Technologies et Dernières Avancées liées aux Systèmes à Faisceau d'Ions Focalisés

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Paris, 3 Déc. 2010

GN MEBA Réunions pédagogiques

"Colonnes électroniques et ioniques - Détecteurs spécifiques associés : Etat de l'art présenté par les constructeurs"

Introduction - What a FIB system can do

Remove Material (2,3)

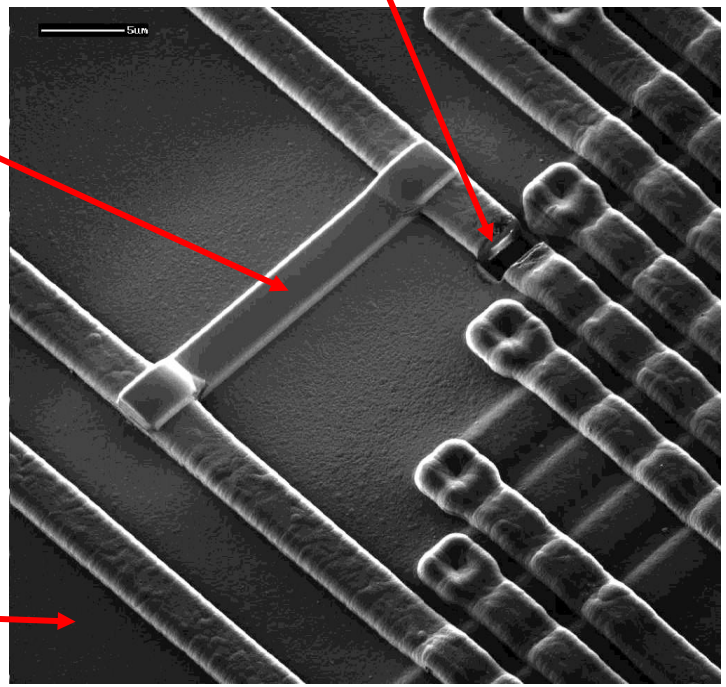
- Sample is sputtered where the FIB is scanned, sometimes with a reactive gas

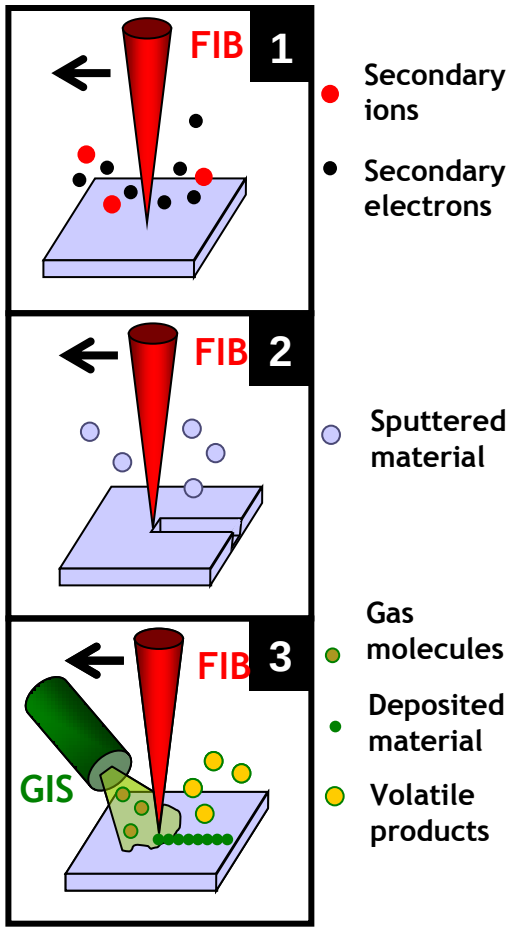
Add Material (3)

- A gas is decomposed where beam is scanned

Form an Image (1)

- Secondary electrons or ions are collected to assemble an image





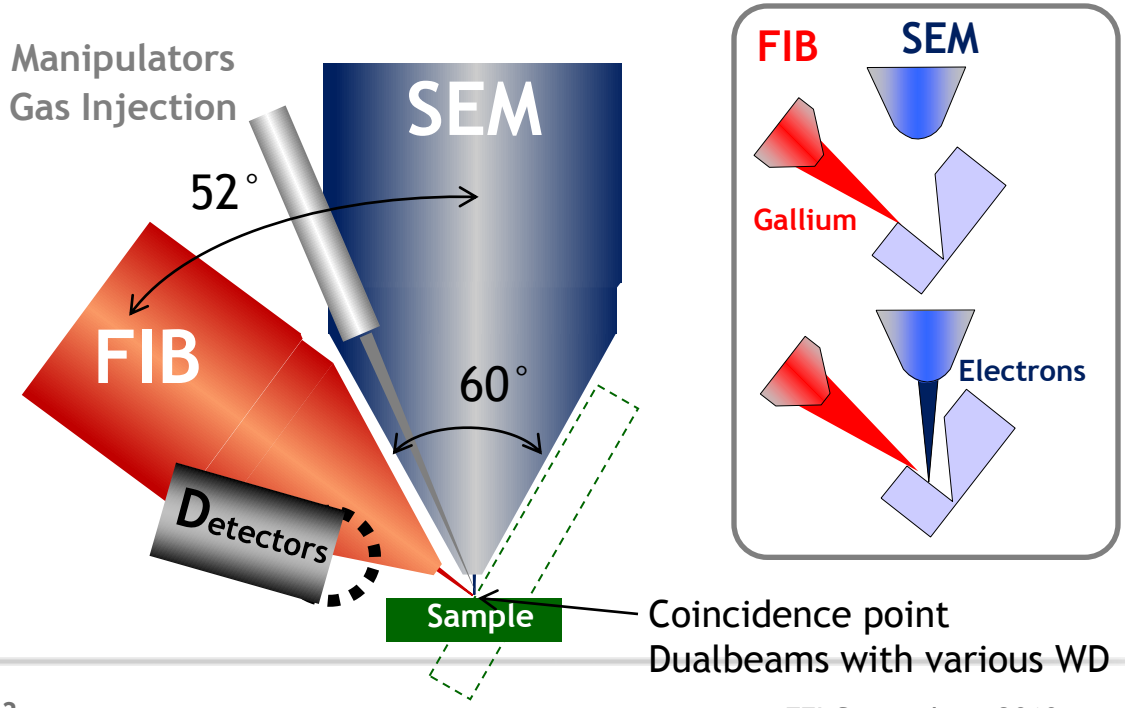
FEI Systems using FIB columns

- FIB system ("single beam")
- FIB column add-on to analysis (SIMS, Auger) or other system (e.g. MBE – molecular beam epitaxy)
- FIB-SEM ("DualBeam™")

FEI V600ACE
(Single Beam FIB)

FEI Magnum
FIB add-on

FEI Helios NanoLab
(DualBeam – also Quanta 3D/FEG)

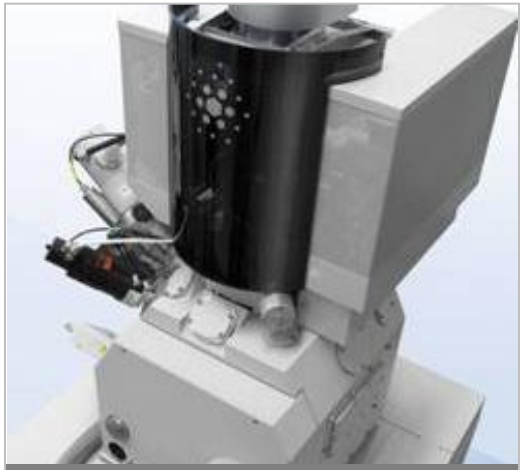


Coincidence point
Dualbeams with various WD

The FEI DualBeam Family 2010

Quanta 3D 200i

Quanta 3D FEG



Helios NanoLab

Basic analytical SDB	HR Analytical SDB	UHR resolution SDB
Low vac / ESEM capable tungsten SEM	Low vac / ESEM capable high current FEG SEM	High resolution immersion FEG SEM
High current & low voltage FIB	High current & low voltage FIB	High resolution, ultra low voltage FIB
General purpose	High resolution, long WD for dynamic experiments or highly topo. samples	Ultra high resolution and high precision

FEI

FEI FIB & DualBeam

Technologies and applications

Core Technologies (all FEI)

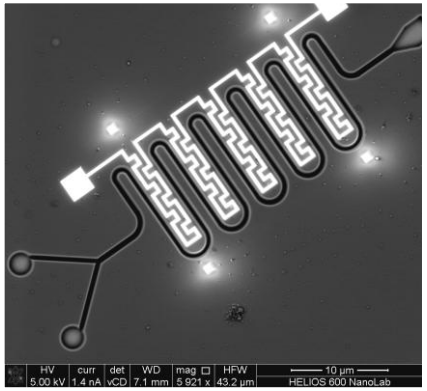
- FIB Source
- FIB Column
- FIB Detection & Imaging
- 16bit scan & Pattern engine
- Gas Injection
- Eucentric stage

Supporting Technologies

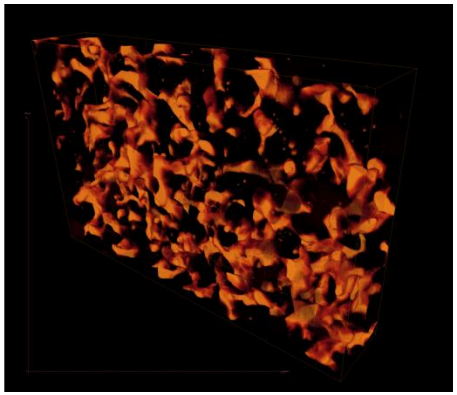
- FIB & SEM simultaneous operation
- FIB writing strategies:
  - Minimum redeposition
  - Writing on charging specimens
- Tools for
  - Sample preparation
  - Automated FIB sectioning (for SE, BSE, EDS, EBSD data collect)
  - Prototyping
  - Customized operation and automation

Application examples

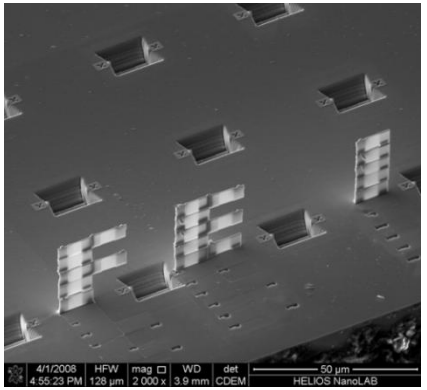
Sample preparat
(here thin sample for S/TEM))



3D prototyping
(here fluidic channel with heater)



Automated 3D sectioning
(fuel cell, court. U. Sabanci)



Custom task automation
(here of sample prep)

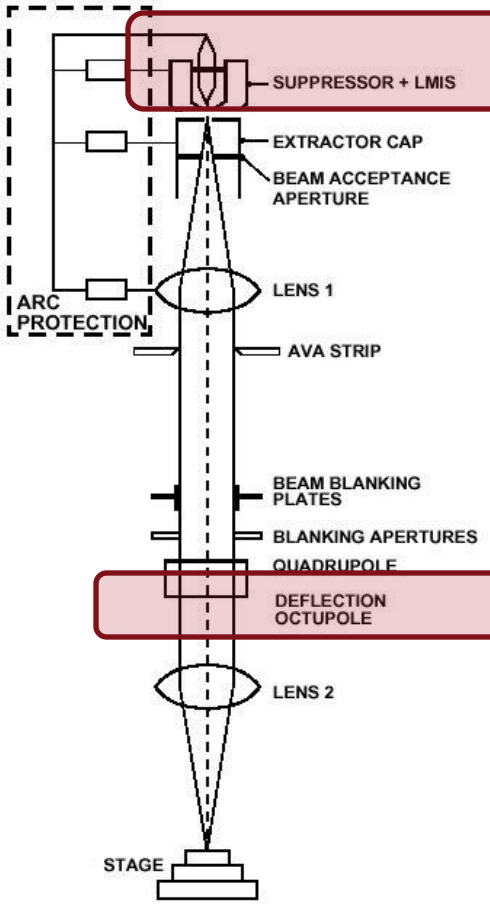
Les Faisceaux d'Ions Focalisés FEI

Technologies de source, colonne et d'imagerie ionique

1. Présentation de la dernière génération de colonne à faisceau d'ions focalisé FEI (Tomahawk™, lancée en 2009-10) : principe et spécificités
2. Comment améliorer et évaluer la performance d'une colonne à faisceau d'ion focalisé
3. Principe et specificités du détecteur ICE pour l'imagerie en électron ou ion secondaire
4. Une génération nouvelle et alternative de faisceaux d'ion focalisé FEI: le Plasma FIB

Introduction to FEI latest FIB Technologies

General optics and specificities



Ion source Ga LMIS **Plasma Source**

optics (model) for operation at high/low kV and high currents

Time-of-Flight (TOF)

SEM / FIB sequential and simultaneous operation

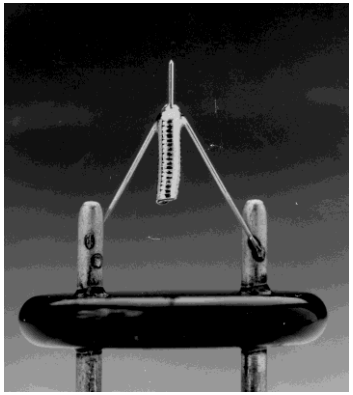
General optics of the FEI Magnum FIB

FEI Tomahawk™ FIB specificities

New: Plasma FIB

Liquid Metal Ion Sources (LMIS)

Why is Ga still the favorite material for LMIS?



FEI Ga LMIS

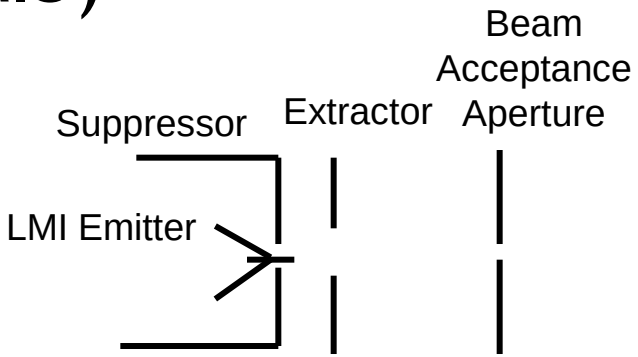
- Desirable properties for LMIS material
  1. Low Melting point (easy to operate)
  2. Low vapor pressure at the melting point (lifetime, beam size)
  3. Slow to oxidize (lifetime, stability)
  4. Non-reactive in liquid phase (lifetime, stability)
  5. Wets materials which can easily be fabricated into substrate emitter (stability)
- How does Ga fit?
  1. Ga melting point 29.8°C but boiling point is 2204°C
  2. Vapor pressure at 450°C is only 10^{-11} mm HG!!!
  3. Wets tungsten easily and is non-reactive with tungsten below 800°C

- Ga is still to date the ideal material for LMIS

FEI

Liquid Metal Ion Sources (LMIS)

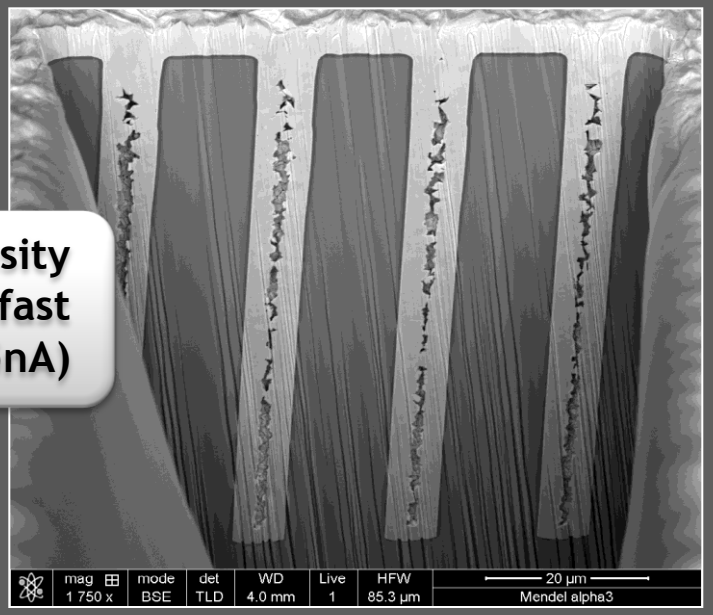
Automating LMIS operation



- Why is LMIS operation important?
  - FIB ease of use
    - in general: no tweaking needed
  - Applications over longer periods: hours, days. Example: preparation of multiple samples, AutoSlice and View (3D tomography)
- **Steadfast™** is an algorithm which provides single pushbutton (On/Off) control of liquid metal ion source (LMIS) operation.
- **Single Pushbutton Operation** is:
  - Start and stabilize emission with 100 % success rate.
  - Maintain emission current inside a user specified window.
  - Heat source as required.
  - Provide user with a warning several hours prior to the source requiring to be heated.
  - Turn off source

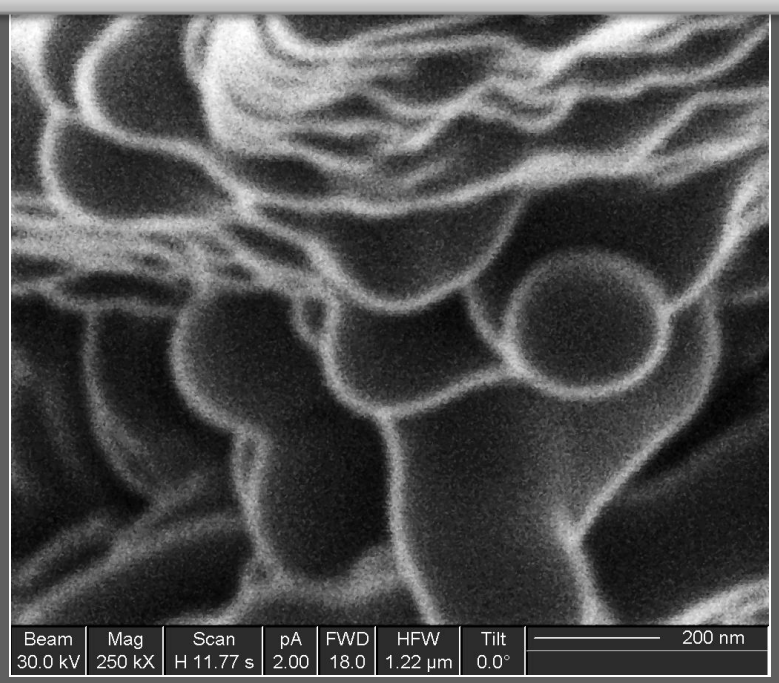
The Tomahawk FIB

Superior beam current density at high currents for fast material removal (up to 65nA)



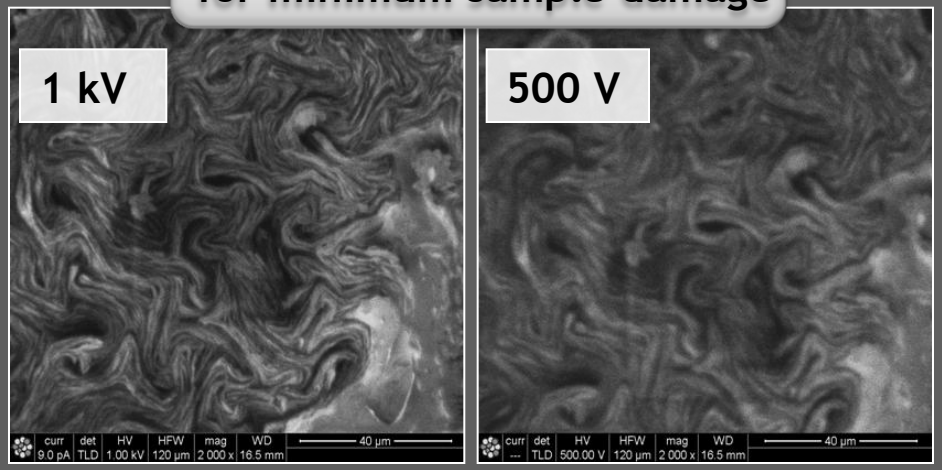
Large FIB cross-sections on TSV

Proven high resolution performance On every system



High resolution 30kV FIB-SE image of graphite

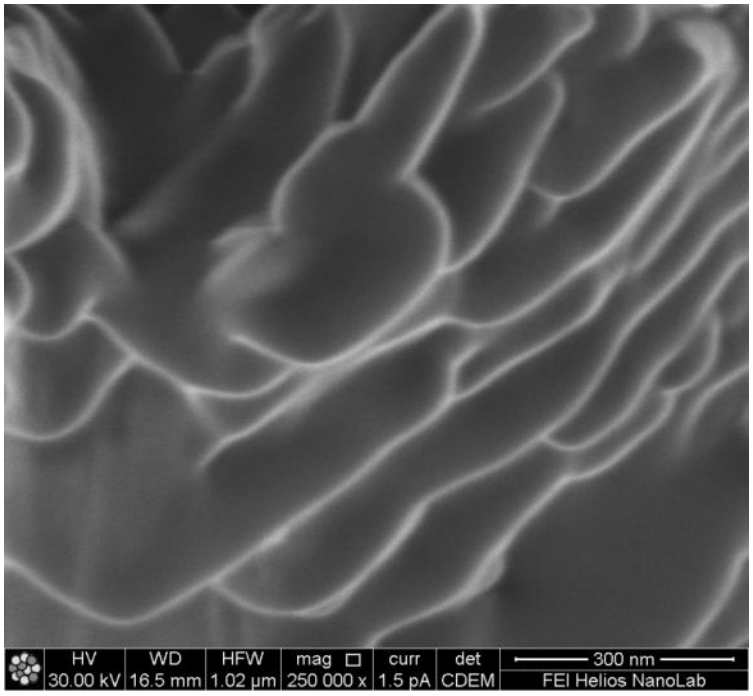
Best low kV performance for minimum sample damage



Low kV FIB-SE images of graphite

Assessing FIB performance

How it is done today – what are the pitfalls?



Tomahawk FIB
Resolution 4.5 nm
What does this number mean?

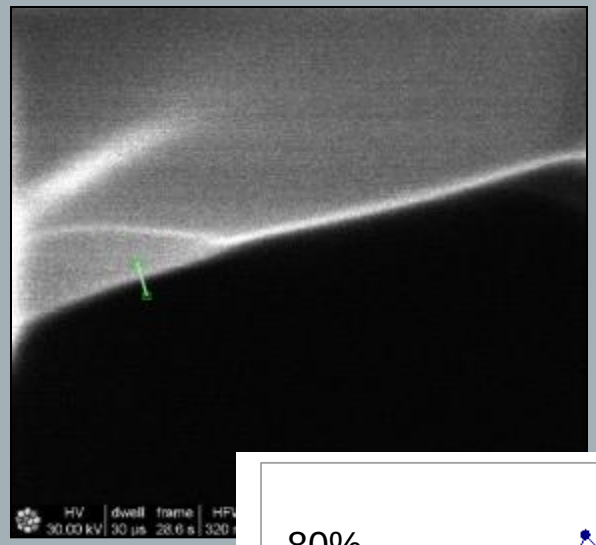
From: Orloff and Roussel, M&M 2010

- **Beam size is often used as a metric** of FIB performance since image resolution is difficult to measure.
  - It is often measured using the rise distance of the beam across a "knife-edge."
- **Pitfalls** that can result in a significant under-estimate of the beam rise distance:
  - Statistical variations in beam current (beam noise);
  - Beam induced changes in the specimen due to sputtering, ion implantation etc ., that can change the secondary electron yield;
  - Instrumental problems (astigmatism, drift etc)
  - Nature of the knife edge and beam-target interactions.

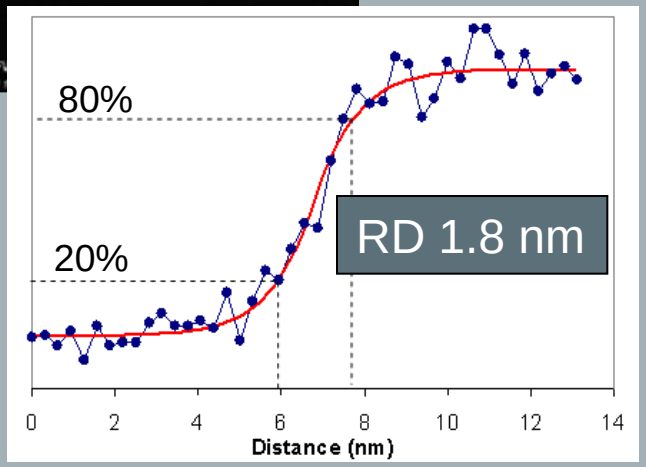
Assessing FIB performance

Measuring resolution using the rise distance method

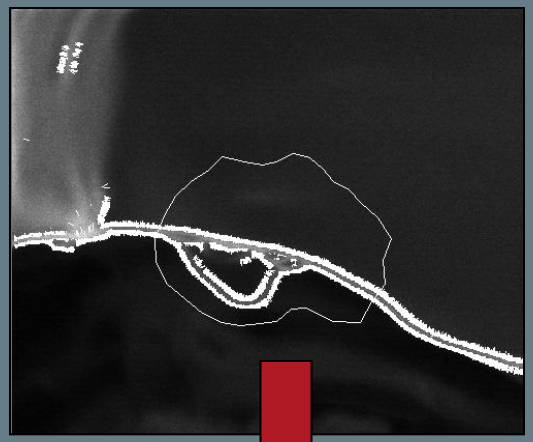
On a single edge



FEI Sidewinder
HFW 320 nm

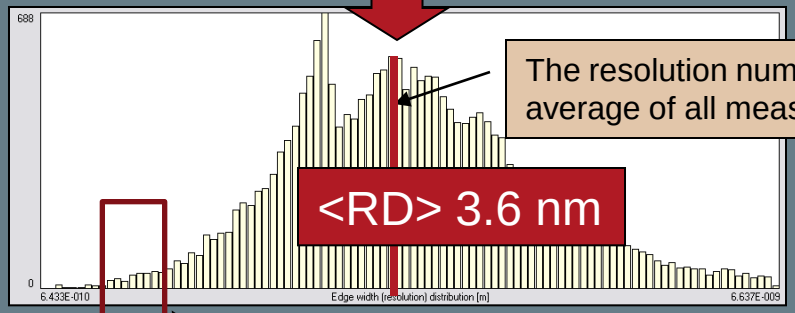


FEI multi-edge statistical method



FEI Sidewinder
HFW 1.02 µm

21,356 edges measured



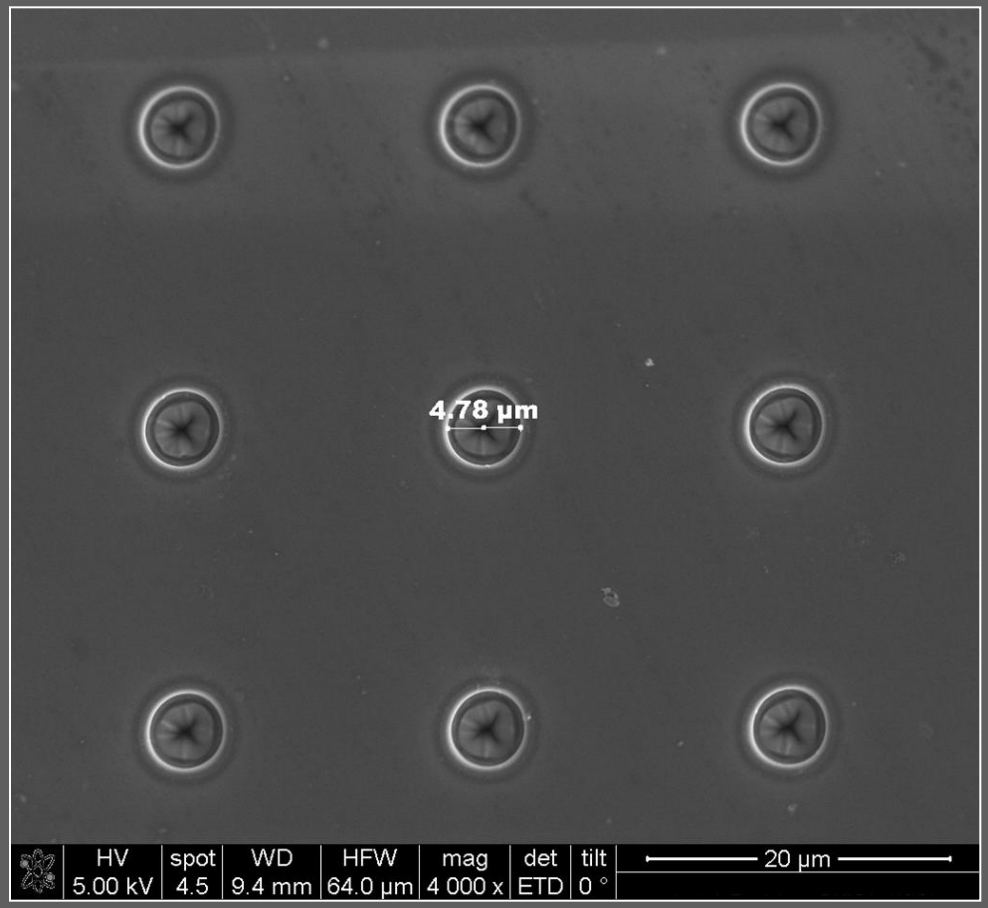
The resolution number is the average of all measurements

Edge distribution graph

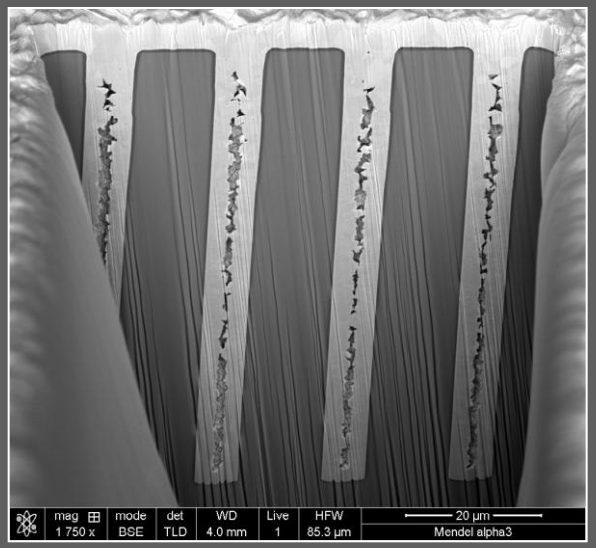
Multiple single edges below RD 2 nm

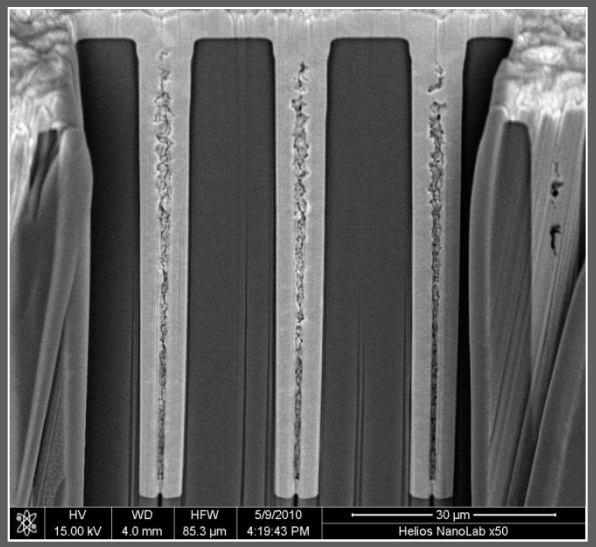
The Tomahawk FIB

Performance at high current



65nA: each spot milled 1 second with a Pitch Size of 20 µm

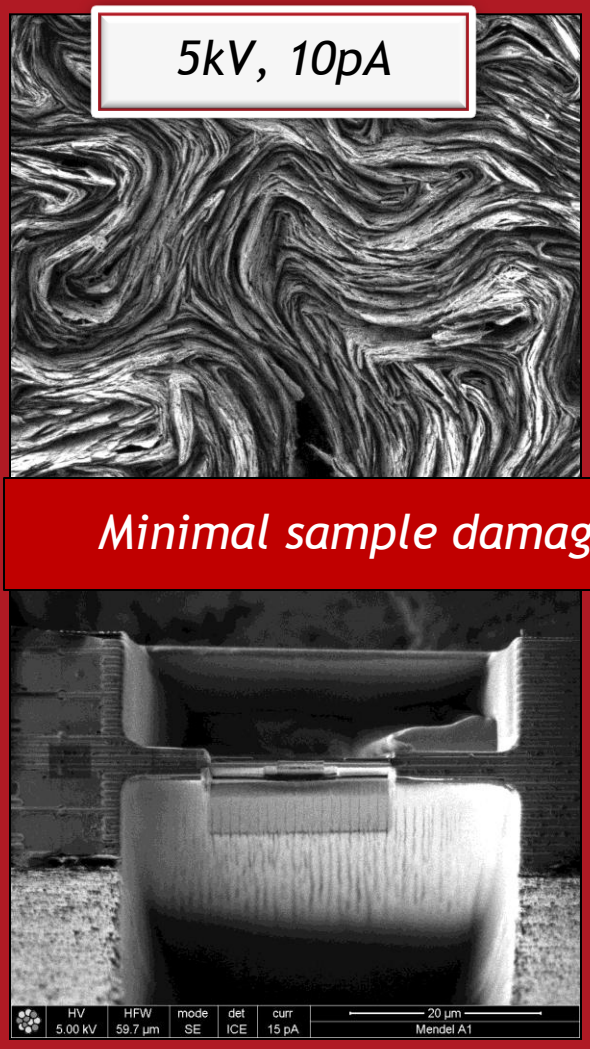


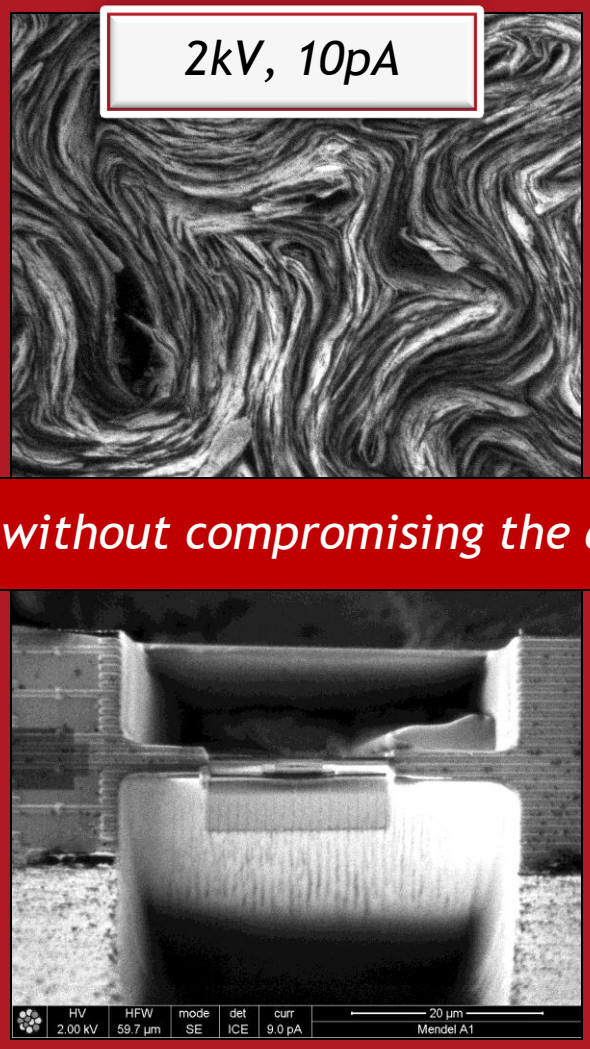


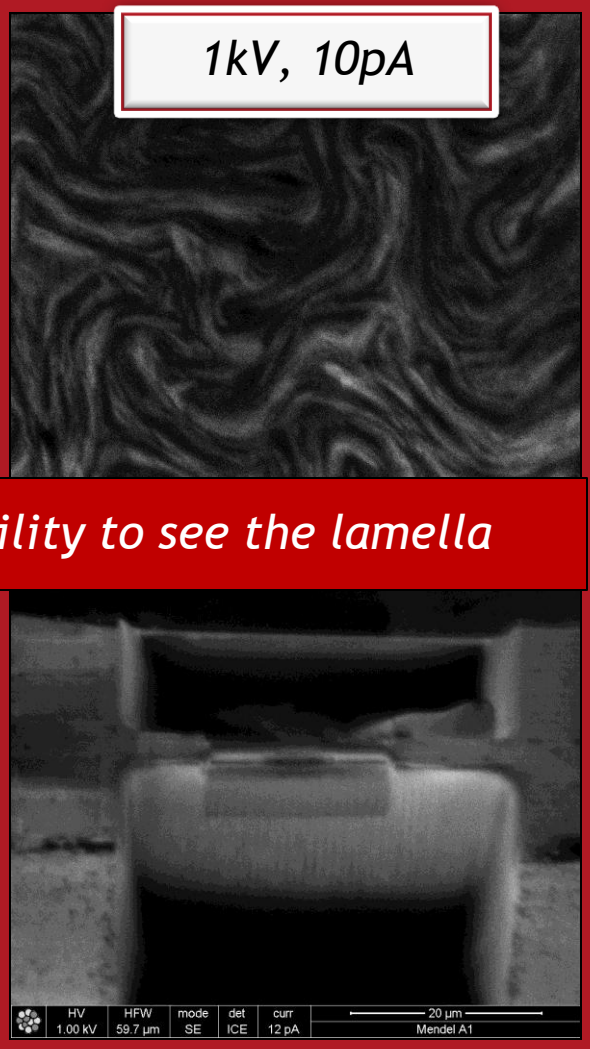
Top: bulk mill - 4 hrs at 65nA
Bottom: edge mill (cleaved sample) - 53 mins at 65nA

The Tomahawk FIB

Performance at low kV



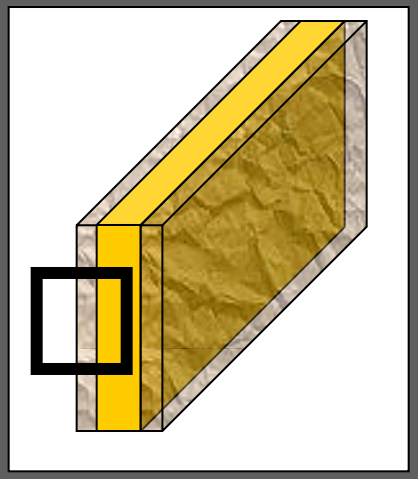


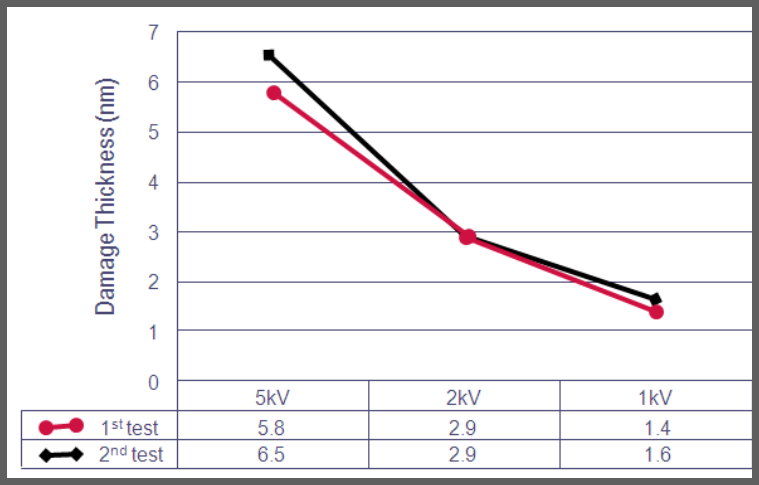


Minimal sample damage without compromising the ability to see the lamella

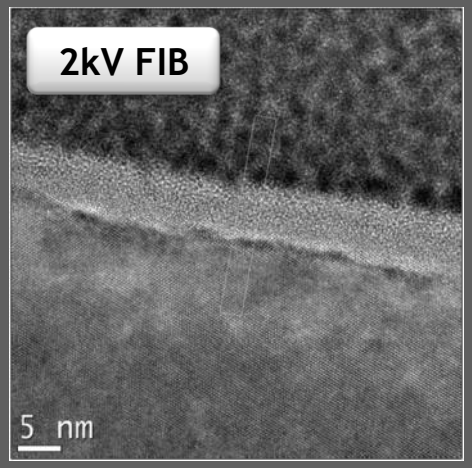
The Tomahawk FIB

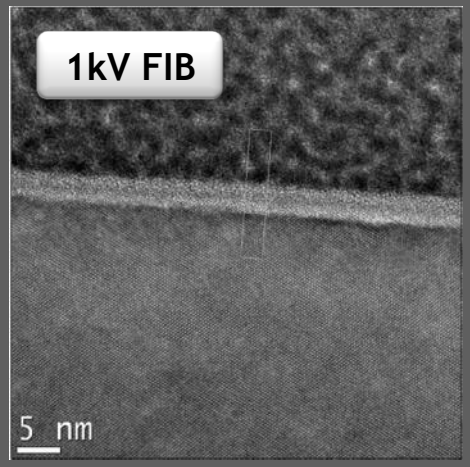
Improved sample preparation quality

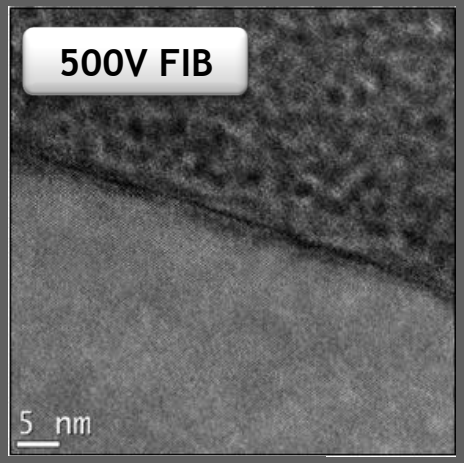


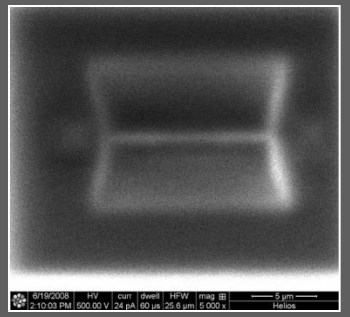


FIB-SE image of the thin sample @ 500V FIB accelerating voltage









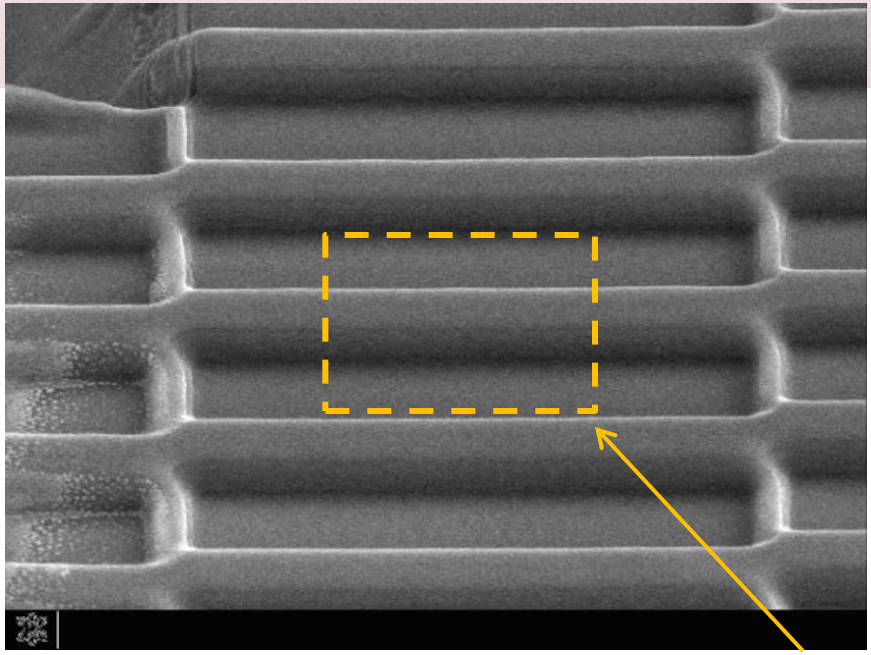
TEM damage thickness evaluation on Si at 2,1 and 0.5kV

FIB & FIB/SEM process monitoring

For FEI FIBs and DualBeams

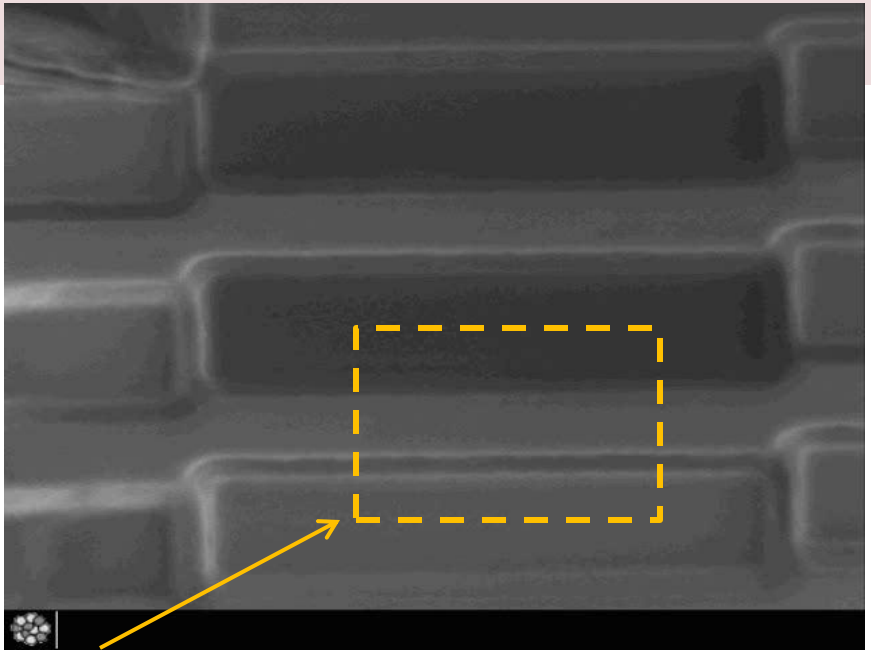
SPI™ & iSPI™

Simultaneous **FIB** milling and **SEM** imaging



iRTM™

Simultaneous **FIB** milling and **FIB** imaging



Same FIB milling area

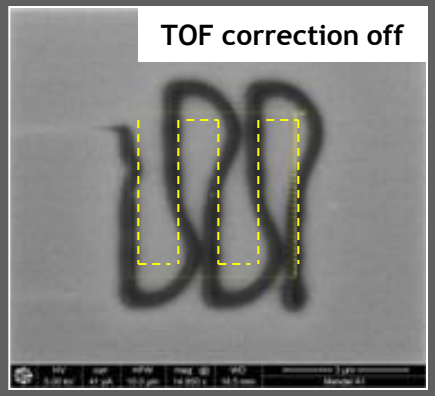
FEI

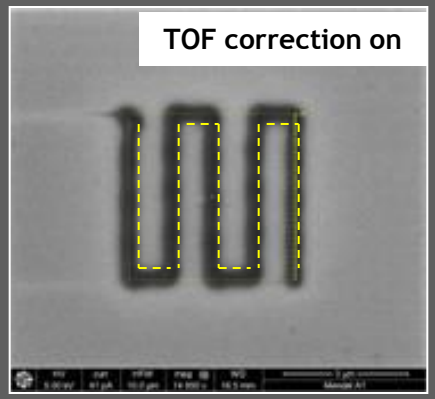
The Tomahawk FIB

Time-of-Flight (TOF) – in practise: more accurate FIB writing

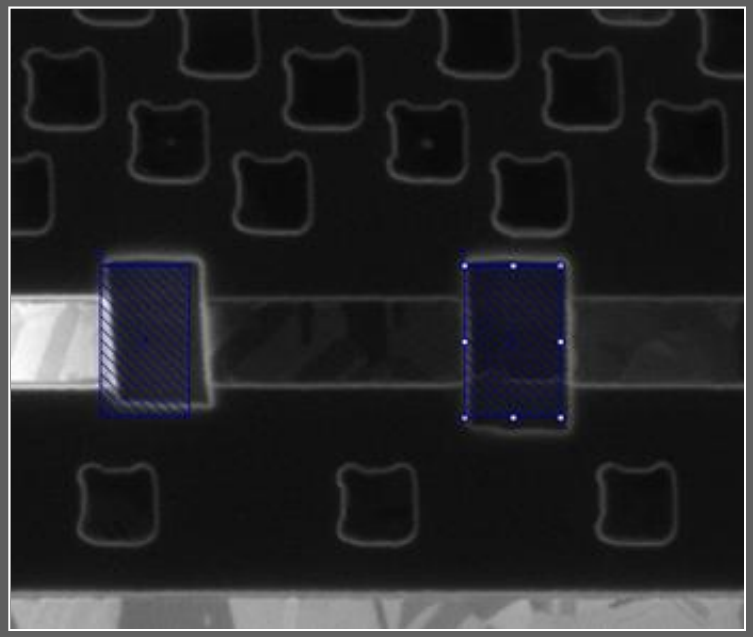
More accurate scan profile, especially with FIB:

- **short dwell times**
  - **operation down to 25ns possible**
- **low kV**





Application example: Cicuit Edit

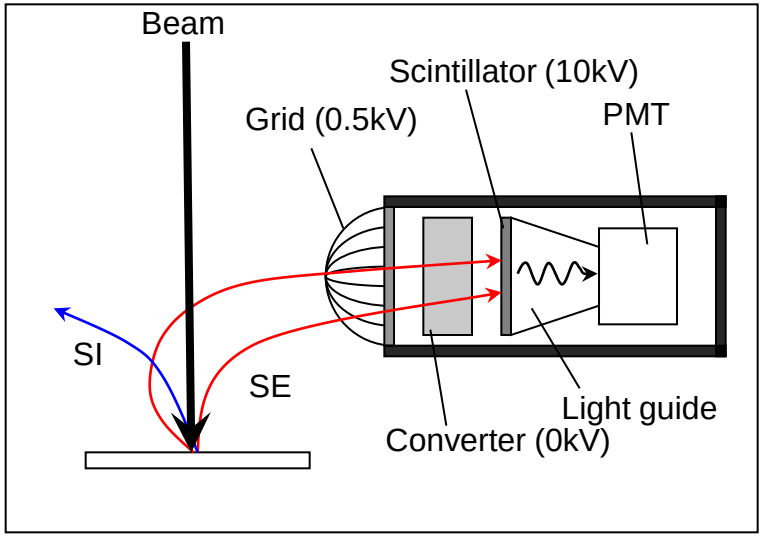


Shrinking nodes and new materials require faster scanning to avoid gas depletion and maintain or improve gas selectivity.
TOF allows faster patterns without pattern distortion

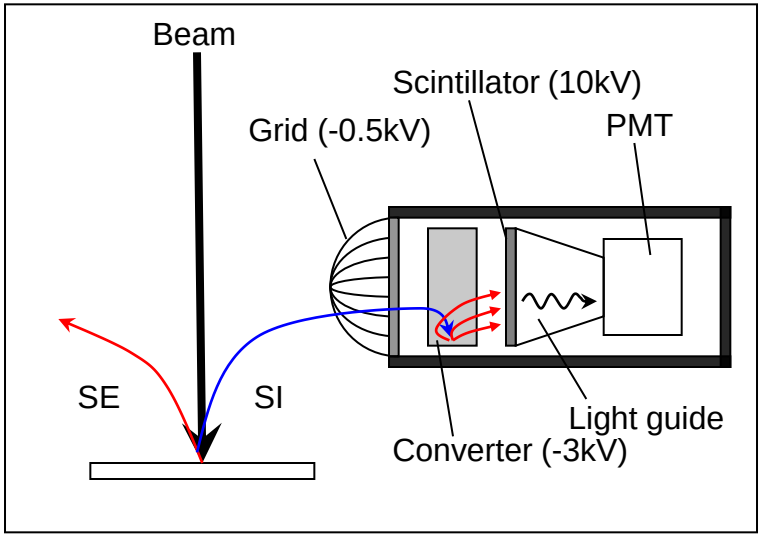
High efficiency FIB imaging

The FEI ICE detector for secondary electron and ion imaging

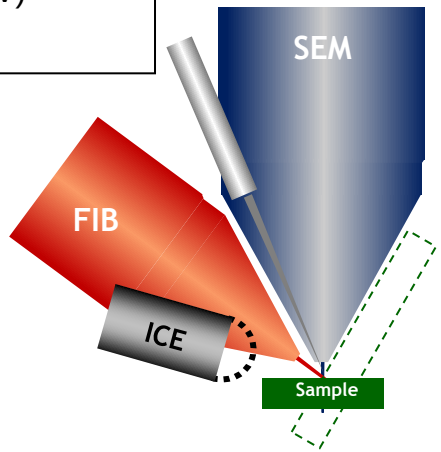
- Patented ICE SE/SI detection modes



Secondary electron mode



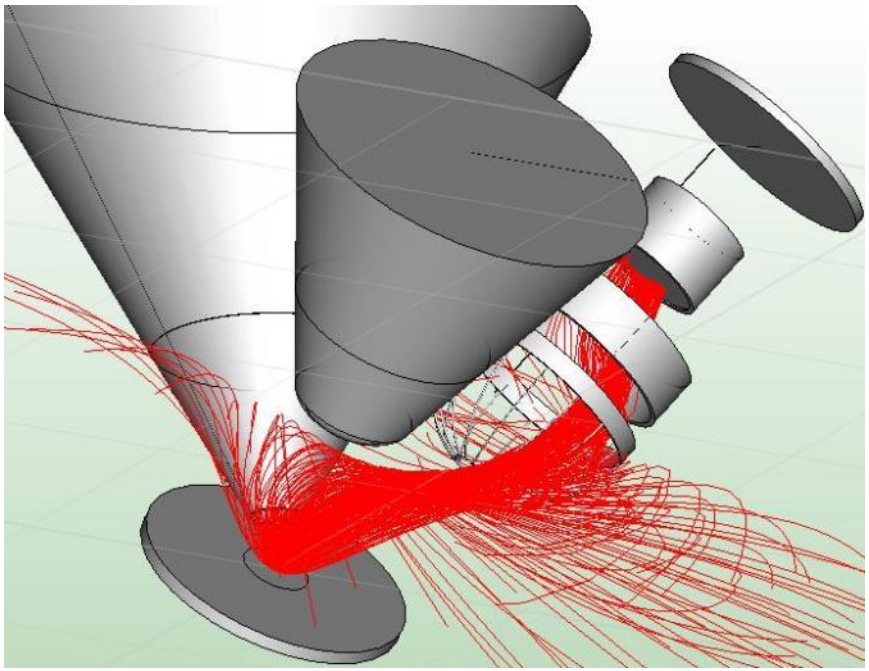
Secondary ion mode



- ICE benefits over its predecessors
  - -Higher collection efficiency (optimized by 3D modeling)
  - -Longer lifetime (no channeltron used for amplification)

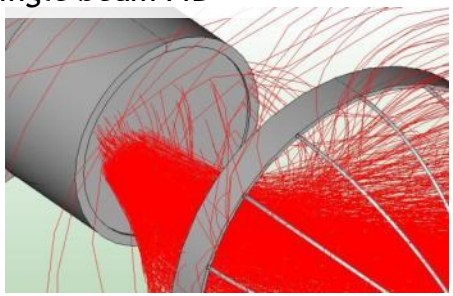
High efficiency FIB imaging
ICE detector – collection efficiency modeling

- The collection efficiency simulations have been carried out using a model which was successfully applied to numerous systems in the past
- Calculations have been performed for both SDB and V600 systems, where ICE1 was placed at the same location as the CDEM
- ICE1 post-grid optic has been carefully optimized to enable efficient transport for all particles (SE, SI, and SE which result from SI conversion at the converter)

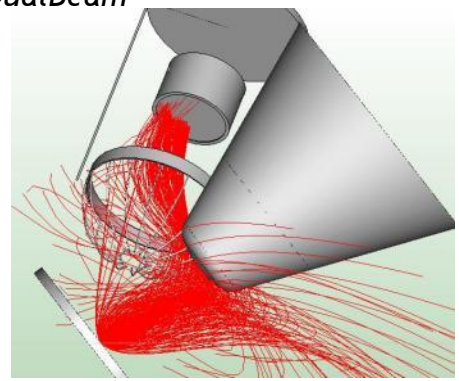


Electron trajectories (250) emitted at 2.75eV and all angles in SDB. The detector shield is hidden for visualization purposes.

Single beam FIB

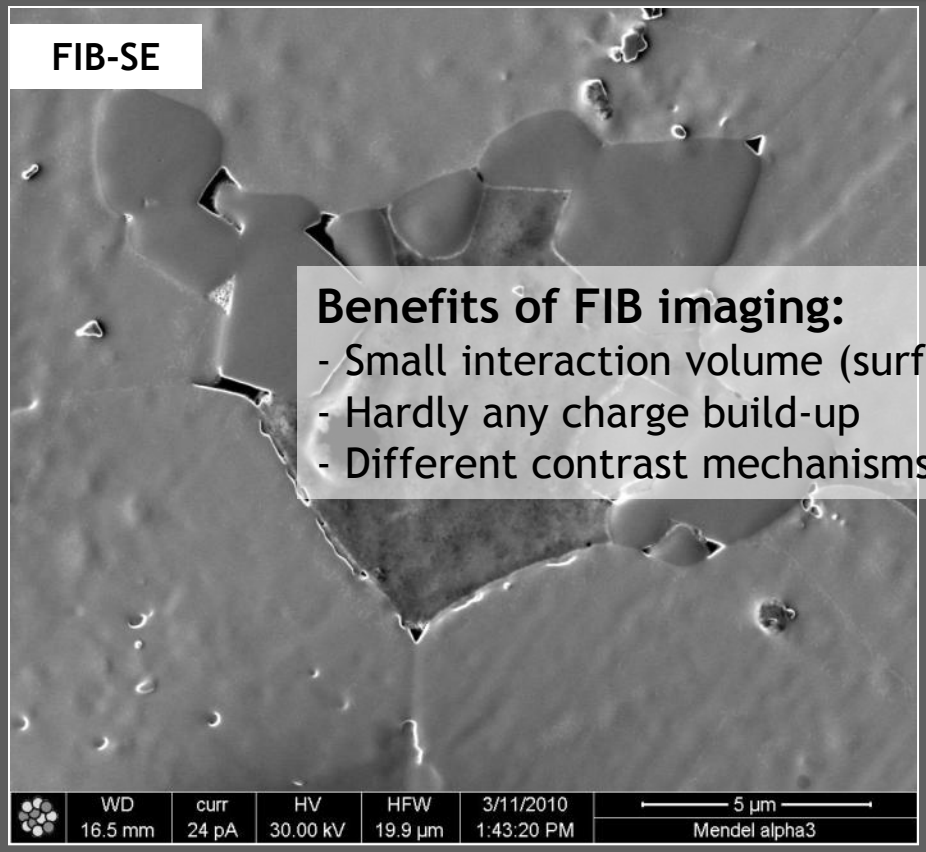


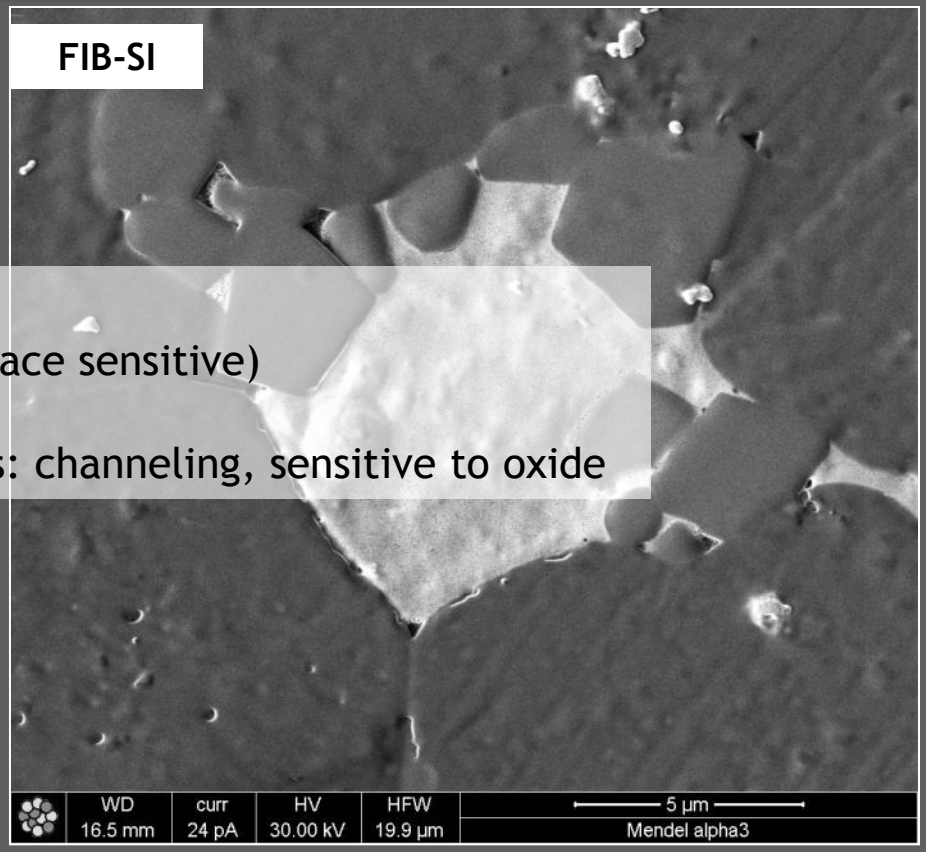
DualBeam



High efficiency FIB imaging
ICE detector – performance improvement and example

Improved performance for FIB-SE and especially FIB-SI imaging



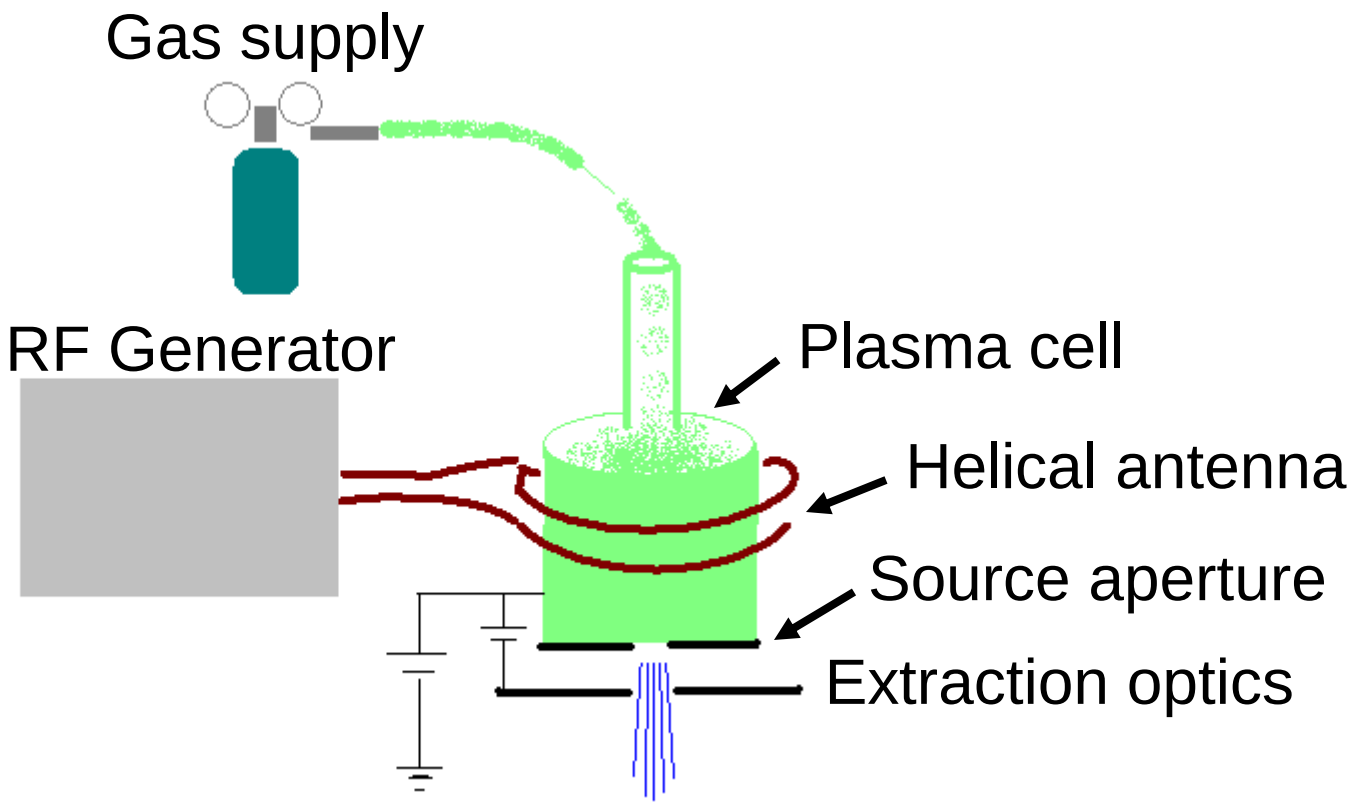


Benefits of FIB imaging:
- Small interaction volume (surface sensitive)
- Hardly any charge build-up
- Different contrast mechanisms: channeling, sensitive to oxide

Zinc oxide + inclusions (Sample courtesy of E. Olsson - Chalmers)

New FIB / ion source in the works

Inductively Coupled Plasma Ion Source

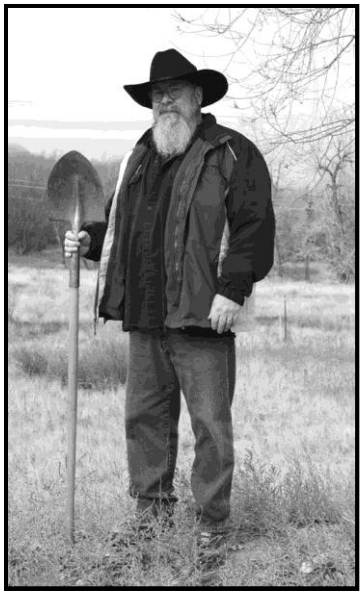


Other species can be though of:
He, Ne, Kr, Ar, Xe, N_2, H_2, O_2, Cl_2…

From: N. Smith et al, JVST 2006

New FIB / ion source in the works

What problems is Plasma FIB designed to solve?



LMIS FIB

Large Volume Removal

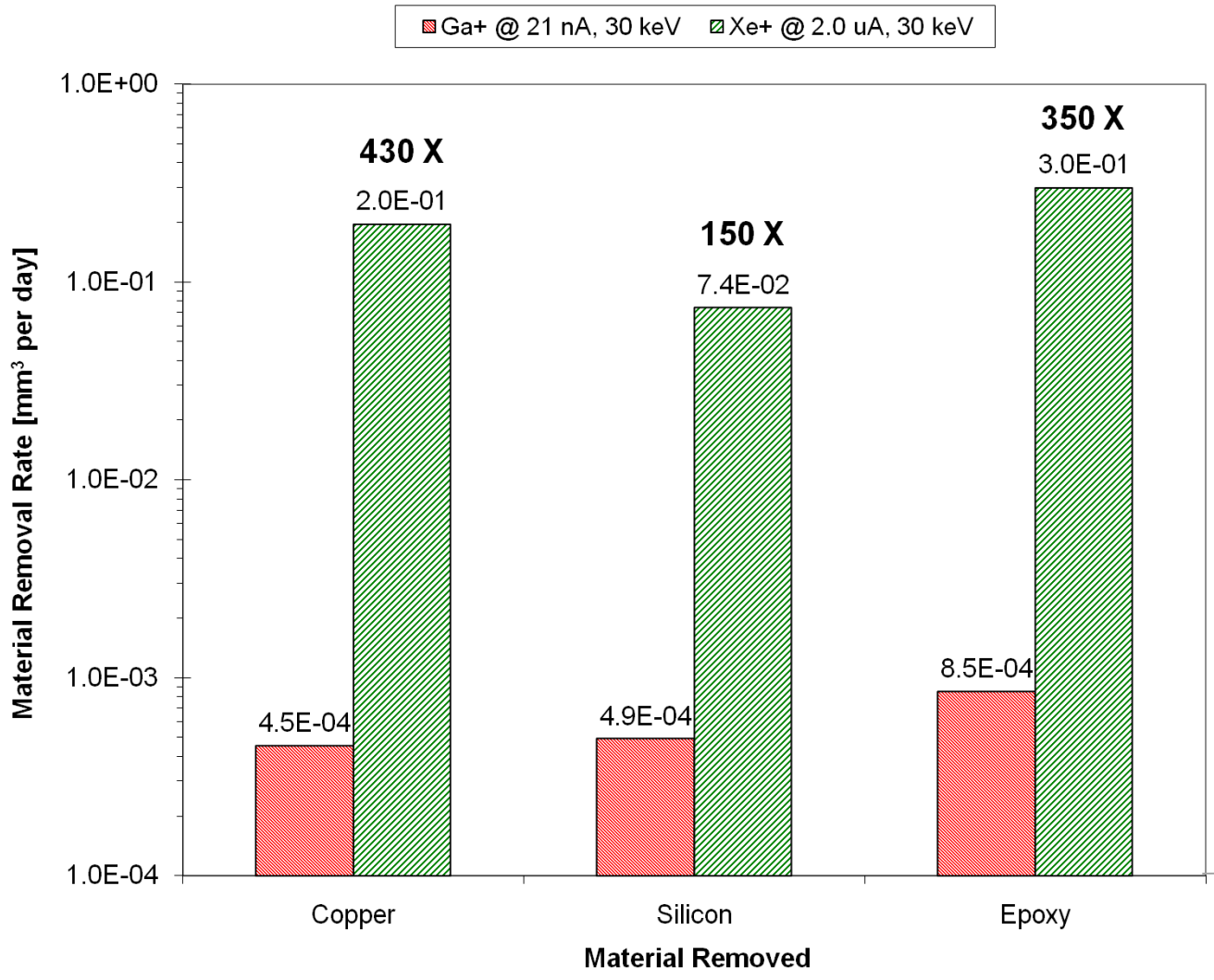
Plasma FIB

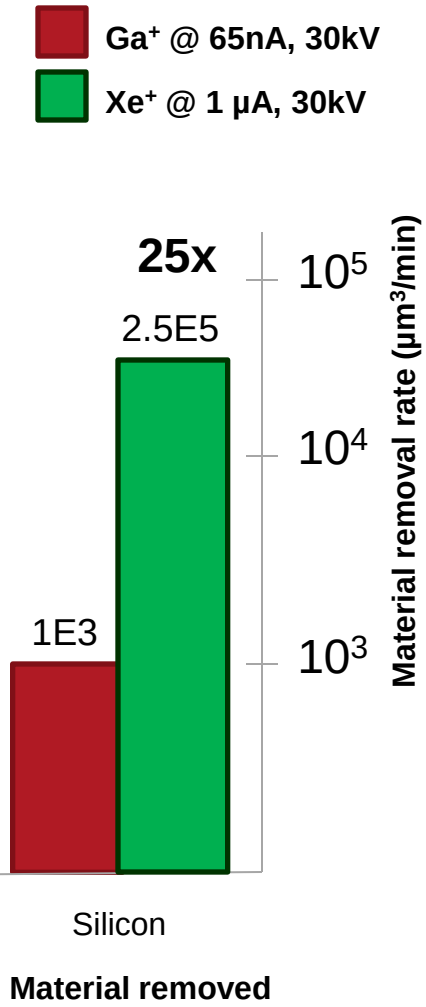
~ 20-65 nA — ~ 20X → ~ 1 µA

A system that provides unique and fast ion milling capabilities for rapid cross sectioning of features from 50 to 1000 microns.

FEI

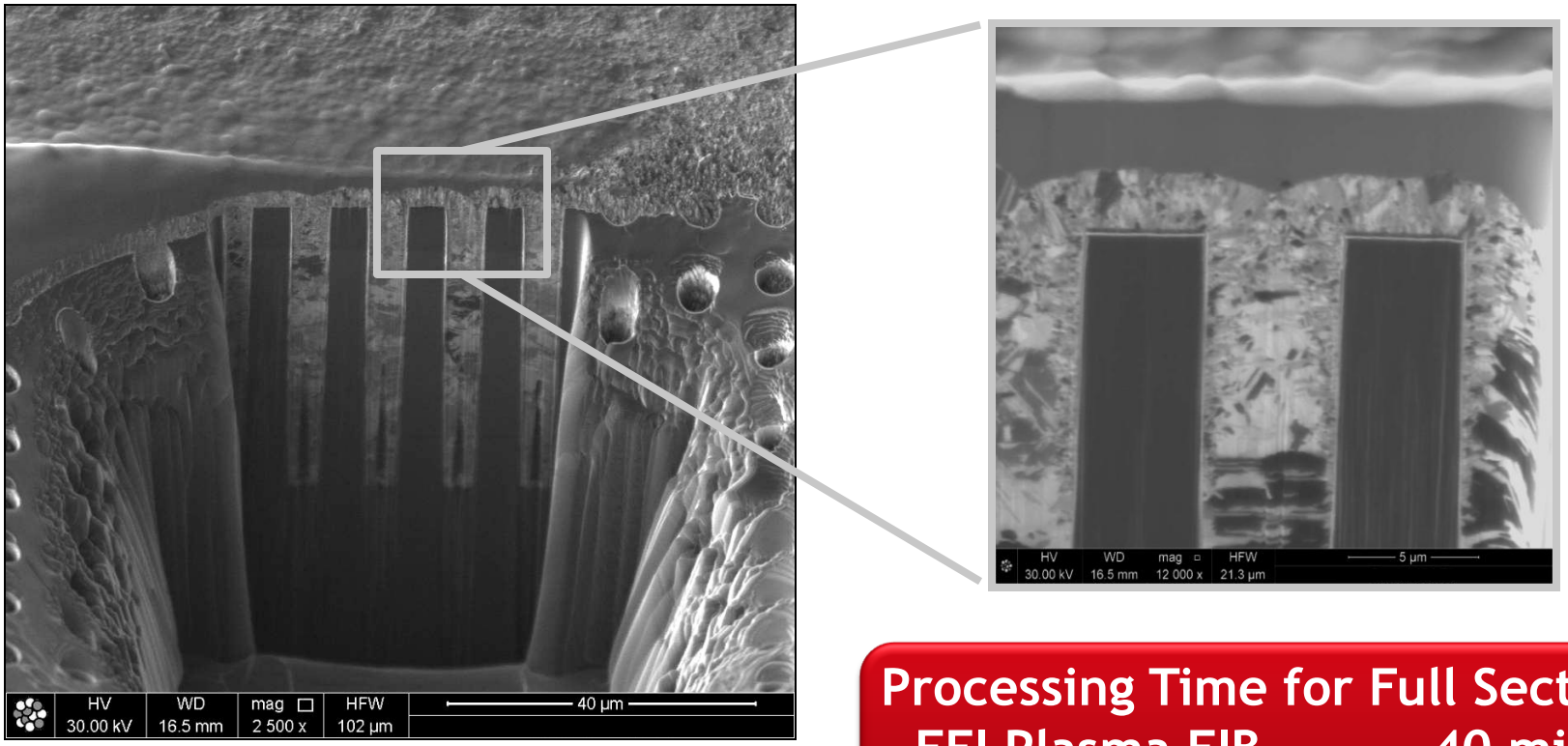
Relative Material Removal Rates - LMIS FIB vs Plasma FIB
Normal Incidence without Gas Chemistry





High throughput TSV analysis

Located, cross-sectioned, polished, imaged with Plasma-FIB



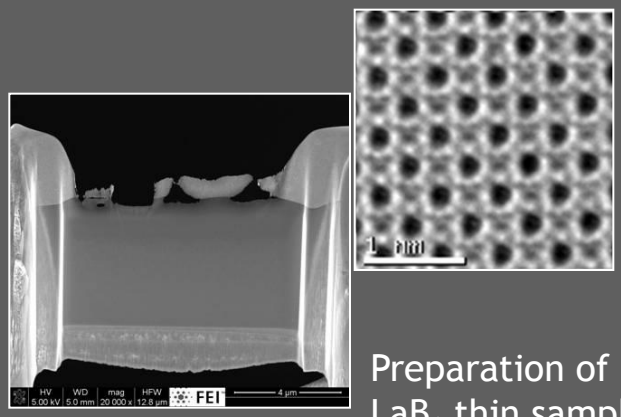
Processing Time for Full Section:
- **FEI Plasma FIB 40 min**
- **Standard Ga FIB >10 hrs**

From: R. Young, IWLPC 2010

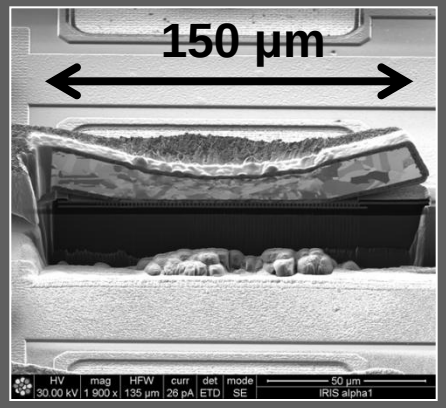
Conclusion

- Multiple innovations at FEI to push FIB technology and applications forwards
- Latest improvements allow for:

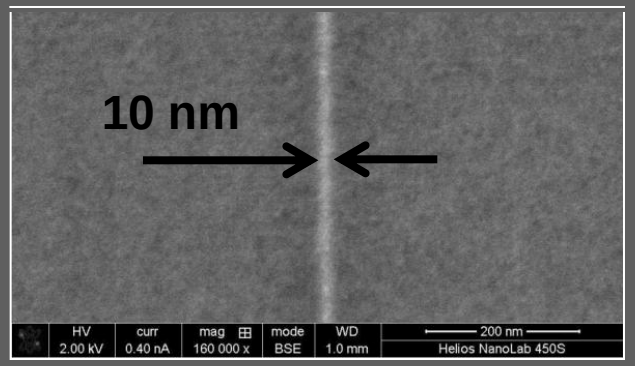
	Tomahawk FIB	Plasma FIB
• More accurate FIB work	Improved optics (incl TOF)	N/A
• Better control of FIB damage removal	low kV performance	To be evaluated
• Faster FIB milling	FIB current up to 65nA	µA range
• New ions	N/A	Xe



Preparation of a LaB_6 thin sample



Large volume removal



Precise writing
here Pt induced FIB deposition

Thank You!

Special thanks to:

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