Honing Scanned Probe Lithography for Atomic-Fidelity Patterning

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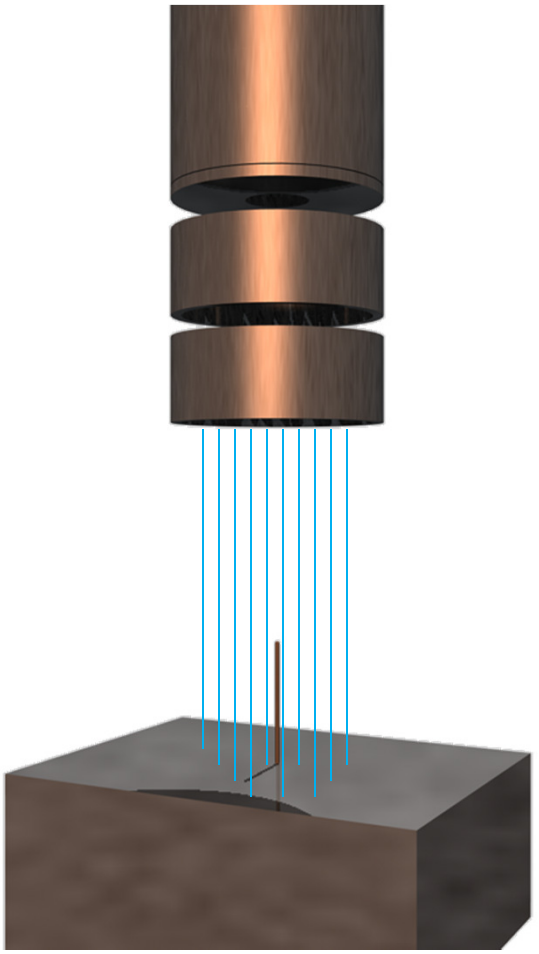
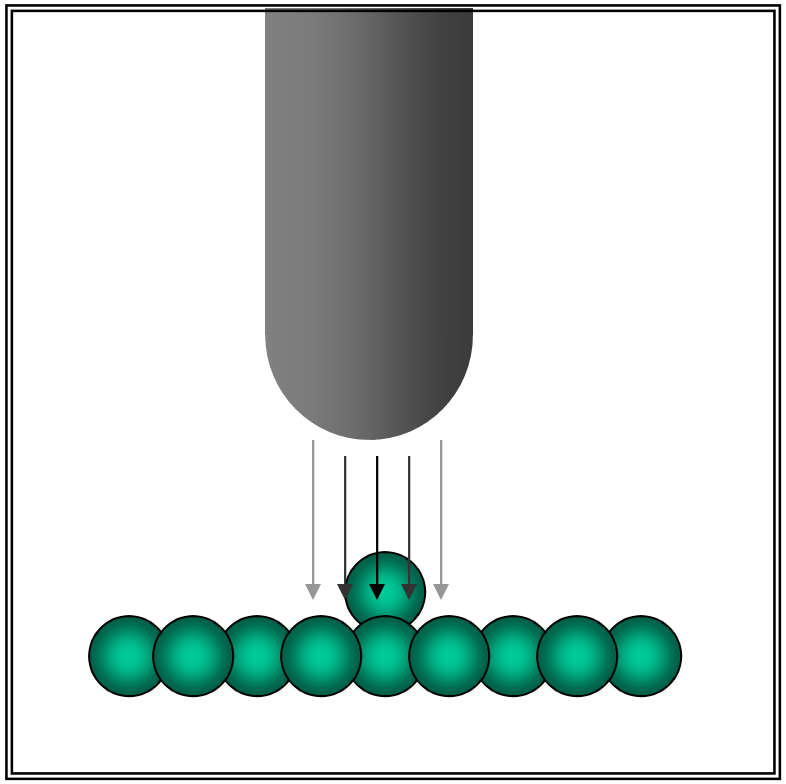
Agenda

- Background
  - Scanning Tunneling Microscopy
  - Electron Stimulated Desorption Patterning
  - Classical Sputter Sharpening
- Field-Directed Sputter Sharpening
  - Applied to Platinum Iridium Alloy
  - Applied to Amorphous Hafnium Diboride
- Electron Stimulated Desorption Patterning
  - Comparing FDSS to Classical Techniques
- Towards Atomic-Fidelity Patterning
  - Atomic-Scale Nanoboxes
  - Lithographic Features with 4-Atom Pitch
  - Large Two-Dimensional Patterns



Background and Motivation – Scanning Tunneling Microscopy

Scanning Tunneling Microscopy



$$D \approx 0.7\sqrt{\frac{R}{\kappa}}$$

Scanning Tunneling Microscopy Probes

- Confinement of electron tunneling current
- Reduction of tip-induced broadening

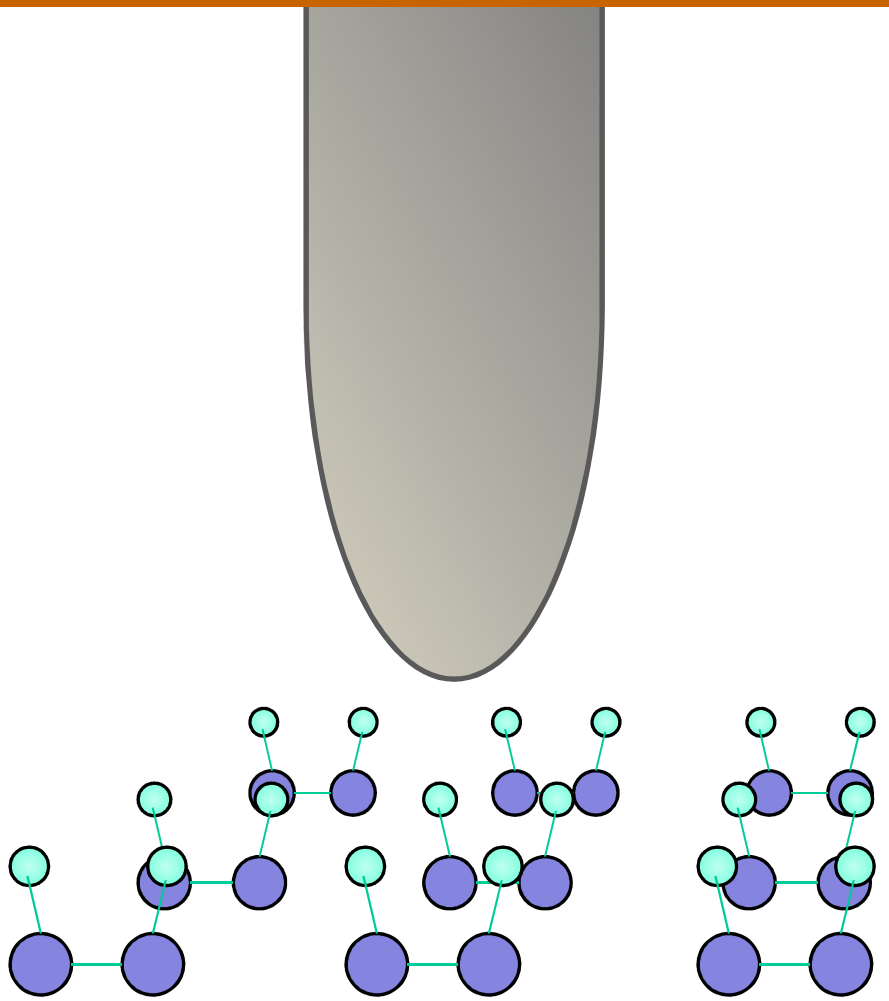
Point Field Emission Sources

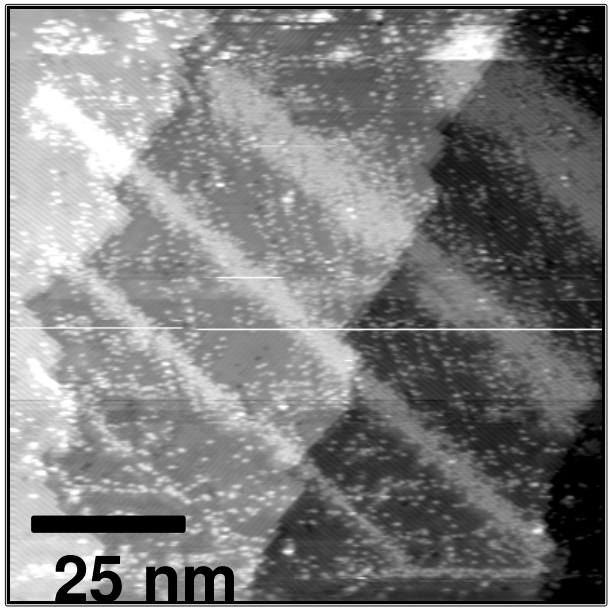
- Electron Microscopy
- Field-Emitter Arrays / Plasma Displays

Field-Ionization Point Sources

- Focused Ion Beam Etching

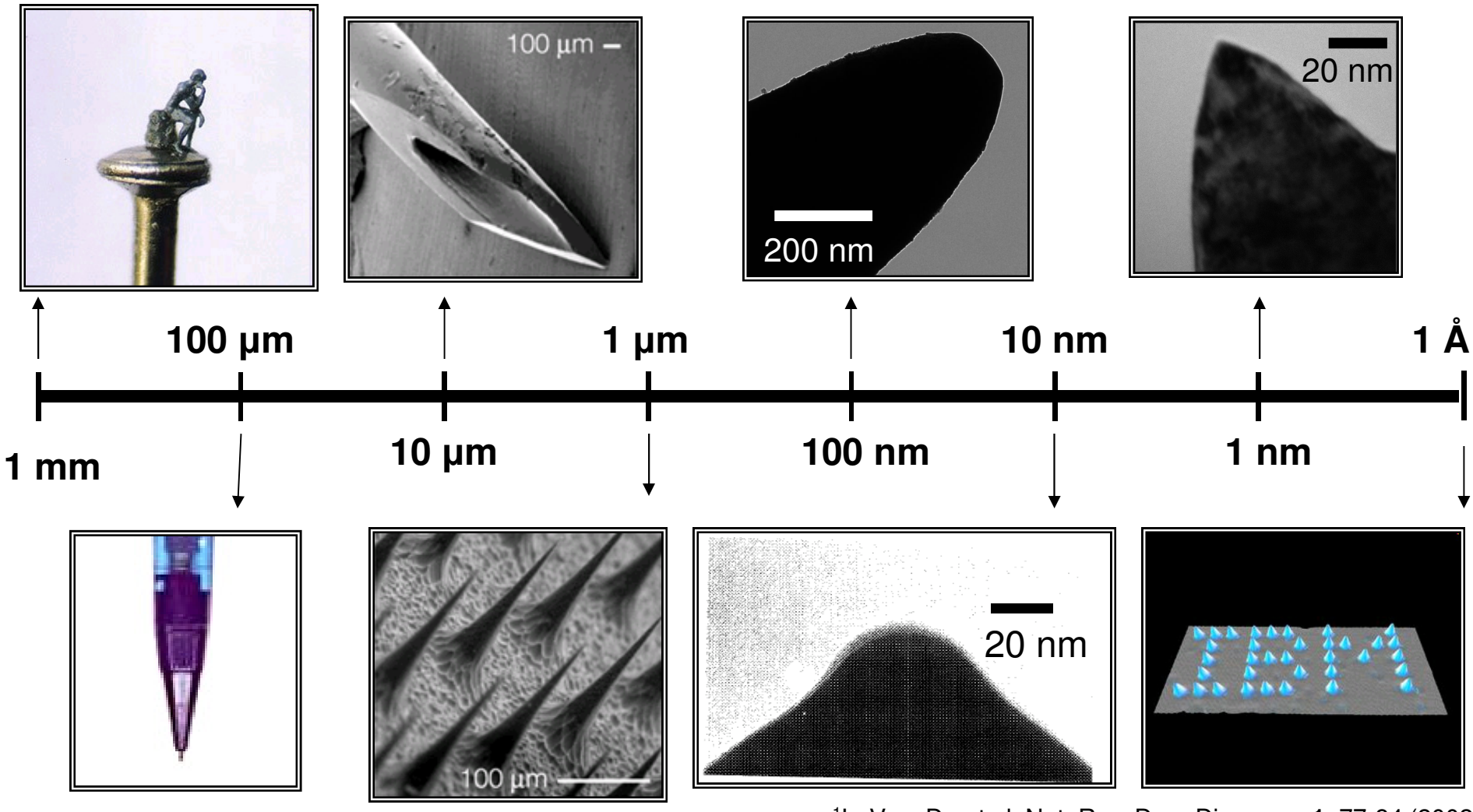
Background and Motivation – Electron Stimulated Desorption





2nA, 2×10^{-3} C/cm
Voltages: 4V, 4.5V, 5V, 5.5V, 6V, 6.5V

An Appreciation of Scale



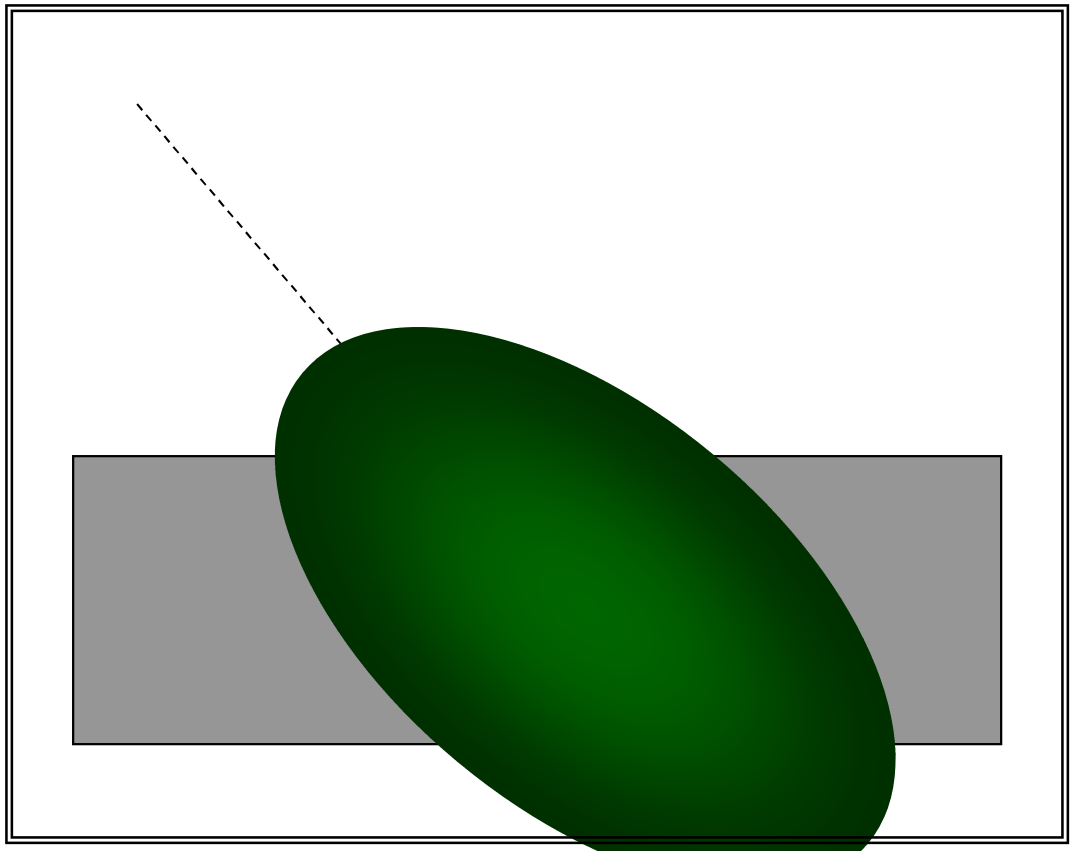
[1]LaVan, D., et al, Nat. Rev. Drug Discovery **1**, 77-84 (2002)

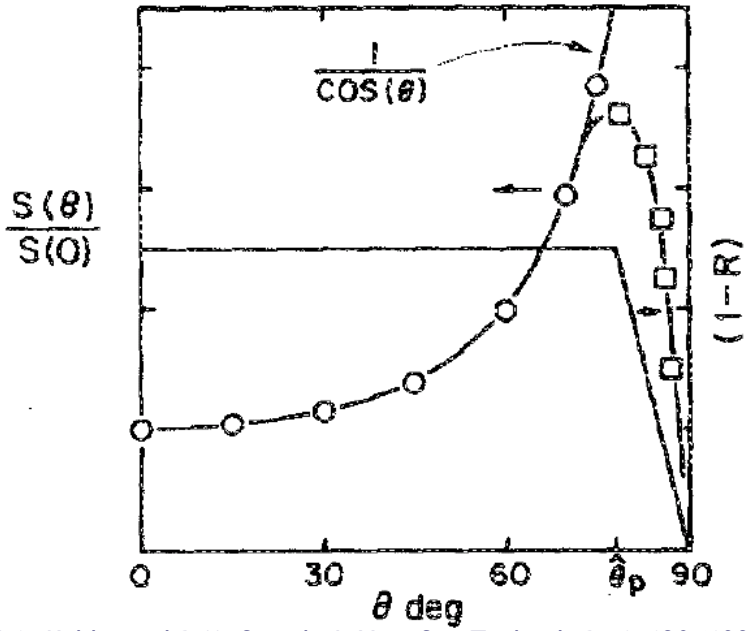
[2]Kubby, J.A., Siegel, B.M., J. Vac Sci Technol. B **4**, 1 (1986)

[3]Eigler, D.M., Schweizer, E.K., Nature **344**, 524-526 (1990)

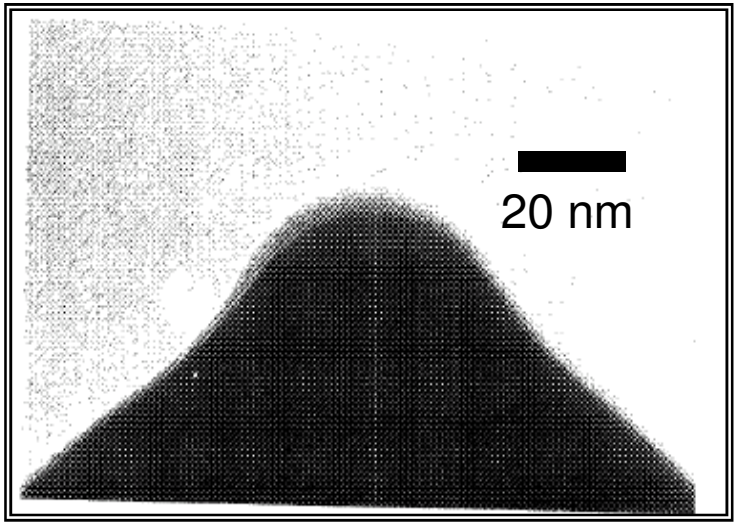
[4]Willard Wigan Collection, http://www.willard-wigan.com/

Background – Classical Sputter Erosion





J.A. Kubby and B.M. Siegel, J. Vac. Sci. Technol. B, 4, 120 (1986)

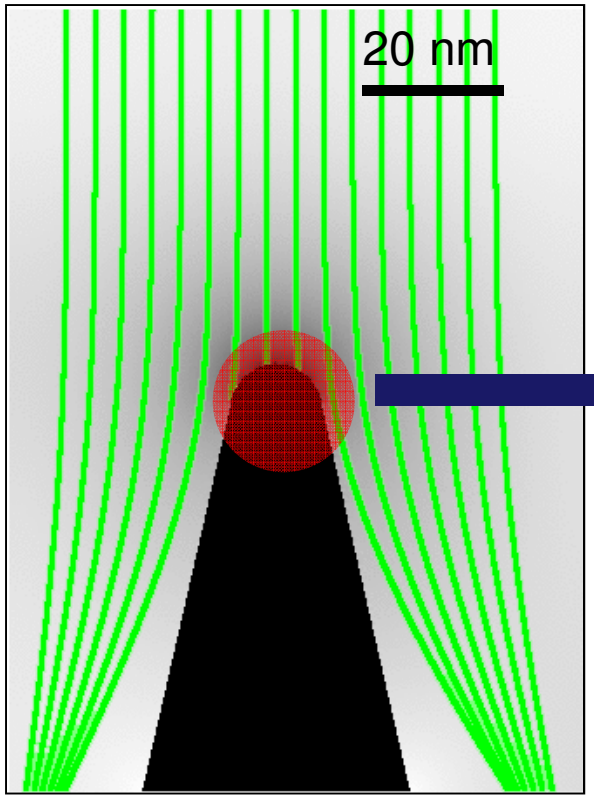


P. Sigmund, J. Mat. Sci., 8, 1545 (1973)

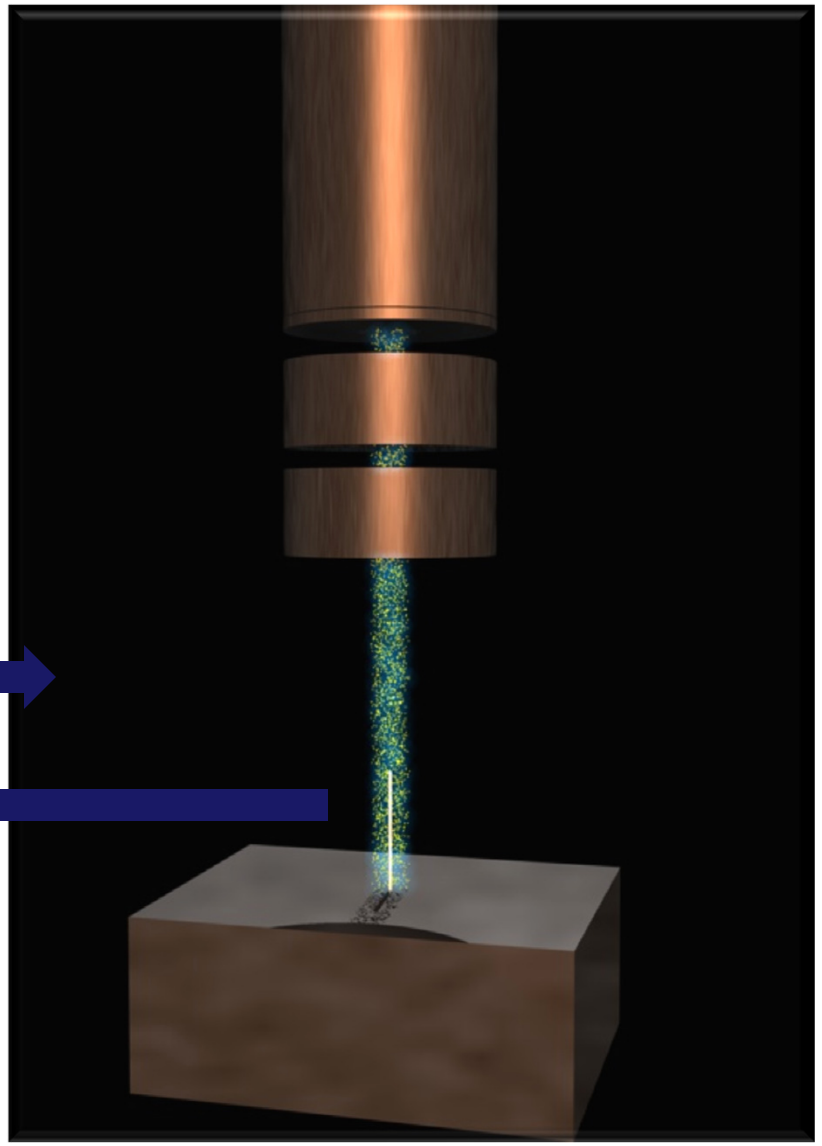
 J.A. Kubby and B.M. Siegel, J. Vac. Sci. Technol. B, 4, 120 (1986)

Field-Directed Sputter Sharpening

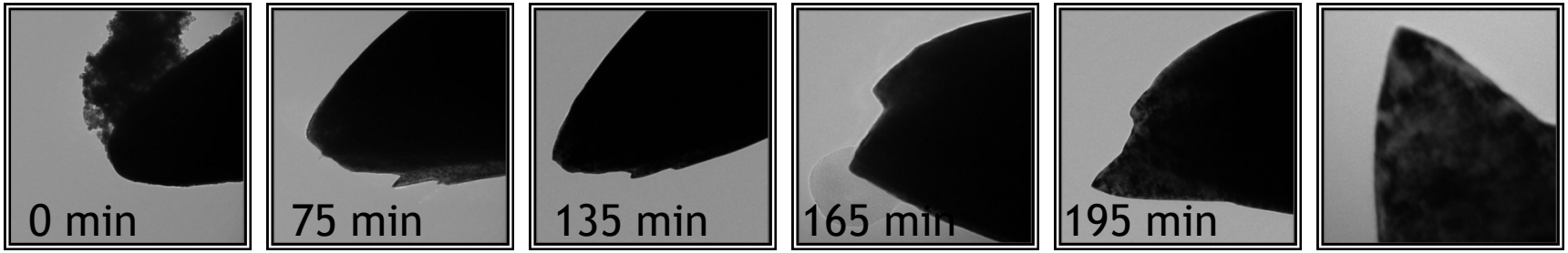
- Unfocused Ion Beam Bombardment
- Conventional Sputter Sharpening
- Field-Directed Sputter Sharpening

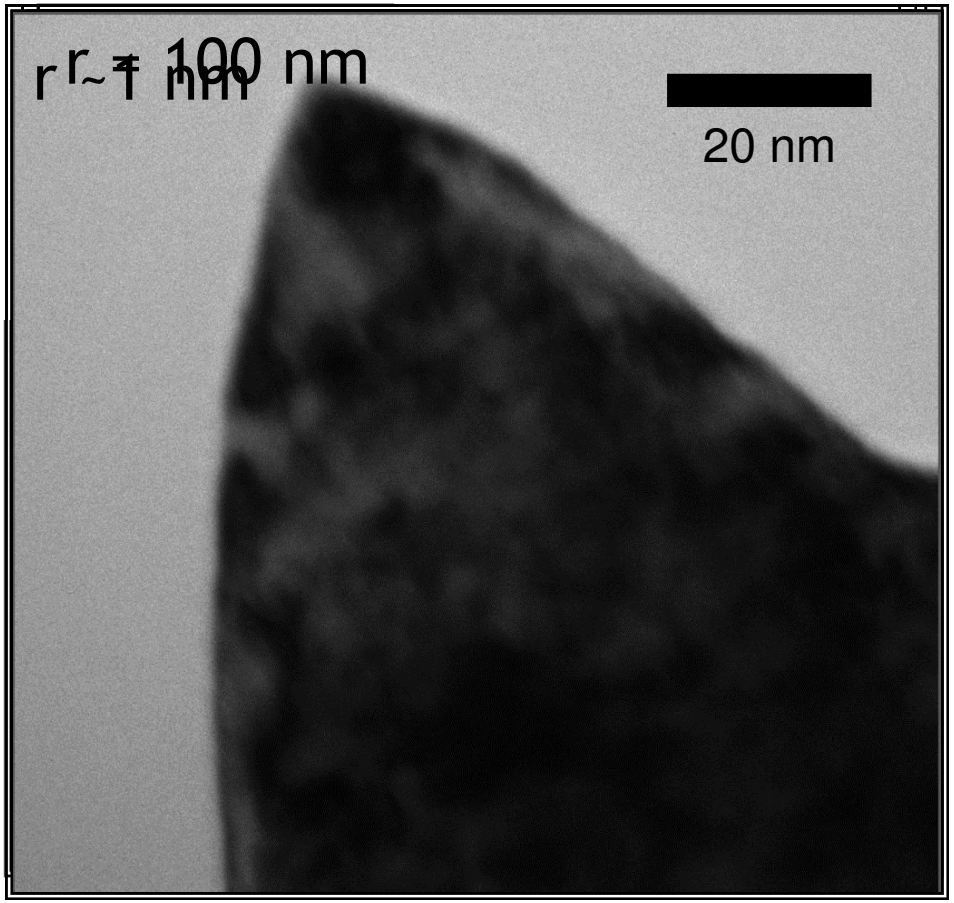


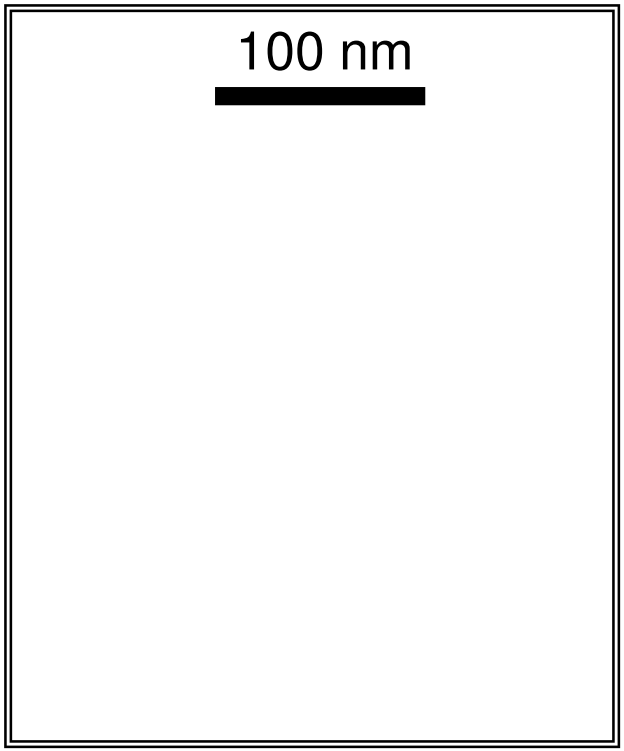
800V/1800V V_r = 0.444



Field-Directed Sputter Sharpening: Platinum-Iridium



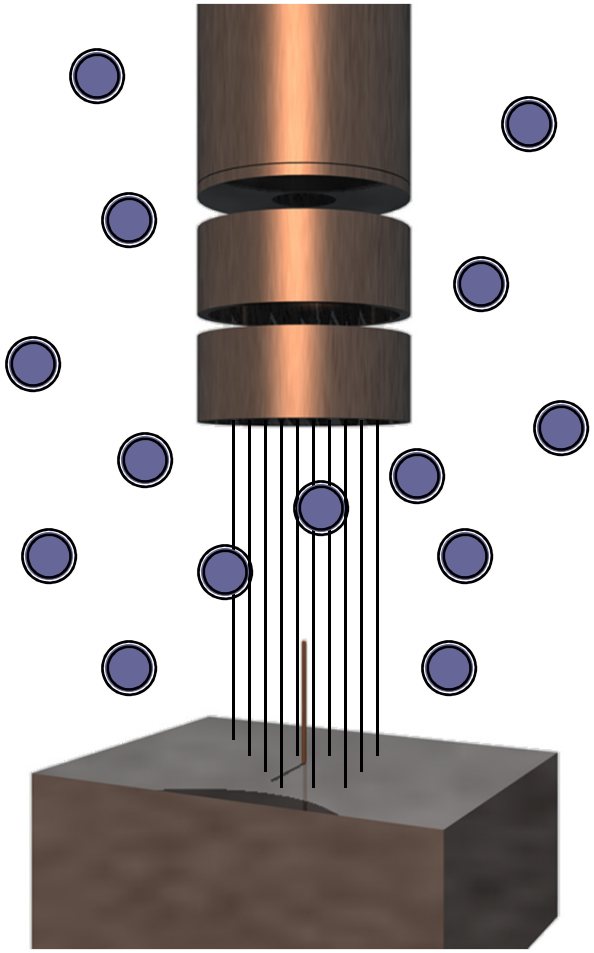




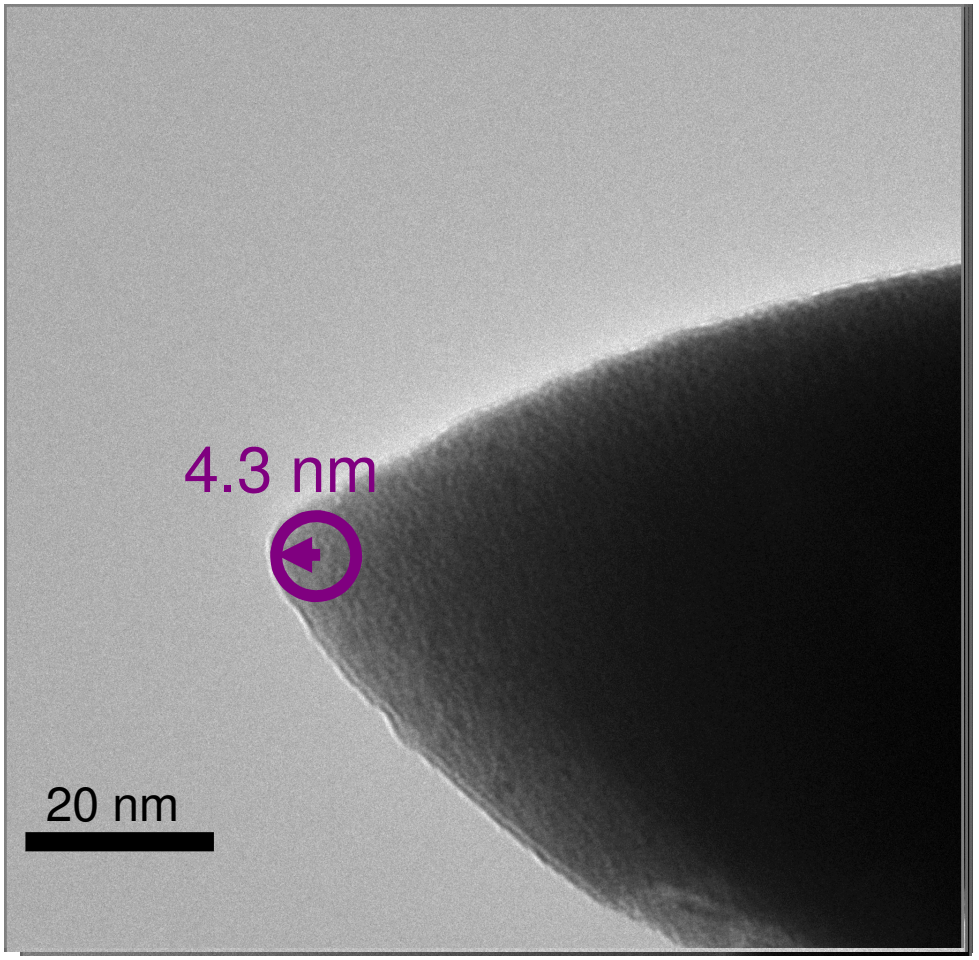
2 keV Ar+ 400V tip bias, Reduced ion current density

Tip from Material Analytical Services Inc. mastest.com

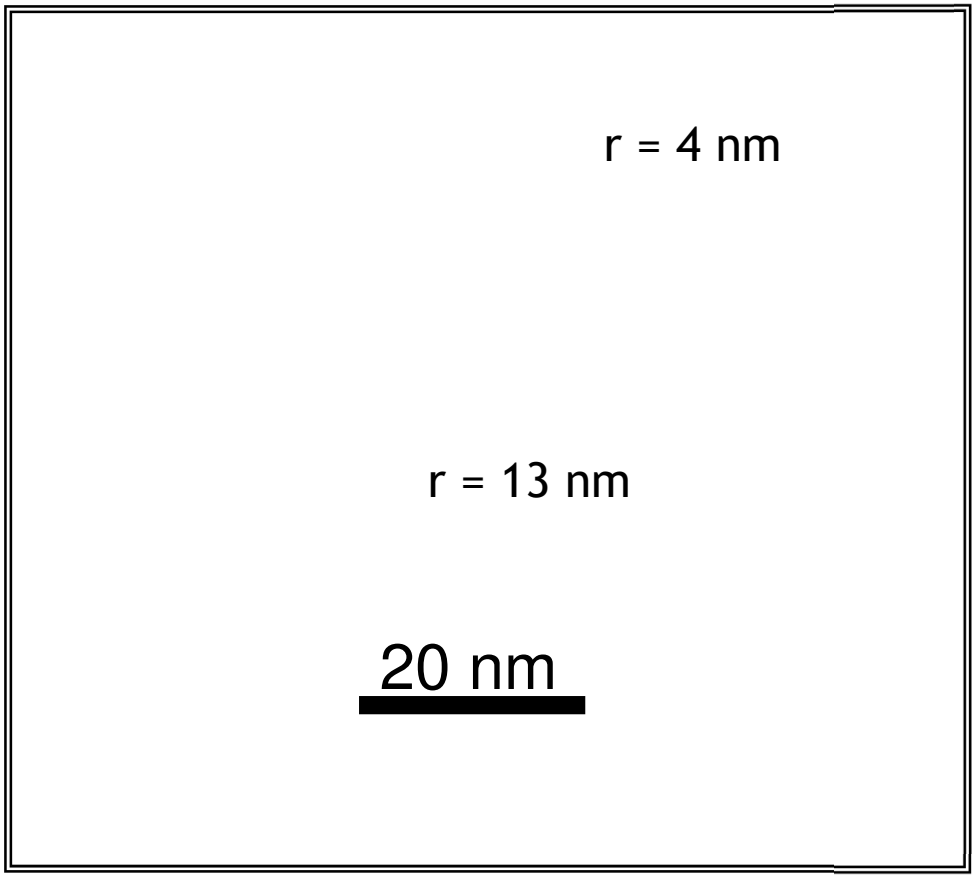
Field-Directed Sputter Sharpening: Hafnium Diboride



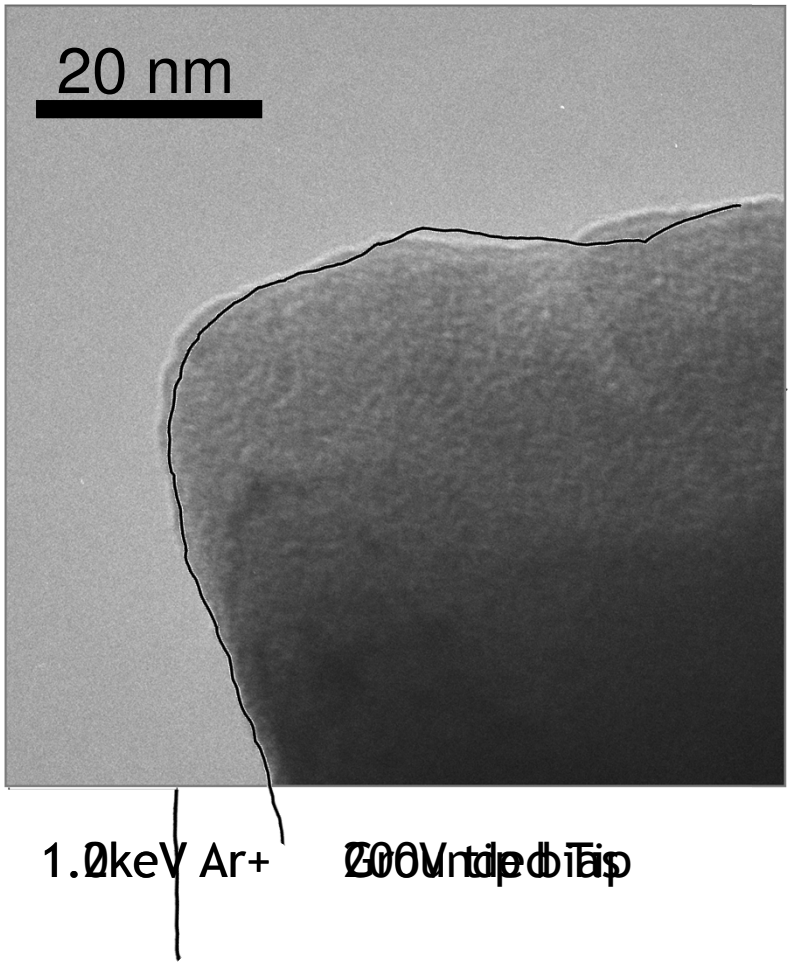
1200eV Ar+, 200V, Hafnium Diboride Tungsten



Field-Directed versus Classical Sputter Sharpening

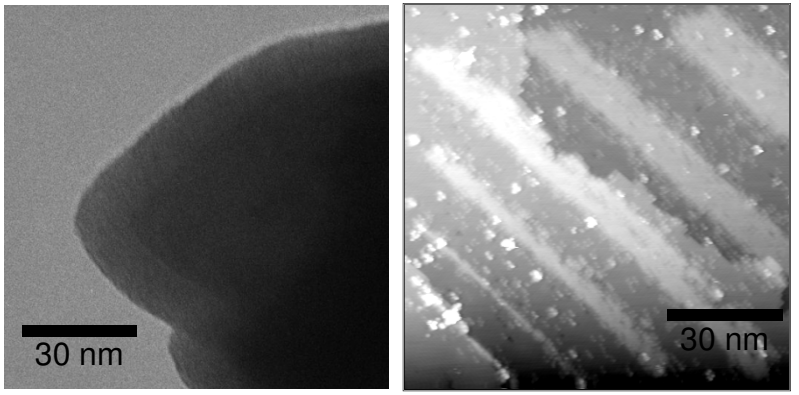


HfB_2 Film, Tungsten Core

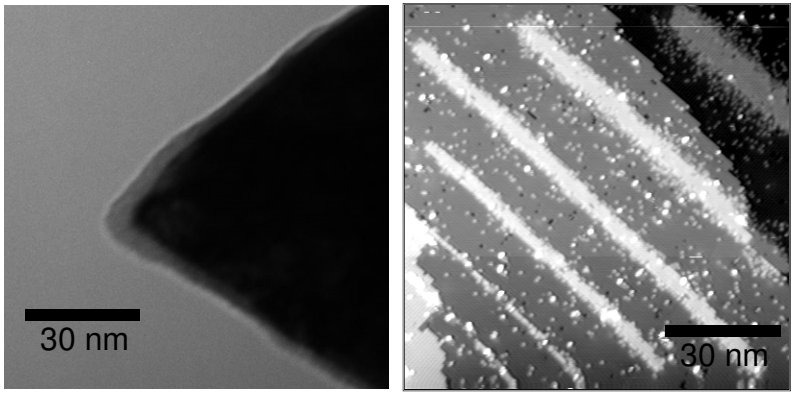


Electron Stimulated Desorption Patterning

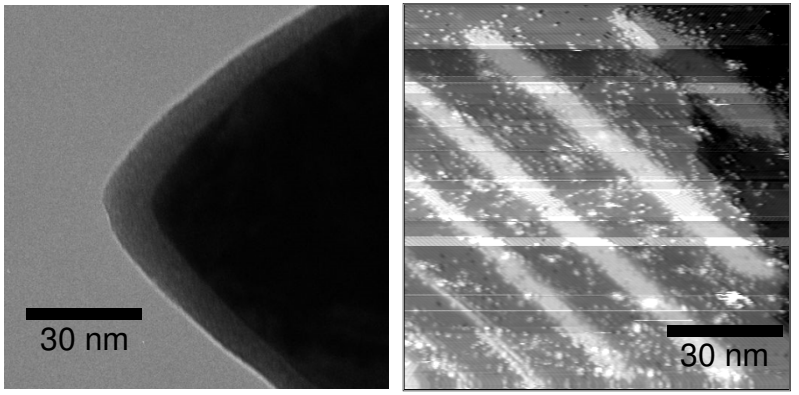
Electrochemical Etching
Core Radius: 5±1 nm
Oxide Radius:11.5±0.5 nm



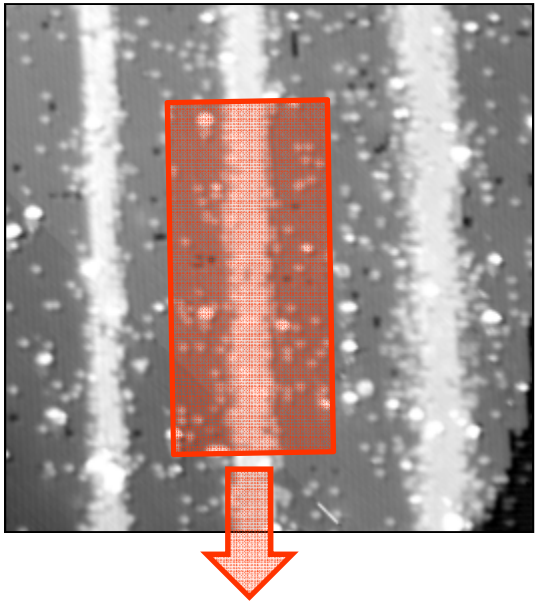
FDSS - V_r = 0.286 (1400/400)
Core Radius: 2±1 nm
Oxide Radius: 5.5±0.5 nm

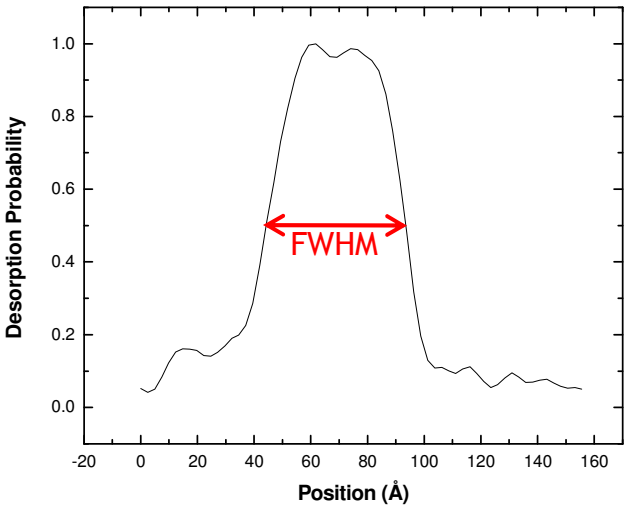


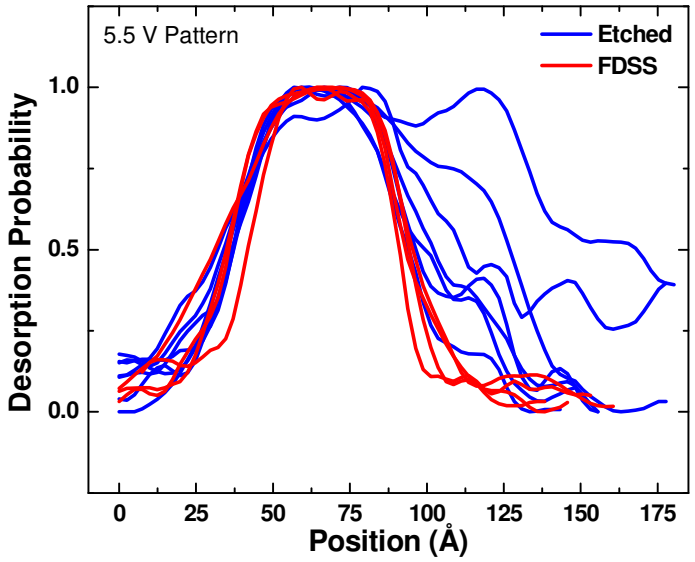
Control - V_r = 0 (1000/0)
Core Radius: 8±1 nm
Oxide Radius: 12.0±0.5 nm

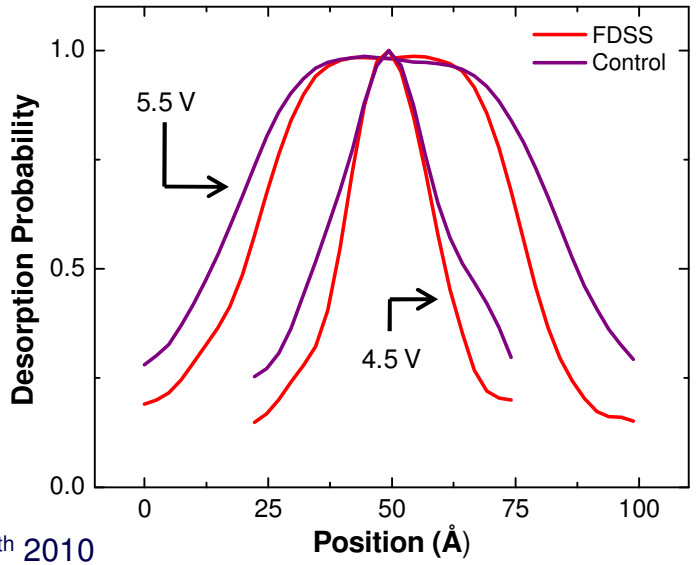


Electron Stimulated Desorption Patterning







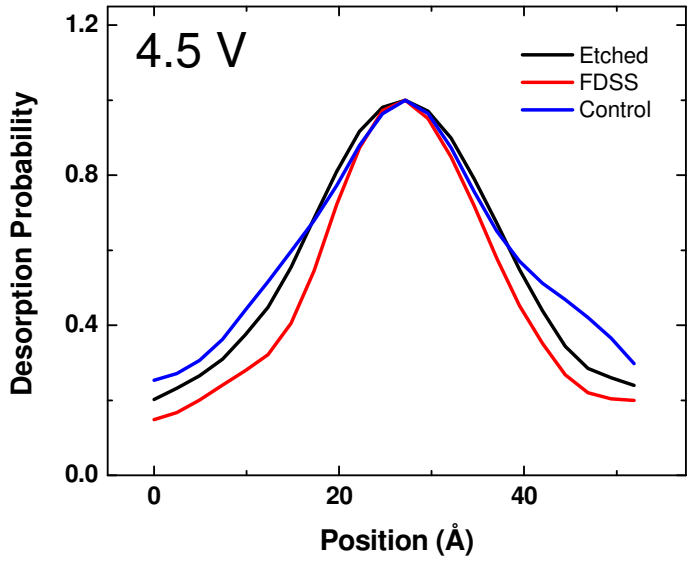


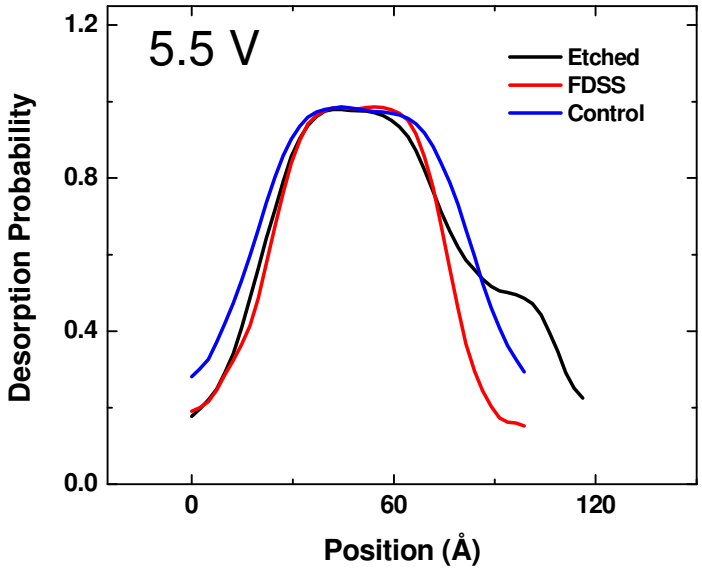
Electron Stimulated Desorption Patterning

4.5 V Patterns	Etched	FDSS	Control
Mean Width (nm)	2.8	2.2	3.1
Std. Dev. (nm)	0.6	0.4	0.9

5.5 V Patterns	Etched	FDSS	Control
Mean Width (nm)	7.9	5.8	7.3
Std. Dev. (nm)	2.7	1.1	1.1

Welch's T-Test	4.5 V Patterns	5.5 V Patterns
Etched/FDSS	p = 0.10	p = 0.10
Etched/Control	p = 0.50	p = 0.65
FDSS/Control	p = 0.06	p = 0.01

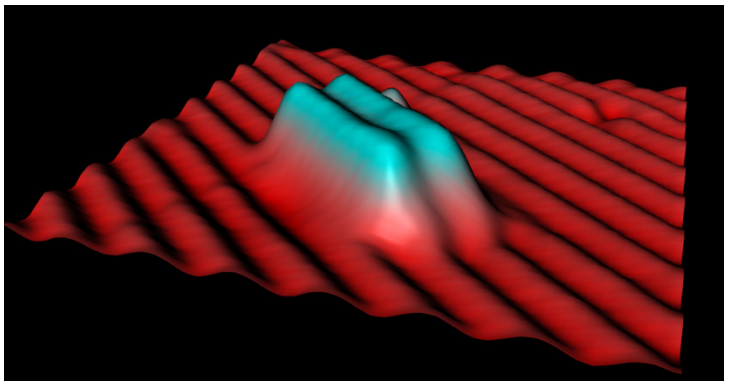




Atomically Precise Patterning of Si(100) 2x1:H Surface

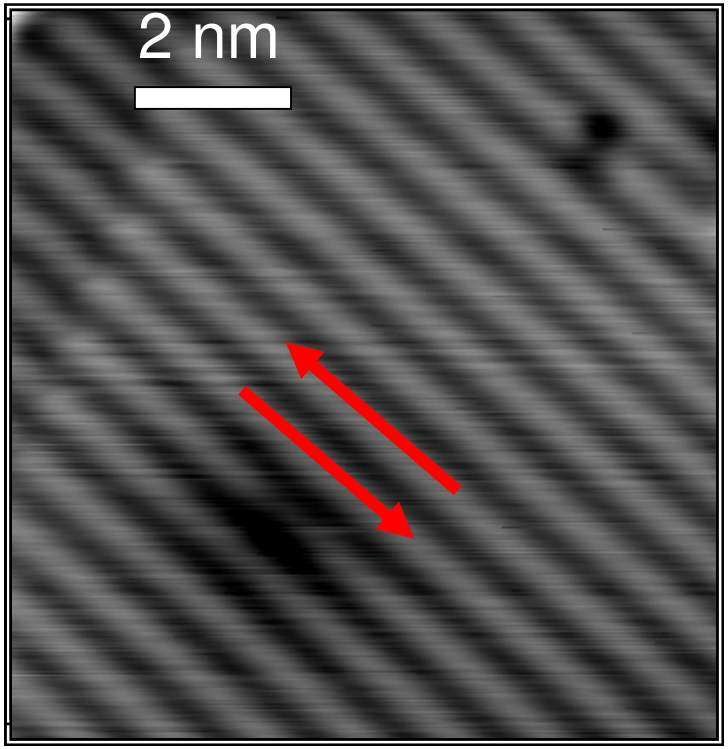
Patterning Abilities

Under optimized conditions, we demonstrate atomic-scale fidelity patterning



Nanobox patterning

We demonstrate our ability to produce nanoscale boxes of near-atomic precision in hydrogen resist.



Patterning conditions:

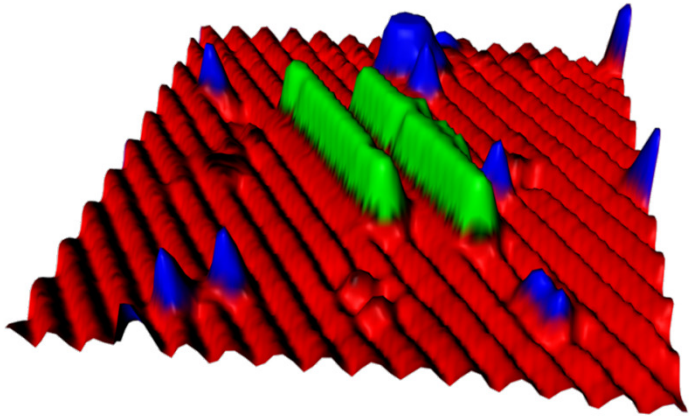
4 V, 2 nA, 2x10-3 C/cm

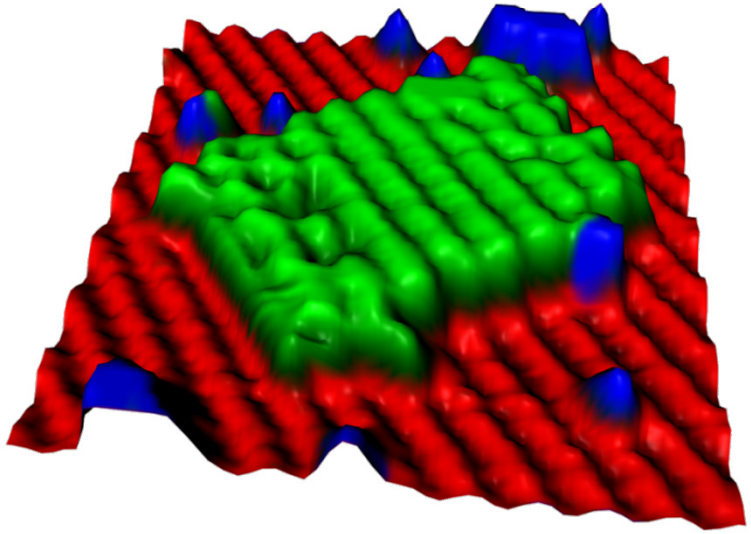
Imaging conditions:

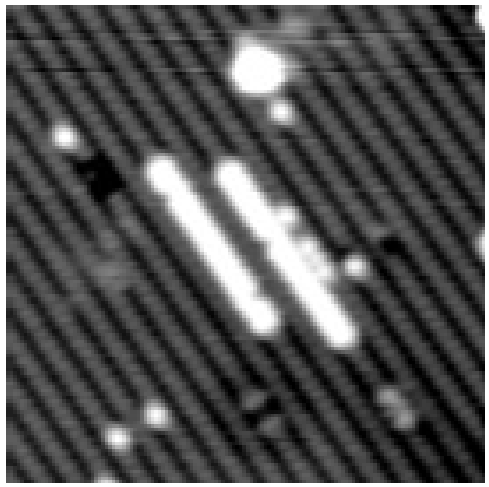
-2 V, 50 pA

Randall, J., et al., J. Vac. Sci. Technol. B, **27** (6) 2764-2768 (2009)

High-Fidelity Nanolithography







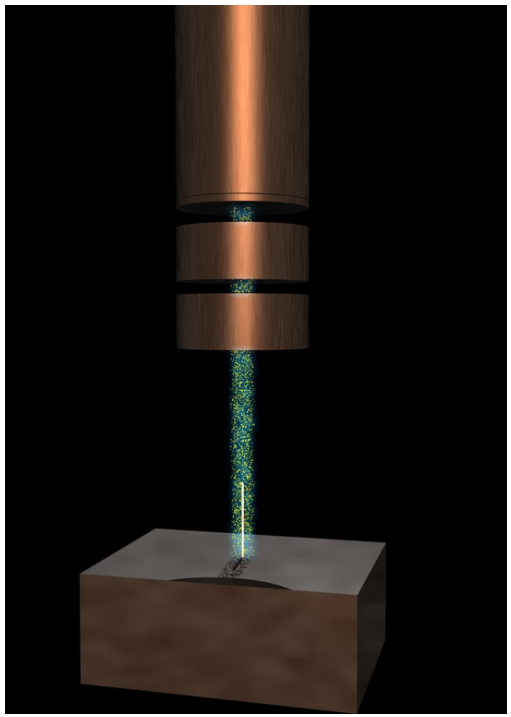
4 nm

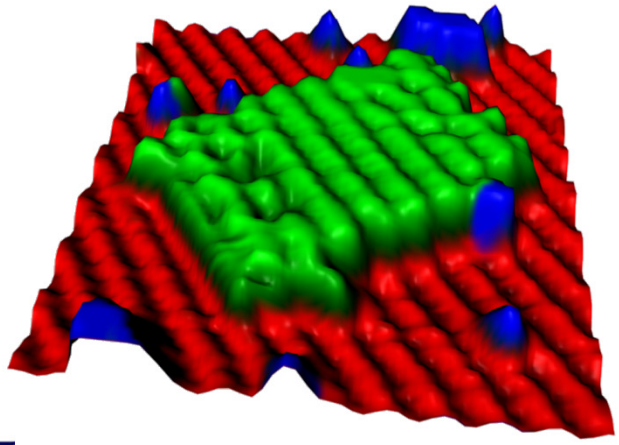
4 nm

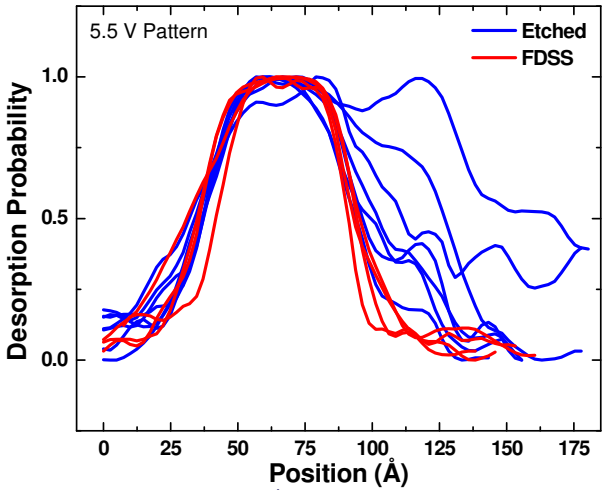
Patterning: 4 V, 2 nA, 2×10^{-3} C/cm
Imaging: -2 V, 50 pA

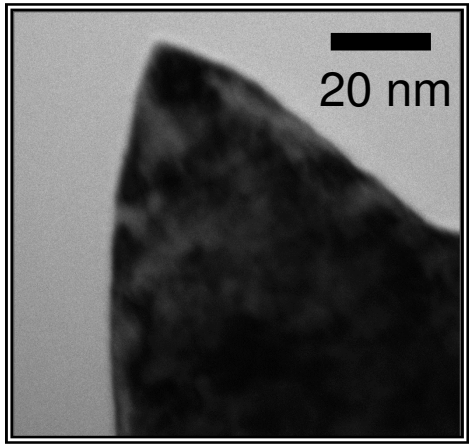
Conclusions

- Field-Directed Sputter Sharpening (FDSS) produces sharp conductive probes on the nanometer and sub-nanometer scale.
- Treatment by FDSS produces a clear improvement in lithographic line width under electron-stimulated desorption patterning.
- Under optimized conditions, FDSS enables reliable and reproducible atomic-scale patterning fidelity, approaching the digital lithographic limit.
- A localized reduction in ion flux results from probe biasing, which may explain the success of FDSS.









Acknowledgements

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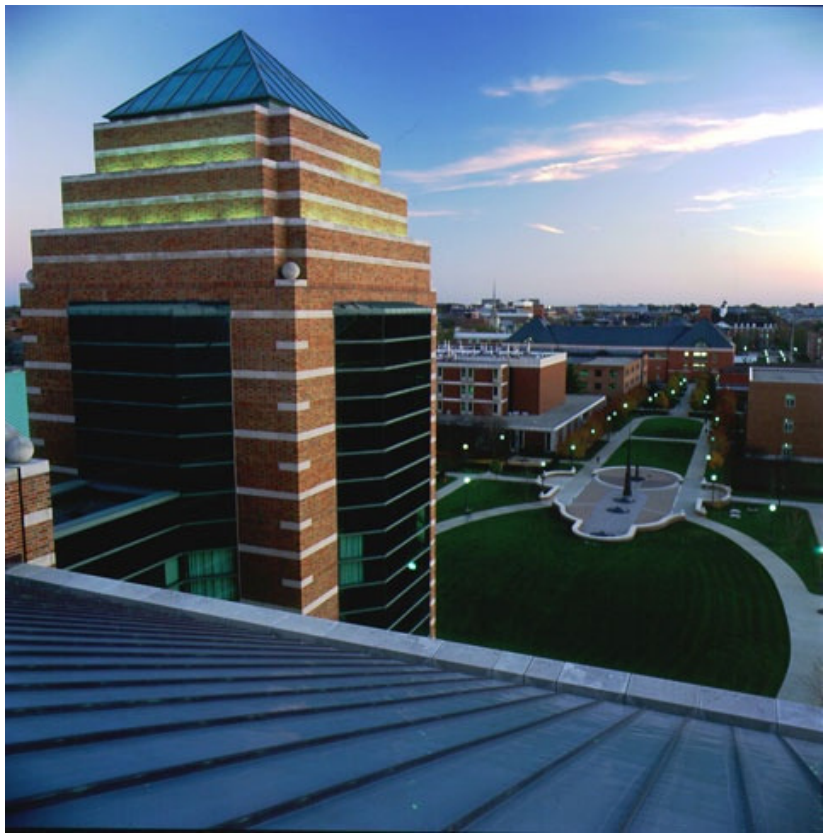

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