Non-destructive Micro to Nanoscale Metal Patterning for Probing Thermal Anisotropy

A standard operating procedure for using stencil lithography in the fabrication of microscale grating structures, submitted to the Stanford Nanofabrication Facilities in partial fulfillment of course requirements for ENGR 241.

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Executive Summary

In this report, a process flow is presented to create periodic metallic gratings on the order of two microns using a stencil lithography technique and low-stress silicon nitride as the membrane material. A thin (60 nm) film of aluminum was then deposited through the stencils, imparting their grating features on a target substrate (silicon), resulting in metallic grating structures on the substrate. A Standard Operating Procedure (SOP) is presented that will detail all the necessary steps and considerations when attempting to fabricate such grating patterns. This was performed with the intent of further development and down-scaling to the eventual goal of nanometer-scale patterns suitable for the wavelength scales of the lasers used in thermal metrology (i.e. Ti:Sapphire, $NdYVO_4$, etc.). The following renderings demonstrate the high-level structure of a single silicon nitride stencil with silicon handle wafer.

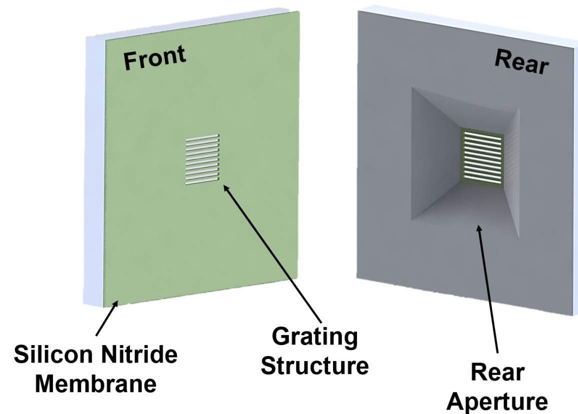

Figure 1: A rendering of the front and rear views of the silicon nitride stencils.

An analysis portion is also presented that details the subtle details of fabricating these sorts of stencils. Key findings include that the grating structures created (on the order of 2 μm width with a pitch of 4 μm) were pushing the limits of the implemented maskless lithography tool (the Hedeilberg MLA150). This was confirmed by carrying out a series dose/defocus test, with even the most promising parameters unable to completely resolve square 2x2 μm features. Linewidth quality was then studied using optical and atomic force microscopy (AFM) as a function of stencil-substrate gap thickness. It was found that the metallic deposition suffers a $\sim$7 nm loss in metal height with a slope of 2° with a relatively large gap size of 30 μm. Grating structures surviving the KOH etch as functions of aspect ratio and silicon nitride thickness.

Additionally, a potassium hydroxide (KOH) etch was used to "free" the grating structures and was characterized as being incomplete, with silicon still adhered beneath the silicon nitride membrane through the rear aperture. Although many gratings did not etch all the way through, those that did often contained this excess silicon that was found to both enhance the structural rigidity of the silicon nitride membrane and not affect the deposition process. A silicon nitride membrane thickness of 200 nm was able to etch through successfully, achieving aspect ratios of up to 50:1 (length of grating to width) without "sticking" due to the forces involved as the water solution dries.

The need to use more sophisticated lithography tools to achieve few hundred nanometer-scale grating widths is motivated and the use of future tools is stressed, such as focused ion beam, (FIB, Helios) and e-beam lithography (EBL, Raith).

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1 Quick-Start Guide

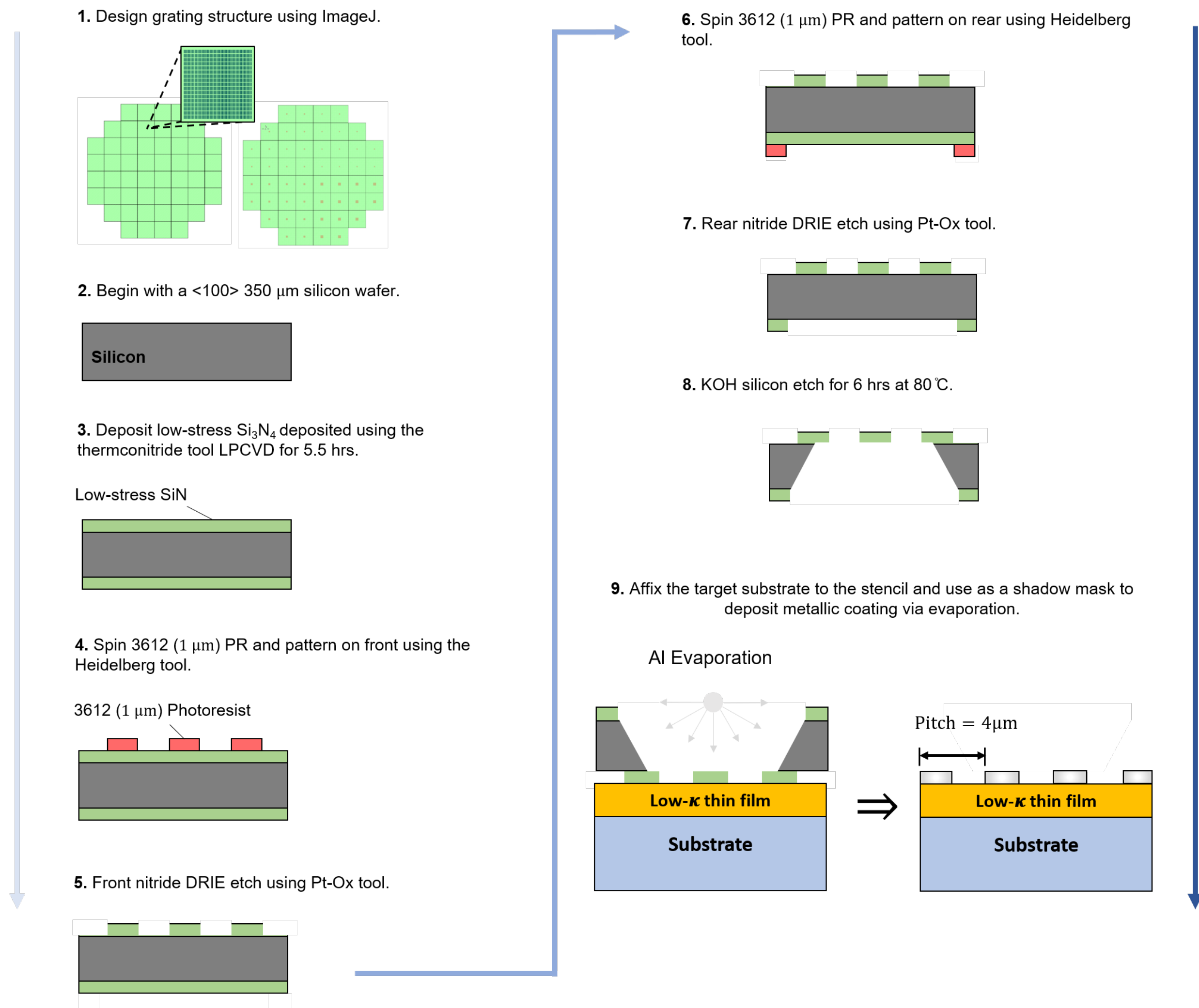


Figure 2: The above figure succinctly describes the high-level process flow that will be referred to in later portions of the report.

2 Project Background

2.1 Optical Polarization

Controlling the polarization of light through periodic gratings is a technique that has seen extensive use throughout the past half century, giving rise to optical components that essentially act as waveplates, absorption filters, and other birefringent materials that have a refractive index dependent on the polarization and propagation direction of the incident light. All of these components are based on aligning a coherent source, or laser, along a portion of the material that will either slow, steer, or absorb/reflect the polarization components of the source. With the ever-increasing fidelity semiconductor fabrication however, periodic grating schemes have been made exceedingly small, thus allowing the control of electromagnetic radiation fields with nanometer-scale wavelengths once limited

by diffraction.

2.2 Optical Methods to Probe Thermal Properties

One of the major applications that require such precise control of radiative fields is thermal metrology. One such technique is time-domain thermoreflectance (TDTR), a method that uses picosecond laser pulses to excite a sample (the "pump" laser) and a continuous laser to monitor its surface temperature response in time (the "probe" laser). These systems use a reflective transducer blanket layer of aluminum deposited on top of the sample to probe the surface temperature response as a proportional change in surface reflectively. The data from the heat input and temperature response signals are translated to physical material properties through a least-square fit to a multilayer thermal model.

3 Motivation & Project Goals

The measurement difficulties in these optical thermal metrology methods, especially involving materials with anisotropic and excessively low thermal conductivity (κ_r) values (e.g. organics, polymers, etc.), is of great fundamental and applied value. For example, TDTR is a non-contact technique and thus ideally suited for high-throughput measurements. However, it suffers from diffraction-limited beam diameters when attempting to invoke a two-dimensional heating geometry (i.e. a scenario where the pump beam diameter is smaller than the in-plane heat diffusion length).

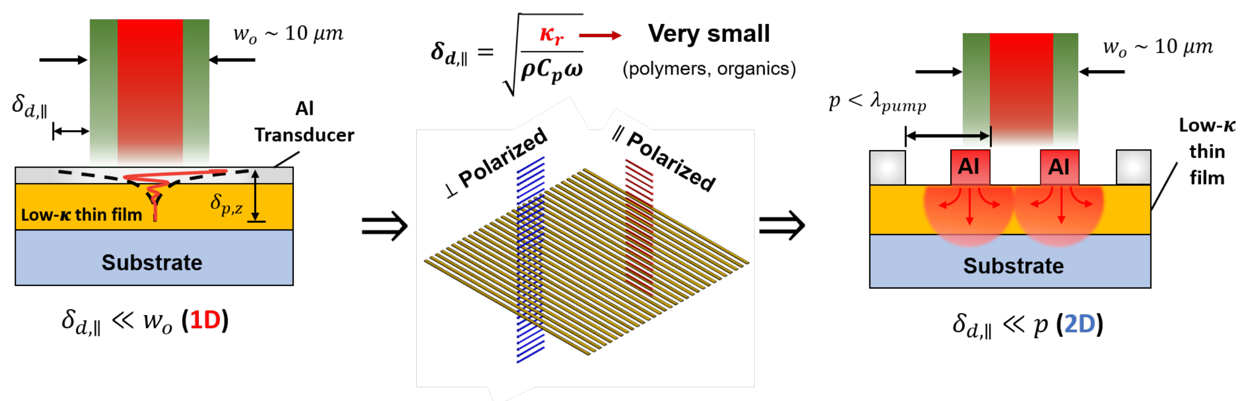


Figure 3: (Left) The traditional TDTR heating geometry, consisting of the "in-plane" diffusion length, $\delta_{d,||}$, being much smaller than the characteristic heating length, or the beam diameter, on the order of $10\mu m$. (Center) A sub-wavelength grating could effectively reflect/absorb the incident laser beam given that its polarization is aligned with the long-side of the grating structure, while perpendicular components are not met with a local electric field and are thus allowed to pass through, not heating the substrate beneath. (Right) The desired heating geometry that is expected to confine incident laser heating to the feature sizes of the nanometer grating itself, invoking a two-dimensional scenario that can be probed to reveal anisotropic thermal properties.

The low-κ_r thin-films of interest are likely to be sensitive to chemical resists and high process temperatures given their organic/polymeric nature. Our goal then is to eventually directly deposit *nanoscale* grating features, or features smaller than the wavelength of the pump beam, on top of the thin-films using stencil lithography described in the proceeding "Introduction" section,(page 4). The grating would essentially act as a wire-grid polarizer, thus avoiding direct substrate laser heating while confining the incident heat input to the sub-laser wavelength length-scales of grating itself, as seen in Figure 3. In this fashion, two-dimensional information can

be captured and in-plane thermal properties can be extracted.

The goals for the first quarter as as follows:

- Confirm the success of the stencil lithography approach for imparting metallic grating features.
- Reveal the structural parameters that effect the survival rates of the grating structures.
- Characterize the KOH etching based on the freeing of the gratings.
- Assess the resulting line quality of the grating structures.

In this study, we present a process flow to create periodic metallic gratings on the order of two microns using a stencil made of silicon nitride with a handle wafer of silicon. This was conducted with the intent of further development and down-scaling to the eventual goal of nanometer-scale patterns suitable for the wavelength scales of the lasers used in thermal metrology (i.e. Ti:Sapphire, Nd:YVO_4, etc.).

4 Introduction - What is Stencil Lithography?

Stencil Lithography is a technique based on the principle of shadow masking a flux of atoms, molecules, or particles to locally modify a the surface of a substrate. This process can accommodate a variety of methods such as deposition, etching, or ion implantation[1].

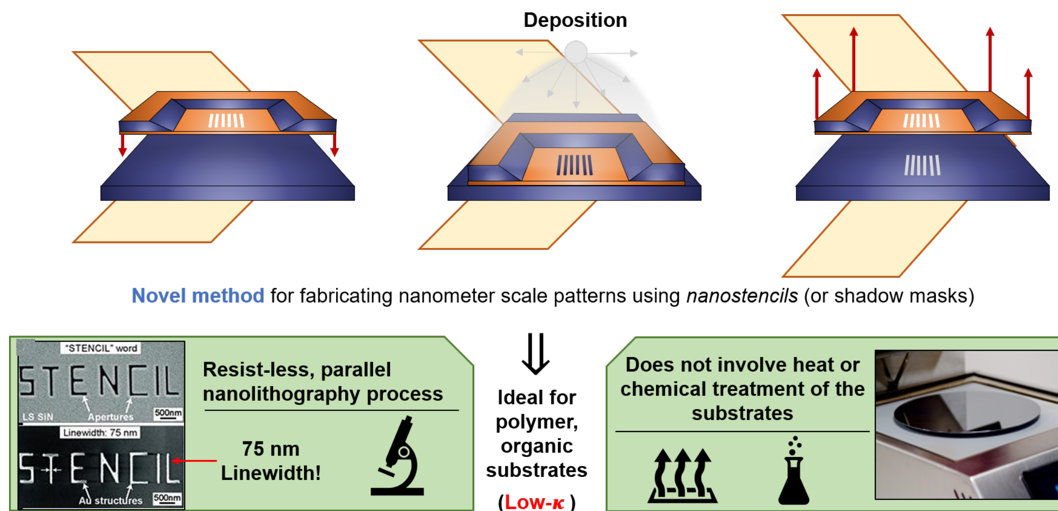


Figure 4: The specific stencil lithography process implemented in this work. A stencil with apertured features is placed on a target substrate while material is deposited on the stencil. The substrate thus gains the features defined by the apertures of the stencil in the form of deposited structures.

This particular project involved material deposition, namely aluminum evaporation, where the stencil is positioned between a target substrate and the evaporation source to mask the deposition of the incident material flux. It is important to note that this process is performed without any resist processing and the features on the stencil are imparted onto the substrate as deposited structures. This resist-less, low-temperature processing was attractive given the highly sensitive organic/polymeric materials under study, as explained in Figure 4. There are however, advantages and disadvantages to this processing scheme, summarized in the table below.

Table 1: The high-level advantages and disadvantages of stencil lithography.

Advantages	Disadvantages
No resist processing, avoiding organic materials, solvents, energy radiation, and mechanical pressure	Blurring due to inherent gap
Easy implementation and applicable with access to physical vapor deposition tools	Clogging if the deposited thickness of the material is on the same order as the stencil aperture size
Allows for reusability being mindful of the clogging effect	Membrane stability can limit aspect ratios that can be achieved using dry etching techniques

5 Depositing Grating Patterns via Stencil Lithography - SOP

5.1 Process Flow

The following subsections describe the details concerning the tools, methods, and subtleties encountered when attempting to deposit grating patterns using stencil lithography. It is assumed that one is dealing with test silicon wafers.

5.1.1 Wet Bench Clean - Wafer Preparation

To begin, the wafers must be cleaned and dried to remove any surface imperfections and organics. This is performed by making use of the wet bench clean facility.

Figure 5: The wetbench clean facility that ensured the removal of surface imperfections and organics. This was performed shortly before the silicon nitride deposition.Adapted from the SNF wiki.

A standard pre-LPCVD recipe is used, consisting of:

SC-1 = 5:1:1; water: H_2O_2: NH_4OH (10 minutes, 50°C), followed by dump/rinse.

Followed by:

SC-2 = 5:1:1; water: H_2O_2: HCl (10 minutes, 50°C), followed by dump/rinse.

Followed by:

Oxide etch = 50:1 HF (30 seconds, RT), followed by dump/rinse.

Followed by:

Spin dry.

Note that the re-filling of the appropriate chemicals may be necessary after viewing the wet bench clean log book. If the number of allowed days the chemicals are allowed to stay stagnant exceeds the last logged entry in the log book, then they must be re-filled. For the sake of brevity, this procedure is omitted and only the steps relevant to cleaning the wafers are detailed.

5.1.2 Depositing Silicon Nitride

The silicon nitride was deposited using the ThermcoNitride furnace, the operation of which is detailed in the proceeding section. Note that this is **step #3** in the "Quick-Start" section on page 1.

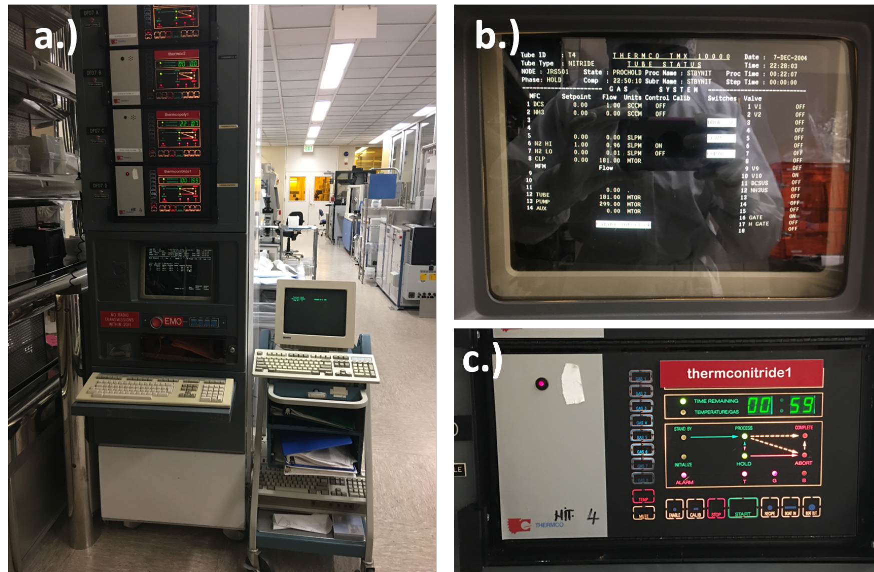


Figure 6: (a) The ThermcoNitride system used to deposit silicon nitride of various thicknesses depending on the time the wafers are subjected to the furnace within. (b) The interface when the system has entered its "PROCHOLD", or process hold state, and running the "STBYNIT" recipe. (c) The tube interface when the desired recipe parameter time has been inputted and is awaiting the user to press the "Start" button.

5.1.2.1 Operating the ThermcoNitride Tool

The basic operating instructions for the ThermcoNitride tool are as follows:

The Tube Status Must be Checked

- Press "Do" key until Main Menu is reached.

- Use arrow keys to highlight Status Menu, then press Return.
- Type in "Tube ID" (4 for ThermcoNitride), then press Return.
- System should be running the "STBYNIT" recipe, in "PROCHOLD", or the process hold state, as seen in Figure 6b; temperature 525°C.

The Tube Must Be Vented

- Press "START". Note that the "STBYNIT" recipe ends when boat is out.
- Load wafers.

When loading the wafers, it is best to have the flat side facing upwards for uniformity. At least three dummy wafers are needed so that two can be placed in front, and one behind your wafer stack. This is to protect the wafers such that the furnace aggressively deposits nitride on the dummy wafers, but not yours.

The Recipe must be loaded

- Enable the tube on Badger.
- Press the "STOP" button until tube is in standby. Press "Do" key until Main Menu is reached.
- Use arrow keys to highlight "Recipe Menu" then press Return. Use arrows keys to highlight "Compile Recipe" then press Return.
- Type in Recipe Name ("LSN" in this case), then press Return. For "Recipe Name #2", press Return.
- For "Parameter Table", press Return. Use arrow keys to highlight "Download Only" then press Return.
- Type in "Tube ID" ("4" for ThermcoNitride), then press Return. Note that the recipe parameter is time. Type the desired delay time (in the HH:MM:SS format, see Table 5.1.2.2). Then press Return. The tool will flash and state "Recipe Compile Succeeded" once recipe is loaded.

Run the Program

- Press "START" to initiate recipe, as seen in Figure **??**c, after 10 seconds press START a second time to initiate the tube close, or "boat in" as seen in Figure7 .

Figure 7: The ThermcoNitride tube "boating in", or being slowly inserted in the furnace to begin deposition and avoid thermal shocks.

- Monitor and log the lowest base pressure, the highest leak back pressure and the pressure during deposition.
- Wait for tube to process wafers. After deposition, the tube will ramp down to 525°C and hold until you press "START". The tube will then vent and open (∼17 min).
- Unload your wafers after they have cooled for several minutes. Press the "STOP" button until the tube is in standby.
- Compile the "STBYNIT" recipe. Press START to initiate tube close.
- "STBYNIT" will leakcheck tube and the stop in the "PROCHOLD", or process hold, step.
- Disable the tube on Badger and mute the tube since it automatically throws an alarm.

If the Leak Check Fails

- Put tube in "Standby" and confirm the state by viweing the tube interface (Figure **??**).
- Compile the "NITYOUT" recipe.
- Press "START" so the recipe can reset the temperature, backfill, and then boat out.

5.1.2.2 ThermcoNitride Recipe

The silicon nitride growth rates decided upon for the thicknesses used in the grating structure are included in the following table. The actual deposition time and thickness uncertainty from the averaged silicon nitride thickness over one side of one wafer. The silicon nitride film thickness is measured using NanoSpec. To minimize the buckling problem or the damage by residual stress of silicon nitride, we use LN3 recipe to deposit low stress silicon nitride film.

Table 2: A summary of the silicon nitride growth times using the ThermcoNitride tool.

Thickness [nm]	Time [HH:MM:SS]	Uncertainty[nm]
100	00:19:15	± 12
200	00:37:15	± 26

5.1.2.3 Confirming Resulting Nitride Thicknesses

The resulting thicknesses were confirmed using the "NanoSpec 210XP" tool, see in the above Figure 8. The tool must be calibrated with the provided silicon wafer before programming the material configuration of your wafer and subsequently taking a measurement.

Figure 8: (Left) The NanoSpec 210XP system used to confirm the nitride thicknesses resulting from the ThermcoNitride deposition. (Right) A closer view of the facility demonstrating the silicon calibration wafer to be used before any measurement.

The general operation of this tool is as follows:

- Place the silicon nitride-deposited wafer on the right side of the stage and the silicon calibration wafer on the left side of the stage.
- If the screen does not show the material configuration selections, press "<CALIB>F9" on the keyboard. Select the program "2) Nitride on Si" and press "<Enter>".
- Select the correct objective (10X) and make sure this objective is installed on the microscope as well. Select "1", indicating the 10X objective and press "<ENTER>". When prompted to "Scan NEW Reference?", select "<YES>".
- Focus on the silicon reference wafer using the 10x objective and press "<MEAS>". When asked to"ENTER SAMPLE ID", generate an ID and press "<ENTER>".
- Press "<ENTER>" again to select the standard index of refraction for the silicon nitride film. Focus the silicon nitride sample using the 10x objective and press "<MEAS>".
- Confirm and document the measurement outputted by the system.

With this tool, the thicknesses were confirmed with an amount of uncertainty, listed in Table 5.1.2.2.

5.1.3 Designing Exposure Areas

The mask is not physical, but rather virtual in the sense that it is not intended to be a physical object. It is a file that will define the features to be exposed for use in maskless lithography.

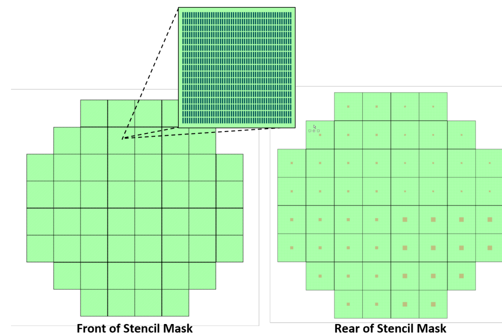


Figure 9: A sample mask design used in the verification of various parameters such as aspect ratio and rear aperture size.

The device size in Figure 9 containing one stencil is a 1 cm square. The aperture sizes should be found considering the geometry in Figure 10. Note the definition of the geometry variables are mentioned in the figure caption.

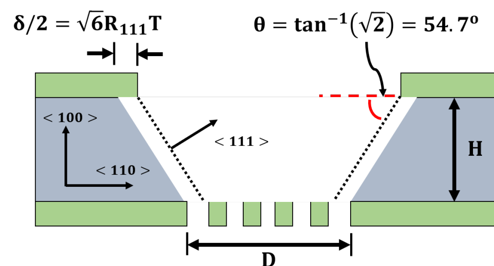


Figure 10: The geometry of the KOH etch geometry, where the "D" is the length size of the grating footprint, "H is the thickness of the silicon handle wafer, and R_{111} is the etch rate in the <111> direction, and T is the etch time.

With the above Figure 10 as a rough estimate, the question of grating aspect ratio is a natural one. This is discussed further in the "Analysis" section on Page 6.

5.1.4 Maskless Lithography

The SVG Coater and Developer were used to spin and bake the $1\mu m$ of 3612 photoresist used here, while the Heidelberg MLA150 was used to expose the grating features. The YES oven was used to prepare the wafers for each of these steps. Note that this is **step #4** in the "Quick-Start" section on page 1.

5.1.4.1 YES Oven - Wafer Preparation

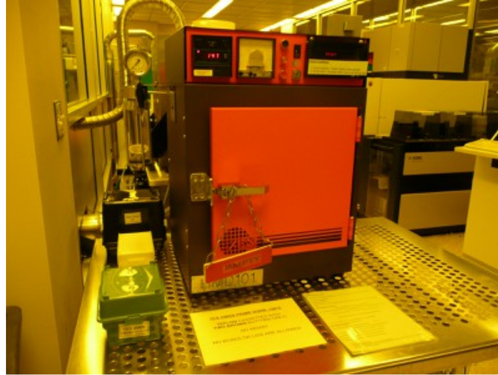


Figure 11: The YES oven used to deposit HMDS (Hexamethyldisilazane) for better coverage and adhesion bewteen oxides and resists. Adapted from the SNF wiki.

The YES oven was used to deposit HMDS (Hexamethyldisilazane), thus allowing better coverage and adhesion between oxides and resists. This is a necessary step that precedes any lithography performed. The basic operating instructions are as follows:

Running the Tool

- Enable the "YES" oven on Badger and be sure to use only the TEFLON cassettes with two brown buttons on the front.
- Load test wafers inside the teflon cassette and place inside the oven. Only the teflon cassette should be placed inside, not the cassette box.
- Close the oven door and turn the sign on the door handle so it reads "IN USE". Press the "START" button. Note that the program runs for ∼35 minutes.
- After the program is finished, as indicated by the persisting alarm, press the "RESET" button.
- Use the hear resistant glove provided to open the oven door and remove the teflon cassette. Place the teflon cassette in its box and remove test wafers.
- Close the oven door and turn the sign on the handle to read "EMPTY". Disable the tool on Badger.

5.1.4.2 SVG Coat Tool - Resist Deposition

Figure 12: (Top row) The SVG Developer tool, and (bottom row) The SVG Coat tool.

As seen in Figure 12, the SVG coat tool is used to deposit 1 μm of 3612 photoresist. The following steps outline the navigation of the recipe manager. Note that **both** tracks 1 and 2 can handle SBR 3612 photoresist.

Setting up

- Enable the "svgcoat" tool on Badger and select track 1 or 2 on the computer screen (right screen for track 1, and left screen for track 2).
- Sign in using the default user login name, "litho", and password, "svg".
- Press "ENTER" and select "Log in".
- Select the "Operator" button at the bottom of the screen, as seen in the bottom-left of Figure 12.

Loading Recipe

- On the recipe computer screen, click "DOWNLOAD Recipe", followed by "Next Recipes" to open the next page.
- Select the coat program associated with a 1 μm SPR 3612 photoresist with a 2 mm edge bead removal (EBR). This is coat program 2 and is referenced as "1.0um wo/VP 2mm EBR".
- After the recipe name appears in the green box in the upper right of the user interface (as seen in bottom left of Figure 12), check that the coat program is correct by pressing the "COAT" button and comparing the process with the laminated sheet corresponding to the recipe next to the tool. Select "Close Window" when finished.
- Select "HPO" and confirm that the hot plate settings are correct upon comparing them to the laminated sheet corresponding to the recipe. Select "Close Window when finished.

Loading wafers

- Get ready to place three dummy wafers in the bottom-most portion of the cassette. Note that the bottom of the cassette is open and is not caged by metal rods, as is the top (as seen in the bottom-right of Figure 12).
- With the parallel and vertical white plastic rods (meant to be wafer-stops) facing downward, load test wafers FACE UP in the successive slots AFTER the dummy wafers, which should have been placed at on the bottom-most portion of the cassette.
- Place the metal cassette on its platform at the side of the track closest to the recipe computer. Make sure the cassette-sensor on the platform is engaged by tilting the cassette slightly to "press" the spring-loaded lever. Note that the orientation of the cassette in Figure 12 is a prime example of HOW NOT TO PLACE THE CASSETTE (it is backwards).
- Place a receiving metal cassette on the side of the track furthest from the recipe computers and make sure the cassette-sensor on the platform is engaged by tilting the cassette slightly to "press" the spring-loaded lever.

Coating Wafers

- Once loaded and receiving cassettes are in place, press "START" to begin.
- Once all wafers have been coated, the receiver cassette can be raised to the unload position by pressing the "TRACK Panel" button, followed by the "RESET Receiver Station" button. Disable the tool on Badger.

5.1.4.3 Heidelberg MLA150 - Exposure

As mentioned previously the Heidelberg MLA150 maskless lithography tool is used to expose the features of the grating structure.

Figure 13: The Heidelberg MLA150 maskless lithography system was used to directly expose the grating features over the $1\mu m$ 3612 photoresist on top of the silicon nitride wafer.

Adapted from the user manual, the high-level process to operate the Heidelberg is summarized in the following Figure 14.

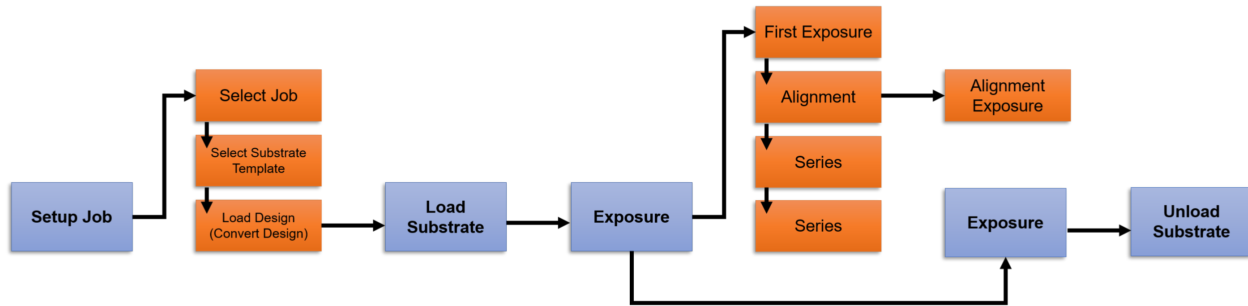


Figure 14: The high-level Heidelberg MLA150 operation process, adapted from the user manual.

The exact operating instructions can be found in the Appendix, on Page A. There is one key detail however, involving the front-to-backside alignment that will be described here.

Front-to-backside Alignment

- Our smallest opening size in one die at the front side of the wafer is 50μm by 50μm. Therefore, it is possible that through-etching process could fail, if the front-side opening and the back-side opening are misaligned by the amount of 50μm
- We use the back-side alignment method to align the mask of the front- and back-side of the wafer.
- Since the Heidelberg has its cameras at the bottom of the stage, we can find the alignment marks exposed from the front-side (from the first exposure step).
- Before doing alignment mark, the user can draw the custom cross-shape alignment marks. The recommended size of the cross alignment mark is two 100μm by 10μm rectangles in a perpendicular cross shape.
- This size of the cross is optimized for the full usage of high resolution cameras located at the bottom of the stage through which we are able to see the mark from the real-time camera images in Heidelberg software
- NOTE that the front-side features and the back-features possess a mirror symmetry when attempting to conduct a through-etching processes.
- After finishing the front-side exposure including alignment marks that will be used for the back-side alignment process, the development, nitride etching, and the removal of the photo-resist layer processes are followed. From this process, with front-size features, alignment marks are produced.
- The alignment marks are located at 4 edges of the wafer, which are (42500μm,0μm), (42500μm,0μm), (0μm,42500μm), and (0μm,-42500μm) respectively
- The other side of the wafer is coated with photo-resist.
- The user must enter four coordination information of locations of the alignment marks and the cross design made by CAD tool. The camera is then automatically moved to one of four locations of the alignment marks from the origin of the wafer found by 10 edge points by Heidelberg machine. This location is near the alignment mark, so the user should find the location of the alignment mark by changing the location of camera and magnification.
- After the detection of the one of the alignment mark locations, the cross-line in the display should be located around the center of the cross exposed by the user in the wafer, which is shown in the display. Then, click alignment button in the software, which automatically do the alignment process from the data generated by image processing algorithm of the software.

- The following steps can be done with the same procedures mentioned above. After one alignment process for the one alignment mark, you can click the 'Next' button for the next alignment process.
- After the alignment processes are finished for the four marks, the exposure processes can then be executed in the same way as that of the first exposure.

5.1.4.4 SVG Developing Tool - Developing

As seen in the top-left of Figure 12, the SVG developing tool is used to develop the 1 μm of SBR 3612 photoresist. The following steps outline the navigation of the recipe manager. Note that **both** tracks 1 and 2 can handle 3612 photoresist.

Setting Up

- Before starting, check the acid waste neutralization system (AWN) is not blinking, located by the wet bench clean facility. Additionally, check that the hotplate temperature is at 110°C and that the "AUTO" mode is selected, as seen in the upper-right of Figure 12.
- Enable the "svgdev" or "svgdev2" for the front and rear tracks, respectively, on Badger.

Loading Recipe

- Press the "station select" button to toggle between the developer and bake stations. Select the developer.
- Type in the desired program number, in this case #3 for the SBR 3612 $1/mum$ recipe, and press "program select".
- Using the provided laminated sheet containing the recipe description, cross-check the recipe with this sheet by pressing "event select" to step through the events and verify that the order of events and associated times are correct.

Loading Wafers

- Similar to the SVG coat tool, the SVG developing tool needs one dummy wafer in the bottom-most portion of the cassette. Note that the bottom of the cassette is open and is not caged by metal rods, as is the top (as seen in the top-left of Figure 12).
- With the parallel and vertical white plastic rods (meant to be wafer-stops) facing downward, load test wafers FACE UP in the successive slots AFTER the dummy wafers, which should have been placed at on the bottom-most portion of the cassette.
- Place the metal cassette on its platform at the left side of the track when one is in front of the user interface controller. Make sure the cassette-sensor on the platform is engaged by tilting the cassette slightly to "press" the spring-loaded lever.
- Place a receiving metal cassette on the side of the track furthest from the user interface controller and make sure the cassette-sensor on the platform is engaged by tilting the cassette slightly to "press" the spring-loaded lever.

Developing Wafers

- Press the "START" to begin developing.Monitor the process and do not walk away.
- When all wafers are processed, raise the cassette by double-clicking the "Index Reset" button on the user interface controller, seen in top-right of Figure 12.
- Remove the cassette from the receiving platform and place the dummy wafers back into their box. Disable the tool on Badger.

5.1.5 Deep Reactive Ion (DRIE) Etching

Note that this encompasses **step #5 and step #7** in the "Quick-Start" section on Page 1.

5.1.5.1 Pt-Ox Tool - Silicon Nitride Etching

PT-Ox is an inductively Coupled Plasma etch system for dielectric material etching.

5.1.5.2 Pt-Ox Recipe

A nitride etching recipe developed by Dr. Woosung Park is used to etch 100 nm of silicon nitride. The details are as follows.

- The recipe consists of 5 iterations to etch away 100 nm of silicon nitride.
- To confirm, measure the resulting thickness of the nitride by using the NanoSpec for various spots locations over one wafer.
- Although the detail control of the recipe of the silicon nitride etch is not in our project scope, it is worth noting that the recipe file name is saved on the Pt-Ox interface and is listed as "woosung_nitride_etch".

5.1.6 Photoresist Removal

5.1.7 Potassium Hydroxide (KOH) Etching

To free the grating structures from the underlying silicon, a KOH etch was implemented, with KOH etching from both the front and the rear of the structure. Note that this is **step #8** in the "Quick-Start" section on Page 1. The following Figure 15 details the various events encountered during a KOH etch.

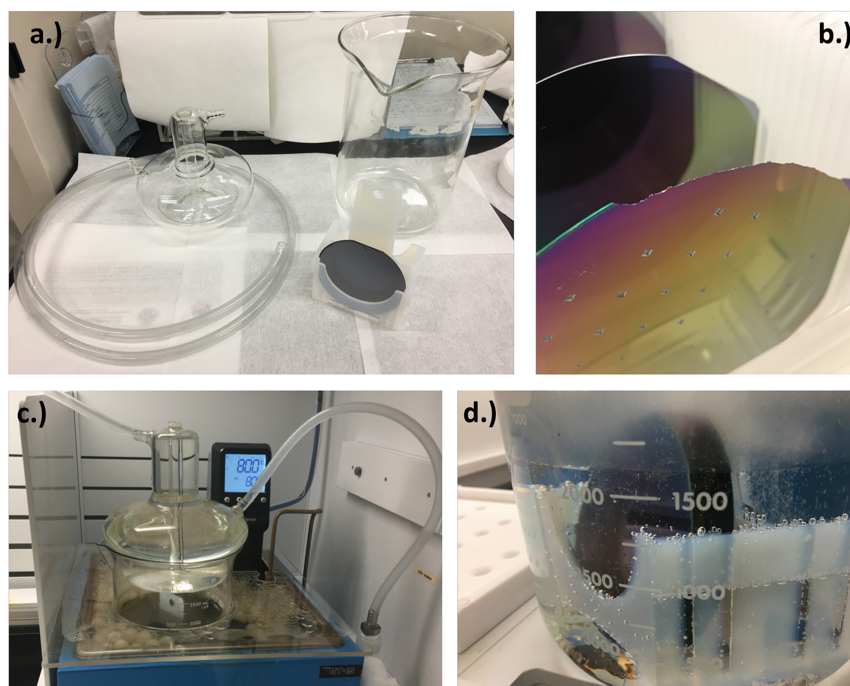


Figure 15: (a) The necessary equipment to perform the KOH etch, (b) a silicon nitride wafer that was chipped during handling, demonstrating the post-etch fragility, (c) the KOH etch setup using a condenser and the boiling pool, and (d) a close-up of the KOH etch on a silicon nitride wafer submerged in solution.

5.1.7.1 KOH Recipe

The recipe for the KOH etch is as follows:

- From the cabinet in front of Wbflexcorr-4, the required equipment is withdrawn. For the KOH to free the silicon nitride grating, large beakers for etching and cleaning are needed, as seen in Figure 15a. To prevent the evaporation during the etching process, a condensing unit including a hose is necessary. The wafer boat to keep the wafer in the solution can be selected based on the size of the wafer.
- First, water is dispensed inside the constant temperature bath (blue color), seen in Figure 15c, until the water level contact the water level sensor. The white ball prevents the wafer from evaporating.
- The etchant needs to be prepared. The ratio is 25 percent acetone, 25 percent DI water and 22.5 percent KOH for the etchant solution
- The beaker including the solution mentioned in the previous step is placed inside the constant temperature bath, as seen in 15d. The condensing unit is placed on the top of the beaker. The hose from which the industrial wafer flows is connected to the bottom nozzle and the other hose is connected to the top nozzle of the unit. This nozzle is directed to the drain. The water switch is then turned on.
- Our target working temperature is 80°C. Therefore, the knob of the temperature controller was tuned to set target temperature as 80°C. It takes around 50 minutes to get to the pre-defined temperature.
- The wafers on the wafer boat should be located carefully and slowly in the heated beaker and the condensing unit is placed carefully on the top of the beaker.
- The etching rate with this recipe is around 50 μm/s.
- After finishing the etching process, the condensing unit is cleaned.
- The remaining etchant should be aspirated and wafer is poured into the beaker again. This step should be done at least three times to make the solution diluted enough for disposal.
- Finish cleaning other equipment provided by SNF.

Note that after the KOH etch, the wafers will likely be more fragile. This can be seen in Figure 15b, where the edge of a KOH etched silicon nitride wafer was chipped off during handling.

5.1.8 Using the Stencil on the Target Substrate

Note that this precedes **step #9** in the "Quick-Start" section on page 1.

5.1.8.1 Target substrate Dicing and Placement

The general process for dicing and placing the target substrate is as follows:

- Dice in dimensions on near the grating array footprint. As mentioned in the "Designing Exposure Areas" section on Page 5.1.3, the grating array footprint is ~1 cm.
- Thoroughly clean both the front stencil grating features and the resulting target substrate pieces with nitrogen gas to remove any dust and particles. This is an immensely important step as the introduction of any objects at the interface between the stencil and target substrate will result in poorer contact.
- Place the stencil wafer on a lab napkin, with the front grating features facing upwards.
- Carefully place the target substrate pieces on top of the stencil wafer, aligning them to the grating structure.

- Cut and place 2-3 small pieces of Kapton tape over the target substrate to stick onto the stencil wafer. Make sure the Kapton tape pieces DO NOT cover other grating structures, or come between the interface between the target substrate and the stencil wafer.

The following Figure 16 demonstrates how the target substrate placement is performed.

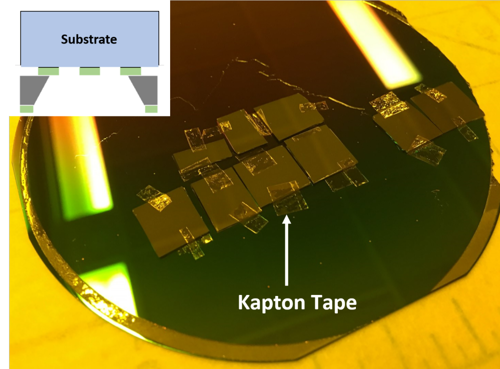


Figure 16: After ~1 cm pieces of a representative silicon substrate were diced, they were placed on top of the grating features as defined by the stencil and held in place using Kapton tape.

5.1.9 AJA Evaporator - Metallic Deposition

The AJA evaporator tool was used to deposit a thin metal film through the silicon nitride stencil. Note that this is **step #9** in the "Quick-Start" section on page 1. For a grating pitch of 4 μm, and grating width of 2 μm, a metallic film of 60 nm was deposited.

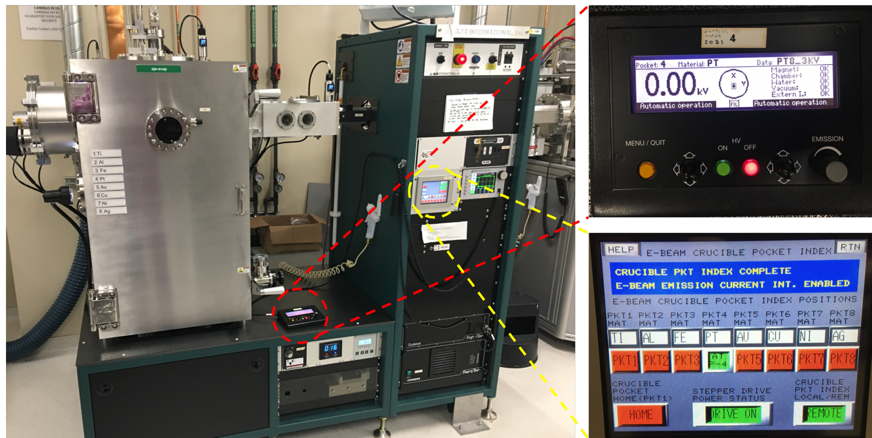


Figure 17: The AJA evaporator tool, along with the user interfaces to input recipes and specify the deposition material.

As will be mentioned in both the "Analysis" section on Page 6 and the "Introduction" section on Page 4, the metal film thickness should generally be much thinner than the negative space width of the grating structure., For a grating pitch of 4 μm, and grating width of 2 μm, a metallic film of 60 nm was deposited.

Figure 18: (Left) The chuck alignment controls for aligning the AJA evaporator chuck, as well as (Right) the load lock where the chuck containing test wafers is placed.

5.1.9.1 AJA Evaporator Recipe

The general process for using the AJA Evaporator with the silicon nitride stencil wafer is as follows:

Loading Sample

- Enable the tool on Badger and check to make sure the base pressure is in the E-7 range, reading the pressure gauge to the right in Figure 18.
- Vent the load lock by switching down the "Vacuum Pumps" switch on the AJA International Power Distribution panel. The load lock should be vented when the pressure gauge reaches a value of ∼7.6E2.
- Mount the stencil wafer using the FLAT chuck to ensure deposition uniformity through the stencil. Make sure to mount the stencil wafer rear-side up so that deposition can occur through the aperture side. Refer to the left side of Figure 19 for more details.

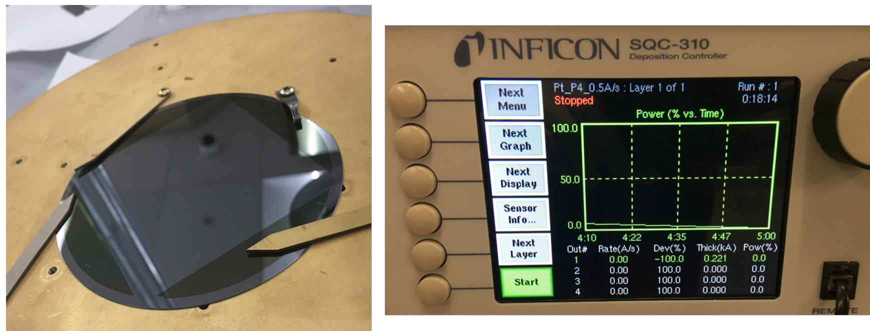


Figure 19: (Left) The stencil wafer is secured rear-side up on the flat chuck of the AJA evaporator. (Right) The AJA evaporator deposition controller and recipe loader.

- Open the load lock lid and place the chuck, face down, in the circular cutout on the load lock arm. Hold the lid down and pump down the load lock by flipping the "Vacuum Pumps" switch up. Wait until the vacuum pressure is below 7E-6.

Transferring Chuck

- Open the window shutter on the left side of the main chamber and turn on the lamp there. Open the window shutter on the front of the chamber and align the polarizer to see inside the chamber. When transferring the chuck, make sure to always have a visual sense of where it is inside the main chamber.
- Open the load lock valve separating the main chamber and the load lock by pressing the red "OFF" button labeled "LLIV" on the touchscreen controller main screen, seen on the lower-right in Figure 17. There should be a noise coming from the valve indicating that it is open. In addition, two red LED lights beneath the load lock must have switched from the top one being illuminated, to the bottom one being illuminated.
- Check that the chuck holder in the main chamber is in the correct position to receive the chuck, with the height indicator set to 90 and the rotation indicator circular outline in the shaft aligned with the circle cutout on the shaft, as seen on the left of Figure 18.
- Slowly move the load lock arm into the main chamber by rotating the small crank to the right of the load lock chamber counter-clockwise until it has reached the end of its travel.
- Transfer the chuck from the load lock arm to the chuck holder by changing the height of the chuck holder from 90 to 70. Retract the load lock arm from the main chamber by rotating the small crank clockwise until it has reached the end of its travel.
- Close the load lock valve by pressing the green "ON" button labeled "LLIV" on the touchscreen controller main screen, seen on the lower-right in Figure 17. There should be a noise coming from the valve indicating that it is closed. In addition, two red LED lights beneath the load lock must have switched from the bottom one being illuminated, to the top one being illuminated.

Running Recipe

- Home the crucible drive by pressing the "Crucible Index Enabled" button on the touchscreen panel. When the crucible index screen appears, press the red "REMOTE" button to switch it to the green "LOCAL" state.
- Press "HOME". The crucible should rotate to Pocket 1, which is usually Ti. Press "LOCAL" to change the selection back to "REMOTE".
- Select the correct material, aluminum, on the "Gameboy" controller, seen in the upper-right of Figure 17, by pressing on the yellow "Menu/Quit" button on the left. Use the left joystick to move the arrows up or down to "Set pocket".
- Use the right joystick to move the arrows up or down to highlight aluminum and select by clicking the joystick to the right. Confirm that the material is chosen as it should be shown in the top bar of the "Gameboy" display by pressing the "Menu/Quit" yellow button once more.
- The recipe must be inputted on the deposition controller, seen on the right of Figure 19. Press the "Next Menu" button until the option below reads "Process Menu", select "Process Menu".
- Use the knob on the right to scroll to a recipe containing aluminum. Press "Select" and then "Edit". Scroll to "Final Thickness" and set it to 0.6 kAngstroms. Note that the deposition rate should be 1 Angstrom per second. Press "Enter" followed by "To Main".
- Make sure the chamber pressure is below 5E-7 before turning on the e-beam power supply, on the right of the overall system portion of Figure 17. It is a green switch labeled "MAIN" at the bottom of the right stack of controlling equipment on the tool. Press the "ON" button under "HV" on the "Gameboy" controller.
- Close the window shutter on the left side of the main chamber used for visual inspection and turn off the light there. Close the window shutter on the front of the chamber.

- Turn on the sample rotation by flipping the switch in the top of the controller box in the lower middle panel of controllers for the tool. The rate knob control should be left as is.
- Press the green "Start" button on the deposition controller. Document the soak 1, soak 2, and deposition power and percentages, as well as the crystal life in the log book.After the deposition is complete, turn off the sample rotation and the e-beam high voltage power supply.
- Open the window shutter on the left side of the main chamber and turn on the lamp again. Open the window shutter on the front of the chamber for visual inspection.
- Open the load lock valve by pressing the red "OFF" button labeled "LLIV" on the touchscreen controller main screen. There should be a noise coming from the valve indicating that it is open. In addition, two red LED lights beneath the load lock must have switched from the top one being illuminated, to the bottom one being illuminated.
- Make sure the height indicator is still set to 70, and that the rotation indicator circular outline in the shaft aligned with the circle cutout on the shaft. Move the load lock arm into the main chamber by rotating the small crank to the right of the load lock chamber counter-clockwise until it has reached the end of its travel. Make use of visual windows to make sure components are moving correctly.
- Transfer the chuck from the chuck holder to the load lock arm by changing the height of the chuck from 70 to 90. Retract the load lock arm from the main chamber by rotating the small crank clockwise until it has reached the end of its travel.
- Close the load lock valve by pressing the green "ON" button labeled "LLIV" on the touchscreen controller main screen. Again, there should be a noise coming from the valve indicating that it is open, along with the red LED lights beneath the load lock switching from the bottom one being illuminated, to the top one being illuminated.
- Vent the load lock by flipping down the "Vacuum Pumps" switch on the AJA International Power Distribution control panel. The pressure gauge should read ∼7.6E2 when the lid can be opened.
- Unmount the chuck and place it on the nearby table. Close the lid manually while flipping the "Vacuum Pumps" switch up for the load lock to be pumped again. Disable the tool on Badger.

At this point, the target substrate should have gained the grating features that the stencil possessed. Much care should be taken when removing the target substrates from the stencil wafer since any kind of sliding might shear the grating structures. Using metal tweezers, gently remove the Kapton tape used to affix the target substrate pieces to the stencil wafer. Since only 2-3 pieces of tape should be holding the target substrate in place, it is advised to remove the substrate by using the Kapton tape on one edge to pull the substrate off on one side while not letting go of the tape. This same piece of tape should be used as leverage to slowly peel off the rest of the tape affixing it to the stencil wafer.

6 Stencil Lithography Grating Analysis

6.1 Surviving Structures

6.1.1 Aspect Ratio and Thickness

Upon completion of the lithographic steps in the process flow, as well as the etching of the silicon nitride, the remaining task was to "free" the grating structure. This was performed via submersion in KOH that would effectively etch the silicon through the rear aperture, as well as through the small grating features in the front of the stencil. The main structural elements, namely length-to-width aspect ratio and silicon nitride thickness, were varied for to provide insight on the kinds of structures that would survive the aforementioned KOH etch. The table below summarizes the experimentation matrix implemented.

Thickness,t [nm]	Aspect Ratio [L:w], where w = $2\mu m$
100	100 50 25 10 5 2.5
200	

Table 3: The experimentation matrix used to probe the effects of silicon nitride membrane thickness and length-to-width grating aspect ratio.

With this experimentation matrix in mind, Figure 20 structures were produced and conclusions drawn based on their structural qualities.

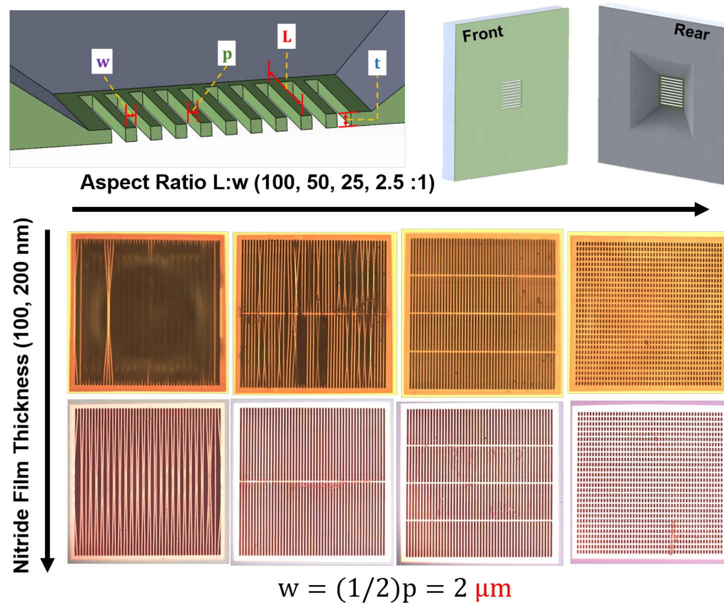


Figure 20: Grating dimension definitions and a sampling of the surviving silicon nitride grating structured as functions of aspect ratio and thickness.

6.2 Etch Characterization

The KOH etch was a pivotal step in the process flow that served to free the grating structure within the silicon nitride membrane. It was a timed etch, and insightful conclusions were drawn based on sheer optical inspection. The following Figure 21 shows a visualization of the surviving/incomplete grating locations on the wafer.

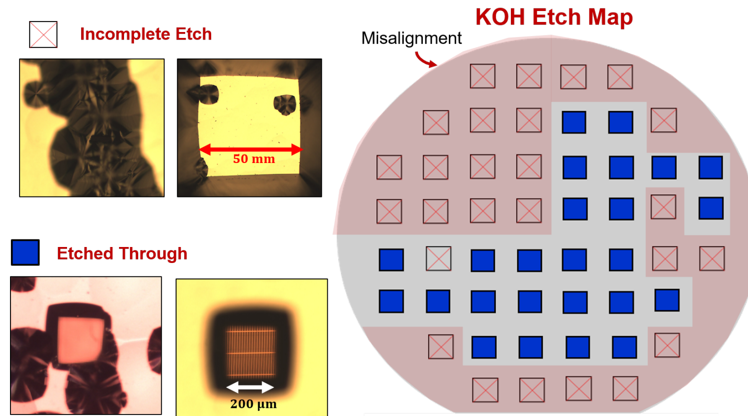


Figure 21: The KOH etch proved to be a significant step in realizing the grating structure and suffered from misalignment issues, as well as an insufficient etch time.

From the above figure, the presence of remnant silicon structures beneath the silicon nitride membrane suggested the etch time was not sufficient. However, the gratings that successfully etched through also contained these silicon structures surrounding and providing them support. They effectively provided a bridge to the greater body of the silicon handle wafer, leading to their structural rigidity.

Additionally, the top left quadrant suffered from gratings that did not free completely, more so than any other region, as seen in Figure 21. This was attributed to the smaller aperture sizes sampled and concentrated in that area, making for a more constrained spread of KOH etchant and thus, less room for error when it came to front and backside alignment when exposing the gratings and apertures. This phenomenon was also deduced to be the culprit for the KOH etch being less successful around the edges of the wafer.

6.3 Linewidth Quality

To test the effect of the linewidth quality of the stencil, the gap size between the target substrate and the stencil was varied between 0, 30, and 60 μm. To provide both qualitative and quantitative insight, both optical and atomic force microscopy (AFM) was conducted on the grating structures.

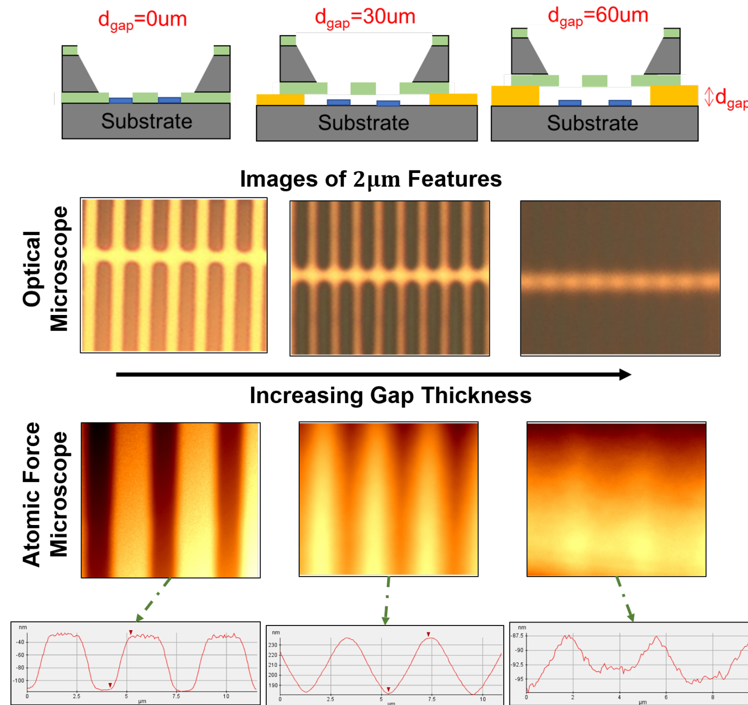


Figure 22: The linewidth quality resulting from stencil lithography was tested to realize the effect of the stencil-target gap size. As seen, the lines begin to noticeably blur after the addition of a 30 μm space between the two materials, and significantly blur after this gap is increased to 60 μm.

6.3.1 Stencil-Substrate Gap Size Variation

As seen in Figure 22, the gap size plays an important role in defining the linewidth quality. As expected, the best quality linewidth was produced by placing the target substrate in direct contact with the stencil wafer. Although the gap size was varied drastically, from 30 μm to 60 μm, it served as a helpful measure to quantify the effect of the linewidth blurring phenomenon. The following Figure 23.

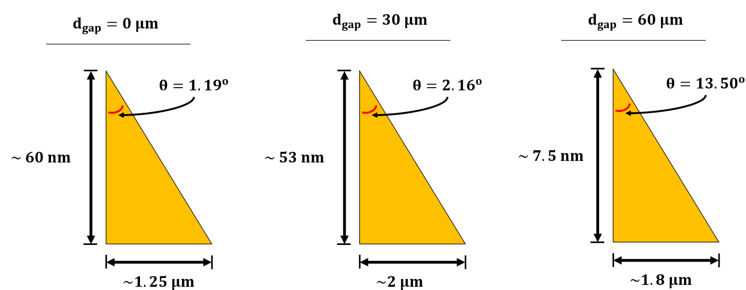


Figure 23: The rough calculations for the slope of the metallic deposition as functions of the stencil-target substrate gap size based on the acquired AFM data.

As seen in the above figure, the calculations for slope indicate that the silicon nitride stencil is quite forgiving when depositing metal. There is little variation in the slope (<1°) and overall thickness of the deposited metal film (~7 nm), even when the gap size of 30 μm is introduced. Only with a gap size of 60 μm does blurring

greatly affect the slope due to a drastic decrease in overall metallic film thickness as a result of deposition directly below the stencil.

7 Project Overview - Autumn 2018

7.1 Motivating More Sophisticated Lithography Techniques

One of the hallmarks of this project involved gaining familiarity with creating such grating structures, as well as validating silicon nitride as a suitable candidate for the stencil material. However, even with features on the order of 2 μm were fabricated, the current process flow is pushing the limits of the implemented exposure methods. From a dose/defocus test to optimize the exposure parameters for such length-scales, it was noted that the Heidelberg MLA150 tool could not properly resolve the smallest of features used in this study (2x2 μm). The following Figure 24 displays the most different results produced by varying the exposure parameters (dose and defocus).

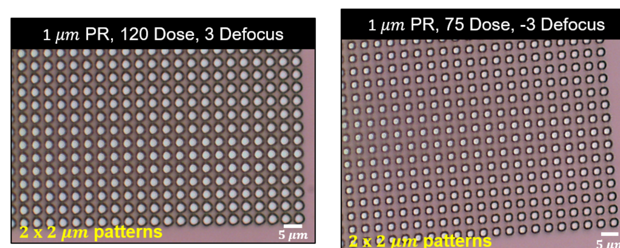


Figure 24: Images detailing the dose and defocus trade study that served to motivate the use of higher resolution lithography techniques. Using the Heidelberg maskless lithography system, the 2x2 μm exposed features are not fully resolved into the squares they should be, indicating the limits of this tool have been reached.

The parameters that yielded the best resolution for the 1 μm SBR 3612 photoresist were a dose of 75, with a defocus of -3. Even when implementing these parameters, the presumed square that would be formed appeared significantly rounded, thus compromising the future grating base structure if this exposure method were to be used for even smaller featuers ($<1\mu m$).

7.2 Budget

The budget was within the allocated amount of $5,000, despite a significant portion being used for equipment training. It is also important to note that perhaps the largest expense was experienced in week 8 of the project, which totaled $1,334.00. This was when a bulk of the work was performed to "free" the grating structure from the silicon handle wafer and involved a ~6 hour etch.

Project Summary				
Allocated Budget	Inventory Expenses	Equipment Training	Equipment Time	Total
$ 5,000.00	$ 1,005.90	$ 1,280.00	$ 2,228.10	**$ 4,513.90**
Week	**Weekly Breakdown**			
5	$ 260.00	$ 400.00	-	$ 660.00
6	-	$ 580.00	-	$ 580.00
7	-	$ 320.00	$ 492.50	$ 812.50
8	-	$ 160.00	$ 1174.00	$ 1334.00
9	-	-	$ 916.50	$ 916.50
10	$ 210.90	-	-	$ 210.90

Figure 25: Both the overall project budget and the weekly breakdown of expenses. Notice the large equipment time expense for week 8, attributed to the costly KOH etch.

7.3 Future Scope

Stencil lithography shows promise as a method to impart grating structures on a target substrate in a non-volatile, non-destructive fashion. This makes it an ideal method candidate for dealing with low-κ materials such as polymers and organics. Moving forward, nanoscale features (on the order of 200 nm) are desired for the particular wavelengths of thermal metrology techniques and as mentioned in the "Motivating More Sophisticated Lithography Techniques" section, transitioning to more sophisticated tools is inevitable.

Additionally, this micro-to-nano study allowed for the identification of certain unforeseen stencil conditions, such as an ideal way to ensure stencil-target substrate contact. Although the effect of this gap size was varied and found to be somewhat forgiving, the slopes observed in Figure 23 demonstrate that this insensitivity is most likely a result of the sheer feature sizes of the grating structure (2 μm widths). If nanometer-scales are to be implemented, the resulting slopes from even a moderate gap size would likely be significant. For this reason, stencil modifications were considered, such as using magnetic forces to ensure the most intimate contact possible.

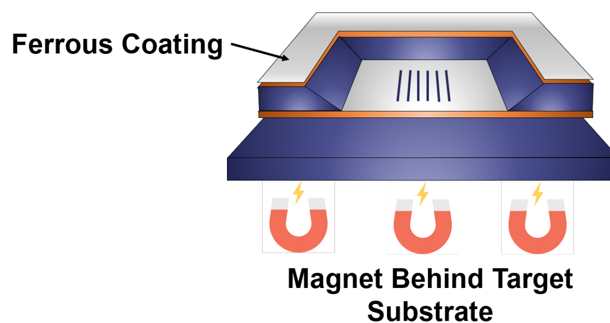


Figure 26: The high-level concept using magnetic force to improve stencil-substrate contact during the deposition process.

Regardless, this study reports the successful fabrication of microscale grating structures using stencil lithography. The resolution limits of the maskless lithography system used to define the gratings were identified and

served to warrant higher resolution lithography techniques moving forward.

8 Project Contributions

Heungdong Kwon and **Christopher Perez** carried out the fabrication in its entirety.

Heungdong Kwon designed the mask layout and carried out the front-and-backside mask alignment in the Heidelberg tool. Christopher Perez conducted the metallic deposition and the optical characterization of the resulting grating structures. The rest of the tasks in the process flow were carried out by both members working together.

9 References

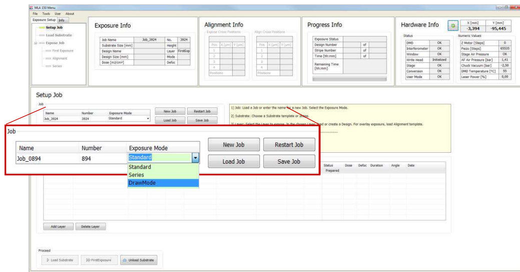
[1] O. Vazquez-Mena, L. Gross, L.G. Villanueva, & J. Brugger, "Resistless nanofabrication by stencil lithography: A review", *Microelectronic Engineering* 132, pp. 236-254, 2018.
[2] SNF Labmembers Wiki, https://snf.stanford.edu/SNF/, 2018.
[3] Heidelberg Industries, "MLA 150 Maskless Aligner", *Doc. No.: DWL-HI-062*,Revision 1, pp. 42-67, 2016.

A Heidelberg MLA150 User Guide

The subsequent pages are adapted from the "MLA 150 Maskless Aligner" user guide from Heidelberg Industries, and detail the steps to effectively expose the grating design[3].

6.1 Select Job

To start the wizard, double-click on the desktop. The ***Exposure Wizard*** opens and automatically creates a new job. This job has a **Name** and a **Number**. The name is editable and can be changed by clicking into the **Name** field. The number is fixed and auto-incrementing.



If you do not intend to start a new job, you can also choose from the following options:

Continue or repeat a job:

- Click **Load Job**.

Repeat an exposed layer of that job:

- Click **Restart Job** and select the job you would like to repeat. The process data of the selected job is deleted and a new job is set up with the same settings but with a new job name/number.

Start another new job after you have finished an exposure job:

- Click **New Job**. The new job has a new number and a new, but editable, name. Continue with the instructions for a new job.

Use the new job that has started automatically with wizard startup:

- From the dropdown list, select one of the available exposure modes:

Standard: To expose a single design for each layer. Overlay exposures are possible in this mode.

Series: To expose designs (e.g. dose test) several times at different positions with varying parameters (dose or/and defoc). It can also be used for finding the appropriate dose and defoc relation for the exposure.

Draw Mode To create boxes, circles or ellipses of arbitrary size limited only by the camera field. Used for creating connections between structures or for repairing imperfections in structures of an exposed layer.

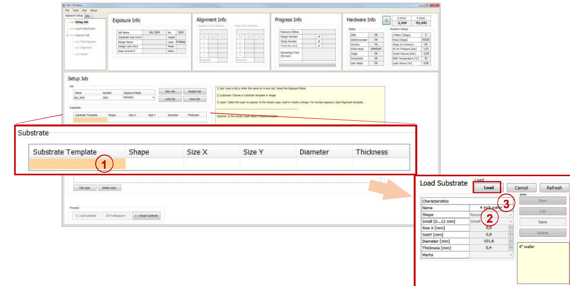
After you have set up the desired job, choose the appropriate substrate and the corresponding substrate template at the system (see *Substrate Template Selection*).

6.2 Select Substrate Template

The system also needs to be provided with the information about the chosen substrate. It offers a list of templates. In case the required template is not available in the list, it is possible to load a new substrate template (only for authorized users).

For selecting a substrate template, follow these instructions:

In the ***Substrate*** frame:



1. Double-click into the value field titled **Substrate Template**.
2. From the list, select your substrate size or at least the shape e.g., automatic_round if you intent to load a wafer.
3. Above the list, click **Load**.

✓ The Substrate frame now displays the selected substrate size or shape and the field is highlighted in green. That means that the task of substrate template selection is done. If a substrate size was selected the fields Size X, Size Y, Diameter and Thickness are filled with the corresponding value.

6.3 Load Design

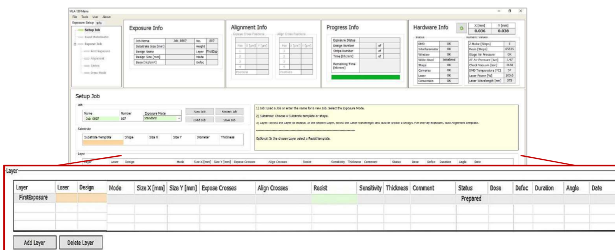
ⓘ In Draw Mode there is no design loading procedure because this mode is for exposing boxes, circles and ellipses of arbitrary size limited only by the camera field. Skip this subchapter and go to *6.5 Load Substrate*.

After you have selected one of the exposure modes (see *6.1 Select Job*) and determined the appropriate substrate template (see *6.2 Select Substrate Template*), you load the design. For loading a design that is not in the list, follow the instructions given in *6.4 Convert Design*. The following sections contain instructions on design loading. Even though the loading procedures differ only slightly from each other in the different modes, read the section that corresponds to the exposure mode you are about to use.

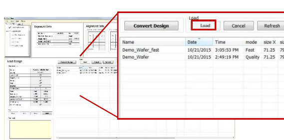
6.3.1 STANDARD: FIRST EXPOSURE

In the **Layer** frame:

1. If available, select a laser from the dropdown list in the **Laser** field.
2. Double-click into the value field titled **Design**. A panel opens containing a list of available design files.



3. From the list, select the required design with a left-click.
4. Click **Load**. Alternatively, double-click on the design name.

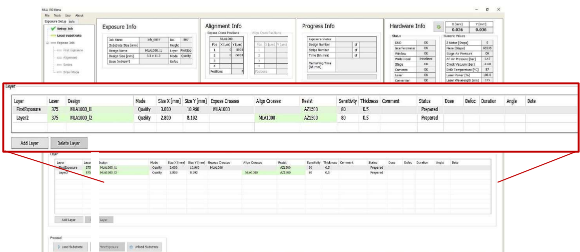


✓ The design is now listed in the ***Layer*** frame.

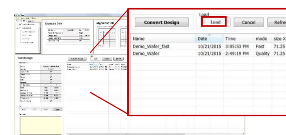
5. Optional: Double-click the value field titled **Resist** and select the appropriate resist type for your application. The recommended dose for exposures on that type of resist is listed automatically in the **Sensitivity** field. In the **Thickness** field the thickness of the resist is displayed. Select the wavelength for the exposure.
6. Optional: It is possible to load a template for alignment crosses which are exposed on the layer. To load this template, double-click into the value field titled **Expose Crosses** and select a bitmap template file from the list. If the template size exceeds 800 x 600 px, the system shows a warning.

6.3.2 STANDARD: ALIGNMENT

For aligned exposures, Layer 2 is the first layer that can be chosen.



1. If available, select a laser from the dropdown list in the **Laser** field.
2. Double-click into the value field titled **Design** in Layer 2. A panel opens containing a list of available design files.
3. From the list, select the desired design file with a left-click.



4. Click **Load**. Alternatively, double-click the name.

✓ The design is now listed in the Layer frame.

5. Double-click into the value field titled **Align Crosses**. A list opens showing several templates with the crosses required for alignment procedures. A special template called `_Manual.xml` is offered for cases in which the cross positions should be selected in the alignment setup. The exposure is then executed with the manually selected alignment positions which are saved afterwards as `[jobname]_AlignPos_L[No. of layer]` (see below). Additionally, if a different template was selected, alignment positions can be changed or even ignored (see *6.7 Setup Overlay Alignment*).

Filename	Date created	User
_Manual.xml	3/11/2015 6:35:43 PM	Alignment Positions
ACC10.xml	3/11/2015 6:35:43 PM	Alignment Positions
Job0502_AlignPos_L1.xml	3/11/2015 6:35:43 PM	Alignment Positions
Job0562_AlignPos_L1.xml	3/11/2015 6:35:43 PM	Alignment Positions
Job0689_AlignPos_L1.xml	3/11/2015 6:35:43 PM	Alignment Positions
positions_ol.xml	3/11/2015 6:35:43 PM	Alignment Positions
positions_pfm.xml	3/11/2015 6:35:43 PM	Alignment Positions
positions_pfm_3_points.xml	3/11/2015 6:35:43 PM	Alignment Positions
positions_pfm_4_points.xml	3/11/2015 6:35:43 PM	Alignment Positions
zero_cross.xml	3/11/2015 6:35:43 PM	Alignment Positions

6. From the list, with a left-click select a template and click **Load**.

✓ The template file is now listed in the **Align Crosses** field.

7. Optional: Double-click into the value field titled **Resist** and select the appropriate resist type for your application. The recommended dose for exposures on that type of resist is listed automatically in the **Sensitivity** field. In the **Thickness** field the thickness of the resist is displayed. Select the wavelength for the exposure

Note: If the first layer does already exist on the substrate, it can be easily skipped.

6.3.3 SERIES

In **Series Mode** the template and design file is selected automatically when choosing **Series Mode** in the ***Set up*** panel (see *6.1 Select Job*). The ***Layer*** frame turns into the ***Series*** frame with different parameters than displayed in the ***Layer*** frame (see below).

In case you need a different design file for your series exposure, follow the instructions given in *6.3.1 Standard: First Exposure.*

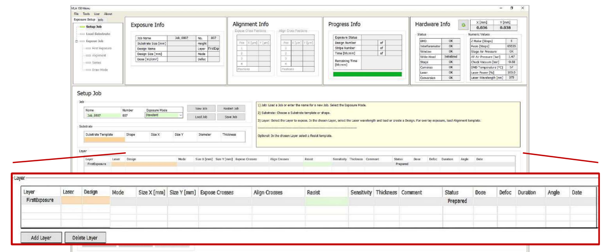
Series

Series Template	Series Mode	Laser	Design	Mode	Size X [mm]	Size Y [mm]	Resist	Sensitivity	Thickness	Comment	Status	Duration	Angle	Date
_Manual	Dose and Defoc	405	rk800	Quality	2.000	5.602	AZ1500	80	0.5		Prepared			

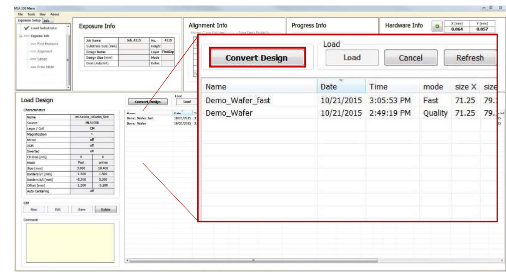
6.4 Convert Design

If you have chosen a listed design file, skip to the next section *6.5 Load Substrate*. For converting a new design, follow these instructions:

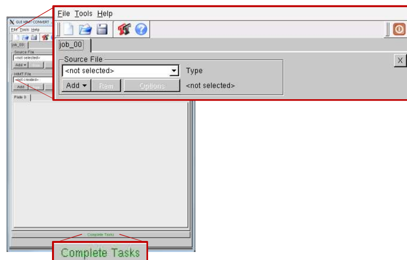
In the ***Layer*** frame:



1. Double-click into the value field titled **Design**. A page containing a list of designs opens. At the bottom you find a button bar.
2. Click **Convert Design**. You are led to the conversion software window.



In the ***Conversion*** window:



3. From the menu bar, select **File →New Job** (alternatively click the sheet icon).
4. You are asked to enter a name for the job. Enter a name and click Ok.
5. Click **Add**, select a design format. A directory opens containing the source files for the selected design format.
6. From the directory, select the file to be converted into the LIC format.
7. If necessary, change settings and / or use the viewer application (see related document *Conversion Job Manager* for more details).
8. Click **Complete Task**. A message box informs about the completion of the process.
9. If the status bar shows 100%, click **Finish**.
10. The conversion software closes automatically.
11. Click into the wizard window to refresh the design list or click **Refresh**. The new file is now listed and available for exposure.

6.5 Load Substrate

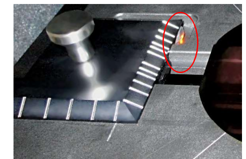
After you have chosen the appropriate substrate, selected a substrate template and loaded a design, you can place the substrate on the chuck. The following instructions guide you through the loading procedure. You also get on-screen instructions inside the yellow **Info Box**.

The chuck is designed to facilitate the manual loading process. It has an indentation surrounding one of the four viewing slots for backside alignment. This indentation makes substrate handling on the chuck easier as it offers space for putting a adjustment aid inside.

ADJUSTMENT AID

The guide bar at the bottom of the adjustment aid is equipped with rest positions corresponding to the different wafer sizes that are possible to be loaded on the chuck. These rest positions are made visible on a measuring scale.

In the example the chuck is loaded with a 4" wafer as it can be seen on the measuring scale matching the mark at the chuck.

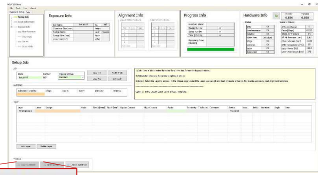


Keep in mind to remove the adjustment aid from the chuck before starting an exposure.

In order to avoid possible damage caused by this adjustment aid, the system is equipped with a monitoring function based on a light barrier control. The Exposure Wizard disables the buttons that lead to all subsequent steps. The exposure function stays blocked until the tool is removed from the chuck.

STEP-BY-STEP SUBSTRATE LOADING

In the ***Setup Job*** panel:

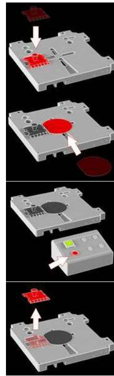


1. Click **Load Substrate**. The stage moves into loading position.

✓ The wizard moves on to the ***Load Substrate*** panel. Wait until the movement has stopped.

NOTICE: **Resist coated substrates get useless when exposed to white light!**
Non-safe light may only be switched on if all substrates are stored in boxes impermeable to light. Otherwise, the substrates become useless.

At the lithography main unit:



2. Push the window button and release it again. The window opens.
3. Place the adjustment aid so that the guide bar, which is located at the bottom, fits into the indentation at the chuck.
4. Adjust the auxiliary tool's position to the substrate size.
5. Use a tweezer to grab the substrate and place the substrate on the chuck.

   Note: Check for correct loading and head position.
6. At the operator panel press the vacuum button.
7. Make sure that the substrate is held tight by the vacuum.
8. Remove the adjustment aid from the chuck.
9. Check the substrate's orientation (see 3.3 *Orientation of Stage and Design*).
10. Close the window by pushing and releasing the button. Go back to the User PC.

11. In the ***Load Substrate*** panel, click **Continue**.
12. Check if the substrate is placed under the write head. If not, see below. If the substrate position is correct, click **Continue**.

Note: In case the substrate is not placed under the write head, click **Cancel**. The stage moves back to loading position. Start the loading procedure again and make sure that vacuum is switched on.

Note: For small substrates the system issues a dialog box if the substrate type has not been completely defined in the step of substrate template selection.

✓ The system searches for the center of the substrate and gives information about the progress via a message box. If you wish to abort the **Find Plate Center** procedure, click **Stop** in the message box and start the loading process again.

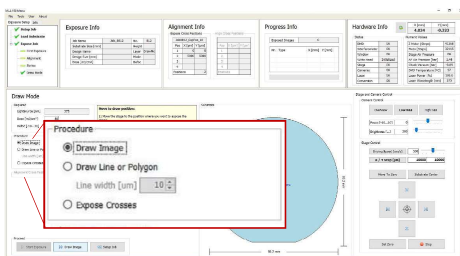
After the successful loading process, the system leads to the next panel:

- In Standard Mode with overlay alignment, the ***Alignment*** panel appears (*6.7 Setup Overlay Alignment*).
- In Draw Mode, the system offers the ***Draw Mode*** panel for creating boxes, circles and ellipses (6.6 Draw Structures).
- In Standard Mode without overlay alignment, you are led directly to the ***Exposure*** panel (*6.8 Expose Design*).
- In Series Mode, the ***Series*** panel shows up offering the exposure procedure (*6.8.3 Series Exposure Procedure*).

6.6 Draw Structures

After having selected the appropriate substrate, you can start drawing the image.

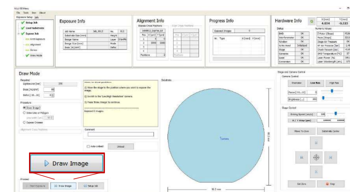
In the ***Draw Mode*** panel



In the ***Procedure*** frame, select the kind of shape to use for image drawing by activating the corresponding radio button:

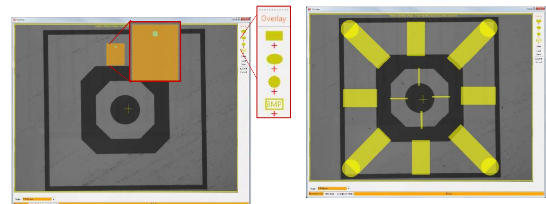
- Draw Image: Activate this option to use the shapes offered in the camera window: rectangle, ellipse, circle or bitmap file.
- Draw Line or Polygon: Use this option to draw lines or polygones (lines with more than two points). Adjust the line width by using the spin control below the radio button.
- Expose crosses: Use this option to expose crosses for alignment orientation without the design (in Standard Mode a design has to be loaded). In the Expose Crosses table you can load the bitmap file for cross exposure.

6.6.1 DRAW IMAGE



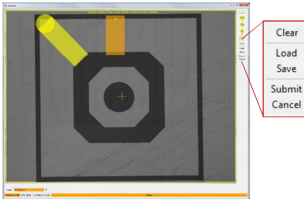
1. Click **Draw Image** and select the area for the structure on the substrate inside the camera window (use the Stage Control section for moving on the substrate).
2. In the camera window select the shapes of the structures that should be drawn onto the substrate by clicking on the corresponding icon.

   ⓘ You can also load an existing file by clicking **Load** and selecting the file from the corresponding folder (usually `C:\HIMT\Designs\Bitmaps`). To directly load a bitmap file click BMP located below the structure icons.
3. To drag the structure to the desired position click into the structure and move the cursor with the mouse button held down. To rotate the structure click into the green dot inside the structure and move the cursor without releasing the mouse button until the desired position has been found.



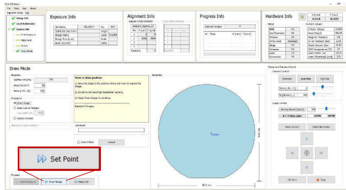
4. To confirm the drawn image, click **Submit** in the menu bar of the camera window. To clear the image, click **Clear** and start again.

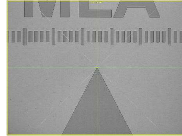
   ⓘ To save the image, click **Save**, insert a name for the file and save it. To cancel the entire drawing procedure, click **Cancel**.



✓ After submission of the created image, work with the camera window is done. Return to the wizard window and the Draw Mode panel in which the exposure process can be started (see *6.8.4 Draw Mode Exposure Procedure*).

6.6.2 DRAW LINE OR POLYGON



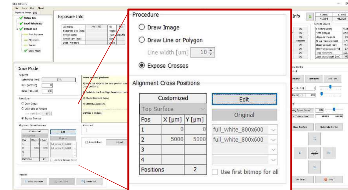


1. In the camera window, move to the area near to the position of the first point of the line or polygon, so that it is visible in the camera image.
2. Click **Set Point**.
3. In the camera window, a crosshair appears. Move the crosshair by moving the mouse to the desired position.

4. Click the left mouse button at the position in which the first point of the line should be set.
5. Move to the next point of the line/polygon by using the arrow buttons of the Control Panel.
6. Click **Set Point**. Repeat the set point procedure.
7. Check the line position in the camera window and click **Accept line**.
8. To draw a polygon, go on with the set point procedure and click **Accept Polygon** to submit the polygon drawing.

✓ After accepting the drawn shapes, work with the camera window is done. Return to the wizard window and the Draw Mode panel in which the exposure process can be started (see *6.8.4 Draw Mode Exposure Procedure*)

6.6.3 EXPOSE CROSSES IN DRAW MODE



If not selected in the ***Setup*** panel, a bitmap file has to be selected for every cross position:

9. Click **Edit** and select a template for every cross position. For selecting the same file in every position, activate the checkbox **Use first bitmap for all**.
10. Enter the positions into the table.
11. Click **Edit** again, to leave the editing mode.

Note: Use **Edit** to change the template selection made in the ***Setup*** panel. Go to back to the original positions from the selected file, click **Original**.

6.7 Setup Overlay Alignment

For exposing the first layer, skip this subchapter and continue with *6.8 Expose Design*.

The MLA150 is able to execute precise alignment exposures. In order to achieve best results, the system offers top side as well as back side alignment. Back side alignment (BSA) is realized by a separate camera unit for back side viewing that is mounted inside the stage and looks to the substrate. Back side alignment is used in the same way as the normal top side alignment. For using the available alignment modes, choose standard exposure mode in the ***Setup Job*** panel.

Top side alignment is supported by three different camera types as mentioned before (see *3.1.3 Optics System*). Back side alignment is supported by two cameras, low and high resolution. The overview camera is still active, but provides only top side view on the substrate.

The Low Res camera is the default camera. For alignment, it is recommended to use the High Res camera as its higher resolution is leading to best alignment results.

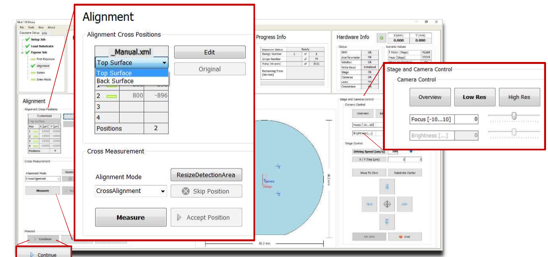
The alignment function offers two different alignment modes, Cross Alignment and Manual Alignment.

- Cross Alignment is an automatic cross detection mode and is recommended to be used as standard mode.
- Manual Alignment is the manual mode for cross detection and is provided for exceptional cases in which the automatic detection might not work properly.

In this chapter, you find the information necessary for executing alignment for overlay exposures. The alignment procedures of top side and back side do not differ from each other, so the following instructions are for both alignment types.

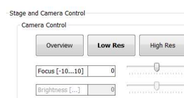
Alignment Procedure

In the ***Alignment*** panel:

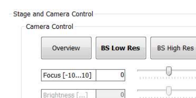


1. If the template `_Manual.xml` for manual setup of the alignment cross coordinates was chosen, select **Top Surface** for top side alignment or **Back Surface** for back side alignment from the dropdown list. The other templates already contain this information.
2. Choose a camera from the **Stage and Camera Control** panel:

Top Surface



Back Surface



	Field of view
Low Res	640 µm x 480
High Res	190 µm x 140 µm
Overview*	20 mm x 20 mm

	Field of view
BS Low Res	min. 364 x 274 µm
BS High Res	min.172 x 130 µm

*Overview cannot access the entire surface of the substrate due to mechanical limits.

Note: Using the **High Res/ BS High Res** camera for alignment is recommended whereas the **Overview** camera is not useful for alignment procedures.

3. From the **Alignment Mode** dropdown list choose between **Cross Alignment** and **Manual Alignment**. This selection can be made for very single cross position.

4. Double-check the positions of the alignment crosses taken from the template file.
   - **Editing**: The Edit button is used for changing the alignment cross positions. Click **Edit** and enter new values. To delete one of the cross coordinates, delete the value and leave the field blank. If, for instance, you intend to skip the second cross position in the list, delete the value, copy the value from the third cross position field into it. Leave the third position field blank. To close the editing process, click **Save**. The positions are stored in a temporary file and turned into a permanent template after exposure start. To restore the original positions from the file, click **Original**.
   - If the template `_Manual.xml` was selected, set the alignment marks manually by using the **Edit** function. For every alignment cross enter the coordinates, click **Save** and then **Accept Position**.
5. Use the Stage Control frame of the Control Panel to move the cross into the camera center (see *7.1 Control Panel*).
6. Determine the alignment marks in:

A Cross Alignment Mode:

- Click **Measure**. The system measures the position of the cross and moves it to the center of the camera window. Examine the positions and click **Accept Position** to confirm it. The procedure moves on to the next alignment cross. In the **Pos** field, the rectangle turns into a check.

ℹ In case of unsatisfying measurements see *7.3.1 Unsatisfying Alignment Measurements*.

B Manual Alignment Mode:

- Click **Measure**. In the camera window, a crosshair appears. Move the crosshair to the position in which the alignment marks should be set and click. The crosshair turns from green to orange.

  Note: For fine positioning use the arrow buttons. You can switch between continuous movement (jogging) and stepwise movement. In step mode enter the **step size** [µm] for X and Y direction into the corresponding fields. In the jogging mode, change the **driving speed** [µm/s] either by using the slider or by clicking into the corresponding field and entering the speed manually. Alternatively, click into the slider field and use the arrow keys for setting the speed

- To center the position of the alignment mark inside the camera window, click **Center Cross**.

Note: It is possible to skip alignment positions by clicking **Skip Position**. This only works if more than two points are available otherwise the button is disabled. In the **Pos** field the rectangle turns into a red cross icon indicating that this coordinate pair was ignored.

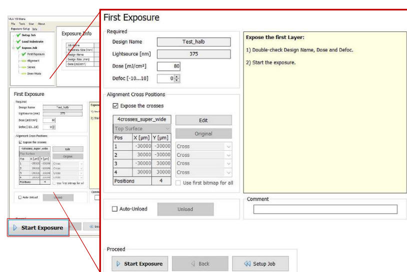
7. Repeat the procedure for all alignment cross positions. Cancelling the alignment procedure is possible by clicking **Cancel**. Alternatively, with **Setup Job** the alignment procedure gets cancelled and the Exposure Wizard moves back to the **Setup Job** panel.
8. Click **Continue**.

✓ The design is now prepared for the exposure process. For information on how to start the exposure process, go to *6.8 Expose Design*.

6.8 Expose Design

The system offers two standard exposure modes, one with and the other one without overlay alignment. Additionally, it is possible to execute series exposures in order to determine the appropriate defoc settings and dose settings for the current exposure job. In Draw Mode you skipped the design loading and created your own structures directly on the substrate inside the camera window (6.6 Draw Structures). The following sections give instructions on how to execute exposures in the different modes.

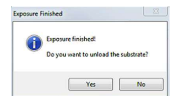
6.8.1 FIRST EXPOSURE PROCEDURE



After having loaded the design and the substrate, you are in the ***First Exposure*** panel.

1. Double-check the design name and the wavelength.
2. If no default value is given, set the **Dose** by entering the value into the text field.
3. Set the **Defoc** by selecting a value with the spin button [-10 to 10]. The defoc allows fine tuning of the exposure focus.
4. Optional: Activate **Auto-Unload** (see *6.9 Unload Substrate*).
5. Optional: Activate **Expose Crosses** if having selected a template before (see *6.3.1 Standard: First Exposure)*. Use **Edit** to change the coordinates or load a different file. It is also possible to load a template here if not having done it before in the design selection. Use **Original** to reset the coordinates to the values given by the template file.
6. Click **Start Exposure**.

✓ The machine is exposing the design. If **Auto-Unload** is not activated, then after completion of the exposure a dialog window pops up asking if the substrate should be unloaded. Click **Yes**, if you want the system to unload the substrate or **No** if the substrate should stay loaded on the chuck e. g., to expose the next layer.

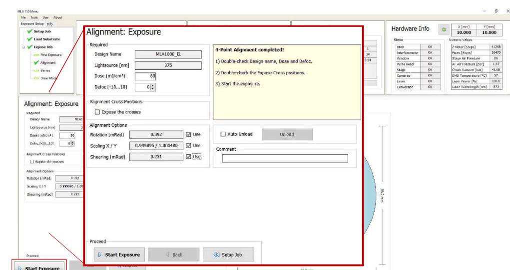


It is also possible to click **No** and unload the substrate by clicking **Unload** in the panel (see *6.9 Substrate Unloading*).

6.8.2 OVERLAY EXPOSURE PROCEDURE

After having loaded the design and the substrate and having prepared the alignment crosses, the substrate is ready to be exposed.

In the ***Alignment: Exposure*** panel



1. Double-check the design name and the wavelength.
2. If no default value is given, set the **Dose** value by entering it into the text field.
3. Set the **Defoc** by selecting a value with the spin buttons (range -10 to 10). The defoc allows fine tuning of the exposure focus.
4. Double-check the **Alignment Cross Positions**.
5. Optional: It is possible to load a template for alignment crosses which are exposed on the layer. To load this template, double-click into the value field titled **Expose Crosses** and select a bitmap template file from the list
6. Chose from the Alignment Options section:

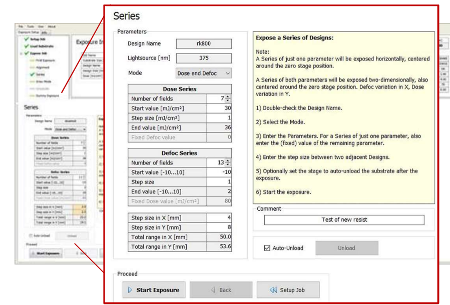
- Rotation [mRad]: If the Use checkbox is activated, the system calculates the rotation of the substrate.
- Scaling X/Y: The system compares the distance measured during alignment with the distance given by the alignment positions. From the deviation a scaling factor results. On this basis the alignment design is shrunk or stretched in order to match the previous layer.
- Shearing [mRad]: The system compensates small distortions such as a rectangle that appears more like a parallelogram.

7. Optional: Activate **Auto-Unload**. The system executes the unloading procedure automatically (see *6.9 Unload Substrate*).
8. Click **Start Exposure**.

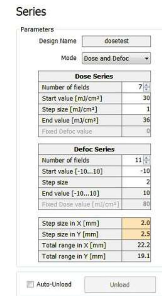
✓ The machine is exposing the design. If **Auto-Unload** is not activated, then after completion of the exposure a dialog window pops up asking if the substrate should be unloaded. Click **Yes**, if you want the system to unload the substrate or **No** if the substrate should stay loaded on the chuck e. g., to expose the next layer.

6.8.3 SERIES EXPOSURE PROCEDURE

After having loaded the substrate and the design, the substrate is ready to be exposed. You are in the ***Series*** panel of the Series mode.



In this panel several values have to be set for series exposure. Find the explanation of the panel elements below:



Mode: Three different selections are possible: **Dose**, **Defoc** or **Dose and Defoc**.

Number of fields: Use the spin button to select the number of fields to be exposed

In the **Dose Series** table, you set the parameters for the series with varying energy values.

In the **Defoc Series** table, you set the parameters for exposing the design with varying defoc values. The defoc allows fine tuning of the exposure focus.

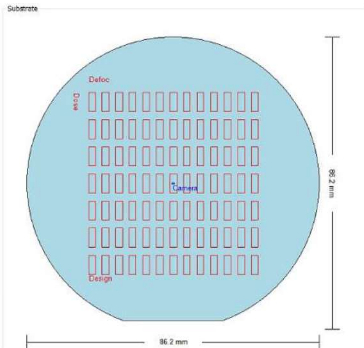
In the bottom table, the **Step size** in x and y direction is determined.

Pay attention to the value in the **Total range** fields. If the total range requires more space than available on the substrate, an error message pops up.

For information about **Auto-Unload** and **Unload** see *6.9 Unload Substrate*.

When choosing **Dose Series** only, the Defoc value is fixed. The Dose value is fixed when **Defoc Series** is active.

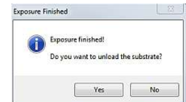
The substrate visualization shows the arrangement of the fields according to the values set in the ***Series*** panel. This feature facilitates the preparation of series exposures. The horizontal fields are for defocus series and the vertical fields represent the dose fields (see below). If the fields overlap, the step size has to be changed to a higher value. If the field arrangement exceeds the substrate surface size, the number of fields has to be reduced.



1. Select from the options in the **Mode** dropdown list: **Dose**, **Defoc** or **Dose and Defoc**.
2. Set the values required for the selected mode.

   Note: Pay attention to the value in the Total range fields. If the total range requires more space than available on the substrate, an error message pops up.
3. If desired, activate **Auto-Unload** (see *6.9 Unload Substrate*).
4. Click **Start Exposure**.

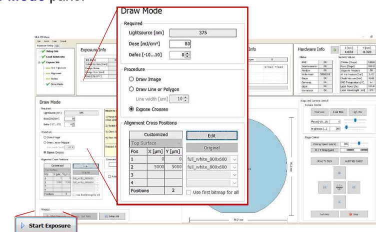
✓ The machine is exposing the design. If **Auto-Unload** is not activated, then after completion of the exposure a dialog window pops up asking if the substrate should be unloaded. Click **Yes**, if you want the system to unload the substrate or **No** if the substrate should stay loaded on the chuck e. g., to expose the next layer.



6.8.4 DRAW MODE EXPOSURE PROCEDURE

After creation and submission of the image, you are still in the Draw Mode panel to start the exposure.

In the ***Draw Mode*** panel



1. Set the **Dose** value by entering the value into the text field.
2. Set the **Defoc** by selecting the value with the spin buttons (range -10 to 10). The defoc allows fine tuning of the exposure focus.
3. Optional: Activate **Auto-Unload**. The system executes the unloading procedure automatically (see *6.9 Unload Substrate*).
4. Click **Start Exposure.**

✓ In the **Progress Info** section the table changes to a list displaying the Draw Mode procedures that are already executed. The most recent one is listed at the top of the list. You also find the information about the type of draw mode image and the coordinates of the center of the image.

6.9 Unload Substrate

For unloading the substrate the system provides a function called **Auto-Unload**. This function is selectable by activating a checkbox. Read more in the information below.

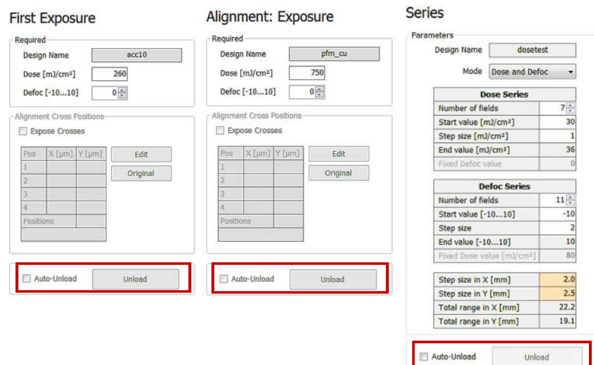


Figure 14: Unloading options in Standard Mode and Series Mode

Auto-Unload

The **Auto-Unload** function automatically brings the stage into unloading position directly after exposure completion. Activate the Auto-Unload function by clicking into the checkbox **before starting the exposure procedure**. Above you see where this checkbox is located in the panels of the different exposure modes (in Draw Mode same location as in First Exposure Mode). After the unloading procedure had finished, the wizard directly leads you back to the ***Setup Job*** Panel where you can start a new job with **New Job**. You can take the substrate from the chuck or leave it there for exposing a further layer.

Unload

Next to the **Auto-Unload** checkbox there is an **Unload button.** Alternatively, it is possible to click this button **after exposure completion**. The stages moves into unloading position. You can take the substrate from the chuck or leave it there for exposing a further layer. To start a new job, go back to ***Setup Job*** panel by clicking on the corresponding navigation button.

Removing the substrate from the chuck

To remove the substrate from the chuck, follow the steps below:

1. Push the window button and release it again. The window opens.
2. At the operator panel switch off the vacuum.

NOTICE: **Resist coated substrates get useless when exposed to white light!**
Non-safe light may only be switched on when all substrates are stored in boxes impermeable to light. Otherwise, the substrates become useless.

3. Carefully take the substrate off the chuck and stow it in an opaque box impermeable to light.
4. Close the window by pushing and releasing the button. If required, click **OK** in the ***Exposure Wizard*** to close the unloading dialog.

Note: This user guide does not give instructions on substrate processing. Processing of the substrate should happen according to the substrate manufacturer's recommendation.