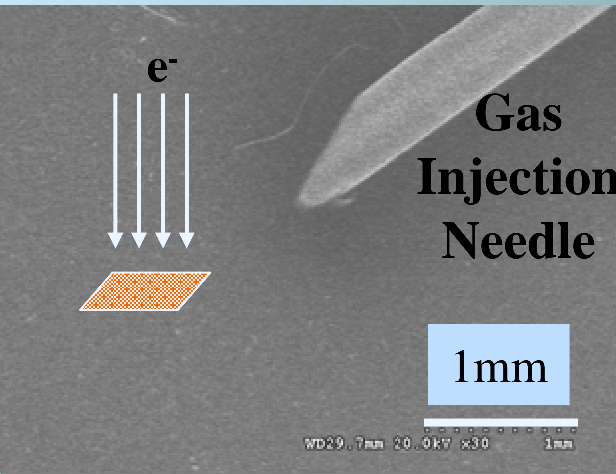
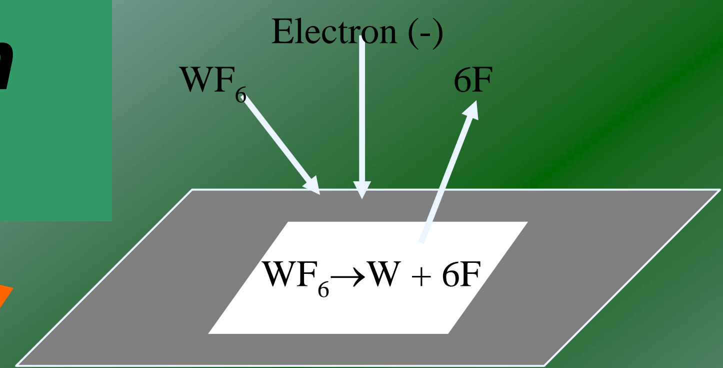
Electron Beam Induced Deposition and Etching Research

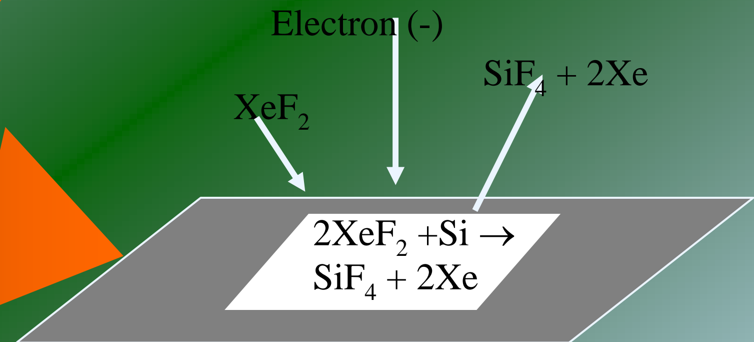
Nanoscale Electron Beam Stimulated Processing



Deposition

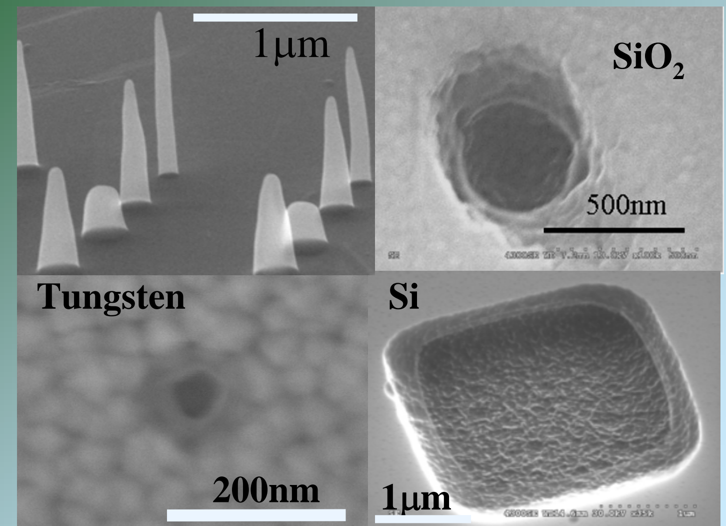
Etching





Applications

- DEAL– Parallel electron beam lithography
- Nanoscale Device Rapid Prototyping
  - Electrical
  - Optical
  - Biological
  - Micro Electro Mechanical
- Nanoscale Repair
  - Chip Repair
  - Lithography Mask Repair
  - High Information Content CD Masters



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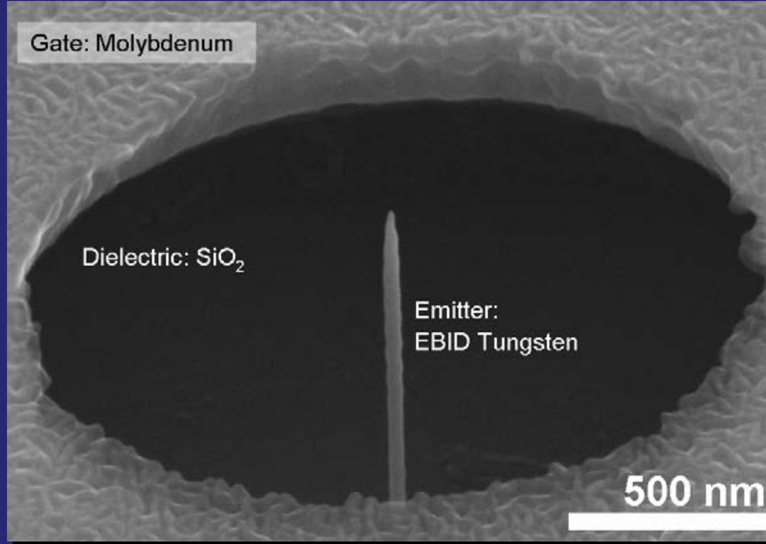
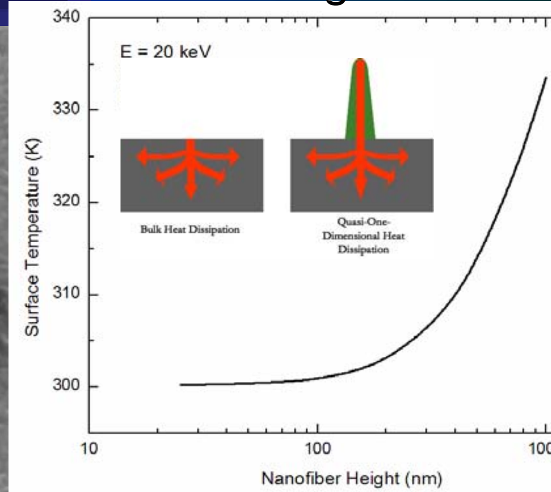
UTK EBIP Research

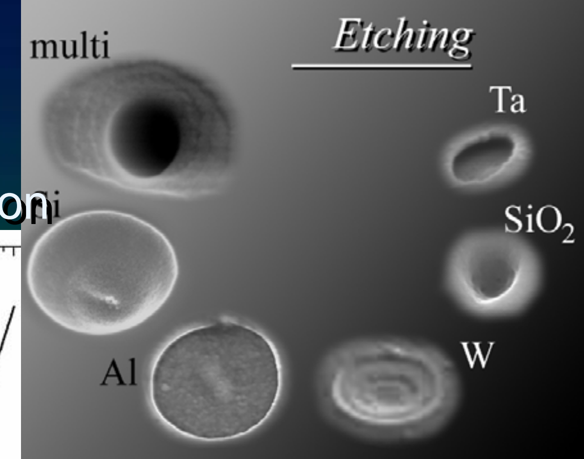
Philip D. Rack

Parallel ebeam lithography system (DEAL)

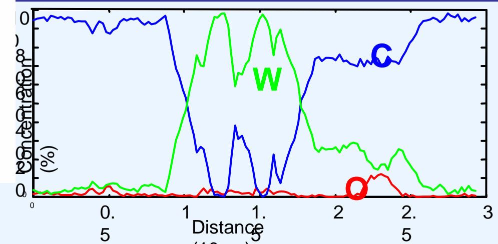


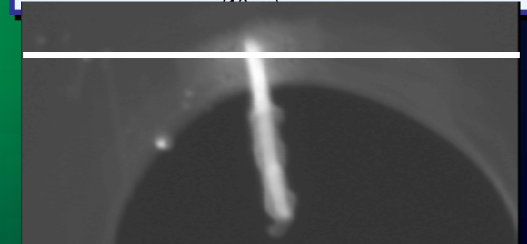
Beam Heating Simulation

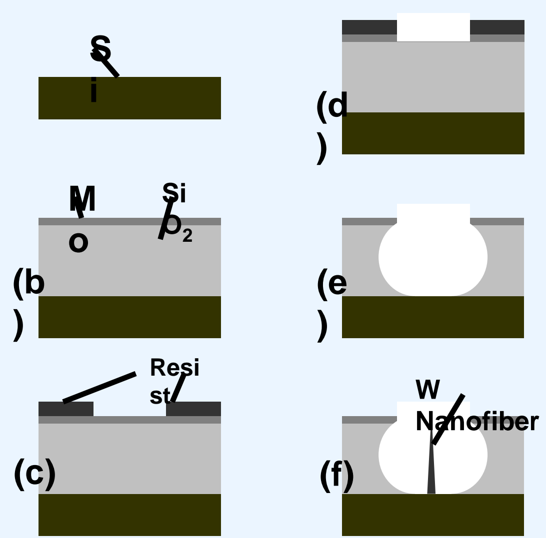




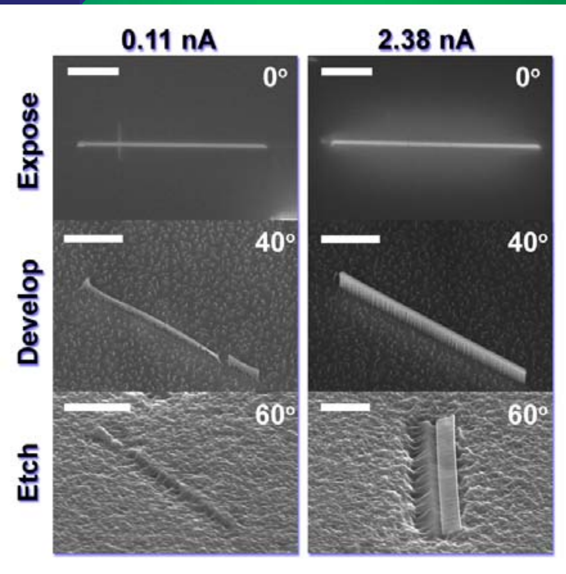
EBID Characterization

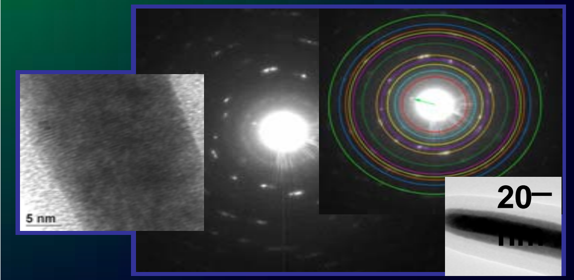






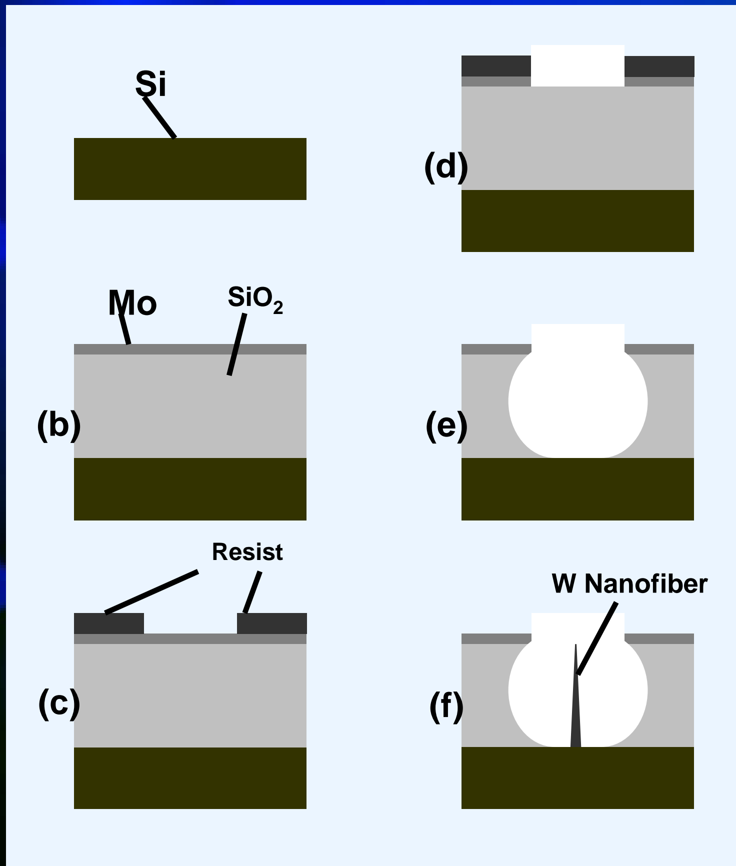
EBID lithography

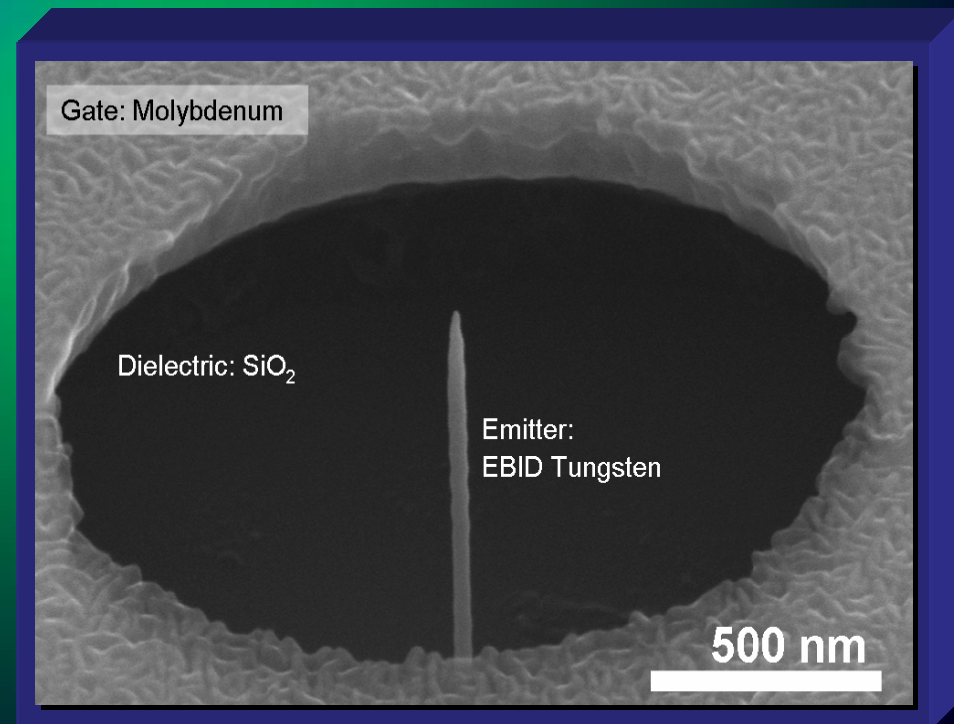




Nanoscale Device Processing

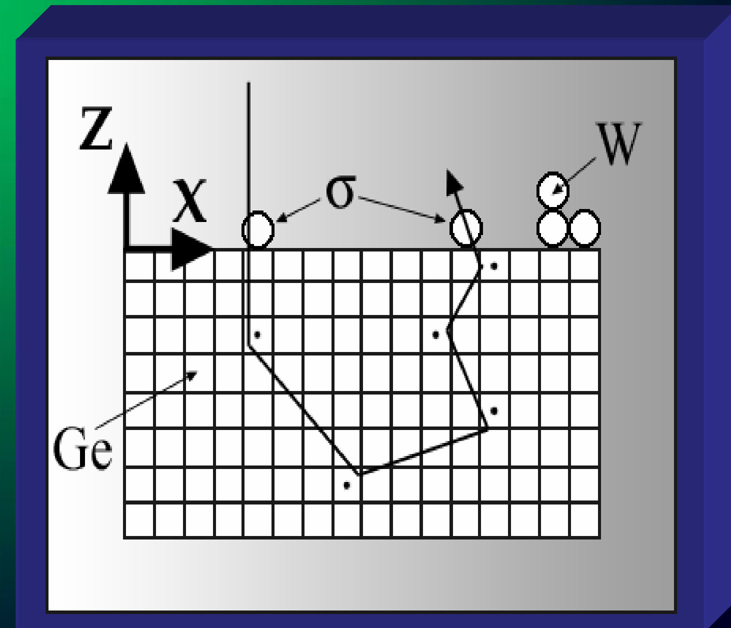
EBID Field Emission Device

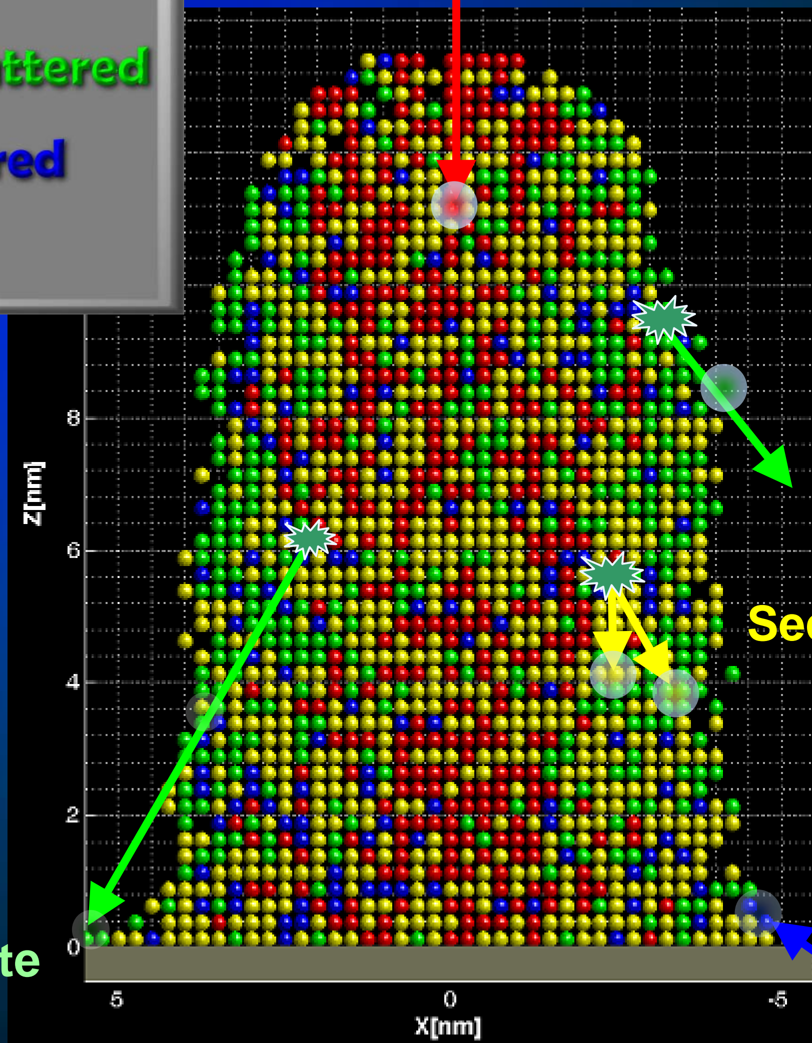




Rack Group EBID/E Simulation

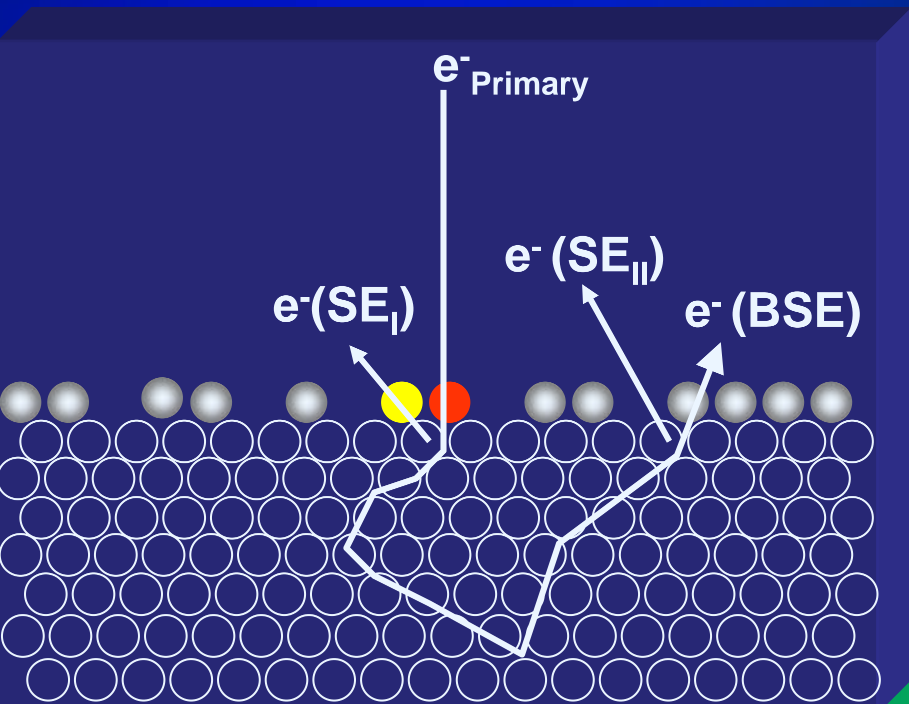
- 3D model
- PE/BSE/FSE/SE tracking
- 3D surface diffusion
- Stationary or rastered beam,(shows effects of varying dwell time, refresh times, etc.)
- Sub-program to estimate localized gas pressure
- Multi-material geometric features
- Deposition and Etching

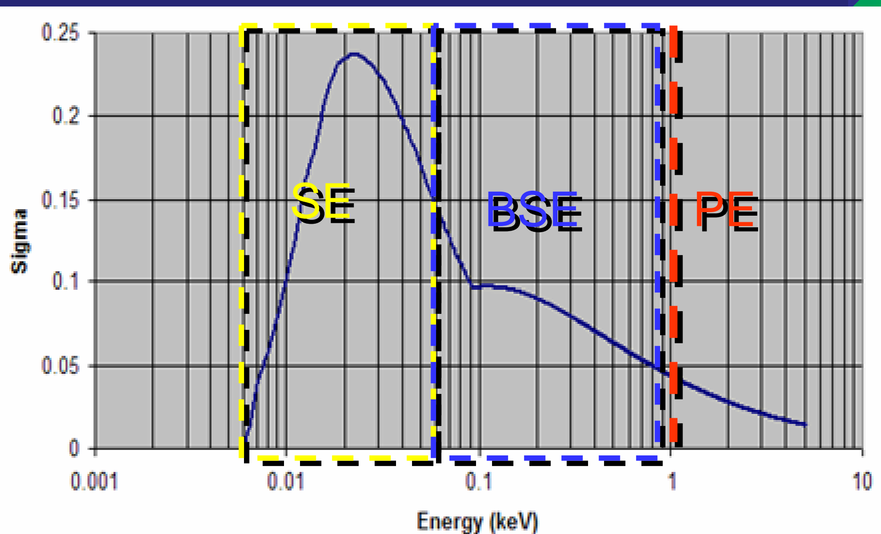




Primary
Forward Scattered
Back Scattered
Secondary
Primary Electron Deposition (PE)
Forward Scattered (FSE)
Secondary Electrons (SE)
FSE into Substrate
Back Scattered (BSE)
Z[nm]
8
6
4
2
0
5
0
-5
X[nm]

Simulation "Q-test"





Primary EBID Test

Gas present at pixel? – **yes** (do Q-test)

$$Q_{PE} = \frac{\sigma(E_{PE}) \times \text{close packed planar density}}{\sigma_{\text{physical cross section of precursor}}}$$

rand < Q? – **yes** (deposit PE atom)

SE_I EBID Test

Gas present at pixel? – **yes** (do Q-test)

$$Q_{SEI} = \frac{\sigma(E_{SEI}) \times \text{close packed planar density}}{\sigma_{\text{physical cross section of precursor}}}$$

rand < Q? – **yes** (deposit SE atom)

SE_{II} EBID Test

Gas present at pixel? – **no** (no Q-test)

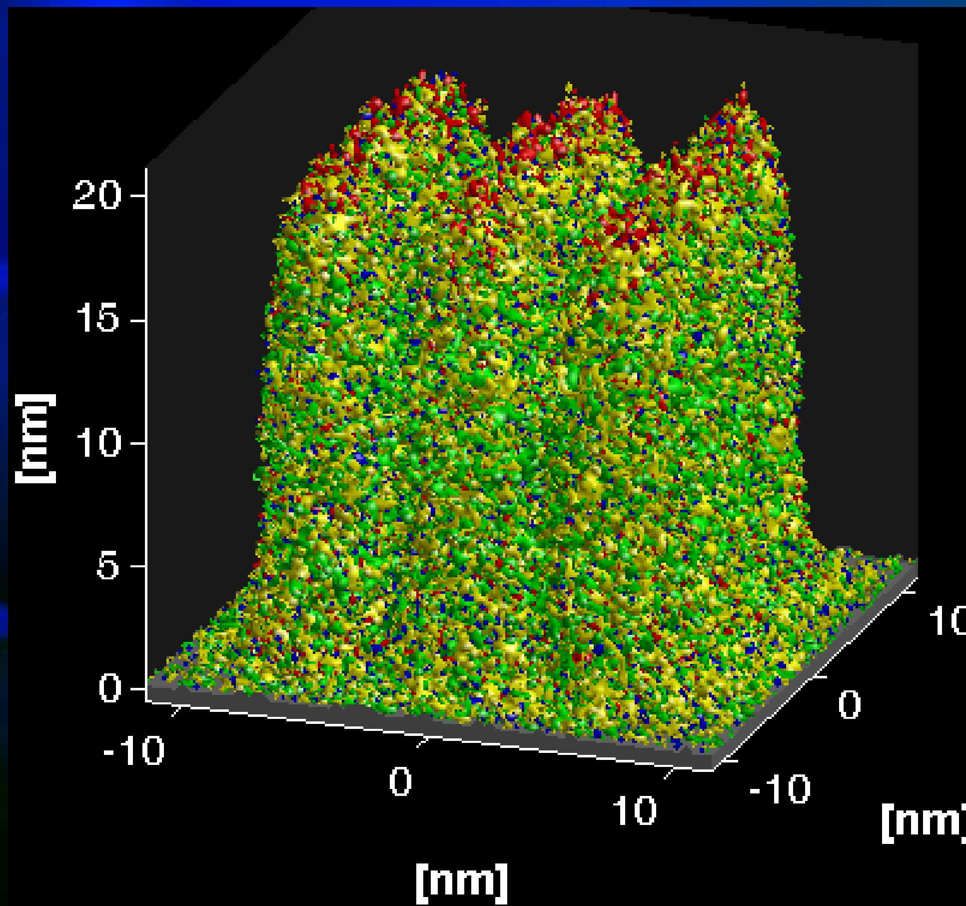
BSE EBID Test

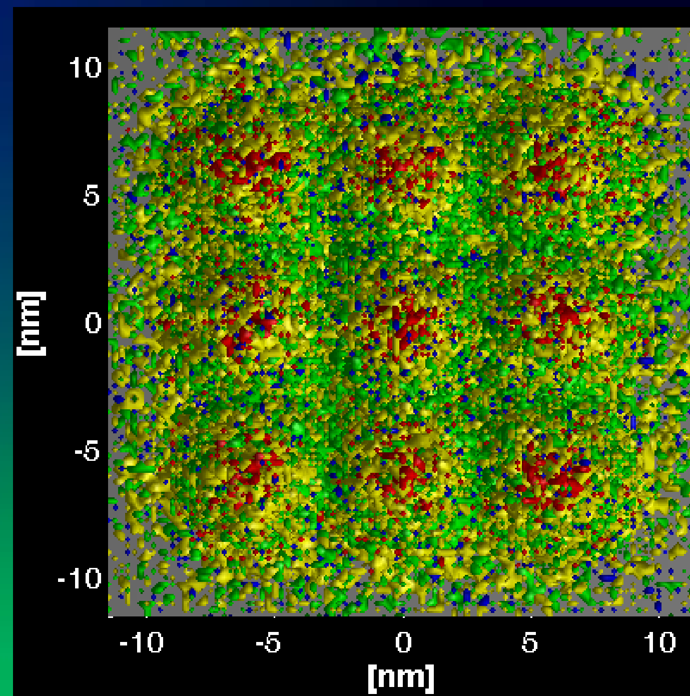
Gas present at pixel? – **yes** (do Q-test)

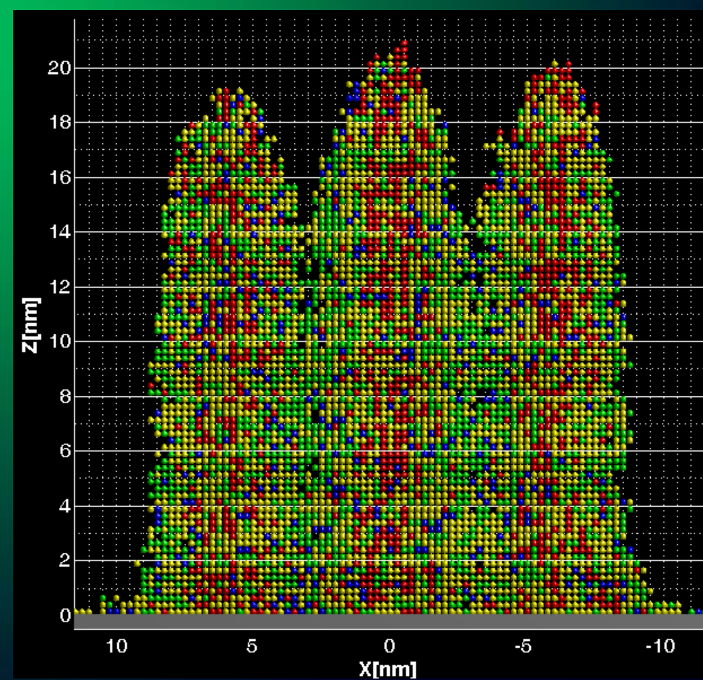
$$Q_{BSE} = \frac{\sigma(E_{BSE}) \times \text{close packed planar density}}{\sigma_{\text{physical cross section of precursor}}}$$

rand > Q? – **no** (no BSE atom)

3x3 rastered beam simulation

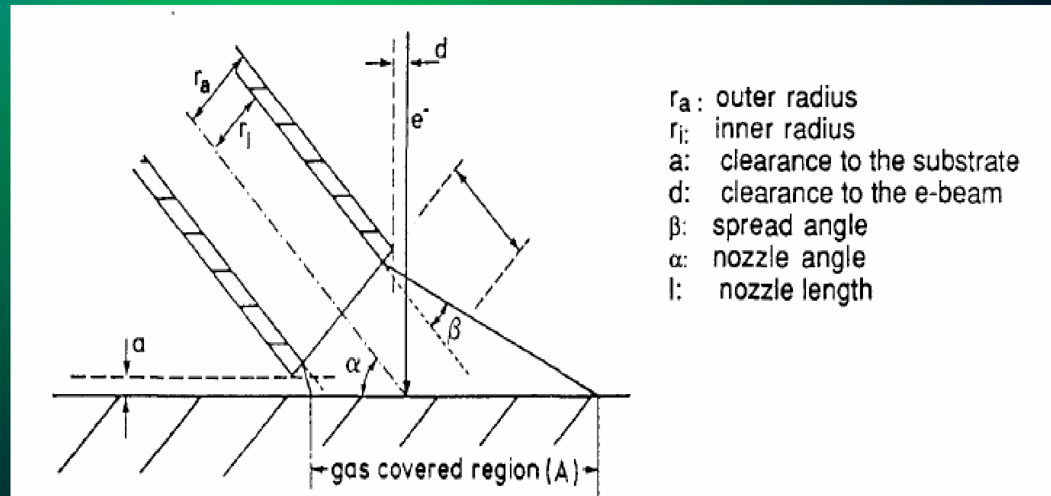




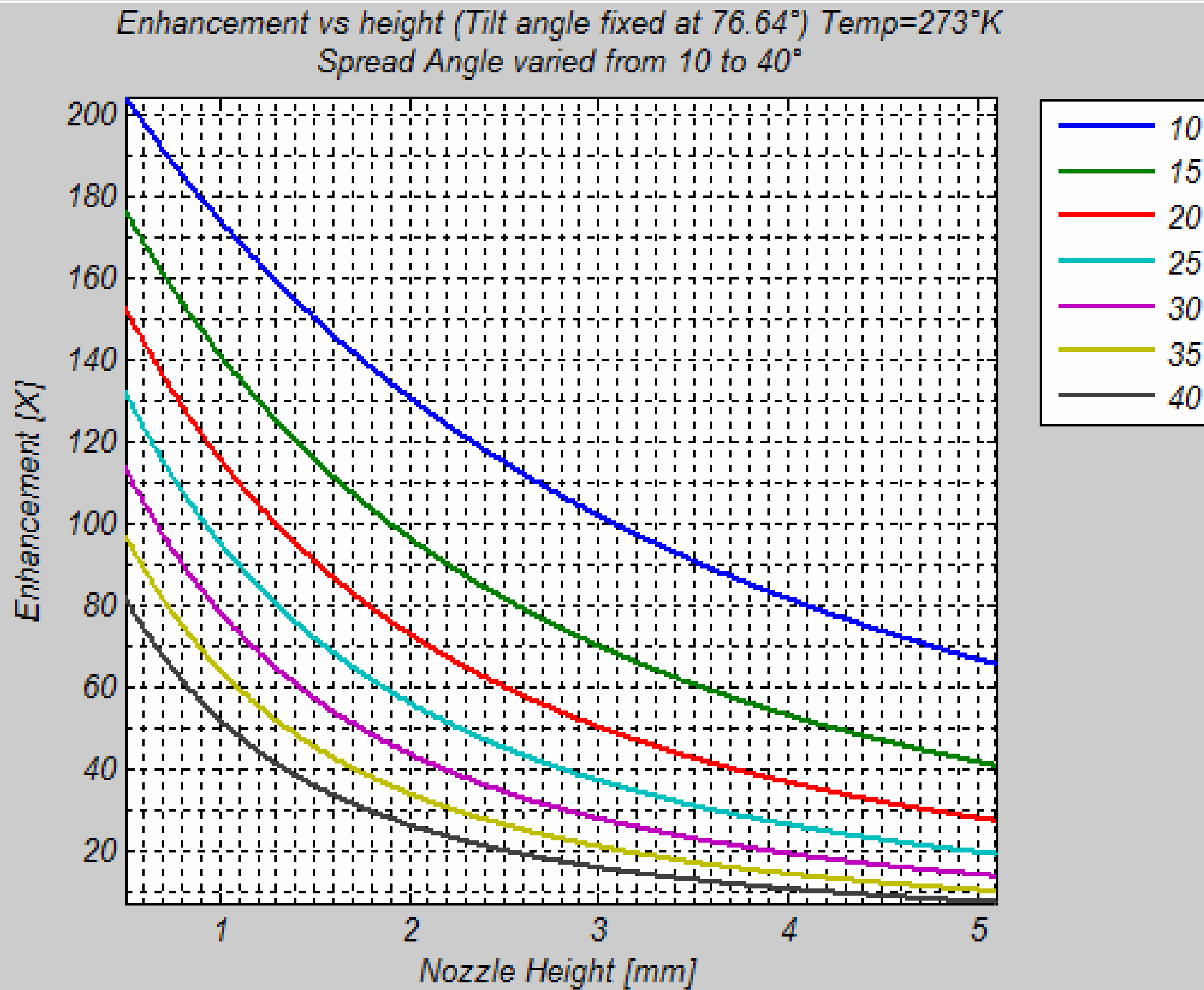


Pressure Simulator

- **Input Variables**
- EITHER:
  - Flow rate of precursor gas, OR Ion Gauge Pressure and Seff
- Precursor Temperature
- Precursor Molecular Weight
- **Geometry Factors:**
  - Outer nozzle radius
  - Inner nozzle radius
  - Substrate clearance
  - Nozzle tilt angle
  - Gas spread angle



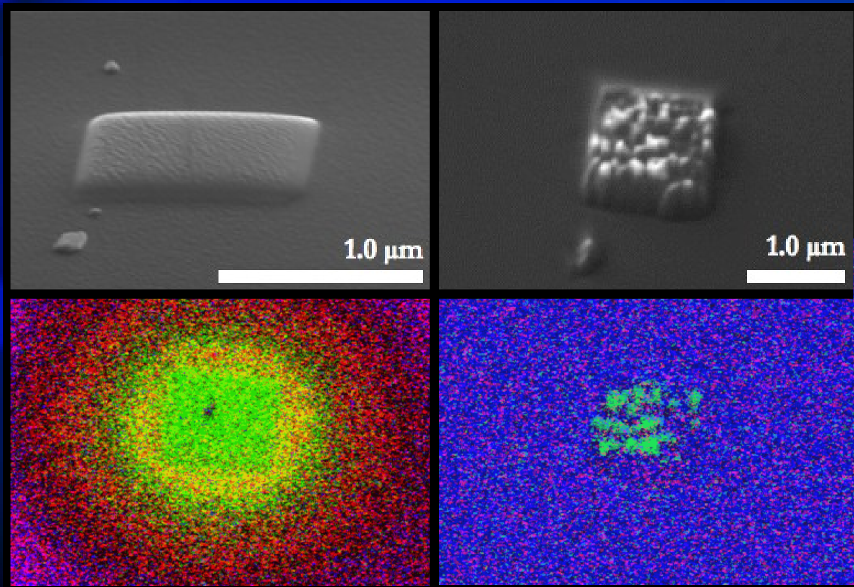
Enhancement



EBID Characterization

As-Deposited

Post-Sputter Profile

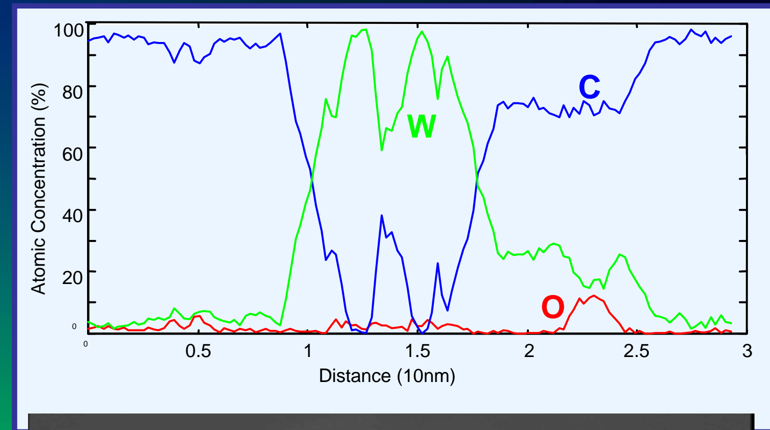


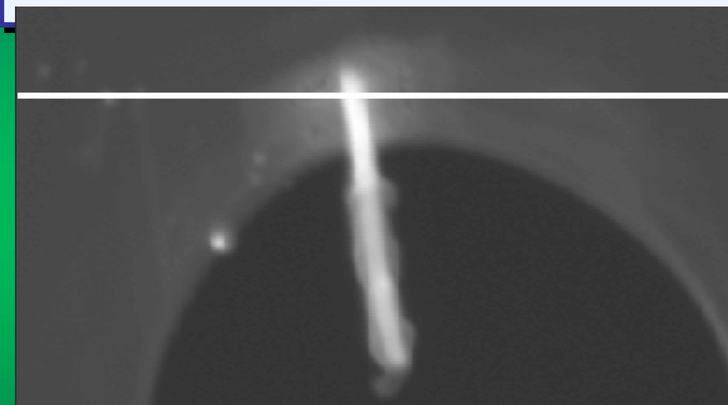
Tungsten

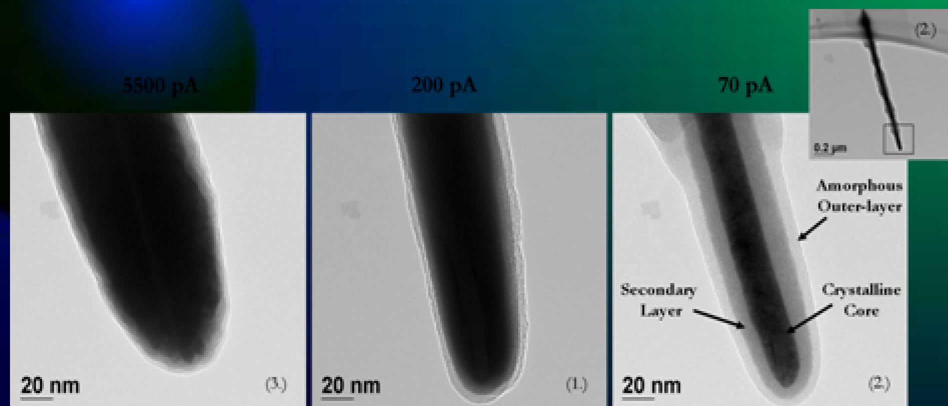
Silicon

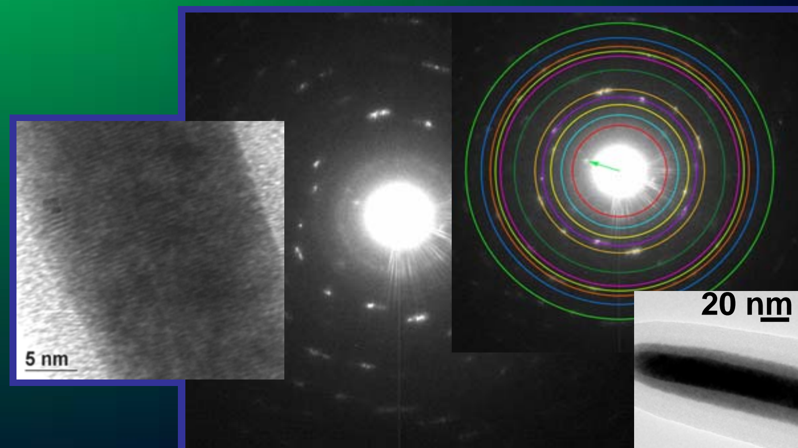
Oxygen

SEM and Element Maps of EBID Tungsten
Before and After Sputter-Depth Profile

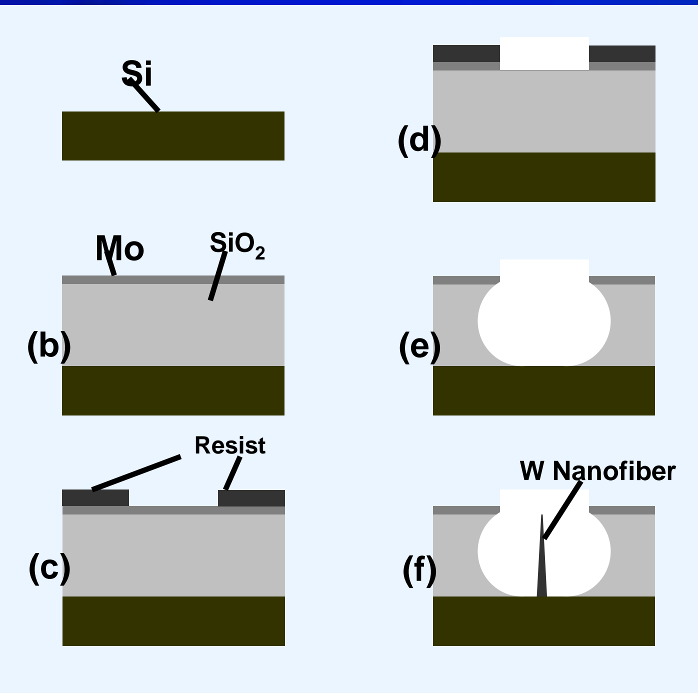


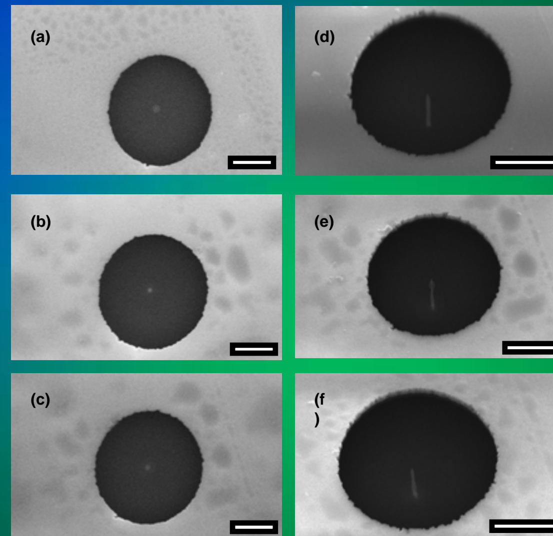


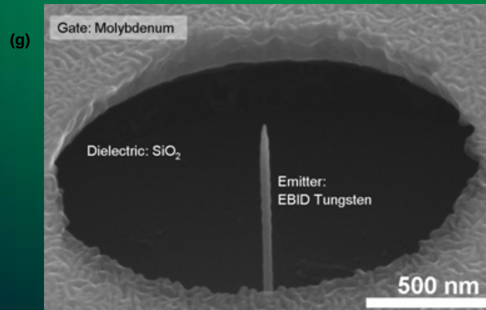


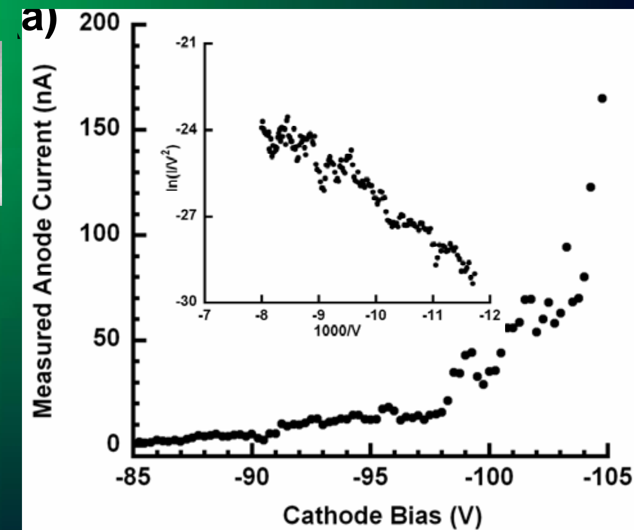


Field Emission Devices

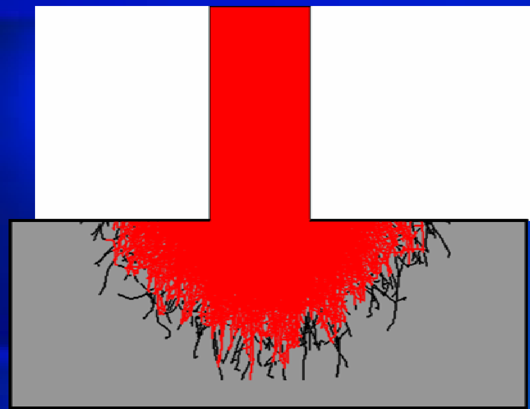






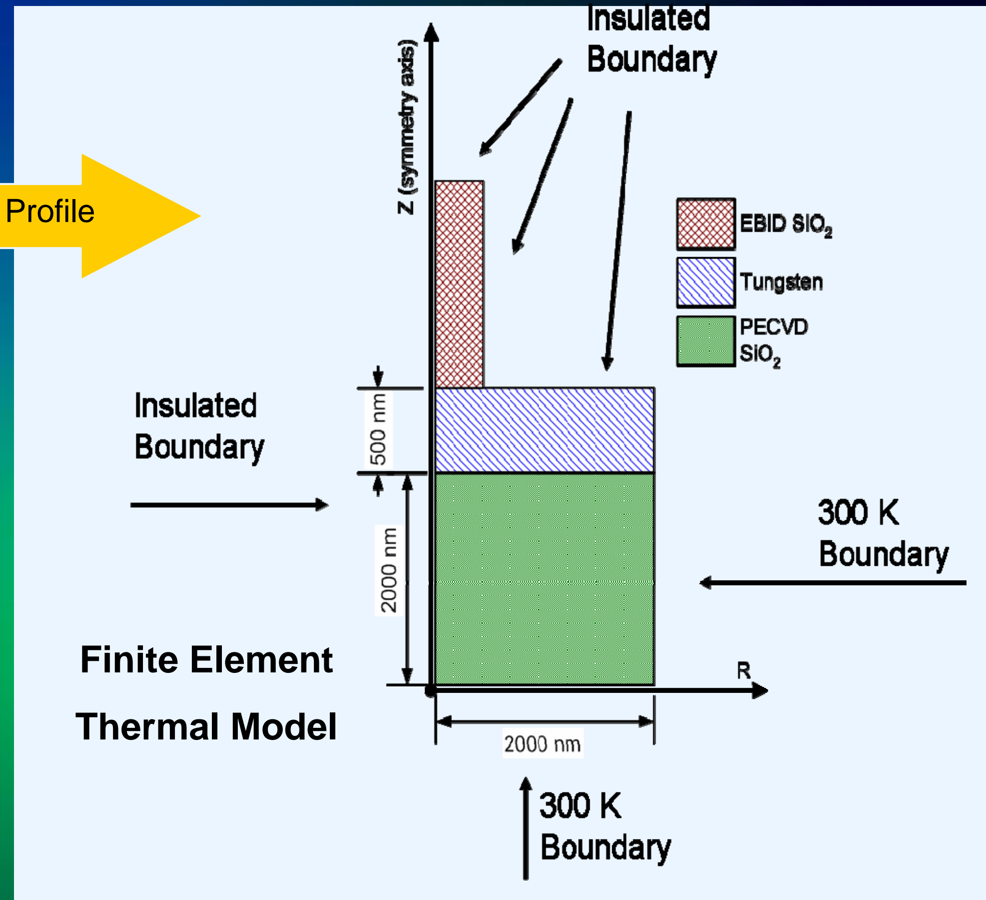


EBID Heating Simulation

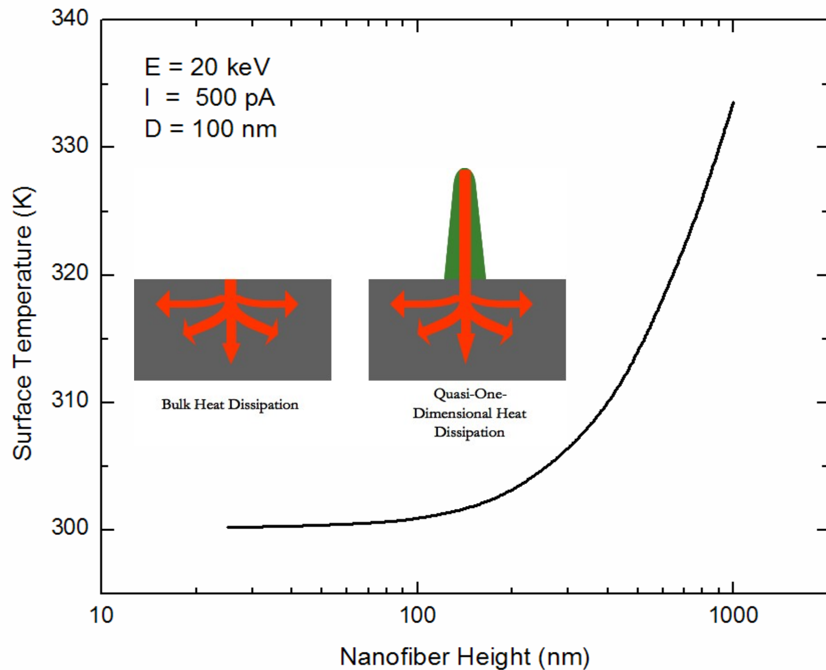


Monte-Carlo Single Scattering Model

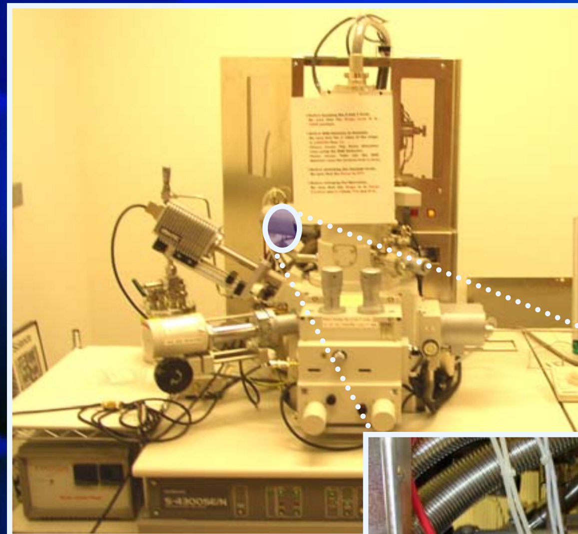
Energy Deposition Profile

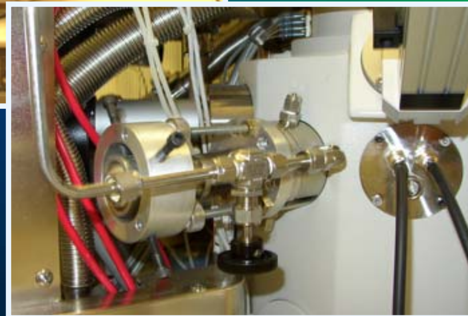


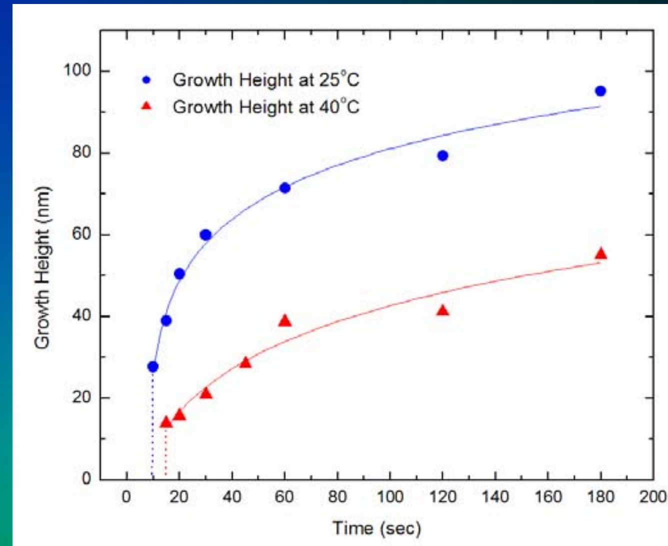
Finite Element Thermal Model

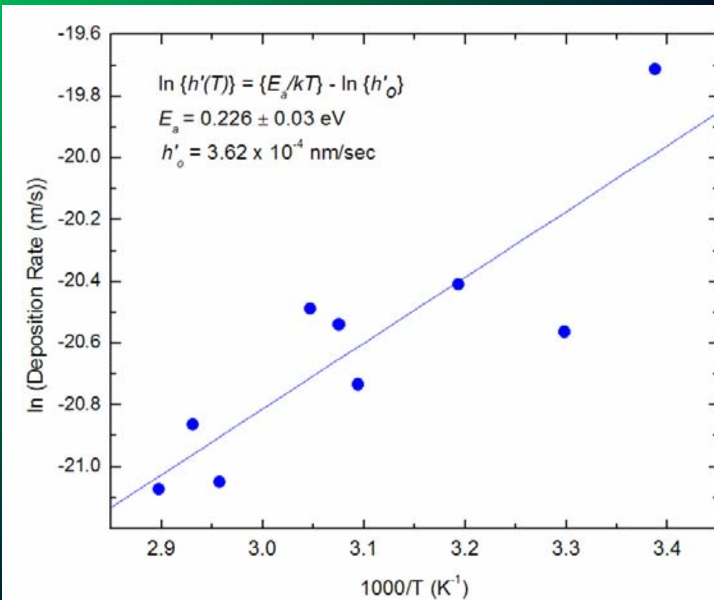


Temperature Dependent EBID

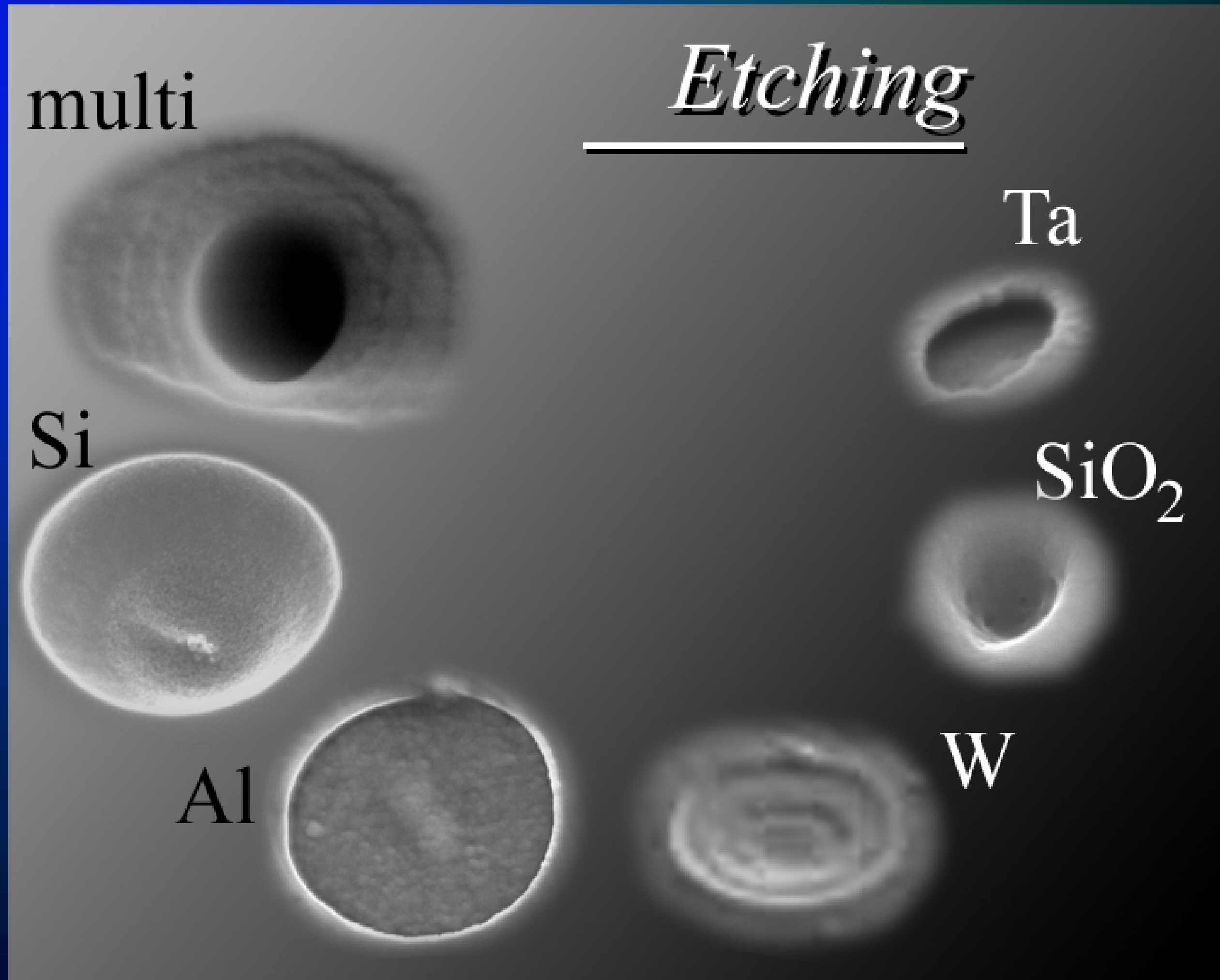




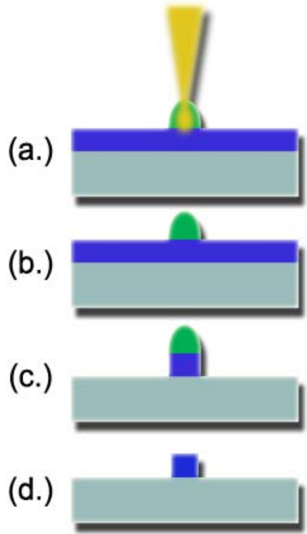


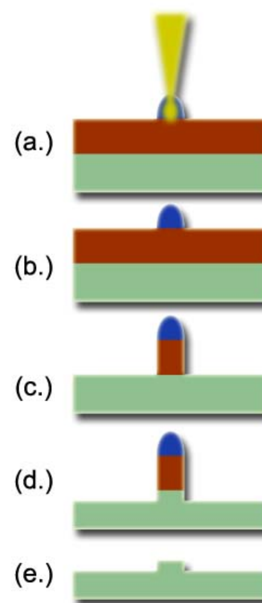


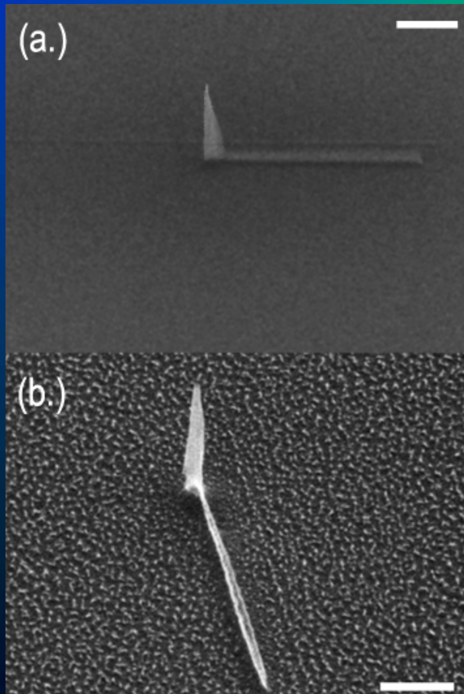
Electron Beam Induced Etching

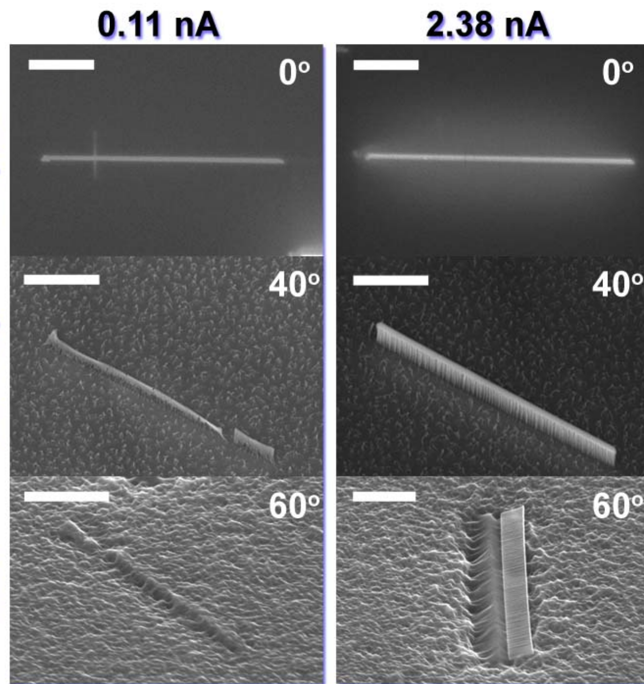


EBID Nanoscale Lithography









Acknowledgements

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