Silicon Nitride Nanoscale Stencils for Non-destructive Metal Grating Patterning

A standard operating procedure for using stencil lithography in the fabrication of nanoscale 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 standard operating procedure (SOP), a process flow is presented to create periodic metallic gratings on the order of 150 nm using a stencil lithography technique. The stencil is comprised of a patterned, 200 nm thick, suspended low-stress silicon nitride (SiN) membrane with silicon as the structural handle material. The process is The following renderings demonstrate the high-level structure of a single silicon nitride stencil with silicon handle wafer.

All the necessary steps and considerations when attempting to fabricate such grating patterns are discussed. Although these stencils were developed with the intent of the grating widths to reach the wavelength scales of the lasers used in thermal metrology (i.e. Ti:Sapphire, $NdYVO_4$, etc.), they can be adjusted and used in a myriad of other applications.

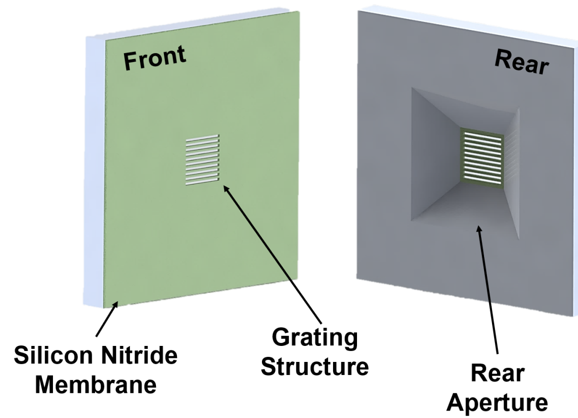

Figure 1: A rendering of the front and rear views of the silicon nitride stencils.

Acknowledgements

Special thanks to our SNF mentors Dr. Usha Raghuram (internal), Dr. J. Provine (external), and Dr. Mark Zdeblick (external), as well as labmates Joe Katz and Woosung Park for their support and insightful advice during the project. We could not have done it without you.

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1 Quick-Start Guide

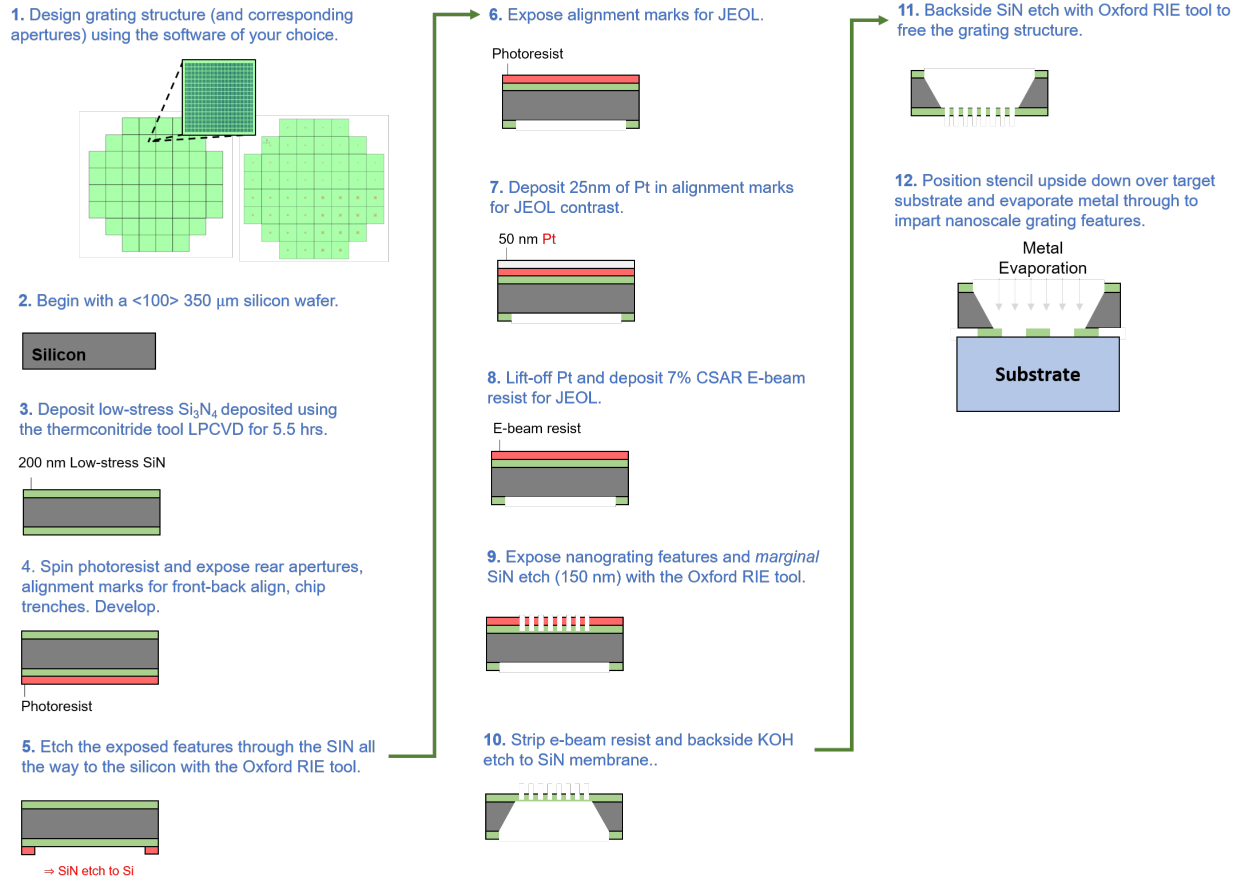


Figure 2: The above figure succinctly describes the high-level process flow that will be referred to in later portions of the report.

2 Depositing Grating Patterns via Stencil Lithography - SOP

2.1 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.

2.1.1 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 3: 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:

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

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

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

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.

2.1.2 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.

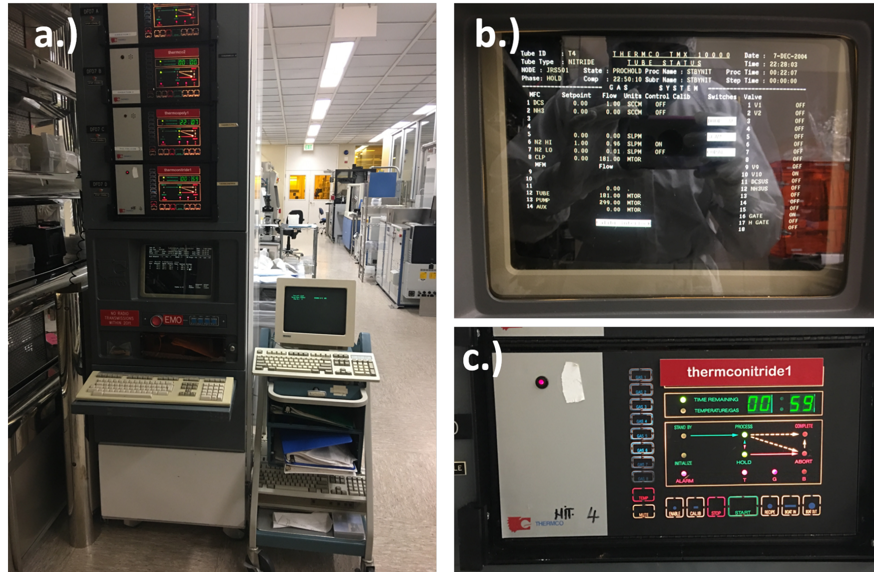


Figure 4: (a) The ThermcoNitride system used to deposit silicon nitride of various thicknesses depending on the time the wafers are subjected to the furnace within. (b) The interface when the system has entered its "PROCHOLD", or process hold state, and running the "STBYNIT" recipe. (c) The tube interface when the desired recipe parameter time has been inputted and is awaiting the user to press the "Start" button.

2.1.2.1 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 1: 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

2.1.2.2 Confirming Resulting Nitride Thicknesses

The resulting thicknesses were confirmed using the "NanoSpec 210XP" tool, see in the above Figure 5. The tool must be calibrated with the provided silicon wafer before programming the material configuration of your wafer and subsequently taking a measurement.

Figure 5: (Left) The NanoSpec 210XP system used to confirm the SiN 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 SiN-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 SiN 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 2.1.2.1.

2.1.3 Designing Exposure Areas of the back side of the wafer

In this process, the masks are not physical, but rather virtual. They are files that will define the features to be exposed for use in maskless lithography, both with the Heidleberg MLA150 (the Heidelberg) and the JEOL JBX-6300FS Electron Beam Lithography System (the JEOL).

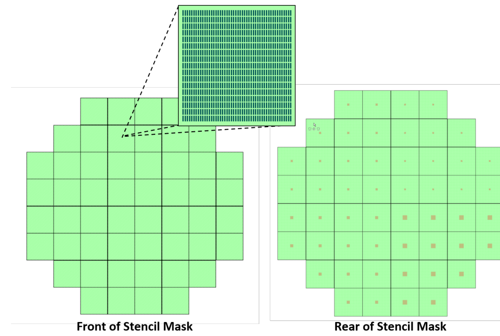


Figure 6: A sample mask design used in the verification of various parameters such as aspect ratio and rear aperture size.

The device size in Figure 6 containing one stencil is a 1 cm square. The aperture sizes should be found considering the geometry in Figure 7. Note the definition of the geometry variables are mentioned in the figure caption.

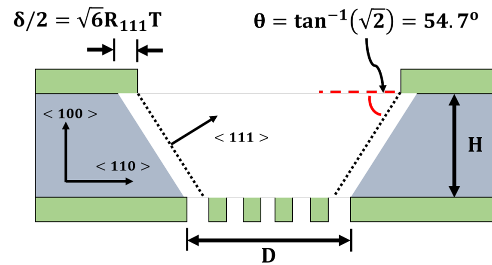


Figure 7: The geometry of the KOH etch geometry, where the "D" is the length size of the grating footprint, "H is the thickness of the silicon handle wafer, and R_{111} is the etch rate in the <111> direction, and T is the etch time.

With the above Figure 7 as a rough estimate, the question of grating aspect ratio is a natural one. This is discussed further in the report associated with this SOP.

2.1.4 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** and **step #6**in the "Quick-Start" section on page 1.

2.1.4.1 YES Oven - Wafer Preparation

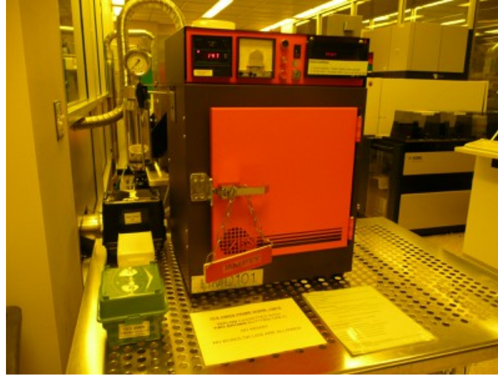


Figure 8: The YES oven used to deposit HMDS (Hexamethyldisilazane) for better coverage and adhesion bewteen oxides and resists. Adapted from the SNF wiki.

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.

2.1.4.2 SVG Coat Tool - Resist Deposition

Figure 9: (Top row) The SVG Developer tool, and (bottom row) The SVG Coat tool.

As seen in Figure 9, 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 9.

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 9), 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 9).
- 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 9 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.

2.1.4.3 Heidelberg MLA150 - Exposure

As mentioned previously the Heidelberg MLA150 maskless lithography tool is used to expose many of the non-nanoscale features of the device.
NOTE: This maskless lithography step comprises both **Step 4** and **Step 6**. In step 4, the rear apertures, alignment marks for front-back wafer alignment, and chip trenches are exposed. Following a SiN etch, step 5 is performed. Step 5 consists of exposing alignment marks for the JEOL. Refer to this section when transitioning from step 5 to step 6.

Figure 10: 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 11.

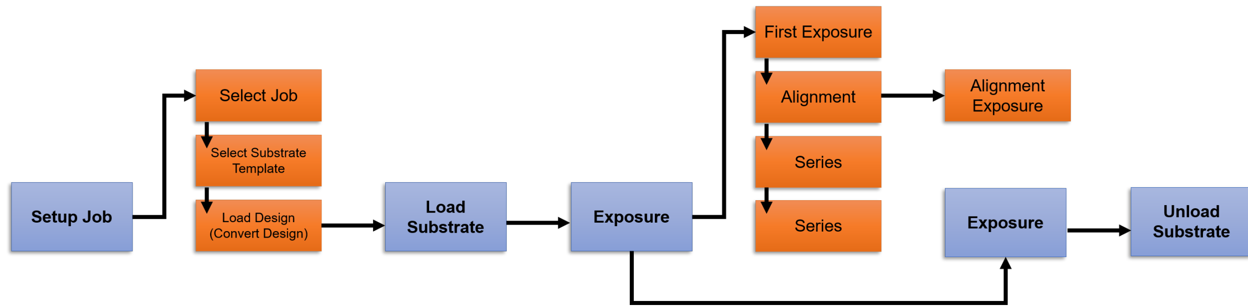


Figure 11: The high-level Heidelberg MLA150 operation process, adapted from the user manual.

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. This is a crucial aspect since the smallest device footprint on the front side of the wafer is (in our case) $5\mu m$ by $5\mu m$. Therefore, it is possible that we could "miss" the device landing within the backside aperture if there is even a misalignment of $5\mu m$.
NOTE: This front-to-backside alignment is relevant to only Step 6, since at this point we would have alignment marks on the back of the wafer to align to.

Front-to-backside Alignment

- Since the Heidelberg has cameras at the bottom of the stage, we can use them to find the alignment marks that had been placed on the backside from step #4.
- Before doing alignment mark, the user can draw the custom cross-shape alignment marks. The recommended size of the cross alignment mark is two $100\mu m$ by $10\mu m$ rectangles in a perpendicular cross shape.
- This size of the cross is optimized for the use of high resolution cameras located at the bottom of the stage through which we are able to see the mark in real-time, as seen in Figure 12.

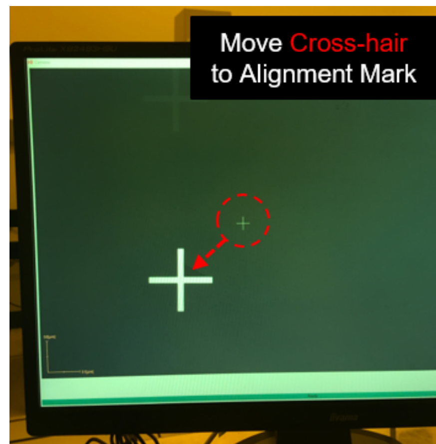


Figure 12: The front-to-back wafer alignment screen in the Heidelberg software. The cross-hairs should be aligned to existing alignment marks on the wafer.

- NOTE that the front-side features and the back-features possess a mirror symmetry when attempting to conduct a through-etching processes. BE CAREFUL.

- The alignment marks are located at 4 edges of the wafer, which are (42500μm,0μm), (42500μm,0μm), (0μm,42500μm), and (0μm,-42500μm) respectively
- The user must manually enter the four coordinates of the alignment marks, as well as the cross designs made by CAD. The camera is then automatically moved to one of these four locations of the alignment marks. The movement does not leave the alignment cross-hairs exactly on the alignment marks, but it is close enough. The user should then find the location of the cross-hairs by changing the location of camera, magnification, and focus so they align with the existing alignment marks.
- After one cross-hair is aligned, click the alignment button in the software. The tool will automatically do the alignment process from the data generated by image processing algorithm of the software.
- After one alignment process for the one alignment mark, you can click the 'Next' button for the next alignment process.
- After the alignment process us finished for the four marks, the exposure processes can then be executed in the same way as that of the first exposure.

2.1.4.4 SVG Developing Tool - Developing

As seen in the top-left of Figure 9, 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 9.
- 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 9).
- 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 9.
- Remove the cassette from the receiving platform and place the dummy wafers back into their box. Disable the tool on Badger.

2.1.5 Reactive Ion (RIE) Etching

Note that this encompasses **step #5 (frontside etch) and step #9 (backside etch)** in the "Quick-Start" section on Page 1.

2.1.5.1 Oxford RIE Tool - Silicon Nitride Etching

The Oxford RIE is a reactive ion etcher (RIE) for etching dielectric materials ($SiO_2, SiNX, etc\cdot$), silicon-based materials (Si, a-Si, poly-Si), and a number of carbon-based materials (polyimide, diamond-like carbon, etc.).

2.1.5.2 Oxford RIE Recipe

A SiN etching recipe developed by Dr. Woosung Park is used to etch 200 nm of SiN. The details are as follows:

- The recipe is one consists of a 75-15-10% $CHF_3-CF_4-O_2$ etch chemistry, timed to achieve a desired etch depth.
- To confirm, measure the resulting thickness of the nitride by using the NanoSpec for various spots locations over one wafer.
- Although the detailed 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 Oxford RIE interface and is listed as "OA-SiN-RIE1".
- The user interface, as well as the steps to edit the recipe with respect to time or accelerating voltage can be seen in the following Figure 13:

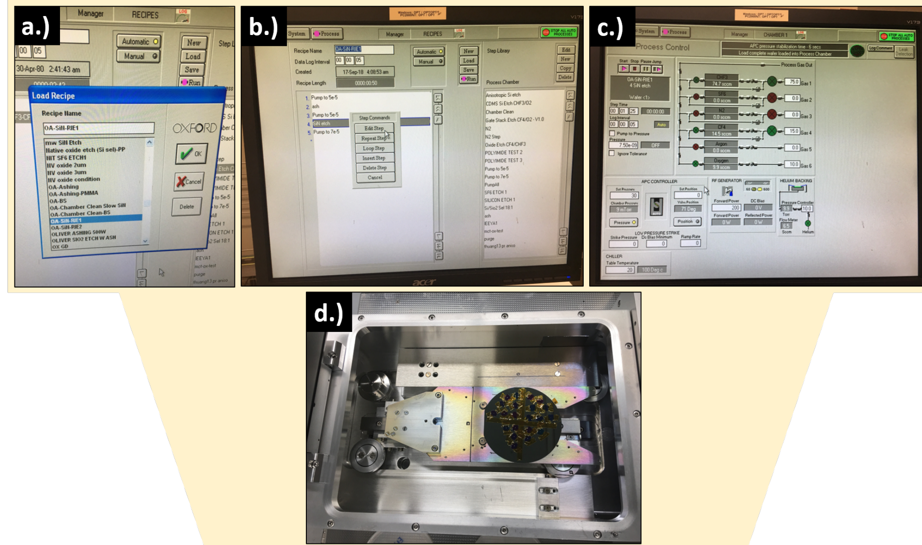


Figure 13: (a) A drop-down list appearing after "Load" is clicked showing the "OA-SiN-RIE1" recipe. (b) Once recipe is loaded, step 4, or the SiN etch step, can be edited to change the accelerating voltage, or the time, as seen in (c). (d) The Oxford RIE loadlock with the individual stencil chip devices taped onto a carrier wafer. NOTE: If **step #5** is carried out, a carrier wafer will not be needed since all devices will be etched together. If **step #9** carried out, then (d) demonstrates how a carrier wafer is used to etch them individually.

2.1.5.3 Frontside (marginal) SiN Etch

For **step #5** (the marginal frontside SiN etch), the entire wafer filled with exposed resist containing grating features should be placed into the loadlock, similar to Figure 13. Since only 150 nm must be etched, an accelerating voltage of 200V and a time of 120 sec was used to achieve this. Refer to Table 2.1.5.5 for a more detailed description of etch conditions.

2.1.5.4 Backside SiN Etch (post KOH etch)

For **step #9**, it is assumed that the KOH etch has already been carried out and the SiN film is now a membrane. The only thing left then, is to flip the stencil, with the device side down, and etch the remaining 50 nm of SiN from the rear. To facilitate the process, it was mentioned in the "Quick-Start Guide" on page 1 that the so-called "chip trenches" would frame the devices to "pop" them out after the KOH etch. The subsequent section shows how this is done.

2.1.5.5 Chip-breaking to Use Individual Stencils (post KOH etch)

The process for breaking the device chips defined by the chip trenches and placing the target substrate is as follows:

- Due to the chip trench "frame" around the device and the crystal orientation of the wafer, the corners of the device should be etched completely, with four triangular holes in each corner of the device. The following Figure 14 details this phenomenon.

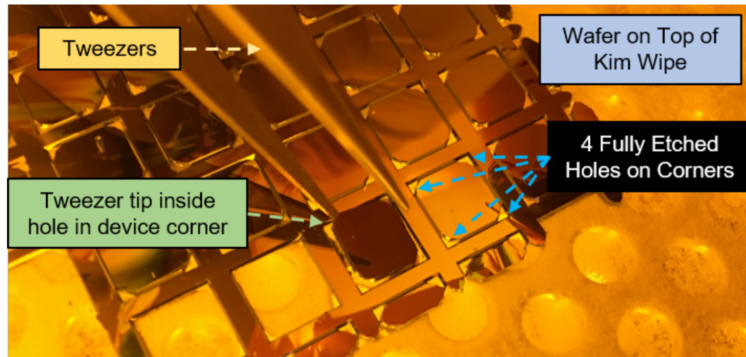


Figure 14: One tip of the (metal) sharp tweezers should be inserted into one fully etched holes located in one of four corners of the device. The tweezers are then gently torqued in such a way to break the device free along the etched trench.

- Place wafer on a clean Kim-wipe with the aperture side down.
- Insert one tip of sharp tweezers into one of the four fully etched corner holes and gently torque the chip until it breaks free from the wafer, as seen in Figure 14. Another wafer tweezer might be needed to press the rest of the wafer down to gain enough torque to break the chip.
- After breaking, thoroughly clean both the device 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.

As seen in Figure 13d, a carrier wafer should be used to etch each individual chip, aperture side up. The chips should be affixed to the carrier wafer via Kapton tape. The most successful etches were found to be at an RIE accelerating voltage of 100V, with an SiN etch time of about 130-140 sec. Refer to Table 2.1.5.5 for a more detailed description of etch conditions.

The following etch rates were compiled as a function of accelerating voltage and time for this particular material stack:

Table 2: A summary of the silicon nitride etch times using the Oxford RIE tool at varying accelerating voltages.

Accelerating Voltage [V]	Etch Rate [nm/s]	Uncertainty[nm/s]
50	0.54	$\pm$0.02
100	0.70	$\pm$0.05
200	1.25	$\pm$0.08

2.1.6 Electron Beam (E-beam) Lithography

One of the most crucial aspects of successful nanoscale gratings is the use of e-beam lithography, present in the "Quick-Start Guide" in **steps #8 and #9**.

2.1.6.1 E-beam Resist and Develop

The e-beam resist used for this flow is 7% CSAR at a thickness of 300 nm. The headway inside the Spilker basement SNSF cleanroom was used for this step. The solvent benches were also used for this step and a AR 600-546 developer was used.

Spin Coating E-beam

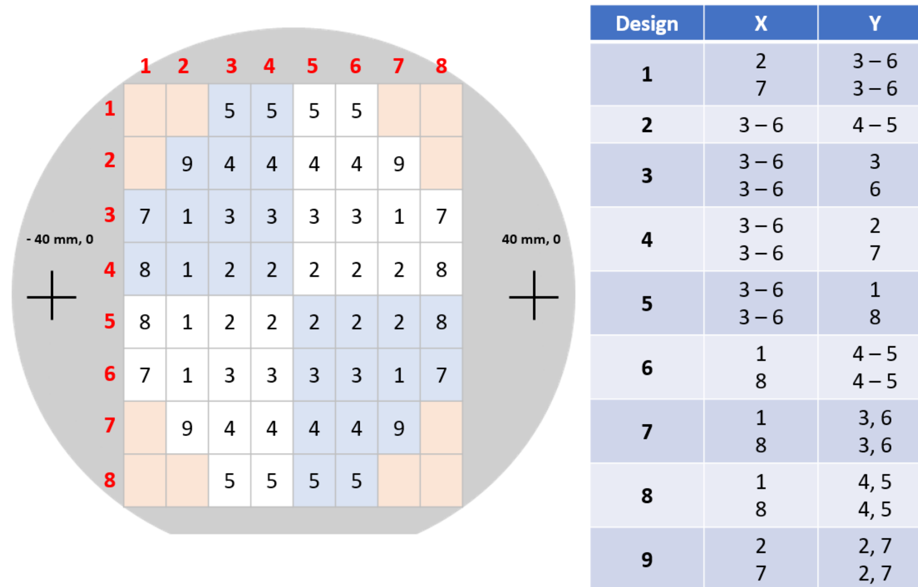
- Prepare a glass pipette using the provided bulbs and glassware. Secure a bottle of 7% CSAR e-beam resist. DO NOT FORGET VINYL GLOVES.
- Make sure the correct chuck is installed on the headway spin coater (one compatible with 4" wafers). Place a dummy wafer and select an arbitrary recipe to check the vacuum and make sure it is OK.
- Place wafer with the device side up onto the chuck and initiate vacuum. Open the bottle of e-beam resist and draw about half of the pipette's worth of resist.
- Select Recipe 1 and make sure you have the pipette ready to deposit resist.
- Begin dispensing e-beam resist on top of the wafer. Make sure to move the pipette in a "spiraling-out" direction until about 75% of the wafer radius has been coated. This should take around 5 seconds.
- Press the green button on the foot controller to initiate the spin and let the recipe run.
- Once recipe is finished, remove the vacuum and place the wafer onto a hotplate at $150\,^{\circ}$C for 1 min.
- Leave to cool on a lab wipe on top of the benches for 1 min. before placing it into your wafer cassette case.
- Return all labware in their proper location.

Developing E-beam

- Prepare a glass container large enough for a wafer and fill with AR 600-546 solvent. DO NOT FORGET VINYL GLOVES.
- Prepare bottles of IPA for rinsing afterward.
- Place wafer inside of the AR 600-546 solvent for 1 min., agitating the solvent gently with wafer tweezers.
- After 1 min., remove wafer from the container and immediately begin rinsing with IPA for 1 min.
- Dry the wafer with an N2 gun and return wafer to wafer cassette case.
- Return all labware in their proper location.

2.1.6.2 JEOL JBX-6300FS Electron Beam Lithography Job File Creation

For grating structures in particular, 1 cm by 1 cm "chips" were deemed a reasonable device sizes. Keeping this in mind, the wafer was symmetrically divided into 52 chips along the x and y axes assuming they run through the center of the wafer. Figure 16 demonstrates how this both looks like, and is interpreted in the JEOL system:



	1	2	3	4	5	6	7	8
1			5	5	5	5		
2		9	4	4	4	4	9	
3	7	1	3	3	3	3	1	7
4	8	1	2	2	2	2	2	8
5	8	1	2	2	2	2	2	8
6	7	1	3	3	3	3	1	7
7		9	4	4	4	4	9	
8			5	5	5	5		

Design	X	Y
1	2 7	3 – 6 3 – 6
2	3 – 6	4 – 5
3	3 – 6 3 – 6	3 6
4	3 – 6 3 – 6	2 7
5	3 – 6 3 – 6	1 8
6	1 8	4 – 5 4 – 5
7	1 8	3, 6 3, 6
8	1 8	4, 5 4, 5
9	2 7	2, 7 2, 7

Figure 15: The JEOL can easily split up the wafer into an 8x8 equally spaced array within the wafer. The numbering system begins at 1,1 for the top left cell, ending at 8,8 for the bottom right cell. The table demonstrates how multiple rows and columns can be copied if the same design exists for those cells.

It is important to note that this SOP does not go into great detail as to how to run the JEOL step-by-step. This SOP only provides high-level details for these particular nanoscale grating structures:

- Import your grating designs (GDSII) into the computer just past of the SNSF Spilker basement gowning area with the BEAMER software.
- Once imported, create a new workflow to begin. On the left, there are base modules you can click-and-drag to begin the workflow logic.
- Create the workflow specified by the subsequent Figure **??**:

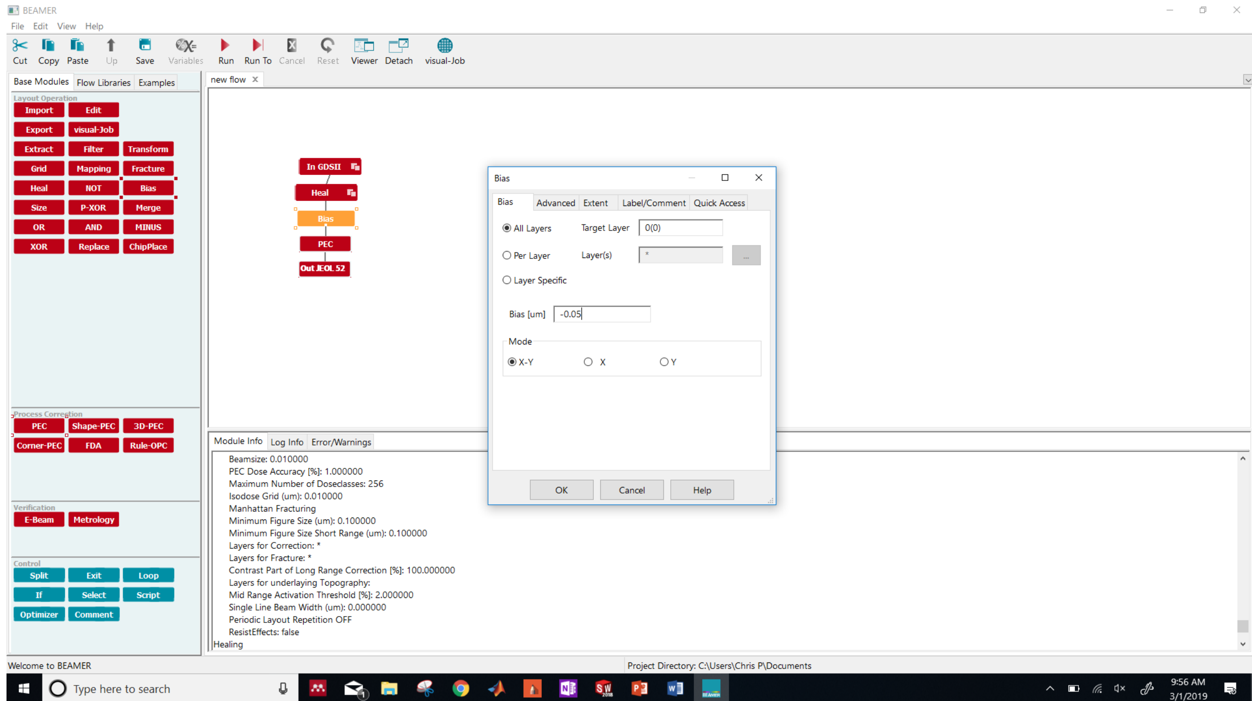


Figure 16: The BEAMER software uses modules to inform the exposure workflow of the JEOL. "In GDSII" imports the design files, while "Heal" meshes all objects within that design to make sure there are no infinitely small edges. "Bias" sets an artificial enlargement or reduction in feature edges to account for slight over or under exposures. "PEC" is proximity field correction, which dynamically changes the base dose amount based on how small the exposed features are. "Out JEOL 52" then exports the workflow into a format the JEOL tool can read.

- Select the base dose as 200 $\mu C/m^2$ and modify the bias to subtract 5 nm. This will end up correcting the underexposed features of the grating.
- Export the job file to the JEOL tool and place the wafer inside the JEOL's wafer mount. Note that this is a pressure-ring system and one must push gently on the rear of the ring while turning to remove it.
- Align the wafer with the screws on the wafer mount (device side down) and place the pressure ring on the back of the wafer. Gently push on the rear of the ring while turning to lock it into place.
- Go to the loadlock and vent. This should take 3 min. The loadlock can be seen in Figure 17:

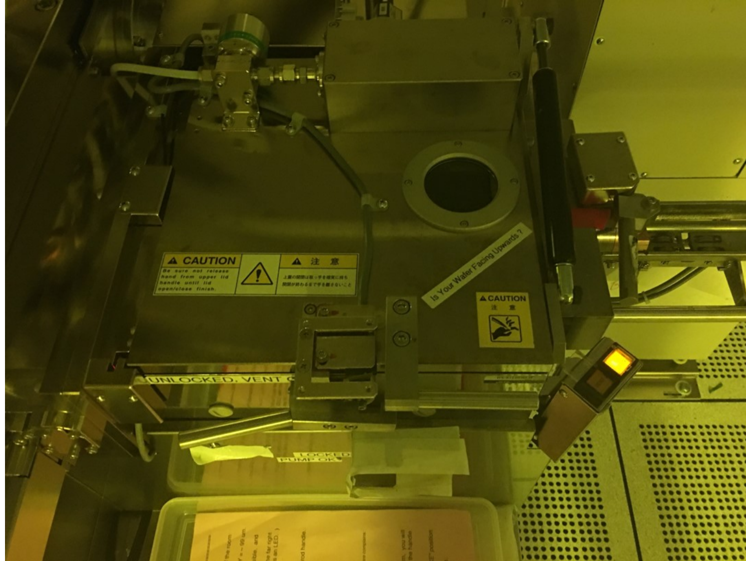


Figure 17: The JEOL load lock contains a cartridge with which to slide the JEOL wafer mount into. Make sure the cartridge is facing the correct direction (there will be red markings indicating which direction this is).

- Open the load lock and remove the cartridge inside. Insert the JEOL wafer mount into the cartridge while making sure it is in the correct direction.
- Insert the cartridge in the load lock and pump down. This should take 5-7 min.
- Use the JEOL software to specify the substrate type (4" silicon wafer) and use the stage controls to find the alignment marks.
- Set the target to align the wafer and open the job file. Load the job file and begin e-beam exposure. For features on this order, this should take 3 min.

2.1.7 Potassium Hydroxide (KOH) Etching

To create a suspended membrane from the underlying silicon, a KOH etch was implemented, with KOH etching from the rear of the structure. Note that this is **step #10** in the "Quick-Start" section on Page 1. The following Figure 18 details the various events encountered during a KOH etch.

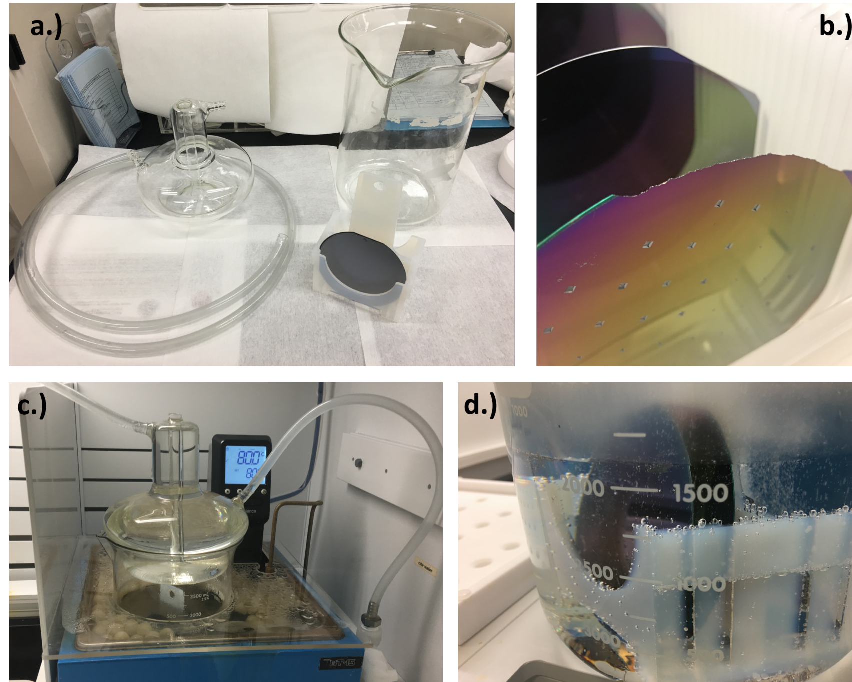


Figure 18: (a) The necessary equipment to perform the KOH etch, (b) a SiN wafer that was chipped during handling, demonstrating the post-etch fragility, (c) the KOH etch setup using a condenser and the boiling pool, and (d) a close-up of the KOH etch on a SiN wafer submerged in solution.

2.1.7.1 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 reach the SiN film, large beakers for etching and cleaning are needed, as seen in Figure 18a. 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 18c, until the water level contacts the bottom of the water level sensor. The white balls contained inside prevent the water 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 18d. 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. For a 350 wafer, the total etch time is 7.5 hours. Over-etching is not too detrimental in this flow since we want to make sure the etch reaches the SiN film with no silicon residue.
- 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 18b, where the edge of a KOH etched SiN wafer was chipped off during handling.

2.1.8 Placing the Stencil on the Target Substrate

Note that this precedes **step #12** (the metallization step) in the "Quick-Start" section on page 1.

- Carefully place the target substrate pieces on top of the stencil chip, aligning them to the grating structure. Make sure the grating side is facing up.
- Cut and place a small piece of Kapton tape over the target substrate to stick onto the stencil wafer. Make sure the Kapton tape pieces DO NOT cover the grating structure, or come between the interface between the target substrate and the stencil wafer.
- The taped substrate and stencil can now be flipped such that the aperture side of the stencil is facing up, ready to have metal deposited through it.

The following Figure 19 demonstrates how the target substrate placement is performed.

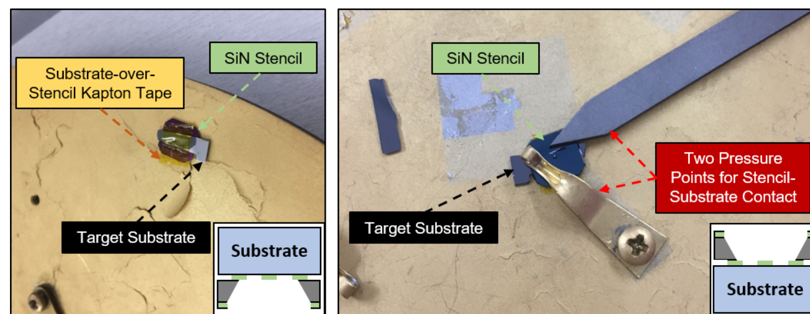


Figure 19: (Left) Kapton tape is used to place a representative silicon substrate to the grating side of the stencil. (Right) Two pressure points are used to create the best stencil-substrate contact once the stencil-substrate is aperture side up.

2.1.9 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 #12** in the "Quick-Start" section on page 1. For a grating pitch of 300 nm, grating width of 150 nm, and grating thickness of 100 nm a metallic film of 25 nm was deposited.

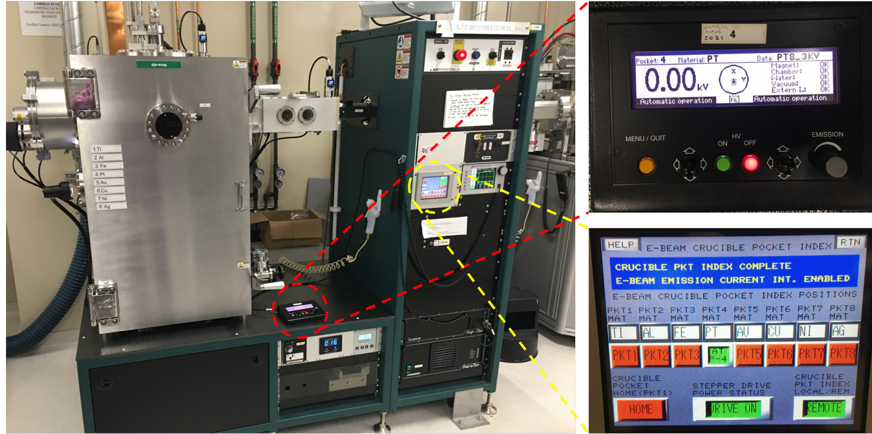


Figure 20: The AJA evaporator tool, along with the user interfaces to input recipes and specify the deposition material.

As mentioned briefly in the "Introduction" section on Page **??**, the metal film thickness should generally be much thinner than the negative space width of the grating structure.

Figure 21: (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.

2.1.9.1 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 21.
- 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 right side of Figure 19 for more details.

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 20. 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 21.
- 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 20. 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 20, 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. 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 0.25 kAngstroms (if depositing 25 nm). 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 20. 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 $\sim$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.

3 References

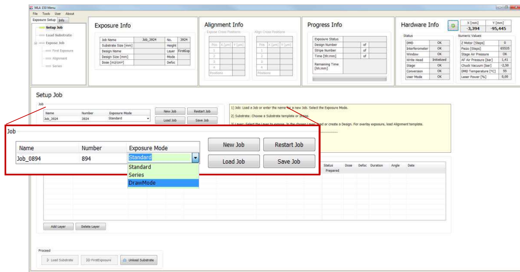
[1] O. Vazquez-Mena, L. Gross, L.G. Villanueva, & J. Brugger, "Resistless nanofabrication by stencil lithography: A review", *Microelectronic Engineering* 132, pp. 236-254, 2018.
[2] SNF Labmembers Wiki, https://snf.stanford.edu/SNF/, 2018.
[3] Heidelberg Industries, "MLA 150 Maskless Aligner", *Doc. 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 [HIMT MLA icon] 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.

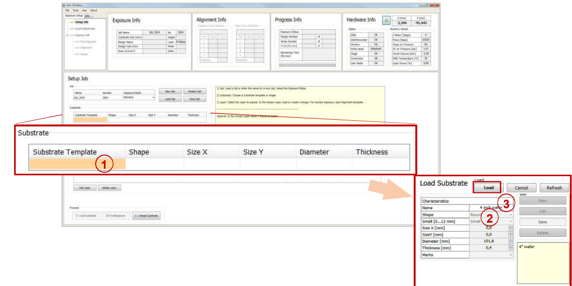
After you have set up the desired job, choose the appropriate substrate and the corresponding substrate template at the system (see *Substrate Template Selection*).

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

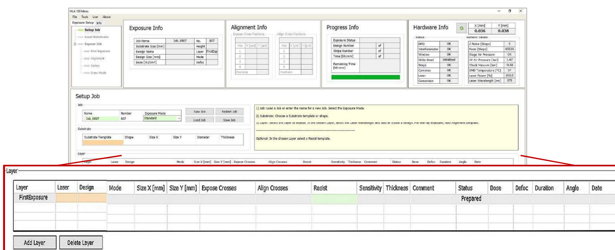
ⓘ In Draw Mode there is no design loading procedure because this mode is for exposing boxes, circles and ellipses of arbitrary size limited only by the camera field. Skip this subchapter and go to *6.5 Load Substrate*.

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.

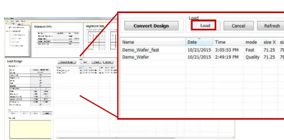
6.3.1 STANDARD: FIRST EXPOSURE

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.

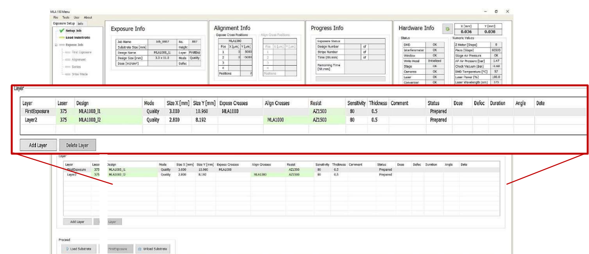


✓ The design is now listed in the ***Layer*** frame.

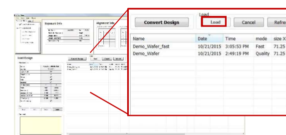
5. Optional: Double-click the value field titled **Resist** and select the appropriate resist type for your application. The recommended dose for exposures on that type of resist is listed automatically in the **Sensitivity** field. In the **Thickness** field the thickness of the resist is displayed.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

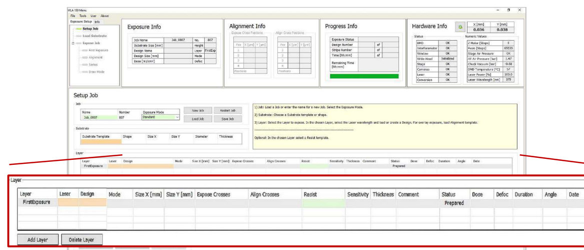
Series

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			

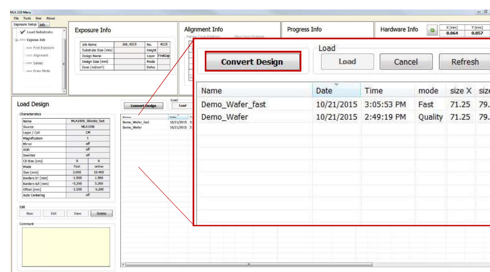
6.4 Convert Design

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:

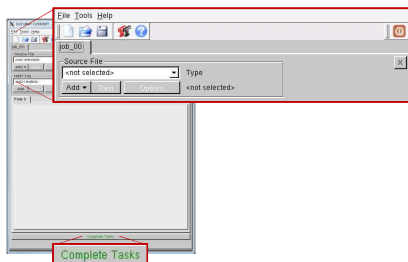
In the ***Layer*** frame:



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

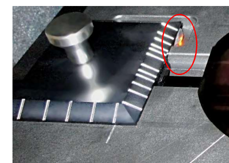
After you have chosen the appropriate substrate, selected a substrate template and loaded a design, you can place the substrate on the chuck. The following instructions guide you through the loading procedure. You also get on-screen instructions inside the yellow **Info Box**.

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.

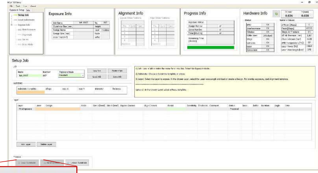


Keep in mind to remove the adjustment aid from the chuck before starting an exposure.

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:

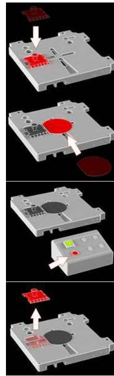


1. Click **Load Substrate**. The stage moves into loading position.

✓ 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.

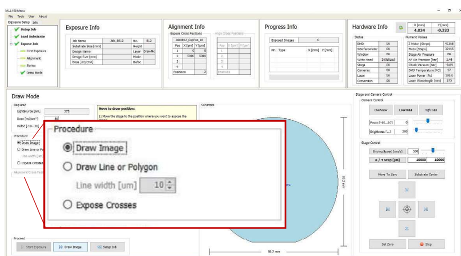
After the successful loading process, the system leads to the next panel:

- 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.

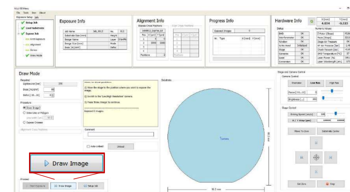
In the ***Draw Mode*** panel



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

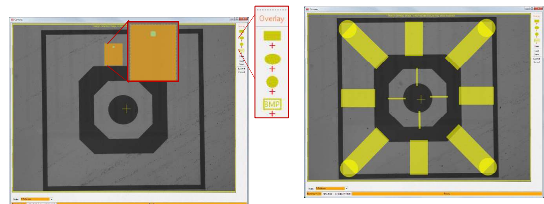
- Draw Image: Activate this option to use the shapes offered in the camera window: rectangle, ellipse, circle or bitmap file.
- Draw Line or Polygon: Use this option to draw lines or polygones (lines with more than two points). Adjust the line width by using the spin control below the radio button.
- 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



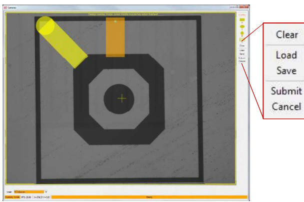
1. Click **Draw Image** and select the area for the structure on the substrate inside the camera window (use the Stage Control section for moving on the substrate).
2. In the camera window select the shapes of the structures that should be drawn onto the substrate by clicking on the corresponding icon.

   ⓘ 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.



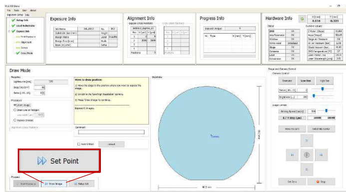
4. To confirm the drawn image, click **Submit** in the menu bar of the camera window. To clear the image, click **Clear** and start again.

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

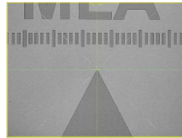


✓ After submission of the created image, work with the camera window is done. Return to the wizard window and the Draw Mode panel in which the exposure process can be started (see *6.8.4 Draw Mode Exposure Procedure*).

6.6.2 DRAW LINE OR POLYGON



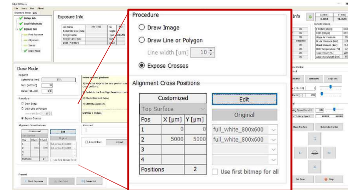
1. In the camera window, move to the area near to the position of the first point of the line or polygon, so that it is visible in the camera image.
2. Click **Set Point**.
3. In the camera window, a crosshair appears. Move the crosshair by moving the mouse to the desired position.



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.

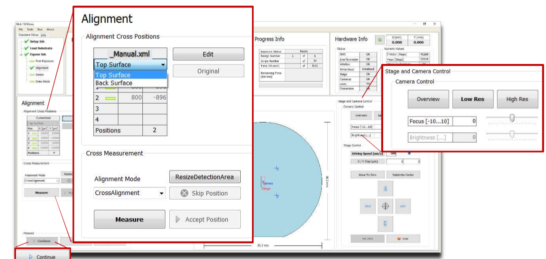
The alignment function offers two different alignment modes, Cross Alignment and Manual Alignment.

- 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.

  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.

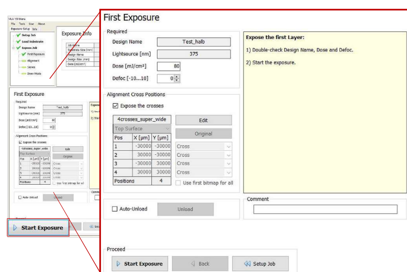
7. Repeat the procedure for all alignment cross positions. Cancelling the alignment procedure is possible by clicking **Cancel**. Alternatively, with **Setup Job** the alignment procedure gets cancelled and the Exposure Wizard moves back to the **Setup Job** panel.
8. Click **Continue**.

✓ 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.

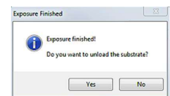
6.8.1 FIRST EXPOSURE PROCEDURE



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.

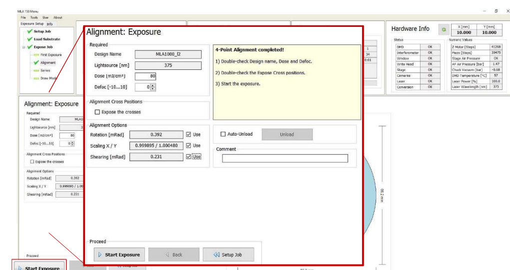


It is also possible to click **No** and unload the substrate by clicking **Unload** in the panel (see *6.9 Substrate Unloading*).

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

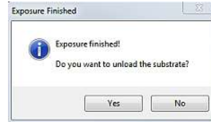


1. Double-check the design name and the wavelength.
2. If no default value is given, set the **Dose** value by entering it into the text field.
3. Set the **Defoc** by selecting a value with the spin buttons (range -10 to 10). The defoc allows fine tuning of the exposure focus.
4. Double-check the **Alignment 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.

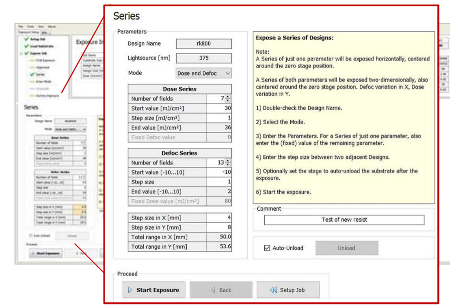
7. Optional: Activate **Auto-Unload**. The system executes the unloading procedure automatically (see *6.9 Unload Substrate*).
8. Click **Start Exposure**.

✓ 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.

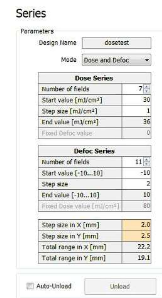


6.8.3 SERIES EXPOSURE PROCEDURE

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.

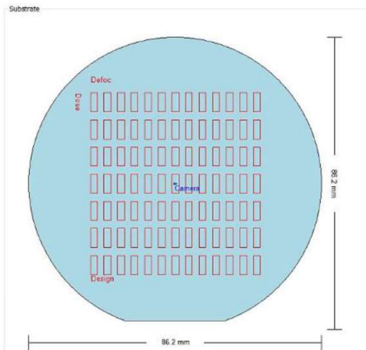
In the bottom table, the **Step size** in x and y direction is determined.

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.

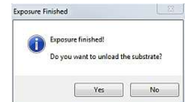


1. Select from the options in the **Mode** dropdown list: **Dose**, **Defoc** or **Dose and Defoc**.
2. Set the values required for the selected mode.

   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**.

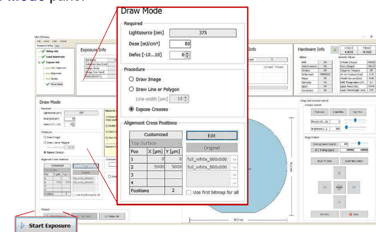
✓ The machine is exposing the design. If **Auto-Unload** is not activated, then after completion of the exposure a dialog window pops up asking if the substrate should be unloaded. Click **Yes**, if you want the system to unload the substrate or **No** if the substrate should stay loaded on the chuck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

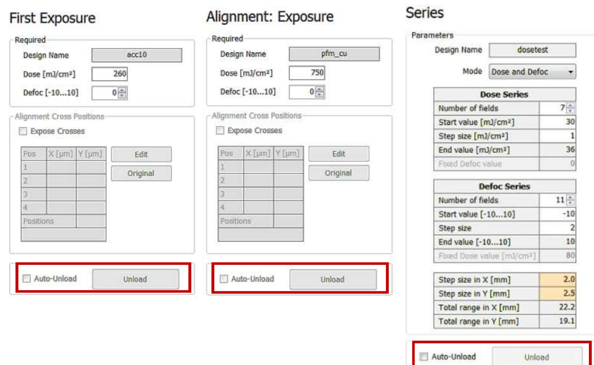


Figure 14: Unloading options in Standard Mode and Series Mode

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.