Focused Ion Beam (FIB)

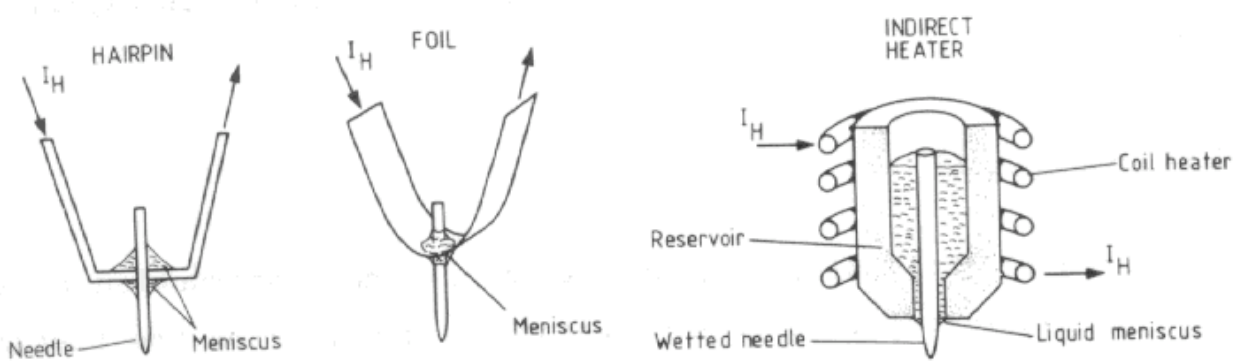
Dr. Navid Asadi

Physical Inspection and AttacKs on ElectronicS (PHIKS)

Presented by: Nitin Varshney

HISTORY

- Liquid Metal Ion Sources, used for droplets in high velocity, low mass spacecraft engines (Krohn, TRW, 1973).
- Ions were also noticed and separately pursued for use in SIMS.
- Tube sources were found to be too unstable, so liquid metal on sharp substrate were pursued.



Why use Ions instead of electrons?

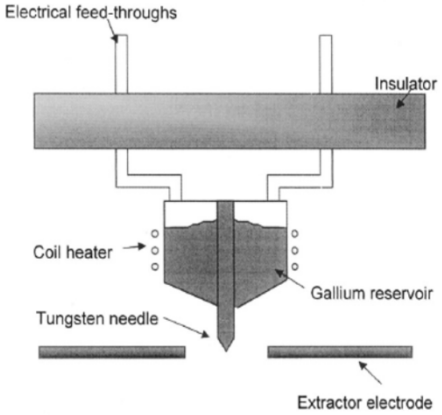
ELECTRONS	IONS
Smaller in size.	Much bigger in size as compared to electrons
Inner shell reactions takes place.	Outer shell reactions occurs , so minimum X-Ray generation.
High penetration depth as compared to ions.	Less penetration depth but high interaction probability
Low mass so they have a higher speed for given energy	Higher mass and slow speed than electrons. But higher momentum which is responsible for milling.
Electrons are negative and light so we use electromagnetic lens.	Ions are positive and heavy therefore we use electrostatic lenses.

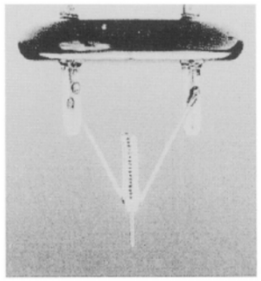
Advantages of using FIB over SEM

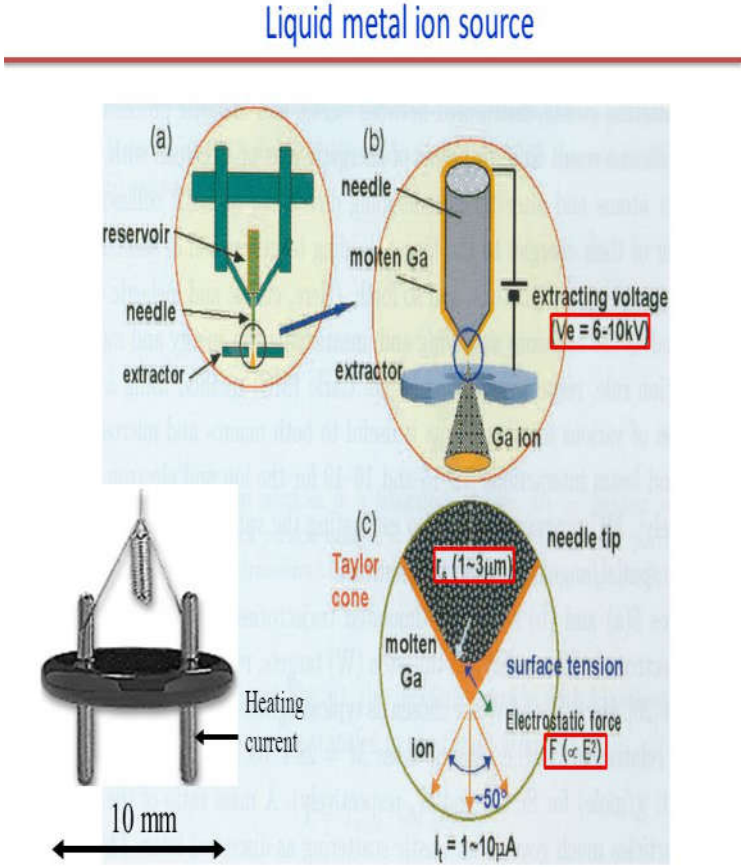
- It can remove Material from the sample.(Etching/Milling)
- It can add material on a specific location in the sample. (Deposition)
- It can provide secondary ion imaging which helps us in determining material contrasts.
- It can also be used for channeling contrasts.
- Helps in preparing the in situ samples.
- Combines the high magnification imaging and sample modification.

Basic Mechanism

- Liquid flows from the reservoir and covers the tip of the solid substrate.
- Taylor Cone formation takes place and at high voltage at the tip, ion generation takes place.
- Ion formation takes place and with the set up the strong electromagnetic field on the counter electrode, ion beam is formed..

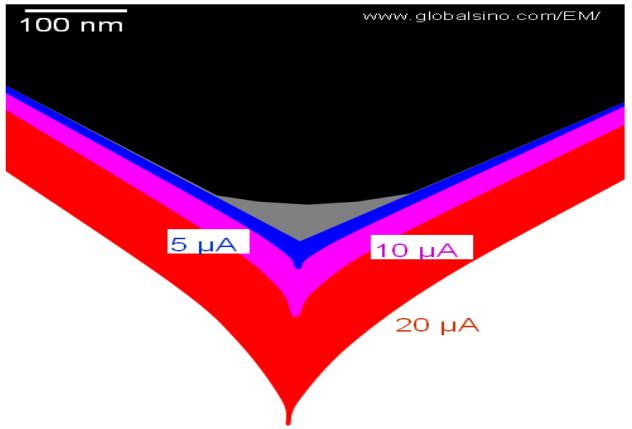






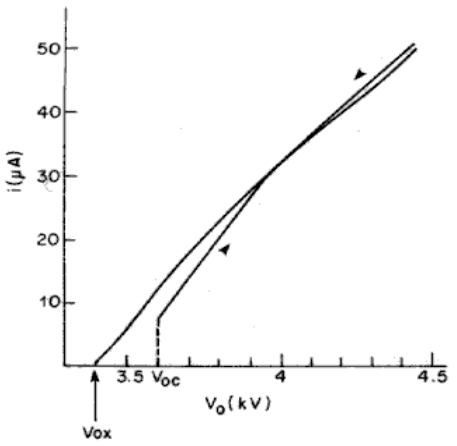
LMIS in an Extractor Field

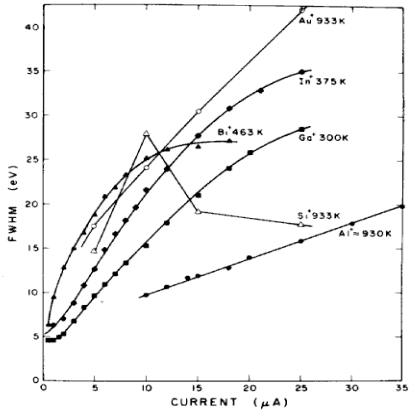
- Jet-like protrusion for Ga LMIS at various currents.
- The tip gets sharper and sharper, and the volume of liquid increases.
- Black portion is the Taylor Cone from the substrate.



Voltage- Current Curve:

- Note “turn-on” behavior in looking at the VI curve.
- Voltage is the extractor voltage
- Current is the total current
- This graph is for an Indium source, but is relative to a gallium source.





Elements used for Liquid Metal Ion Source

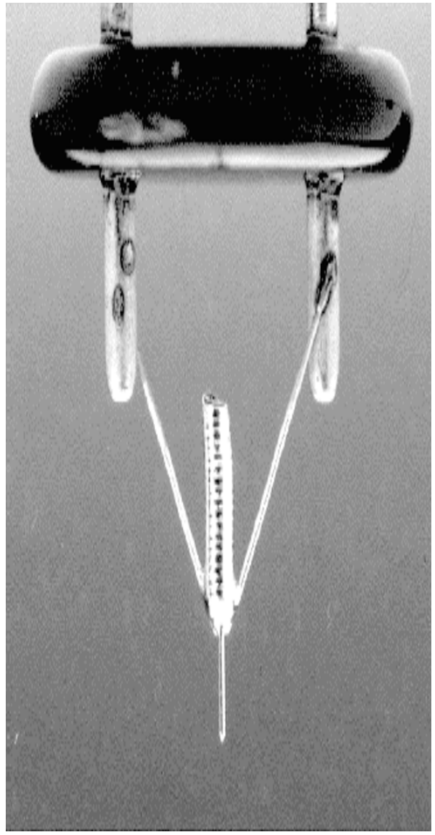
- All the atoms marked as yellow in the periodic table can be used for building LMIS.
- Amongst these, Gallium is the most popular element used to make Ion source in the Focused Ion Beam.

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Unq	Unp	Unh												

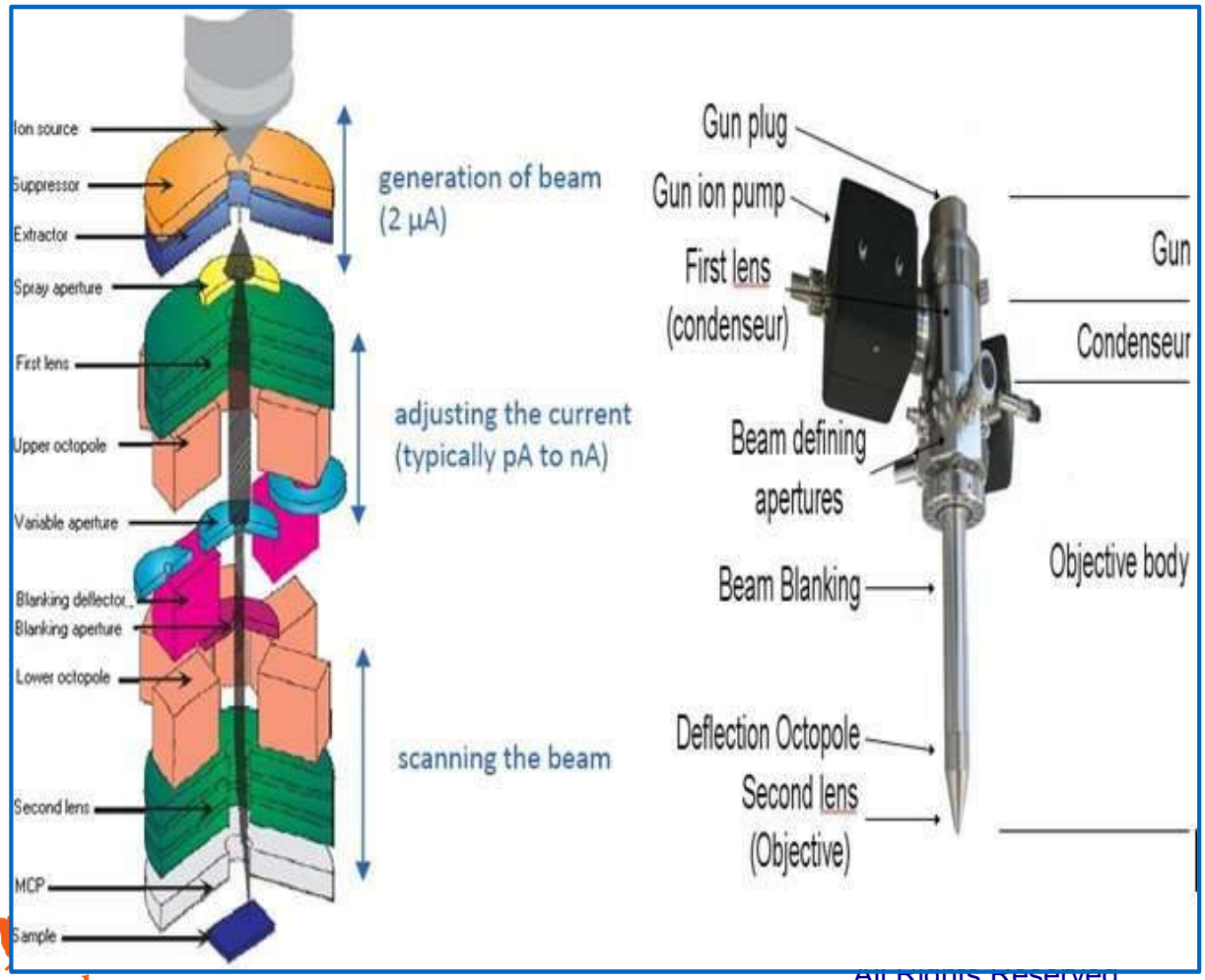
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

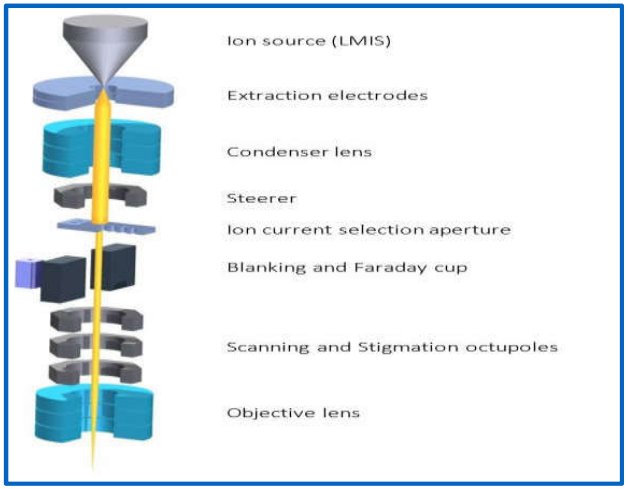
Advantages of using Gallium

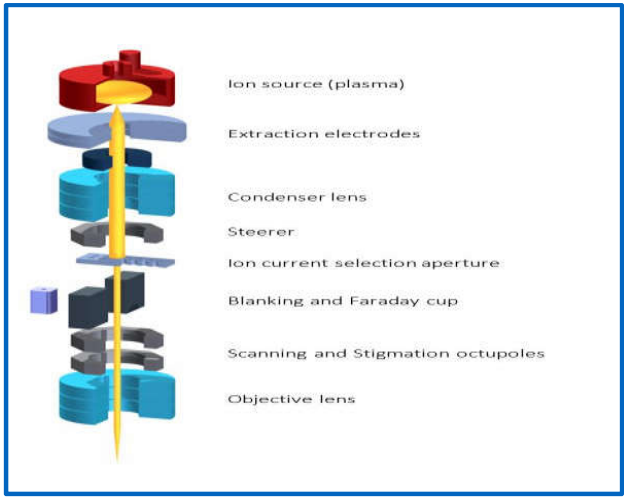
- The element Ga is metallic and has a low melting temperature.
- The Ga can be contained in a very small volume so the gun has a long practical life time.
- A high brightness is obtained due to the surface potential, the flow properties of Gallium, the sharpness of the tip and the construction of the gun which results in both ionized and field emission.
- The element Gallium is nicely positioned in the center of the table and its momentum transfer capability is optimum for most of the metals.
- It can be operated at the room temperature and is compatible with the high vacuum.



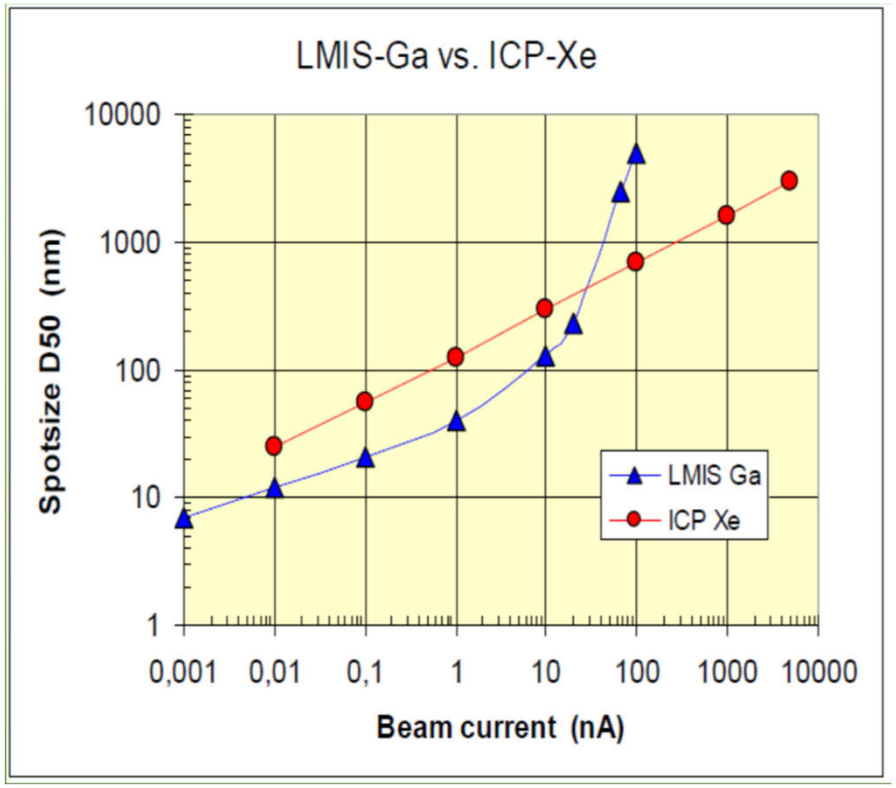
Generalized Construction of FIB Column

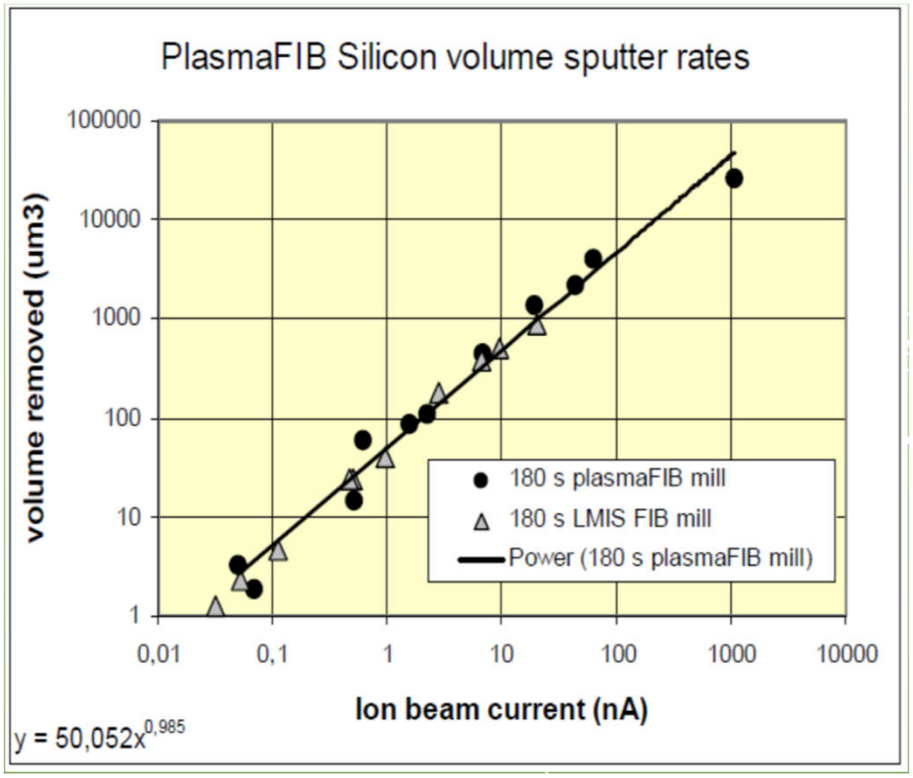






FIB FLAVORS: LMIS Ga FIB vs Plasma (Xe) FIB



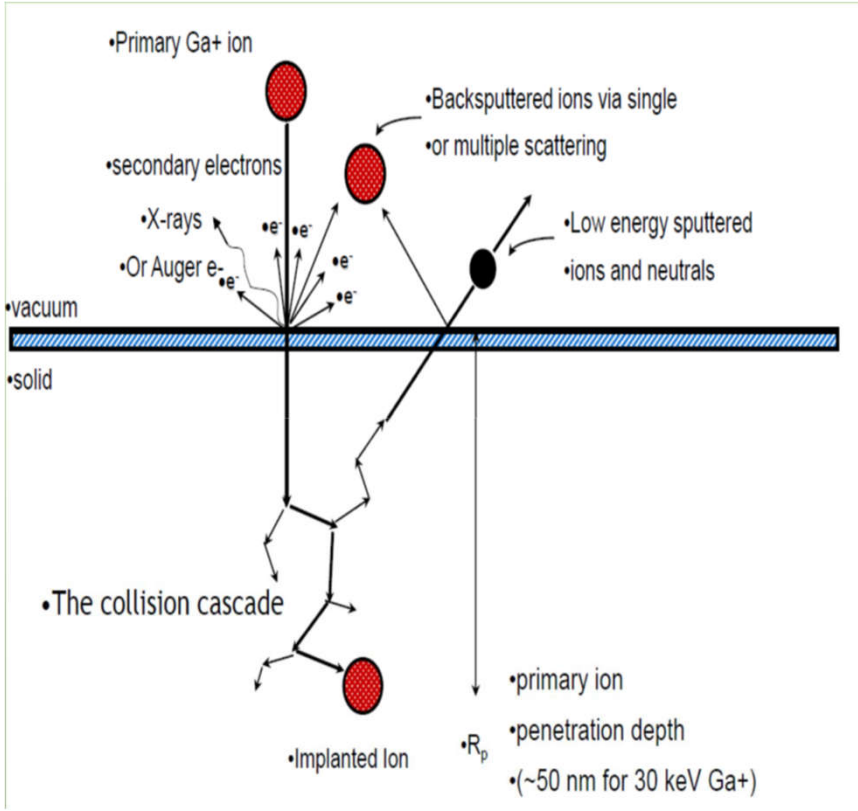


Difference between FIB and SEM Instrumentation

FIB (Focused Ion Beam)	SEM (Scanning Electron Microscope)
Control of the ion beam current is realized by selecting different apertures. For the ion beam each of the selected apertures has an optimized performance.	Control of the beam current in SEM is done by selecting different demagnification factors .
The milling aspects of the FIB are so important that patterning is a standard capability of the system.	For a SEM, patterning is mainly added for the sake of e-beam lithography.
It has an ion beam detector.	It has a secondary electron detector, back scattered electron detector , STEM, X-ray detector.
FIB can be equipped with an flood gun or a Gas Injection System (GIS).	SEM doesn't have a GIS injection system because there is no charging.
Column is equipped with electrostatic lenses.	SEM column is equipped with electromagnetic lenses.

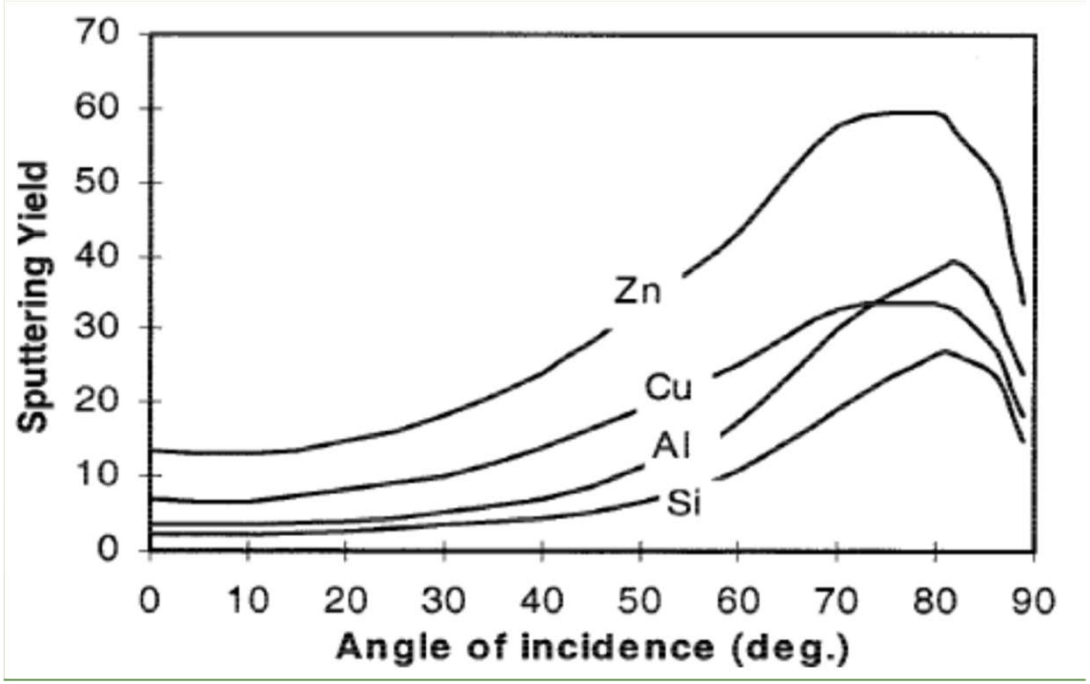
Ion–Solid Interactions

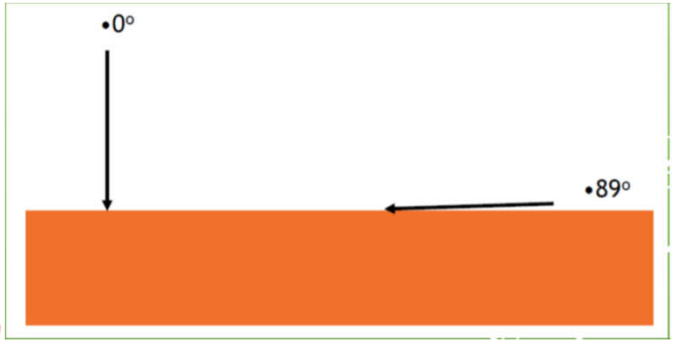
- Sputtering occurs as the result of a series of elastic collisions where momentum is transferred from the incident ions to the target atoms within a collision cascade region.
- A surface atom may be ejected as a sputtered particle if it receives a component of kinetic energy that is sufficient to overcome the surface binding energy of the target material.
- The secondary electrons and secondary ions are collected and detected to form images.



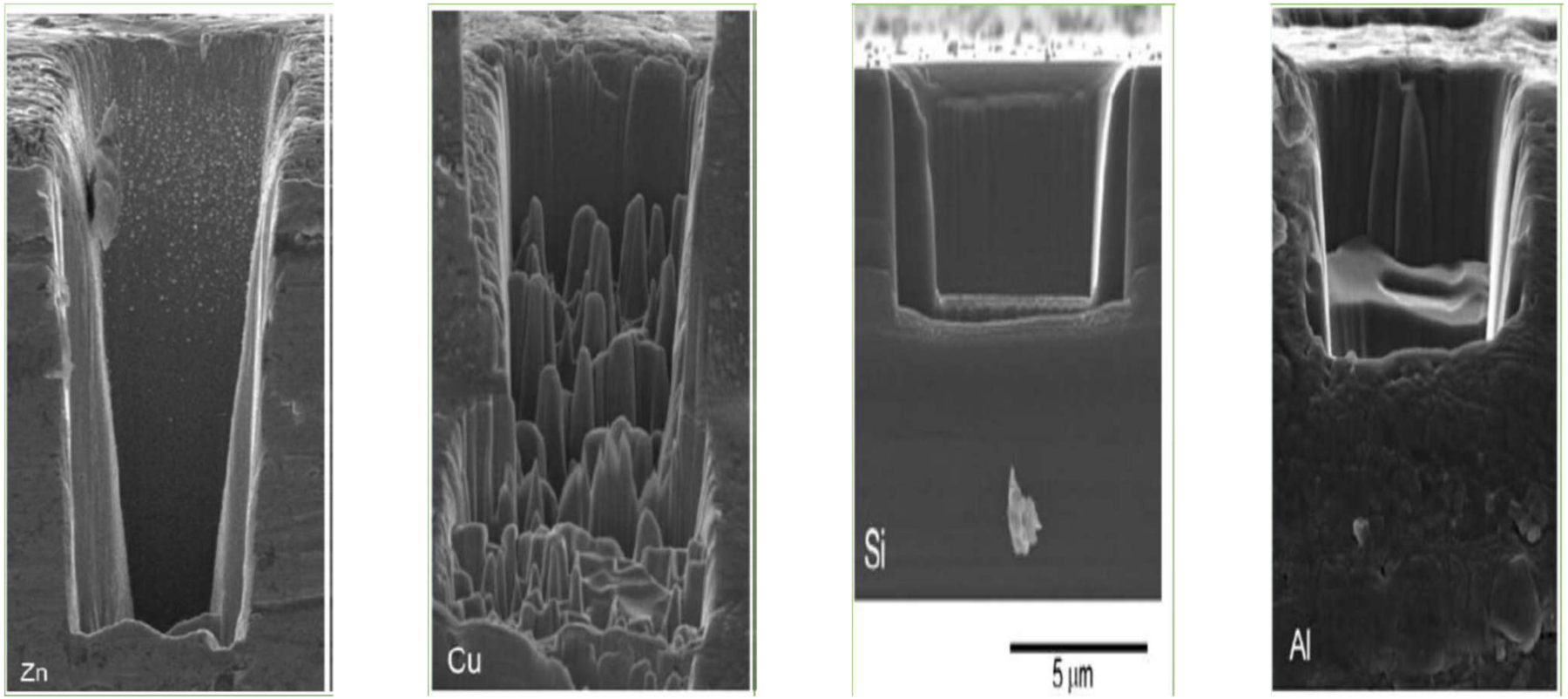
Sputter Rate vs Incident Angle

- Sputter yield increases with angle of incidence.
- Energy is concentrated on a thinner and thinner area as the incident angle gets increased.
- At maximum angle, reflection starts to occur which is responsible for the reducing sputter yield.



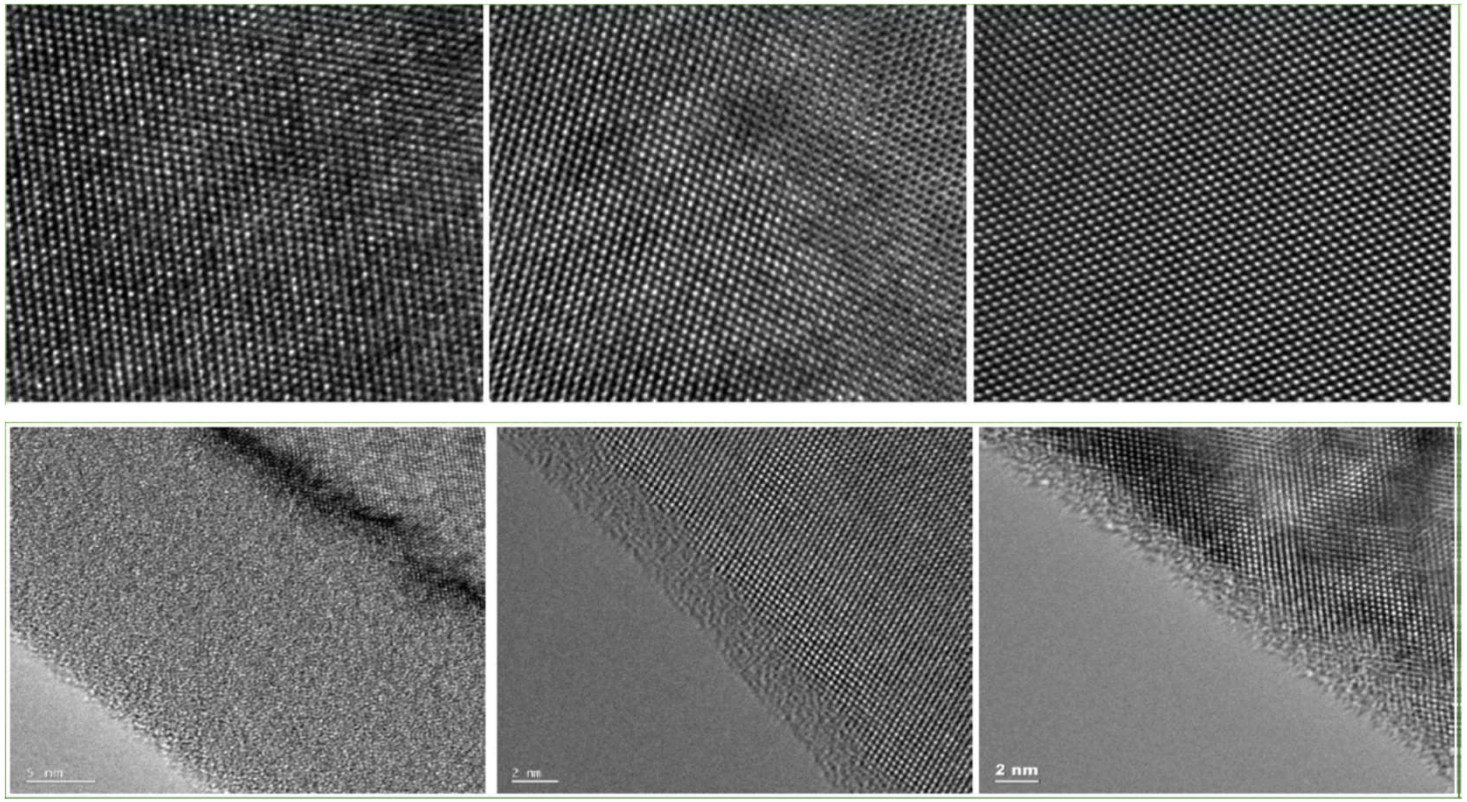


Milling Rate for Different Materials



All cuts were done under the same conditions and are presented at the same magnification

FIB Surface Beam Damage as a Function of Voltage



30 keV	5 keV	2 keV
~ 21 nm	~ 2 nm	0.5nm -1.5nm

Schematic Diagram of FIB-SEM columns inside the chamber

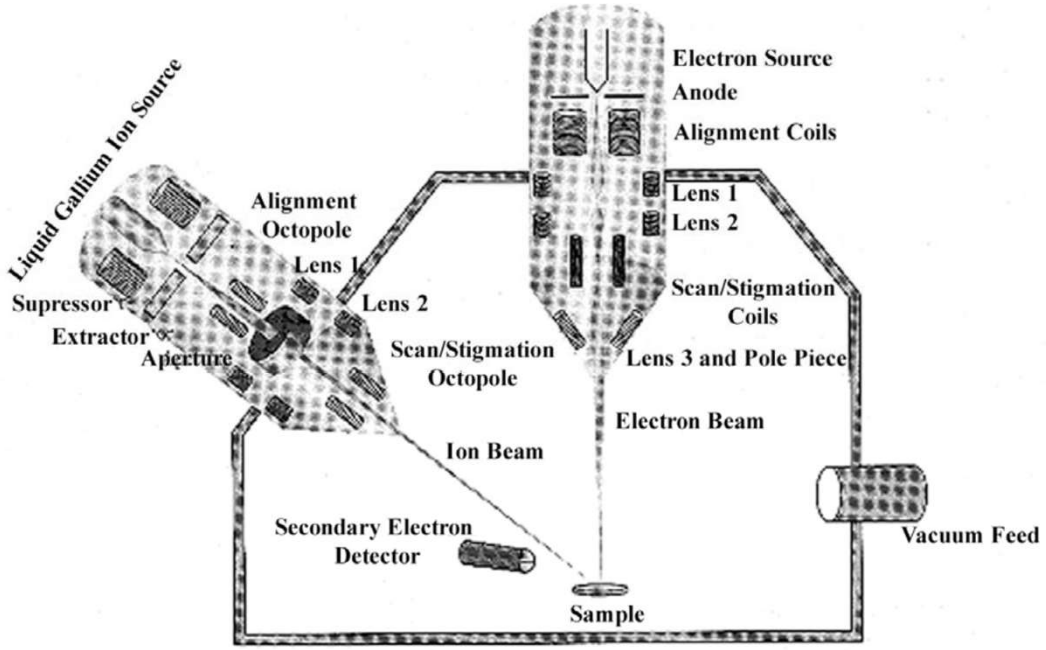
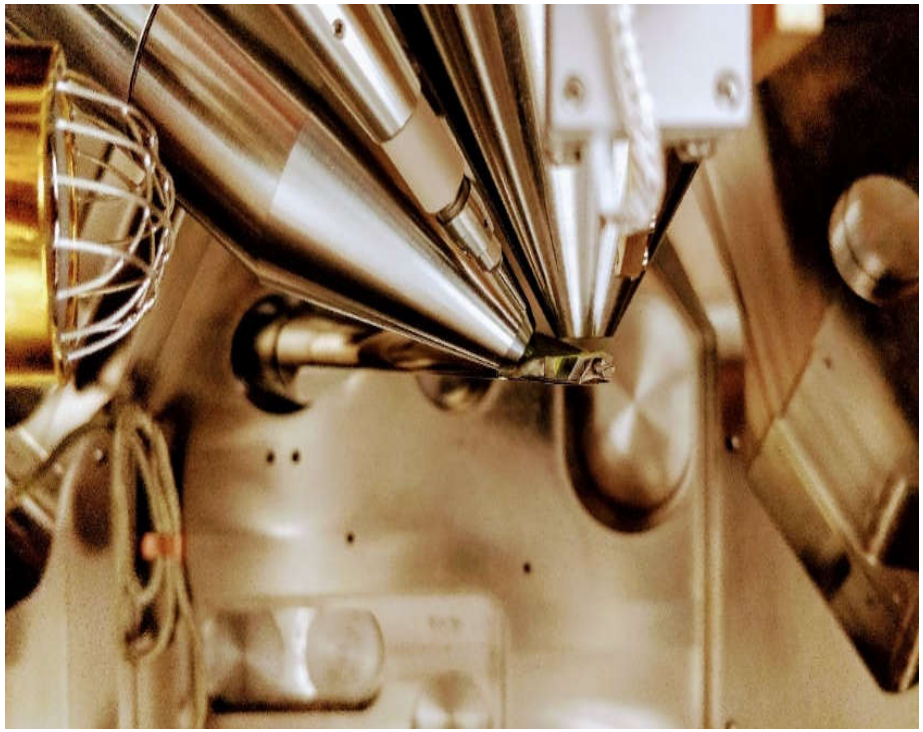
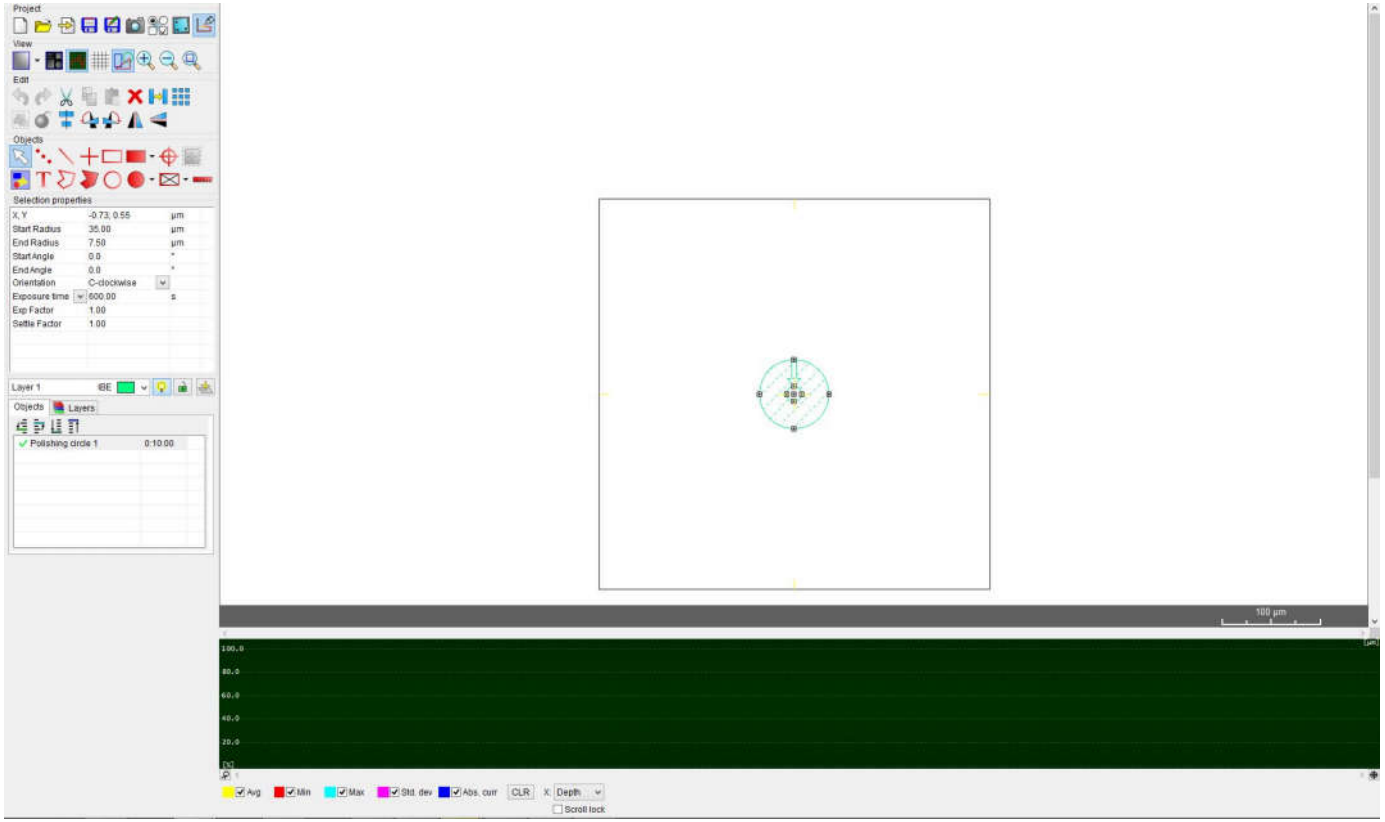


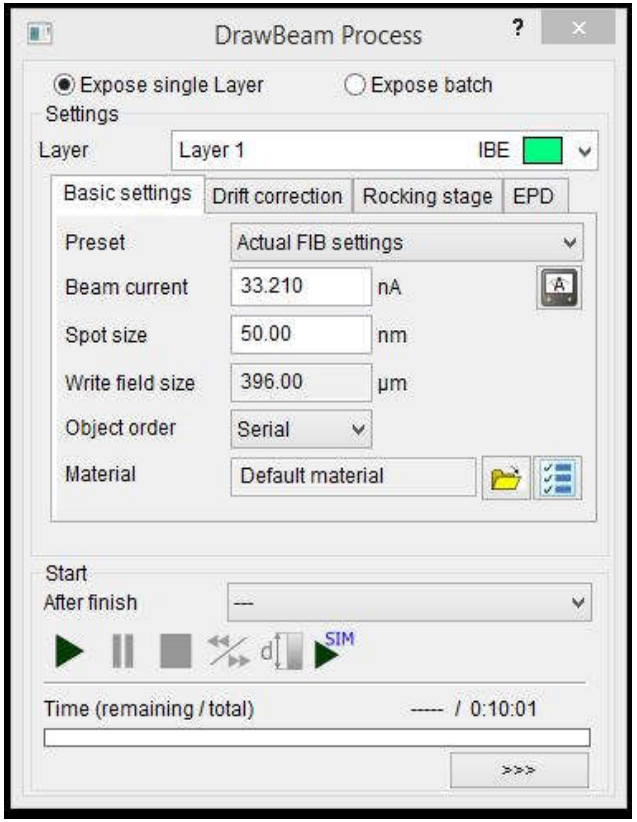
Figure. A FIB Instrument showing the Ion and Electron columns and the specimen inside the vacuum chamber



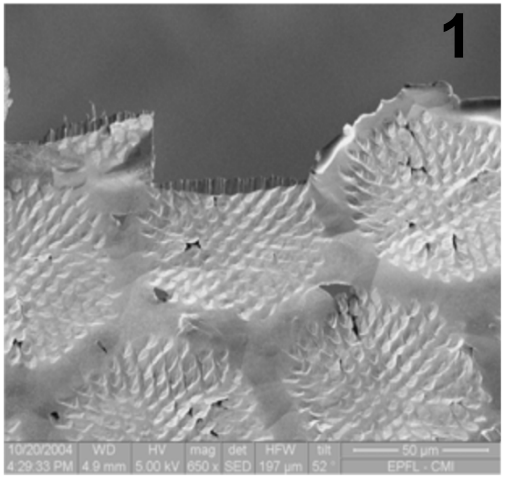
Draw Beam Panel

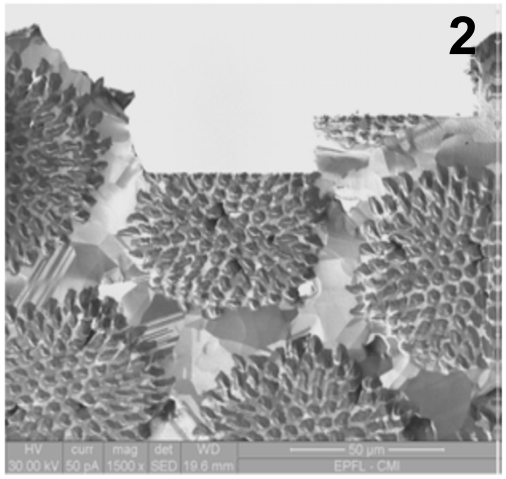
Draw Beam is an inbuild software used to work for all kinds of applications in FIB-SEM.

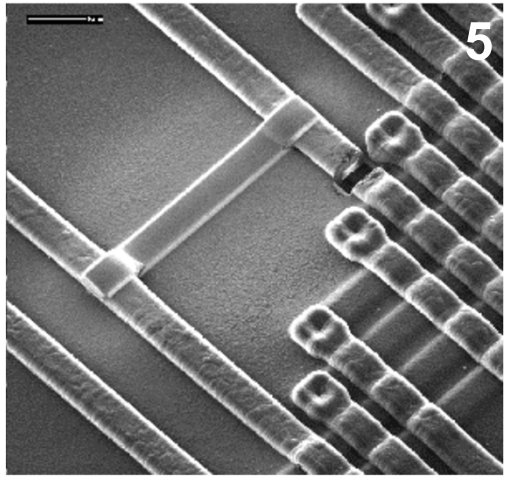


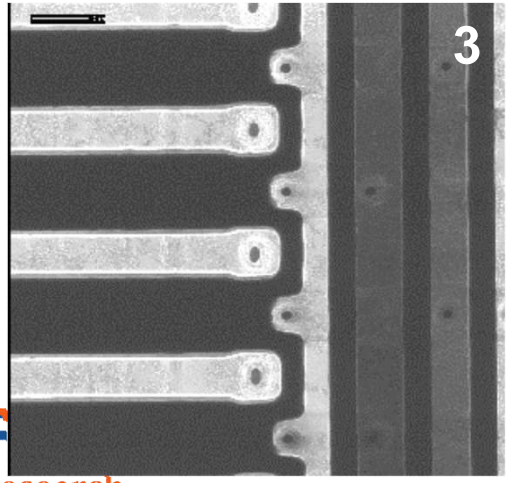


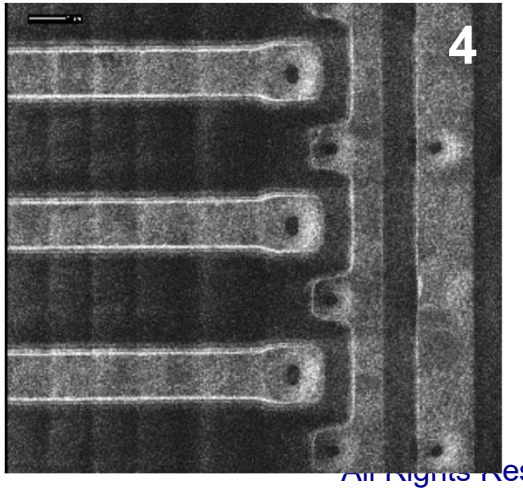
Contrast Mechanism











Images 1 and 2 : Materials Contrast

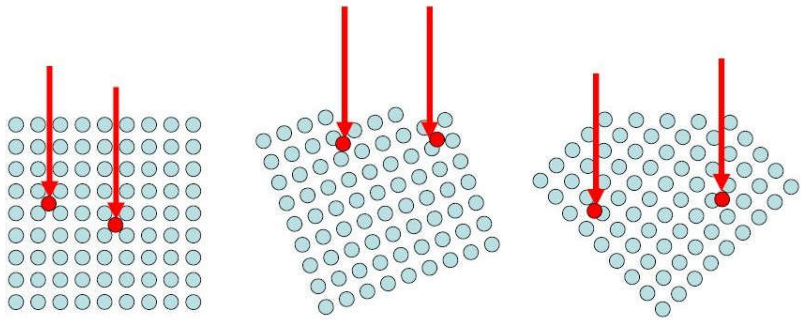
Images 3 and 4: Voltage contrast

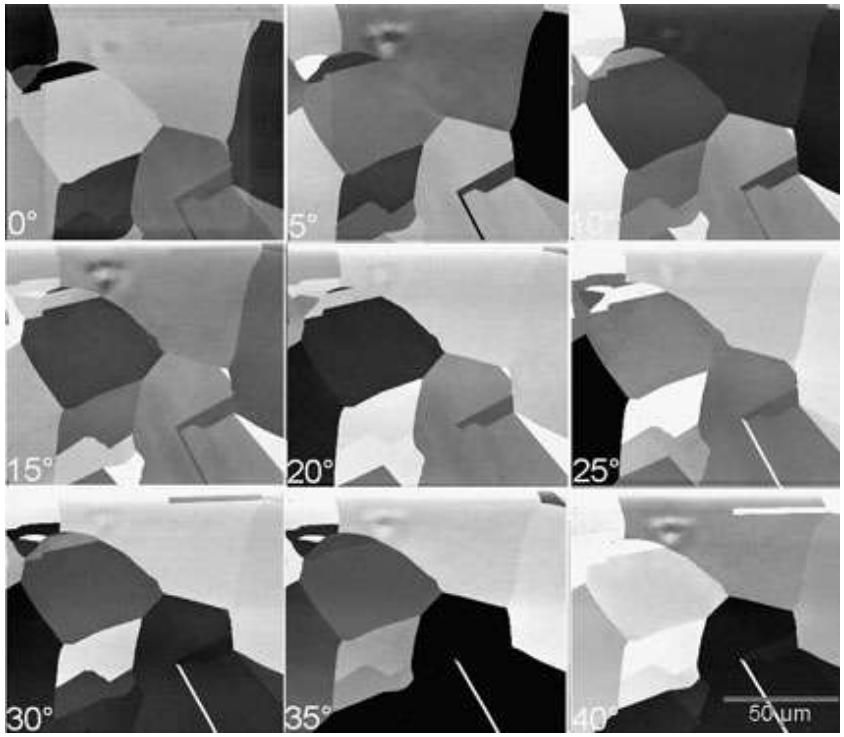
Image 5: Topographical contrast

Research

Ion Channeling Contrast

- Ions penetrate deeper in crystalline material for certain grain boundaries.
- Those channeled ions have lower sputtering yield. (lower milling rate)
- Secondary electron yields are also lower for the areas channeling better.

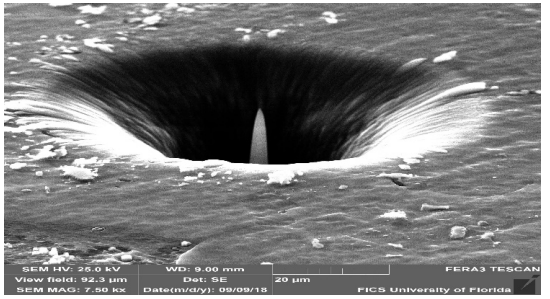


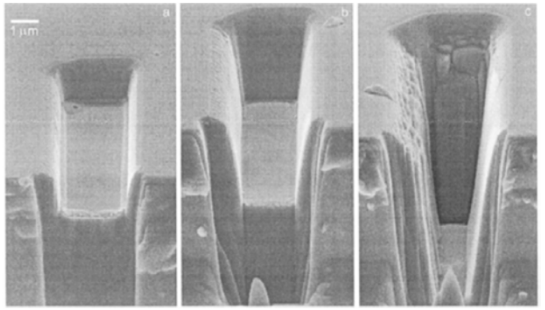


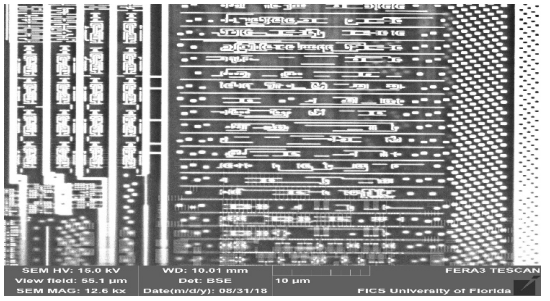
Applications of FIB

Milling/Etching:

- Etching takes place as a result of physical sputtering of the target.
- An understanding of sputtering requires consideration of the interaction between an ion beam and the target.
- FIBs are most often used to create features of high aspect ratio.
- Sputtered material and back sputtered ions may therefore deposit on surfaces that are in close proximity to the active milling site.

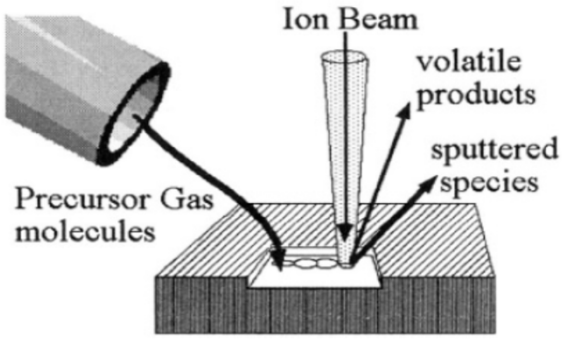


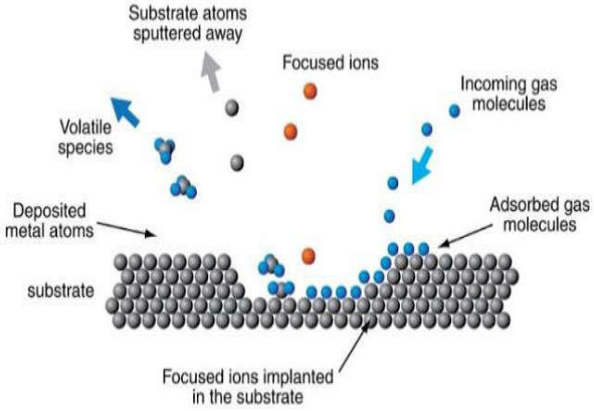




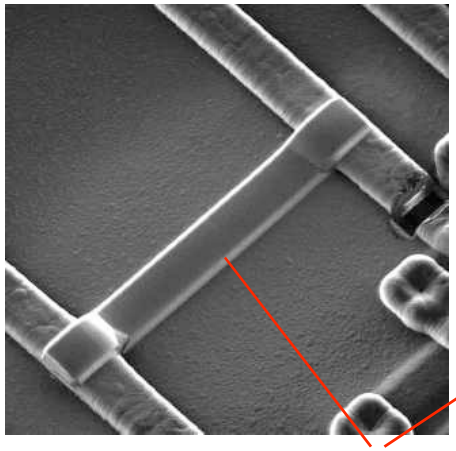
Deposition

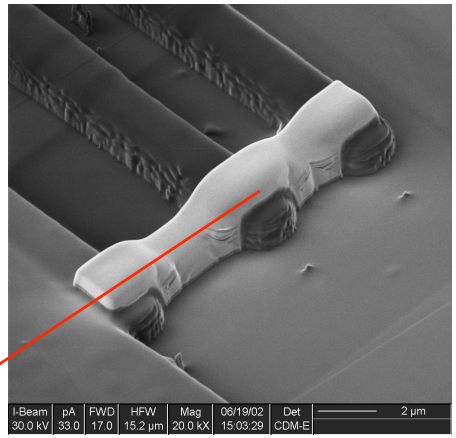
- FIB material deposition is currently commonly employed for deposition of conductors and insulators for IC circuit edit and for deposition of material in multiple micromachining applications.
- Many precursors that have been successfully used for FIB deposition, those whose FIB induced decomposition results in metal deposition (e.g. W, Pt, Au, Al, and Cu) are the most commonly used.
- All deposited films contain not only the desired metals but also incorporate impurities from the incompletely decomposed precursor and contain ions from the focused ion beam.

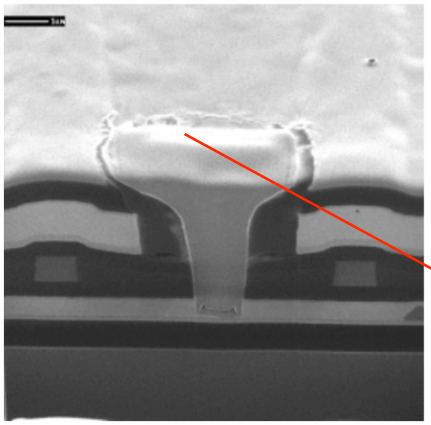




Examples

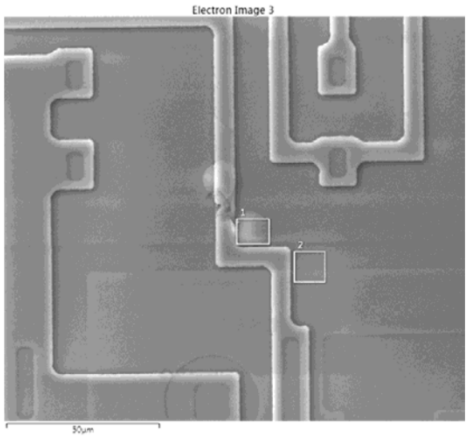


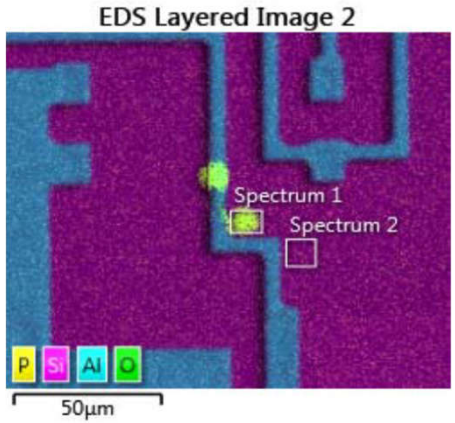




FIB Deposited Pt

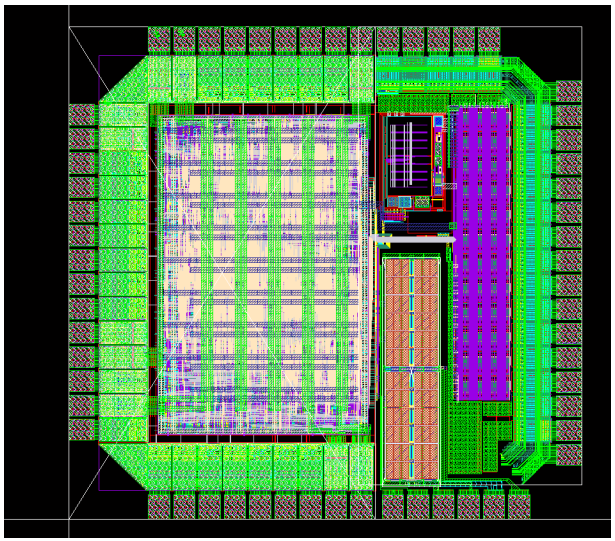
FIB Deposited Insulator

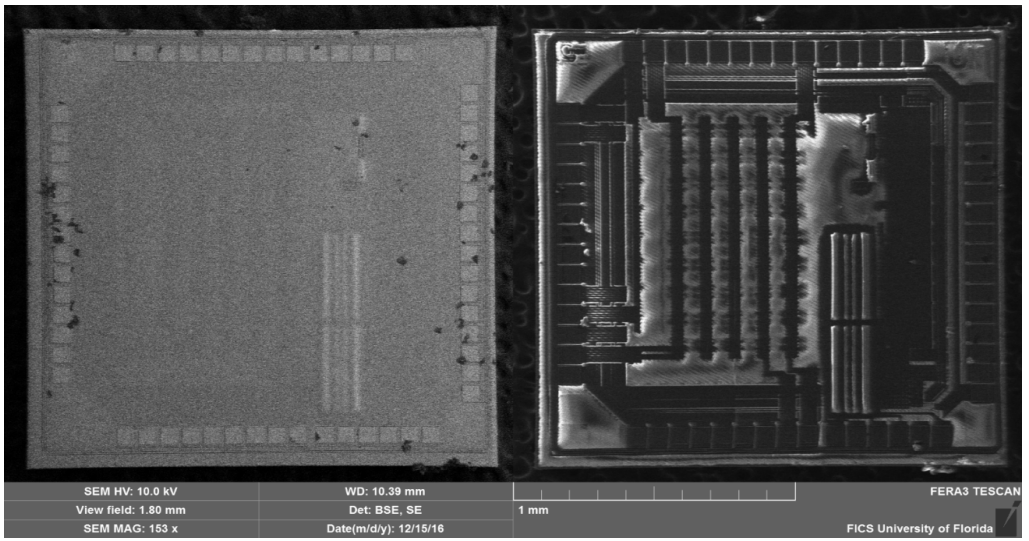


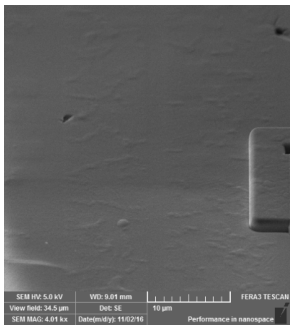


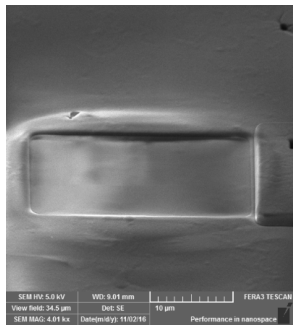
Application in Failure Analysis

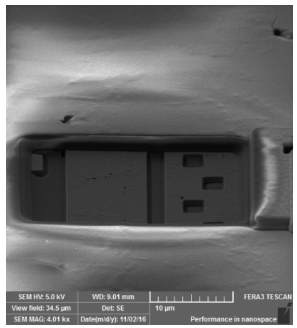
Circuit Edit on Analog IC

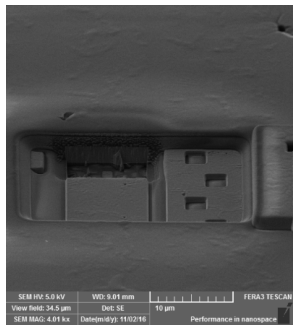


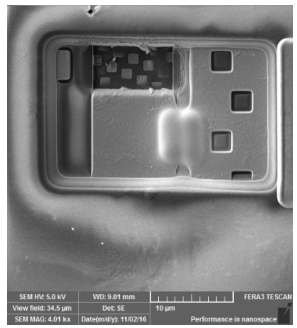






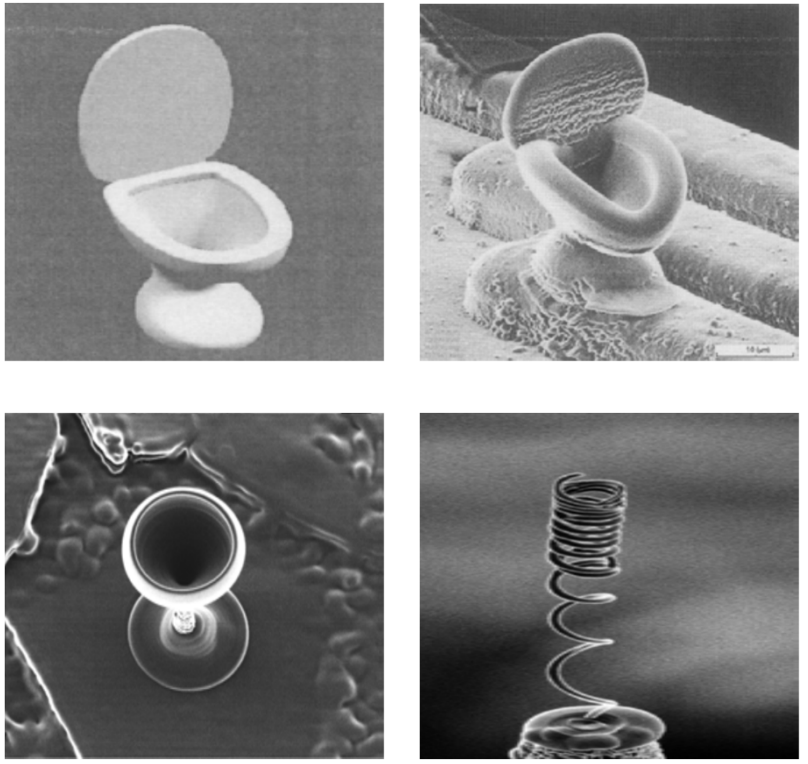




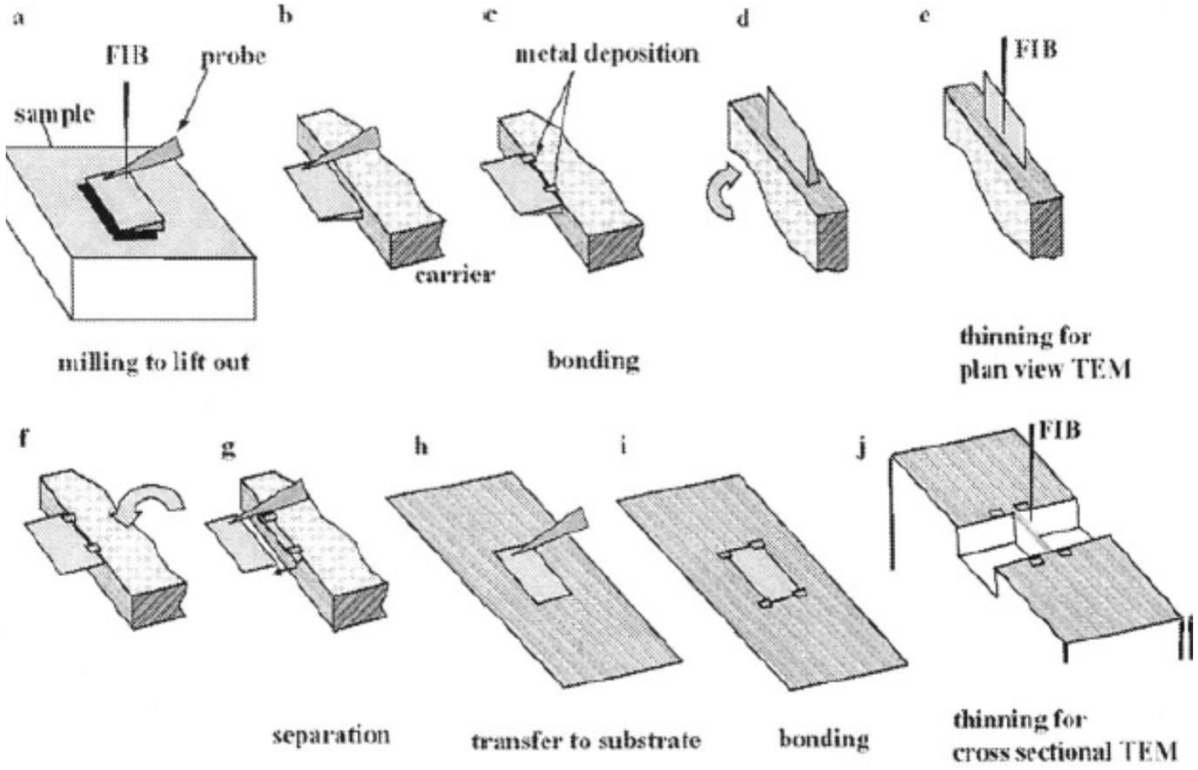


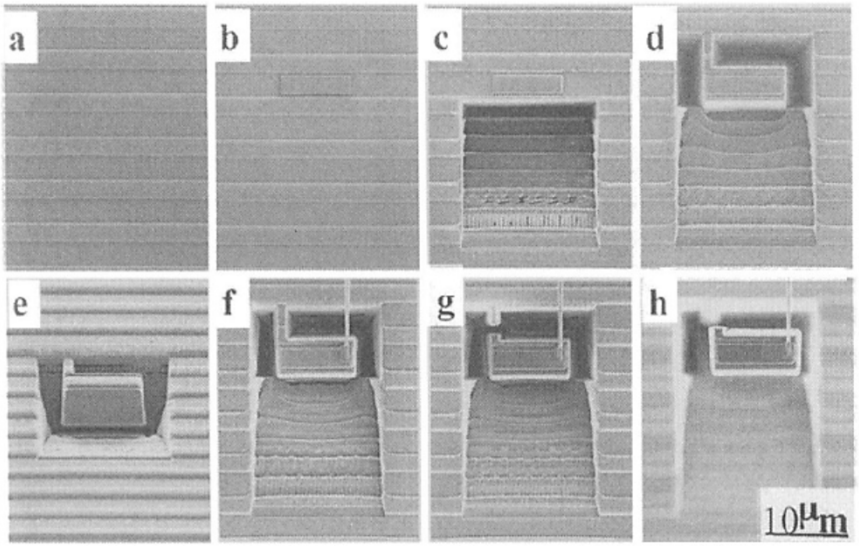
3D- Nanofabrication

- The three-dimensional nanofabrication technology is also can be seen as a special type of FIB deposition.
- Using the FIB-CVD technique, it allows the formation of 3D structures that cannot be made with existing technologies.
- First, the user makes a CAD file of any three-dimensional structure and then this CAD data is divided in the Z-axis direction into several pieces of data to make a series of FIB processing data automatically.



Micro-sampling for TEM





Series of FIB images showing the procedure for the FIB micro-sample preparation.

Companies / Vendors of Focused Ion Beam

1.TESCAN
2.ZEISS
3.FEI COMPANY
4.HITACHI
5.Raith GmbH
6.JEOL