COLORADO SCHOOL OF MINES

ATOM PROBE AND (S)TEM ANALYSIS OF SEMICONDUCTOR AND OXIDE NANOSTRUCTURES

David R. Diercks and Brian P. Gorman

Department of Metallurgical and Materials Engineering, Colorado School of Mines, Golden, CO 80401

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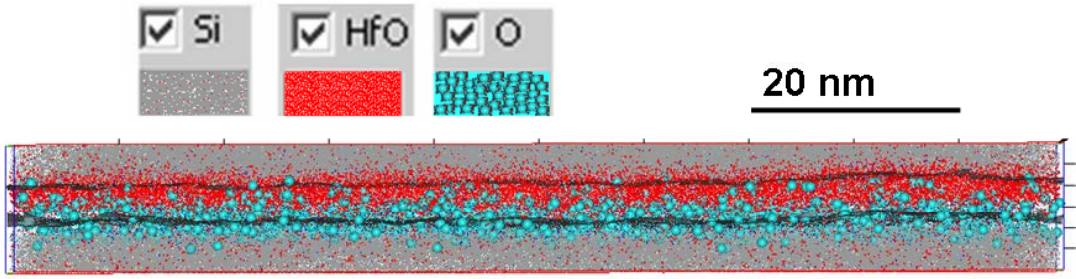
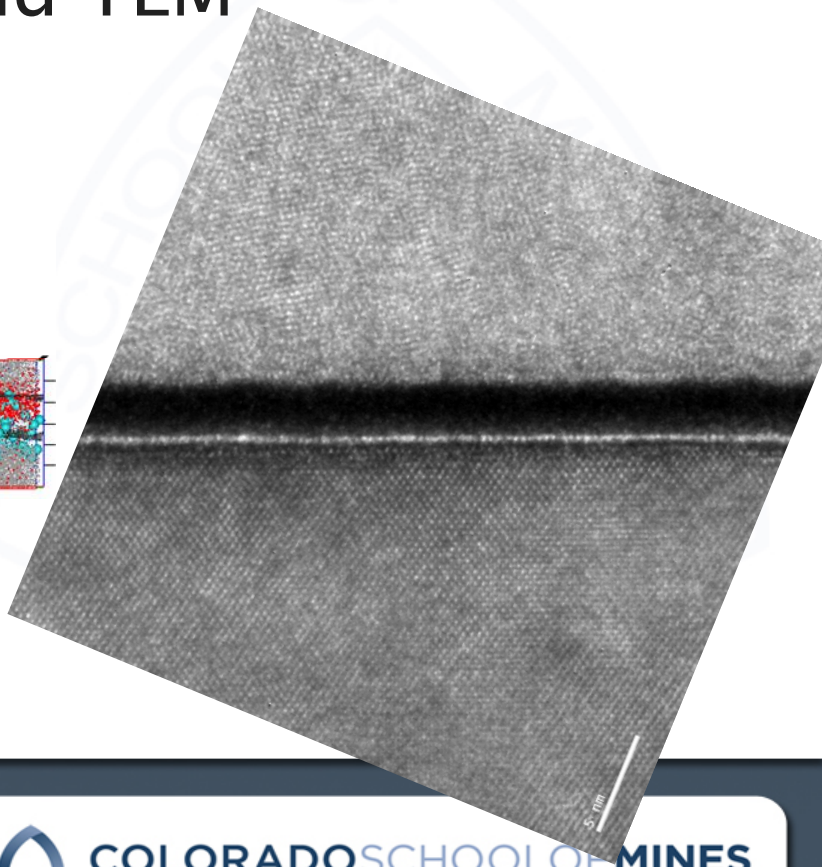
Combined TEM and Atom Probe Tomography

- Advantages of TEM prior to atom probe analysis
  - Can verify feature of interest is contained in sample tip
  - Direct measurement of shank angle, volume, layer spacing, etc. – assists in generating accurate reconstructions
  - Direct determination of d-spacing, crystal structure, crystallographic orientation(s), and crystal defects
- Advantages of TEM after atom probe analysis
  - Can determine tip shape resulting from analysis – assists in determining local field
  - Can determine volume analyzed
  - Assess analysis parameters

Co-examination of High-k stacks with APT and TEM

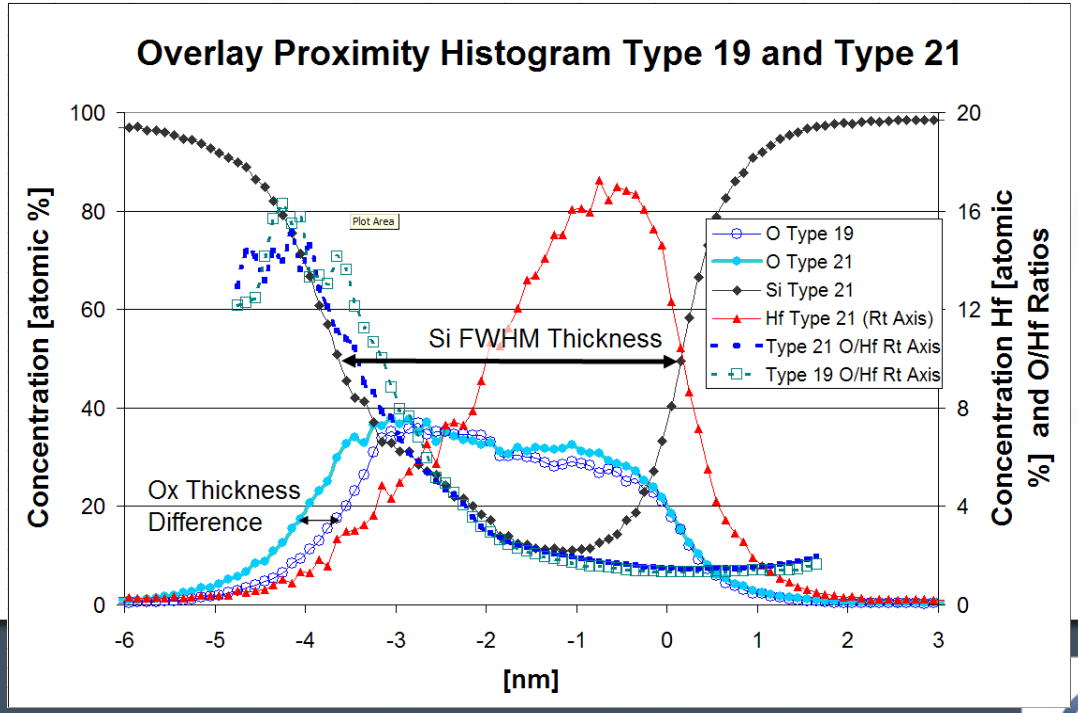
- Si / HfO_2 / poly Si stack
- Ex-situ (separate APT and TEM specimens)

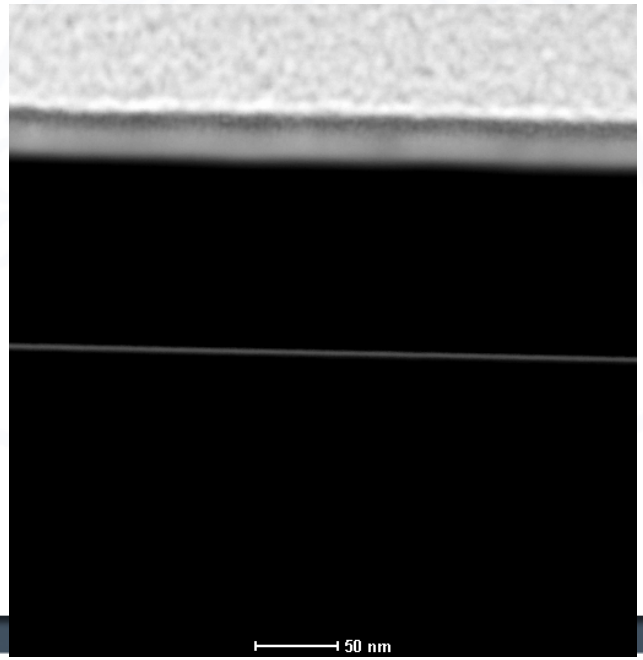




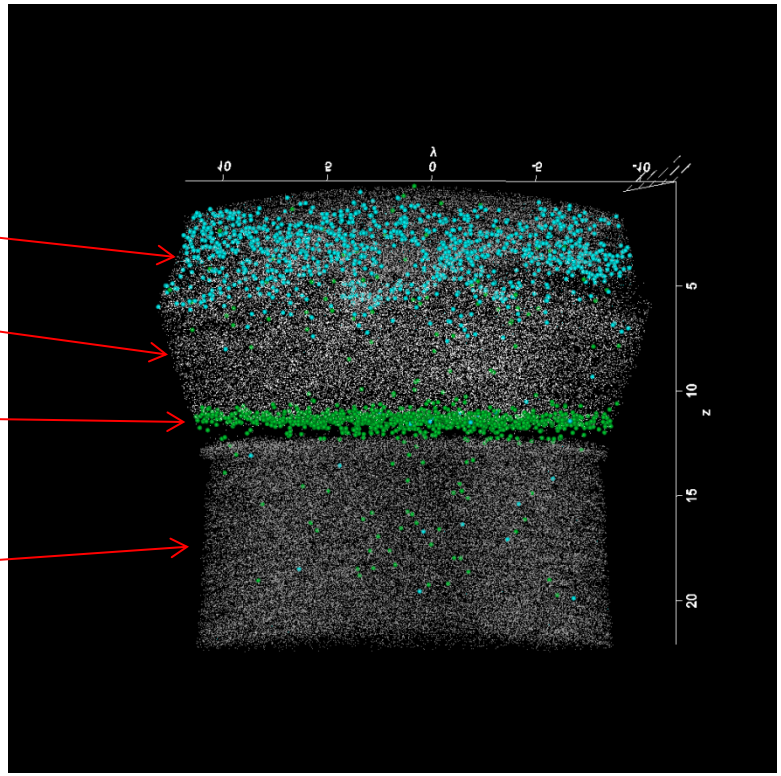
Co-examination of High-k stacks with APT and TEM

- Compared with HRTEM and STEM-HAADF, APT results in 25% thicker films
  - Reconstruction or Calibration issue?
  - Method of determination?
  - Sample variability?

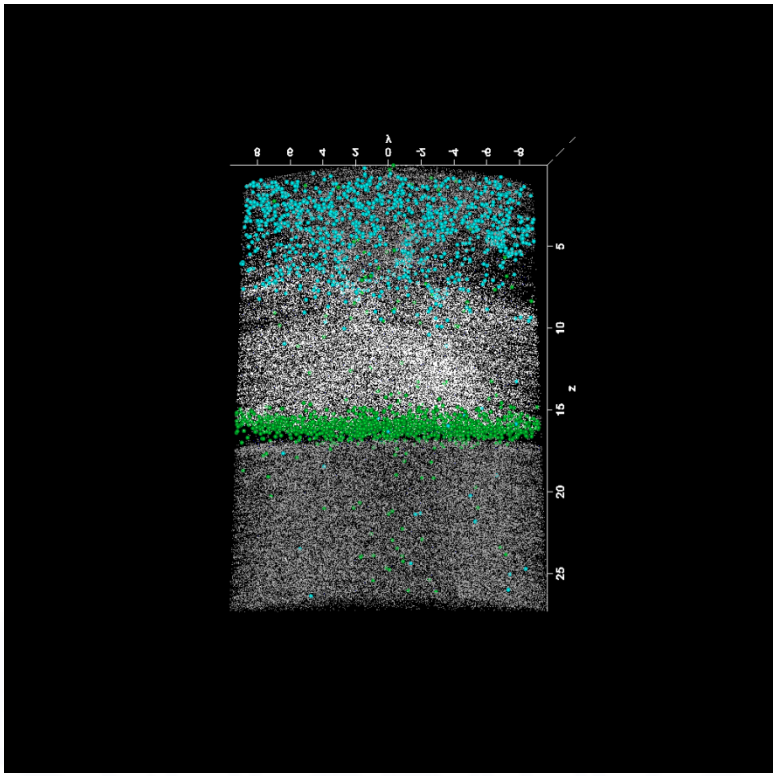




High-k Stack Reconstruction Comparison

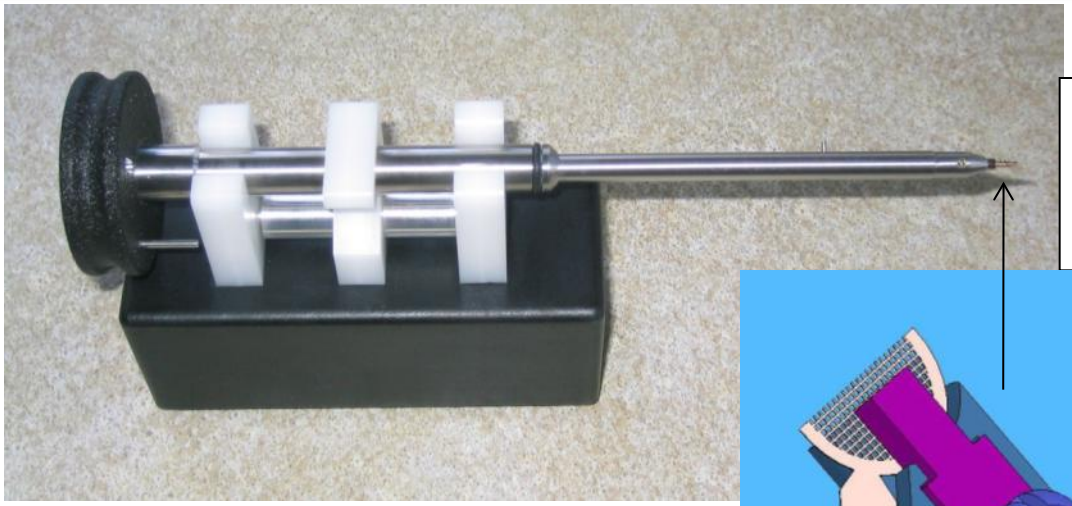


V/kr volume

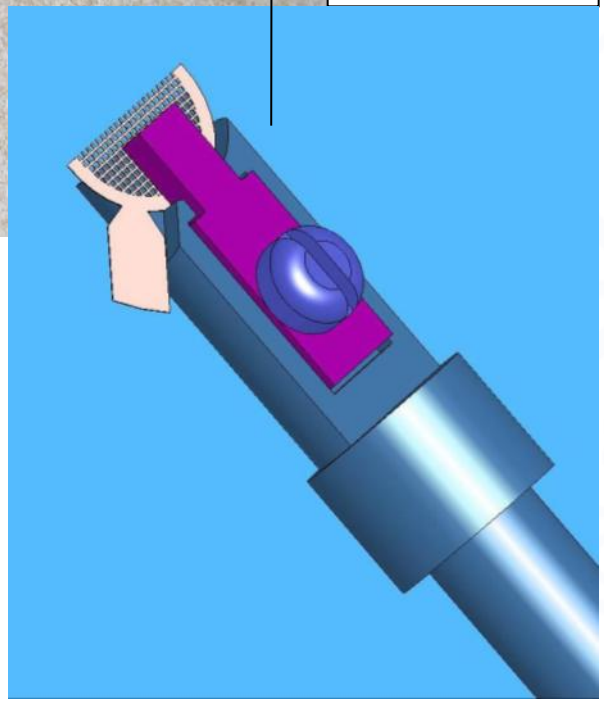


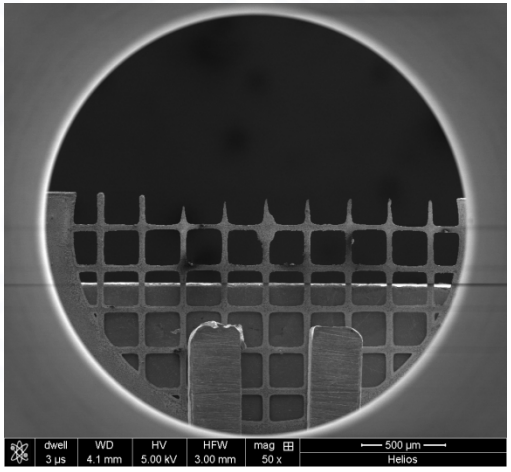
Volume from diameter, constant shank angle

TEM and APT hardware



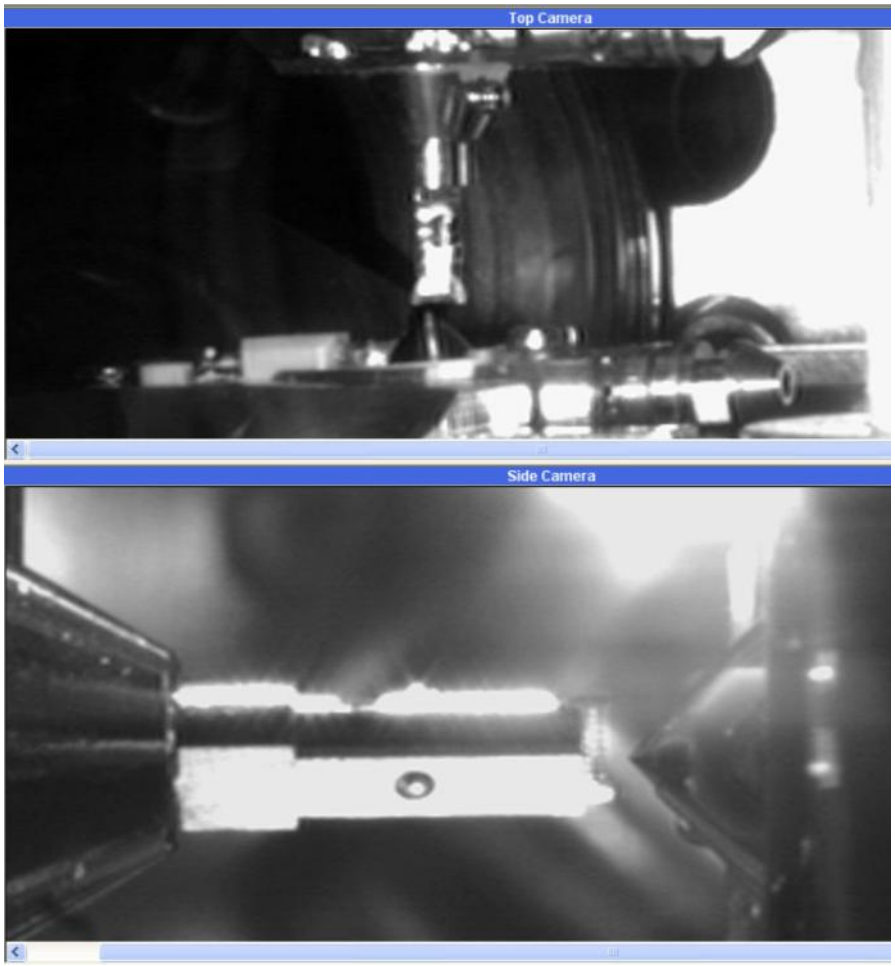
Removable
Grid
Holder Tip

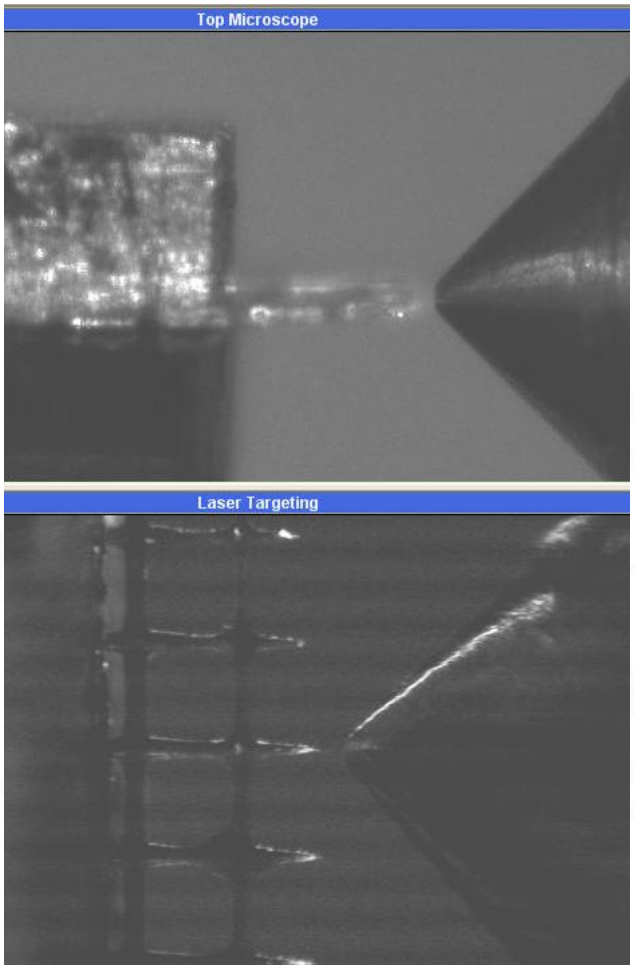




Allows for transport between:
FIB/SEM (preparation)
TEM (analysis)
Atom Probe (analysis)

TEM and APT Hardware

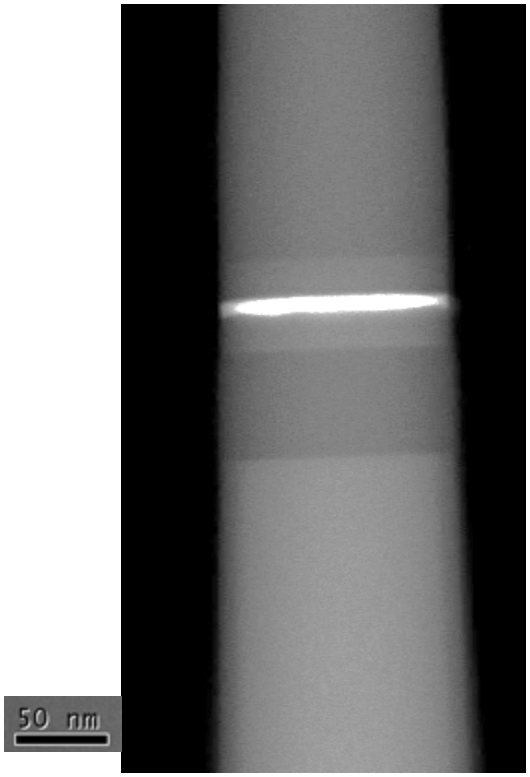


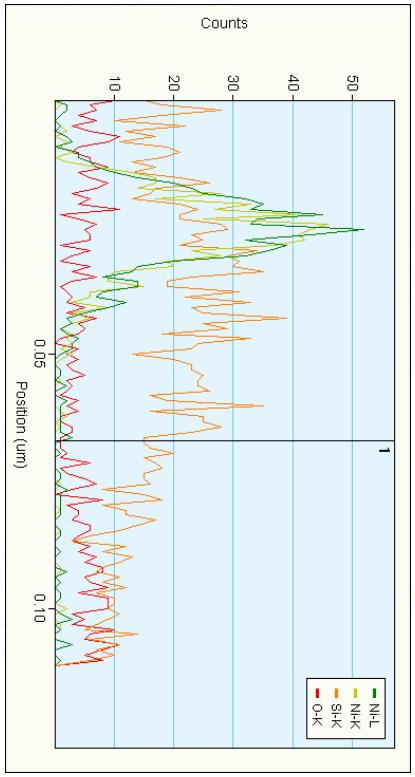


Microelectronic stack

- Poly Si / NiSi / Si / SiO_x / Si stack

As-produced APT specimen (STEM-HAADF and EDS)

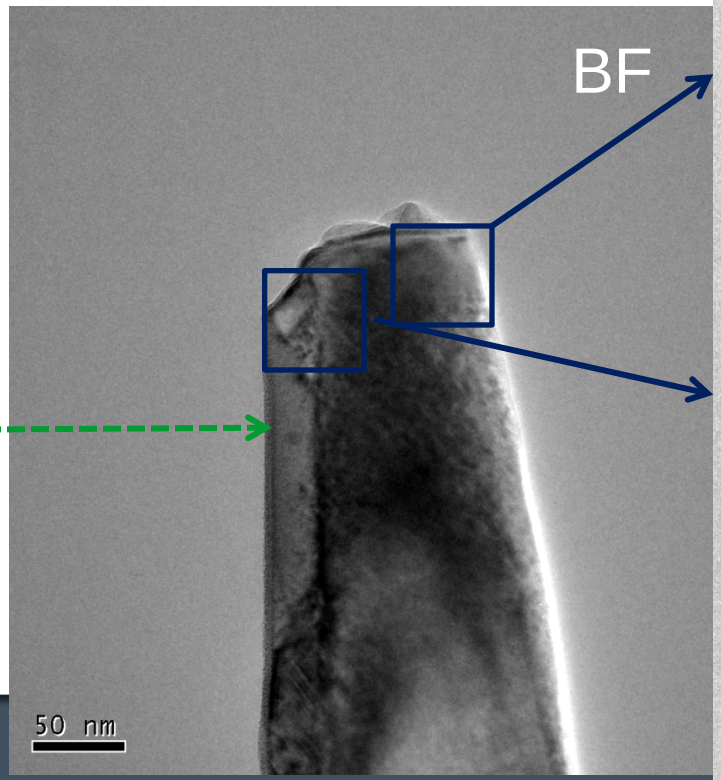




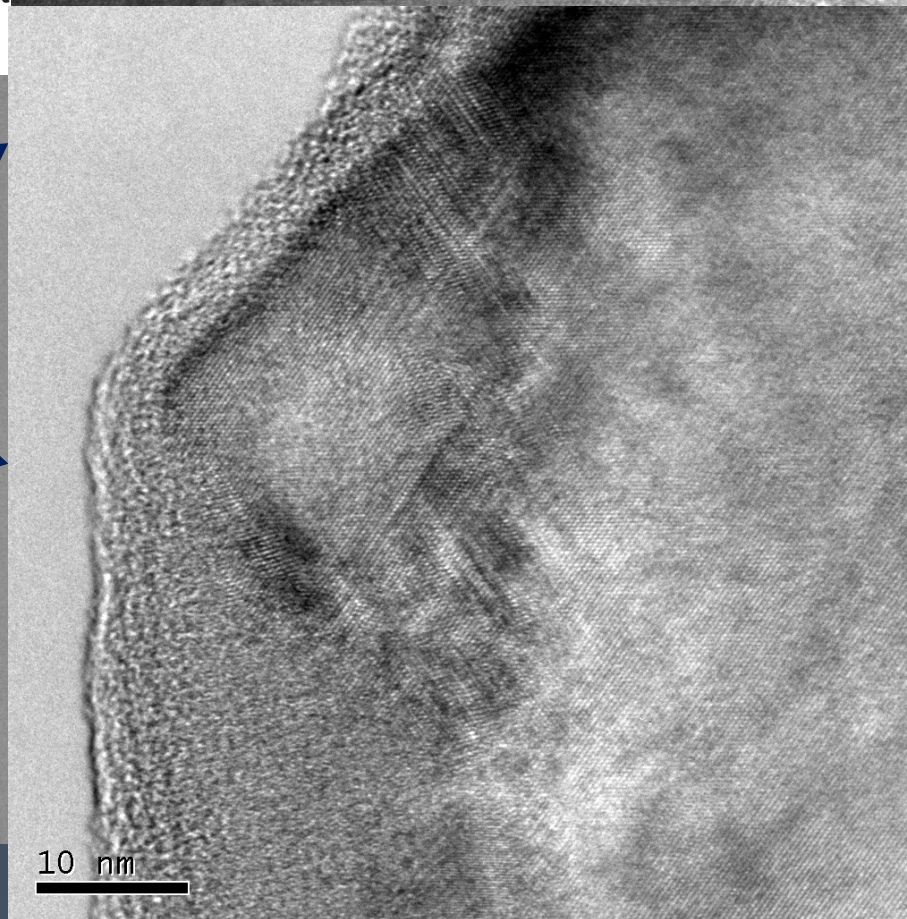
Post APT Analysis

Side of specimen away from laser pulse – no damage

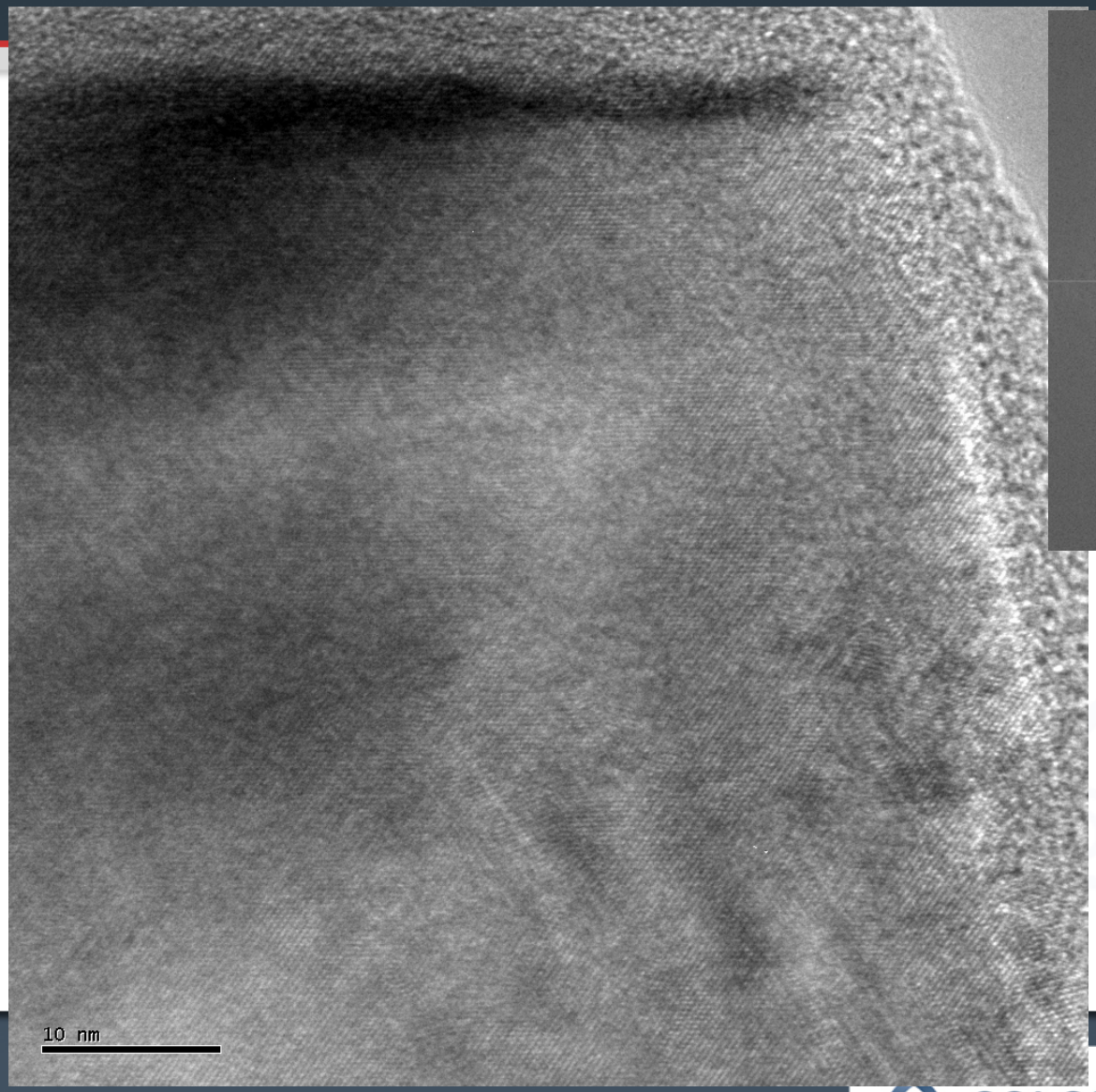
- After Laser Pulsed APT (
  - Failure at Si / SiO_x interface
  - Significant morphological cha

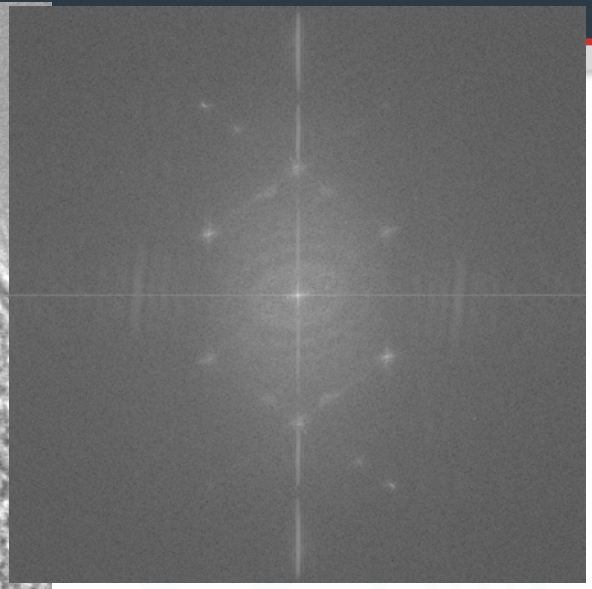


Side of specimen facing laser pulse – amorphization, structural defects



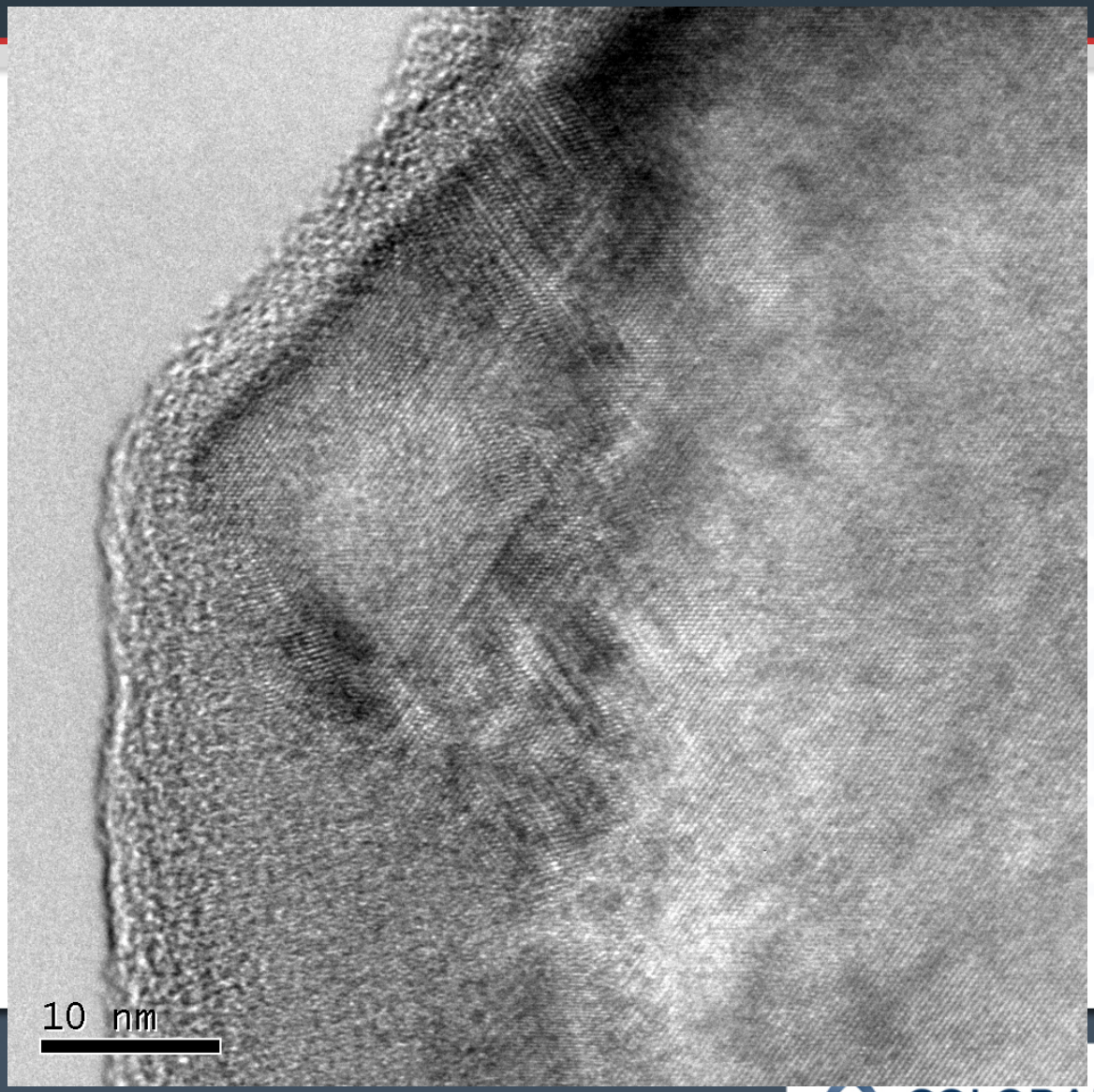
Post APT Analysis





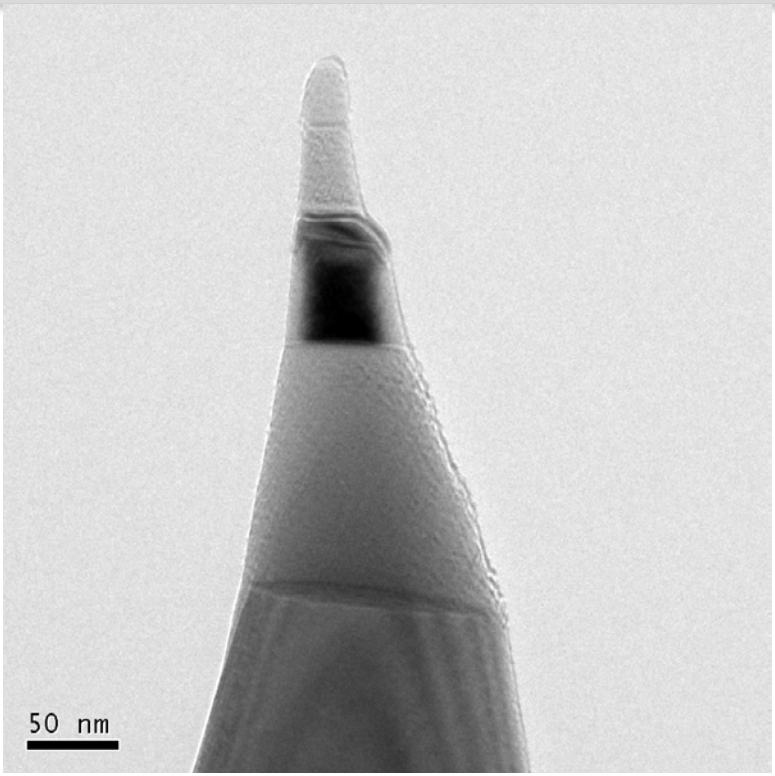
Top and Side of specimen away from laser pulse – no damage

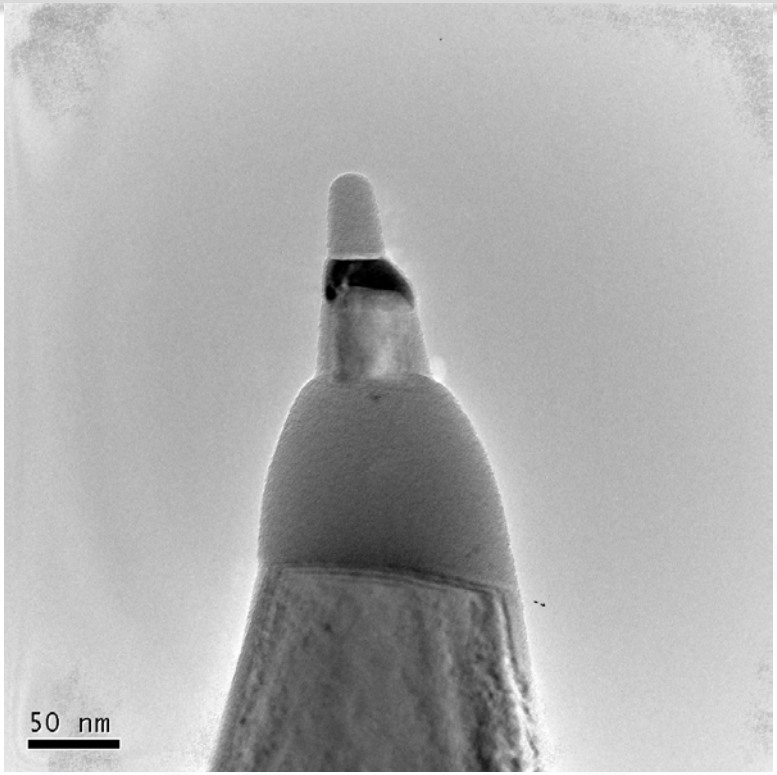
Post APT Analysis



Top and Side of specimen facing laser pulse – amorphization, structural defects

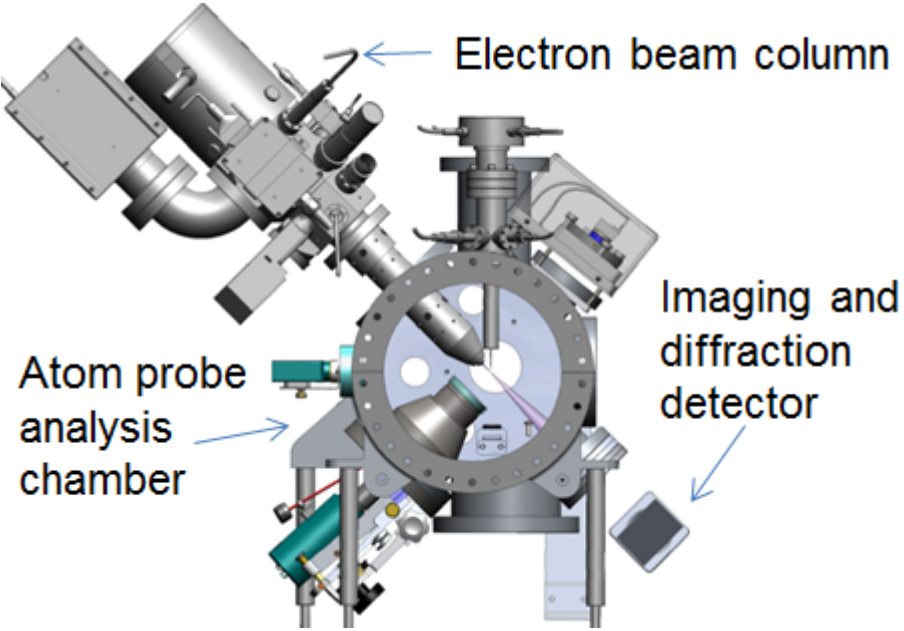
Post APT Analysis – SOI

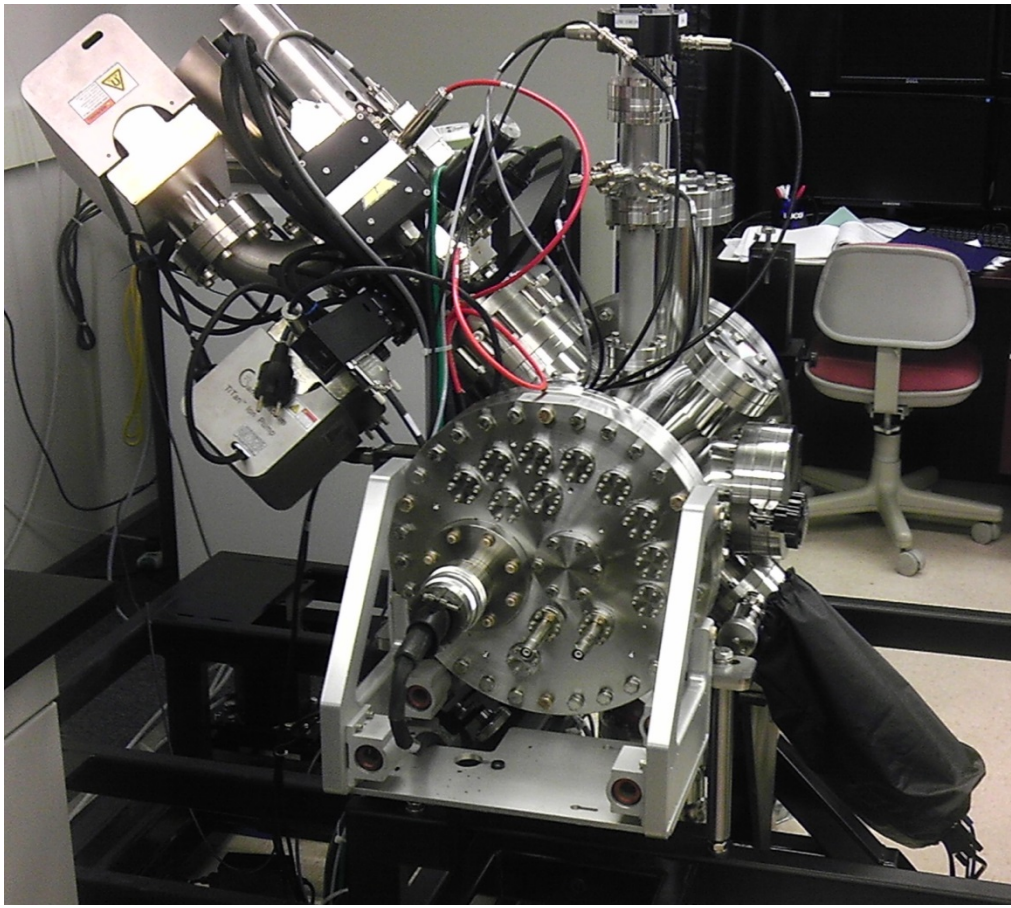




- Measurable evaporated material and uniform tip shape
- Significant changes in insulator layer

Dynamic Atom Probe – combined EM and APT in one instrument





This atom probe instrument is supported under NSF Award Number 1040456.

Correlative TEM and APT summary

- Can provide complementary information
- Can be used to assist in generating accurate reconstructions
- Can provide feedback on APT analysis conditions
- In-situ rapid thermal quenching and analysis.

Going forward

- How to best incorporate into atom probe data?
  - Provide dynamic feedback during analysis?
  - Adjust reconstruction after the analysis?
- Other methods of feedback / detection
  - Tip shape from laser scan
  - Species being detected
  - Uniformity of evaporation
  - Additional detectors / attachments