adolphe merkle institute
excellence in pure and applied nanoscience
UNIVERSITY OF FRIBOURG SWITZERLAND

Focused ion beam

Introduction

Version 10 – May 2025

PART II – BASIC MILLING CONCEPTS

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excellence in pure and applied nanoscience
UNIVERSITY OF FRIBOURG SWITZERLAND

D Vanhecke | Adolphe Merkle Institute | University of Fribourg | Switzerland

Notes:

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Universal rules

Rule 1: don't touch a control if you are not sure of the outcome of that action

Rule 2: never, ever force anything beyond finger strength

Rule 3: wear gloves when touching anything that goes into the chamber

Rule 4: if in doubt, ask for help

Prerequisites:

Sample loaded
Sample at eucentric height
Electron beam on
Maps software started

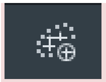
Saving images

After a tile scan was recorded, it can be saved.

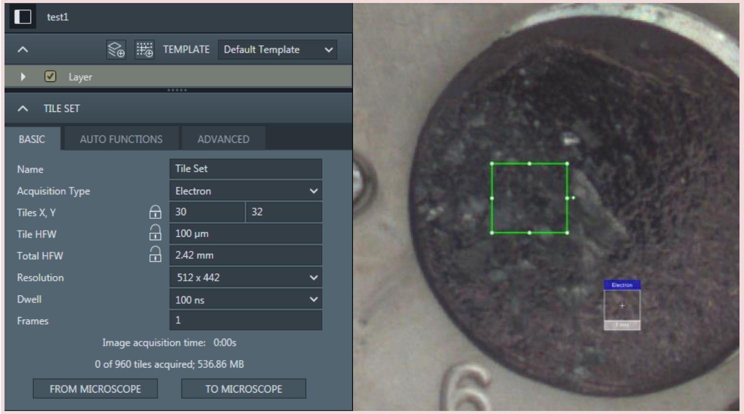
Experiment: save tile scan

Click the 'Save image to file button'

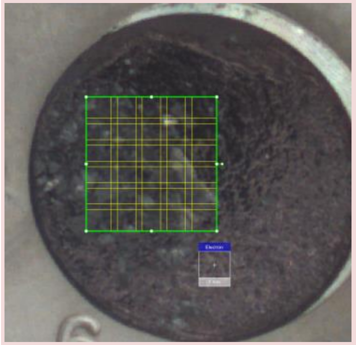
Select the region you want to export


A freehand tile set

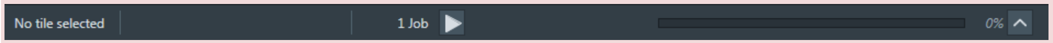
Use the appropriate pattern and draw on the region of interest. Then, from the left menu, click '**From microscope**'



This reads the settings of the microscope and calculates the number of tiles that are required. The image is updated:



Run the tile scan by clicking the run icon at the bottom (1 job waiting):



Demonstration: saving data in Maps 3.3

Demonstration: Login onto the FIB software

Prerequisites:

Running xT server

Running UI

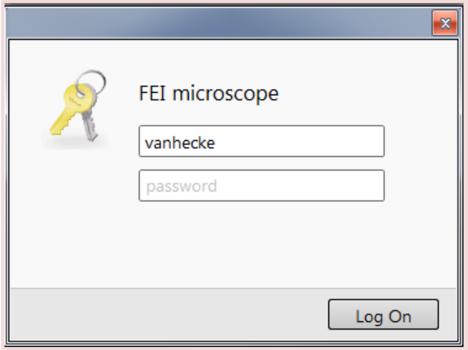
Action:

Login using your FIB account

Load the personal settings and history of the user

Experiment

After startup of the UI, a username and password are requested.



Username: your last name, with capital, no accents, umlauts, etc.

Password: your first name (no capitals, accents, umlauts, etc.)

Click log On

Demonstration: correlative microscopy (Maps 3.3)

Prerequisites:

Sample loaded

Sample at eucentric height

Electron beam on

Start the Maps 3.3 software

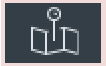
Select Maps 3.3 from the top left FEI menu: 

Or double click the icon on the left screen: 

The software will open and request to open an existing project, or start a new project.

Note: each project's name must be unique. Make sure you save on the support PC!

Experiment: import the nav-cam picture

 on the top right, click this button to load the nav-cam picture from the Xt software.

Note: the precision of this image is not very great. Expect mismatches of several mm.

Experiment: create a tile-scan

Step 1: setup a single image in the xT software (see above)

Calculate the resolution = HFW / pixels along the x axis

Step 2: Click the tile scan icon in Maps

There are 3 types of tile scans:

 A square tile set

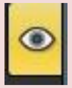
 A circular tile set

2. Insert the STEM detector

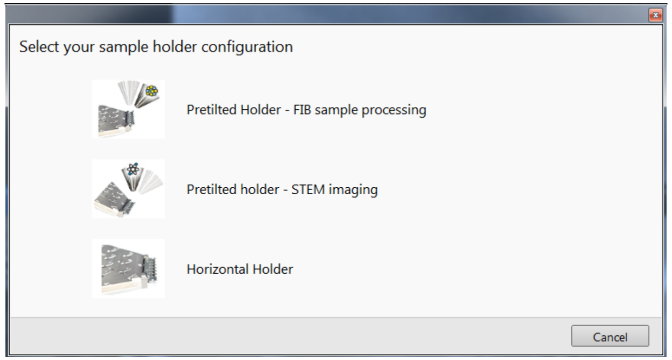
Doublecheck in the chamber view if the path below the stage is free.
Doublecheck you are in focus, at 7mm

Experiment: insert the STEM detector

In the menu Detectors:
- Select the STEM3 detector from the dropdown list
- Click 'Insert'

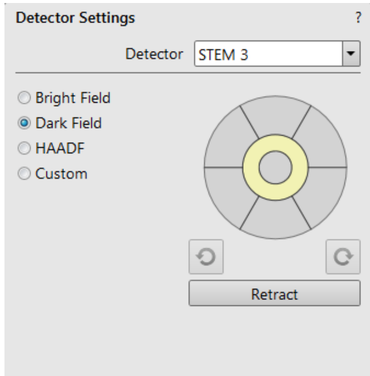


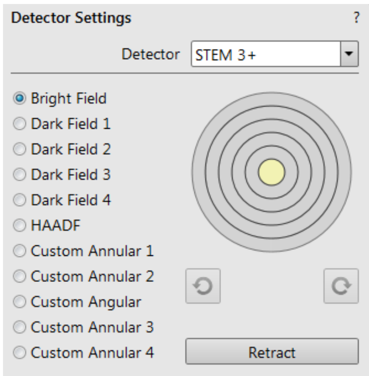
A window will appear:



Select the relevant option, i.e. the situation which describes the stage and the rowbar.

STEM 3 and STE3M+ allow to select different prats of the detector be active.

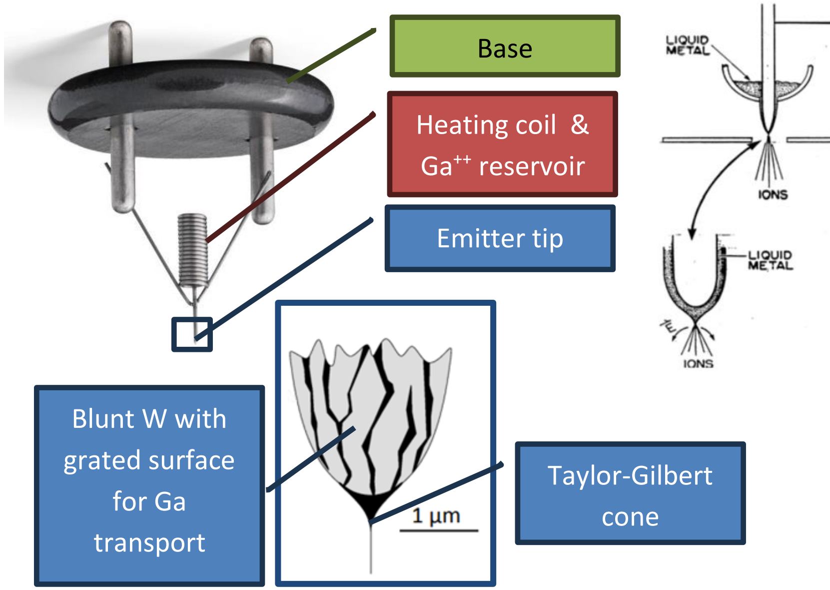




Demonstration: The LMIS (liquid metal ion source)

Prerequisites:
Running xT server
Running UI

Background on the ion beam



Why Ga ions?

M_p = 29.8°C (liquid at RT)

Vapor pressure low (useable in high vacuum)

Narrow energy distribution

Electrons	Ions
very small	Big -> outer shell reactions (no x-rays)
inner shell reactions	High interaction probability
High penetration depth	less penetration depth
Low mass -> higher speed for given energy	High mass -> slow speed but high Momentum -> milling !!! Ions can remain trapped -> doping
Negatively charged	Positively charged
Magnetic lens (Lorentz force)	Electrostatic lenses

Demonstration: Switch the beams on

Prerequisites:

Sample loaded

Learn to switch e-beam and ion beam on

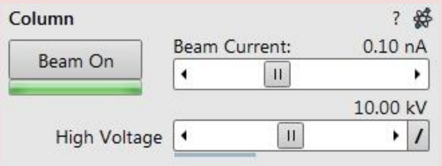
If the system is in standby, you will find a green bar under the “Beam On”

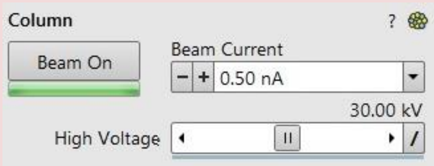
Experiment

Select the electron beam quadrant (top left)

In the Beam control  > Column. Check the bar under the button “Beam On”.

Repeat for the ion beam: first click on the ion beam quadrant (top right)





Electron beam and ion beam both with green progress bars: **standby**.

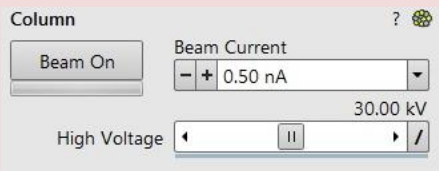
Click both Beam On to start the FIB

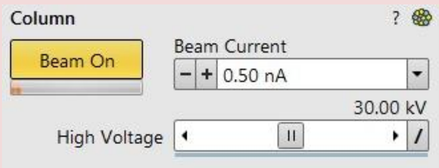
If the system is in sleep mode, you will find a gray bar under the ion “Beam On”

Experiment

Electron beam: same as standby

Ion beam: the progress bar will be gray. Click the Beam On.





The gray progress bar will turn red then orange then yellow, while progressing.

It will take about 15 minutes to startup the ion beam.

Demonstration: STEM imaging Demonstration

Prerequisites:

Eucentric height, beam focused, 7mm working distance

Coincidence point set

Stage tilt: 52°

Ion beam and e-beam aligned

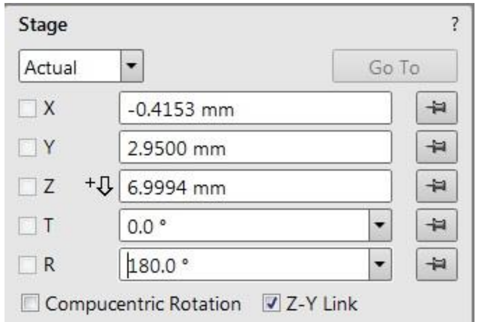
Use the STEM detector

Experiment: Link the stage (CRUCIAL)

In the electron beam (0°)

- Proper imaging setting, magnification: sufficient (>1500 X)
- Focus an area of interest
- Link the stage
- Go to 7 mm WD (at 0 degree)
- Set eucentric (CTRL+F)

1. Rotate the stage 180 degrees:



Demonstration: Making a cross section using EDX

Prerequisites:

Eucentric height, beam focused, 7mm working distance
Coincidence point set
Ion beam and e-beam aligned

Produce a cross section

Experiment: EDX on a cross section

- Adjust the formula for Y: Y > 3 x Z (or more). Because BSEs produce X rays in the gap.
- make a second bulk milling on the right side of your ROI to avoid shadowing. You will end up with an L-shaped gap (below and on the right of the ROI).
- Be careful with the interpretation: the imaging is from under an angle, which means that shallow layers may overlap.

Demonstration: an empty LMIS?

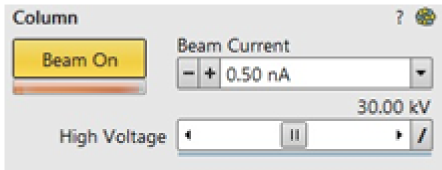
Prerequisites:

Sample loaded

Learn how to recognize am empty LMIS

There is no sensor of how full the Ga reservoir still is. There is no warning when it is empty. When the LMIS needs to be replaced, the following will happen:

- During heating up of the LMIS, the system remains in the orange phase, never turns green (after waiting 30 minutes or more)
- When you hoover with the mouse over the orange bar, you will get the lifetime of the current LMIS. An LMIS has a livetime of 1500 to 2000 hours[1]



If this situation occurs, inform the admin and cancel your session. Generally, an LMIS exchange need about 4-10 days for exchange (depending on the availablility of technical engineers).

[1] With notable upt (2700 hours) and downs (800 hours)

Demonstration: e-beam Pt deposition

Prerequisites:

Sample loaded

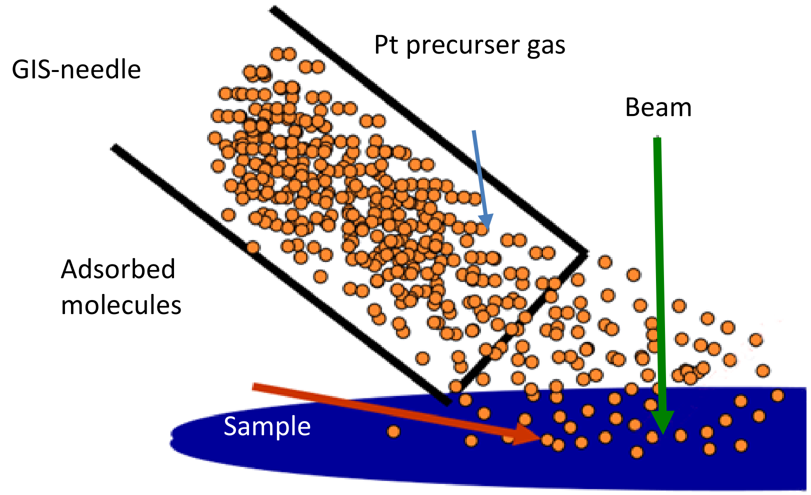
Electron beam on

Eucentric height, focused, WD=7mm

Learn to deposit Pt using the e-beam

Pt deposition using the e-beam marks is used to ensure a proper beam coincidence point setting if no landmarks are available.

IT IS CRITICAL TO BE AT 7 mm WD, IN FOCUS at eucentric height



Note: Pt deposition is usually done with the ion beam, but can also be perfomed with the electron beam

Demonstration: Measuring and making annotations

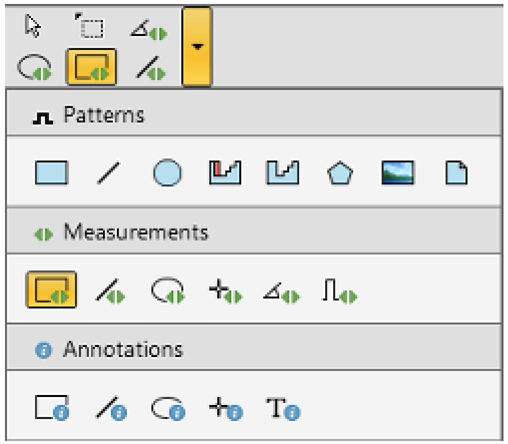
Prerequisites:

Eucentric height, beam focused, 7mm working distance

Coincidence point set

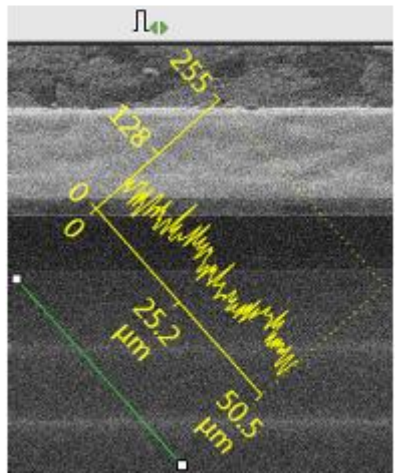
Ion beam and e-beam aligned

Measure lengths, surfaces, on the image using the Patterns / Measurements / Annotations



Click the down arrow to access the Patterns / Measurements / Annotations tool. The numerical values of linear distances, diameters, angles, or areas of the image are updated while drawing and shown alongside or within the finished measured item.

The Measurement tool dimensions scales with the image; when changing magnification, the shown tools change their size accordingly.

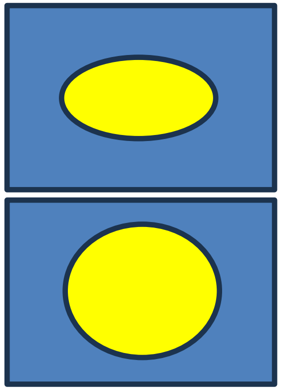


On the contrary, the Annotation shapes and texts have their sizes fixed relatively to the display. The Measurements / Intensity profile delineates the imaging profile across a freely drawn line.

Note: to save: tick "With overlay" and save as JPG (24 bit) to keep the colors,

Tilt angle correction

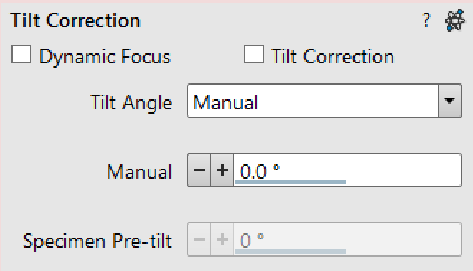
At an angle of 52°, there is a vertical copression that is related to the cosine of that angle (61,6%). For a perfectly round object (top: tilted image at 52°, bottom: original at 0°):



To circumvent this effect, and allow quantification (surface, diameter, length …) of objects, correct for the tilting angle,

Experiment: Correct for the tilting angle

In Beam control, find Tilt correction & tick Tilt correction



Tilt Angle: Automatic
The correction is set for the current tilt angle (and possible specimen pre-tilts)

Tilt Angle: Automatic (cross section)
The correction is set for a 52°tilt angle (typical cross section angle)

Tilt Angle: Manual
The correction can be set for any tilt angle between +90° and -90°

Dynamic focus
The foxus will change as the beam scans from top to bottom, trying to compensate the working distance for out-of-focus parts of the sanple due to the tilt.

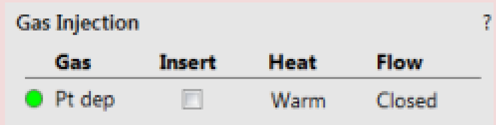
Experiment

Make sure your sample is at eucentric height, focused and the WD=7 mm. Hit CTRL+f Under Patterning > chose a rectangle. Set e.g. 5 µm x 5 µm, deposit using the Pt application (Pt e-dep surface). The rectangle has a green border

Patterning settings
- XYZ: 5µm x 5µm x 0.5µm
- 15 µs dwell time
- Application Pt e-dep surface
(e beam induced deposition)

Microscope settings
(might slightly vary on your sample):
- Standard mode
- Magnification: 2000 X or higher
- Acceleration voltage: 5 KV
- Beam current: set until time is 3-5 minutes.

Insert the GIS needle
In the patterning tab ( ), near the bottom, Find the Gas injection menu[2].



- Assure the camera view is live
- Double check if you really are at 7 mm!!
- Then tick “insert” box
You hear a soft “tick” sound and in the camera quadrant you see the needle

Adjust the contrast and brightness
The GIS needle absorbs a significant part of the SE signal and will darken your image.
- Press F9 to adjust Brigtness and contrast
- Optional: zoom out in the SEM quadrant (below 1000X) to the the needle

Start patterning
In the top menu, click the start patterning icon
During patterning, you can pause or stop the patterning

[2] The icon is green, Heat = warm and the flow is closed.

Finishing the patterning

When finished:
- retract the GIS needle.
- Hit F9 to update the brightness and contrast
- Select the pattern in the quadrant and remove it (press DEL)

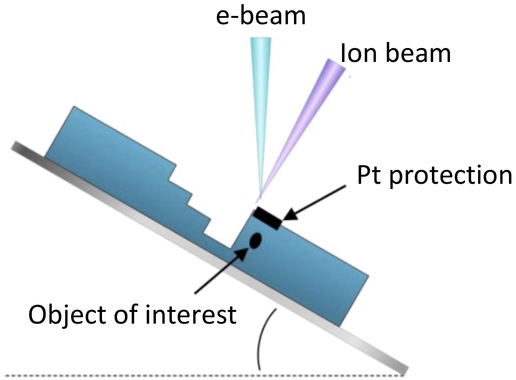
Note: e- beam deposition is soft and slow, iSPI is not possible

Demonstration: imaging a cross section

Prerequisites:

Eucentric height, beam focused, 7mm working distance
Coincidence point set
Ion beam and e-beam aligned
Cross section made

Now image the result of your cross section in the e beam



Tilt angle

Due to the tilt angle, the SEM image is not seen in an orthogonal, planar dimension.

Hence: you have to compensate for the distorted aspect ratio.

Experiment: Imaging

- Go to a very low ion beam current (10 pA)
- Switch to OptiTilt and use T1 and T2.
- Press F9
- Curtaining issues: Do not use the ETD, since curtaining is the strongest in that detector. Use T1.
- Lower beam currents: more focused Beam, but more curtaining.

- Change the stage tilt angle for a correction factor between 0.5-1.5° (i.e. between 50.5° and 51.5° absolute angle). The higher the ion beam current, the higher the correction angle
- refresh the ion beam image (F9). X and Y as above.
- Z: 1/4 of the previous setting.
- run the patterning

Overtilt

Repeat the patterning (do not change the settings), but overtilt the stage for the same factor (e.g. 53.5° if you used 50.5° before). Proceed carefully and do not evoke a pole touch!

- You can use the iSPY: this will temporarily stop the patterning temporarily, make a SEM image and continue

Demonstration: Beam coincidence point

Prerequisites:

Sample loaded
Electron beam on
Eucentric height, focused, WD=7mm

Set the beam coincidence point

A proper beam coincidence point is crucial to use the FIB beam. A proper beam coincidence point assures that the FIB beam is focused on the SEM image.

Experiment

Reset beam shift

- Beam > beam shift > right click > reset

Landmark definition

Search for a landmark in your SEM image and center it at the yellow cross (if there is none, get one in the overlay, see below)
- Focus, link, WD = 7mm, CTRL + f to set to eucentric height
- Magnification: around 5000 X, 5 kV, 0.4 nA

Activate the overlay crosshair

- View > center cross (or shift + F5)

Tilt the stage

- Tilt the stage to about 5°. Watch the landmark move up or down. Bring it back to ints central position, either by:
→ In the CCD quadrant (Bottom right): hold the middle mouse button.
→ move the mouse down/up to move the landmark accordingly.
- Iterate over 5-10° steps until you reach 52°. Keep an eye on the stage in the chamber view: **do not touch the pole piece with the sample!**

The intensity of the signal will increase as tilt increases. Also: try CTRL + e and CTRL + i

Demonstration: Aligning electron and ion beam

Prerequisites:
Sample loaded
Electron beam on
Eucentric height, beam focused, 7mm working distance
Coincidence point set

Find where the ion beam and the electron beam meet

Important notice:

The ion beam will destroy your sample surface (unless it is protected by layers of Pt).
Do not continuously image with an ion beam!

Use low currents for imaging! (30 pA or lower)

Use single image only

Experiment

Align the FIB image

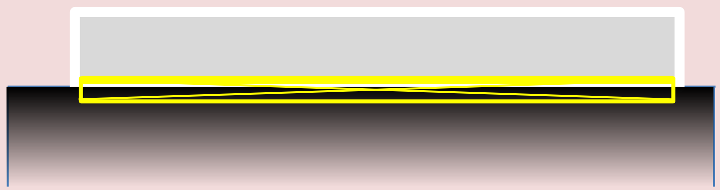
- Image with the Ga ion beam:
  - use a low beam current (10 pA or about), 30 kV
  - Zoom out to a magnification below what you had in the electron beam.
  - Press CTRL + f. Assure the working distance is **19 mm**
  - press F9
  - Assure you have low current, dwell times below 1 µs, live camera settings. Then press F6 and press F6 immediately again (will record 1 image)
  - Find an object that is present in both the electron image and the ion image.

- Polishing

Which current to use?
Polishing is done at a lower ion beam current than the bulk mill. Typically, you start the polishing at 2 steps down the ion beam current list. E.g. if the bulk milling was done at 5nA, you start the polishing at 1 nA (jumping over 3 nA).
You may need to do the polishing iteratively (e.g. 1 nA, 0.3 nA, 50 pA).

Experiment: Polishing

- Set the ion beam current 2 steps lower (in the list) compared to bulk milling
- place a **cleaning cross section** between the Pt deposition and the edge (or a little bit over it) of the hole the bulk milling made before.
- Height: place it just a little bit into to Pt. Assure that the patter starts outside the Pt pad, and ends (=thick yellow line) inside the pad.
- Width of the section: about as wide as the Pt deposition
- Depth: same as the bulk milling setting



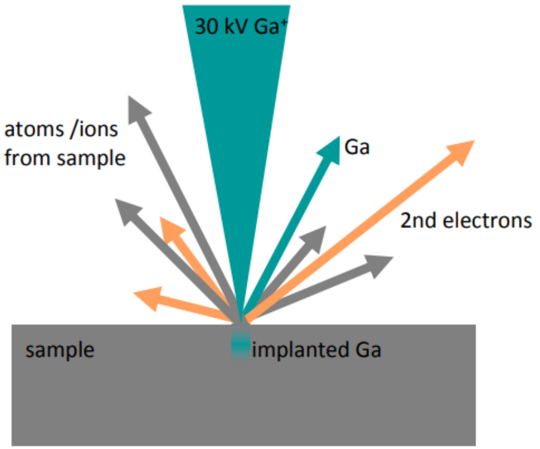
- Start the patterning

Repeat at the same or lower beam currents (down to 50 pA), if needed.

Experiment: advanced polishing with beam shape correction

Use a rocking stage to improve on the polishing. The same concept of lowering beam currents in 2 steps applies.
Undertilt

Note: iSPI is possible. Use the brightness / contrast buttons on the physical control panel to adjust B/C, not F9



Ga^+ beam hits substrate and yields
- secondary electrons
- sputterd atoms and ions
- implantation of Ga
- amorphisation /recrystallization

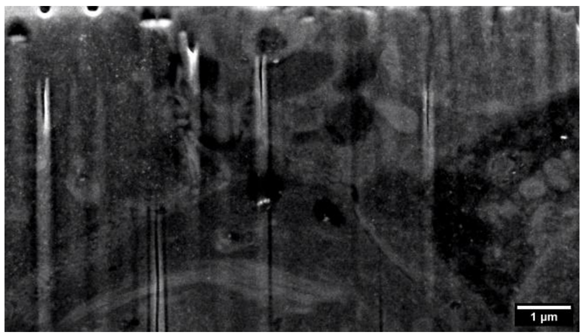
3 FIBing "modes":
- imaging, milling and deposition happen simultaneously
- ion current + atmosphere
  → pronounce one aspect!

Remarks.
i) Implantation and amorphisation also occur at grazing incidence.
ii) Depth of damage layer depends also on energy of Ga^+.

- Impinging Ga^+ always mill a little bit and produce secondary electrons
- Sample surface is damaged more with increasing Ga^+ exposure

- Curtaining effect

The curtaining effect in FIB milling refers to the formation of vertical streaks or "curtains" on the milled surface. This occurs due to variations in the milling rates of different materials (e.g. porous inclusions) or milling angles within the sample (see page 24). When a sample contains



materials with different sputtering yields, the ion beam removes material at different rates, leading to uneven surfaces. The polishing step reduces the curtaining effect.

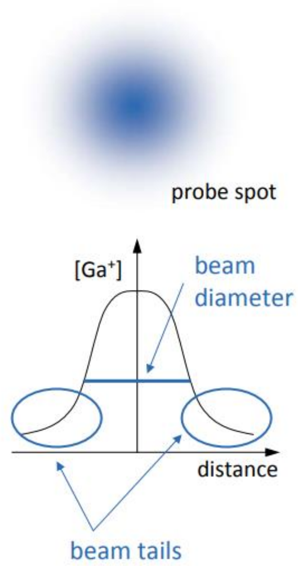
If the same object is not in the middle (use the center cross):

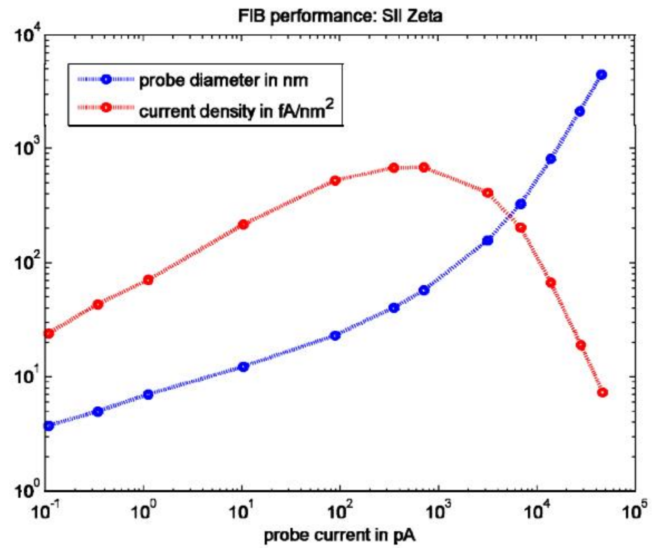
- Use beam shift XY to put it in the middle of the Ion beam image:

1. Open the beam control. Watch the Beam shift module
2. Grab the object / landmark with LMB while holding shift. The mouse icon will change into a hand with a blue sleeve.
3. Move the mouse (holding shift and LMB) to the center cross. The marker in the beam shift module should not reach the borders of the control. The image will not change.
4. release the mouse

Alternatively, use the shift XY buttons are on the physical control panel below the central screen. Note that here you will need a live ion image. switch off the FIB imaging as soon as the landmark is aligned (you are milling away your sample).

Setting: couple magnifications to OFF





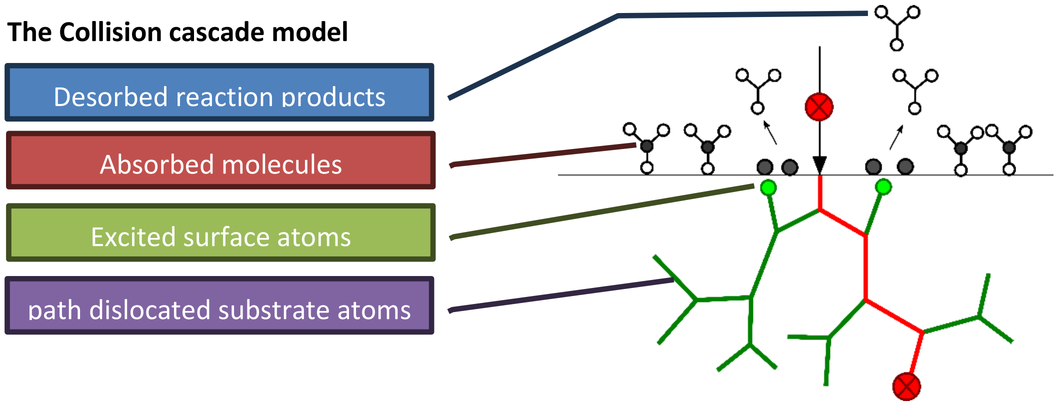
Small current → narrow beam

Demonstration: Pt deposition with the ion beam

Prerequisites:
Sample loaded
Electron beam on
Eucentric height, beam focused, 7mm working distance
Coincidence point set
Stage tilt: 52°

Deposit Pt with the ion beam

The Collision cascade model



Experiment

Patterning settings
- Choose a rectangle (easiest)
- XYZ: XY, usually < 20, Z usually between 0.1 and 1 µm
- Application: Pt dep

Microscope settings:
- Magnification: 2000 X or higher (Standard mode, ETD detector)
- Ion acceleration voltage: 30 KV
- Beam current: CALCULATE! Using this formula:

$$Current\ (pA) = X(\mu m) \cdot Y(\mu m) \cdot 6\ (\frac{pA}{\mu m^2})$$

- select Pt dep (not Si) in the application
- calculate the Ga current required using the magic number 6 (pA/µm2).

$$Current\ (pA) = X(\mu m) \cdot Y(\mu m) \cdot 6\ (\frac{pA}{\mu m^2})$$

* e.g. 10 µm x 4 µm x 6 = 240 pA
* Use this value and chose the closest current for the Ga beam

too much current and you will mill instead of deposit
Too less current will destroy your vacuum
6 is the magic number!

- You should get a time round 3-5 minutes
- Insert the Pt GIS
- Press F9 in the ion image (this will contrast/brightness correct and take a snapshot). Make sure you have the ETD selected
- Check the position of the rectangle, overlay the e-beam deposited marker.
- Run the deposition
- retract the GIS needle

- Milling

Experiment: Bulk mill

- Use the **regular cross section** (RCS) pattern.
- Position it just below the Pt deposition you just made, and a bit wider than the Pt deposition pad (about 10%), exactly touching the Pt above it. The pattern is yellow
- Application: Si multipass (4 passes)
- determine / decide on the depth (e.g. 5 µm)
- calculate the Y, with at least Y > 2 times Z. If you intend to do EDX, a factor of 3 is at least needed.
- Pick a Ga ion beam current to mill between 2-5 minutes
- Check your SEM image before you start the milling. F9 to adjust brightness contrast
- Start the patterning ()

- Microscope settings (will obviously vary depending on the sample)
  * Standard mode
  * 2000 X (or higher)
  * 2 KV
  * 1.6 nA beam current (to start with, see below)
- Patterning settings:
  * set X, Y: 20µm x 2µm
  * Z = 500 nm
  * Set the current to get a estimate time of 5-7 minutes
- Click start patterning

Note: e- beam deposition is slow, iSPI is not possible

- retract the GIS needle. Hit F9. remove the pattern.

A proper beam coincidence point is crucial to use the FIB beam. A proper beam coincidence point assures that the FIB beam is focused on the SEM image.

Experiment: setup beam-coincidence point

Set the BCP. You may use the deposition from the step before as a marker.
CTRL + i (will tilt to 52° – ion beam)
CTRL + e (will tilt to 0° – electron beam)
Align the e-beam to the ion beam precisely.

- Protecting your object of interest

Experiment: ion beam Pt deposition (MANDATORY)

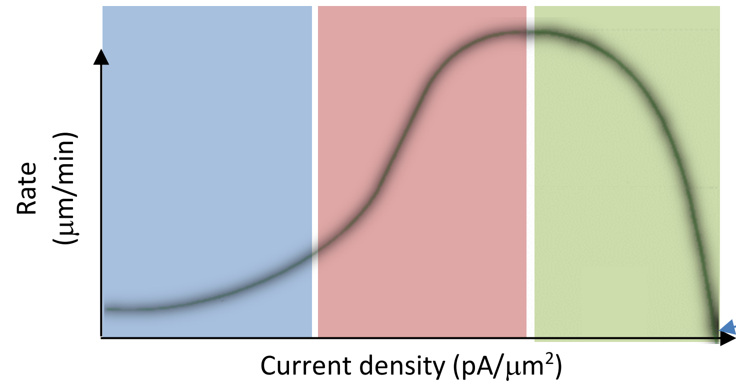
Pt deposition with the Ga ion beam (in the **Ga ion image**)

- First glance: Do not make an image with the Ga ion beam!
- Draw a rectangle in the Ga ion image with the patterning tool (e.g. 20µm x 2µm)
- z= about 1 µm

Where X = width of the pattern in µm, Y = height of the pattern in µm.

Choose the ion beam current to be as close as possible to the calculated value
  Example: a 20 µm x 20 µm rectangle → 6 x 20 x 20 = 2400 pA (actual value: 3 nA)
  Example: a 2 µm x 3 µm rectangle → 6 x 2 x 3 = 36 pA (actual value: 30 pA)

Failing to choose the correct beam current will either ruin your vacuum or create a hole in your object.



High-efficiency deposition per ion
- Ion dose on each pass does not decompose all gas
- Slow layer growth rate, Long deposition time
- Excess gas may affect vacuum

High-efficiency growth rate
- Each beam scan uses up nearly all precursor gas
- Fastest layer growth rate

2-6 pA/µm^2

Milling effects
- All gas is used up by only part of ion dose
- Remaining ions sputter / mill the surface

Demonstration: Patterning types

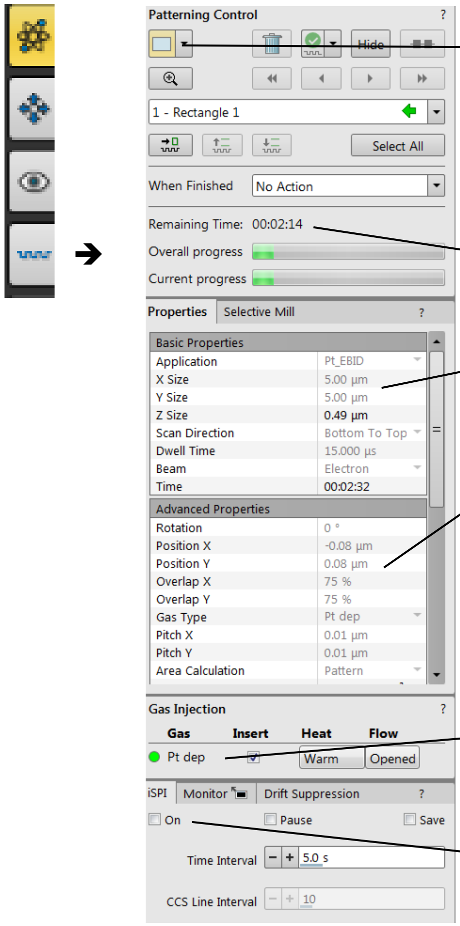
Prerequisites:

Sample loaded

Electron beam on

Eucentric height, focused, WD=7mm, either at 0° or 52°

Information of the different pattering types



Pattern type selector (see Toolbar icons also): Rectangle / Line / Circle / Cleaning Cross Section / Regular Cross Section / Polygon / Bitmap / Stream File

Time indicator

Pattern size settings

Array settings, passes, …

Pt Deposition

iSPI: imaging during deposition

Demonstration: Making a cross section

Prerequisites:

Eucentric height, beam focused, 7mm working distance

Coincidence point set

Ion beam and e-beam aligned

Produce a cross section

- Preparation

The settings used here are generic and should be seen as a starting point for delveloppinf the settings needed for your specific application and/or sample.

Experiment: preparation

In the electron beam (0°)

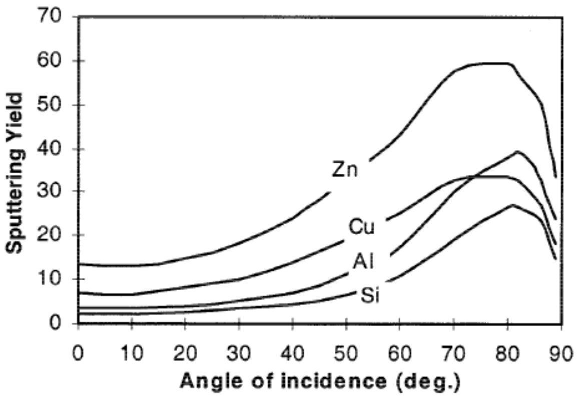
- Proper imaging setting, magnification: sufficient (1500+ X)
- Focus the region
- Link the stage
- Go to 7 mm WD (at 0 degree)
- Set eucentric (CTRL+F)

Make 100% sure you are in focus, eucentric and at 7mm. Incorrect settings will damage the instrument

(Optional) experiment: protect the ROI using e-beam Pt deposition

- Insert the GIS needle
  - * If it drops a shadow on your image: Press F9
  - * If the needle is visible: increase magnification
- Select a rectangle and draw a pattern in the e-beam quadrant.
- As application, choose Pt_EBID (E beam induced deposition). The rectangle should be green

- Sputter yield depends on target material



Similar to the Mohs scale of hardness of solids (graphene = soft, diamond is hard), each material has a tendency to get sputtered by the Ga ion beam. The sputter rates are not a function of the Mohs scale.

Crystalline structures will cause channeling of the ions depending on the Bragg conditions. Hence, crystalline structures will not mill to a flat surface.

Material	**Sputter rate (μm³ /nC)**
Si	0.27
TEOS	0.24
Al	0.3
Al_2O_3	0.08
GaAs	0.61
InP	1.20
Au	1.50
TiN	0.15
Si_3N_4	0.20
C	0.18
Ti	0.37
Cr	0.10

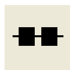
Material	**Sputter rate (μm³ /nC)**
Fe	0.29
Ni	0.14
Cu	0.25
Mo	0.12
Ta	0.32
W	0.12
MgO	0.15
TiO	0.15
Fe_2O_3	0.25
Pt	0.23
PMMA	0.40

Pattern types

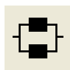
Patterns are automatically assigned to one or more particular processes, distinguishable by a different cross-hatch.

- Rectangle / Line / Circle / Polygon pattern: both milling and deposition.
- Cleaning Cross Section: milling line by line (each line with set number of passes).
- Regular Cross Section: has two possibilities selectable in the Property editor:
  - Multipass – processes entire pattern and starts again (with set number of passes)
  - Stairstep – the pattern is created as a compilation of five rectangles with specified overlap between them. Each one is processed with the set number of passes.
- The Bitmap pattern enables importing bitmaps as a pattern. It must be 24 bit RGB bitmap, each pixel consists of:
  - Red component – actually not used
  - Green component – determines if the beam is blanked.
  - Any value other then 0 activates the beam
  - Blue component – determines the dwell time per pixel:

Serial vs parallel patterning



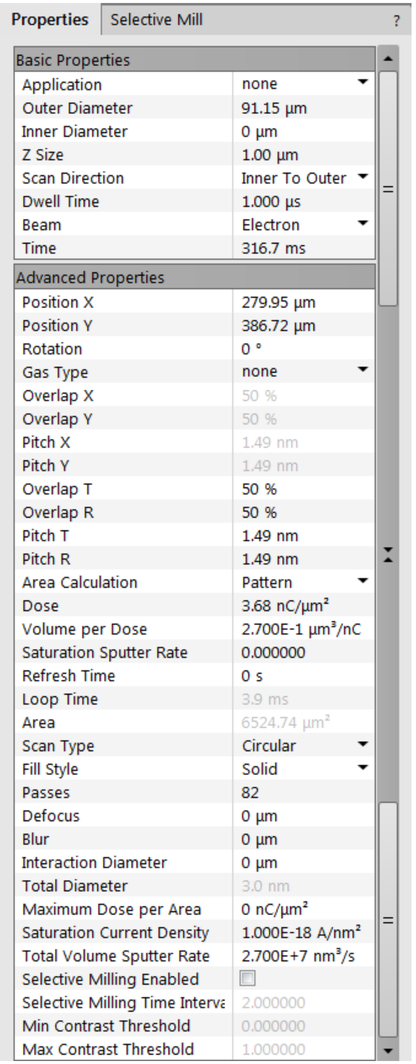
This is the default patterning mode. All patterns defined on the screen are processed consecutively; milling / deposition is completed on one pattern before moving to the next one. Serial patterning is always used with cleaning cross section milling.



All patterns defined on the screen are processed concurrently, one pass of the beam is completed on all patterns before moving to the second pass. Parallel patterning is typically used to avoid a redeposition of material on the adjacent areas.

Pattern properties

A pattern can have many associated parameters, which can be set via the Property module:



Application
clicking on the value slot enables a down arrow bringing a drop down list of applications. Choosing the required one sets the subsequent properties.

X / Y / Z size
Dimensions of the pattern

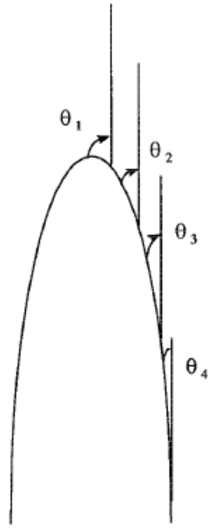
Scan Direction
Scan movement direction (Bottom to Top; Top to Bottom)

Dwell Time
A time the beam spends on a single pixel per pass (rounded to a multiple of 25 ns).

Beam
The beam used for patterning

Time
required to process this pattern. Calculated from the different parameters

Rotation
Rotation of the patterns (the positive direction is clockwise)

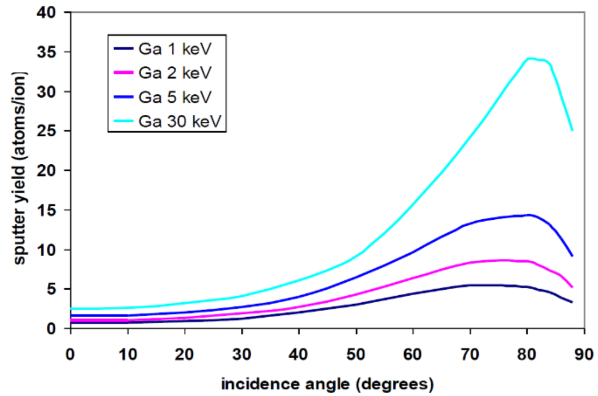


$$\theta_1 \neq \theta_2 \neq \theta_2 \neq \theta_4$$

Asperities on a surface will be FIB milled at different rates due to topographic effects on milling. The topographic effects will grow and exacerbate as FIB milling continues.
This is why surfaces are "never" FIB milled from top-down, but rather, are created by FIB milling at high incident angles.

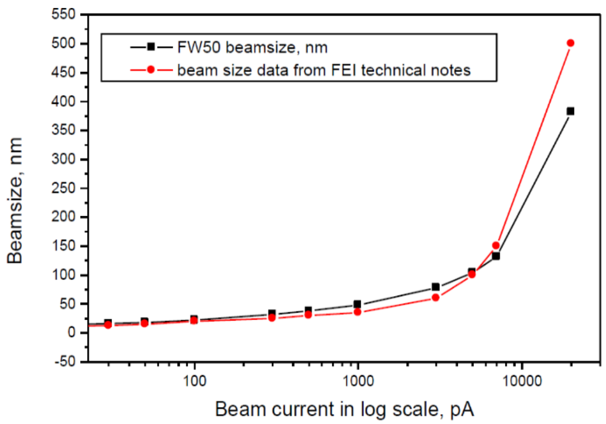
See also page 30, Curtaining effect.

- Sputter yield depends on ion acceleration voltage



30 keV is the maximum voltage of the ion gun. Always use 30 kV, unless clearly mentioned otherwise.

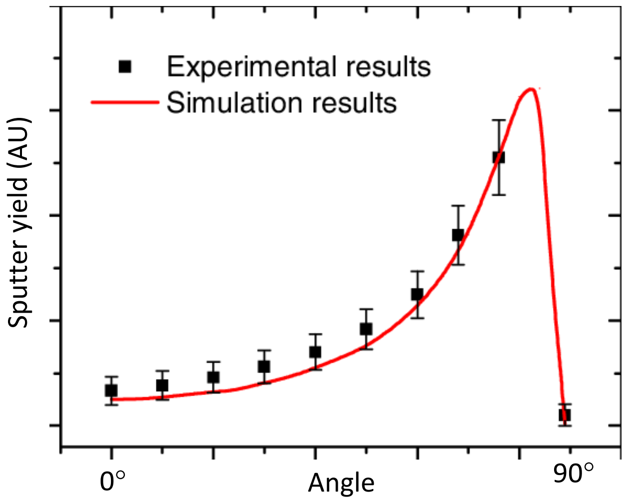
- Ion beam morphology



The higher the ion current, the wider, larger the ion beam.

Index	Beam current	Aperture diameter (um)	Beam diameter
0	1.5	0.008	7.0
1	10	0.016	13.0
2	30	0.025	17.0
3	50	0.032	19.0
4	**100**	0.042	24.0
5	300	0.068	31.0
6	500	0.087	35.0
7	**1000**	0.118	44.0
8	3000	0.198	66.0
9	5000	0.250	85.0
10	7000	0.294	102.0
11	15000	0.420	182.0
12	30000	0.600	210.0
13	50000	0.750	300.0
14	maxmium	1000.000	400.0

- Sputter yield depends on sputter angle



The milling efficiency is a function of the local curvature of the sample. Milling works most efficiently between 75-85°. At 90° the sputter yield is near zero. Hence, do not mill samples that are not flat: you will end up with a preferentially milled object.

Position X / Y

Position of the pattern relative to the origin (the display center)

Overlap X / Y

Sets the beam diameter overlap. The value of the overlap can be positive (=array) or negative (=overlapping) depending on a particular application. The overlap parameter influences the Area Calculation and the Dose.

Gas Type

the gas to be used to process the pattern (or None if no gas is to be used). This determines the pattern color onscreen (yellow for milling, green for Pt deposition).

Pitch X / Y

Sets the pitch between two spots. Alternative to overlap.

Area Calculation

Defines how the patterning area will be calculated in order to get the most accurate value of the Dose. This value is related with the OverlapX/Y. The Pattern (default) / Array are set for positive / negative overlaps.

Volume per Dose

The volume of material that is removed per charge

Saturation Sputter Rate

The maximum linear sputter rate for a given gas. For Gas = None this is 0 (actually not used).

Refresh Time

The minimum loop time that must at least elapse before the next pass, so that the adsorbed gas can be refreshed

Loop Time

The time required for a single pass (read only)

Area

The surface area of the pattern (read only)

ScanType

the Serpentine means the beam proceeds from left to right and back from right to left, while the Raster scans from left to right, then the beam returns to the left starting point

Fill Style

One can choose either to mill a solid (area) or just a frame (box and circular types only)

Passes

The number of the beam scans over the pattern

Defocus of the beam (WD change)

Influences the Total Diameter and Area Calculation. It allows focusing above / below (negative / positive value) the sample surface

Blur
Like Defocus, but specifying the (additional) diameter of the blurred spot

Interaction Diameter for an infinitely small beam
Influences the Total diameter

Total Diameter
the combination of the beam diameter and interaction diameter influences the OverlapX/Y and PitchX/Y values (read only)

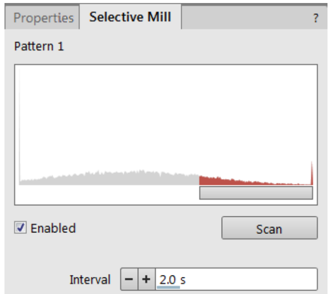
Maximum Dose per Area
describes the adsorbed gas layer, allowing a certain dose to be deposited at a higher rate than the saturation current density, allowing a temporary higher rate (actually not used)

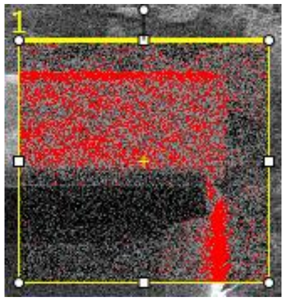
Saturation Current Density
The current at which 63% of the saturation sputter rate is reached (actually not used)

Total Volume Sputter Rate – the speed at which material is removed or deposited (actually not used)

Selective Milling Enabled / Selective Milling Time Interval / Min Contrast Threshold / Max Contrast Threshold items
Correspond to the Selective Mill tab module elements: Enabled check box / Interval adjuster / left / right border of the grey level to be processed for the selected pattern.

Selective milling





Selects to be milled pixels based on their grey level. The scan button reads the pattern area grey level histogram (only ion image).

Demonstration: Basic milling concepts

Prerequisites:
Sample loaded
Electron beam on
Eucentric height, focused, WD=7mm
Beam coincidence point set

Milling practicalities

- Ions version electrons

		FIB	SEM	Ratio
Particle	type	Ga+ ion	electron	
	elementary charge	+1	-1	
	particle size	0.2 nm	0.00001 nm	20.000
	mass	1.2 .10⁻²⁵ kg	9.1.10⁻³¹ kg	130.000
	velocity at 30 kV	2.8.10⁵ m/s	1.0 10⁸ m/s	0.0028
	velocity at 2 kV	7.3.10⁴ m/s	2.6.10⁷ m/s	0.0028
	momentum at 30 kV	3.4.10⁻²⁰ kgm/s	9.1.10⁻²³ kgm/s	370
	momentum at 2 kV	8.8.10⁻²¹ kgm/s	2.4.10⁻²³ kgm/s	370
Beam	size	nm range	nm range	
	energy	up to 30 kV	up to 30 kV	
	current	pA to nA range	pA to uA range	
Penetration depth	In polymer at 30 kV	60 nm	12000 nm	
	In polymer at 2 kV	12 nm	100 nm	
	In iron at 30 kV	20 nm	1800 nm	
	In iron at 2 kV	4 nm	25 nm	
Average electrons	secondary electrons	100 - 200	50 - 75	
signal per 100				
particles at 20 kV	back scattered electron	0	30 - 50	
	substrate atom	500	0	
	secondary ion	30	0	
	x-ray	0	0.7	