary electron suppression voltage to G3.

For the Semion Multi RFEA system application, the SCU acts as a multi-voltage source meter. The Semion Multi software allows the user to configure the grid voltages in the RFEA sensor and to measure the ion current reaching the collectors. The outline specifications are as follows:

Working Voltage Ranges

Table 3-2: Voltage ranges for SCU output channels.

Channel	Minimum Voltage	Maximum Voltage	Voltage Accuracy
G1	N/A	N/A	N/A
G2	0	+/-1500	+/- 1%
G3	0	+/-1500	+/- 1%
COLLECTOR	0	-1600	+/- 1%

Source Channel Current Measurement Ranges[1]

[1]Minimum current 15nA

Table 3-3: Current measuring ranges for the SCU.

Range	Minimum Current	Maximum Current
1	-6 µA	+6 µA
2	-60 µA	+60 µA

The SCU connects to a host PC via USB. The operation of the SCU is covered in more detail in the following sections.

Figure 3-7: Semion Multi data acquisition unit.

4 Semion Multi Hardware Installation

This section describes the installation procedure for the Semion Multi RFEA system hardware. Diagrams and photos provided in this section may deviate from the user's actual system hardware; this is due to the multiple variations in chamber layout, sensor holder design and feed-through specification. However, the system installation should be similar for most platforms.

4.1 Pre-Install Checklist

The following components are required for the Semion Multi system installation;

- 13 Button Probes mounted in Button Probe holder
- Vacuum feed-through assembly
- 4 x HV BNC cables, 3m long
- Semion Multi Control Unit (SCU) & mains cable
- USB cable and communications cable
- Semion Multi software installer
- PC with spare USB port

Tools

- Tools may be required to access the plasma chamber to facilitate the placement and installation of the sensor/sensor holder and to attach the feed-through and filter box to the reactor.
- Cleaning materials to wipe down the sensor before placement in the plasma chamber.

4.2 Installation

Step 1

Place the sensor assembly in the reactor at the desired location. Figure 4.2-1 shows a 300mm Semion Multi RFEA probe.

Step 2

Once the probe is secure, feed the probe cable through a chamber vacuum port where the feed-through will be connected. The system is equipped with a CF40 flange as standard.

Step 3

The next step involves attaching the sensor cable to the feed-through assembly. The 17 pin plug at the end of the sensor cable mates directly to the matching socket in the re-entrant ceramic tube section of the feedthrough. There is only one orientation in which the plug will mate to the socket.

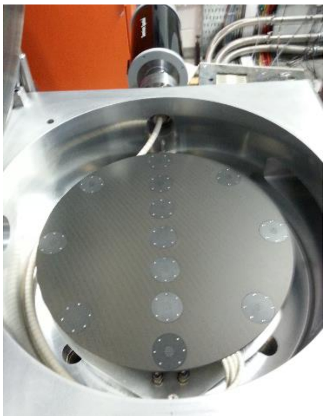


Figure 4-1: Semion Multi probe installation.

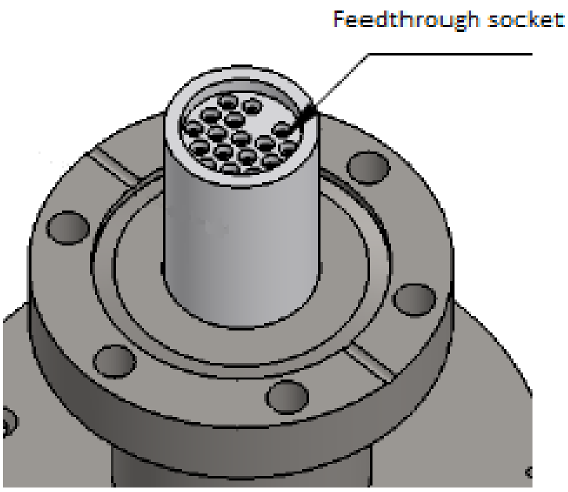


Figure 4-2: Schematic of the 17 pin feedthrough socket which accepts the plug from the Semion Multi sensor cable.

Figure 4-3: The Semion Multi sensor cable plug.

Step 4

Once the sensor cable is plugged fully into the feedthrough socket the CF40 flange should be bolted securely to the matching CF40 chamber flange. If the vacuum chamber is equipped with the KF flange type then an adapter can be requested at the time of order.

4.3 SCU to Feedthrough Connection

The Semion Multi control unit voltage output channels are labelled to match the appropriate connectors on the feedthrough assembly. This is to ensure that the correct voltages are applied to the correct grids inside the RFEA sensor. Connect the HV BNC and COMMS cables supplied according to Table 4-1 below.

The cable connections are as follows:

Table 4-1: SCU -to-Feedthrough connection details.

Feedthrough	Semion Multi Control Unit
Not connected	Grid 1
Grid 2	Grid 2
Grid 3	Grid 3
Collector	Collector
Comms	Comms

5 Software Installation

This section details the installation of the Semion Multi application software.

Note: It is recommended that the user has Administrator access rights to install the software.

5.1 Semion Multi Application Software

To install the Semion Multi software:

1. Ensure that the Semion Multi hardware is disconnected from PC.
2. Launch the Semion Multi software installer. The “Preparing to install” dialogue may be displayed.
3. A security dialogue, similar to that shown in Figure 5-1 may appear and can be ignored by choosing “Run”

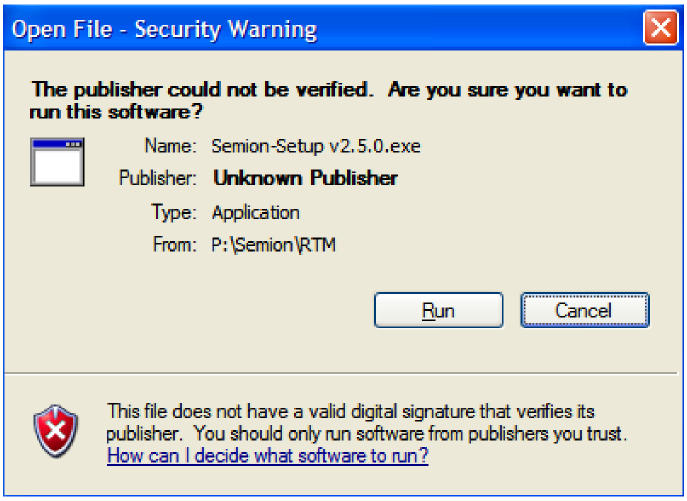


Figure 5-1: Security warning dialog.

4. The installer splash screen will be shown.

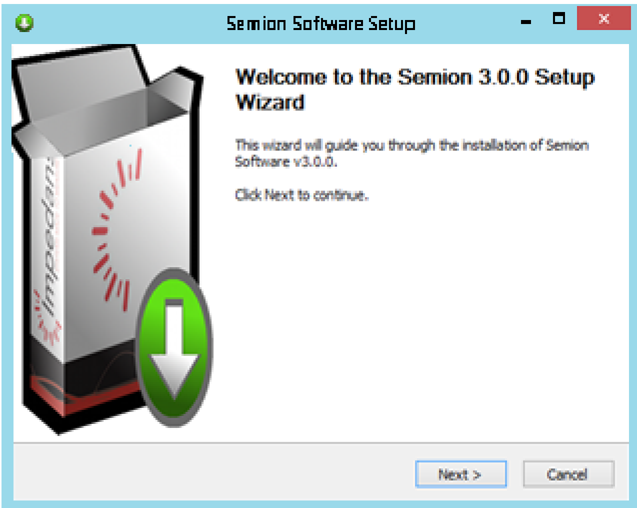


Figure 5-2: Semion Multi software setup wizard.

5. To install the Semion Multi software click “Next”.

6. **Choose Components**: The Semion Multi application is enabled by default. The user can also specify if they wish to create a 'Desktop shortcut' and 'Remove previous Semion Multi User Settings'.

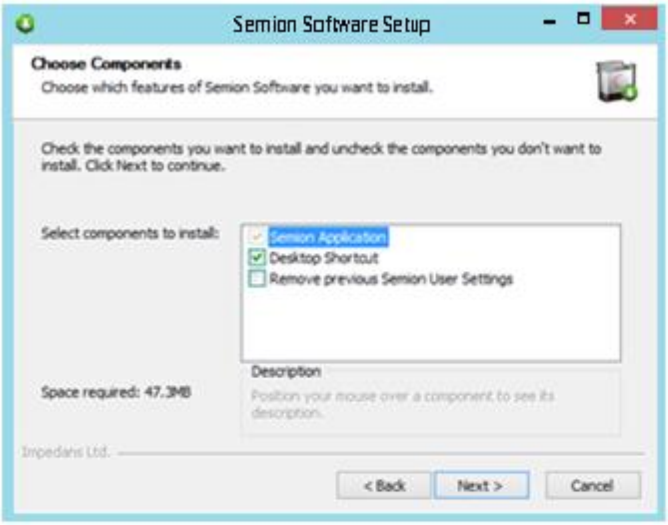


Figure 5-3: Components installation selection wizard.

7. In the case where the Semion Multi software was installed and errors with the installation were encountered, it is advised to select the "Remove previous Semion Multi User Settings" option.

8. **Choose Install Location:** Click "Next" to proceed. Then select the 'Destination Folder' for the installation. The default location is shown below. Click 'Install'.

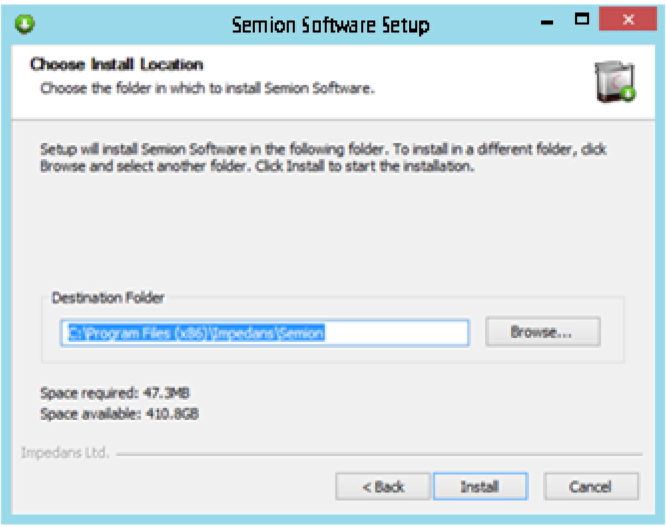


Figure 5-4: Install location selection.

9. The software and USB drivers will now be installed or upgraded as required. The following screen will appear. The installation may take a few minutes to complete.

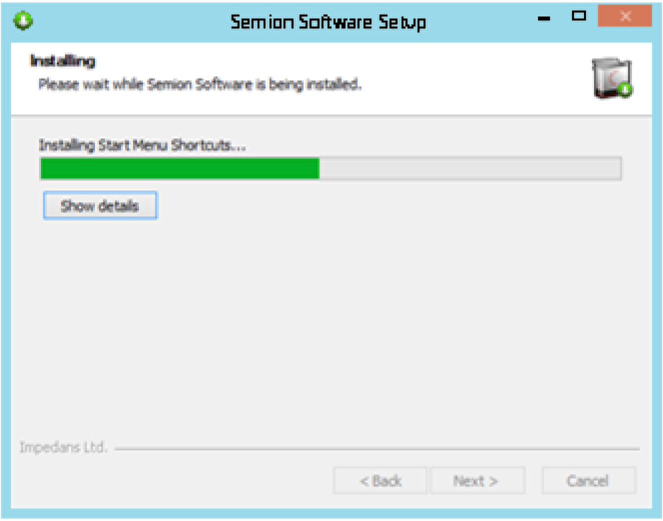


Figure 5-5: Screenshot of software installation.

10. Complete the Semion Multi software installation by clicking ‘Finish’.

Figure 5-6: Complete the installation.

11. If the ‘Launch Semion Multi Application’ check box was enabled then the software will launch automatically. Otherwise go to the installation directory and run the executable file.

12. When the Semion Multi application software is launched the following Graphical User Interface (GUI) will be displayed. The application software installation can be found on the CD supplied with the system.

5.2 USB Driver Installation

The Bitwise USB device driver is installed on to the system during the software installation, but it normally requires an additional step when the Semion Multi system hardware is connected to the PC and switched on for the first time.

1. Connect the SCU to the PC and power it on. Windows will detect a new USB device and will request to install a driver for it.

2. Choose “Install software automatically (Recommended)” and click Next.
3. Windows will copy the required files from the systems driver storage location.
4. A message will appear to notify that the software has not passed Windows Logo testing. This is normal, select “Continue Anyway” to proceed.

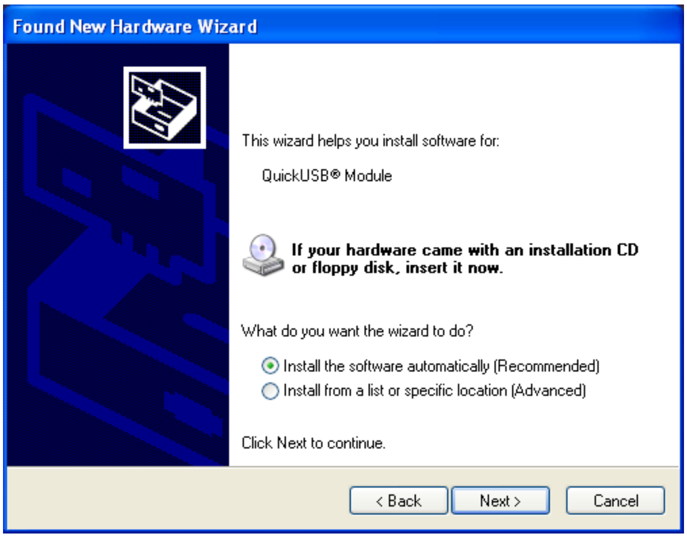


Figure 5-7: USB driver installation wizard.

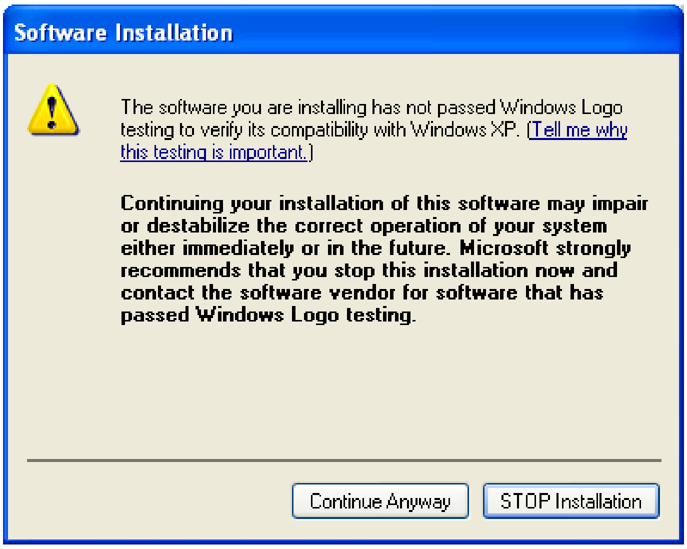


Figure 5-8: Software installation notification.

5. When the USB driver installation is complete click “Finish”.

Note: *This procedure may need to be repeated if the SCU is connected to another USB port.*

6 Semion Multi Software User Guide

With the software installation complete, the Semion Multi system is ready to be initialised and configured for ion energy distribution measurements. This section details the main features of the Semion Multi software.

The Semion Multi GUI is designed to allow the user to configure the properties of the data acquisition to generate the current-voltage characteristic and resultant IEDF with adequate energy range, energy resolution and signal-to-noise ratio. The application software can be configured to perform single or a defined number of scans automatically.

When performing a series of scans automatically, it is possible to average all the data recorded to increase the signal to noise ratio or view all the recorded data for each scan separately.

6.1 Initializing the Semion Multi System

To initiate communication between the SCU and the PC through the application software, the followings steps should be followed:

- Connect all cables between the SCU and the PC.
- Power on the SCU hardware.
- Launch the Semion Multi application software

6.2 Semion Multi GUI Overview

A screenshot of the Semion Multi GUI is shown in Figure 6-1.

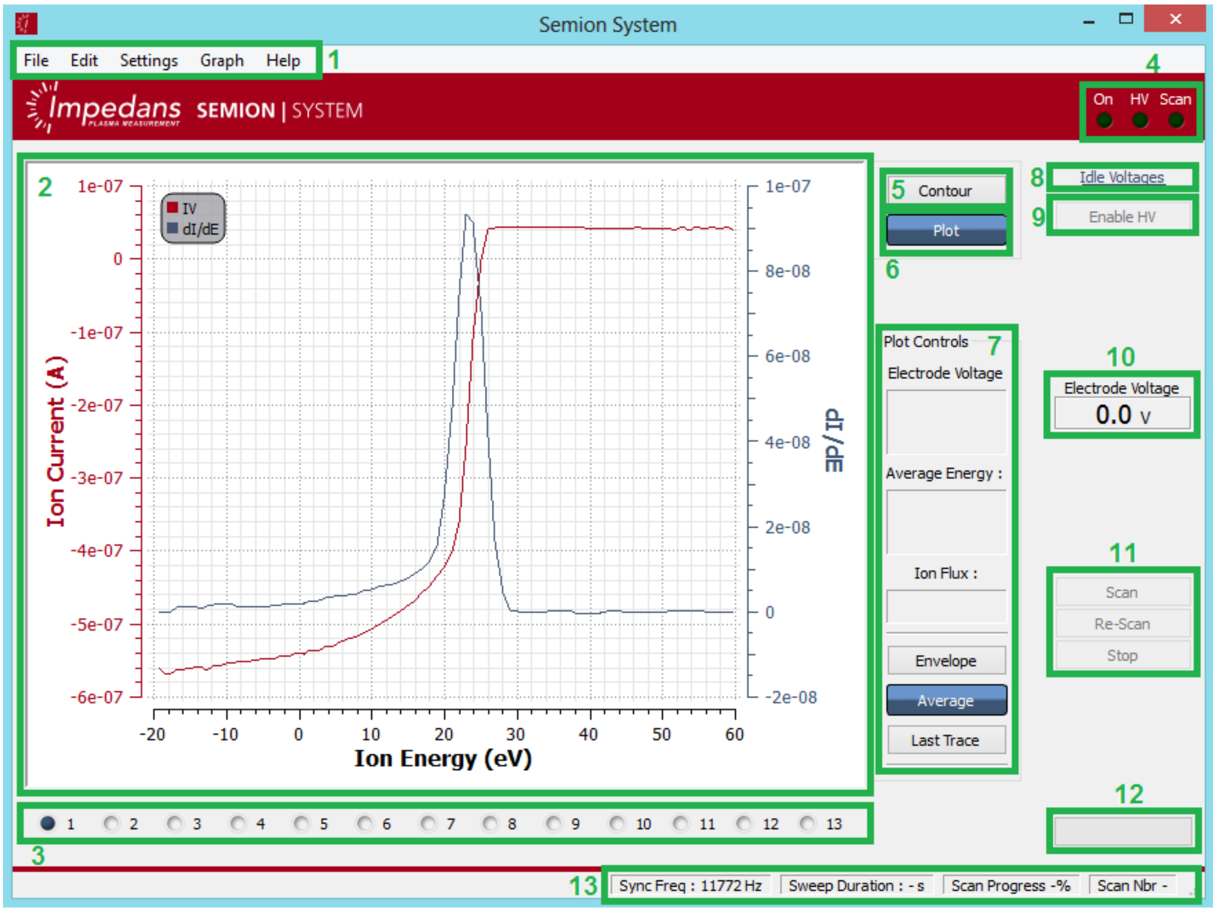


Figure 6-1: Semion Multi Graphical User Interface.

The screen can be broken into 13 main sections as described below:

1. Main Toolbar
2. Graphical Display
3. Sensor Selection Bar
4. Connection Indicators
5. Contour Map
6. XY Plot
7. Plot Controls
8. Idle Voltage
9. Enable HV
10. Electrode Voltage
11. Scan Control
12. Scan Progress Bar
13. Status Indicator

6.2.1 Main Toolbar

The main toolbar contains a number of menus which are used to configure the data capture, analysis, export etc. The tool bar menus are discussed in detail in section **Error! Reference source not found.**.

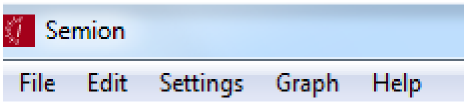


Figure 6-2: Main toolbar menus.

6.2.2 Graphical Display

The main graph window displays the current-voltage (IV) characteristic and its first derivative which is proportional to the ion energy distribution function. These graphical display is controlled by the ‘Plot controls’ menu seen in Figure 6-11. The different graph options are discussed in more detail in the following sections.

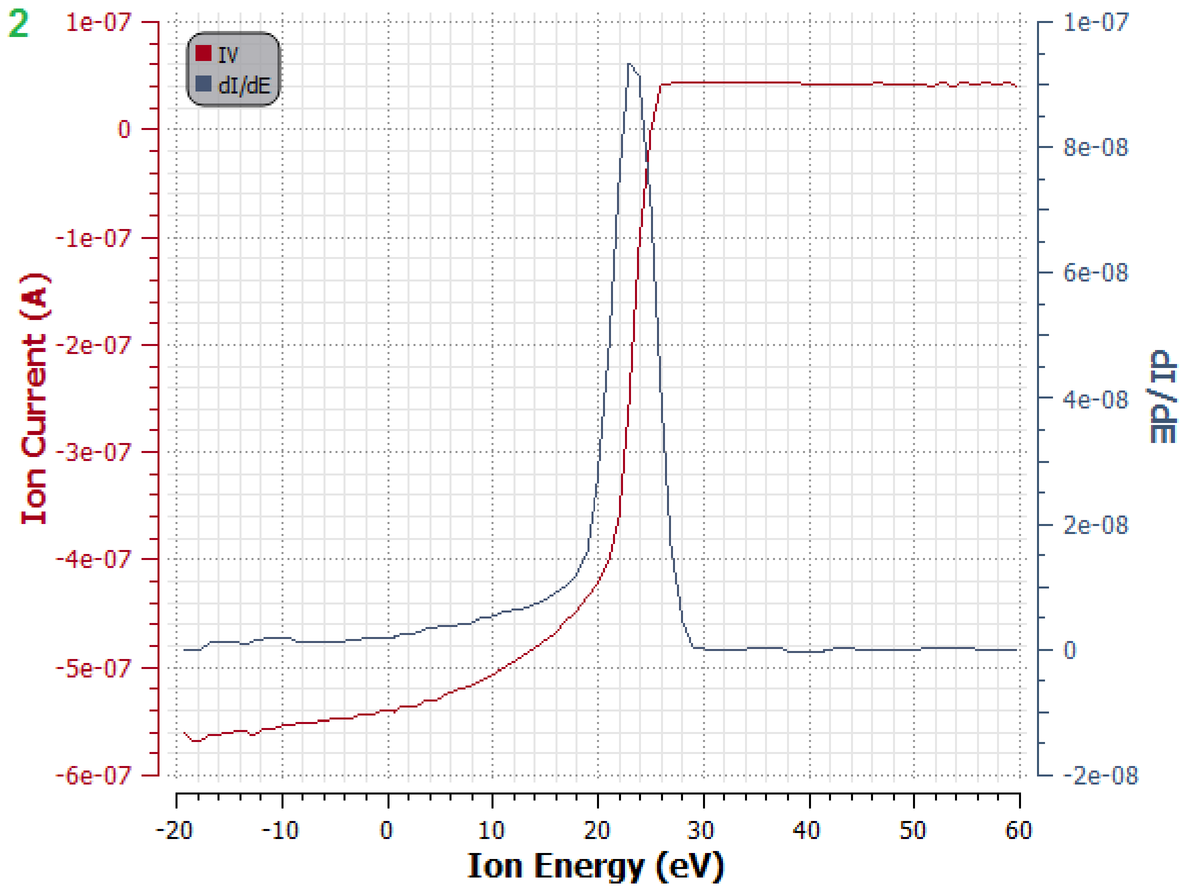


Figure 6-3: XY Plot.

6.2.3 Sensor Selection Bar

The sensor selection bar in the Semion Multi-Sensor mode enables the display of data from an individual sensor in the form of a plot in the graphic window. The data for a sensor is displayed by selecting the appropriately numbered tab.

Figure 6-4: Multi sensor selection bar

6.2.4 Connection Indicators

The connection indicator display in the top right hand corner of the GUI allows the user to see the status of a number of parameters. These parameters are:

1. On
2. HV (High Voltage)
3. Scan

The 'On' indicator light turns green when the software initiates communication with the Semion Multi sensor control unit. This is done automatically once the USB cable is connected and the hardware is powered on.

The ‘HV’ indicator light turns green when the ‘Enable High Voltage’ option is selected. This prepares the internal HV power supplies for data acquisition.

The ‘Scan’ indicator light turns green when the software is running a scan.

Figure 6-5: Connection Indicators

6.2.5 Contour Map

The contour map displays a profile of the measured average energy and ion flux from the 13 individual sensors. The average energy data is displayed in a place-holder above each sensor’s graphical representation, with the ion flux data in a place-holder below. Each graphical sensor representation is numbered.

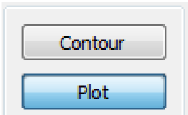


Figure 6-6: Graphical display options

In contour mode there is a colour coding scheme in place. In the average energy function, red represents the highest measured energy, while blue represents the lowest value measured. There are a number of different ways that this data can be displayed. The controls for this display are:

Figure 6-7: Contour plot controls

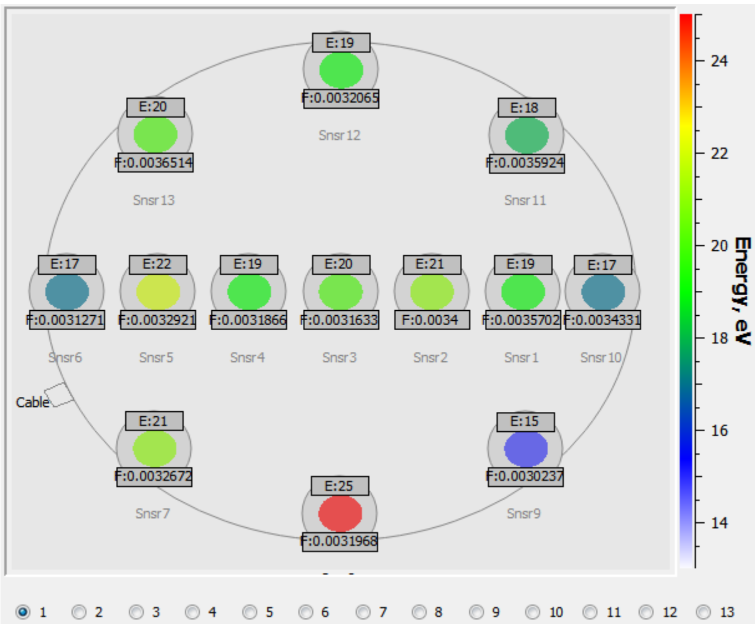


Figure 6-8: Contour map - 'Labels' on and ‘Interpolation’ off.

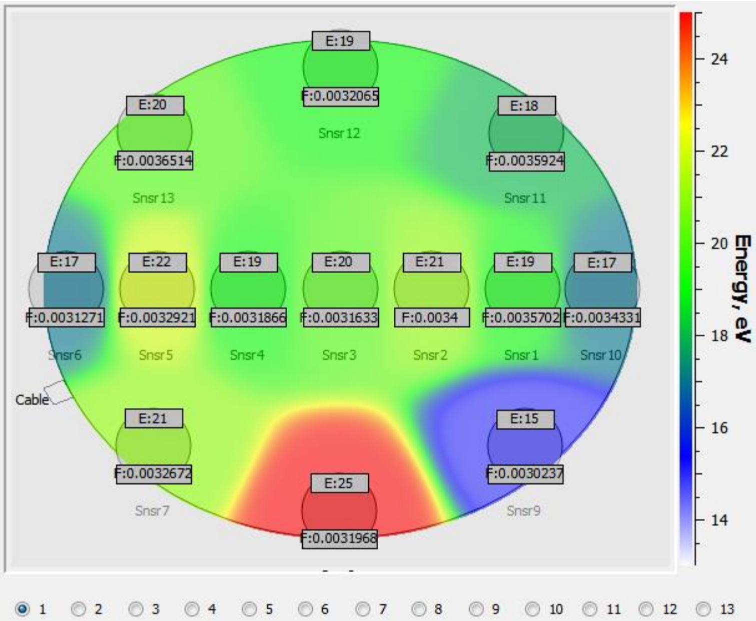


Figure 6-9: Contour map - 'Labels' on, 'Interpolation' on.

In the two figures above, the labels containing sensor measurement data have remained on. The figure below displays the effect of turning these labels off, with interpolation mode still on.

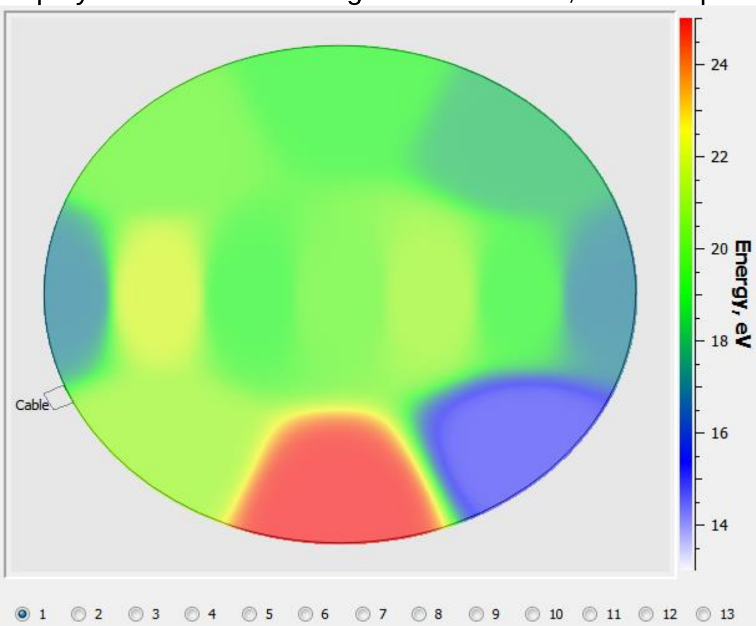


Figure 6-10: Contour map - 'Labels' off, 'Interpolation' on.

6.2.6 Plot – XY

The plot option displays a plot of IV and IEDF against energy. The IV plot has units of [A] on the left hand y-axis and the IEDF is measured in units of [a.u.] on the right-hand y-axis.

6.2.7 Plot Controls

The plot that is displayed can be controlled by selecting envelope, average or last trace. An individual sensor data can be selected by clicking the appropriate number on the selection bar at the bottom of the graph.

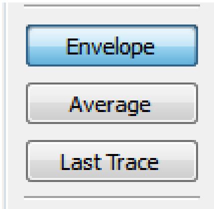


Figure 6-11: Plot controls

- **Average**
  The average function displays the average of all individual scans collected.

- **Envelope**
  The envelope function displays all the individual scans on the graph at the same time.

- **Last Trace**
  The last trace function displays the last scan only.

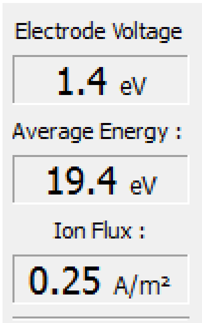


Figure 6-12: Displayed Parameters determined from the IEDF measurement.

A set of indicators can be found to the right of the graphical display:

- **Electrode Voltage**
  The time averaged electrode voltage (often referred to as Vdc).

- **Average Energy**
  The average energy of the measured distribution function.

- **Ion Flux**
  The approximated ion flux determined by integration of the measured IEDF.

Underneath the main graphical display there is a secondary graph. This graph is used for a number of purposes:

- Time Averaged Mode – Time Trend Display
  The user can configure the system to plot a time trend graph of the average energy or ion flux. This graph gives plots the parameter selected versus time. Left click on the graph area to enable a cursor to allow scrolling through the individual time frames. The main graph will display the IV curve and IEDF for the time frame selected.

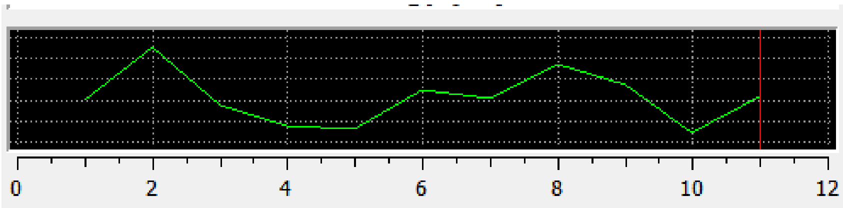


Figure 6-13: Plasma parameter evolution graph.

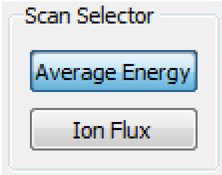


Figure 6-14: Scan selector controls

- Time Resolved Mode – Pulse Trend Display
  The user can also configure a time resolved scan to plot the IEDF and ion flux as a function of time through the synchronisation pulse period. Left click on the graph area to enable a cursor to allow scrolling through the individual time frames. The main graph will display the IV curve and IEDF for the time frame selected.

The scan selector has two options:

1. Average Energy
2. Ion Flux

Average Energy
The average energy of the IEDF.

Ion Flux
The ion flux determined through integration of the IEDF.

6.2.8 Idle Voltage

When the idle voltage function is selected the following graphic window is displayed in the main GUI:

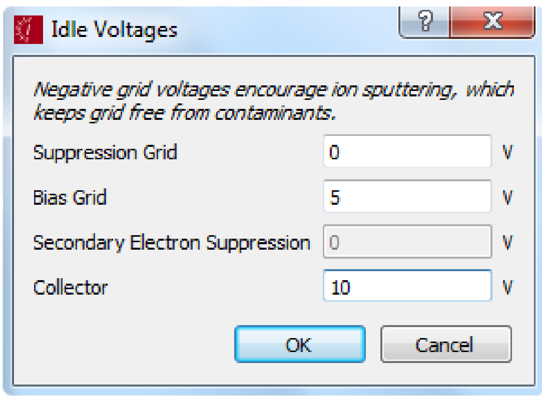


Figure 6-15: Idle voltages display

Through this dialog the user is able to adjust a series of grid voltage values including the suppression grid voltage (Grid 1), bias grid voltage (Grid 2) and the collector voltage. The secondary electron suppression (G3) is biased to -10V relative to the collector. These voltages are applied to the grids when the unit is in idle mode and can help to keep the grids clean while plasma is running.

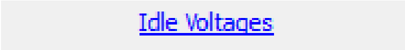


Figure 6-16: Idle voltages.

6.2.9 High Voltage Control

The Enable HV function arms the internal HV power supplies for data acquisition.

It should be noted that when the enable HV function is not selected, only temperature scans can be performed.

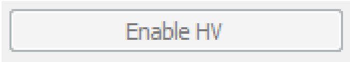


Figure 6-17: Enable HV option

6.2.10 Electrode Voltage

The Electrode Voltage indicator displays the time averaged potential of the sensor surface during the measurement. This voltage is the reference potential for the RFEA measurements.

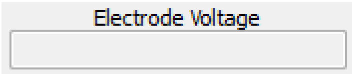


Figure 6-18: Electrode voltage display

6.2.11 Scan Control

The scan control allows the user to select the type of scan to be performed. There are three main scan types.

6.2.11.1 Temperature

A temperature scan provides the temperature of the button probes. Note that the Temperature scan is enabled by default. Once the Scan Type is selected the ‘Traces Per Scan’ control must be updated. This defines the number of individual consecutive scans to be performed and averaged together to provide adequate signal to noise ratio. Setting ‘0’ will instruct the hardware to continue scanning and averaging until the user clicks ‘Stop’. When any value >0 is entered the hardware will perform that number of scans before stopping.

The ‘Multiple Scans’ option allows the user to run multiple consecutive scans to look at the time trend of the substrate parameters.

- Interval; defines the length of time that the scan configured in ‘Scan Type’ is repeated and averaged. The user must ensure that the time duration of the ‘Scan Type’ configured is less that the ‘Interval’ selected.
- Length; defines the overall time duration for the ‘Multiple Scans’ to run.

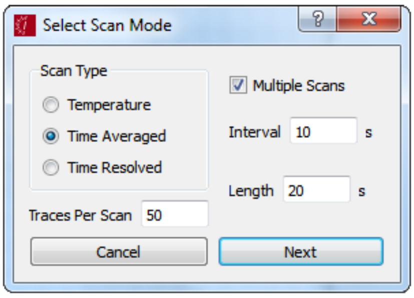


Figure 6-19: Simple mode scan settings

6.2.11.2 Time Averaged

This option selects the time averaged ion energy distribution measurement. Once the 'Scan Type' is configured, click 'Next'. Four menu screens will then be available for fine tuning the data acquisition for the 'Scan Type selected:

1. Voltages
2. Timing
3. Sync

An option for Quick Settings is also available in the top right hand side of the window.

Voltages

The 'Voltages' menu allows the user to configure the grid voltages for ion energy distribution measurements.

- Grid 1; used to repel plasma electrons that enter the RFEA, this value is not configurable but it set equal to the Collector voltage.
- Grid 2 Start; the starting point for the ion retarding potential sweep.
- Grid 2 End; the end point of the retarding potential sweep.
- Grid 2 Step; the step size of the retarding potential sweep
- Grid 3; used to suppress secondary electron emission from the collector, recommended -10V relative to Collector potential.
- Current Range; select the most suitable current range based on the ion current level detected.

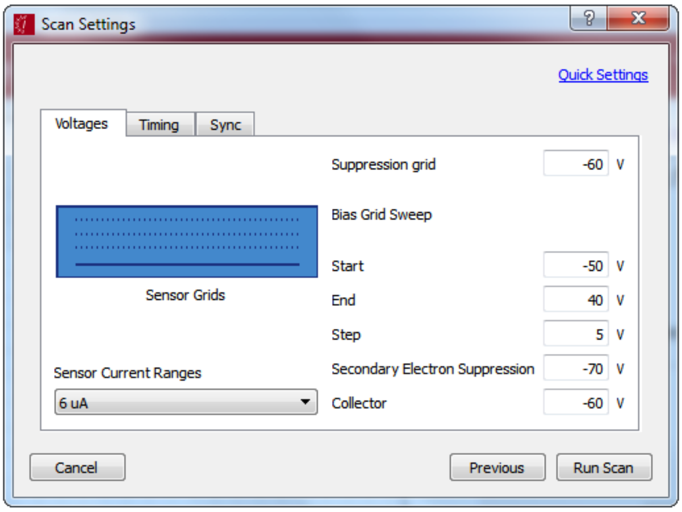


Figure 6-20: Advanced scan settings - voltages tab.

Timing
The timing menu contains a range of user-defined settings that control the settling times of the voltages applied to various grids in the RFEA during a scan. The settling delays are used to delay data capture until the transient currents that can be excited in the SCU circuitry have dissipated. These are detailed as follows:

- **Bias Grid settling time from the end of previous scan**
This delay (T1) is used to set a time delay between the end of one scan and the beginning of next. The purpose is to allow any displacement current induced in the system (as a result of the voltage switching from a large positive voltage at the end of one scan to a large negative voltage at the beginning of the next scan) to dissipate before beginning data collection for the next scan. This is illustrated in figure 6.2-12.

- **Bias Grid settling time from the end of previous step**
This delay (T2) is used to introduce a time delay, after the application of each individual voltage step, before current measurement begins. The purpose is to allow displacement currents induced during the voltage switch to dissipate before current measurement is initiated.

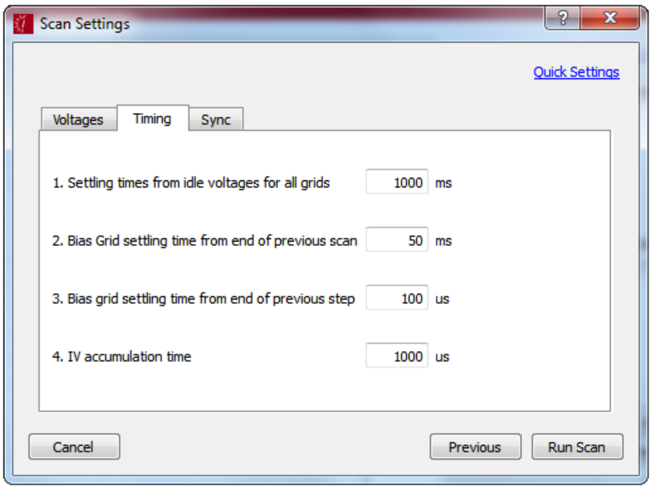


Figure 6-21: Advanced scan settings timing tab

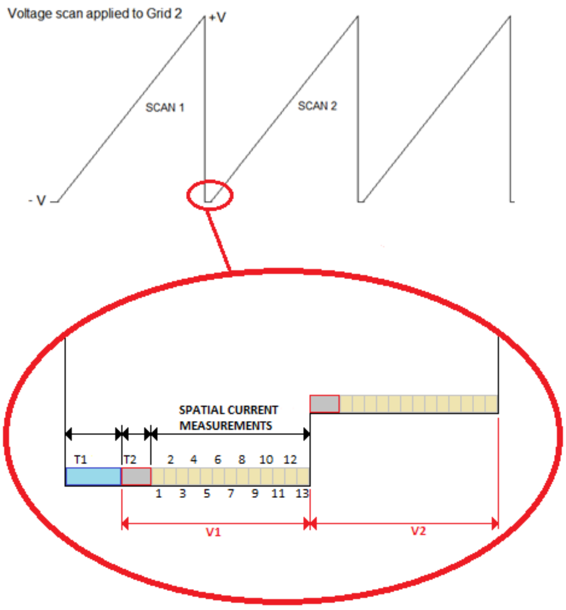


Figure 6-22: Schematic representation of the scan voltage applied to Grid 2. T1 is a time delay applied at the end of each scan, T2 is a time delay applied after each voltage step is set (V1 and V2 in this figure). After T2 has completed, the current to each collector is measured (in series using multiplexing) for the specified number of data samples.

- **IV accumulation time**

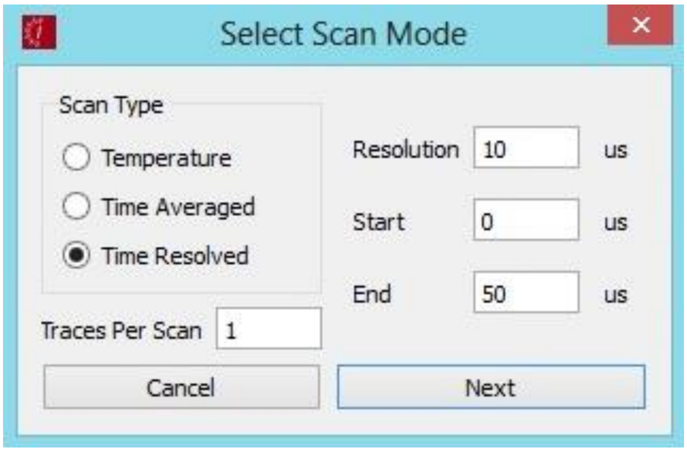
Time duration for ion current sampling for each button probe at each voltage step. The recommended setting is 2000us for initial tests. This can be reduced to speed up data acquisition if signal levels are sufficient. The sampling rate is 1us.

6.2.11.3 Time Resolved

The Time Resolved mode allows the user to measure the IEDF at specified times through a SYNC period.

- Resolution: this is the time window over which the IEDF is to be acquired and averaged. The resolution is 5us as standard.
- Start: the start time for the first time frame after the sync edge is received.

- End: the end of the time resolved acquisition window through the sync period.



Sync

The sync menu is used to configure time resolved scanning. An external TTL sync signal must be connected to the 'SYNC' input on the data acquisition unit.

- Resolution: time frame resolution for time resolved measurements, minimum is 5us.
- Start: start time relative to the 'Sync Edge'.
- End: end time during the sync period, must be less than (or equal to) the sync period.

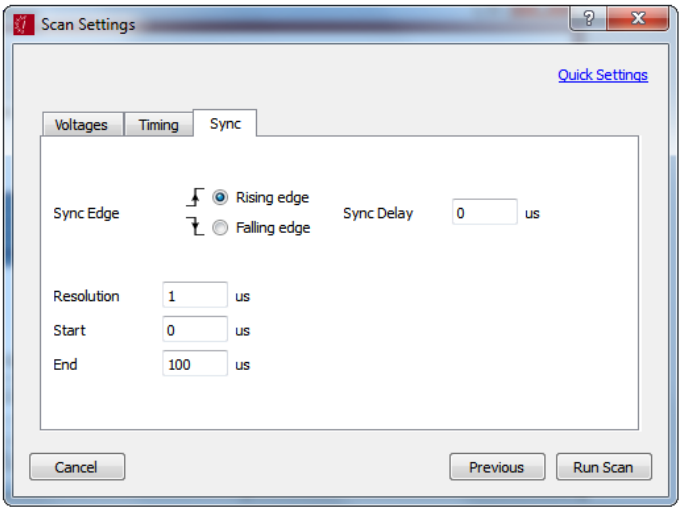


Figure 6-23: Sync menu.

6.2.11.4 Quick Settings

Selecting the 'Quick Settings' tab opens the following window. It provides a simplified range of settings which can be adjusted by the user. In this mode the user selects the Energy Range and Resolution and the software algorithm determines all the required grid voltages.

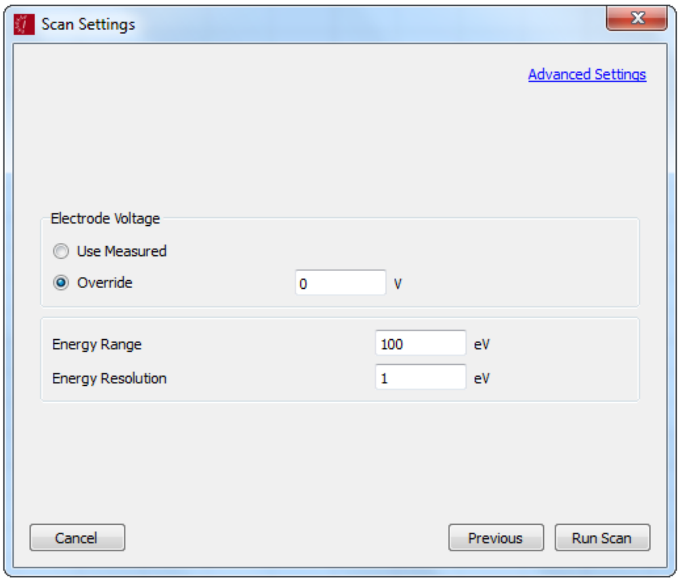


Figure 6-24: Scan settings- quick settings

Run Scan

Click on the ‘Run Scan’ button to initiate a scan as per the settings configured.

- **Re-Scan;** allows to user to re-scan with identical settings to the last scan performed.
- **Stop;** click once to stop the scan when the current sequence has finished, click twice to stop immediately.

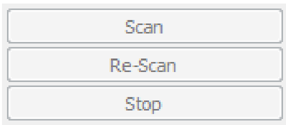


Figure 6-25: Scan initiator

6.2.12 Scan Progress Bar

The scan progress bar graphic displays the number of scans that have been completed in numerical form and as a graphical bar representation; the progress is displayed as percentage complete below the graphical progress bar.

Figure 6-26: Scan progression bar graphic

6.2.13 Progress Details

The progress details display a text description of how far a scan has progressed. It is situated in the bottom right-hand corner of the interface, and details the number of scans completed and this number as a percentage of the total scans completed.

Figure 6-27: Progress details

6.3 Main Toolbar Functionality

The main toolbar, located above the graphical display contains four menus – File, Edit, Graph, and Help.

6.3.1 File

The File menu is used primarily for loading, saving and exporting the measured data. The File menu has a number of sub menus as shown in figure 6-33.

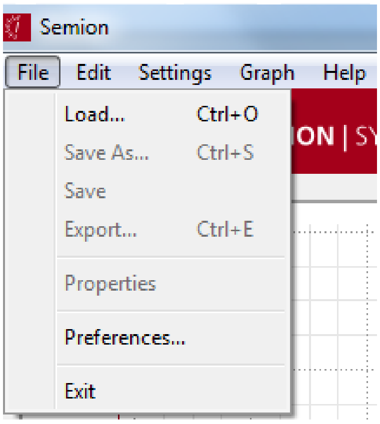


Figure 6-28: File menu.

- **Load**
The Load function allows the user to load previously saved .sdf files for review and further analysis.
- **Save As**
The Save As function allows the user to save the existing data in the native software format in a user specified location.
- **Save**
The Save function allows the user to save the existing data in the native software format in the default location.
- **Export**
The export function allows the data to be exported to spreadsheet (.csv) or Matlab (.mat) format. The dialog window also allows users to choose which data is to be exported. The 'only results' function exports only the data measurement results. The 'include averaged traces' and 'include all traces' export the average scan trace data and all the scan trace data respectively.

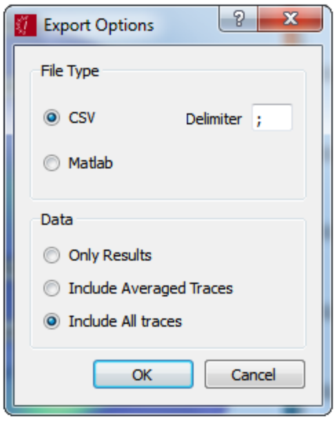


Figure 6-29: Export options dialog.

- **Properties**

The properties function opens a window with sensor parameter information, including voltages, temperature and ion flux.

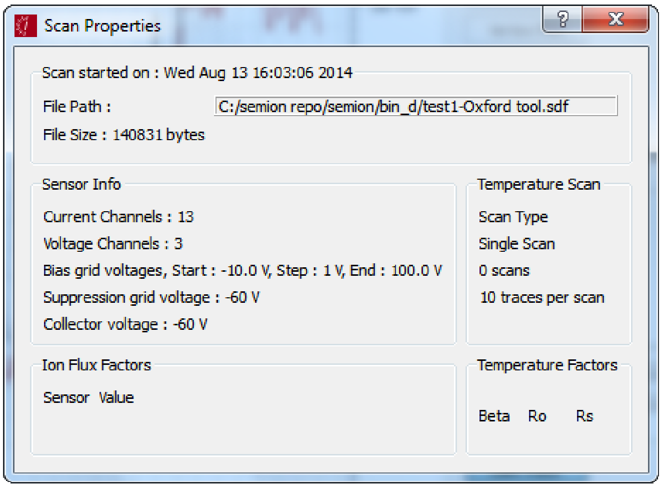


Figure 6-30: Properties window

- **Preferences**

The preferences function provides the user with advanced options for saving and logging data during a measurement session.

.

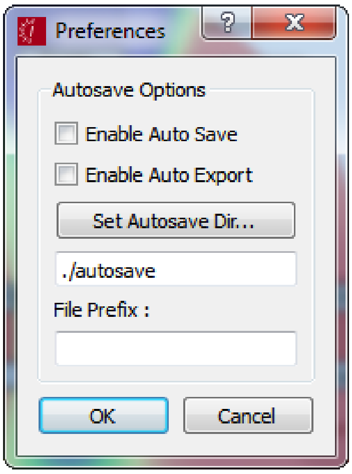


Figure 6-31: File menu and corresponding sub-menus.

Enabling the **'Auto save'** option and selecting the desired Directory location will configure the software to save all acquired data during the measurement session.

Enabling the **'Auto export'** option and selecting the desired Directory location will configure the software to export all acquired data during the measurement session.

6.3.2 Edit

The Edit menu provides an option to copy all data currently displayed in a format that can be pasted directly into a spreadsheet program such as Excel.

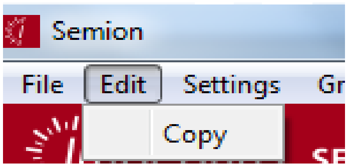


Figure 6-32: 'Edit' menu.

6.3.3 Settings

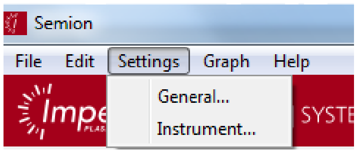
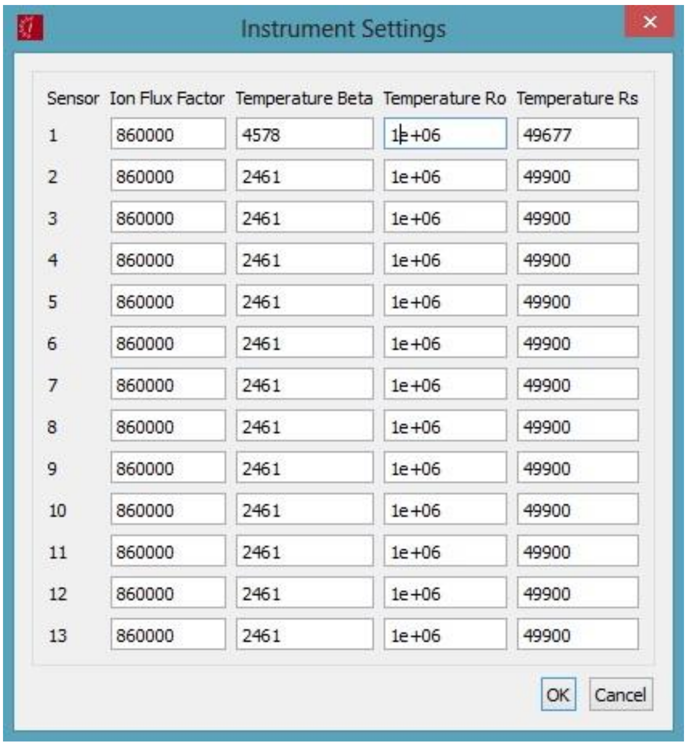


Figure 6-33: 'Settings' menu

Selecting the ‘Instrument’ tab in the ‘Settings’ menu displays a window similar to that shown below. This window is used to configure a set of constants associated with the button probe RFEA sensing elements:

- Ion Flux Factor; scaling factor used to convert measured current to absolute current density at the surface of the sensor. The default value is 860000. This value is the same for all standard button probes.
- Temperature Beta; coefficient associated with the temperature calibration of the button probe. This parameter will be clearly labelled on the hardware delivered.
- Temperature R_0; coefficient associated with the temperature calibration of the button probe. This parameter will be clearly labelled on the hardware delivered.
- Temperature R_S; coefficient associated with the temperature calibration of the button probe. This parameter will be clearly labelled on the hardware delivered.



Sensor	Ion Flux Factor	Temperature Beta	Temperature Ro	Temperature Rs
1	860000	4578	1e+06	49677
2	860000	2461	1e+06	49900
3	860000	2461	1e+06	49900
4	860000	2461	1e+06	49900
5	860000	2461	1e+06	49900
6	860000	2461	1e+06	49900
7	860000	2461	1e+06	49900
8	860000	2461	1e+06	49900
9	860000	2461	1e+06	49900
10	860000	2461	1e+06	49900
11	860000	2461	1e+06	49900
12	860000	2461	1e+06	49900
13	860000	2461	1e+06	49900

Figure 6-34: Instrument settings

6.3.4 Graph

The Graph menu has a number of options for controlling the graphical display.

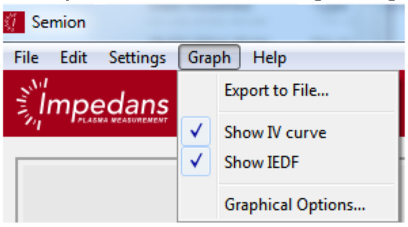


Figure 6-35: 'Graph' menu

- **Export to File**

Export to file allows the user to export the graph to a .pdf document.

- **Show IV Curve**

This option controls the display of the IV curve on the plot area. Deselecting it removes the plot from the screen.

- **Show IEDF**

This option controls the display of the IEDF curve on the plot area. Deselecting it removes the plot from the screen.

- **Graphical Options**

Selecting the 'Graphical Options' function will display the following window

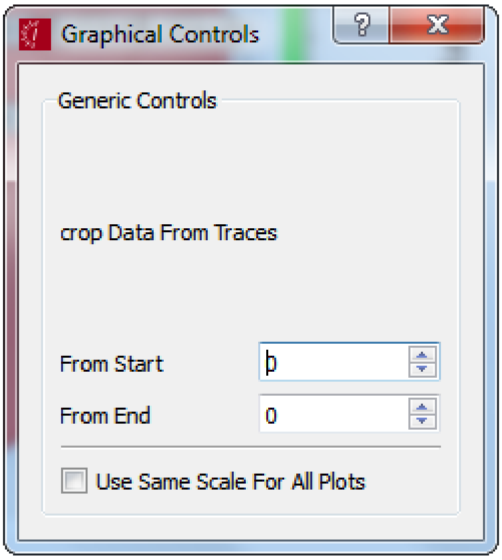


Figure 6-36: Graphical controls

This option allows the user to crop data points from the beginning and end of the graph. This can be useful if spikes occur at the beginning or end of the IEDF trace due to the numerical differentiation technique.

6.3.5 Help

The Help menu has a number of options to assist the user.

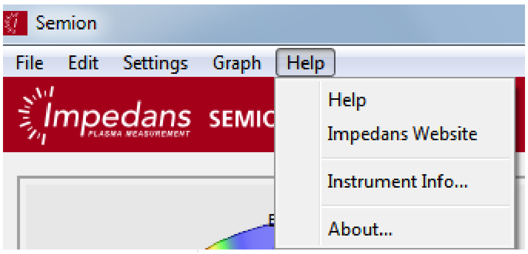


Figure 6-37: 'Help' menu.

Help
Clicking Help will open the Installation and User Guide.

Impedans website
Takes the user directly to the Impedans website.

Instrument Info
Provides information about the instrument hardware.

About
Clicking ‘About’ will open a window containing detailed information about the Semion Multi firmware and software versions.

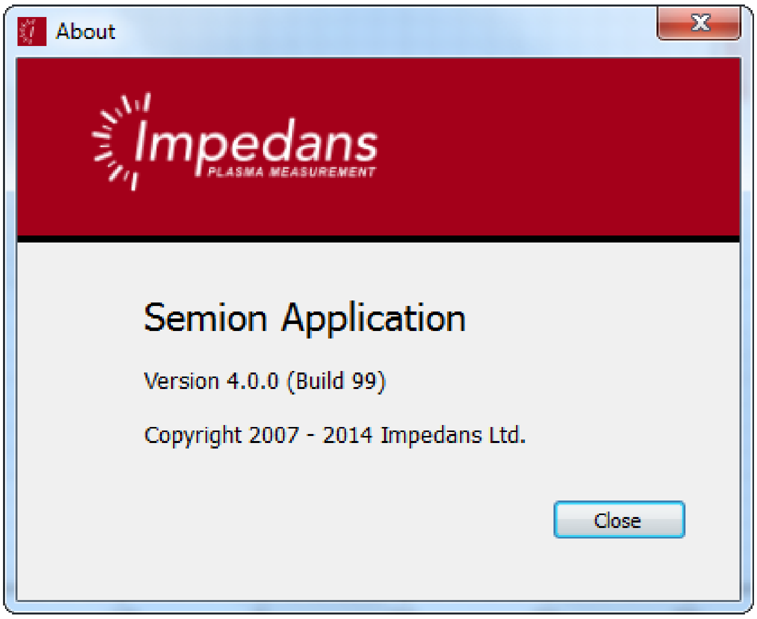


Figure 6-38: Semion Multi system information dialog.

7 Semion Multi – Theory of operation

The Semion Multi System consists of 13 retarding field energy analysers which are used to measure the ion energy distribution, ion flux and ion angular distribution at multiple spatial locations at a surface in a plasma reactor. That surface can be at ground potential (reactor wall), DC biased or RF biased (typically the substrate holder). For the majority of applications the RFEA will be mounted on the substrate holder, in place of the substrate.

7.1 RFEA Configuration

With the Semion Multi System hardware and software installed and initiated, the system can be configured to measure the ion energy distributions. Once the plasma is running under appropriate conditions, data collection can begin. The following schematic shows the RFEA structure and the bias configuration for each of the grids and the collector that make up this device.

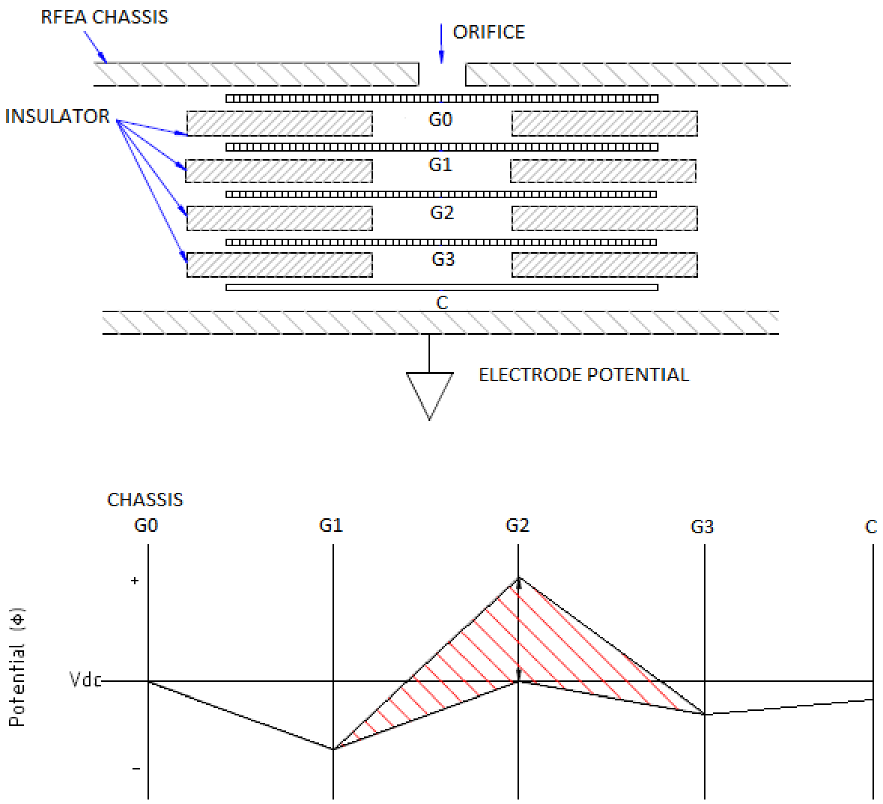


Figure 7-1: Schematic of RFEA structure and the bias configuration for positive ion discrimination.

- **G_0:** is a nickel grid with 20µm diameter aperture size whose function is to reduce the diameter of the sampling orifice to less than the Debye length to prevent plasma forming inside the RFEA structure.
- **G_1:** is a grid, with the same dimensions as G_0, to which a negative bias is applied, to repel plasma electrons (typically -60V relative to the DC potential of G_0).
- **G_2:** is a grid, with the same dimensions as G_0 and G_1, to which a positive potential sweep is applied to discriminate positive ions based on their energy.
- **G_3:** is a grid, again with the same dimensions, which is biased negatively with respect to C to prevent secondary electrons escaping from C (typically -10V relative to C).
- **C:** is the collector electrode to which a negative bias is applied to attract the ions for detection (typically -40V relative to G_0).

7.2 RFEA Operation

The following section describes how to set the potentials on the RFEA grids and collector plate to obtain accurate IED measurements at a surface in a plasma discharge.

7.2.1 Purpose of the Grids and Collector Plate

- The orifices (800 micron diameter) face the plasma and allow a sample of the ions into the RFEA for analysis.
- Grid G_0 covers the orifices from the back side (it is electrically connected to the orifice plate) to reduce the open area seen by the plasma. The grids (all identical) have a hole-size of 20 microns (50% transmission), which means that the open area seen by the plasma is 20 microns and will be below the Debye length for most plasma conditions encountered.
- Grid G_1 is used to repel any electrons that enter the analyser. The presence of electrons can distort the IED being measured. A negative dc bias, with respect to G_0 is applied to form a retarding field for the negatively charged electrons. Generally -60 V dc, with respect to G_0 is sufficient to repel all the electrons that enter the RFEA.
- Grid G_2 is used to discriminate ions with different energies. When a dc potential is applied to G_2 a dc electric field between G_2 and G_0 results. If the dc potential of G_2 is more positive than the dc potential of G_0 a retarding field to the positively charged ions is created.
- The Collector, C, is used to collect and record the ion current, as a function of discriminator potential, which passes through the discriminating field. A negative dc potential is applied to C. This potential is generally set to the same potential as G_1.
- Grid G_3, located between G_2 and C, is biased about 10V more negative than C. This creates a retarding potential for secondary electrons that can be emitted from the surface of C due to energetic ion impact. Thus, secondary electrons are immediately reflected back to C and the true IV characteristic can be measured.

7.2.2 Purpose of the Filters

- The Semion Multi RFEA is often placed on an rf biased surface. The orifice plate (which is part of the RFEA body) will then be rf biased to the same potential as the surface. Thus, to achieve accurate IEDF measurements all of the grids and collector plate must also be biased to the same rf potential.
- The RFEA is designed to have relatively large inter-layer capacitance (approximately 100 pF). The filters are designed to have high input impedance for the frequency range specified. This allows the rf potential at the analyser body to be almost fully coupled to the grids and collector since the filter input impedance is always much greater than the impedance associated with the inter-layer capacitance.
- The filters also have greater than 60 dB of attenuation at the output over the frequency range specified, preventing any significant rf current reaching the Semion Multi™ data acquisition unit.

7.2.3 Bias Settings for RFEA Grids and Collector Plate

Retarding Potential Sweep (G_2)

A potential sweep is applied to G_2 to provide the retarding field that discriminates ions based on their energy. The starting point of the sweep should create a 0 V retarding potential, for the incoming positive ions, between G_2 and G_0. This starting point allows ions of all energies through the RFEA for collection. In order to create this 0 V retarding potential (0 eV retarding field) G_2 is set to have the same dc potential as G_0. For example if the analyser is mounted on a grounded surface the RFEA body, and thus G_0, are biased to 0 V dc and so the starting point of the sweep is 0 V dc. If the RFEA is mounted on a capacitively coupled, rf driven electrode the RFEA body may be biased to a negative dc potential. For example this bias may be -100 V dc. In this case the 0 V retarding potential is created by starting the sweep at -100 V dc.

When a dc bias is present on RFEA body and G_0 it must be accounted for. The dc bias is measured automatically by the system and the data presented is corrected for this bias. The dc bias will be indicted in the GUI. The user may override the system determined dc bias is desired. The software adjusts the energy axis of the IED appropriately. The end point of the sweep should be set to the value where all ions are prevented from reaching the collector by the retarding field. The range of the scan should be increased until the collected ion current falls, and settles at, zero amps.

Electron repelling potential (G_1)
G_1 is normally biased 60 V dc more negative than G_0. If G_0 is at ground potential (0 V dc) then -60 V dc is applied. If G_0 is at -100 V dc then -160 V dc is applied to G_1 and so on.

Collector plate potential (C)
It has been determined experimentally that the collector voltage should be set at approximately -40V relative to G_0 to achieve optimum results.

Secondary suppression potential (G_3)
The potential applied to the secondary suppression grid is fixed at -10V relative to C.

Note: *The bias settings for the electron repelling grid and for the collector plate outlined above should serve as a good theoretical starting point for obtaining an accurate IED measurement. However there are situations where these settings need to be optimized e.g. -60 V may not always be sufficient to repel all the plasma electrons etc.*

7.2.4 Sample IEDF Measurement

Here we use the experimental set up shown in figure 7.2.-1 to demonstrate a typical IEDF measurement at the powered electrode in a CCP reactor.

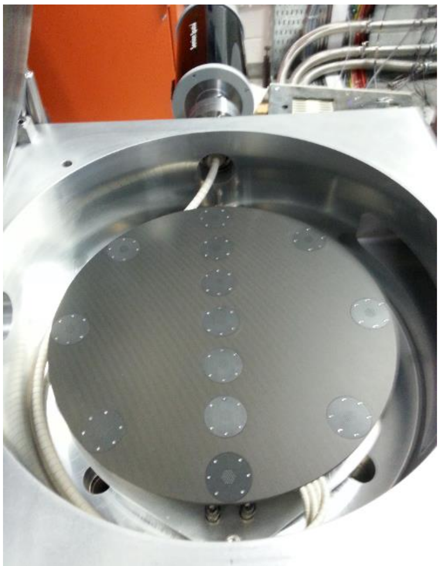


Figure 7-2: Schematic of experimental set-up.

The measurement was performed with the RFEA mounted on the substrate holder powered with 50W of RF power at a frequency of 13.56 MHz. Argon gas was used at a background pressure of 20mTorr.

A typical IV characteristic and resulting IEDF are shown in figure 7.2-2. The ‘saddle-shaped’ structure associated with RF biased sheath is clearly visible.

Impedans have a large database of data which covers a wide range of applications in grounded, DC (standard and pulsed), and RF biased processes. Our team is ready to answer any queries on the application of the Semion Multi™ system which is not covered in this user manual. Contact Impedans at our support center to discuss your application.

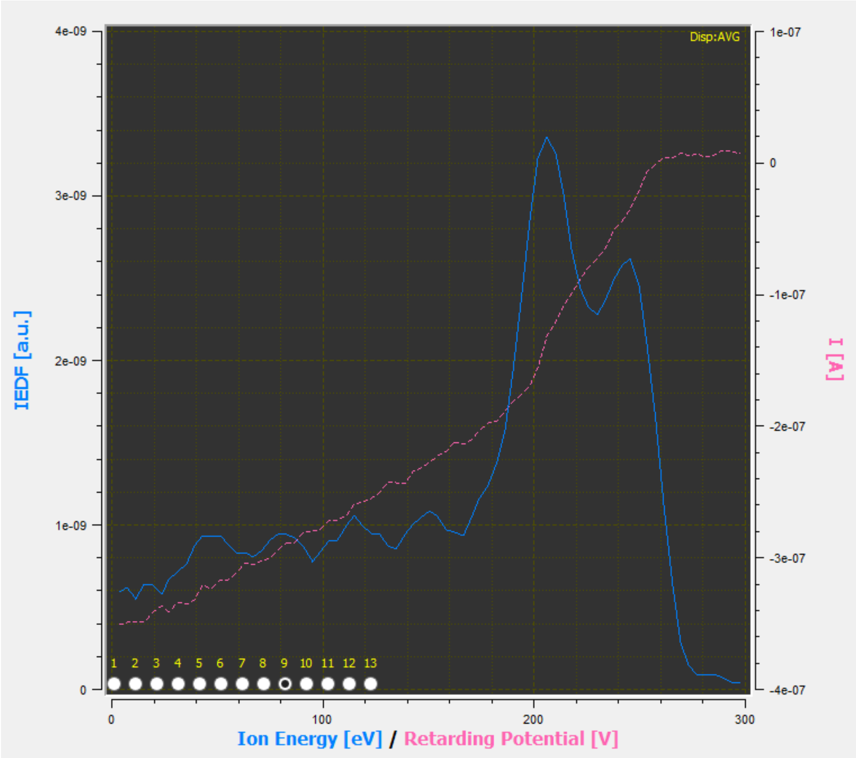


Figure 7-3: Sample IV characteristic and IEDF measurement in an RF CCP discharge.

8 Appendices

8.1 Appendix A: IEDF Calculation

The first derivative of the IV characteristic is proportional to the IEDF. The first derivative is calculated numerically using the method described below.

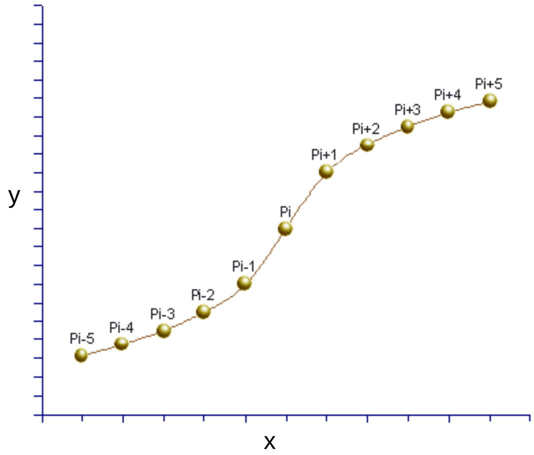


Figure 8-1: Sample IEDF plot calculation.

The formulae for the various methods are as follows:

Method 1:

$$f'(x_i) = \frac{y_i - y_{i-1}}{x_i - x_{i-1}}$$

Method 2 to 5:

$$f'(x_i) = \frac{\sum_{j=1}^{n} y_{i+j} - \sum_{j=1}^{n} y_{i-j}}{\sum_{j=1}^{n} x_{i+j} - \sum_{j=1}^{n} x_{i-j}}$$

where n=2 for Method 2, n=3 for Method 3, n=4 for Method 4, n=5 for Method 5 and P_i has co-ordinates $[x_i, y_i]$.

8.2 Appendix B: Ion Flux Density and Average Energy Calculations

The Semion Multi software calculates the total ion flux J_I<Am^{-2}> to the surface on which the sensor is mounted using a trapezoidal integration of the ion energy distribution (*IED*) arriving at the collector, scaled by a constant that incorporates the ion collection area (*A*) and the combined transmission of the grids (*T*)

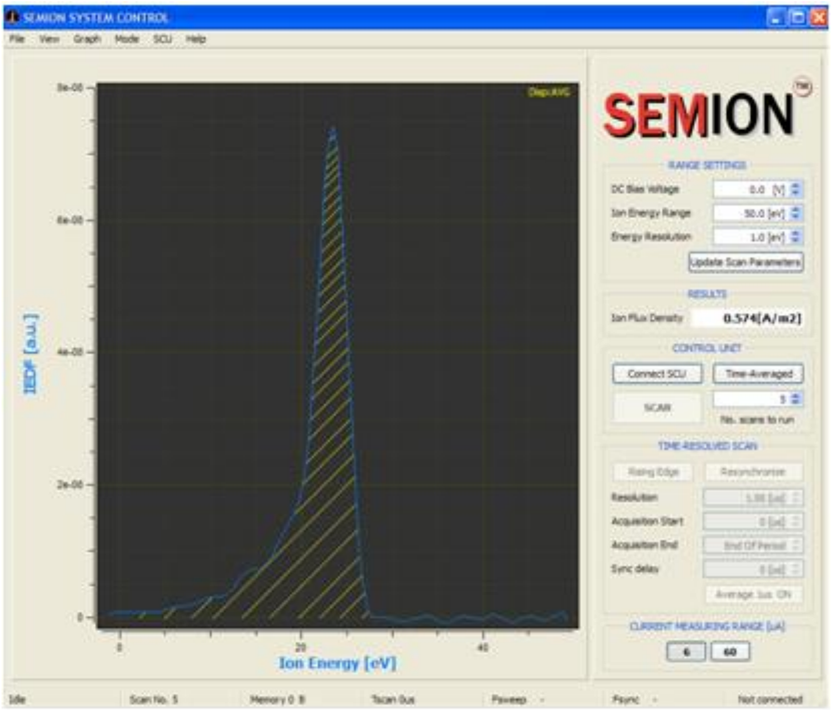


Figure 8-2: Ion flux density calculation.

$$J_i = \frac{\left(\int_{E_{\min}}^{E_{\max}} IEDdE\right)}{AT}$$

where E_{min} and E_{max} are the minimum and maximum energy displayed in the graphical user interface (GUI). If points are removed from the displayed IED using the advanced graphing feature the integral will be automatically recalculated. This allows the user to remove any unwanted features that may be present at the end points of the IED when the acquisition sweep frequency is high. The integration is performed using the trapezoidal rule:

$$\int_{E_{\min}}^{E_{\max}} IEDdE = \frac{1}{2}\sum_{i=1}^{n}(y_i + y_{i-1})(x_i - x_{i-1}),$$

where x_i and y_i are the points of the IED and *n* is the number of points. The collection area is given by the area of the orifice which consists of 37 circular holes each of diameter 800µm:

$$A = \pi r^2 \times 37 = 1.86 \times 10^{-5} m^2$$

The transmission of each of the 4 grids is 50% and so:

$$T = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = 0.0625$$

The screenshot in figure B shows an IED where the hatched area is calculated using the integration described above. In addition a user defined multiplication factor can be input to calculate the absolute ion flux and this calculated ion flux is displayed as shown. The default scaling factor is *1/AT* as defined above.

The average energy of IEDF is determined using the equation

$$E_i = \int_{E_{min}}^{E_{max}} Ef(E)dE / \int_{E_{min}}^{E_{max}} f(E)dE$$

8.3 Appendix C: Recommended Software Settings

This guide is provided to help the user configure the Semion Multi application software using the recommended software settings proposed by the product development team.

Advanced Settings mode

To configure the software correctly the user should launch the software and initialize the SCU as described in earlier sections. Recommended settings are shown in Figure 8-3.

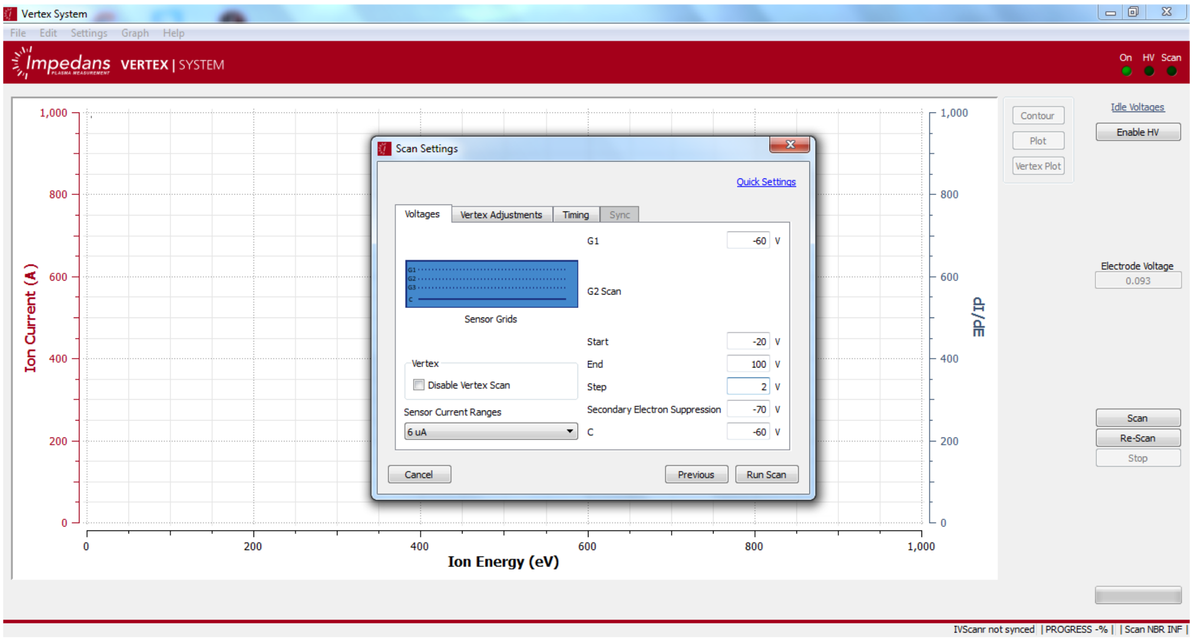


Figure 8-3: Recommended settings for Semion Multi software configuration.

Voltages

- Collector -60V (relative to Electrode Voltage)
- Grid 1 -60V (relative to Electrode Voltage)
- Grid 2 Start -20V (relative to Electrode Voltage)
- Grid 2 End Point where ion current drops to zero
- Step 1% of the scan range

The recommendation is to set all idle voltages to 0V. Advanced users may find uses for non-zero idle voltage settings.

Timing

- Bias Grid settling time from the end of previous scan 10ms
- Bias Grid settling time from the end of previous step 100us
- IV accumulation 2000us

It is recommended that the integration time is set to a value of 2000 μs. This will ensure optimal signal to noise performance. If the data has low noise levels then the integration time setting can be reduced to speed up data acquisition.

These recommended settling delays have been determined experimentally. If a large dip or peak in the ion current is seen at the beginning of the IV curve it may be due to displacement currents flowing in the SCU™ circuitry. In this scenario the settling delays should be increased.

Quick Settings Mode

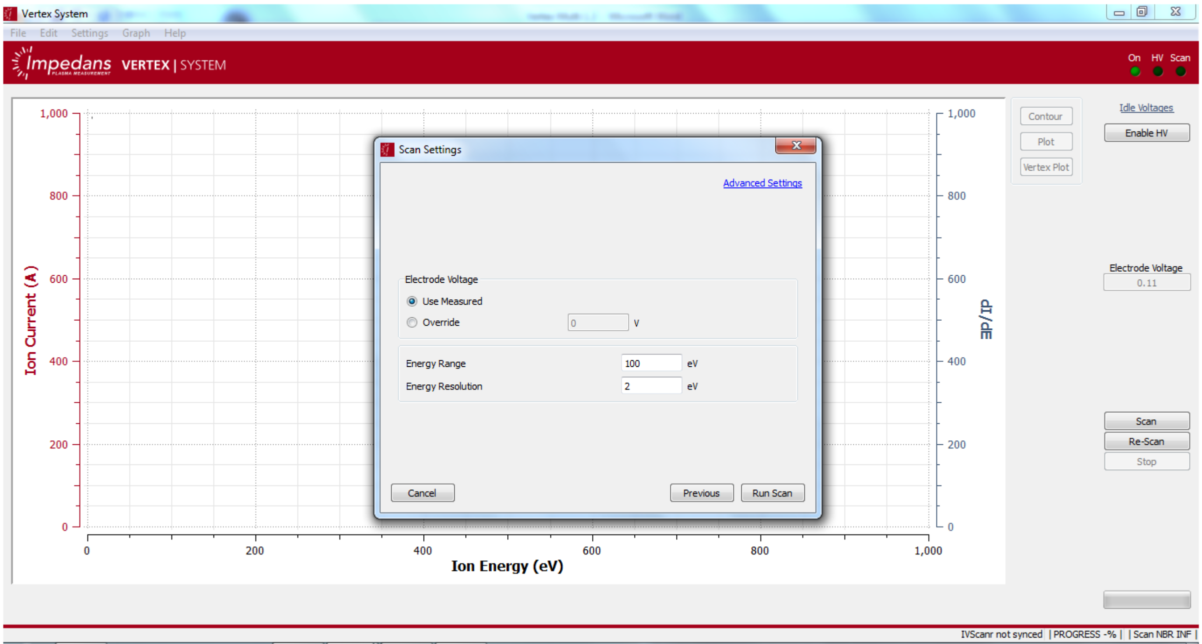


Figure 8-4: Semion Multi software setup - automatic mode.

Range Settings

- Energy Range   100 eV
- Energy Resolution   1 eV

Set the Ion Energy Range as required. If the expected range is unknown then a good guess is 100 eV. The range can be adjusted up or down depending on the first measurement.

Set the energy resolution. This is typically about 1% of the energy range to see all the features in the ion energy distribution.

Click ‘Run Scan’ to initiate data acquisition.

8.4 Appendix D: Semion Multi Probe Numbering

The figure below shows the rear view of the standard 300mm Semion Multi holder with Button Probe numbering. The two screws at either side of each number are used to hold each Button Probe in place. To remove a Button Probe simply unscrew the two M2x5 screws and the Button Probe will be released from the holder.

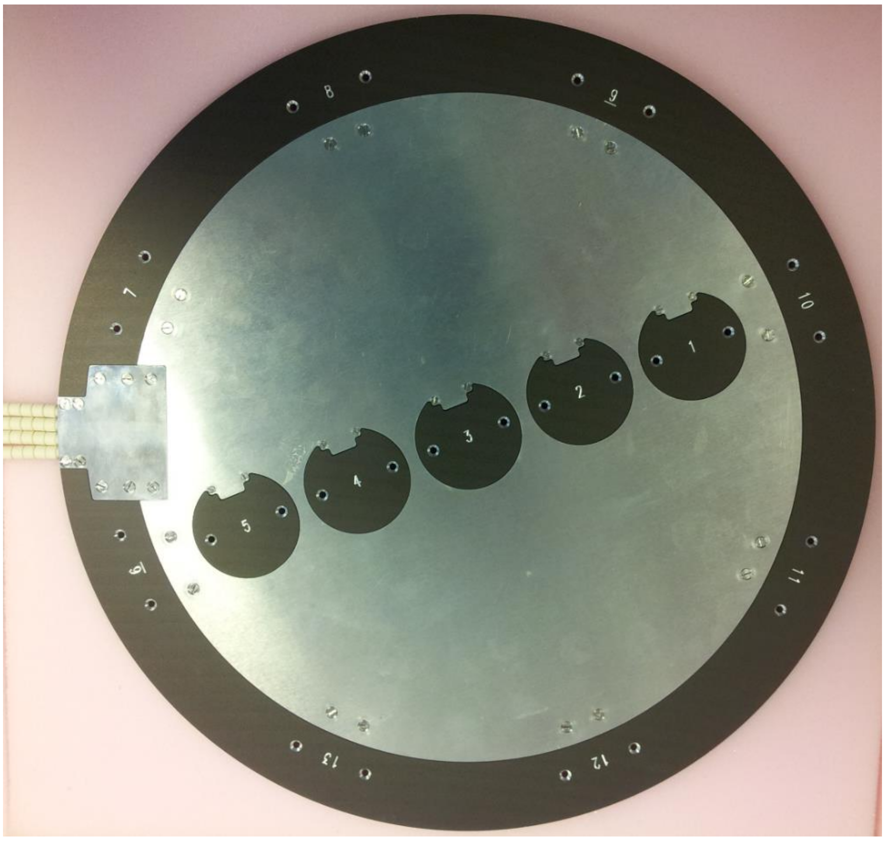


Figure 8-5: Rear view of Semion Multi holder with Button Probe numbering.

The following instructions should be followed to safely install and remove Button Probe from the holder.

1. Place the holder and Button Probe assembly face down on a smooth surface so as not to damage the orifice plate of the probe. Then remove the two M2x5mm screw from the rear of the assembly to release the Button Probe

2. Place the new Button Probe into the vacant position in the holder by lining up the spring contacts of the Button Probe with the receiver contacts in the holder. Hold in position and turn the holder over to fix the mounting screw in positions.

The system is now ready for installation and IEDF measurements can be performed immediately.

References

D. Gahan, B. Dolinaj and M. B. Hopkins, *Rev. Sci. Instrum.,* 79, 033502 (2008).