



Building College-University
Partnerships for Nanotechnology
Workforce Development

Focused Ion Beam (FIB): “Seeing” and “Processing” at the Nano-Scale

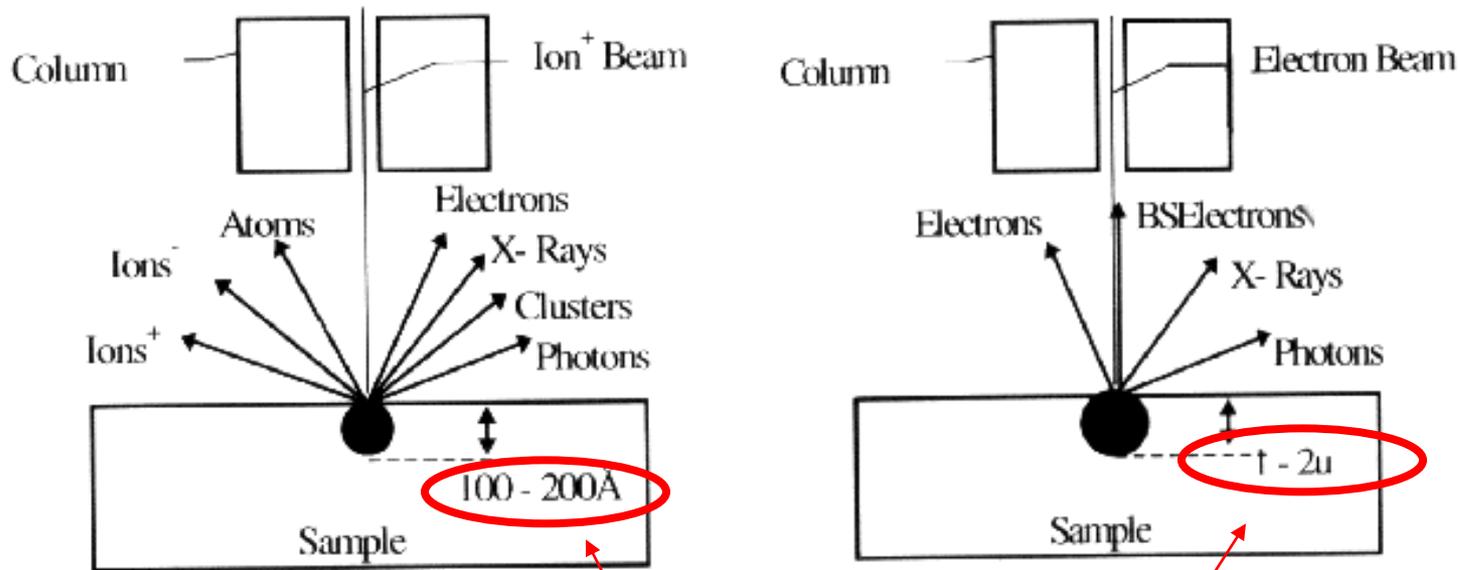
Outline

- FIB Overview
- FIB Operation
- FIB Applications

FIB overview

Ebeam vs. Ion Beam

- Beam Interactions



Milling as it scans sample surface

No damage as it scans sample surface

Note difference in interaction volume

Applications of Focused Ion Beam (FIB)

1. Ion beam lithography
2. Image Analysis
3. Film Deposition
4. Ion Milling (Dry Etching)

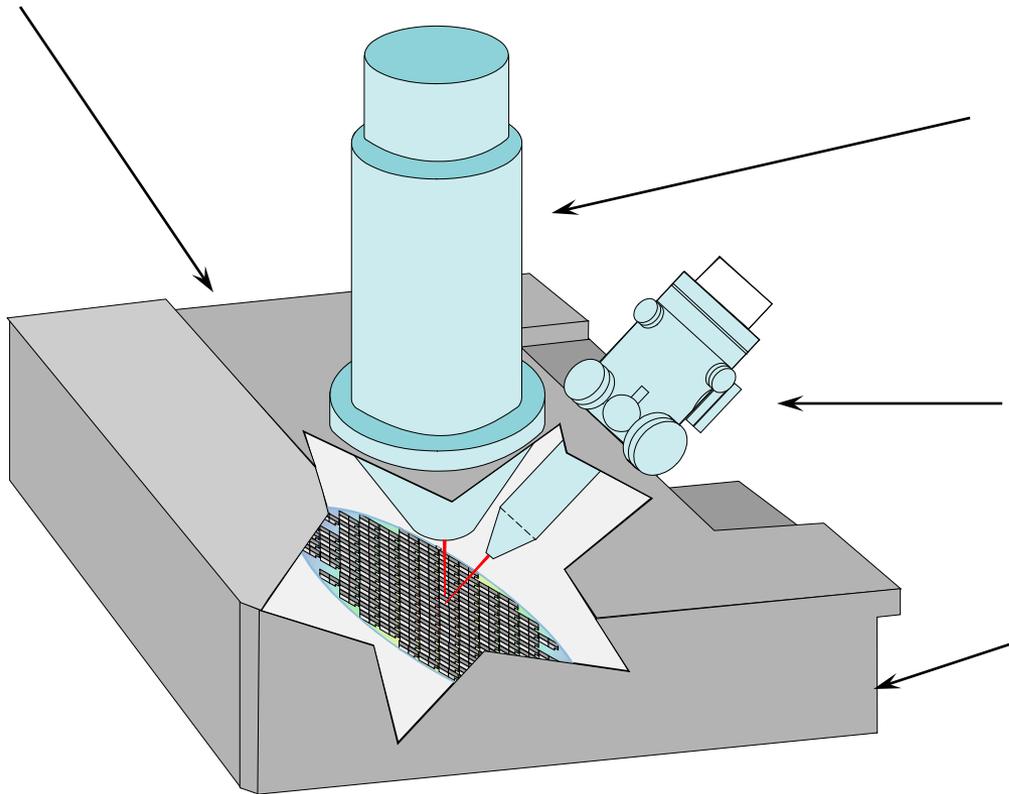
Typical Configuration of FIB

Door

Electron Column

Ion Column

Vacuum Chamber



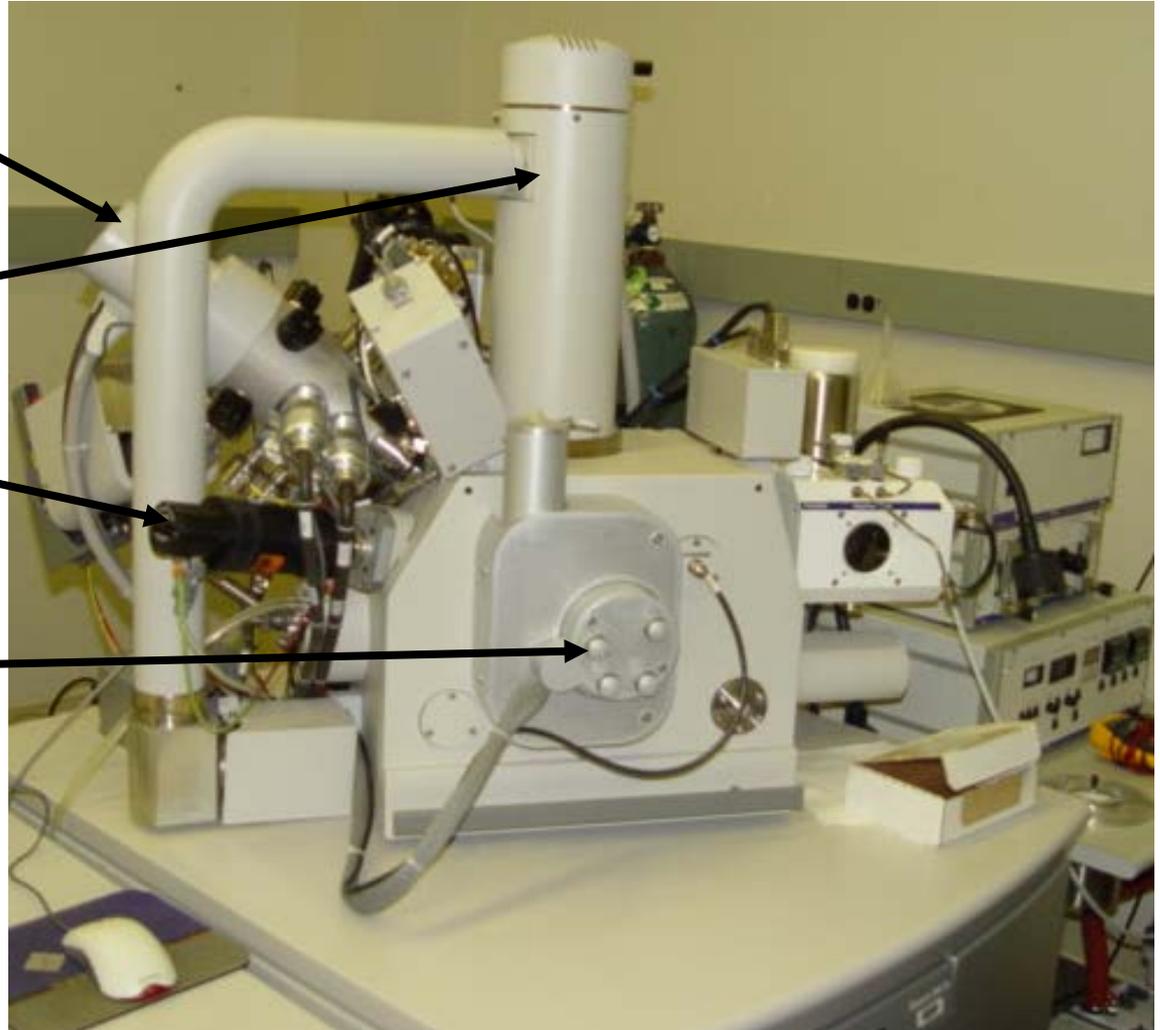
Typical Configuration of FIB (continued)

Ion column (Ion pump showing)

Electron Column

Pt Gas Injection System (GIS)

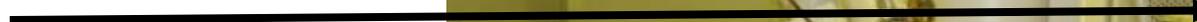
Stage motors



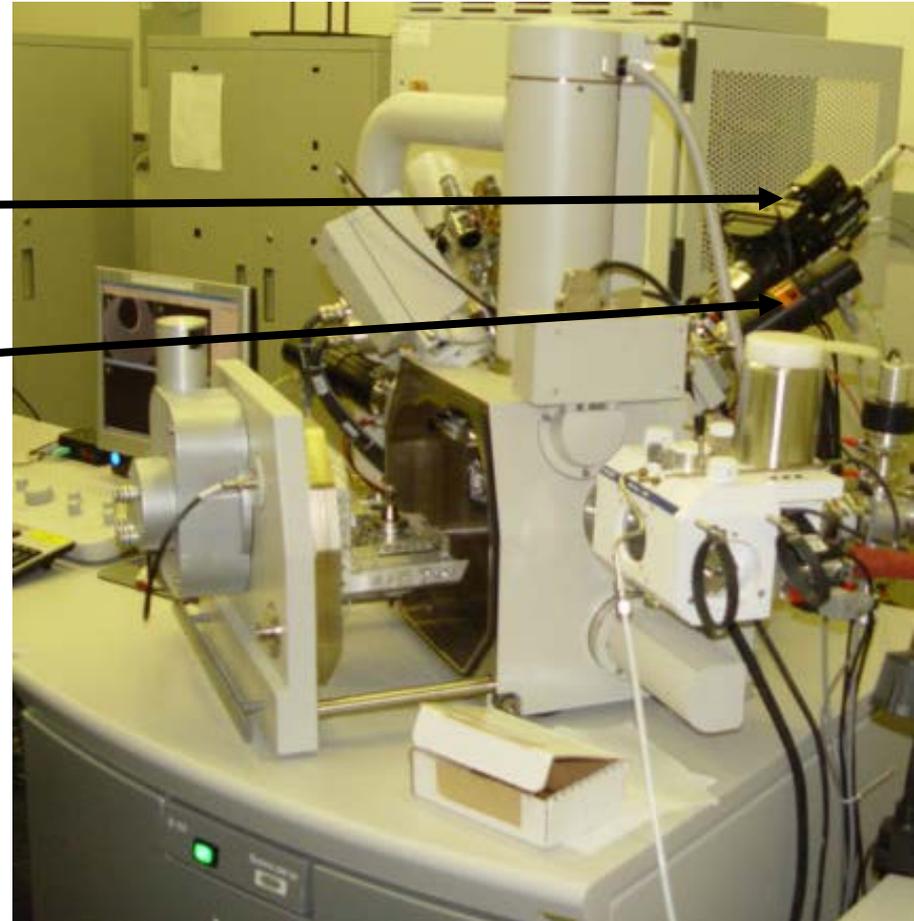
FEI Quanta 3D system

Typical Configuration of FIB (continued)

Omniprobe

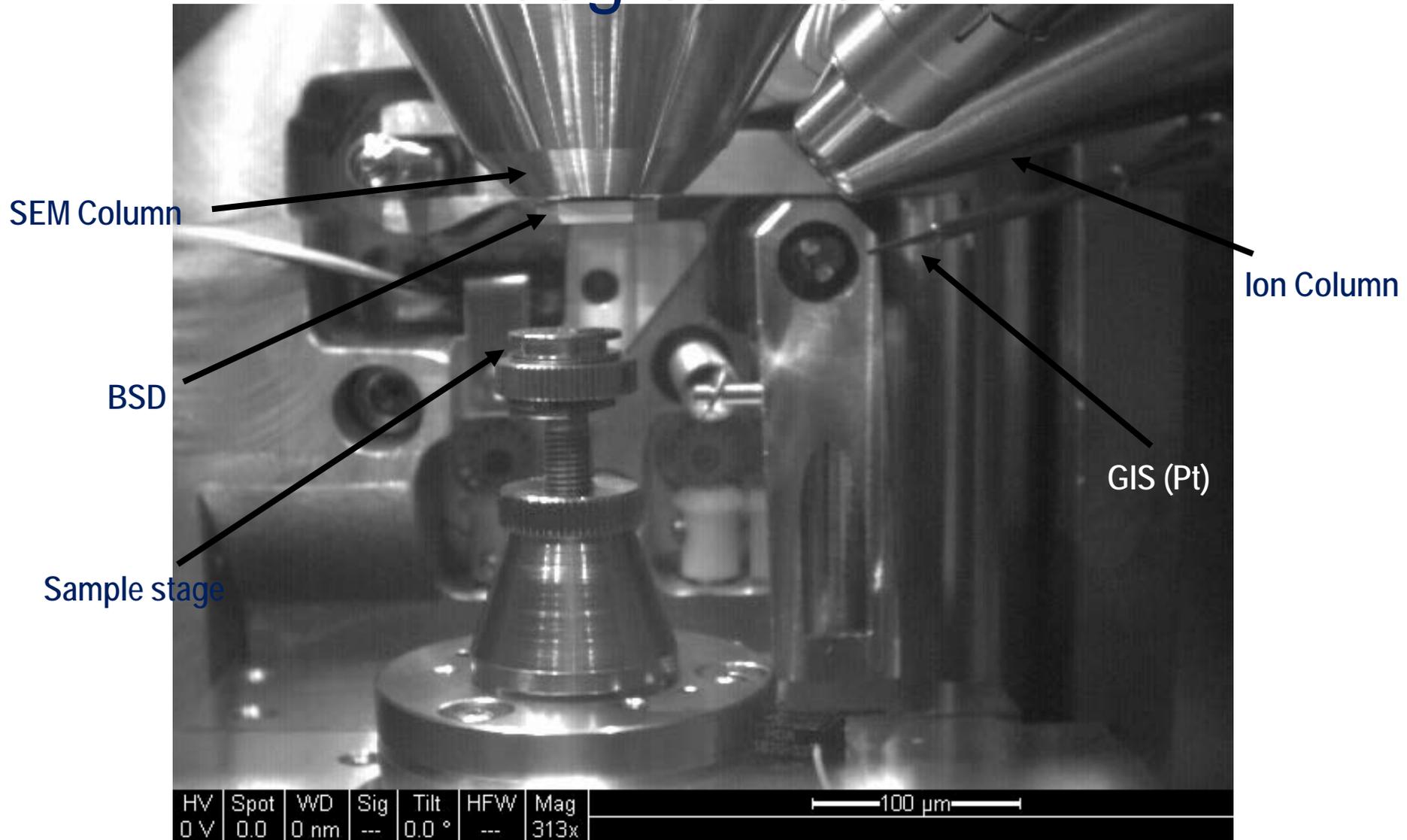


Tungsten Gas Injection System (GIS)



FEI Quanta 3D system

Typical Configuration of FIB (continued): 0 degree tilted



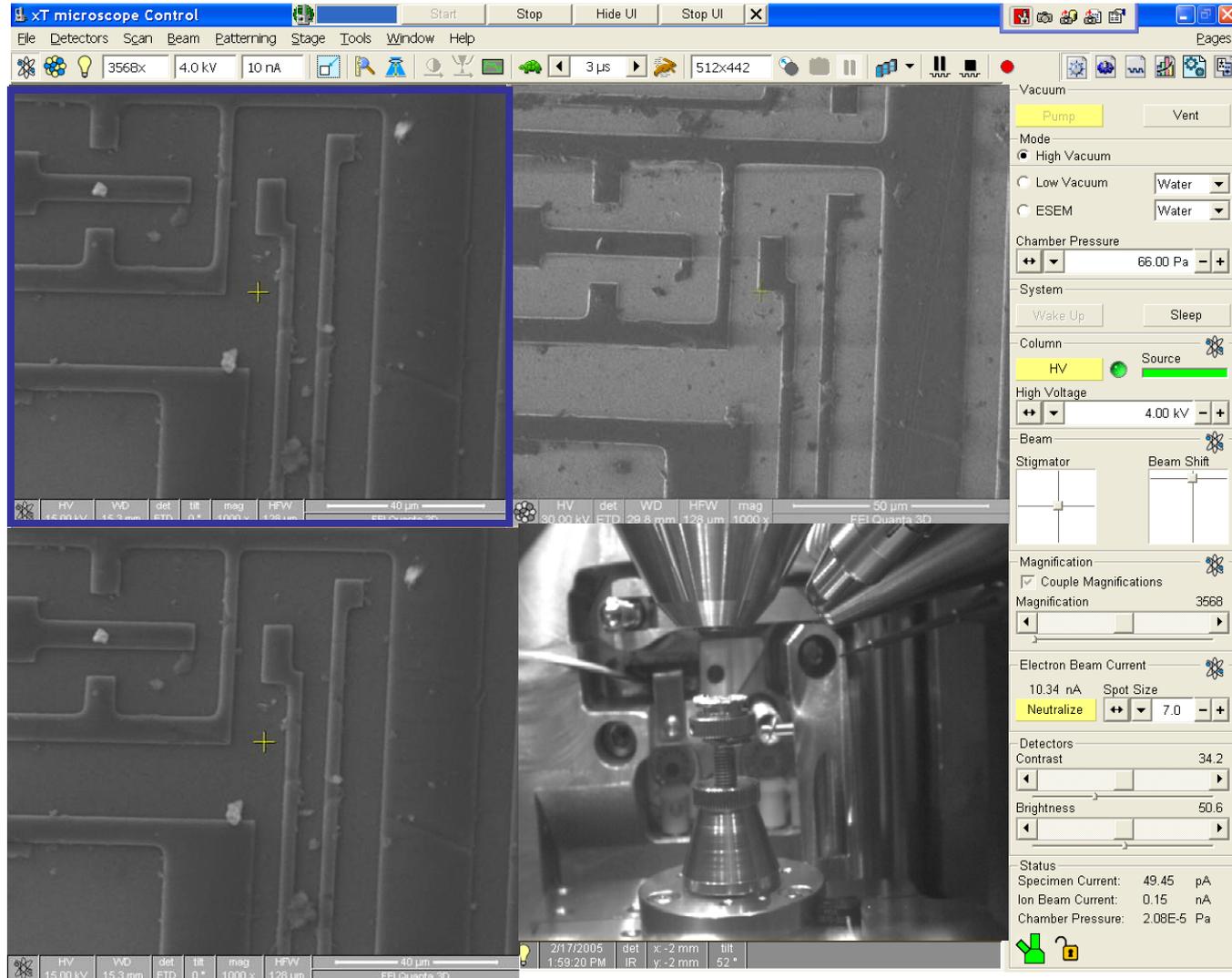
Typical Configuration of FIB (continued): 52 degree tilted

The screenshot displays the xT microscope Control software interface. The main window shows a grayscale image of a specimen, tilted at 52.0 degrees. The interface includes a menu bar (File, Detectors, Scan, Beam, Patterning, Stage, Tools, Window, Help) and a toolbar with various icons. The right-hand side contains several control panels:

- Vacuum:** Pump (yellow), Vent, Mode (High Vacuum selected), Low Vacuum (Water), ESEM (Water), Chamber Pressure (66.00 Pa).
- System:** Wake Up, Sleep.
- Column:** HV (yellow), Source, High Voltage (30.00 kV).
- Beam:** Stigmator, Beam Shift.
- Magnification:** Couple Magnifications (checked), Magnification (3105).
- Electron Beam Current:** 10.34 nA, Spot Size (7.0), Neutralize (yellow).
- Detectors:** Contrast (34.2), Brightness (40.2).
- Status:** Specimen Current: 50.94 pA, Ion Beam Current: 0.15 nA, Chamber Pressure: 1.91E-5 Pa.

At the bottom of the image, a status bar displays the following parameters: HV 0 V, Spot 0.0, WD 0 nm, Sig ---, Tilt 52.0°, HFW ---, Mag 10000x. A scale bar indicates 2 μm.

Typical Configuration of FIB (continued): User Interface

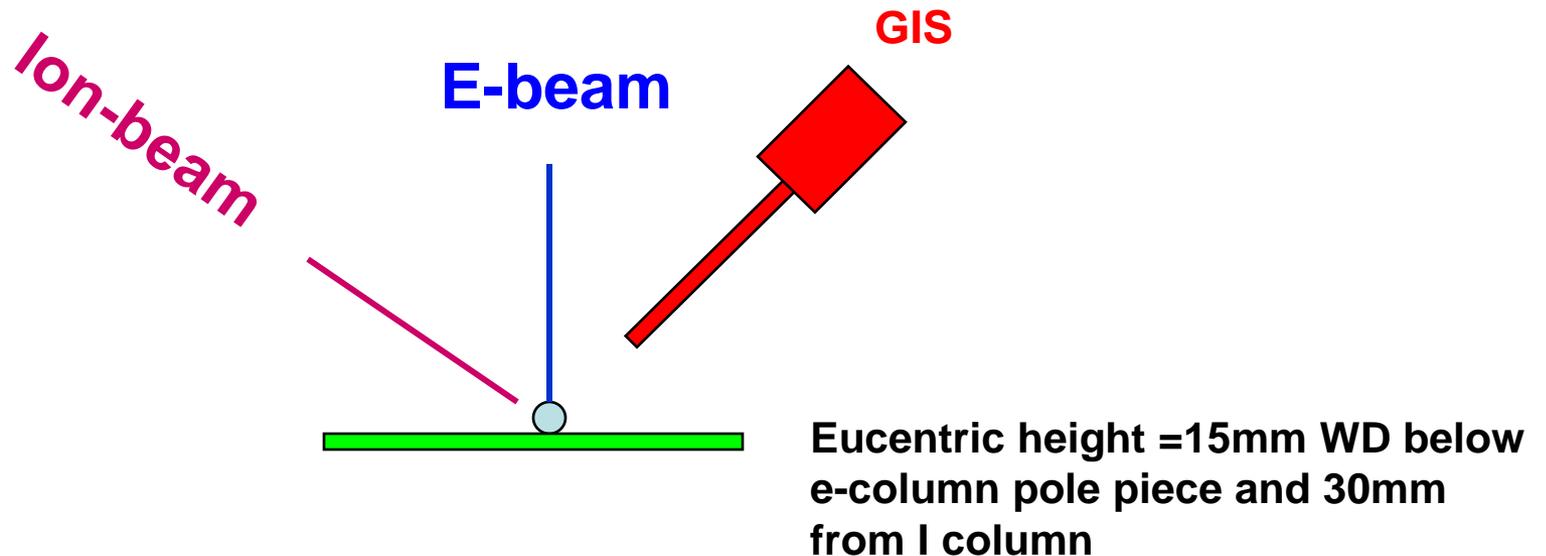


Typical Configuration of FIB (continued): User Interface



FIB operation

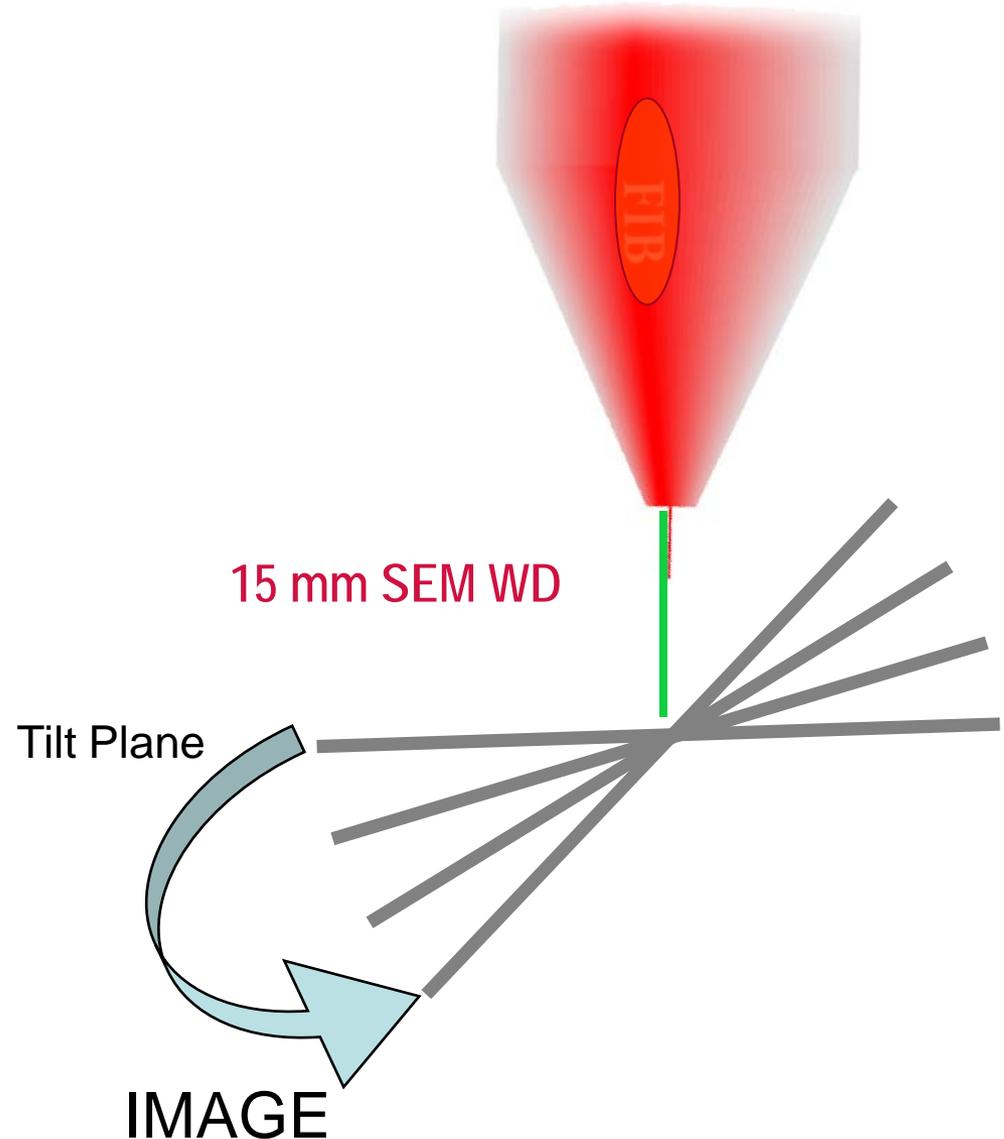
What is Eucentric Point ?



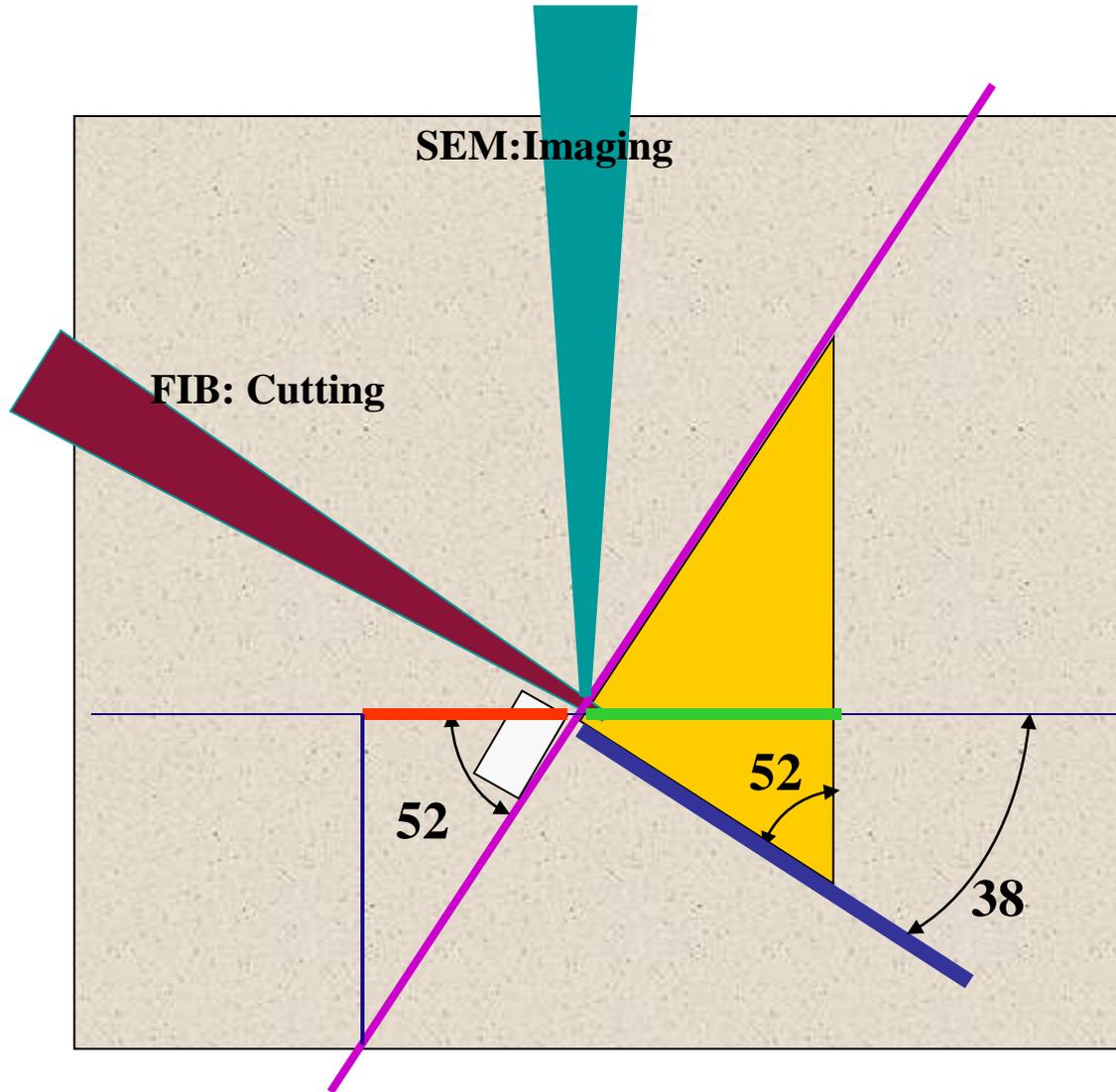
All equipment is pointed to one central spot !!

What is Eucentric Point ? (continued)

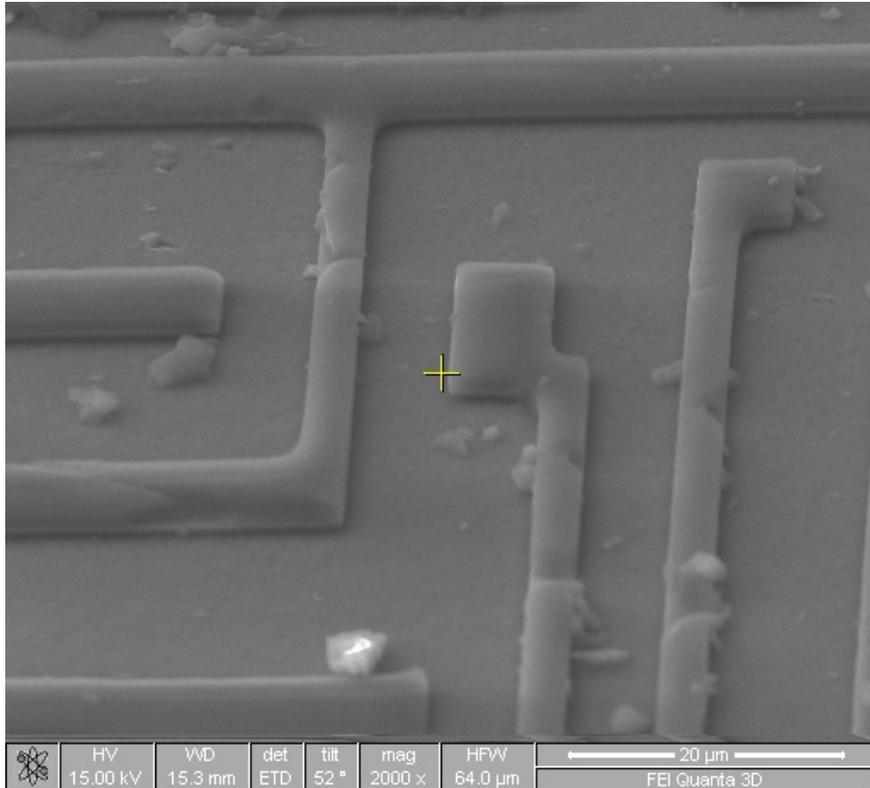
- All aligned:
 - “Eucentric” is a point in the stage height control (“Z”) where the sample’s image does not move when the sample is tilted.
 - SEM imaging is used to find the physical point.



Eucentric Point (continued)



Eucentric Point (continued) – 52 degree tilted Images

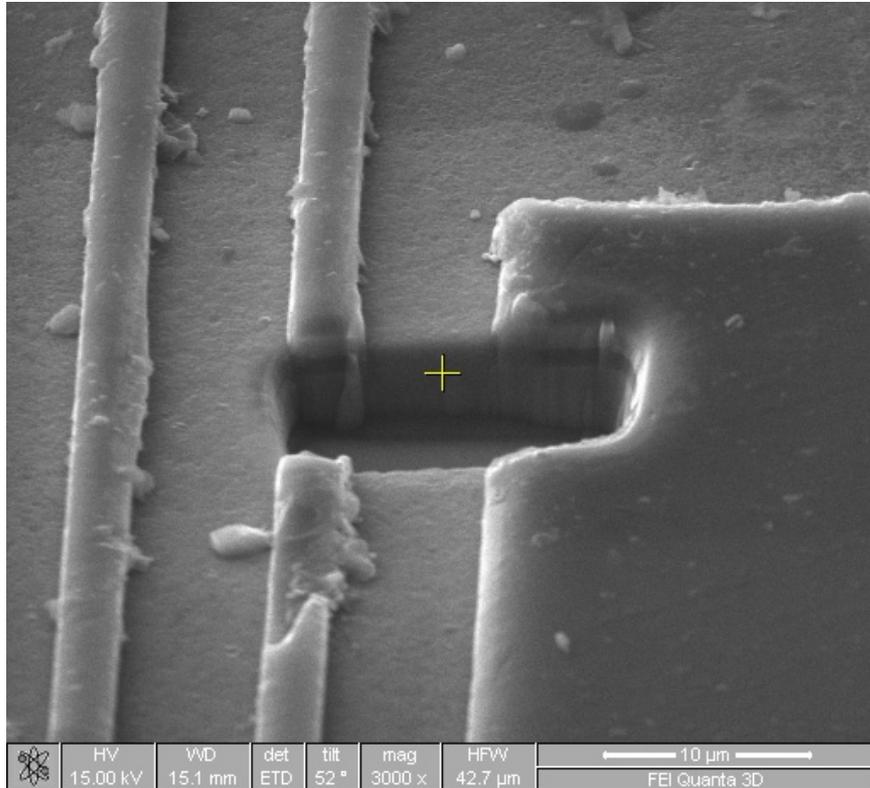


SE image  is foreshortened. The upper part of the image is at a longer WD than the lower portion of the image.

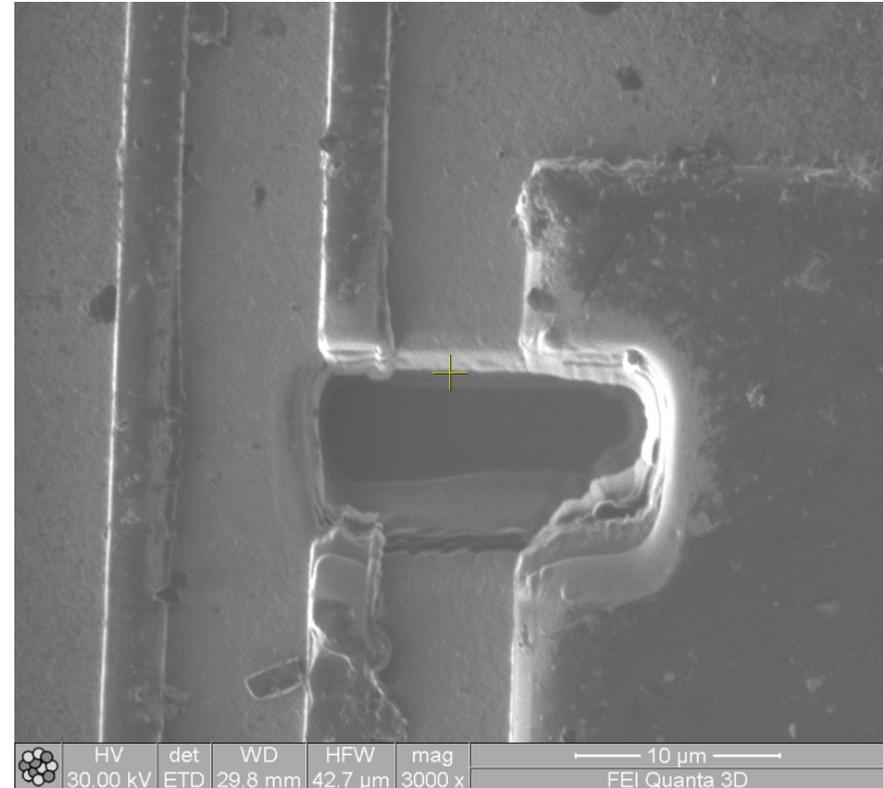


Ion image  - Appears to be looking straight on.

Eucentric Point (continued) – 52 degree tilted Images



SE image can look into the milled area.



Ion image is doing the cutting and “looking” down in the sample.

Eucentric Point Finding Steps

- “Eucentric” is the point on the height of the stage in which the sample stays centered as the stage is tilted.
- It’s assumed you are at about 15 mm WD (having done a Z<>FWD and moved the stage previously)
- Only after finding the eucentric point, you have coincidence alignment of the beams!

Eucentric Point Finding Steps (continued)

- You will perform the following steps in the upcoming slides:
 - Start at '0' degrees tilt
 - Note a feature of interest and bring to a feature of interest (e.g., center of crosshairs)
 - Tilt the stage to a positive 52 degrees
 - Watch the image move either up or down on the screen
 - Adjust the "Z" height on the specimen door to bring feature back to the center of the screen
 - You may have to do this several times at higher and higher magnifications to get perfect eucentricity

Fine Alignment of Ion Beam

The screenshot displays the xT microscope Control software interface. The main window shows a grayscale image of a specimen with a 5 µm scale bar. Below the image, technical parameters are listed:

HV	Spot	WD	Sig	Tilt	HFV	Mag
30.0 kV	0.0	29.98 mm	SE	0.0 °	21.33 µm	12000x

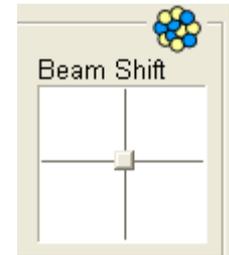
Below this, a larger image shows the microscope's internal structure with a 100 µm scale bar and another set of parameters:

HV	Spot	WD	Sig	Tilt	HFV	Mag
20.0 kV	7.0	15.30 mm	A+B	0.0 °	0.64 mm	200x

The right-hand side of the interface contains a control panel with the following sections:

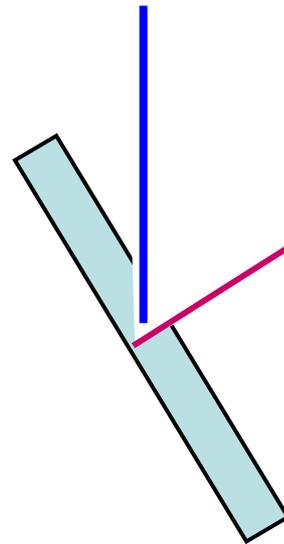
- Vacuum:** Pump, Vent, Mode (High Vacuum, Low Vacuum, ESEM), Chamber Pressure (66.00 Pa).
- System:** Wake Up, Sleep.
- Column:** HV, Source.
- High Voltage:** 30.00 kV.
- Beam:** Stigmator, Beam Shift.
- Magnification:** Couple Magnifications, Magnification (3105).
- Electron Beam Current:** 10.34 nA, Spot Size (7.0), Neutralize.
- Detectors:** Contrast (34.2), Brightness (40.2).
- Status:** Specimen Current (50.94 pA), Ion Beam Current (0.15 nA), Chamber Pressure (1.91E-5 Pa).

A red arrow points from the Beam Shift control in the software to a separate, larger 'Beam Shift' control panel on the right, which features a crosshair for fine alignment.



We just set up the sample to face the
Ion beam

E-Beam



Ion-Beam

Ion Beam Operation

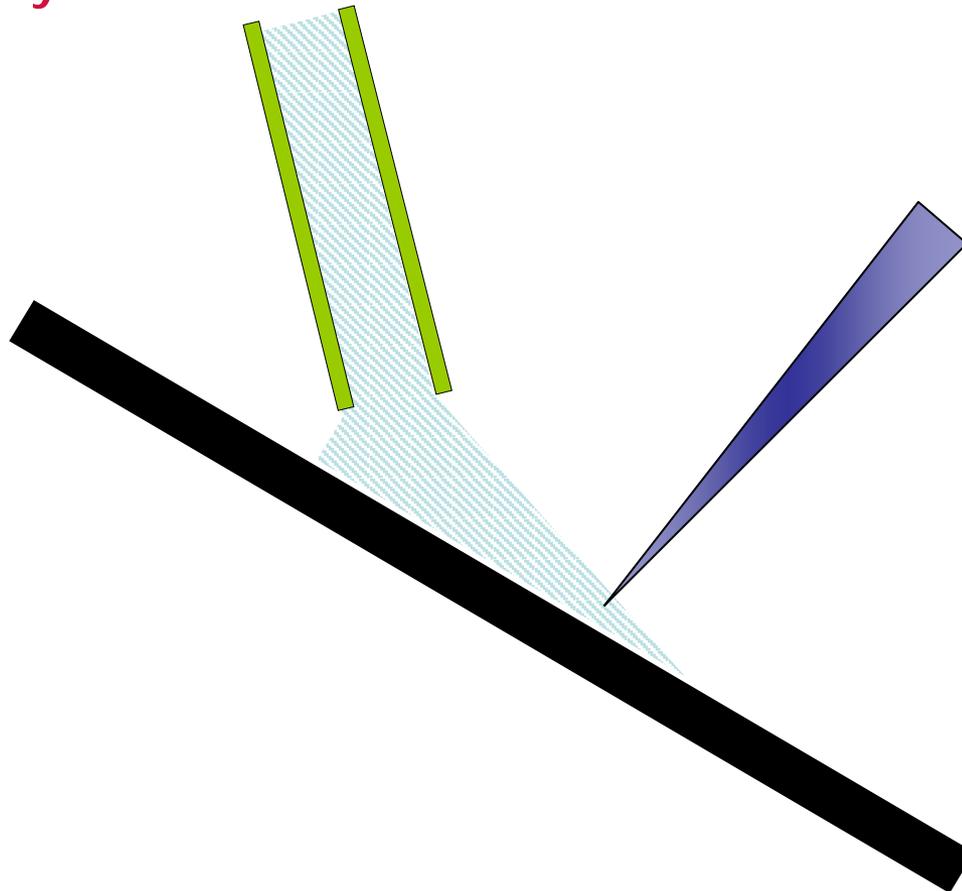
- The ion beam will damage your sample when viewing. It is important to use a small beam size when imaging!
- When getting ready to mill with a large beam current, you must focus quickly and in as few of scans as possible!
- While milling or depositing a film, you can highlight Quad 1 (SE column) and take a photo (F2) or click “snapshot.” or. It will pause the Ion beam and grab a quick SE image to see status of the Ion milling operation.

Film Deposition (Pt)

- Pt. deposition can be used for many applications.
 - adding a conductive layer to a non conductive sample
 - setting up a pattern, to prevent “curtaining” with the FIB
 - adhesive attachment for mechanical testing
 - This tutorial will cover the second point: making a protective shield for further processing

Film Deposition (Pt)-continued

Gas Injection System



Ion Beam

Film Deposition (Pt)- Find Deposition Spot

- Click on the third Icon - the Patterning Page
- This page controls:
- Patterning type including size
- Progress of mill or deposition
- Gas injection
- End Point Monitor

The screenshot displays the xT microscope Control software interface. The main window shows a grayscale image of a surface with a pattern icon overlaid. A red arrow points to this icon, and a black arrow points to the Patterning icon in the top toolbar. The right-hand sidebar contains several control panels:

- Pattern**: Includes a 'Pattern' icon and a 'HIDE' button.
- Basic**: A table with columns 'Name' and 'Value'.

Name	Value
Application	
X size	0µm
Y size	0µm
Z size	0µm
DwellTime	0s
Rel. Int. Diam.(%)	0%
Beam	Electron
TotalTime	0s
- Progress**: Shows 'Remaining Time : 0:03:23', 'Overall Progress' (a green progress bar), and 'CCS Line Progr.' (a green progress bar).
- Gas Injection**: Includes 'Overview' and 'Details' tabs. A table shows gas injection settings:

In Gas Type	Heat	Flow
<input type="checkbox"/> Pt dep	Cold	Closed
<input type="checkbox"/> SCM	Cold	Closed
- End Point Monitor**: Includes 'Graphs', 'Options', and 'Scaling' tabs. A graph shows a signal in [nA] over time, with values 48.4, -1.6, 330.4, and 390.4.
- Status**: Shows 'Specimen Current: 47.49 pA', 'Ion Beam Current: 0.15 nA', and 'Chamber Pressure: 2.08E-5 Pa'.

The bottom status bar displays various parameters: HV (20.0 kV), Spot (7.0), WD (15.30 mm), Sig (A+B), Tilt (0.0 °), HFW (0.64 mm), Mag (200x), and a 100 µm scale bar. A second status bar shows HV (0 V), Spot (0.0), WD (0 nm), Sig (52.0 °), HFW (2.00/26 PM), Mag (10000x), and a 2 µm scale bar.

Film Deposition (Pt)-Warm up the Pt Source

- Double click “cold” to toggle on “warm”
- -This heats the Pt. Gas deposition system.

The screenshot shows the xT microscope Control software interface. The main window displays a dark field image of a sample with a 5 µm scale bar. The interface includes a menu bar (File, Detectors, Scan, Beam, Patterning, Stage, Tools, Window, Help) and a toolbar with various icons. On the right side, there are several control panels:

- Pattern**: Includes buttons for pattern selection and navigation.
- Basic / Advanced**: A table showing parameters and their values.
- Progress**: Shows remaining time (0:03:23) and overall progress (CCS Line Progr.).
- Gas Injection**: Includes an Overview/Details tab and a table for gas injection settings.
- End Point Monitor**: Includes a Graphs/Options/Scaling tab and a graph showing current over time.
- Status**: Shows specimen current (47.49 pA), ion beam current (0.15 nA), and chamber pressure (2.08E-5 Pa).

A black arrow points from the text 'Double click “cold” to toggle on “warm”' to the 'Pt dep' checkbox in the Gas Injection panel.

Name	Value
Application	
X size	0µm
Y size	0µm
Z size	0µm
DwellTime	0s
Rel. Int. Diam.(%)	0%
Beam	Electron
TotalTime	0s

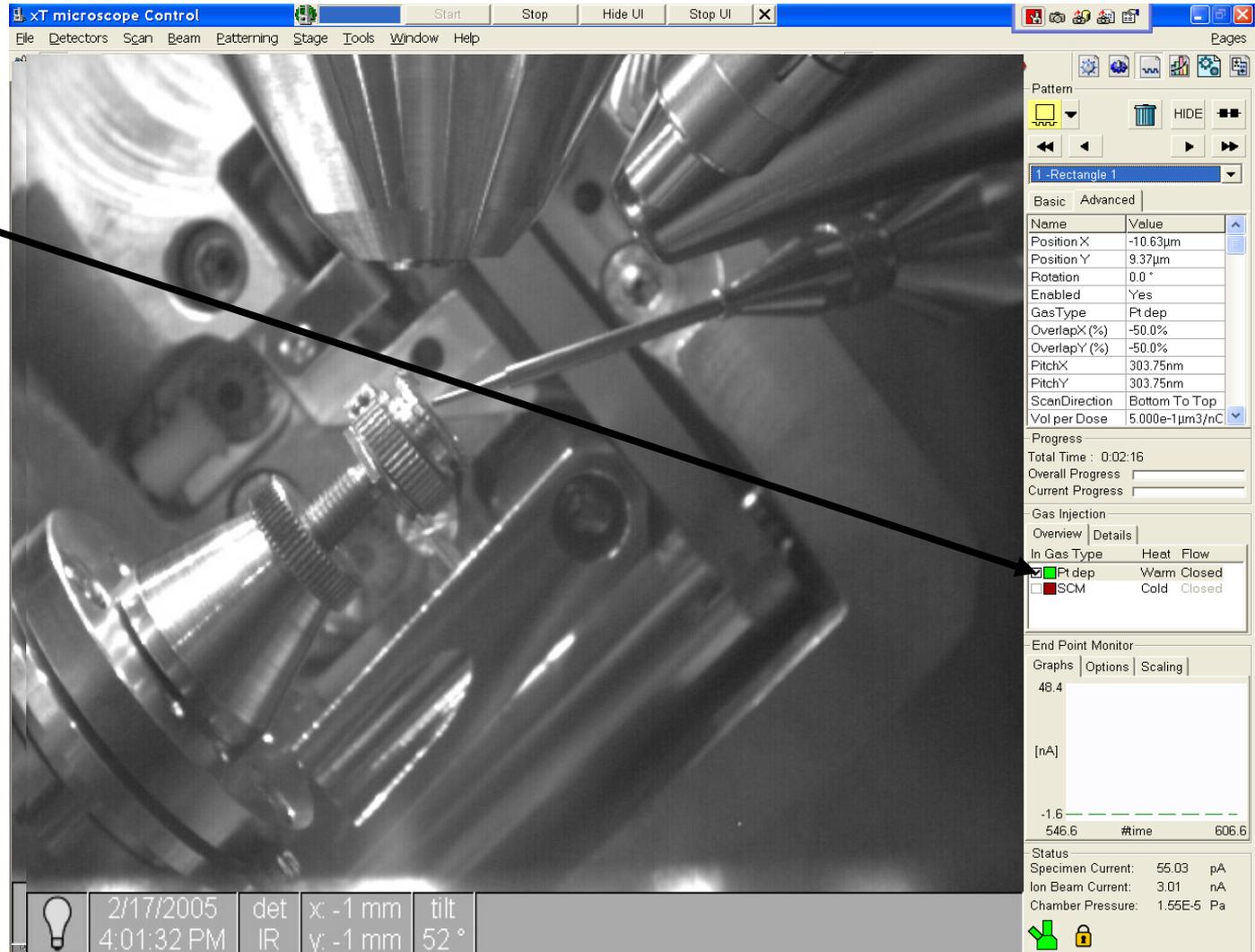
In Gas	Heat	Flow
<input checked="" type="checkbox"/> Pt dep	Cold	Closed
<input type="checkbox"/> SCM	Cold	Closed

HV	Spot	WD	Sig	Tilt	HFV	Mag
30.0 kV	0.0	29.98 mm	SE	0.0 °	21.33 µm	12000x

5 µm

Film Deposition (Pt)-Insert Pt Gas Injector

- Click on click box under “In”, to inject the GIS needle
- Check Quad 4 to see that the needle appears to be inserted properly



Film Deposition (Pt)-Define the Deposition Area

- Select “Rectangle”.
- Draw a rectangle on the frozen Ion image by clicking and dragging the left mouse button.
- Make the rectangle about 10 X 1 X 1 Micron in X,Y, and Z values.
- Increase mag so rectangle fills large fraction of screen
- Verify “Pt dep” is selected as application on the “basic” tab

The screenshot displays the xT microscope Control software interface. The main window shows a grayscale image of a specimen with a green rectangle drawn over it. The 'Pattern' window is open, showing the 'Basic' tab with the following settings:

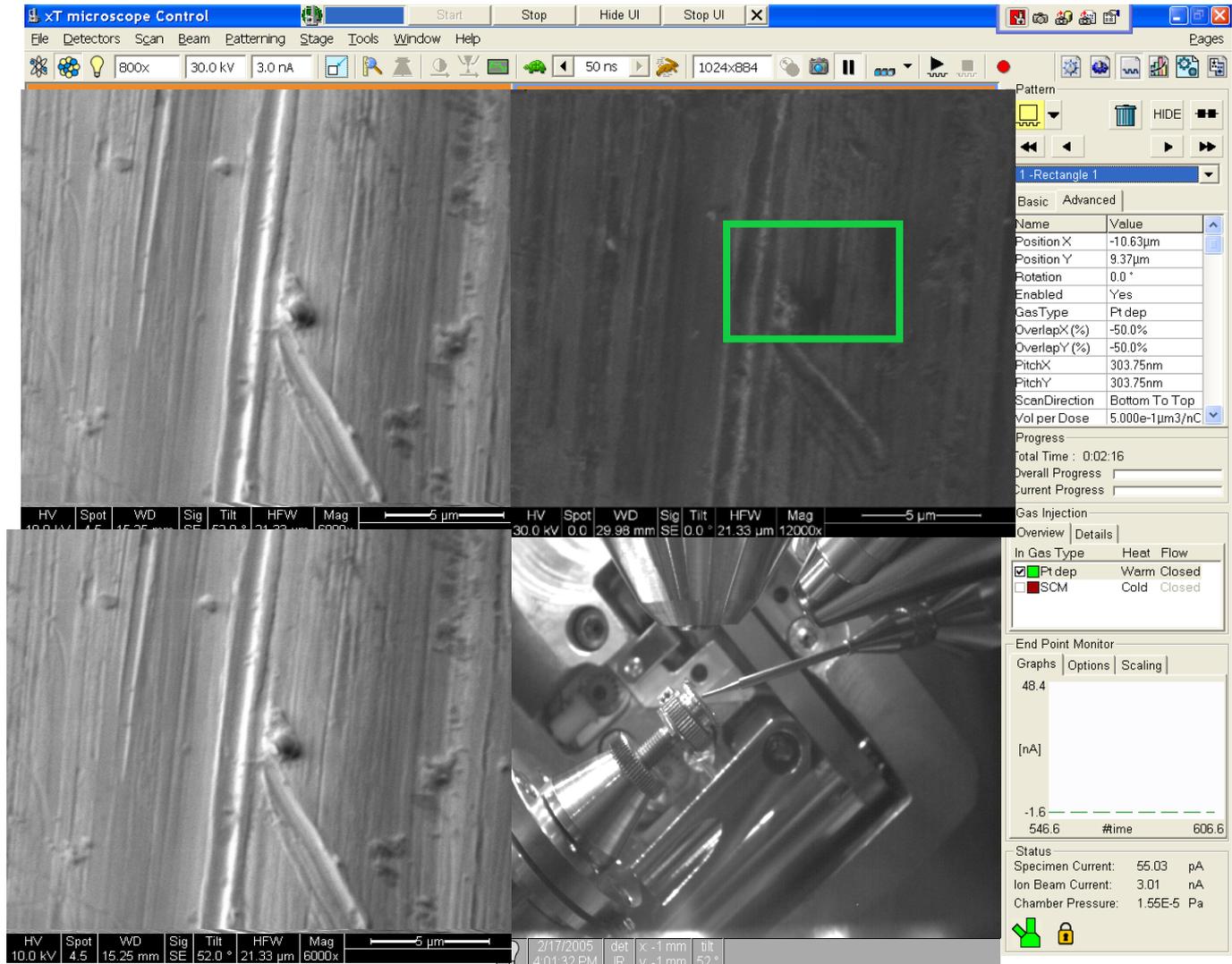
Name	Value
Application	pt dep
X size	10.00µm
Y size	1.00µm
Z size	500.00nm
DwellTime	200.00ns
Rel. Int. Diam.(%)	150.0%
Beam	Ion
TotalTime	0:05:47

The 'Advanced' tab is also visible, showing various parameters such as 'Value', 'Ptdep', and 'Bottom To Top'. The status bar at the bottom of the interface displays the following information:

HV	Spot	WD	Sig	Tilt	HFW	Mag	Scale
30.0 kV	0.0	29.98 mm	SE	0.0 °	21.33 µm	12000x	5 µm

Film Deposition (Pt)- Deposition Condition Setup

- Set Ion current to 0.10 nA for dep.
- Un Pause and quickly focus, if a “Beam Shift” is necessary, move image so that it is still aligned to SEM image.
- Re-alignment of the deposition pattern box may also be necessary.



Film Deposition (Pt)-Start Deposition

- Start the Dep by clicking the “Start” icon
- Note the various parameters in Pattern menu. These will become more important to you later, but its good to get exposed now, while you are waiting for a deposition.

The screenshot displays the xT microscope Control software interface. The main window shows a dark field image with a green rectangular region of interest. The interface includes a menu bar (File, Detectors, Scan, Beam, Patterning, Stage, Tools, Window, Help) and a toolbar with various icons. A 'Start' icon is highlighted with a black arrow. The right-hand panel contains the 'Pattern' menu, showing parameters for '1-Rectangle 1'. The status bar at the bottom displays various parameters: HV (30.0 kV), Spot (0.0), WD (29.98 mm), Sig (SE), Tilt (0.0 °), HFW (21.33 μm), Mag (12000x), and a 5 μm scale bar. The right-hand panel also shows 'Gas Injection' settings (Pt dep checked, SCM unchecked) and 'End Point Monitor' graphs.

Name	Value
Position X	-10.63μm
Position Y	9.37μm
Rotation	0.0 °
Enabled	Yes
GasType	Pt dep
OverlapX (%)	-50.0%
OverlapY (%)	-50.0%
PitchX	303.75nm
PitchY	303.75nm
ScanDirection	Bottom To Top
Vol per Dose	5.000e-1μm3/nC

Parameter	Value
HV	30.0 kV
Spot	0.0
WD	29.98 mm
Sig	SE
Tilt	0.0 °
HFW	21.33 μm
Mag	12000x

Film Deposition (Pt)- Deposition Progress Check

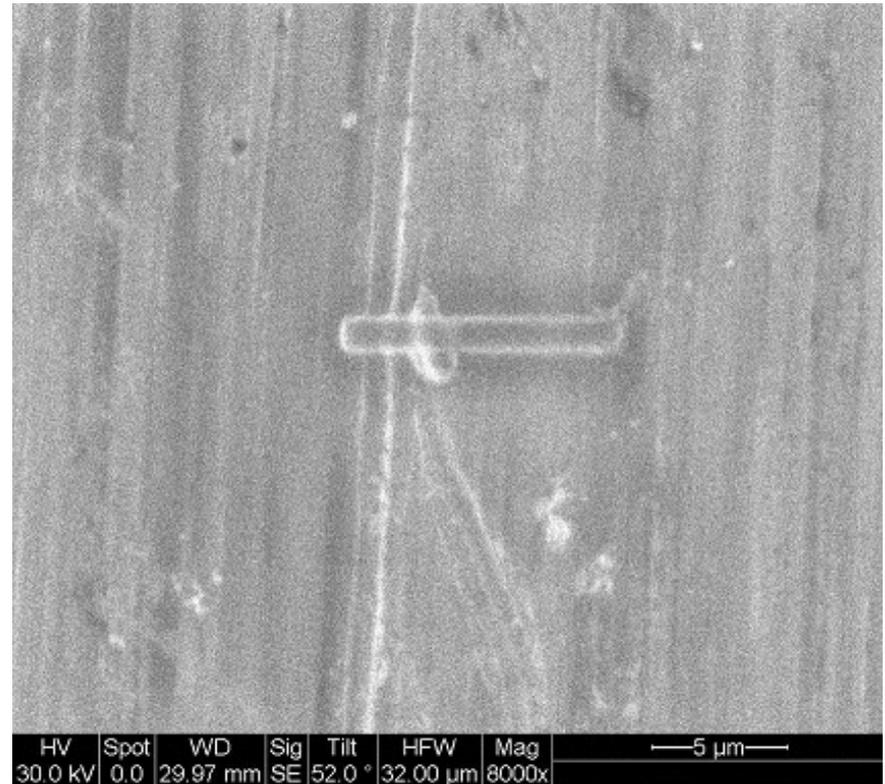
- You may take a quick peak at the depositions, as it progresses by using the “Snapshot” feature.
- - Enable Quad 1
- - Click on the “SnapShot” icon



Film Deposition (Pt)- Images of Deposited Film



Electron beam image

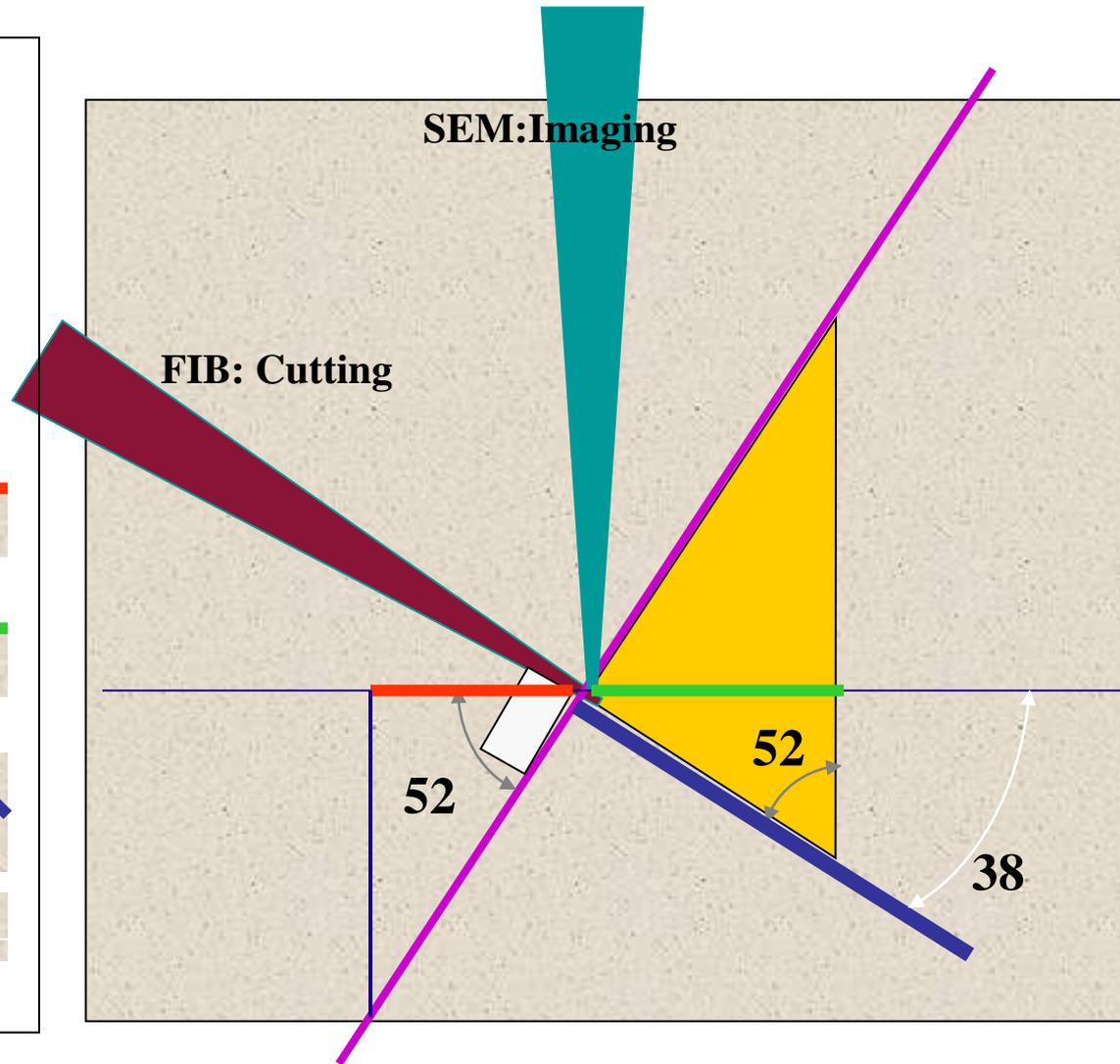


Ion beam image

Ion Milling

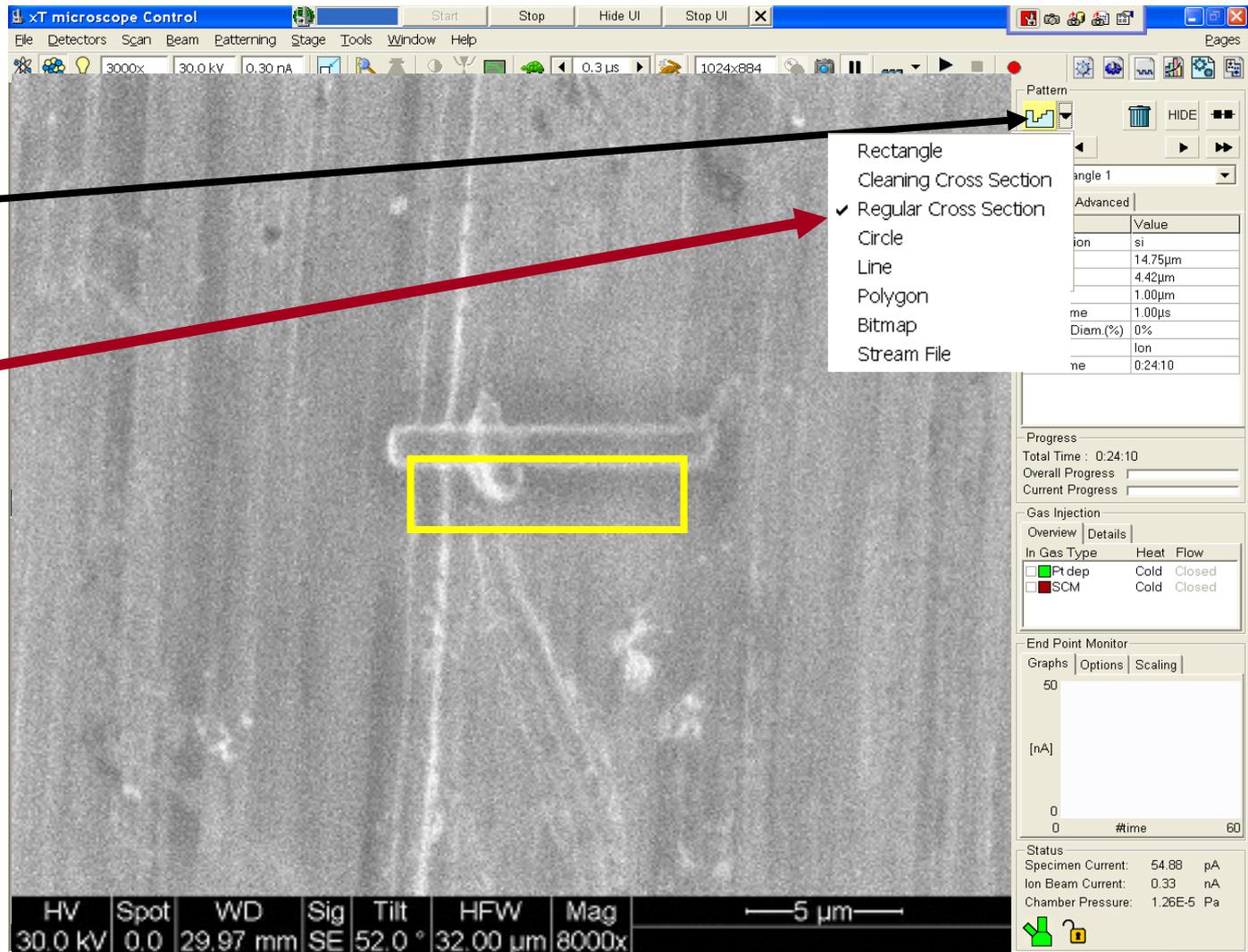
Key

- Metal deposition
- SEM
- FIB
- Sample plane
- Cross section
- Projection of sample plane to SEM image plane
- Projection of cross section plane to SEM plane
- Cross section image surface
- Stage at 0°



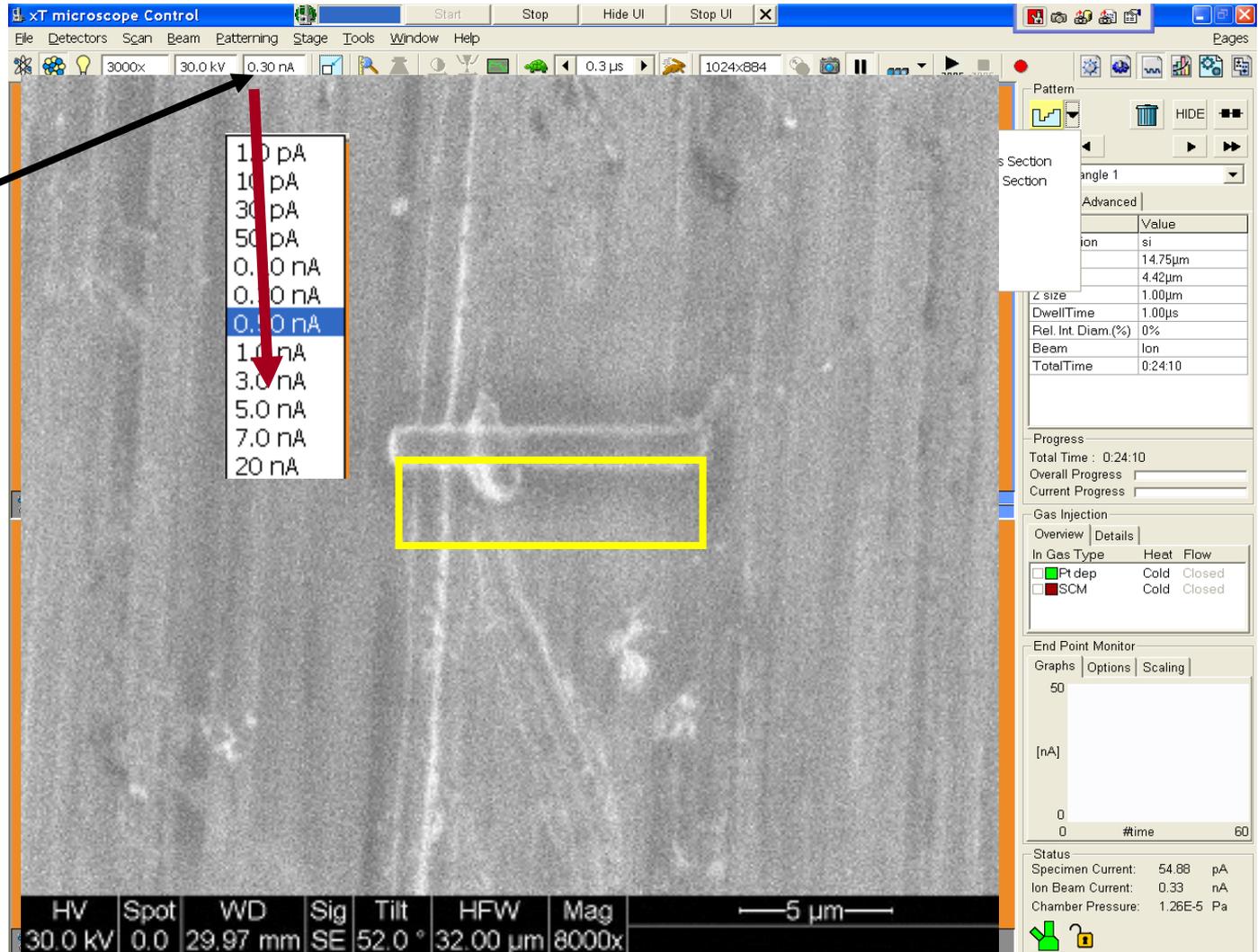
Ion Milling: Basic Step

- Start with “Regular Cross Section”
- Click and draw a rectangular box on the prepared sample
- Align the rectangle just below the Pt.dep area
- Set “Application” to “Si”, as default cutting parameters



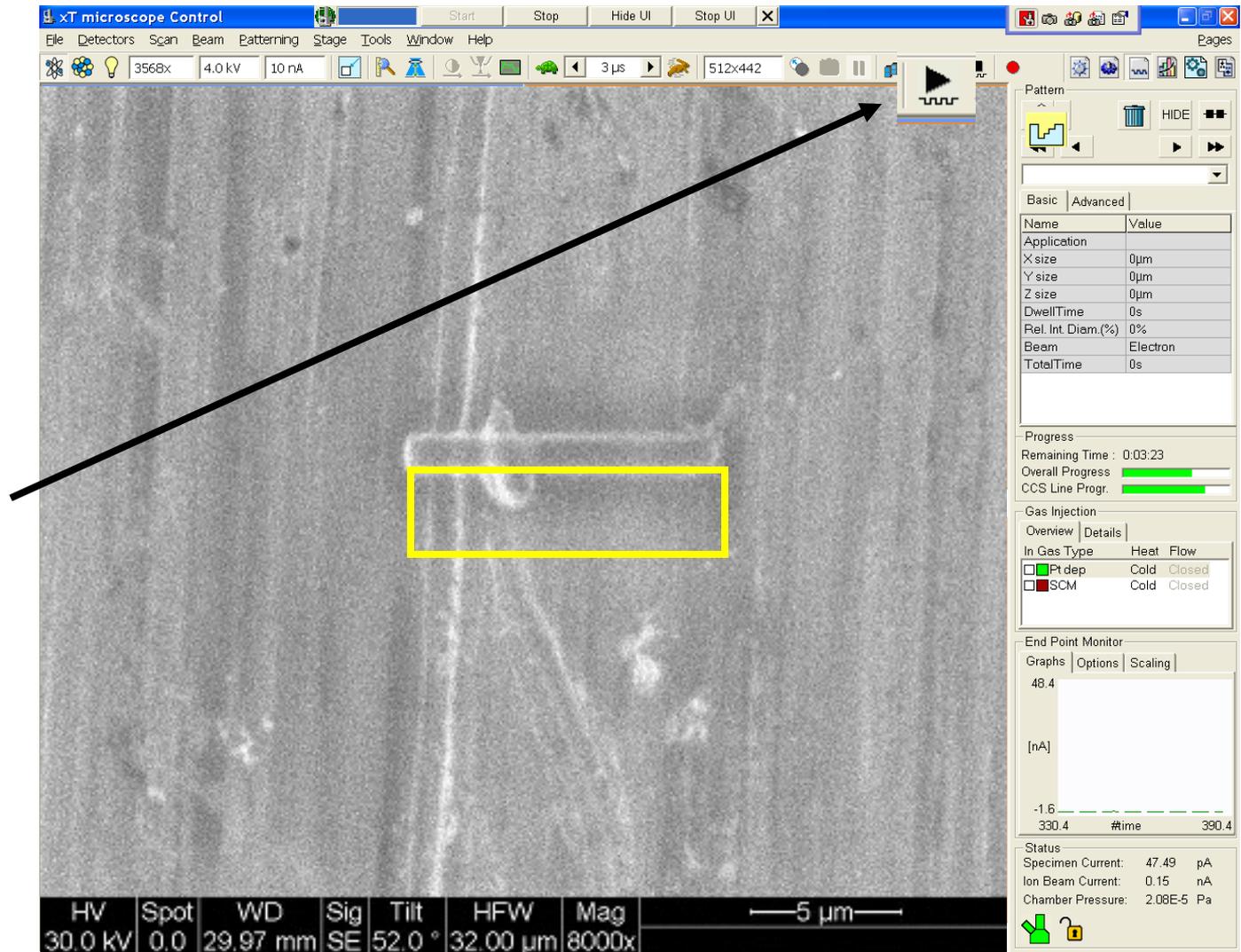
Ion Milling: Ion Beam Setup

- Increase the ion beam current to 5 nA
- Quickly scan and focus (you are milling as you scan)
- Pause as soon as the image is in focus
- Re-align the milling pattern if necessary on the frozen image



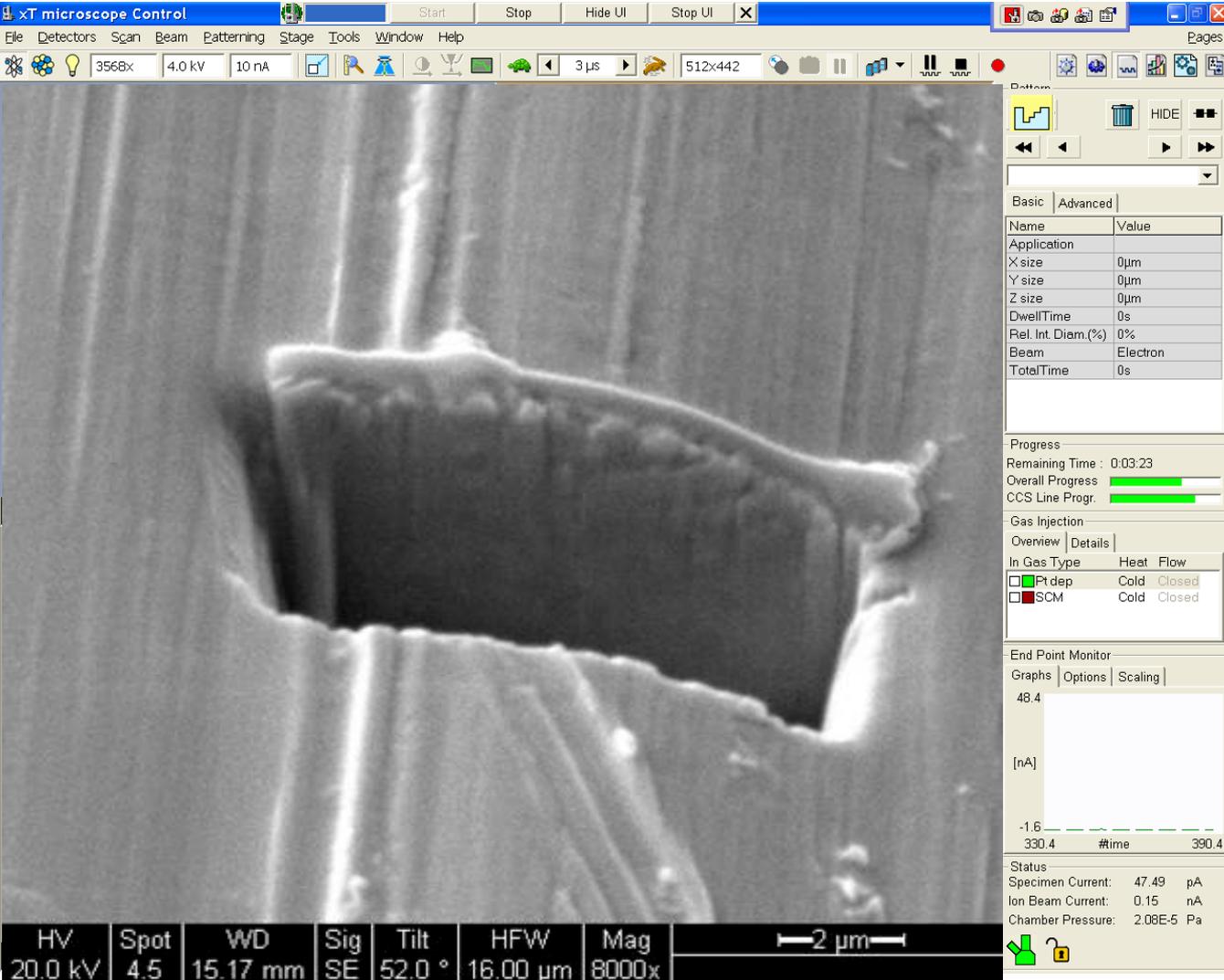
Ion Milling: Milling

- Verify that the rough cross section is 10 X 4.5 X 4 microns deep and aligned just touching the Pt. Dep pattern.
- Start Milling
- If you have a BSD, you may image live in Quad 3 as the sample is milled.



Ion Milling: Progress Check

- Milling has now started
- Note time remaining
- Take a break for that time period (tell your boss its an order)
- If you are curious, click on Quad 1 and then “snapshot”. That will give you a quick SE image of your milling progress



The screenshot displays the xT microscope control software interface. The main window shows a grayscale SEM image of a milled specimen. The interface includes a menu bar (File, Detectors, Scan, Beam, Patterning, Stage, Tools, Window, Help) and a toolbar with various icons. The status bar at the bottom provides technical details:

HV	Spot	WD	Sig	Tilt	HFWD	Mag	Scale
20.0 kV	4.5	15.17 mm	SE	52.0 °	16.00 μm	8000x	2 μm

On the right side, there are several panels:

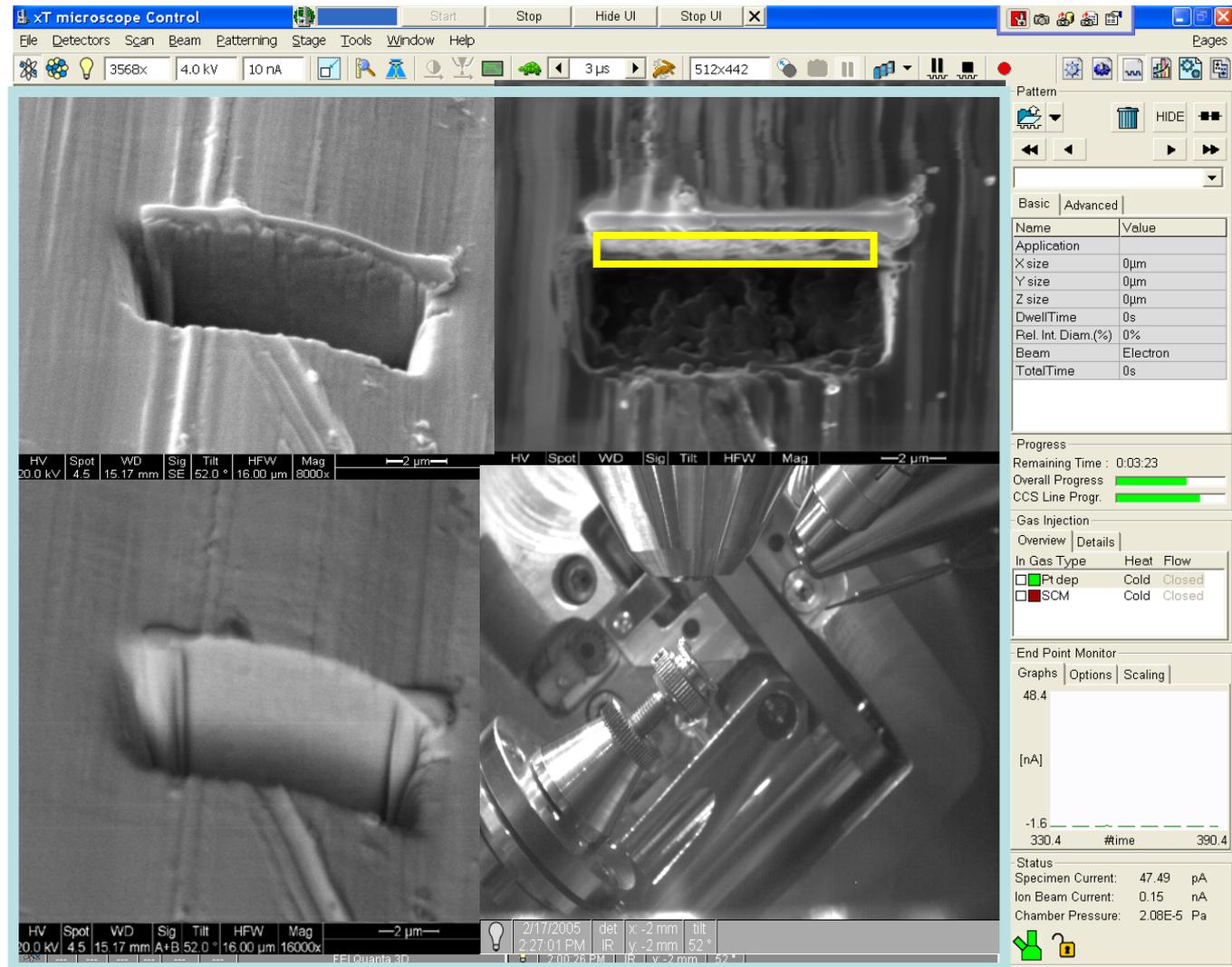
- Basic** / **Advanced** tabs with a table of parameters:

Name	Value
Application	
X size	0 μm
Y size	0 μm
Z size	0 μm
DwellTime	0s
Rel. Int. Diam.(%)	0%
Beam	Electron
TotalTime	0s

- Progress** panel showing Remaining Time: 0:03:23, Overall Progress, and CCS Line Progr. progress bars.
- Gas Injection** panel with Overview and Details tabs, showing In Gas Type, Heat, and Flow settings for Pt dep and SCM.
- End Point Monitor** panel with Graphs, Options, and Scaling tabs, showing a graph of current (nA) vs. time (#time).
- Status** panel showing Specimen Current: 47.49 pA, Ion Beam Current: 0.15 nA, and Chamber Pressure: 2.08E-5 Pa.

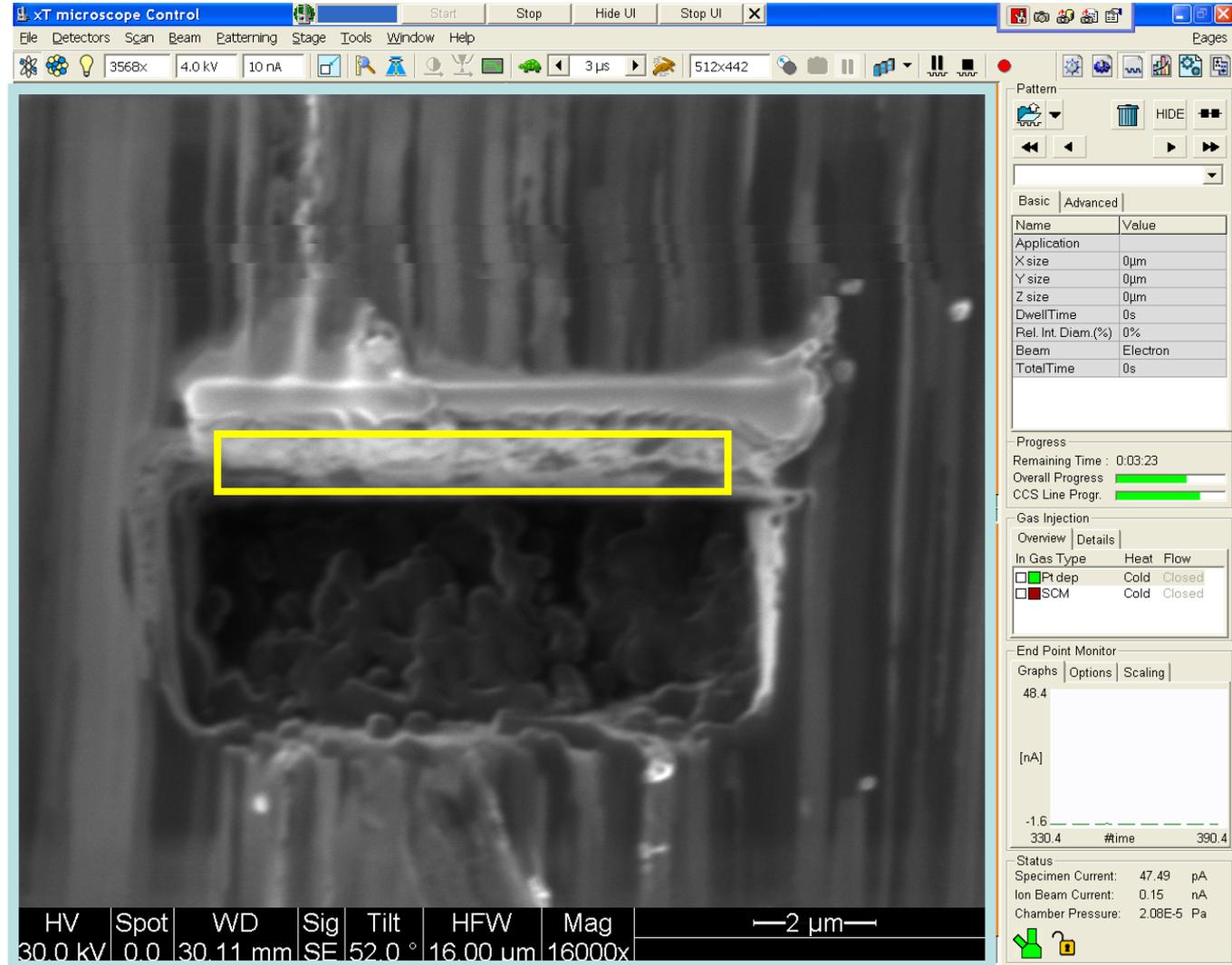
Ion Milling: Cleaning Cut

- View the rough cut with the SEM
- Click on Quad 2 and adjust ion beam current to 0.3 nA
- Select “cleaning cross section” pattern
- Scan and focus with the ion beam and then pause
- Redraw a smaller pattern on the frozen ion beam image
- Use a depth 1/3rd that of the regular cross section
- Start milling

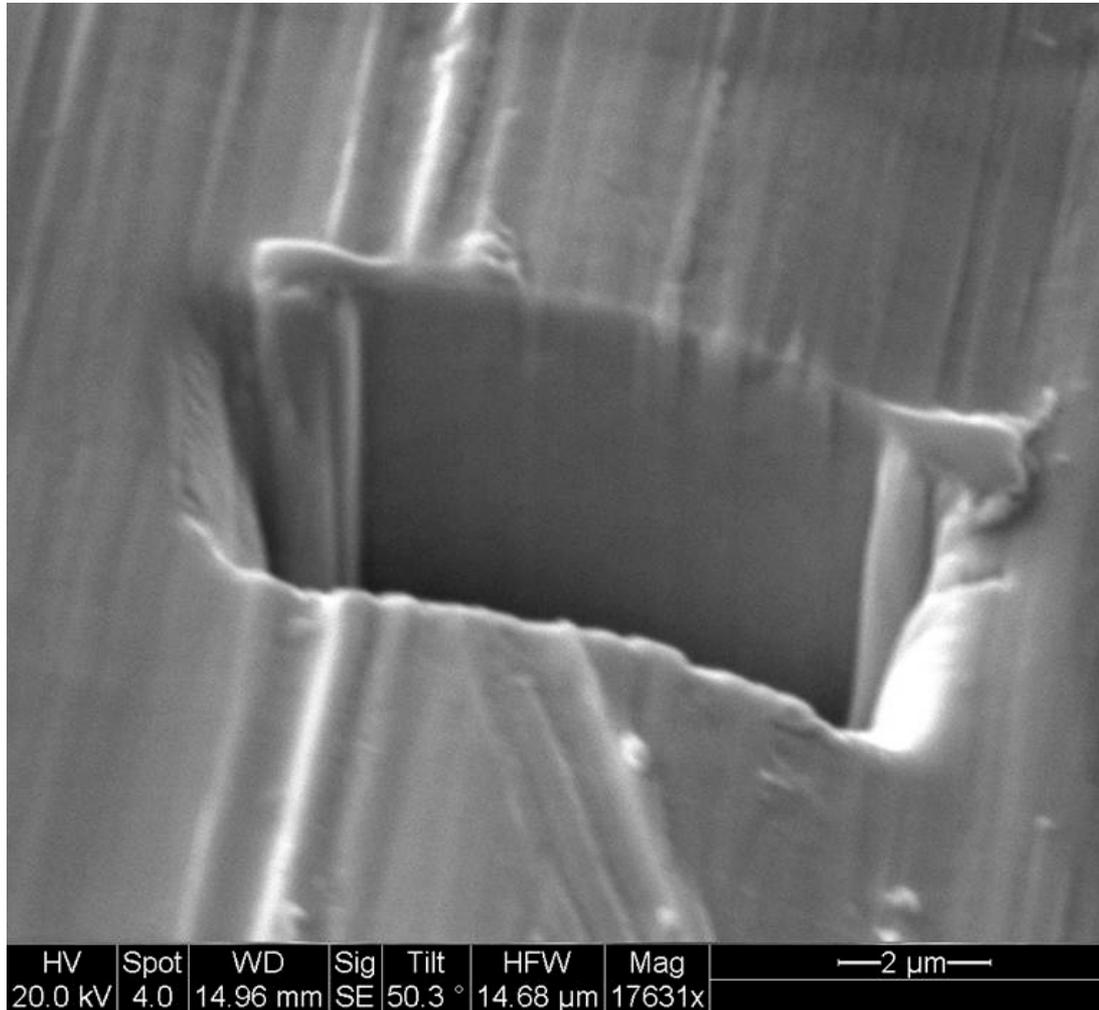


Ion Milling: Cleaning Cut

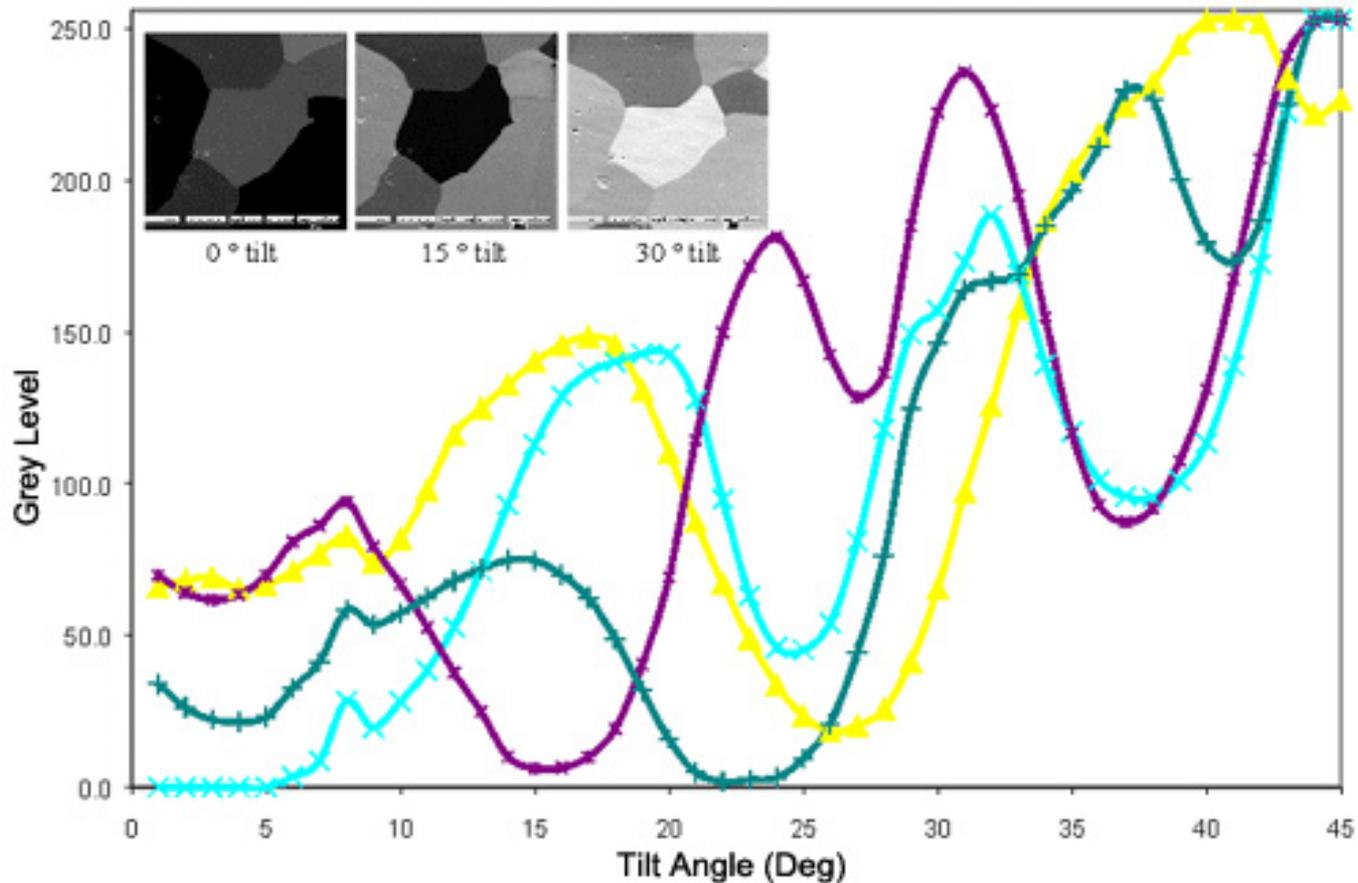
- View the rough cut with the SEM
- Click on Quad 2 and adjust ion beam current down to 50 pA
- Select “cleaning cross section”
- Scan and focus with the ion beam and then pause
- Redraw a smaller pattern on the frozen ion beam image
- Start milling



Ion Milling: SEM Image of the Cut



FIB Grain Contrast



FIB is more than four times as intense as that produced by backscattered electrons in the SEM, and results in spectacular grain contrast, as can easily be seen in the FIB image of aluminum grains in the image.

<http://www.fibics.com/fib/tutorials/Grain-Orientation-Contrast/6/>

FIB Grain Images: W filament

The screenshot displays the xT microscope control software interface. The main window shows a grayscale image of a tungsten (W) filament grain. The interface includes a menu bar (File, Detectors, Scan, Beam, Patterning, Stage, Tools, Window, Help) and a toolbar with various icons. The right-hand control panel contains the following sections:

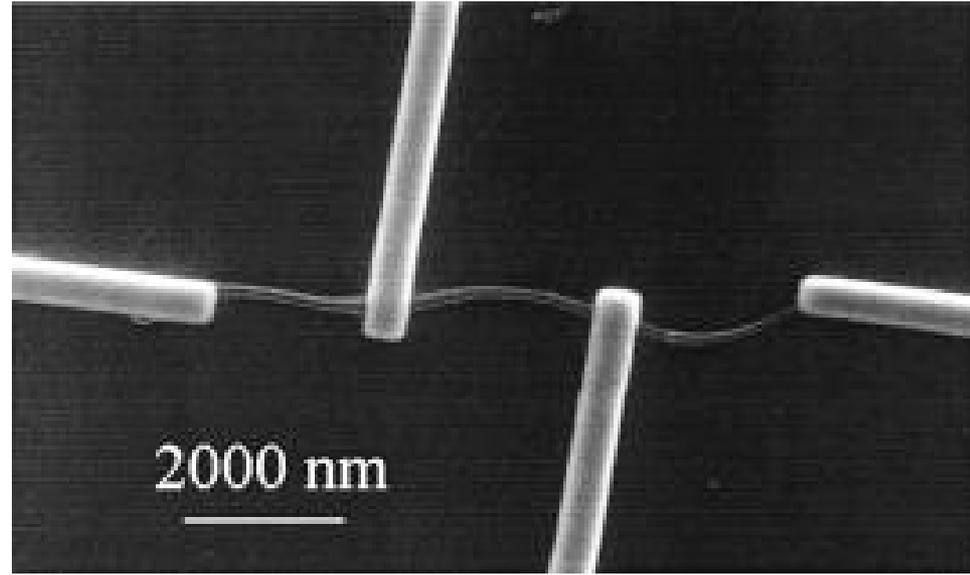
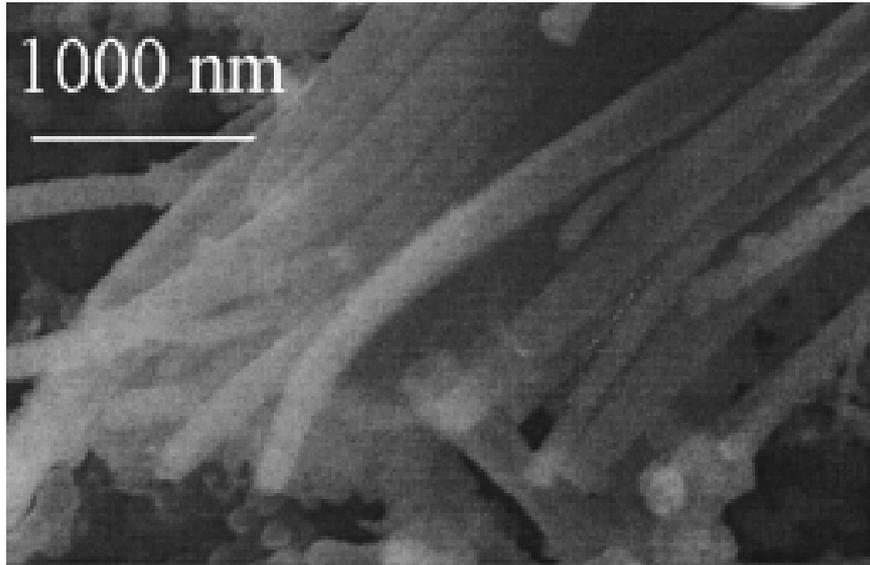
- Stage:** Map, Coordinates, Tilt Correction. Actual coordinates: X: -1.7457 mm, Y: -2.3840 mm, Z: 15.4145 mm, T: 52.0°, R: -20.2°.
- Rotation:** Scan Rotation: 0.0°.
- Detector Settings:** Detector: ETD, Mode: Secondary Electrons, Grid Voltage: 250.
- Detectors:** Contrast: 34.2, Brightness: 50.6.
- Status:** Specimen Current: 49.80 pA, Ion Beam Current: 0.15 nA, Chamber Pressure: 2.08E-5 Pa.

At the bottom of the image area, there is a status bar with the following parameters:

HV	Spot	WD	Sig	Tilt	HFV	Mag	—2 μm—
30.0 kV	0.0	30.09 mm	SE	0.0°	12.80 μm	20000x	

FIB Applications

Electrode Formation for Nanowires



Y. Long et. al, Appl. Phys. Lett. (2003)

Cross Sectional TEM Sample Preparation

