Standard Operating Procedure

Nabity NPGS

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1. Pattern Design and Preparation

Basic knowledge:

The center of the SEM's total scanning area should correspond to the origin of your pattern,

If you need to do alignment. The center of alignment marks should be set at (0,0).

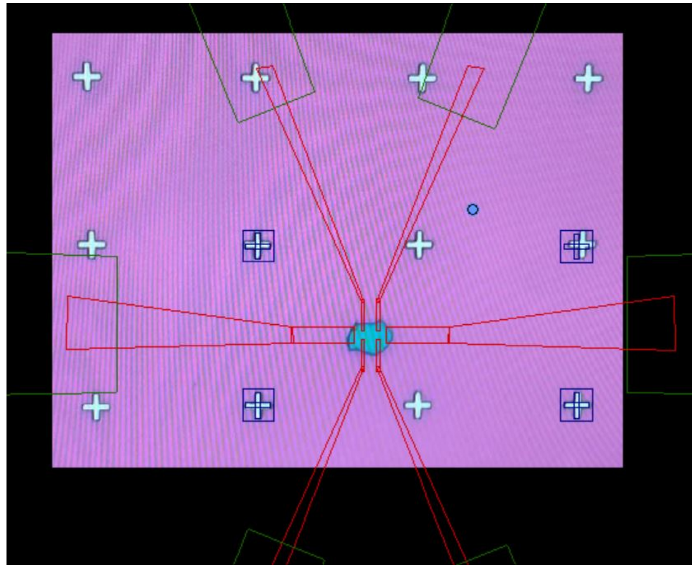
The value of Mag Scale = Magnification x Scale of SEM = 216000. The magnification of SEM will be set by the size of your pattern and this Mag Scale.

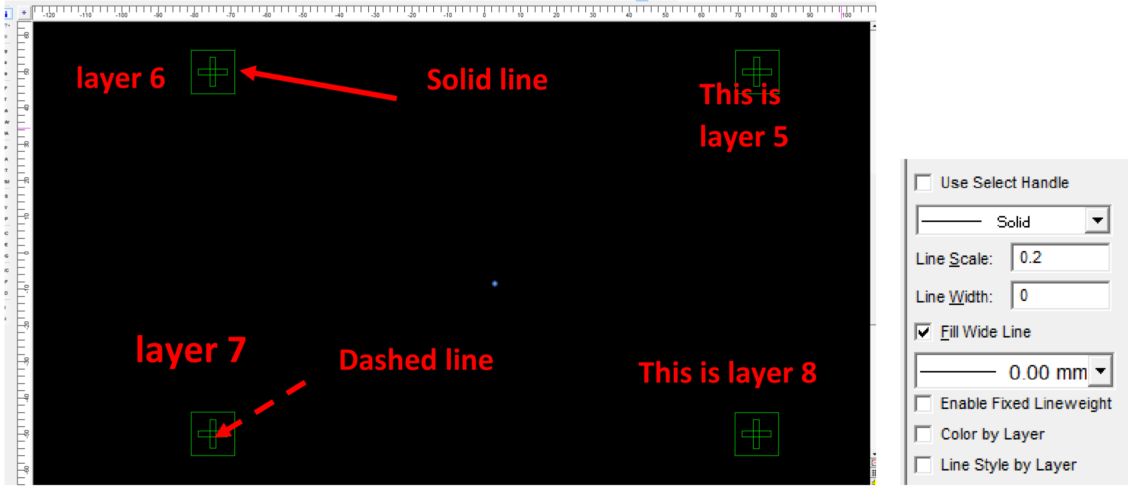
Design Alignment Mark in DesignCAD

Nanometer Pattern Generation System (NPGS) uses DesignCAD to draw pattern. You can use LayoutEditor or AutoCAD but save as .dc or .dcd file.

Note: The pattern should be drawn using polyline, polygon, box.

1. Take a picture of your sample using optical microscope. Import it to DesignCAD, or LayoutEditor.
2. Choose appropriate alignment marks. The principle to choose alignment mark is:
   - The sample is around the center of four marks.
   - The four alignment marks should be far away from your sample, at least 50 um.
   Note: The center of alignment marks will be the center of SEM scanning area.





3. Draw alignment marks in DesignCAD. here each alignment mark is composed by two cross boxed.
   - ➢ Please make sure the size of cross is exactly same to your alignment mark on substrate.
   - ➢ The position is consistent to alignment marks you chose in your sample image.
4. Highlight cross mark in your design, click Info Box, choose line type as Solid. Similar to all other alignment crosses.
   Note: Here you must set line type of your cross as Solid line.
5. Set each cross mark in one layer, here are layer 5 (Info Box 5), 6, 7, and 8.
6. For each alignment mark, draw a big box which can include cross mark.
   This box defines the scanning window when running alignment. The resist inside of this box will be exposed. It cannot be very small since it is hard to find alignment mark. It cannot be very large since it will exposure more area of resist. For 10 um long mark, the length of window could be 15um.
7. Set the line type of each window as Dashed.
8. Set each window in one layer, should be same to each cross mark. Here are layer 5 (Info Box 5), 6, 7, and 8 for each window.

Design Pattern in DesignCAD

Nanometer Pattern Generation System (NPGS) uses DesignCAD to draw pattern. You can use LayoutEditor or AutoCAD but save as .dc or .dcd file.

Note: The pattern should be drawn using polyline, polygon, box.

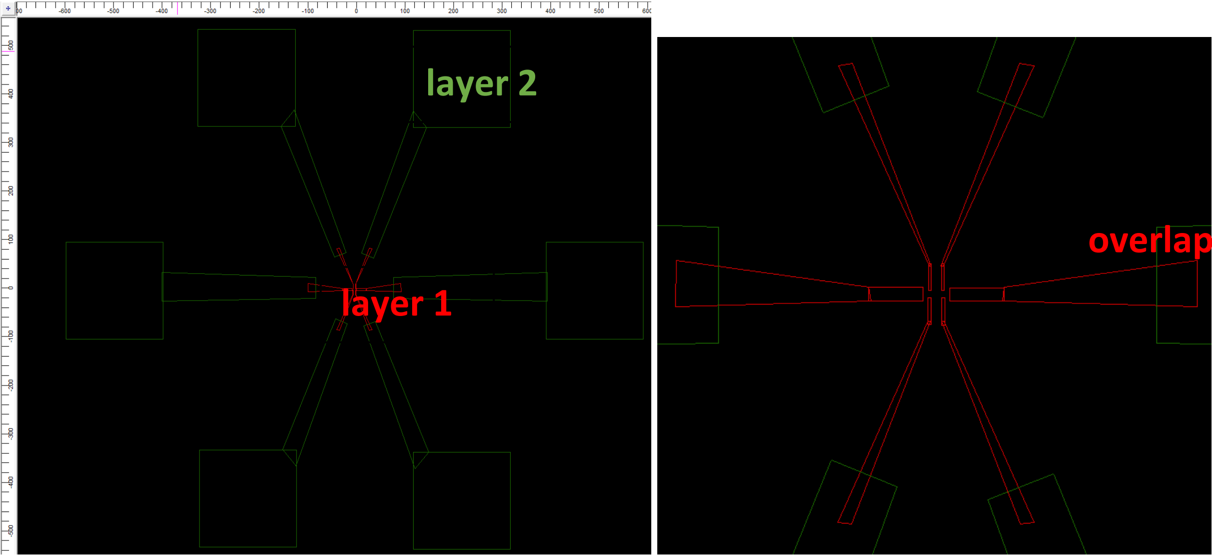
The value of Mag Scale = Magnification x Scale of SEM = 216000.

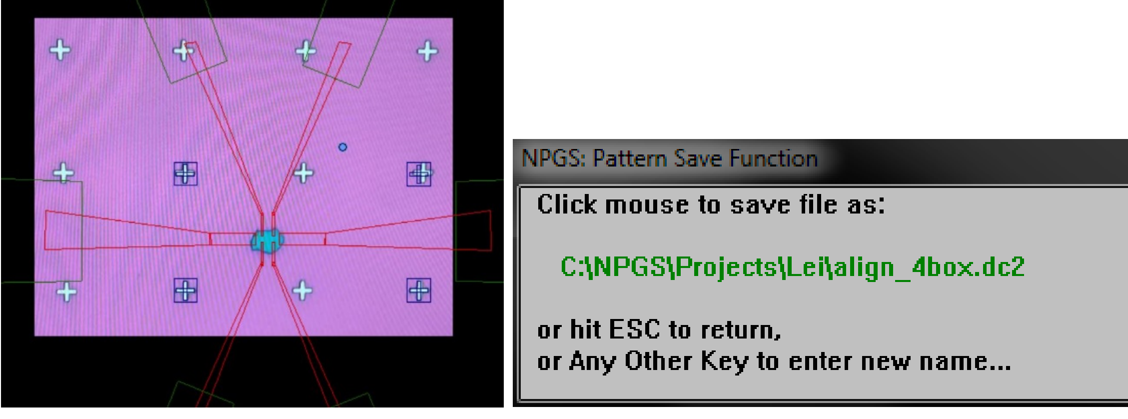
1. Draw your pattern. In your design, if you have some features smaller than 10 um and your total pattern size is ~1000um, it's better to separate into two layers.

In the below Hall bar design, it is recommended to draw the whole device in 2 layers.

- ➢ Layer 1: small structure in Red, with minimum probe width ~ 1um, the total length is ~ 200um.
- ➢ Layer 2: large pad in Green. The total length/ field size is 1200um.

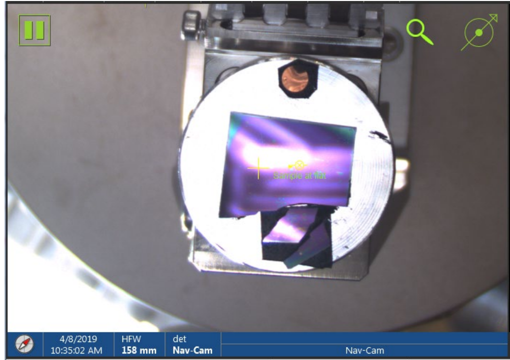
2. Change layer number. Highlight the pattern you want to set, click to change layer #.
3. Set the line type of pattern as .
4. Put the center of your pattern in correct location.
    - ➢ If you need alignment marks, the center of pattern should be exact on top of your sample. This might not be at the origin. It depends on the alignment mark and sample position.
    - ➢ If you don't need alignment, the location of the center of your pattern does not matter.
5. Make sure the overlap between layer 1 and layer 2 are large enough. This will compensate the shit when change magnification or current between layer 1 and 2.
6. To save your file, go to NPGS (top menu) ➔Save-Saves to current NPGS project➔click mouse to save or any other key to save as a new file.



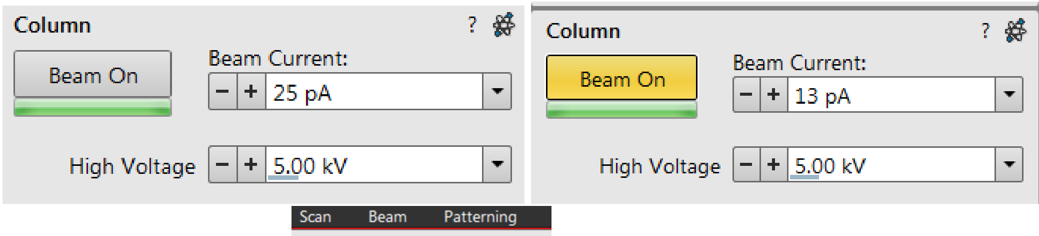


Load Sample

1. Mount your sample with spin coated resist on pin stub which has a Faraday Cup. Make sure your sample orientation is consistent to following picture. This will be beneficial for alignment.
2. Make sure the substrate is on the same level.
3. Use tweezers to make scratch at four corners of substrate, this will be very helpful for SEM focus.
4. Blow your sample using N2 gun.
5. Load the sample following the other SOP, wait until the pressure is 1.5x10-6 mbar.
6. Take Nav-Cam Photo in Stage. Click Stage, then click Take Nav-Cam Photo.



7. Click electron window and highlight it (The status bar should be blue). Turn on e-beam gun by pressing “Beam On”. The Beam on window should become yellow.

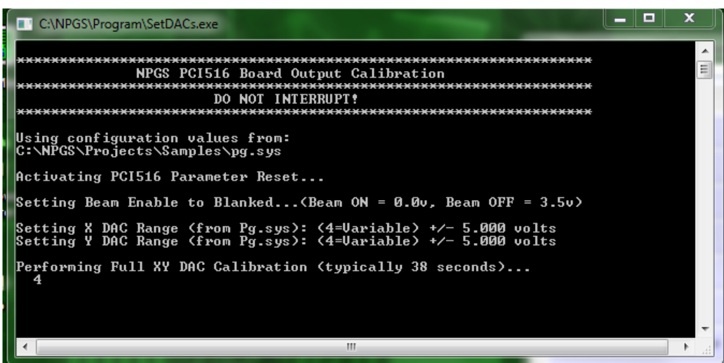


8. Set SEM voltage to 30 kV (Scan | Beam | Patterning: 30.00 kV, 13 pA), the current as 0.8 nA or other value that you prefer.

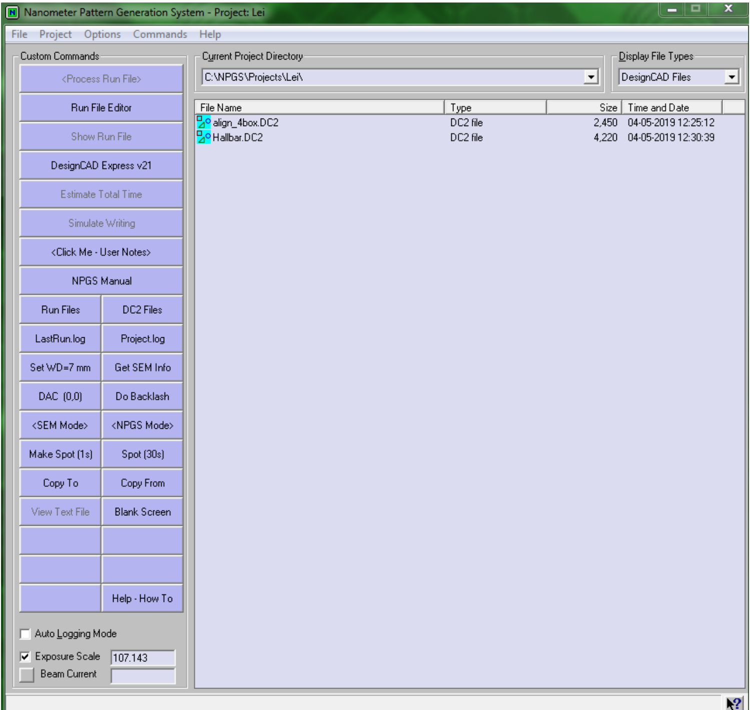
9. Locate Faraday cup by clicking on the bottom left window. Find the hole and adjust focus to get a clear image.
10. Zoom in the hole and then Check the beam current reading on bottom window Specimen Current: 0 pA, write down the value of specimen current.

Turn on NPGS

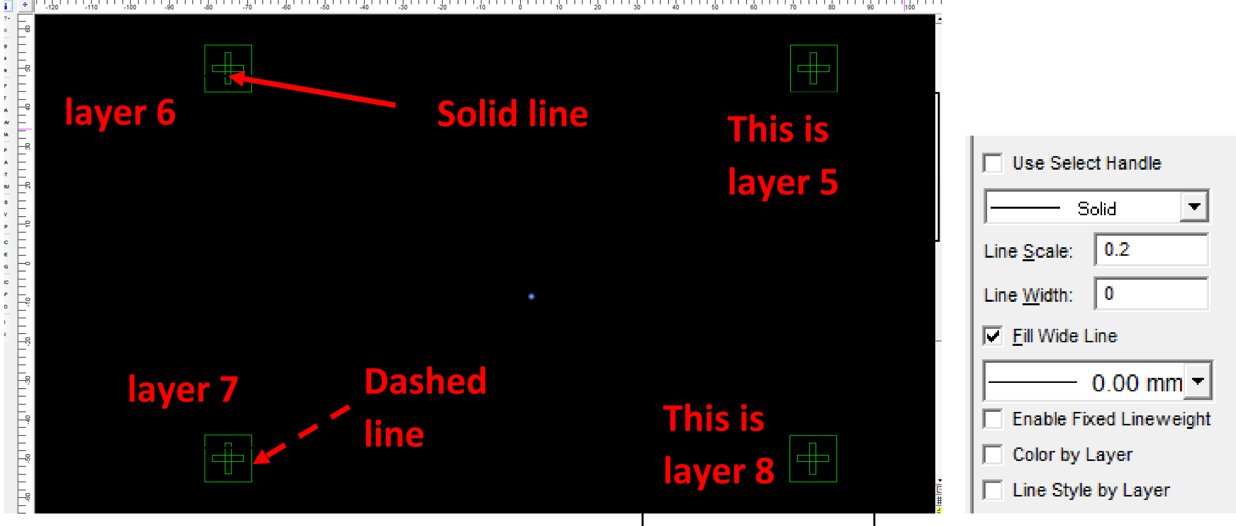
1. Click INPUT ➔DVI of right display screen to switch to Nabity desktop.
2. Double click NPGS Menu to open software, a DOS window pops out to calibrate DAC (Digital Analog Converter), wait until it is done.



3. Click Skip PDF or OK to launch PDF file.



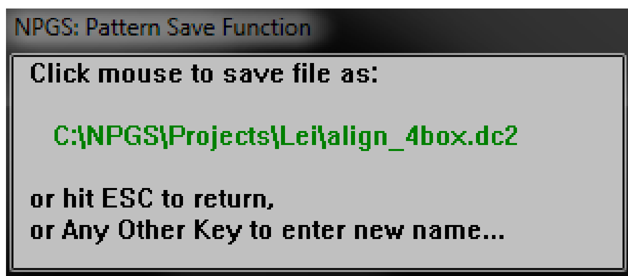
4. Click DC2 Files to load /copy your pattern design. Highlight the pattern and right click➔ DesignCAD Express v21 to open your file.



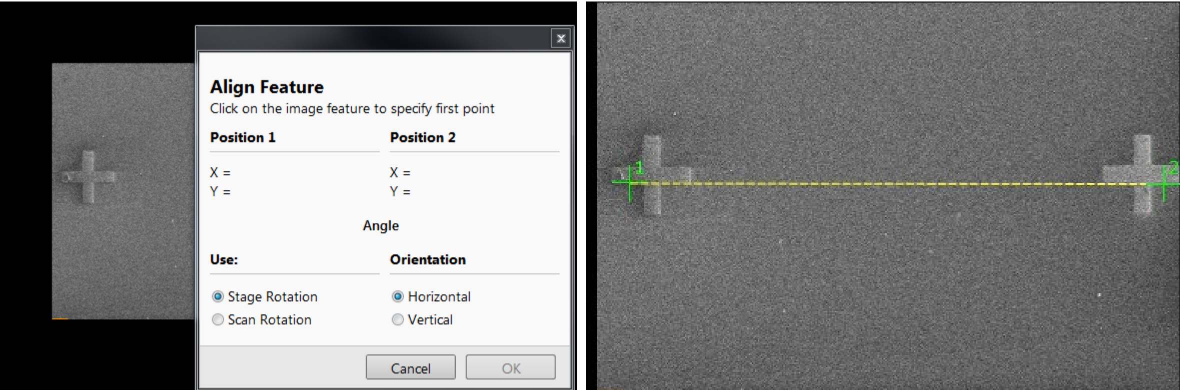
For example, this figure shows alignment marks. The cross is set as solid line, the big window is dashed line.

Each cross and window are set as one layer, here set as layer 5, 6, 7, and 8.

5. Make any change if you need.
6. To save your file, go NPGS ➔Save-Saves to current NPGS project➔click mouse to save or any other key to save as a new file.



7. Align your sample. Find two alignment marks, focus and get a clear image. Go to Stage Stage ➔ Align Feature, draw a line from one point to the other, make field around 100um, click ok.



Focus and make spot

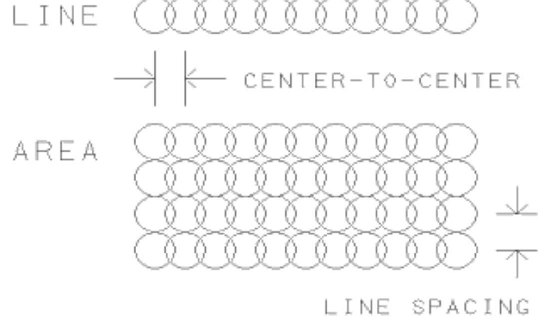
1. Find a small particle or the scratch of resist, focus and adjust stigmation to get a very good image.
2. To make a spot, click Spot (30s) at SEM Mode. A counting down window pops up. Note: Do Not switch to NPGS Mode when make spot.

3. If focus is not good, a spot may not clear. Spot again. Adjust fine focus and stigmation to get a clear round spot, with diameter around 40nm.
   Note: if you pattern is very large; a clear spot is not necessary.
4. If it is hard to make a spot at 30kV, you can try 10kV, 20kV first, and then increase to 30kV. Remember the writing voltage for pattern is suggested to be 30kV.

Create Run Files

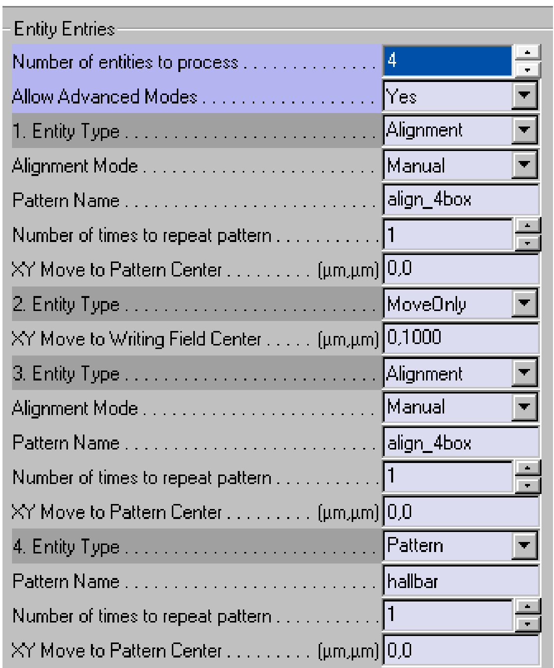
1. Click [Run Files] to load or set up a run files in NPGS software.
2. Edit a run file. Highlight any file, right click mouse ➔ click Run File Editor to open and edit it.
3. Create a run file. Highlight the empty region, click [Run File Editor] to set up a new run files. For example: there are 4 entities to process in below run file.
4. In Number of entities to process, click [⇕] to add or delete the entity.
   Note: if you want to change the order of entity, highlight that entity, left click mouse and drag to the order you want.
5. In the drop-down menu next to "Allow Advance Modes" choose "Yes".
6. Entity Type: Here are some important entities. Alignment, Pattern, MoveOnly.
   - Alignment. This is to align your substrate. Here you need to double click to load your alignment pattern.
   - MoveOnly. After initial alignment, the stage will move to the designed location according to distance we set using "XY Move to Writing Field Center". It is recommended to move around 1000 um or less each time. There will be big off if move too far for alignment.
   - Pattern: This is the command to write your designed pattern. Load pattern name by double clicking.
7. Pattern Name: double left click to load your pattern.

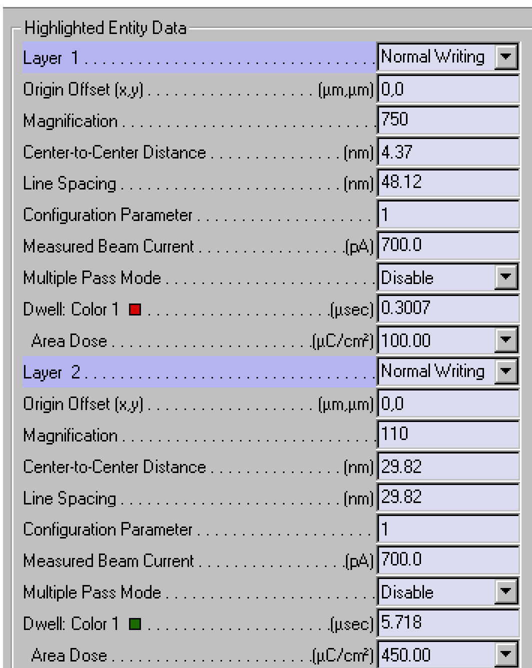
8. **Alignment entity**, you will see subsections on the right side of the window corresponding to each layer/alignment mark. Here is a brief description of the important parameters:
   a. Origin offset: usually set as 0,0.
   b. Magnification: when importing the pattern file, Run File Editor automatically gives a recommended value. We can choose this vale. It is recommended to set the SEM to this magnification prior to writing. Note that the pattern and alignment magnifications should be set to the same or similar value.
   c. Center-to-center distance and line spacing: you can use the recommended values Run File Editor suggests. The smaller the value, the longer of scan/writing time.



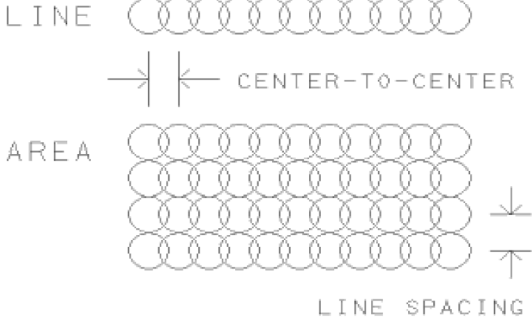
   d. Configuration Parameter: set to 1.

e. Measured beam current: enter the beam current you measured from the SEM. 400pA ~5 nA is good.
f. Dwell: the exposure time per point. Note that higher numbers will give higher quality images but will expose the resist more.
g. When all parameter is ready, click save and enter a name. Click Exit to close run file.



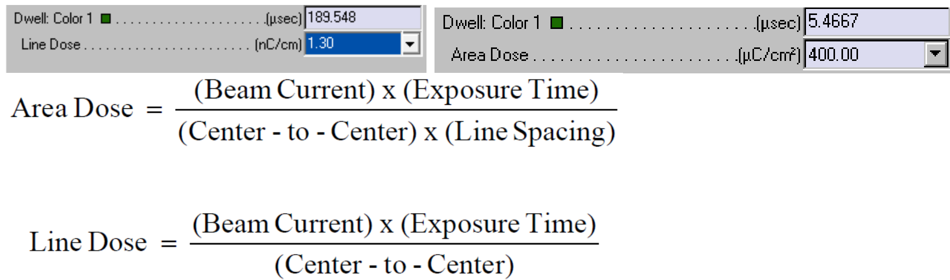


9. In the **pattern entity**, the important parameters are:
   a. Origin Offset: Leave this at 0,0 for easiest use. Remember, the center of the SEM's total scanning area should correspond to the origin of your design files.
   b. Magnification: when importing the pattern file, Run File Editor automatically gives a recommended value. We can choose this vale. It is recommended to set the SEM to this magnification prior to writing.
   c. Center-to-Center Distance and Line Spacing: These two parameters determine the space between dots that the SEM writes. Smaller spacing improves polygon quality (smoothness, resolution, uniformity), you can set to a small valve for small pattern, but it takes longer time for writing.



d. Measured Beam Current: Enter your measured value.
e. Configuration Parameter: DO NOT CHANGE THIS. It should remain 1.
f. Multiple Pass Mode: Not relevant for e-beam writing. Leave this disabled.
g. Dwell: This is the amount of time the SEM spends exposing each dot. It will be automatically calculated from the beam current and dose.
h. Dose: If you pattern is filled polygon, Line Does should be changed to Area Dose. This is the amount of charge that the beam will deposit per unit area, and depends on your resist and substrate. **If you pattern is filled polygon, click the drop down menu to choose an Area dose,** and enter a good dose value.
At some point, you should manually write patterns at different doses and look and see which dose works best.
For 30kV microscopes exposing PMMA,
   - Area dose is 100-200 $\mu C/cm^2$ for small structure, length ~10 um;
   - Area dose is 300 - 600 $\mu C/cm^2$ for large pattern, length >100 um.

The larger area dose, the longer writing time.



$$\text{Area Dose} = \frac{(\text{Beam Current}) \times (\text{Exposure Time})}{(\text{Center - to - Center}) \times (\text{Line Spacing})}$$

$$\text{Line Dose} = \frac{(\text{Beam Current}) \times (\text{Exposure Time})}{(\text{Center - to - Center})}$$

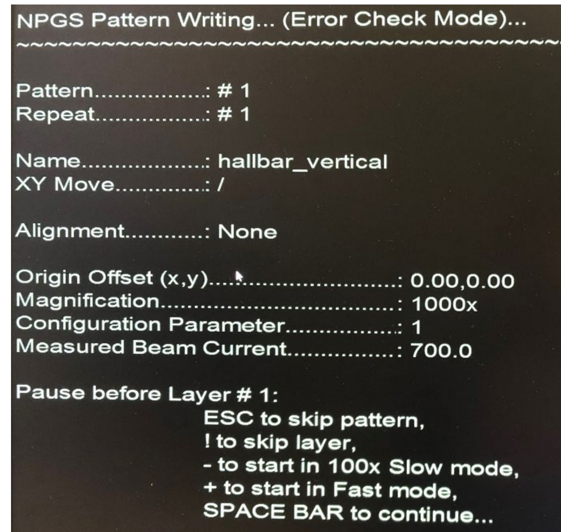
$$\text{Point Dose} = (\text{Beam Current}) \times (\text{Exposure Time})$$

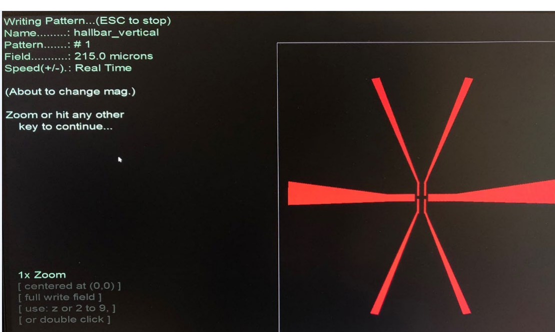
Note: If a dwell is entered, the corresponding dose is recalculated to match the time. If a dose is entered, the dwell is recalculated to match the dose.

10. Save Run file. Click Save to save your file.
11. Click Exit to close run file.

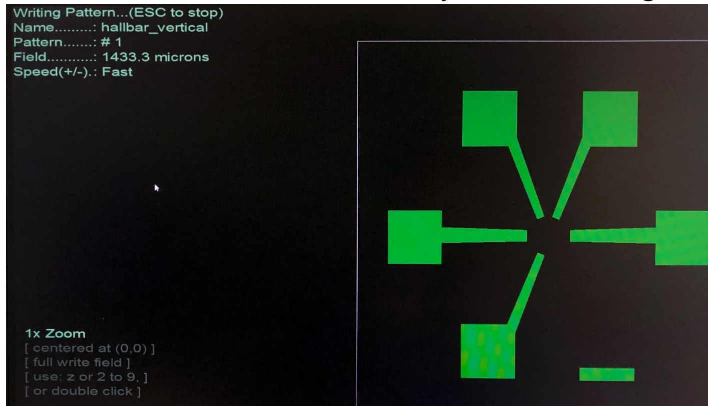
Stimulate Writing & Estimate Total Time

1. Highlight the run file you need.
2. Click Stimulate Writing Simulate Writing to see how the NPGS runs and whether it is correct.

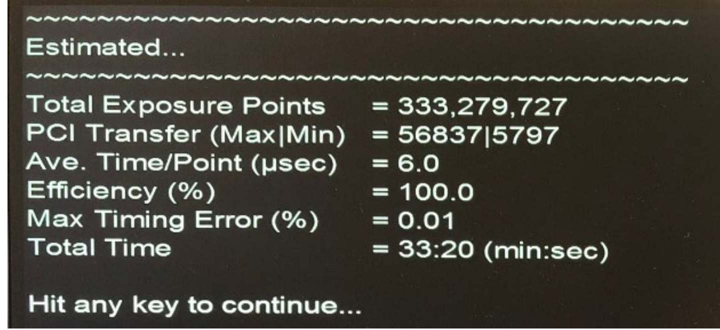




3. Hit SPACE to continue. You will see the 1st layer writing.
4. Hit SPACE to continue. The 2nd layer starts writing. Hit SPACE to continue.



5. The total time is shown below. If you think writing time is too long, you can increase Beam Current in run file.



6. Hit any key to finish.
7. To check the total time estimated, highlight the run file, then click Estimate Total Time .
8. Hit SPACE key to continue.

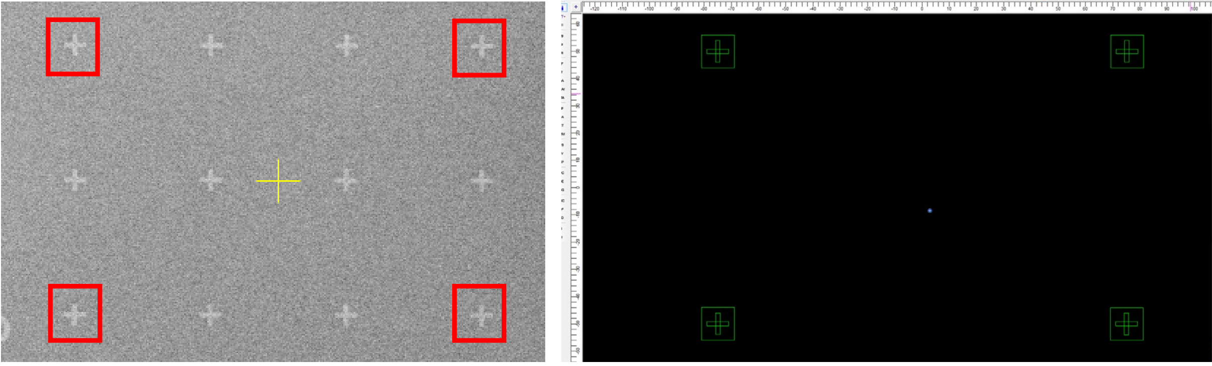
```
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Time Check Mode...
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Total # of Pattern Entities..................: 1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Select Processing Option:
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Hit ESC to quit,
Hit 'I' to see the Individual pattern writing time results, or
Any Other Key to see only a summary for the entire run file...
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
```

9. Below shows the total writing time.

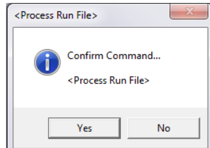
```
Time Check Results...
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Total # of Pattern Entities..................: 1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
Total # of Exposure Patterns.............: 1
     -time estimate...............................: 33:21 (min:sec)
Total # of Stage Moves.......................: 0
Total # of Exposure Points.................: 333,279,727
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
The Graphical Overview mode is not available when
there are no stage moves.

Hit any key to finish...
```

Align substrate

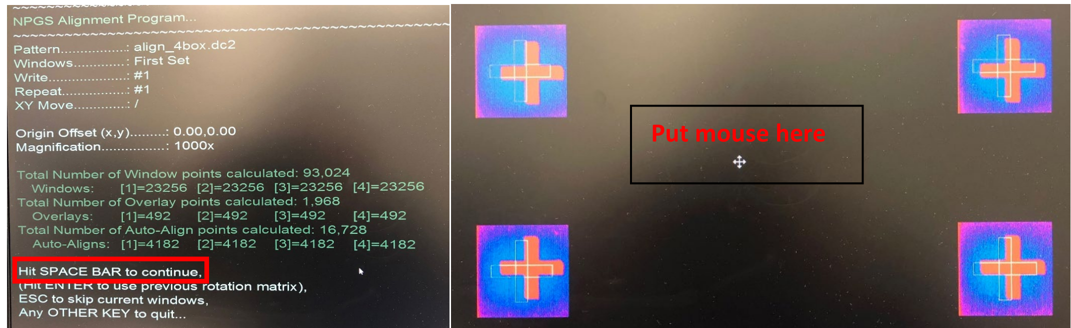
1. Make sure the SEM voltage is 30kV, set the beam current to the same valve in your run file. For example, 0.8 nA.
2. Get a good focus on the surface of resist. Make sure you have scratched the four corners of substrate.
3. Locate the center of your alignment mark. For example, we are going to align four marks at corners, the cross should be located the center of four marks.
   Note: The center of the SEM's total scanning area should correspond to the origin of your design pattern. For alignment, it means the center of four alignment marks.



4. Click NPGS Mode <NPGS Mode> on Nabity PC. Check and make sure the top right corner of SEM window displays External.
5. Hightlight the alignment run file you want and then click <Process Run File>. Click Yes to confirm Command.



6. Hit SPACE Bar on keyboard to continue. You can see SEM is scanning 4 windows.



7. The red crosses are your alignment marks on Si wafer. The yellow cross lines are alignment pattern of DesignCAD. We need to make these two types of marks overlap.
8. Move aligment marks to get overlap. Put the mouse in the center of four marks, if you see a cross you can left click mouse and hold and then move to make sure they are overlap. Sometime the crosses are not overlap perfectly, it is good as long as the center of two types overlay.

9. Click **R** on top left to recalculate and scan marks.

?,A,B,C1,D,e,f,J,M,N,O,p1,Q,R,s,S,T,W,Z,Enter
(Click to Recalculate)

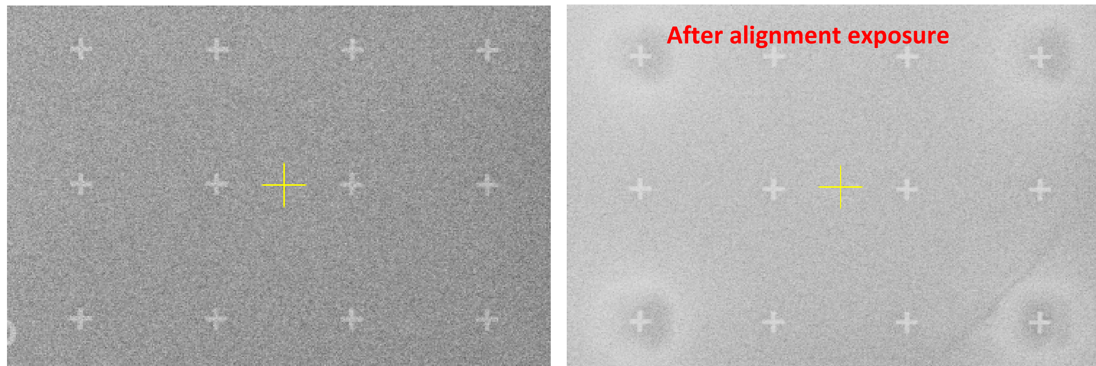
10. If overlay is good. Click **Enter** ➔ then Press **y** on the keyboard to recalculate matrix before saving.

e,f,J,M,N,O,p1,Q,R,s,S,T,W,Z,Enter
ve and Close Windows)
Recalculate matrix before saving? ([y],n,Esc)

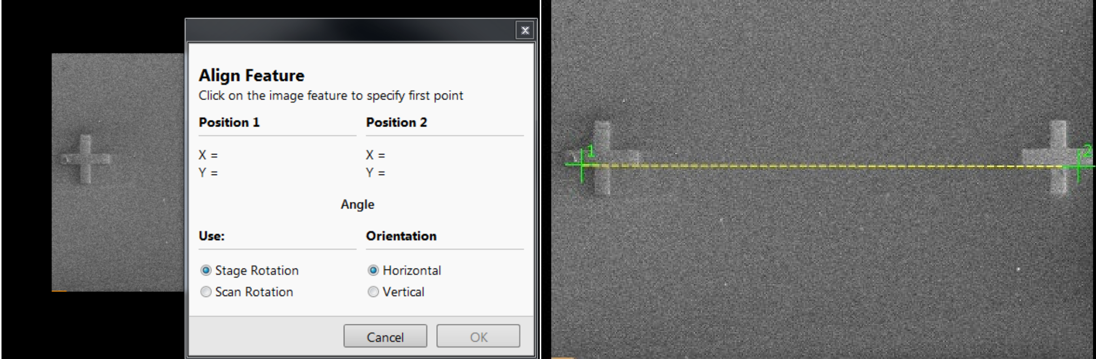
11. Press **n** on keyboard to Not Repeat Alignment.

NPGS: Repeat Alignment? ([n] y,!,q=quit,?):

12. Click SEM mode to check your alignment exposure.

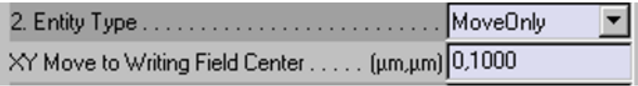


13. If you think there is big off and you can align sample again. Go to stage➔ align ➔draw align from one point to the other, make field around 100um, click ok.

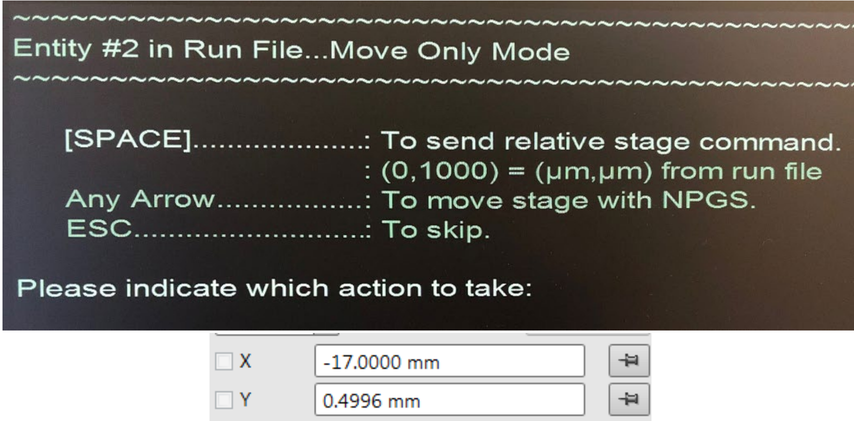


Move stage

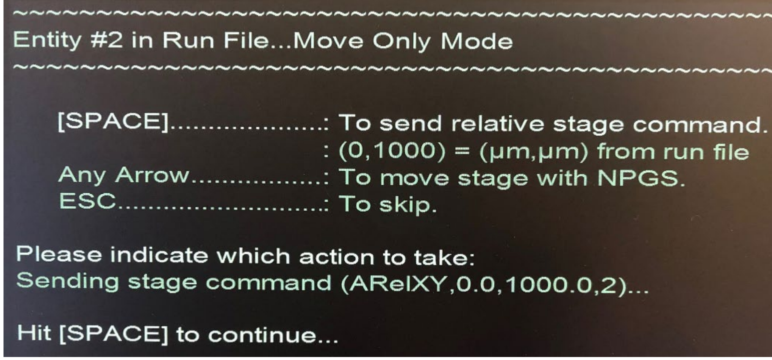
1. In the run file, you can move stage to any location if you know the distance. Here XY Move to Writing Field Center (0, 1000) um command will move up by 1000 um.



2. When the run file starts the command, the screen displays as following. Hit **SPACE** bar on keyboard to move stage. You can record the coordinates to see whether it moved correctly.

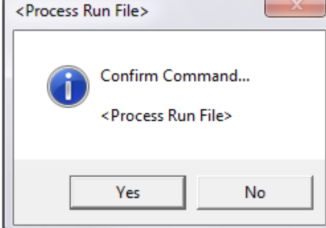


3. After stage was moved, hit space again to continue.



Write pattern

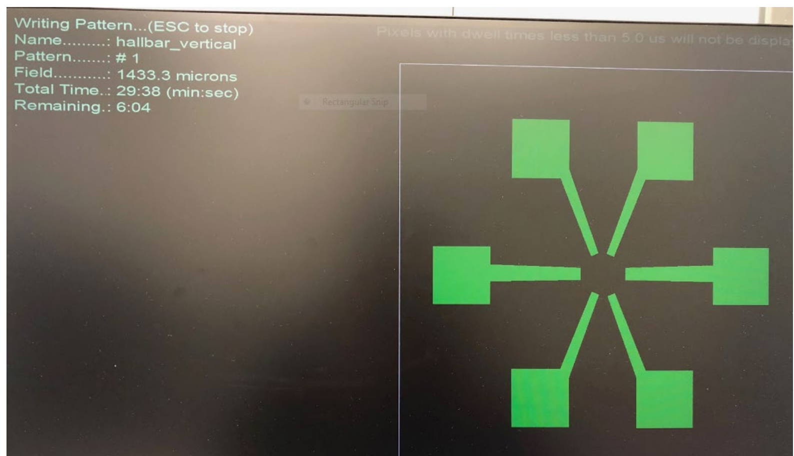
1. Check SEM voltage is 30kV, the beam current is the value you need.
2. Check SEM is in <NPGS Mode> on Nabity PC. You should see the top right corner of SEM window displays External.
3. Check your run file is ok.
4. Highlight the run file you need to write. Click <Process Run File>.
5. Confirm Command by clicking Yes.



6. The following figure show entity for patterning. you can check the information. Then hit SPACE BAR to continue.

```
NPGS Pattern Writing...

Pattern................: # 1
Repeat................: # 1

Name..................: hallbar
XY Move.............: /

Alignment............: Enabled
Mag....................:   1.000
X Offset...............:   0.000
Y Offset...............:   0.000

Origin Offset (x,y)..........................: 0.00,0.00
Magnification.................................: 750x
Configuration Parameter................: 1
Measured Beam Current...............: 700.0

Pause before Layer # 1:
                    ESC to skip pattern,
                    ! to skip layer,
                    SPACE BAR to continue...
```

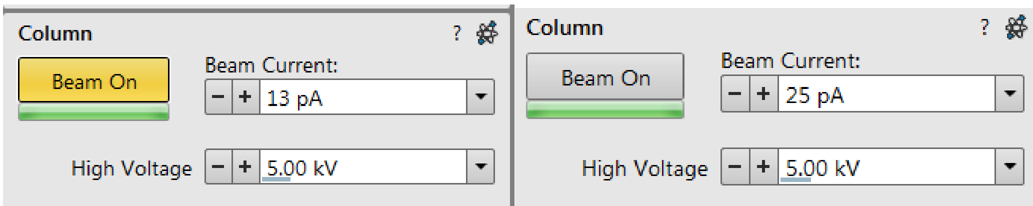
7. NPGS will start the 1st layer writing, then the 2nd layer. Hit ESC to stop pattern writing if needed.



8. Hit SPACE when it is done. Click sample position to Move to a safe region.
9. Continue next pattern writing if needed.

Close NPGS

1. Make sure your sample is far from SEM scanning region.
2. Lower the current to 25 pA or 13 pA.
3. Lower the voltage to 5kV.
4. Click <SEM Mode> to release external control of NPGS. This is essential for users who doesn't need Nabity NPGS.
5. Close NPGS software.
6. Turn off e beam by clicking "Beam On". The yellow Beam on window should become green after turning off.



7. Switch back the screen by pressing INPUT and DP.

Unload Sample

Follow the Basic Operation SOP to unload your sample.