ORION NanoFab – a Helium Ion Microscope Advances in Nanofabrication and Imaging

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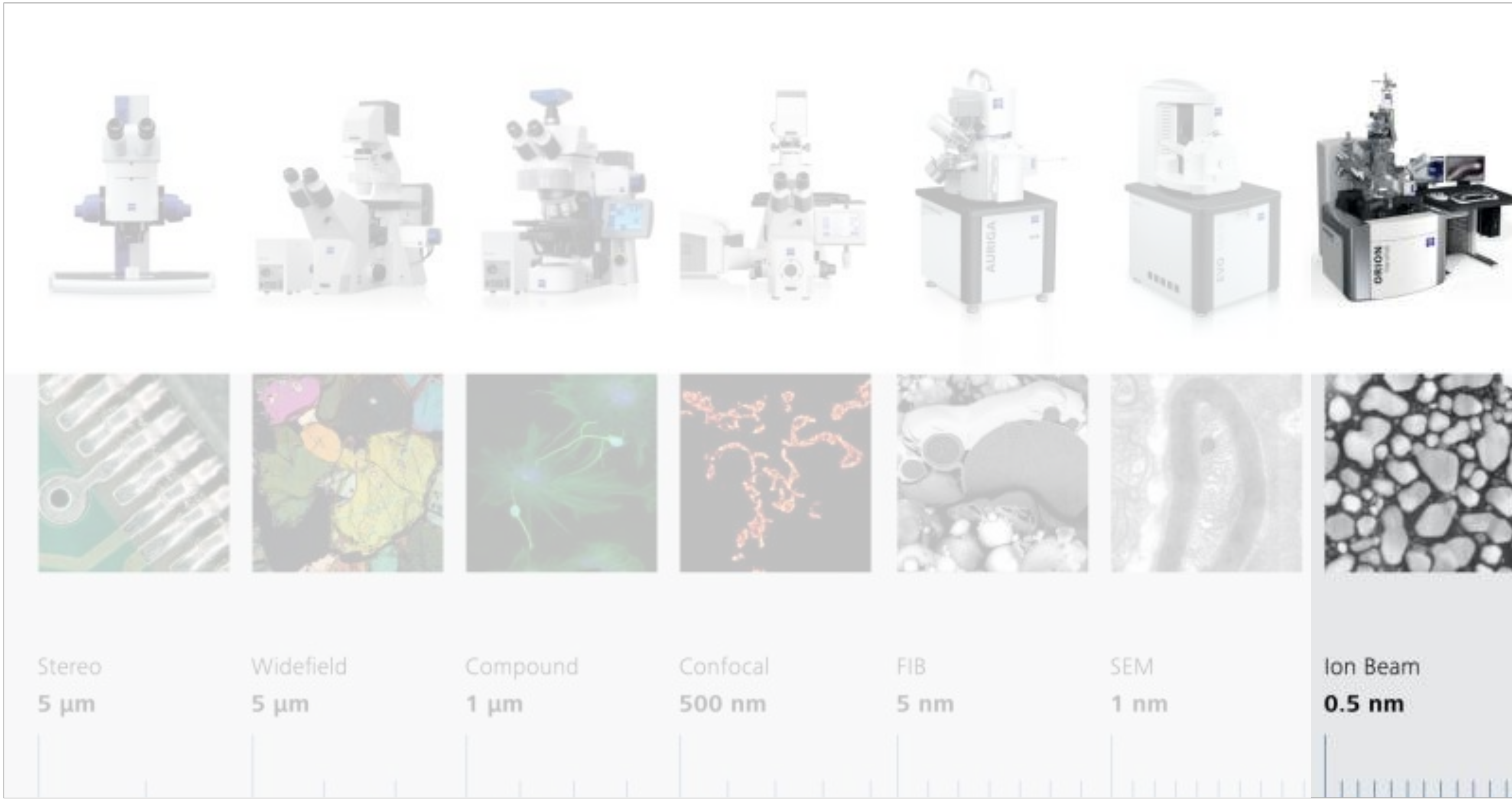
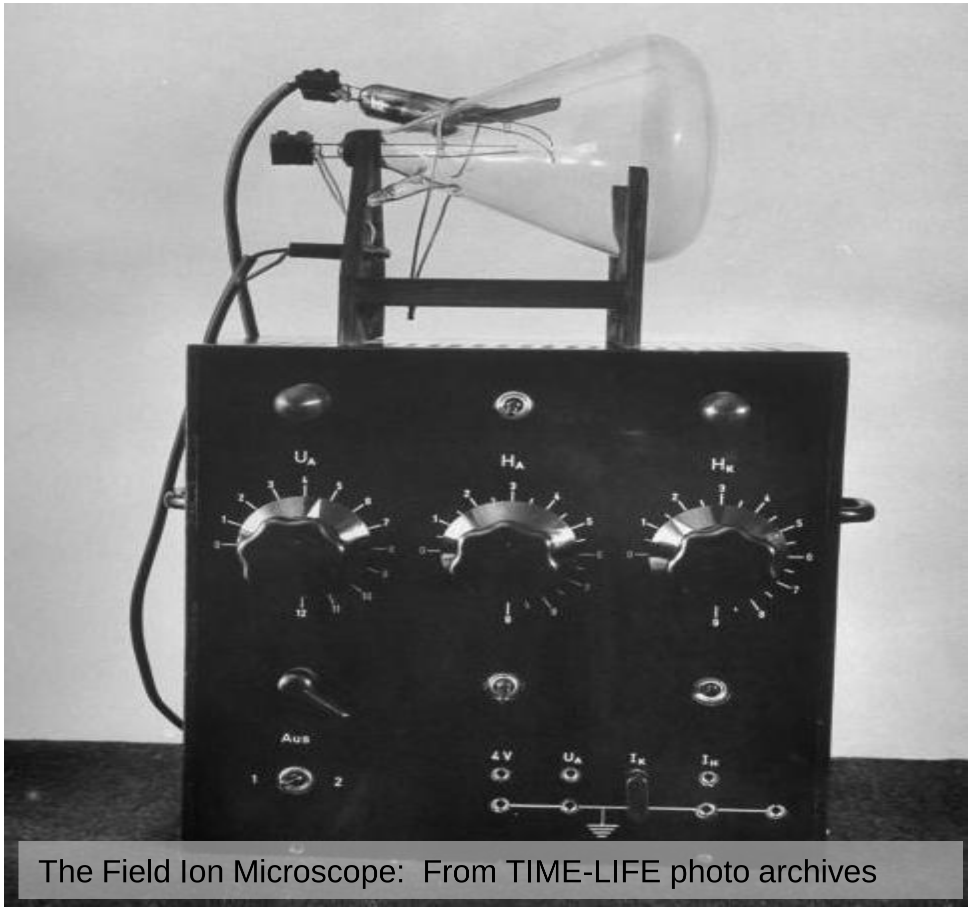
Microscopy Product Portfolio



From the micrometer to the sub-nanometer scale…

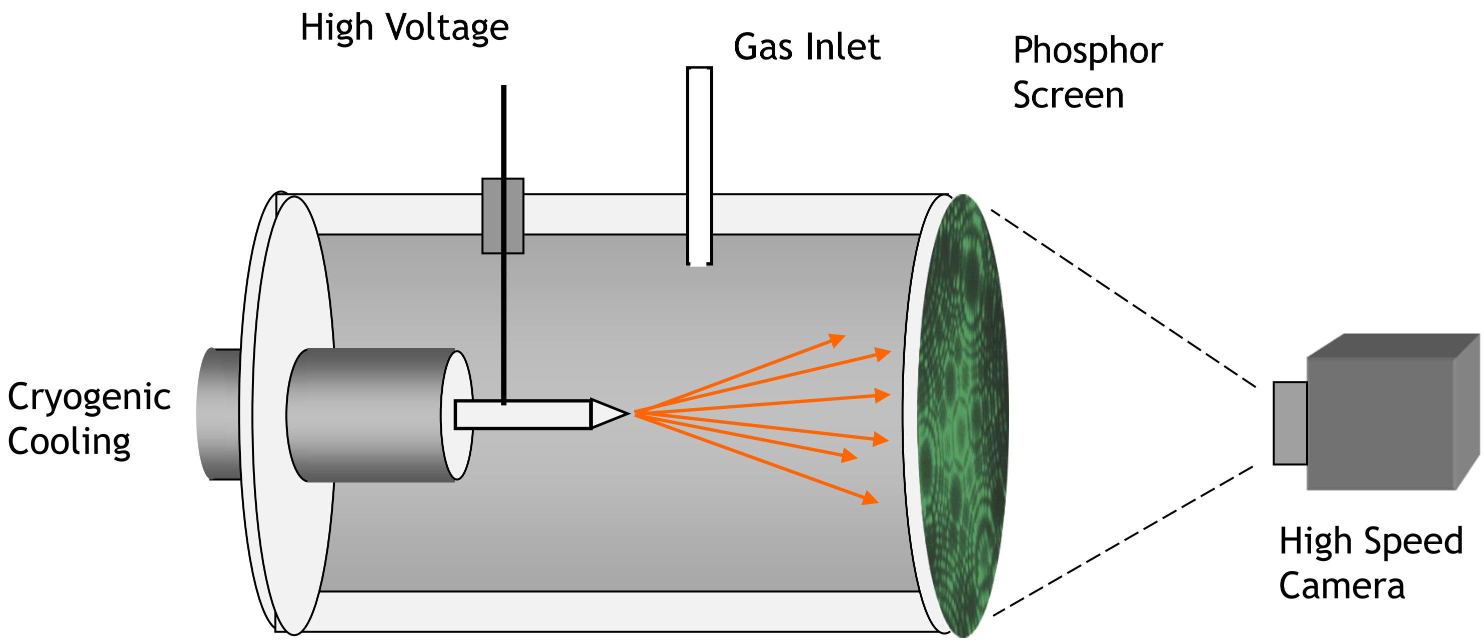
History of the Gas Field Ion Source

Erwin Müller
(1911-1977)

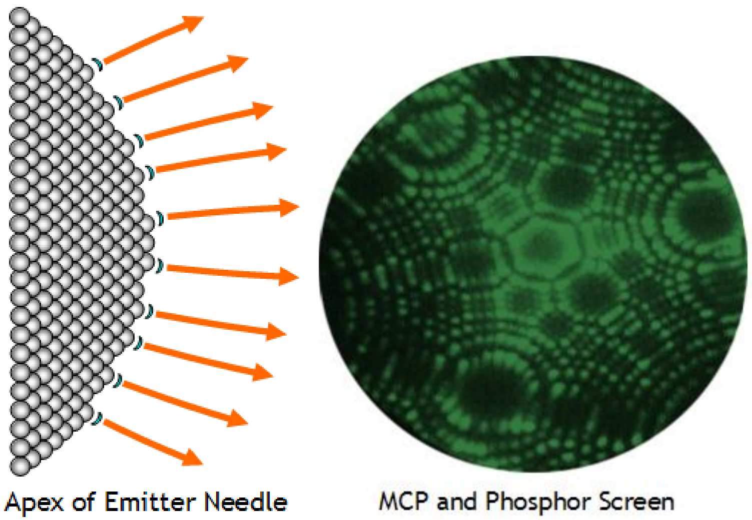


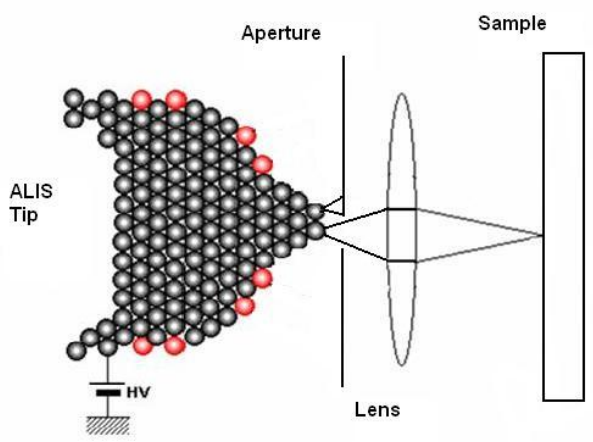
The Field Ion Microscope: From TIME-LIFE photo archives

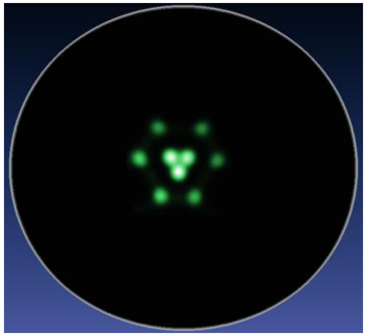
History of the Gas Field Ion Source



How to use a single atom to emit a beam of ions





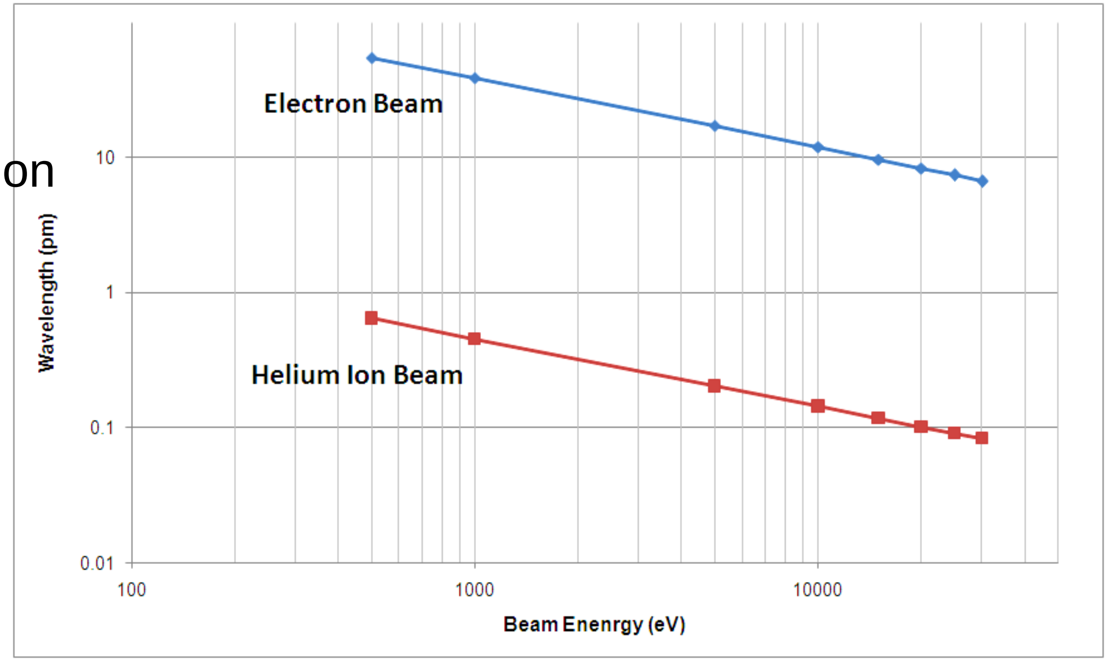


- FIM tip created via chemical etching
- ALIS tip formed with additional reshaping
- 3 atom shelf called the “trimer” created through field evaporation
- Single atom selected to form the final probe
- Results in a sub-angstrom virtual source with high brightness (5x10^9 A/(cm^2 sr)) and low energy spread (<1eV)

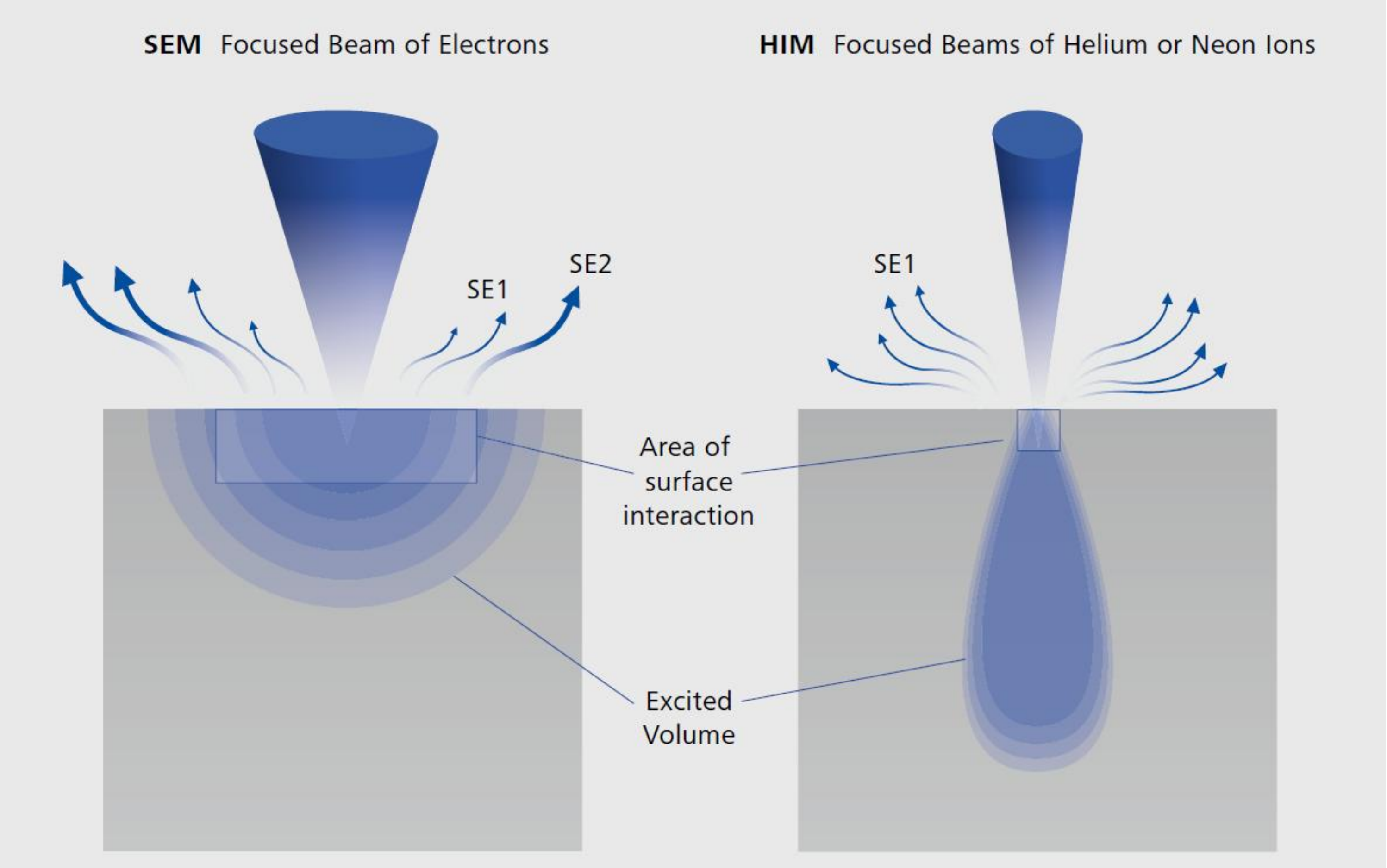
Resolution

• Ions have lower velocity than electrons of equivalent energy – therefore the **wavelength** of the ion beam is **smaller** than electrons.

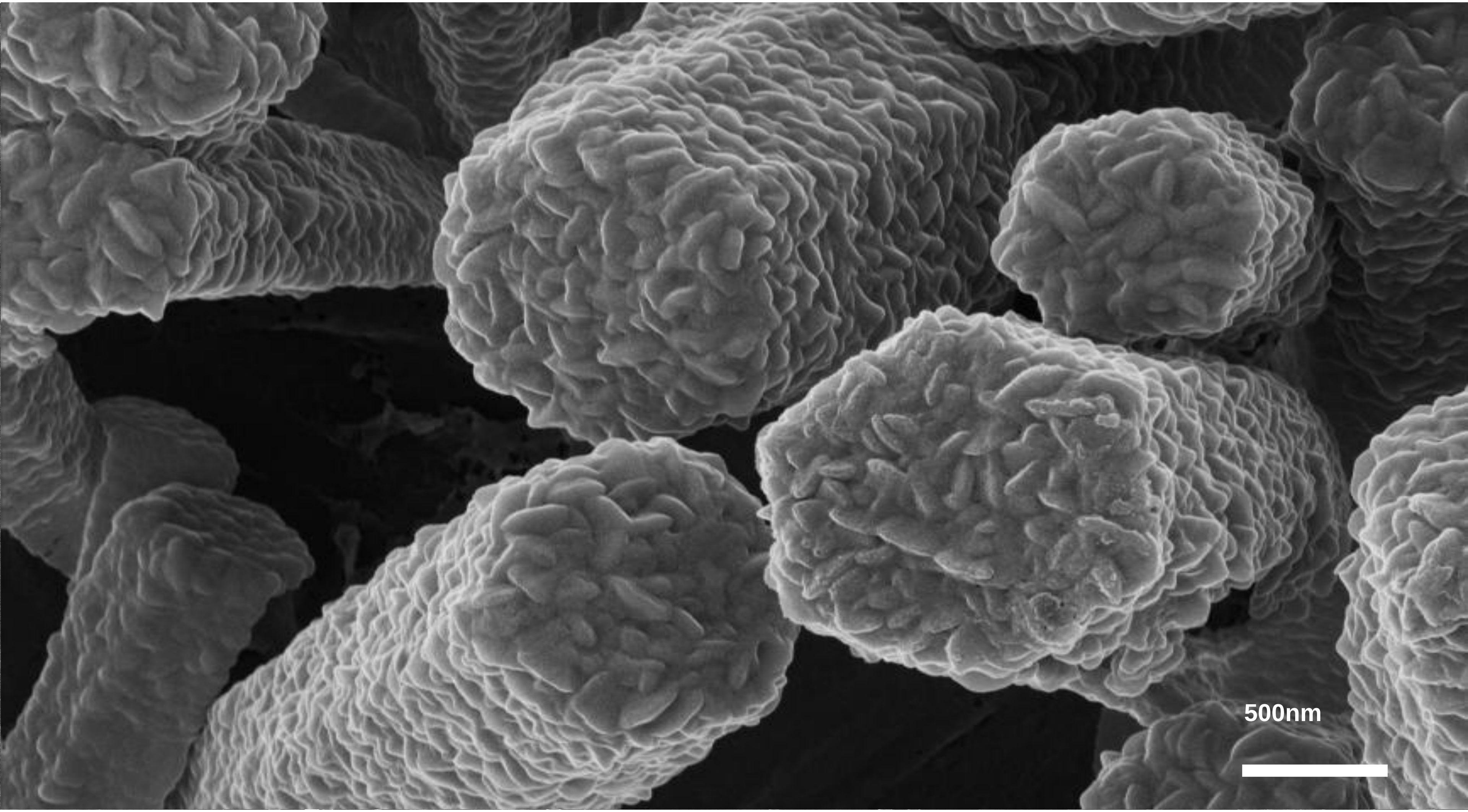
• Resolution is dependent on wavelength – **smaller is better**.



Small Interaction volume



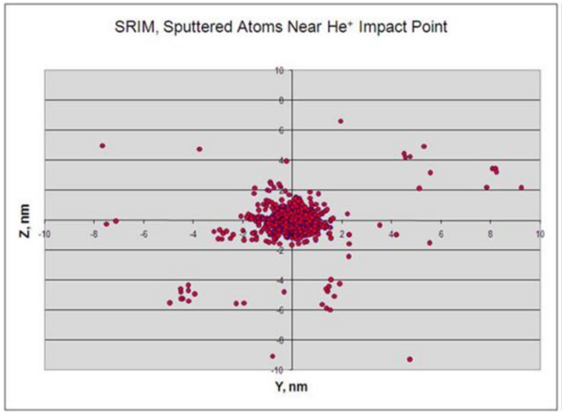
HIM - Imaging

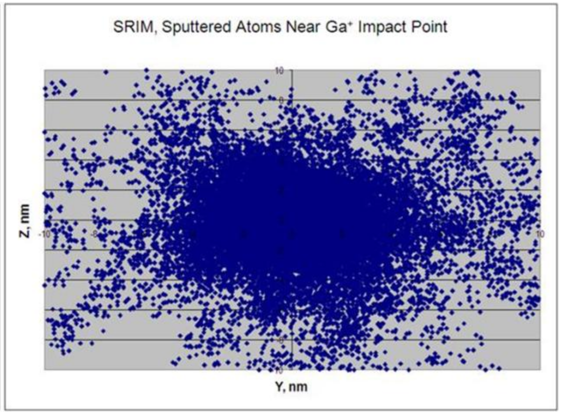


Sputtering

Particle	Mass (amu)	Relative Mass
Electron	0.000548	1
Helium	4.0026	7299
Neon	20.1797	36824
Gallium	69.723	127231

Electrons do not have enough mass to cause sputtering in materials.





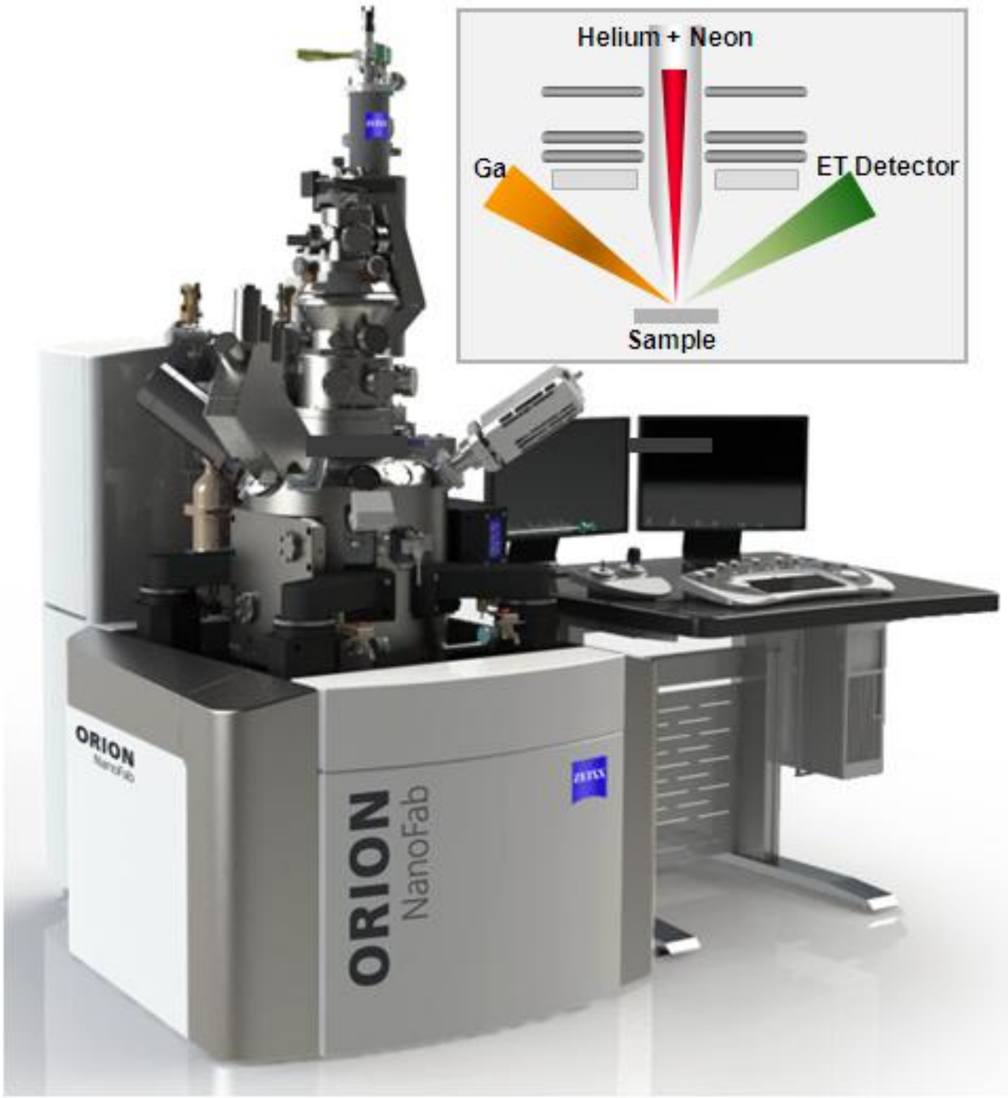
He and Ne have lower mass than Ga which allows for **precise and controlled machining.**

Ga has greater mass that allows for **rapid material removal.**

•10,000 incoming He ions sputter ~1600 Au atoms (sputter yield ~0.16) whereas 10,000 incoming Ga ions sputter ~17,000 Au atoms (sputter yield ~17)

•Analysis of ±10nm region shows that the gold sputtered by He (red particles on the left) originates in a ±2nm region whereas gold sputtered by Ga (blue particles on the right) originates in ±10nm region.

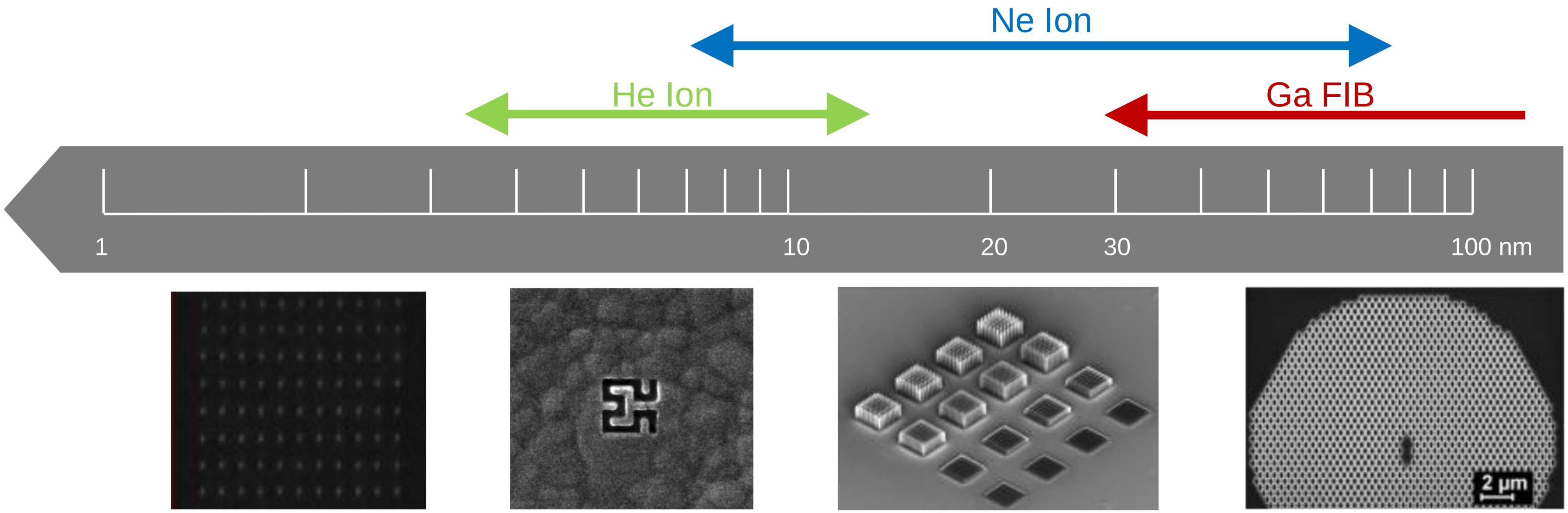
Combining three ion beams on a single platform



- **3D Nanofabrication** of sub-10nm structures.
- **High Resolution Imaging (0.5nm)** for nanoscale research.
- **Precise Machining** with He/Ne beams and **Rapid Prototyping** with Ga beam.
- **Configurable** architecture to address specific imaging and nanofabrication applications.

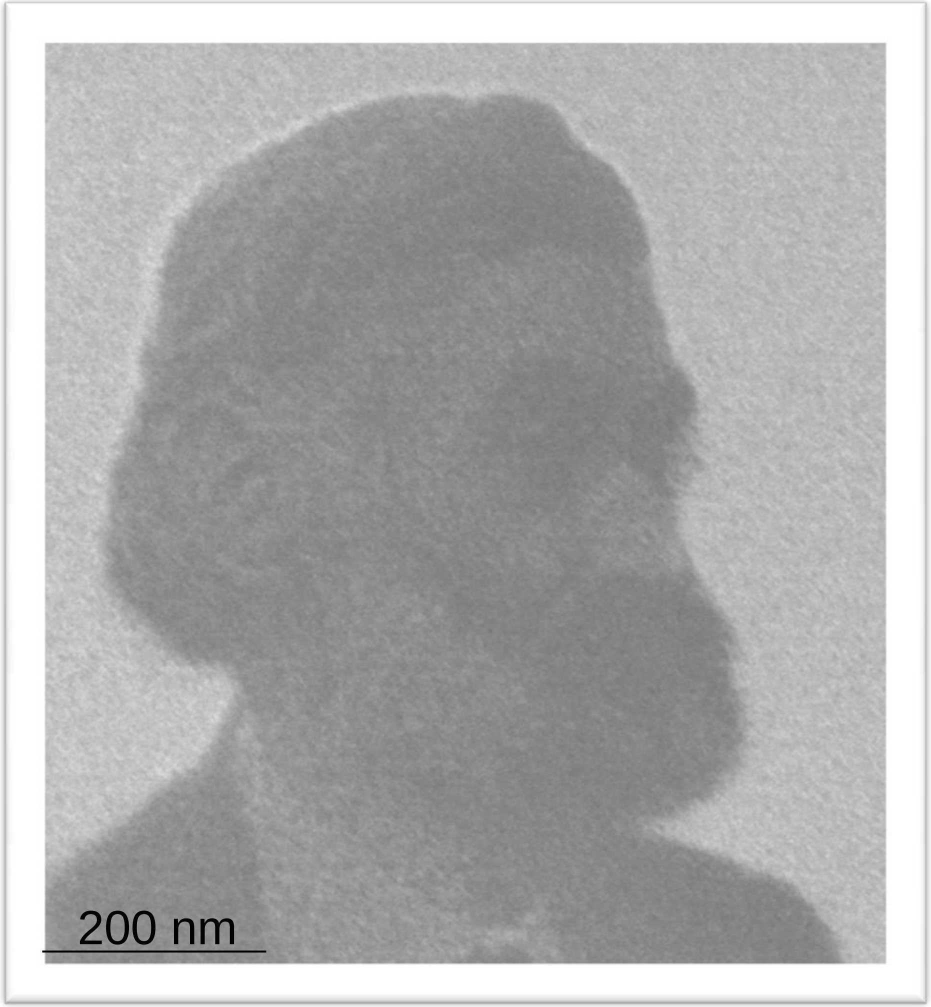
Nanofabrication with He/Ne – Motivation

- Interest in fabrication in 1-100nm size range.
- Gallium works well for rapid removal of large amounts of matter but not for fabricating structures below 30nm
- With helium and neon ion beams we can fabricate smaller structures with greater precision and control.

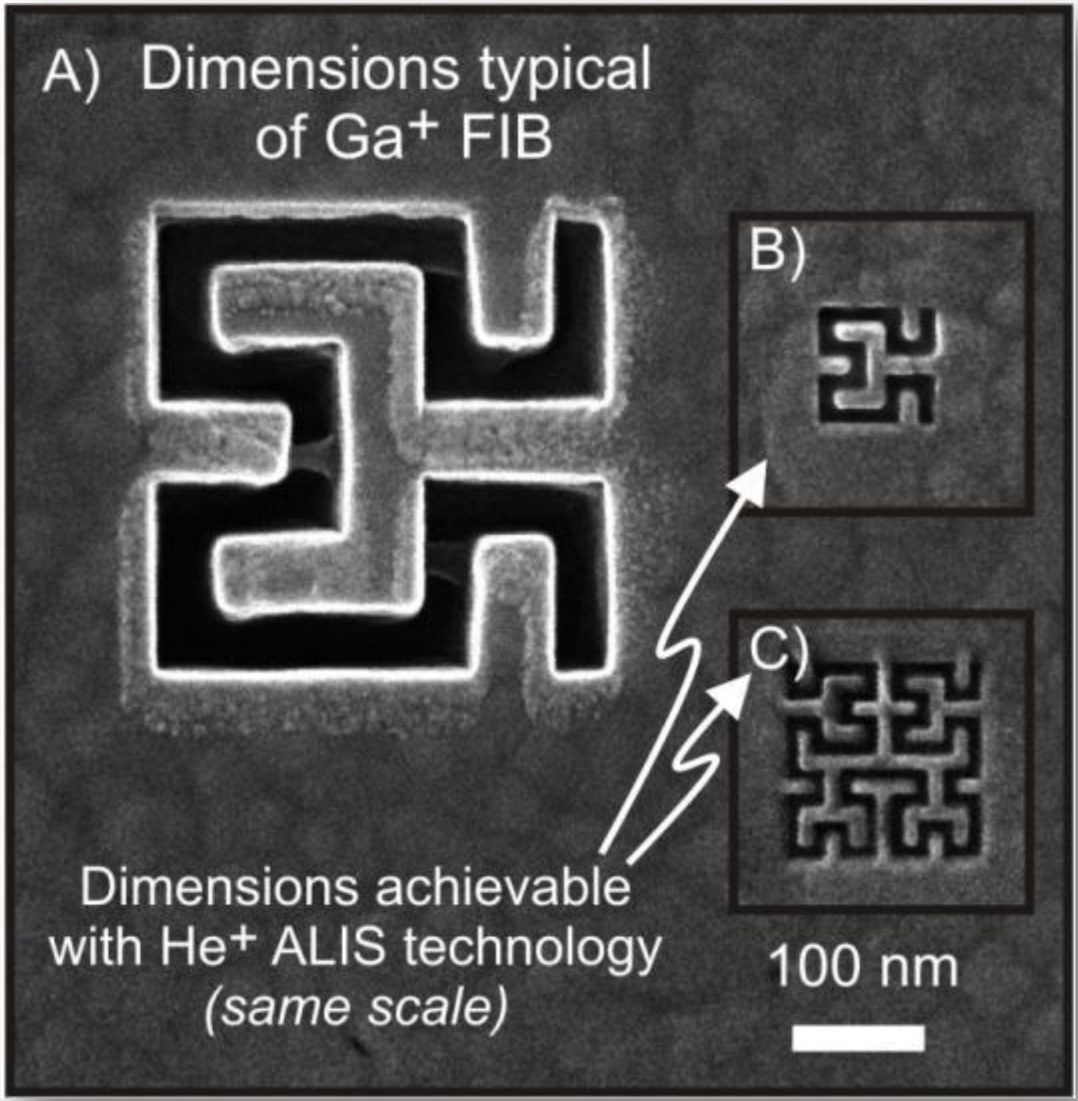


Nanopores
Plasmonics
Deposition
Large Array Photonics

Ernst Abbe below his own limit

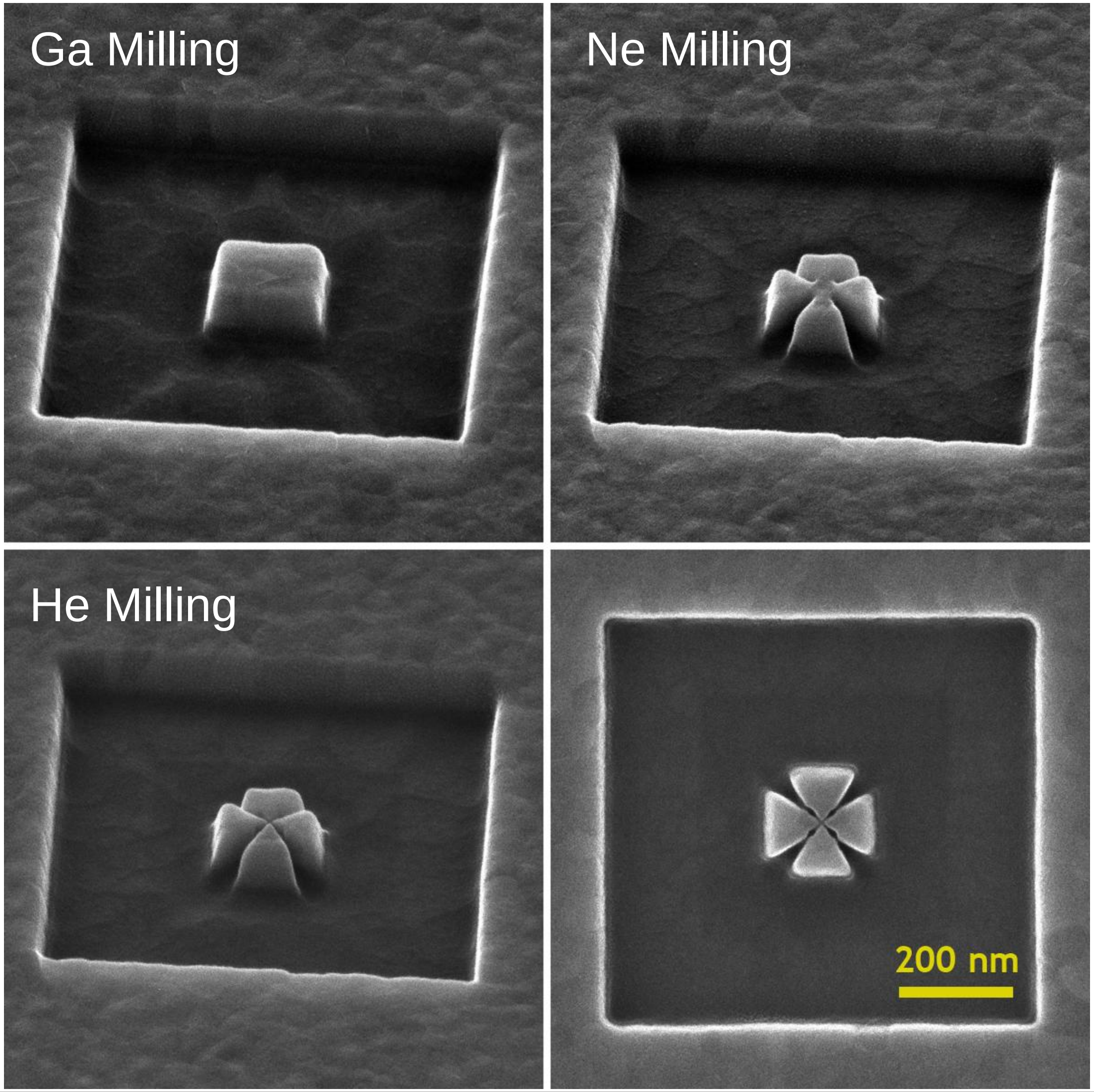


Ion Beam Milling
Ga FIB vs. Helium Ion Beam



Courtesy: Dan Pickard, NUS

Multi-ion beam machining



Unique Attributes: Helium Ion Microscopy

HIM Benefits

Resolution – small probe size (0.35nm) allowing high resolution imaging; 3X better resolution than FESEM; 4X higher secondary yield; 0.5-15 pA probe current

Surface Detail – signal produced from the top 2-5nm of the sample surface, higher surface sensitivity than SEM

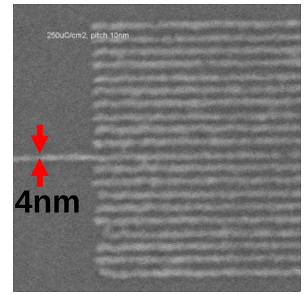
Depth of Field – ~5X higher depth of field than high resolution Field Emission SEMs

Charge Control – ability to image insulating samples without any surface coatings and no charging artifacts, better charge control than SEM

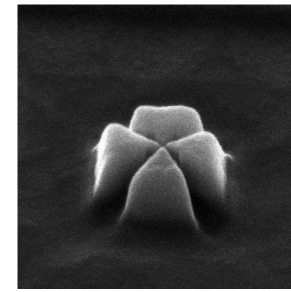
Low Sputter Rates – precise and controlled fabrication of sub-10nm structures, not possible with Ga FIB

Applications Focus Areas

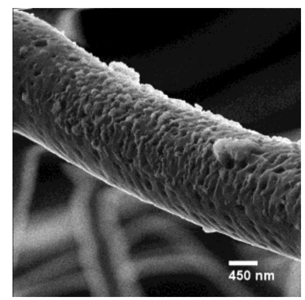
Nanofabrication



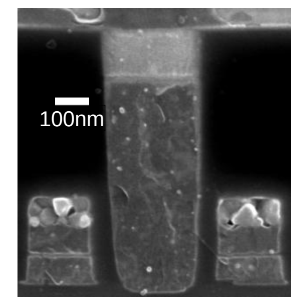
Lithography


Nanophotonics

Mat. Imaging

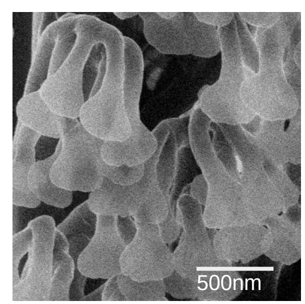


Polymer Imaging

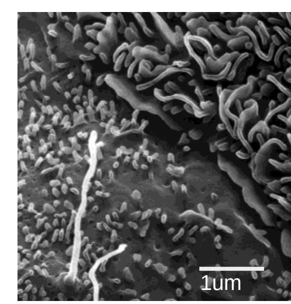


Failure Analysis

Organic Imaging



Biomimetics

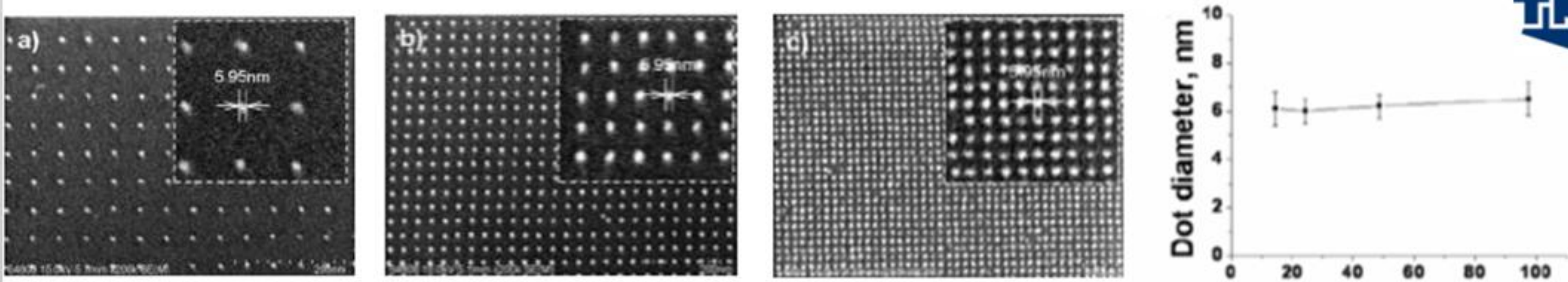


Cellular Ultrastructure

Key Applications

1 Lithography

6 nm dots irrespective of pitch – NO PROXIMITY EFFECT



Pitch = 48 nm

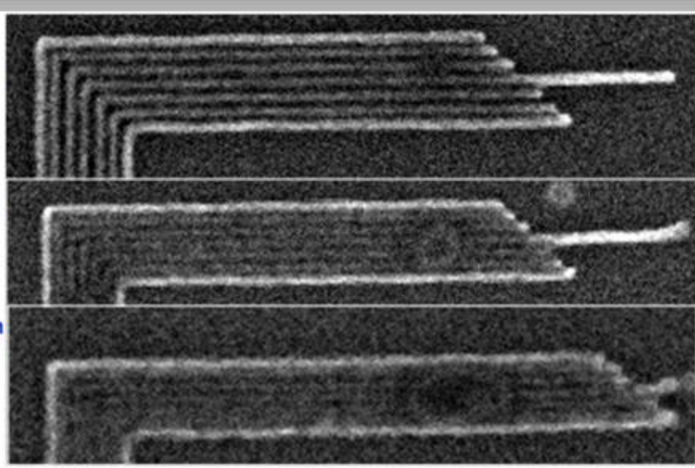
Pitch = 24 nm

Pitch = 14 nm

Half-pitch = 5 nm
Dose = 68 ions/nm

Half-pitch = 4 nm
Dose = 56 ions/nm

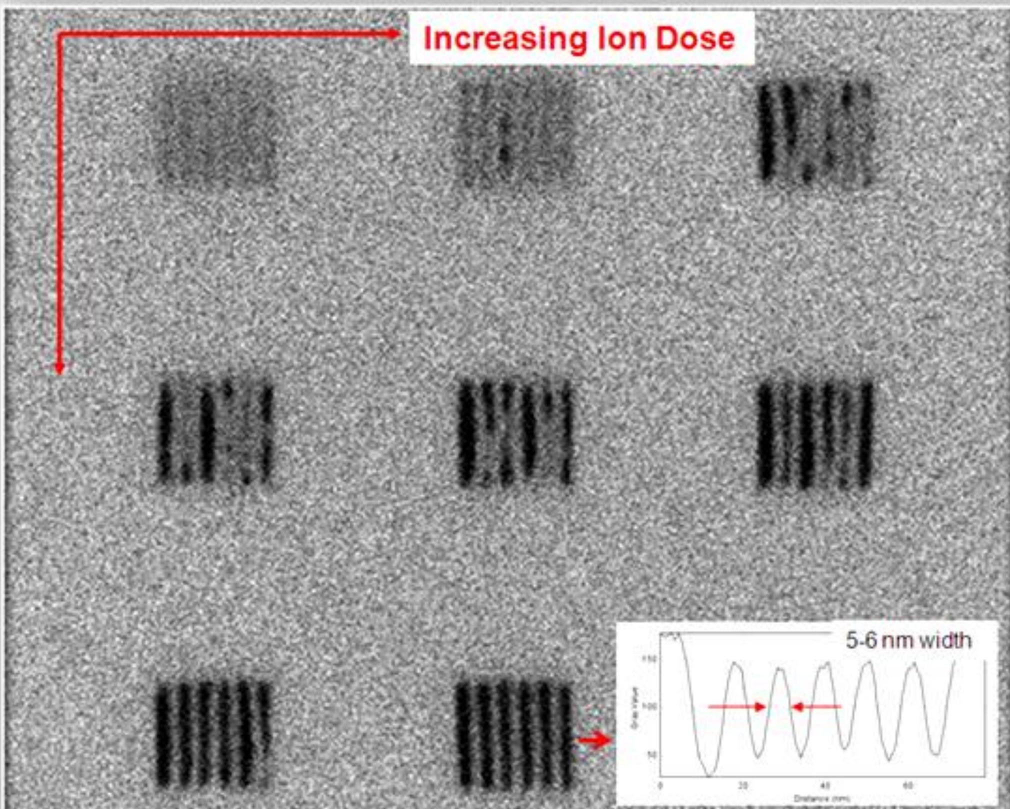
Half-pitch = 3.5 nm
Dose = 49 ions/nm

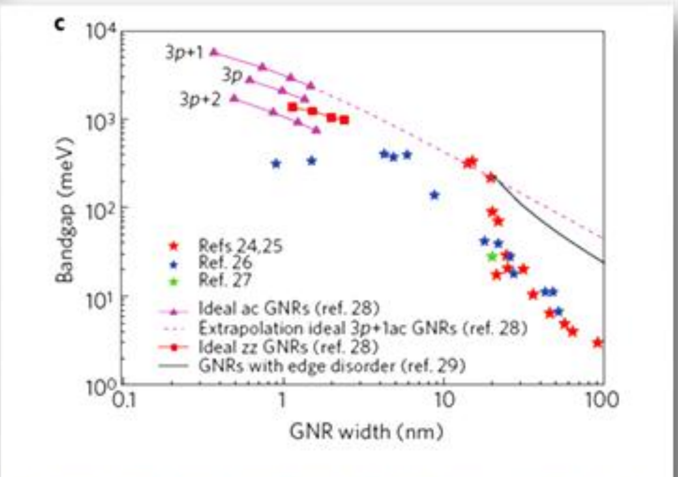


- Structures patterned in resist using helium ions show no proximity effect i.e. feature size does not vary with pattern density.
- Helium and neon ion beam expose resist with lower dose than electron beam due to the higher SE yield.

Key Applications

2 Graphene Patterning



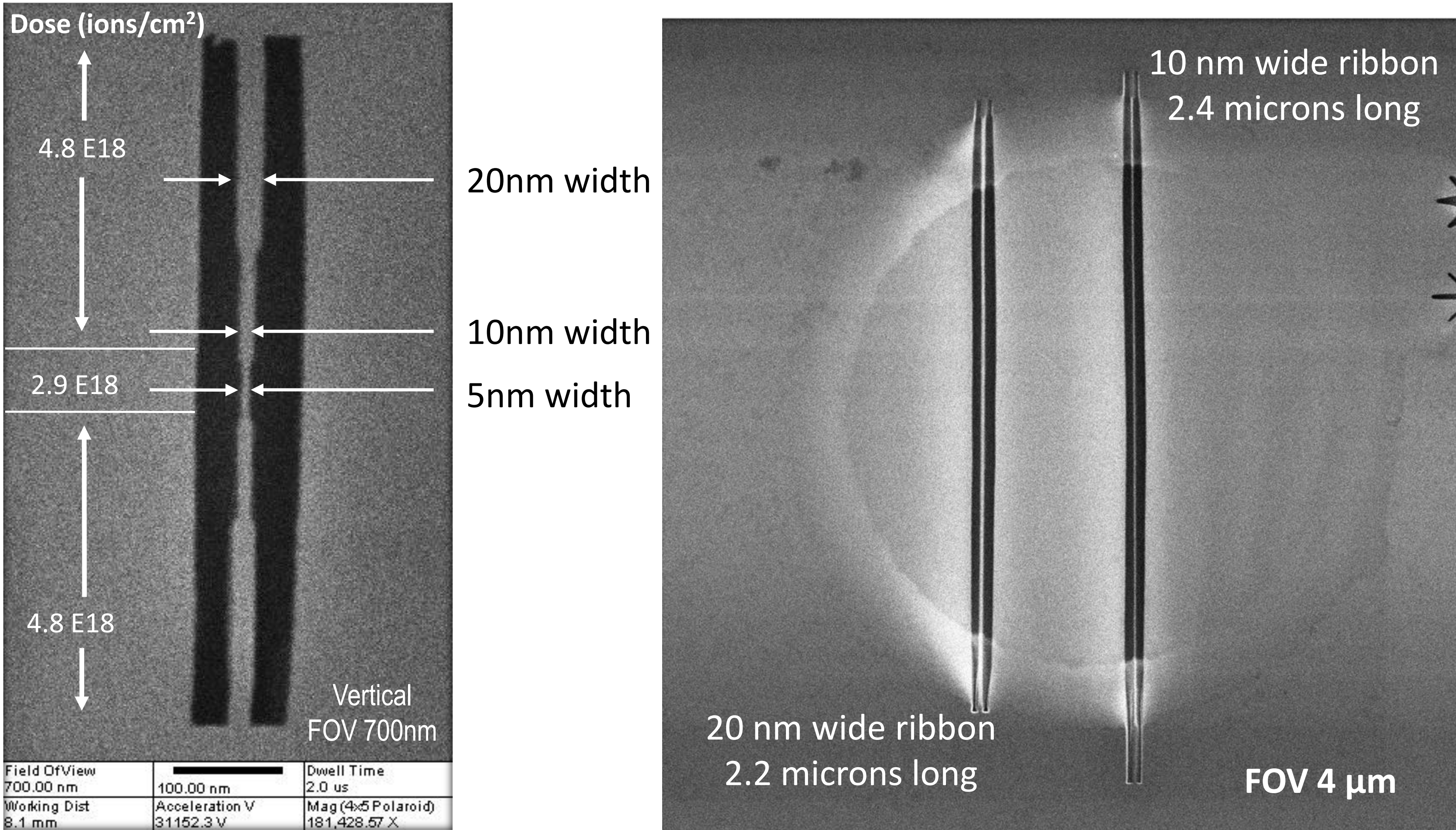


*Source: "Graphene Transistors", Nature Nanotechnology, 2010, 5, 487-496

- The bandgap of graphene can be modulated by making nanoribbons.
- Helium ions can be used to both image and pattern graphene.
- The beam dose can be easily adjusted allowing precise control of graphene machining and 5-6nm wide dense arrays can be fabricated.

He Ion Beam Milling

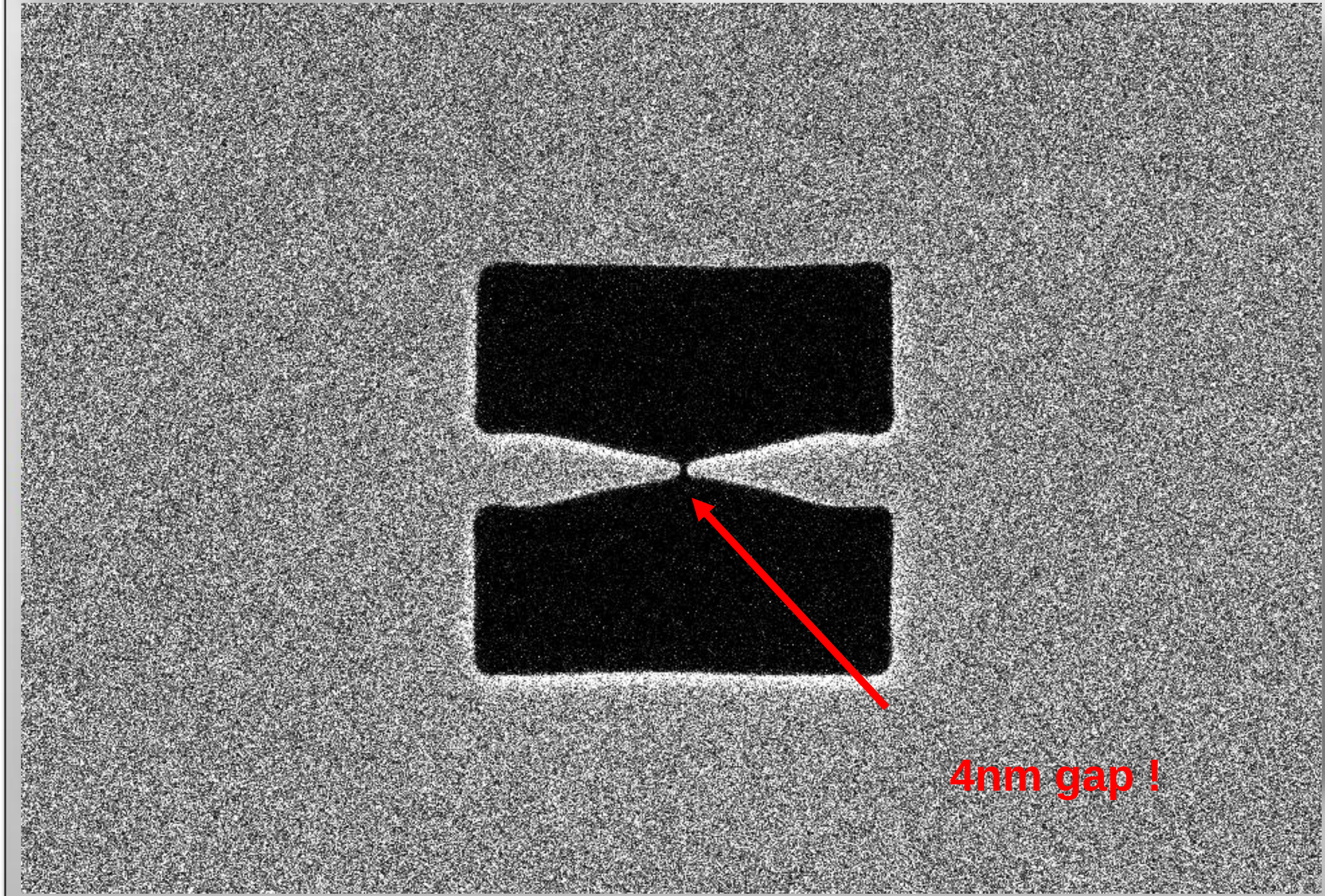
Graphene Nanoribbons (GNR)



*Courtesy: Dan Pickard, NUS

Key Applications

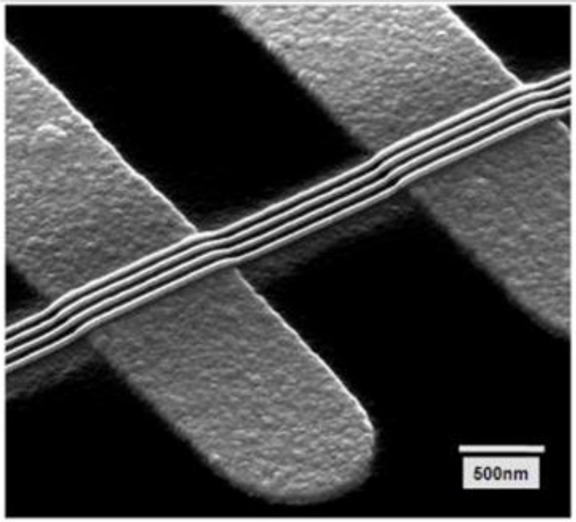
3 Plasmonics



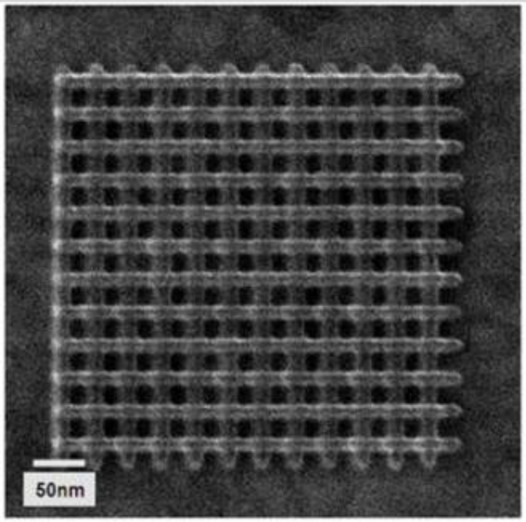
- Surface plasmon resonance is the basis for a number of sensor applications.
- Helium ion beam can be used for structuring these at smaller length scales than the Ga-FIB which is critical for performance.
- The helium ion beam preserves the atomic level structure with minimal lattice disruption.

Key Applications

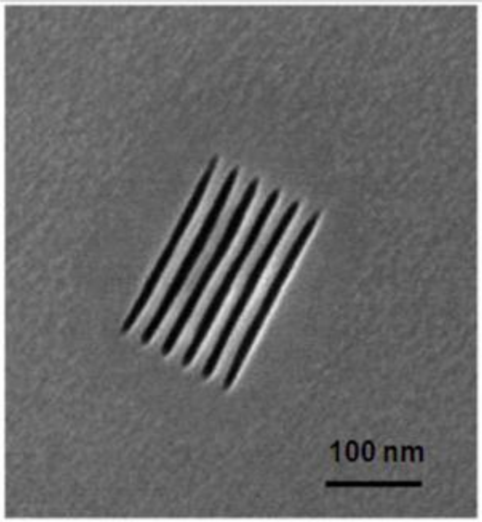
4 Deposition and Etching



50nm metal lines with 100uΩ.cm resistivity



15nm insulators with $10^{11}\Omega$.cm resistivity

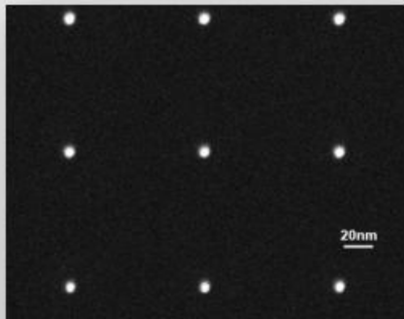


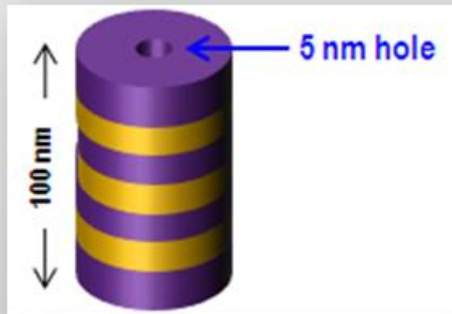
12nm lines etched in TaN absorber layer

- Helium and neon ion beams, in conjunction with gas chemistries, can be used to deposit and etch metals and insulators.
- The small probe size and insignificant beam tails result in finer deposits than possible with Ga.

Key Applications

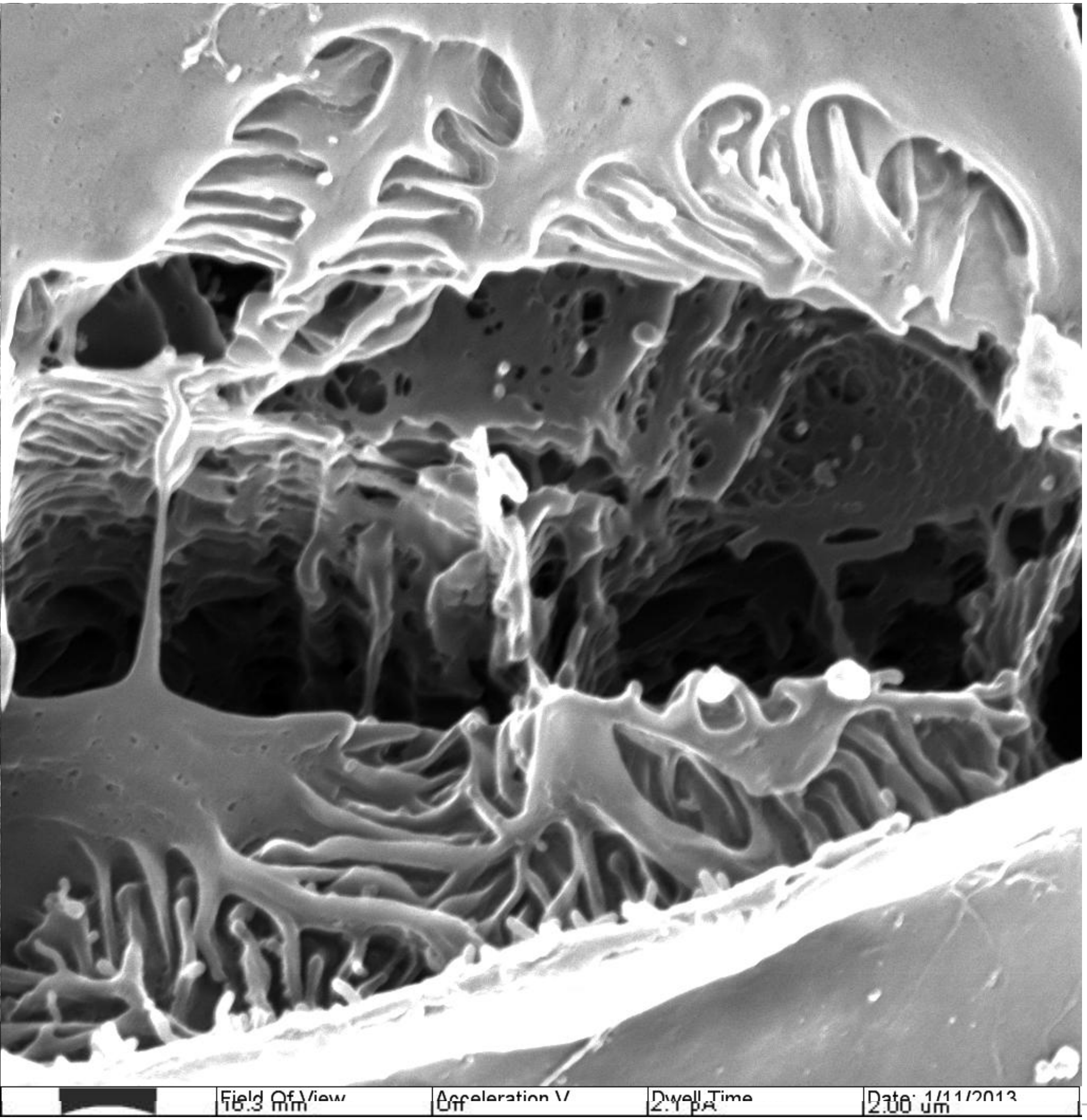
5 Solid State Nanopores

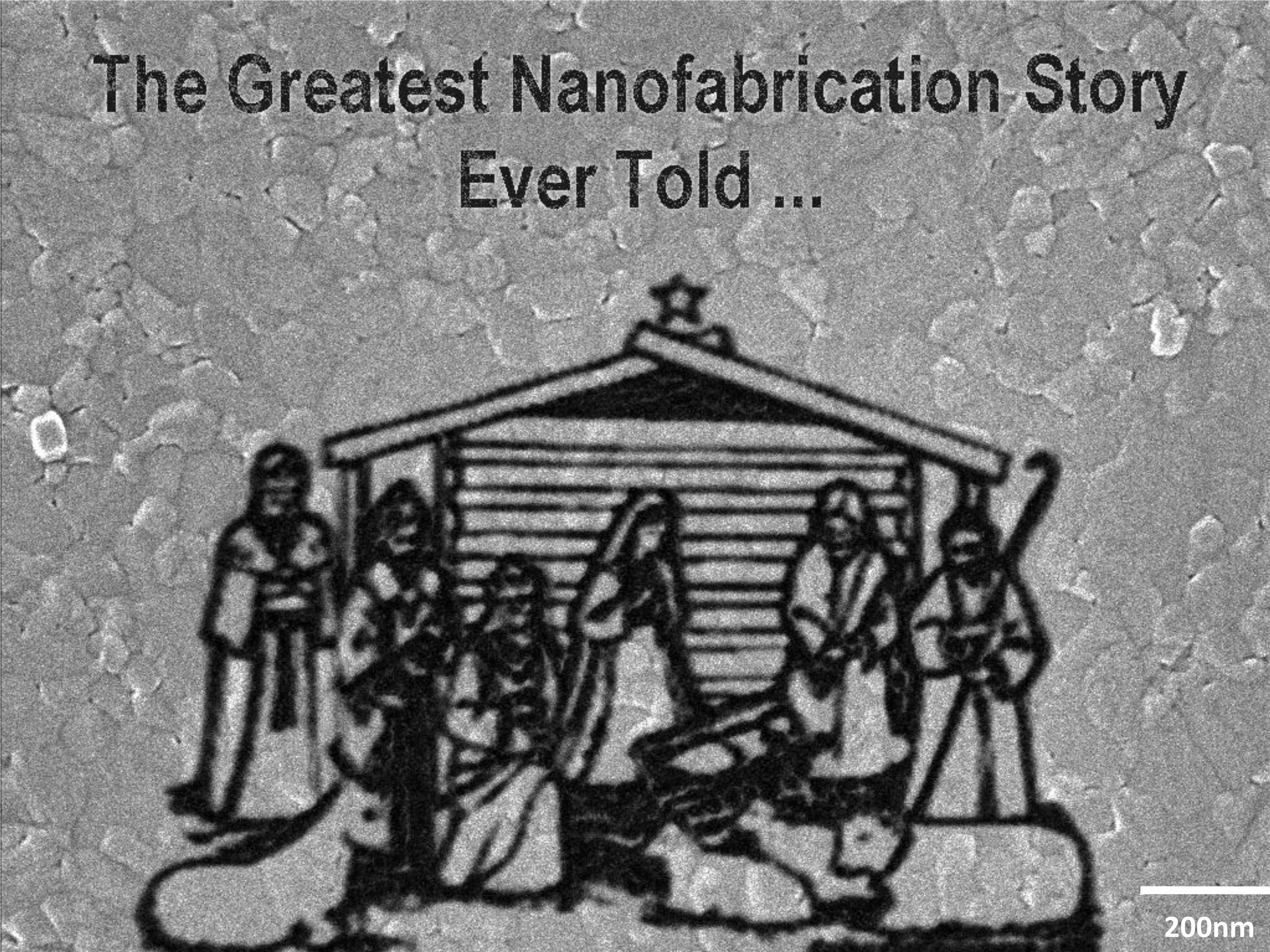




- Nanopores (ranging from 2nm-50nm) are being used for DNA sequencing and for making protein sensors.
- Conventional techniques for making solid state nanopores involve TEM (10min/pore) or FIB (20nm or larger).
- Helium ions can be used to make sub 5nm pores in 1ms-15s.
- Hole uniformity of +/-1nm

New Applications
Neon cutting of organic material




The Greatest Nanofabrication Story
Ever Told ...
200nm

ZEISS

We make it visible.