CORAL Name: EBL-Elionix-HS50

Location: L14
Category: Lithography
Contact: Juan Ferrera, Mark Mondol

Contents

Introduction **1**

Safety **2**

User Qualifications and Responsibilities **2**

Operating Procedures **2**
- Substrate Loading 2
- Column Setup 3
- Exposure Setup 9
- Substrate unloading 15

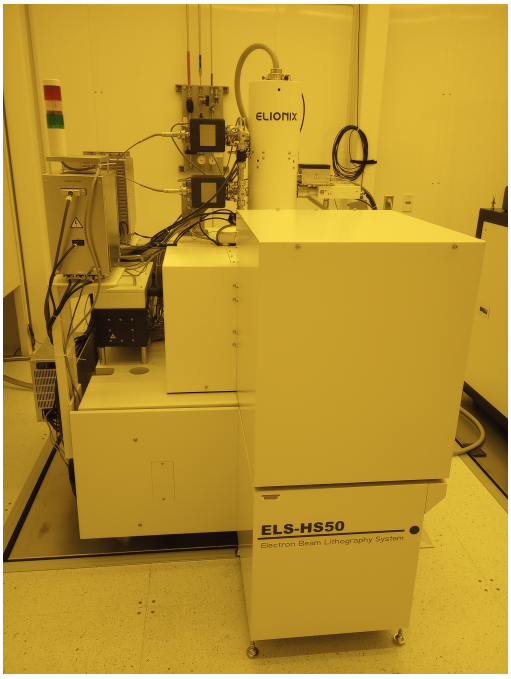
Appendices **16**
- A. Exposing a matrix 16
- B. Aligned exposure 17

Introduction

The Elionix ELS-HS50 is a high speed, high resolution electron-beam lithography (EBL) tool. It operates at 50 kV, with a beam diameter that ranges from 2.5 nm at 2 nA beam current to 10 nm at 100 nA. Even higher currents are possible, up to 1 μA. The pixel clock has a maximum frequency of 100 MHz.

It has a robotic loadlock with six slots. Sample holders can be loaded into the chamber, exposed and unloaded under remote control. Currently there are two wafer holders and two sample holders for small substrates. The wafer holders can accommodate wafers between 2 and 8 inches in diameter.

The HS50 instrument is located in a special imaging room that is designed to minimize mechanical and EM noise. Additionally, the instrument sits atop an active vibration isolation platform and the room has active EM cancellation, all designed to increase the tool's performance and resolution. The control console for the HS50 is located outside of the room in the L10 clean bay so that the presence of an operator will not affect the writing process.



Safety

- Stage position is measured with a laser interferometer, which is enclosed under normal operation. This makes it a Class 1 laser device. No protection is necessary.
- The airlock door is a possible pinch point.
- There are various cables and fluid lines at the back and on the sides of the column, which constitute trip hazards and could seriously damage the machine if tripped upon. Do not walk around the column or to the back to the room.
- The system utilizes high voltage. Under normal operation the user is protected from it. Do not attempt to bypass any system interlocks or to open any of the instrument panels, unless specifically instructed to do so.

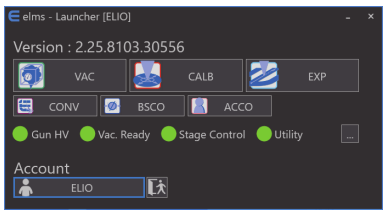
User Qualifications and Responsibilities

- Only users who have undergone training and are qualified with CORAL are allowed to use the system.
- All screws on sample/wafer holders should be finger-tight ($\sim$1 Nm of torque). Any extra torque will not result in a firmer hold, and will only distort the ultra-flat reference surface of the holder.
- If a screw or any other part of the sample holders is dropped/lost/damaged, it is the responsibility of the user to inform the staff member in charge of the machine. There will not be any repercussions whatsoever, and we would like to know as soon as possible so we can replace the part.

Operating Procedures

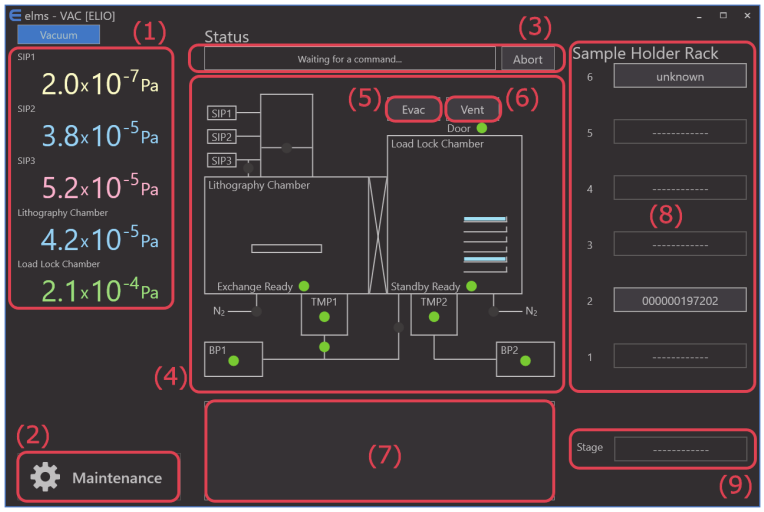
Substrate Loading

1. Engage the tool in CORAL.
2. Start the software and log in.
   (a) The main Elionix interface program “elms” is usually running. (If not, start it by double-clicking the icon on the desktop):



   (b) Log in by clicking the icon under **Account**.
3. Vent the loadlock, mount sample and pump loadlock down.

(a) Start the **VAC** program:



(b) Vent the loadlock by clicking on **VENT** (6 in the diagram)

(c) Wait for the loadlock to reach atmospheric pressure ($\sim 1 \times 10^5$ Pa).

(d) Remove the desired sample/wafer holder from the loadlock rack. While sliding the holder out lift slightly, so that the holder's location pins can clear the rack. Don't close the door, as this will immediately start the loadlock vacuum pump.

(e) Place the holder on the mounting fixture and mount your sample/wafer.

(f) Using the multimeter, check for electrical conductivity between the sample surface and the holder. If the sample is not grounded you will most likely have charging problems.

(g) Slide the holder back into its place on the rack. Be careful to mount in the right orientation: the holder's barcode should be on the lower right. Again, lift slightly while sliding in. Check that the holder is properly seated in the rack: you should not be able to move it more than an millimeter or so.

(h) Close and latch the loadlock door. Pumpdown will start automatically.

4. Load holder into the main chamber.

(a) The sample holders in the loadlock will be identified during pumpdown. Holders present in the loadlock will be displayed in the **Sample Holder Rack** (8) section of the window.

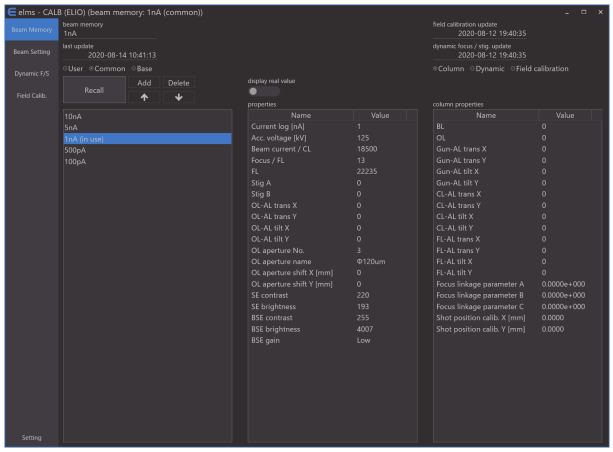
If there is a holder in the main chamber, it will be shown in the **Stage** (9) section. It will have to be unloaded before another sample holder can be loaded in.

(b) When the loadlock has reached the necessary pressure, the **Exchange Ready** and **Standby Ready** pilots will light up. At this point it is possible to transfer a sample holder into the lithography chamber. Click on the icon that corresponds to the holder to be loaded in. When the holder has been loaded in, the message "Sample holder loading finished" will be displayed in the info window (7).

Column Setup

1. Recall and save column parameters for a given beam current.

(a) Start the **CALB** module from the elms launcher. You will be presented with the following window:



Beam memories are parameter sets that calibrate the column for a given beam current. There are three kinds: base, common and user. The “base” memory contains the basic column calibration. It is accessible only to Elionix service engineers. The “common” memories calibrate the column for different beam currents. They are read-only for regular users. These are to be copied into “user” private memories for each user.

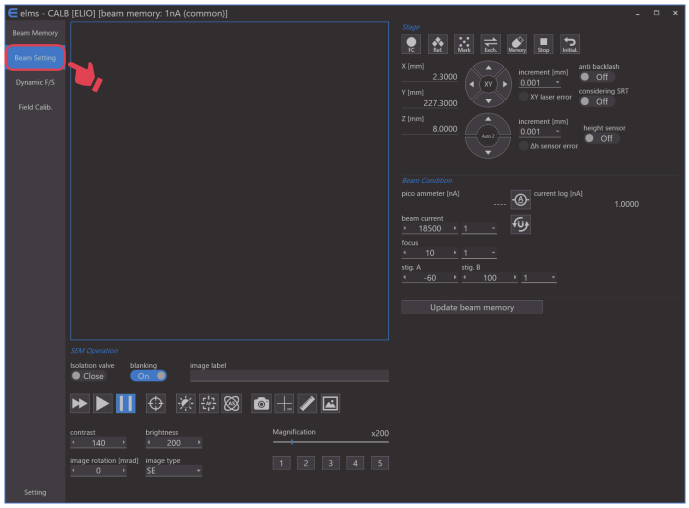
(b) If necessary, copy a beam memory from the “Common” space to the “User” space. Select the “Common” space by clicking on the radio button. Select a particular beam current by clicking on it. Click on **Recall** to load the parameters. Then select the “user” space and click on **Save as** to save it to your private user space.

(c) If you already have a user beam memory for that particular beam current, recall it from your “user” space.

(d) “User” beam bemories need to be updated after a gun change or column realignment. Staff will notify users when this happens.

2. Adjust beam current.

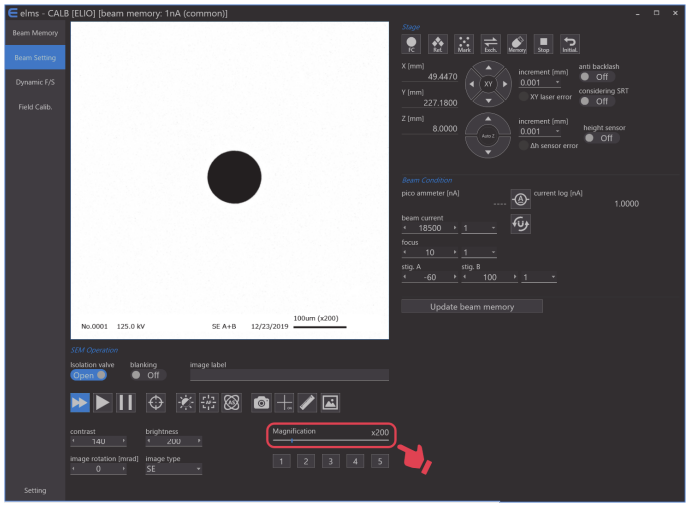
(a) Click on the **Beam Setting** tab on the left of the CALB window. The window will appear as follows:



(b) Click on the Faraday cup button  to move stage to the faraday cup.

(c) The **Isolation valve** control, on the lower left should say “Close”, i.e., the valve is closed. Click on it to open the isolation valve.

(d) To verify that the beam is centered on the Faraday cup start an SEM scan by clicking the slow-scan ▶ or fast-scan ⏩ buttons. Select a magnification of 200X. You should see an image of the Faraday cup:



The Faraday cup should be centered on the image. If it is not, adjust the stage position until it is: right-click on the image, and select **Stage moving** from the pop-up menu. Left click in the middle of the Faraday cup image to center it.

(e) Click on the “scan stop” button ⏸ to stop SEM scanning.

(f) Click on the pico-ammeter button Ⓐ to measure the beam current.

(g) If the beam current is different from its nominal value, adjust it by changing the value of the condenser lens (**beam current**) control. Decreasing this value will increase the beam current and vice-versa. Choose a step of 10 to the right of the control. It is not crucial to get the beam current exactly to its nominal value, because the system will measure it just before exposure, and adjust dwell times to get the correct dose. A difference of $\sim 1\%$ is acceptable.

(h) After the condenser lens has been changed, the column needs to be degaussed. Click the ammeter button again to stop the measurement. Click on the “hysteresis clear” button to degauss the column.

(i) Measure the beam current again. If the value has changed after degaussing, repeat the current adjustment/degaussing cycle.

(j) Click on **Update beam memory** to save beam current settings.

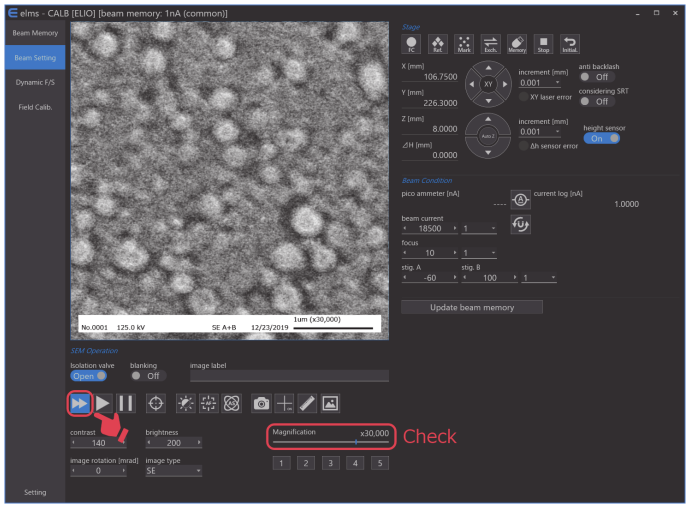
3. Adjust beam focus and stigmation.

(a) Click on the reference Ref. button to move the stage to the reference sample.

(b) Start a fast SEM scan, and select a low magnification.

(c) When the beam scans over an area carbon contamination builds up on the surface. This will make the image darker. Find an area of the reference sample that has no carbon contamination. Right-click on the image, and select **Stage moving** from the pop-up menu. Click on the image to center it on a clean part of the reference sample.

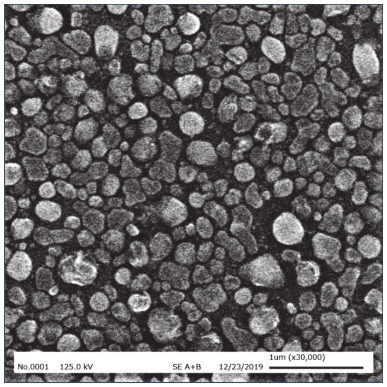
(d) Increase the magnification at least x30,000. You can use magnification preset number 5 to get a magnification of x50,000.



(e) Click on the auto-bc button to adjust image contrast and brightness to levels that are optimal for beam adjustment. You can also use the numerical controls **contrast** and **brightness** to perform this adjustment manually.

(f) Click on the auto-focus button to focus the beam automatically.

(g) Click on the auto-stigmation button to null out stigmation. At this point the image should look distinctly sharper:



(h) You can focus and stigmate the beam manually by selecting **Focus** or **Stig** from the right-click pop-up menu on the SEM image. For focus left-click and drag from side to side to focus. For stigmation, drag left/right and up/down to adjust the two parameters of the stigmator. The automatic routines do a very good job of optimizing the beam, but if you're doing work at the highest resolution, or simply don't trust the routines, you can do these adjusments manually.

(i) Click on **Update beam memory**.

4. Set up dynamic focus and stigmation (optional).

(a) At this point the beam is focussed and stigmated at the center of the deflection field. This will not be the case when the beam is deflected away from the center, and small corrections will be needed. If you require the highest resolution across the entire field, you can enable dynamic focus/stigmation correction. It is somewhat laborious to set it up, though.

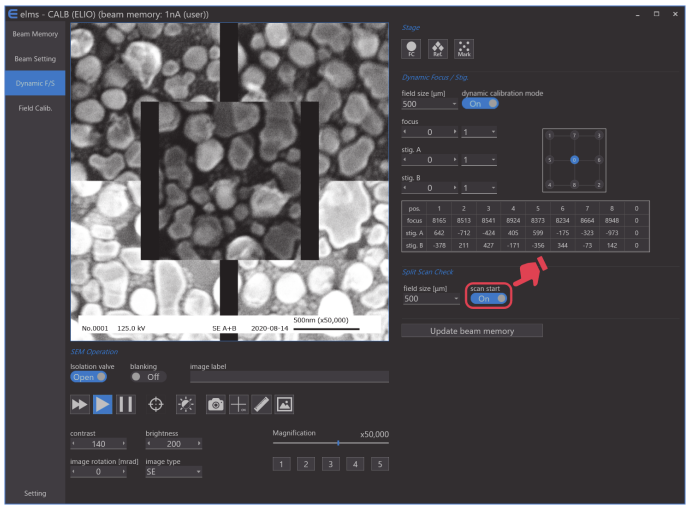
(b) Select the **Dynamic F/S** tab.

(c) You must be scanning a clean area of the reference sample. (See previous section.)

(d) In the **Dynamic Focus/Stig.** section the field size is permamently set to 1500 μm. The settings for the standard 1000 μm field will be interpolated from the values measured for the larger field.

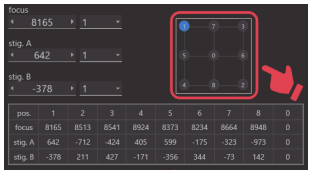
(e) Turn on **dynamic calibration mode**

(f) To do a spot-check of focus/stig at the corners of the field, under **Split Scan Check**, turn **scan start** on. The system will display images correponding to the center and the corners of the 1500 μm field.



(g) Turn **scan start** off.

(h) If images at the corners of the field are blurred, it will be necessary to calibrate the interpolation table. Select a region by clicking on it in the region selector:



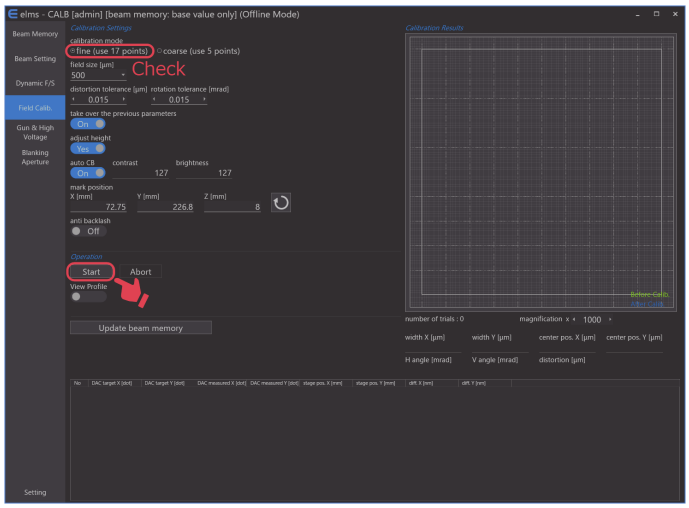
(i) Adjust brightness/contrast, focus, and stigmation as was done for the center of the field (see previous section).

(j) Repeat for all regions except for region 0, which is the center.

(k) Click on **Update beam memory**.

5. Calibrate deflection field.

(a) Click on tab **Field calib** on the left of the CALB window.



(b) Select a field size of 1000 μm.

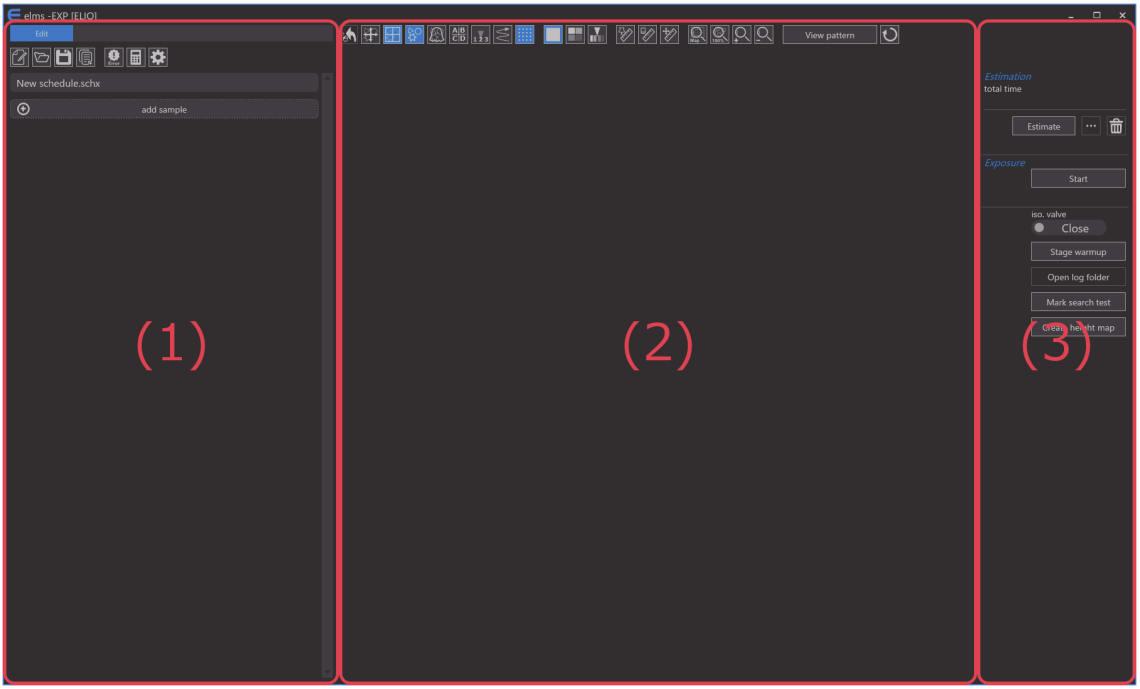
(c) Select **fine**.

(d) Click **start**.

(e) The beam deflection parameters will be calibrated against the stage motion. The interim results are shown as a market plot in the graph on the right. The calibration usually converges after two iterations. To minimize stitching errors the distortion and rotation tolerances can be set to 10 nm and 10 μrad respectively, but the convergence will be slower.

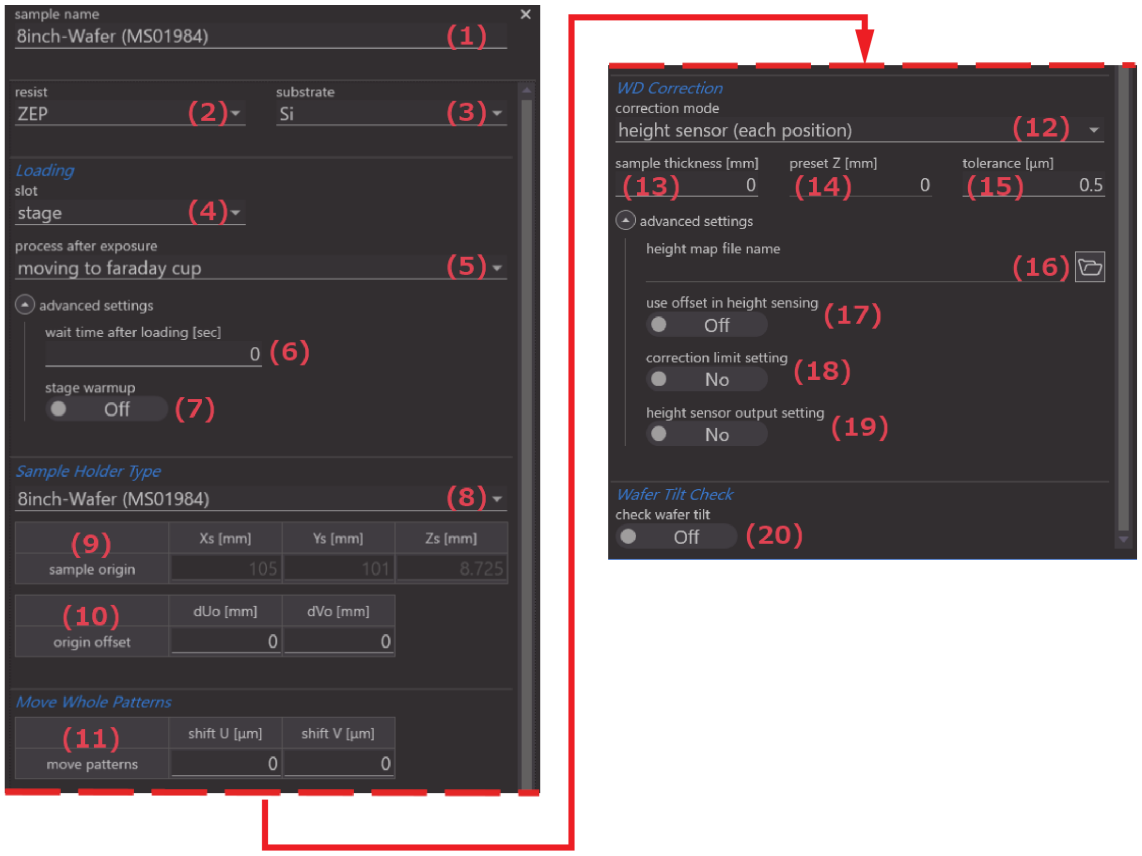
Exposure Setup

1. Start the **EXP** program from the elms launcher. This will be used to construct a schedule file for the exposure.



The **EXP** window has three main sections. The leftmost column (1) is the schedule editing column, which will display the schedule file's structure. (2) is the CAD pattern display area, where a schematic of the chosen sample holder will be shown, as well as any defined exposure files in the requested positions. This graphical display makes it easier to lay out an exposure schdule, so that the exposed patterns will be exposed in the correct locations relative to the sample's edges. The rightmost column (3) contains execution buttons for various areas.

2. Add a sample card by clicking on **add sample**, and fill in parameters.



(a) **Sample name (1), resist (2), and substrate (3):** Will be output in the log file for future reference.

(b) **Loading – slot (4):** The sample holder is already loaded, so select “stage”. If you wish to load a particular substrate holder from the loadlock into the chamber, make sure that no holder has been loaded yet, and then select the holdr’s slot here.

(c) **Process after exposure (5):** Specifies which operation to perform after all patterns have been exposed. The substrate holder can placed back in the loadlock, the stage can move to the Faraday cup, or the stage can be left at its last position.

(d) **Sample holder type (8):** Determines an origin shift, depending on which sample holder type is chosed. For small substrate holders, the origin is shifted to the lower left corner of the substrate chosen. For wafer holders, the origin is shifted to the center of the wafer. Also a sketch of the sample holder is shown, which facilitates placement of the exposed fields on the substrate.

For multipiece holders, an extra parameter will be added, **small sample size**: enter x and y values to display an outline of the sample on the holder.

(e) **Sample origin (9)** This parameter is preset according to the **sample holder type**. If the type is “free input”, the origin coordinates can be defined here.

(f) **origin offset (10) and move whole patterns (11):** Shift all patterns defined in this card. These is can be left at zero, and the patterns shifted graphically at a later stage.

(g) **WD correction – correction mode (12):** This is an important parameter, since it determines how the system will ensure that the sample surface coincides with the calibration plane.

When “height sensor (each position)” is selected, the Z position is adjusted using the optical height sensor every time for each exposure field. This is the preferred setting, given that the sample is reflective and the sensor can measure the surface height.

If there are structures that interfere with the optical height sensor, but there are locations where the surface is devoid of these and the hight sensor is functional, select “height map”. A height map created in advanced is specified in the sample card, and the exposure is performed while moving to the Z position calculated according to the XY position of each field. It is also possible to create a height map by measuring the Z position at which the electron beam is in focus at three locations.

When “Preset Z” is selected, the Z position is first moved to the “Preset Z” height described below, and the exposure proceeds at that height.

There are other choices: “height sensor (1st. position only)” and “No move”.

(h) **Sample thickness (13):** An estimate of the sample thickness is used to compute **preset Z (14)**. The nominal working distance to the substrate holder surface is 8 mm. **preset Z** will be calculated by subtracting the sample thickness input here from 8 mm. For reference, the following table lists standard thicknesses for silicon wafers.

wafer diameter [in]	nominal thickness [mm]
2	0.275
3	0.375
4	0.525
6	0.675
8	0.725

(i) **Preset Z (14):** Set this value directly or with the aid of the “Sample thickness” parameter. If the height sensor is not working for a particular substrate, the preset Z can be measured by imaging a structure on the sample surface in SEM mode, and changing the Z height until it is in focus. This will expose the resist at this location.

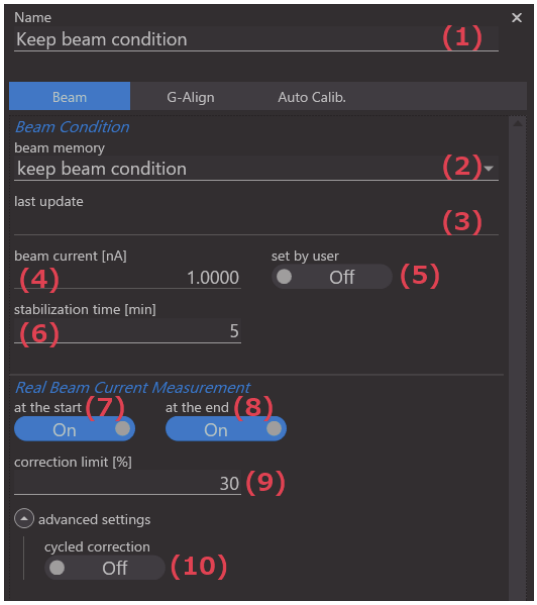
(j) **Tolerance (15):** The default value of 0.5 μm is adequate for most purposes.

(k) **height map file name (16)**: If using a height map, choose the file where it’s stored. Creation of a height map will be described below.

(l) The rest of the parameters can be left with the default values, unless there is a special need.

(m) When all parameters have been entered. Click on the ✕ button to dismiss the window.

3. Add a beam card by clicking on **add beam card** inside the sample card. The beam card definition window has three tabs. The first one is **Beam**. Fill in necessary parameters:



   (a) **Name (1)**: Input a label to be displayed as an identification when the schedule file is listed.

   (b) **Beam memory (2):** Select which beam memory file to load. To use the current beam parameters already present in memory, select “keep beam condition”.

   (c) **Last update (3):** Displays the last update date and time of the beam memory to be loaded.

   (d) **Beam current (4)**: This value will be entered by the software, either from the beam memory to be loaded, or from the last current measured if “keep beam condition” is selected. This value will be used to calculate dwell times when setting up exposure cards (see below).

   (e) **Set by user (5):** Make sure this is off.

   (f) **Stabilization time**: Wait time after a beam memory is loaded.

   (g) **Real Beam current measurement:** “At the start” (7) causes the beam current to be measured immediately prior to exposure, and dwell time corrected accordingly. If “At the end” (8) is enabled the beam current will also be measured at the end and logged, to give an idea of how stable the beam current was during exposure.

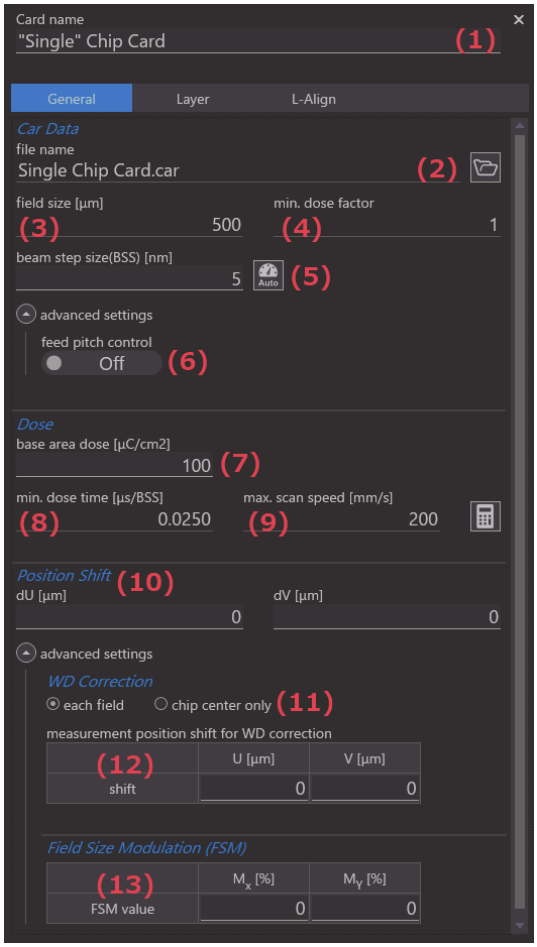
   (h) **Correction limit (9):** The maximum deviation the system from the nominal current input in (4) that the system will correct for without giving an error message.

   (i) **Cycled correction (10):** Correct for beam current drift at regular intervals during the exposure.

4. The other two tabs, **G-Align** and **Auto Calib.** are related to more advanced functionality. The use of **G-Align** to perform global alignment is outlined in Appendix B. **Auto Calib.** is beyond the scope of this SOP. See the system administrators or consult the HS-50 documentation.

5. Click on the ✕ button to dismiss the window.

6. Add a chip/exposure card by clicking on **add card** inside the beam card. Select either “Single exposure” or “Matrix” (to expose an array of patterns or a dose matrix). The following covers setup of a single exposure. For a matrix exposure, see Appendix A.



(a) **Card name (1)**: Type a distinctive name, which will be displayed in the schedule listing.

(b) **File name (2):** Select the .car pattern file to be exposed. Click on the button. A file selection dialog will appear. Select a .car file.

(c) When the pattern file is loaded, the field size defined in the pattern file will be displayed in **(3)**. **(4)** will show the minimum dose factor (relative dose) present in the pattern file.

(d) Input the desired base dose into **base area dose (7).** The base dose will be multiplied by each shape’s dose multiplier.

(e) Click on the **(5)** button. The software will calculate the smallest beam step such that the smallest dose (base dose times the minimum dose factor) is exposed at a dwell time as close to 10 ns as possible. You can also enter a value for the beam step size at **beam step size (BSS) (5)** directly, as long as the resultant **min. dose time (8)** is larger than 10 ns. (100 MHz stepping frequency). The dose calculator ( ) is useful in determining the relationship between step sizes and stepping frequencies. This relationship can also be derived from the following expression:

$$D_A = \frac{i_b \cdot t_d}{d_{BS}^2},$$

where D_A is the area dose, i_B is the beam current, t_d is the dwell time, and d_{BS} is the beam-stepping distance.

(f) To shift this pattern's coordinates, such as when exposing multiple pattern cards in one beam card, enter relative shift amounts in the **Position Shift (10)** entries.

7. Click on the button to dismiss the window.
8. Add more exposure cards as needed.
9. Move pattern exposure to substrate center. As exposure cards are added, the pattern is placed such that the (0, 0) coordinates of the CAD file coincide with the sample's origin. This will most likely not be the desired location. To shift all patterns together, click on the button, which is the second button on the superior part of the CAD pattern display area. A window will to specify how the patterns are to be moved. The default action is to define the start point of the move as the extent center (the center point between the maximum and minimum coordinates in x and y) and the end point with a mouse click. In the CAD display area, click on the position of the substrate where you want the extent center to be located. For more precise positioning, you may also type numerical coordinates into the "mouse-click" area. Other options to specify pattern moves are available.

   To shift the origin by an exact amount, enter numerical values in the **Position Shift (10)** fields of each chip/exposure card dialog.
10. Save the schedule file: Click on the save button above the schedule definition column. A standard save-file dialog will appear. Enter name and location for the schedule file.
11. Estimate exposure time. Click on **Estimate** in the execution button area. The software will calculate and display an approximate exposure time. Make sure you have saved the schdule file prior to this step, or the program will hang.
12. Start the exposure: click on the **Start** button.
13. When the exposure is finished a notice will appear.
14. Click on the **iso. valve** button to close the isolation valve. You may then unload the sample holder.

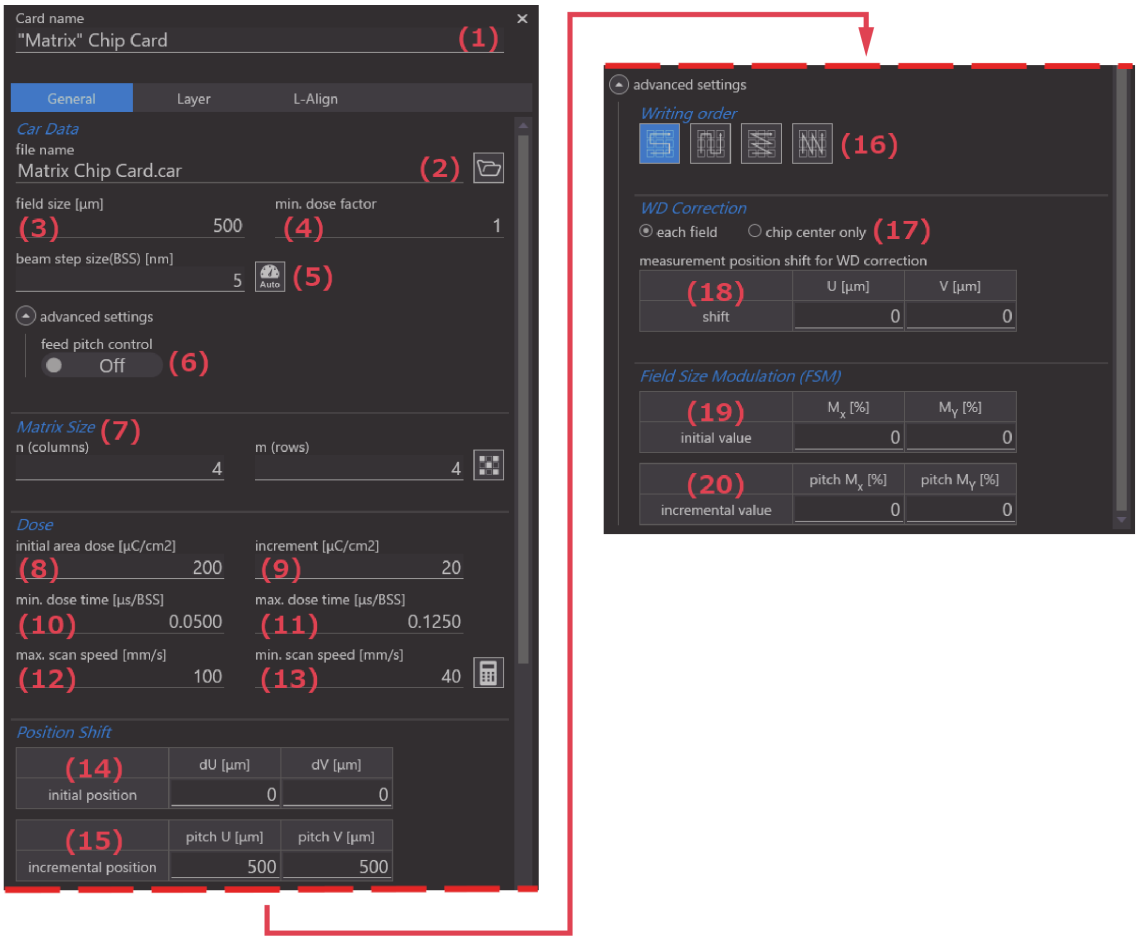
Substrate unloading

1. Return to the **VAC** program.
2. Click on the substrate holder's icon in the **Stage** section. The holder will be unloaded and placed into the loadlock sample holder rack.
3. Click on the **Vent** button.
4. When the loadlock reaches atmospheric pressure, open the loadlock door and remove substrate holder from the rack.
5. Place the holder on the mounting fixture and unmount your sample/wafer.
6. Return the holder to the loadlock.
7. Close and latch the loadlock door.
8. Log out of the elms system by clicking the logout button .
9. Disengage from CORAL.

Appendices

A. Exposing a pattern matrix

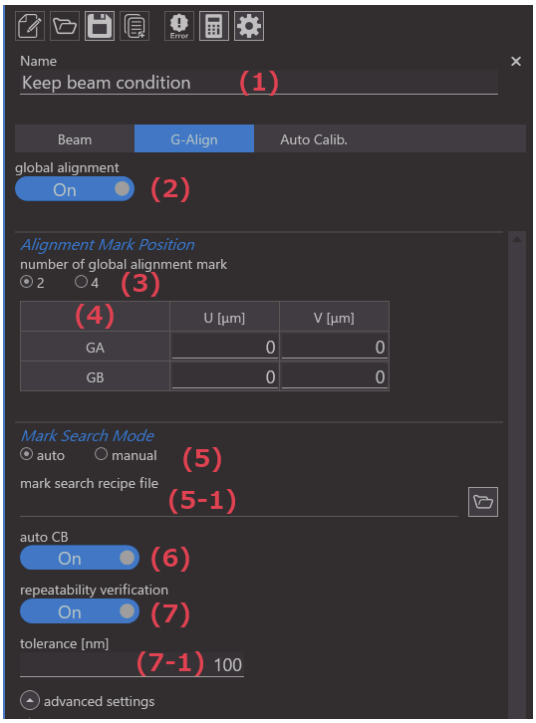
If “Matrix” is selected when adding an exposure card, more parameters will be displayed in the card definition window:



1. Use **Matrix size (7)** to define the number of columns and rows.
2. If all instances are to have the same dose, enter it in **inital area dose (8)**. Leave **increment (9)** at 0.
3. To perform a dose matrix, enter the desired dose increment into **(9)**.
4. Enter a position offset for the first instance into **initial position (14)**.
5. Enter position increments in x and y into **incremental position (15)**.
6. The writing order is of particular importance when doing a dose matrix. Select is from the options shown in **(16)**.
7. When defining the **beam step size (5)**, the **initial area dose (8)**, and the **increment (9)**, take care that **min. dose time (10)** is larger than 10 ns.

B. Aligned exposure

While defining a beam card, if the **G-Align** tab is chosen, the following dialog will be displayed:



This is used to configure global alignment, in which an alignment procedure will be performed prior to exposing all exposure cards defined within this beam card.

1. Click on the **global alignment (2)** button to enable the procedure.
2. Select the number of alignment marks to be used in **(3)**.
3. Enter the *design* coordinates for the marks, i.e., the coordinates of the mark centers as defined in the GDS design.
4. Select **auto** or **manual** alignment in **(5)**. If automatic alignment is chosen, use the **mark search recipe file (5-1)** dialog to load a recipe file. The setup of this file is a complicated process. See the HS-50 documentation.
5. If **auto CB (6)** is enabled, brightness and contrast will be optimized automatically for each one of the alignment marks. It is recommended this this is enabled.
6. **Repeatability verification (7):** If this parameter is enabled, the registration process will be performed twice, and the results will be compared. If the difference is less than the **tolerance (7-1)**, the exposure will continue. Otherwise an error will be raised.