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Stanford Nano Shared Facilities
NanoPatterning Cleanroom

E-Beam Lithography: A Practical Guide

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USER EXPERIENCE

Introduction

Every researcher comes from a unique background with varying degrees of lab experiences. This practical guide will focus on how to navigate Stanford Nano Shared Facilities: NanoPatterning Cleanroom. As our name implies, the NanoPatterning Cleanroom (NPC) revolves around our electron beam lithography capabilities for nanoscale fabrication. Our facility is proud to provide researchers with all the equipment necessary to create an e-beam lithography (EBL) process from start to finish. This Practical Guide will inform the user on what equipment, services and materials NPC provides to our e-beam community to better support each user's process development. The NPC staff is a valuable resource to train users and help tackle each user's EBL challenges.

PROCESS GOALS AND FLOW

Application

Ideally, everything in a process can be optimized. However, users may be more concerned about one process parameter over another depending on the application. For example, photonic applications may require smaller beam currents, step sizes or specific tool equipped with a fixed-beam-moving-stage (FBMS) in order for low edge roughness to prevent signal loss. Quantum devices may desire sub 10-nm features to align to previous EBL layers and require more alignment steps and thereby increase tool usage time. A production prototype might be concerned with minimizing exposure time and prefer higher beam currents and larger writing fields. Whatever desired application, a researcher may choose to focus on optimizing one particular aspect. Therefore, consider the application to optimize certain specifications.

Another consideration is what is the final pattern transfer method? The final pattern transfer will determine what process parameters to choose. Knowing what the smallest and largest features in your pattern will help determine other parameters of your process like aspect ratios of a feature to select the resist thickness. The final pattern transfer would determine whether the resist should be a single layer of etch resistant material or a bi-layer resist stack for better lift-off profile and the thickness of the layers. The substrate size and material used will determine how simple or complex the EBL process might be because there is a great different between a 3 inch silicon wafer versus a 1x1 mm^2 sapphire die.

These subjects will be briefly reviewed in the following sections for your consideration.

PATTERN DESIGN AND PREPARATION

Computer-Aided Design (CAD)

EBL is a maskless or direct-write process. In order for the EBL system to write a pattern, the user must input a pattern file into the EBL system to write. The patterns are usually designed using computer-aided design (CAD) software. Free CAD software can be downloaded online through various vendors. All major CAD files can be used at NCP.

Fracturing Pattern Data

Once a CAD file containing pattern designs is created, the pattern needs to be converted from the CAD file format into a machine readable format. This conversion is known as *fracturing*. In general, EBL systems come with conversion software from the manufacturer, but they can be quite limited in its application. Hence, data fracturing software companies provide specialized software to output EBL system readable files.

Fracturing software is capable of manipulating pattern data such as merging separate layers, removing overlapping layers so as not to overexpose a region, and add positive or negative bias to grow or shrink a pattern. Furthermore, fracturing software includes advanced features that are extremely helpful to EBL. Although each of these advanced features can be delved deeper, a few can be mentioned here. Proximity effect correction (PEC) takes into account the total energy a resist is exposed to at a particular area and corrects the exposure dose based on simulated results; edge features would be exposed with higher doses than non-edge features. Another advanced technique is sleeve and fill where the outline of a large area is exposed using smaller beam currents and/or step sizes for higher resolution and inner portion of an area is "filled" with a larger beam. Another example is field position control where adjacent write fields can be strategically placed so that stitching boundaries can be minimized. Please see GeniSys BEAMER more examples of fracturing techniques.

GeniSys BEAMER

The NPC provides GeniSys BEAMER for data fracturing. This software operates on a designated cleanroom computer. Users can log-in to the computer and access their CAD files through USB or online access. Once the pattern is fractured, the fractured machine readable file can be transferred through the NPC network to the appropriate EBL system.

SUBSTRATE

Lithography is a temporary process used to transfer a permanent pattern onto a desired material, the substrate. In semiconductor processing, substrates generally consist of Si, Ge, GaAs, InP, GaN, etc. As a research facility, various substrates have been processed in the cleanroom including non-traditional materials like diamond and sapphire.

Not only can materials vary, but the shape and size may also affect your EBL process. Processing a 3 inch Si wafer is quite different than processing a 1x1 mm^2 diamond die. The EBL systems are equipped with sample holders for a variety of shapes and sizes.
Moreover, the transparency of a material could complicate a process as some EBL tools use laser height sensing based on a surface reflection to ensure beam focus. If needed, markers on transparent substrates can be used for height measurements.

Similarly, the conductivity of the substrate is important to avoid charging affects. The electron beam needs to have a path for the current to travel through and requires for sample materials to be of a conductive. Insulating materials will cause charging effects resulting in random exposure patterns because the exposure position cannot be controlled. Non-conductive samples require a charge dissipation layer to properly expose a pattern so as not to distort the beam. A conductive layer is needed for insulating materials.

A sample should not outgas, as this would deteriorate vacuum levels because EBL depends on a high vacuum environment in order to operate. Therefore, no samples that outgas should be used in EBL.

No matter what the substrate is, the NPC has done its best to accommodate various substrate materials.

RESIST

Resist Stocking

Many e-beam lithography resists exists in the industry with varying prices and quality. NPC staff have chosen several industry standard resists to provide to the e-beam lithography users based on its process capabilities, material quality and economic feasibility. Stocked resists are provided in the table below along with its respective solvents for further dilution. For more information regarding each resist, click on the link for its name.

Bringing in Resist

To bring in new resists, use the SNSF-NPC User External Chemical Intake Form. Should the user decide to bring in their own resist, all bottles must be checked-in with NPC staff, recorded by NPC staff on Stanford's ChemTracker inventory software, and labeled appropriately with user name, Stanford ID, group or company, and contact information. Make sure original chemical information is legible. Resists not supplied by NPC can be brought in by the user after consulting with NPC staff. If there is enough user base requests for a new resist, NPC can evaluate stocking options. The table below includes acceptable resists in the NPC.

Positive E-beam Resist

Vendor	Resist Name	Solvent	Developer	Product Info
Allresist GmbH	AR-P CSAR 62	Anisole	MIBK, MIBK:IPA, Xylenes	6200.04
				6200.09
				6200.13
Kayaku	495 PMMA	Anisole	MIBK, MIBK:IPA	495 PMMA A4
				495 PMMA A8
	950 PMMA	Anisole	MIBK, MIBK:IPA	950 PMMA A2
				950 PMMA A3
				950 PMMA A4
				950 PMMA A8
	Copolymer	Ethyl Lactate	MIBK, MIBK:IPA	MMA (8.5) MAA EL 11
				MMA (8.5) MAA EL 13
	PMGI	T-thinner	MF-312, MF-319, TMAH	PMGI SF5
The following positive resists are not provided, but acceptable to bring into NPC.				
ZEON	ZEP 520A	Anisole	MIBK, MIBK:IPA, n-Amyl Acetate Xylenes	

Negative E-beam Resist

Vendor	Resist Name	Solvent	Developer	Product Info
MicroChem	ma-N	Thinner mr-T 1090	MF-312, MF-319, 351 Developer	2403
				2405
The following negative resists are not provided, but acceptable to bring into NPC.				
Dow Corning, Applied Quantum Materials	HSQ HSQ	MIBK	MF-312, MF-319, 351 Developer	

Adhesion Promotion and Charge Dissipating Layer

Charge dissipation layer needs to be removed with a water rinse prior to developing wafer. *NOTE: Electra 92 is NOT compatible with ma-N. Use mr-Conductive Layer for ma-N.*

Vendor	Name	Use	Solvent
Allresists GmbH	Electra 92 5090.02	Charge Dissipation	Water, IPA
DisChem	DisCharge H2O	Charge Dissipation	Water or IPA
DisChem	Surpass 3000 Surpass 4000	Adhesion Promotion	Water
The following solutions are not provided, but acceptable to bring into NPC.			
Showa Denko	E-Spacer	Charge Dissipation	Water
Micro Chemicals	HMDS	Adhesion Promotion	
micro resist technology	mr-Conductive Layer	Charge Dissipation	

Mixing New Resist

It is very important that users DO NOT contaminate the original manufacturer resist bottle. For mixing new concentrations, solvents, amber jars, pipettes, and labels are provided. Always take out resist from the original manufacturer bottle and NEVER put back resist into the source bottle or it will be contaminated.

How to Dilute Resist

Generally, resists are polymers dissolved in solvents that come in various concentrations. If a given concentration is spinning too thick, the resist can be diluted for thinner layers by adding the appropriate solvents. Each of the resists and their respective solvents are listed in the table above. SNSF stocks the solvents in the EBL Resist solvent cabinet in the wet bench area.

To dilute to a specific concentration, see the examples below using a scale to measure by % Solids by weight. Select an amber jar from the desk drawer to the left of the EBL Resist solvent cabinet. You may choose to do a solvent clean and N2 dry or use the bottle as is. Zero the bottle on the scale and begin to add the resist. Once the resist is weighed, calculate the amount of thinner needed. To mix the solution, close the bottle and shake or a general use stir bar can be found in the general use glassware storage rack.

Example of % Solids by Weight from 950k PMMA A8 to A4: $\frac{(A8)}{(A8)+X} = \frac{4}{8}$ | X = A-thinner

Example of % Solids by Weight from MMA(8.5)MAA EL13 to EL6: $\frac{(EL13)}{(EL13)+X} = \frac{6}{13}$ | X = EL-thinner

Example of % Solids by Weight from ma-N 2403 to 2401: Add to 10 g of ma-N 2403 about 16 g of recommended thinner mr-T 1090.

Example of % Solids by Weight from ma-N 2405 to 2401: Add to 10 g of ma-N 2405 about 26 g of recommended thinner mr-T 1090.

Spinning Resist

NPC provides a sample preparation area complete with a programmable spinner. Consumables of plastic pipettes, glass pipettes and bulbs, and syringes, aluminum foil, cleanroom wipes, swabs are stocked. Acetone, IPA, Methanol, and Remover PG are also available.

Programmable Spinner

NPC offers access to a Headway Research PWM32 Spinner System. Currently the spinner is set with 9 spin recipes listed below.

Recipe	Spin Speed (rpm)	Time (sec)	Ramp (rpm)
0	Custom	Custom	Custom
1	1000	60	2000
2	1500	60	2000
3	2000	60	2000
4	2500	60	2000
5	3000	60	2000
6	3500	60	2000
7	4000	60	2000
8	4500	60	2000
9	5000	60	2000

Recipe setting "0" is open for user customization. A typical spin coat program contains features included in the diagram below. Each step is adjusted accordingly with resist characteristics considering desired thickness, uniformity, viscosity, etc.

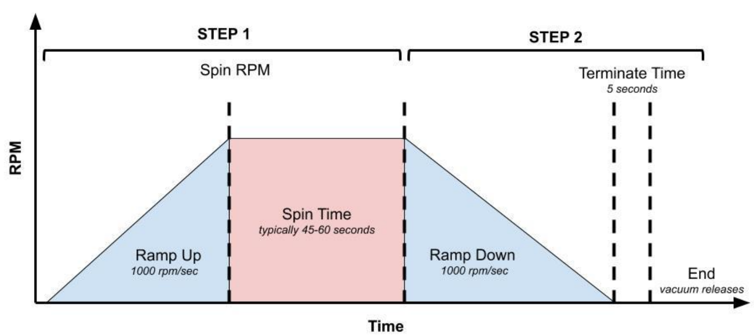


Figure 1: A process diagram of several features of a typical spin program.

To set a custom recipe, follow these instructions. This spinner is equipped with varying vacuum chuck sizes capable of spinning from pieces up to 6 in wafers. For 8 in wafers, please ask NPC staff. For pieces smaller than the provided chuck sizes, users can mount samples onto a carrier wafer to spin on resist. For mounted samples, allow a longer bake time to ensure the solvent properly evaporates.

Spin Curves

Common Manufacturer Spin Curves are posted at the spinner bench. Spin curves are helpful references to estimate the spin speed for a user specified thickness. The best know method for accurate thickness results is to use Si test wafers to determine your final spin speed. To do this, estimate a spin speed based on the spin curve and desired thickness. Measure the thickness using the ellipsometer. Based on the measured thickness, adjust the spin speed respectively until the desired thickness is obtained. For manufacturer spin curves, see the resist table above.

Hot Plates

The NPC is complete with several hot plate options for all resist baking needs. Five (5) hot plates are provided in the sample preparation bench. The hotplates are calibrated by the NPC Staff, However, it is recommended for each researcher to have their own reference thermometer to record temperatures specific their own processes.

A Triple Hot Plate has standard set points of 90°C, 120°C and 150°C. Other temperatures can also be set. However, the Triple Hot Plate is **NOT** to be used above **230°C** because the Teflon coating will deteriorate and delaminate. Use only Teflon coated tweezers on these hotplates to prevent surface scratches.

Two programmable hot plates by Torrey Pines Scientific are also available.

One additional hotplate is available for lift-off processes for heating Remover-PG up to 70°C. This hotplate is stored above the sample preparation bench. Staff training and approval is necessary before using a heated lift-off process.

NOTE: Aluminum foil is not recommended as the foil cannot be flattened perfectly and may not provide even heat distribution. Thick aluminum sheets are provided should the user need them.

RESIST THICKNESS MEASUREMENTS

To measure the thickness of resist, the NPC provides several options for before and after exposure.

Ellipsometry

The lab is equipped with a Film Sense FS-1 Ellipsometer. The Film Sense FS-1 Multi-Wavelength Ellipsometer provides fast and reliable thin film measurements. The film thickness of most transparent thin films from 0 – 1000 nm can be determined. Optical constants, n & k, and other film properties can also be measured for many samples.

Several commonly used resist parameters are already programmed into the system. Simply choose the correct model description and measure the resist thickness. New resist models can also be programmed. Additional training is required and can be found on SNSF's website.

Profilometry

A profilometer measures the surface profile of a sample. Once a resist coated sample is exposed and developed, the profilometer can be used to measure the step height of the resist and substrate surface. This can be used to confirm an ellipsometry measurement.

Our cleanroom has a Dektak XT-S Stylus Profiler that is capable of quickly and accurately measuring feature heights on a surface. With noise levels approaching 2-3nm it is capable of resolving step heights as small as 10nm. Variable force and measurement length settings make measurements possible on a wide range of materials and structures. A magnified video targeting system permits positioning the needle tip near small surface features. Additional training is required and can be found on SNSF's website.

Laser Microscopy

Laser microscopy can assist in creating height profiles after resist is developed. The Keyence has a Z-axis resolution of 0.5 nm.

The NPC offers a Keyence VK-X Series 3D Laser Scanning Confocal Microscope. The Keyence VK-X Series 3D Laser Scanning Confocal Microscope provides non-contact, nanometer-level profile, roughness, and film thickness data on any material. The lateral resolution of the microscope is 120 nm using the 408 nm Violet laser light. This tool requires special training; follow these instructions.

ALIGNMENT & ALIGNMENT MARKS

Unaligned Write

Most often, the first process layer does not require any alignment. This is simply an EBL exposure onto a blank substrate. If the experiment only needs one process layer, then an unaligned write, or free-write, is sufficient. However, if a process requires two or more lithography processing steps, this would require the use of alignment marks.

Aligned Write

Aligned writes require the use of alignment marks. The alignment marks are fabricated on a previous step using either photo or e-beam lithography during the initial layer or the immediately preceding layer. Additionally, once a marker is used for one step, the resist is exposed and developed so that any fabrication steps would destroy those markers. Please see the next section on aligning multiple layers. Therefore, using aligned writes require some forethought of the whole fabrication process. Below are a few tips on setting up aligned writes.

Whether if one layer aligns well to another layer is described as the overlay accuracy. Keep in mind that the overlay accuracy is only as good as the tool tolerance used to define the markers. For example, photolithography defined markers have a realistic resolution on the micrometer scale, whereas EBL defined markers would be accurate to nanometer resolution. Therefore, using an EBL defined marker would allow subsequent layers to align a few orders of magnitude better than a photolithography defined marker.

Global Marks

There are different sets of alignment marks needed to teach the tool where to find the markers and what the markers refer to. The first type of markers are the global marks. The user must teach the tool the global mark locations in order to orient the whole wafer. These consist of markers that are along the four edges or corners of the whole sample and allows coarse alignment and rotation adjustments. Each sample should have at least two global marks, but four are recommended because two markers would mainly allow one-dimensional adjustments, while four markers allow x- and y-axis shifts, scaling, skew and rotation adjustments.

Global marks must be fabricated on a previous step. Global marks can be unique markers used specifically for global alignment. Or they can also be local markers used during the same write. The important factor is that the global mark locations are defined for the tool to locate and set up a coordinate system.

Local/Chip Marks

Just as global marks define the coarse coordinates of the whole sample, local marks define the fine coordinates of each region. Since the smaller local regions are usually chips, the term chip marks are used synonymously. Local marks are usually located on the corners of each chip used to create a chip coordinate system. These locations are also defined by the user for the tool to set up a coordinate system.

As previously mentioned, multiple aligned writes require multiple sets of markers for each layer. A few tips to creating new alignment marks are to 1) separate each marker by a distance of 100um so as not to cross-contaminate, 2) using different marker designs and/or sizes to distinguish between each set, 3) make the markers at least relatively equidistant to the center of the chip or if possible, make them closer towards the center than the previous set of markers.

Fabricating Alignment Marks

Now that the types of alignment marks are defined, it is important to determine how to fabricate these alignment marks. Alignment marks can be made from different materials or through different processes. Most commonly used processes for creating markers are etch or metal deposition. Traditionally, the concept of marker recognition is based on the contrast determined by the backscatter detector, especially for high kV systems. Below is a diagram showing the signal contrast.

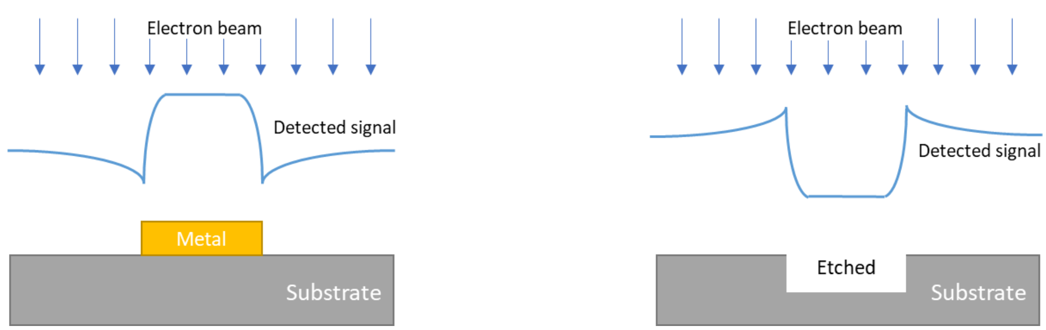


Figure 2: The different contrast levels detected between a marker and the substrate is demonstrated between a metal (left) and an etched marker (right).

For an etched marker, the depth of etch must be deep enough to cause contrast in the backscatter detector. Considering that an etch process is a hole of the same material, the contrast is not based on material but topography. Therefore, etched markers are generally on the order of microns (~2 µm) rather than nanometers. The NPC is equipped with a reactive ion etcher (RIE: Oxford PlasmaPro 80). Please see Section X: Pattern Transfer.

If the material is a deposited metal, the metal should be a relatively heavier material with high atomic number than the substrate and thick enough so the electron beam would not penetrate through the material. For example, 75nm layer of Au or Pt on top of a Si substrate will work for a 100kV EBL system. The material contrast between the substrate and the marker is large enough for the backscatter detector to detect a signal. In comparison, 5nm of Au may not work because a 100kV electron beam would shoot through it and not have enough Au material to backscatter electrons. The NPC is equipped with a metal evaporator tool (KJL evaporator). Please see Section X: Pattern Transfer.

Marker Shapes and Sizes

In addition to marker fabrication, the marker shape and size must be specified in the CAD design. Below is a chart of typical marker dimensions. For photolithography designed markers, larger dimensions are acceptable.

NOTE: ASML markers are not preferred for the JEOL as the markers are usually shallowly etched and additional lines outside of the cross region give false signals.

Markers	Design	Length	Width	Tool Preference
Global Marks	Cross	> 100 µm	3 µm	Voyager
	Square	25-50 µm	25-50 µm	Voyager, EBPG
Local Marks	Cross	> 10 µm	1-3 µm	Voyager
	L	> 10 µm	3 µm	Voyager
	Square	5-30 µm	5-30 µm	Voyager, EBPG

Aligning Multiple Processing Steps

Many experiments require multiple layers of processing and alignment. When markers are used, the resist is exposed so that the markers are also exposed after developing and subsequent processing steps which may cause markers to not be reusable. Below are two methods on how to processing multiple alignment steps.

Creating Multiple Alignment Markers

If a design requires several layers of alignment, then a new set of markers are needed for each of those aligned layers. All the markers can be put down on the initial layer so that additional layers align to the first level. Also, additional markers can be exposed for specific layers.

Exposing Markers with Critical Fine Feature Layers

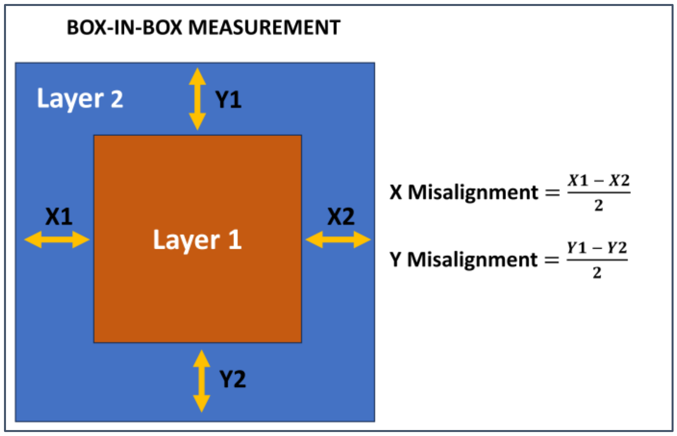
If there is a critical fine feature layer (ie. Features with sub-200nm) during your first level process that will be aligned to with a second level process, include the marker layer with the fine feature layer so that the critical features will be written during the same exposure and beam current to provide the best alignment. Do not expose markers at a level for large patterns with a different or larger beam current or the markers or the next level process may not align well to the first level fine features.

Marker Open

Markers may become covered by additional processes such as oxide layers for isolation that are not penetrable by the electron beam. Marker opens are large rectangles exposed in resist during etch steps to remove thick layers of oxide.

Measuring Misalignment

The overlay accuracy between different layers can be measured using traditional verniers in the X and Y directions. For samples with limited size and real estate, Box-in-Box measurements may also be added to compare overlay between layers. An example of a Box-in-Box design is below. Box-in-Box measurements can be analyzed using an SEM.


BOX-IN-BOX MEASUREMENT
Layer 2
Y1
X1
Layer 1
X2
Y2
X Misalignment = $\frac{X1 - X2}{2}$
Y Misalignment = $\frac{Y1 - Y2}{2}$

E-BEAM LITHOGRAPHY SYSTEMS

The NPC is currently home to three e-beam lithography systems. Although each tool has many special features, the main difference to each system is the operating acceleration voltage of the electron beam. Below are a few distinguishing specifications of the three systems.

E-beam Lithography System	Raith Voyager	Raith EBPG 5200 Plus
Min. Beam Diameter*	<8 nm	0.6 nm
Min. Isolated Line Width*	<10 nm	<10 nm
Beam Current Range	50 pA – 40 nA	50 pA – 350 nA
Acceleration Voltage	10, 50 kV	100 kV
Writing Field Size	500 µm	1000 µm
Deflection System	50 MHz	125 MHz
Overlay	≤ 25 nm |mean| + 3 sigma	± 7 nm / 500 µm ± 8 nm / 1000 µm
Stitching	≤ 30 nm |mean| + 3 sigma	± 15 nm / 500 µm ± 20 nm / 1000 µm
Available Sample Holders	Pieces, 4in, 8 in	Pieces, 3in, 4in, 6in, 8 in
Fixed Beam Moving Stage	Yes	No
Staff Member	Stanley Lin	Rich Tiberio / Stanley Lin

Raith Voyager

Training

Each of the EBL systems are from different manufacturers that use different operating instructions, systems and software. Therefore, each of the systems require separate tool operations training. Please specify which tool you are interested in using during the new user EBL Intake Form.

Should any problems arise during a user session, contact the EBL staff. Contact information is located at the end of this document.

General Information

High Vacuum

In order for the electron beam to function, this requires a high vacuum environment. Make sure your sample does not outgas. If the sample outgases, the EBL chamber will not be able to pump down to operating levels. This may cause pump down processes to time out and other adverse consequences. Additionally, the vacuum environment can be affected if dust, lint, fibers and other particles enter the EBL loading and main chambers. Preventative measures should be taken to ensure no particles can contaminate the high vacuum environment. This includes and is not limited to using a nitrogen gun to blow off the sample and the holder, wearing gloves over the cleanroom suit cuffs, minimized use of cleanroom wipes in EBL preparation area, and wearing a face mask covering the mouth.

High Voltage

Each EBL system operates at its respective high voltages. Do not touch any portion of the EBL column, cables or wires. The emitter material is biased with a high voltage so that electrons can be extracted from the emitter to form a beam using electromagnetic lenses. In the process, x-rays are produced, but are contained within the column. Do not attempt to tamper with the column.

Personal and Tool Safety

In general, there are several pinch points to be aware of. Depending on the tool selected there are various mechanical loading doors, loading arms and valves. Different sample holders have different loading procedures and mechanism. For example, set screws should be finger tightened and not over-tighten. If any mechanism does not function properly, do not exert additional force to the mechanism as this may damage the tool. Ask other users or EBL staff for assistance.

DEVELOPERS AND RESIST STRIPPERS

Developer Stocking

Many e-beam resist developers exist in the industry with varying prices and quality. Resist companies often offer their own brand of developers specific to their resist at a premium. NPC staff have chosen several industry standard developers to provide to the e-beam lithography users based on its process capabilities, material quality and economic feasibility. Stocked developers are provided in the table below along with its respective solvents for dilution. If a user would like to bring in a new chemical, use the SNSF-NPC User External Chemical Intake Form.

Wet Benches

Developers come in different forms and concentrations. Depending on the type of resist, users may require a solvent or aqueous developer. The user must develop their sample in the corresponding wet benches. NPC has three wet benches for solvents, bases and acids. All users are required to complete a wet bench training covering safety and operating procedures. If you require wet bench training, sign up on the **training calendar**.

Ultrasonic Bath

The Solvent Bench is equipped with a SweepSONIK ultrasonic bath operating at 104 kHz. This bath may assist in cleaning samples and metal lift-off processes.

Developers

Vendor	Name	Resist	Dilute With	Wet Bench
Fisher Scientific	**Xylenes**	ZEP 520A		Solvent
	IPA	CSAR 62, ZEP 520A		Solvent
	25% TMAH	HSQ, ma-N	Water	Base
	351 Developer	HSQ, ma-N	Water	Base
MicroChemicals	**MIBK**	CSAR 62, PMMA, Copolymer, ZEP 520A	IPA	Solvent
	MIBK:IPA :: 1:1			
	MIBK:IPA :: 1:3			
	MF-312	HSQ, ma-N	Water	Base (4.9% TMAH)
	MF-319			Base (2.2% TMAH)

Resist Strippers

Vendor	Name	Resist	Wet Bench
Fisher Scientific	**48% Hydrofluoric Acid**	HSQ	Acid
	Buffered Oxide Etch (BOE) 6:1		Acid
	Acetone	PMMA, Copolymer, ZEP 520A, ma-N	Solvent
	Methanol	Rinse	Solvent
	IPA		Solvent
Kayaku	**Remover PG (NMP)**	PMMA, Copolymer, ZEP 520A, AR-P CSAR 62, ma-N	Solvent

Caution

In theory, all chemicals should be treated with the same respect whether using a common solvent or a strong acid or base. In reality, constant reminders are needed. Therefore, it is important to identify two chemicals that have reported fatal injuries.

TMAH is a toxic base. Any exposure to any amount of TMAH can cause injury. In particular, 25% TMAH has been documented to cause fatal injuries in the following study. Therefore, the staff highly recommend using alternative developers for user processes. The NPC stocks comparable developers including MF-312 and MF-319 with lower TMAH concentrations and 351 Developer.

Hydrofluoric Acid (HF) is a strong acid that penetrates the skin and attacks the calcium in the bone and can lead to fatal injuries. Buffered Oxide Etch (BOE) contains HF.

The mentioned chemicals are not exhaustive of all NPC dangerous chemicals, but those for EBL processing. Wet bench training must be completed prior to using the wet benches.

INSPECTION

In order to inspect the results of your pattern in resist or final pattern transfer, the NPC offers several characterization tools.

Optical Microscopy

The NPC has an Olympus microscope with lens magnifications of 5x, 20x, 50x and 100x. The Dark Field objectives to 20x permits inspection of some nanoscale features not visible in Bright Field. The microscope is connected to a computer with image capturing software. This microscope does not require specialized training.

Laser Microscopy

The NPC offers a Keyence VK-X Series 3D Laser Scanning Confocal Microscope. The Keyence VK-X Series 3D Laser Scanning Confocal Microscope provides non-contact, nanometer-level profile, roughness, and film thickness data on any material. The lateral resolution of the microscope is 120 nm using the 408 nm Violet laser light. This tool requires special training; follow these instructions.

Scanning Electron Microscopy

The NPC is equipped with a FEI Nova NanoSEM 450 for analyzing nanometer scale features with sub-2nm resolution. This SEM has operating voltages between 500V to 30kV. It is equipped with an Everhardt-Thornley SE detector. In addition, the in-lens SE (TLD-SE) and the in-lens BSE (TLD-BSE) are also available for ultra-high resolution imaging.

The Nova NanoSEM is complete with a variety of sample holders from pieces up to 4 in wafers. The stage has a maximum travel range of 110 x 110 mm^2 and can be rotated 360° as well as tilted from -15° to 75°. For greater tilt angles, pre-tilted specimen holders of 45° and 90° can be mounted.

The NanoSEM is upgraded with a QuickLoader, a smaller load chamber that allows for faster loading of pieces. This circumvents having to vent the whole SEM chamber in order to load a substrate saving up to 10 minutes of loading and unloading time. The Nova NanoSEM requires additional training; please see the following instructions.

PATTERN TRANSFER

Since lithography is only a temporary pattern layer and a means to a goal, it requires a pattern transfer technique. The NPC is furnished with two main pattern transfer tools: Metallization and Etch.

Metal

The metal deposition tool in the NPC is manufactured by Kurt J. Lesker Company. It uses an e-beam evaporation technique. Some key features includes sample sizes from pieces to 6 in wafers. Stocked materials are Ag, Al, Au, Cr, Cu, Ge, Ni, Pd, Pt, and Ti. For more information regarding equipment and special training, follow these instructions.

Etch

An equally important pattern transfer method is etching into a material. The NPC operates an Oxford 80 Reactive Ion Etcher. Key features offered by this equipment include sample sizes of up to 8 in wafers and a RF generator of 300 W, 13.56 Mhz. Standard etch recipes for silicon and silicon oxides are readily available. Ar or O plasma recipes can be used for cleaning substrates and removing resists. There are five different gases plumbed into the chamber: CHF_3, CF_4, Ar, O_2, and SF_6.

Additional recipes can be created with NPC staff guidance once a user is trained and qualified. For more information and training, follow these instructions.

MORE INFORMATION

Stanford University is proud to be a part of the National Nanotechnology Coordinated Infrastructure (NNCI) Network. For more information regarding the NNCI Network, please see https://www.nnci.net/. Below are a few additional resources that may help you in your nanofabrication projects.

Institution	NNCI	Resource	Website
Stanford University	√	nano@stanford	https://www.edx.org/course/nano-stanford
Duke University	√	EBL Intro Video	https://www.coursera.org/learn/nanotechnology
UC Berkeley		EBL Class, Slides and Videos	Electron Beam Lithography Class
UC Santa Barbara		Bi-Layer Metal Lift-off	https://www.nanotech.ucsb.edu/wiki/images/b/bc/Liftoff-Techniques.pdf
Please suggest additional resources to the email below.			

CONTACT INFORMATION

For more information, questions or suggestions, contact the NPC staff: nano-ebeam-staff@lists.stanford.edu.

Staff Charges

If the user requires additional training outside of the standard training session, additional staff charges will be assessed based on the SNSF Fee Schedule.

Tool Related Issues

If a tool issue arises, report the problem on the Badger-SNSF software as "Problem."
If the tool is inoperable, report the status on the Badger-SNSF software as "Shut Down."
Send a follow-up email to the email above. NPC Staff will address the issue.

Emergencies

For emergencies that would cause harm to a person or the tool, call the NPC Staff at 650-391-6975.

ABOUT THIS DOCUMENT

Version History

Date	Editor	Change Log
8/7/2019	Stanley Lin	Initial Document
8/13/2019	Grant Shao	Edited
11/01/2019	Stanley Lin	Updated Charge Dissipation and Markers section
11/14/2019	Stanley Lin	Updated Resist Stripper section
11/27/2019	Stanley Lin	Edited
12/04/2019	Stanley Lin	Added Resist Thickness Measurement section
12/06/2019	Stanley Lin	Updated Spin Curves
08/07/2020	Stanley Lin	Updated Multiple Alignment section
09/14/2020	Stanley Lin	Added Dilute Resist section
12/4/2020	Stanley Lin	Updated links
2/22/2020	Stanley Lin	PMGI and Dilute Resist
1/26/2022	Stanley Lin	mr-Conductive Layer
11/11/2022	Stanley Lin	Removed JEOL, Nabity, Added DisCharge H2O
04/17/2023	Stanley Lin	Updated Xylenes for CSAR, EBPG 5200 Plus, Removed JEOL
02/01/2023	Stanley Lin	Added Box-in-Box measurement

Contributing To This Document

We encourage everyone to contribute to this document. Please follow these steps to integrate your comments/additions/suggestions:

- Save this file to your computer
- Turn on the “track-changes” feature in Word
- Make your comments/additions/suggestions and save the file
- Email the finished document to the contact indicated above

If there are sections that you think would help better complete this document, please email your general suggestions to nano-ebeam-staff@lists.stanford.edu.