

# Advanced Characterization of Memristors

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New AC-STEM At Sandia (~\$4M)

Memristor NTM LDRD FY 12-14



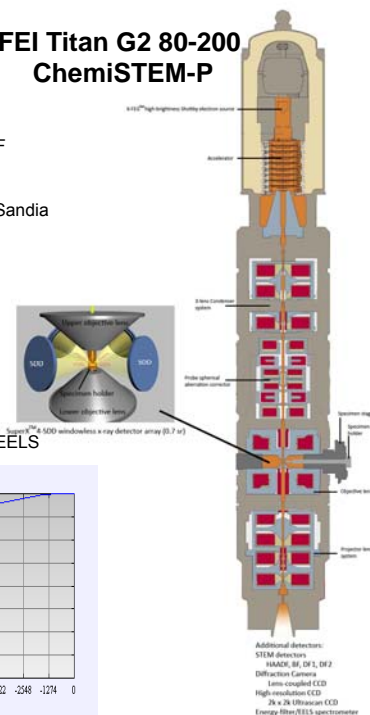
## Room modifications (~\$700k)

- Temperature stability of 0.1°C/30 min with low airflow
- Low EM fields, low floor vibrations, quiet

## Microscope (~\$3.2M)

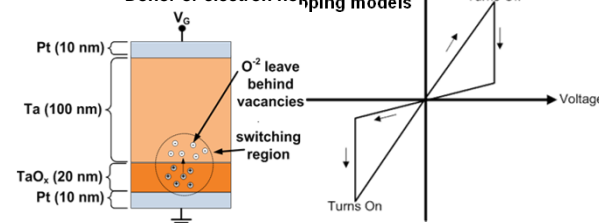
- Funded by Readiness in Technical Base and Facilities RTBF Program Office (MS&T ERC recommendation helped)
- Resource for both NW and S&T
- Super analytical tool, 50-100x better than other systems at Sandia
  - High-brightness Shottky emitter
  - Three condenser lenses
  - CEOS D-COR Cs probe corrector. Corrects:
    - Out to fourth-order aberrations
    - Fifth-order spherical aberration
    - Six-fold astigmatism
  - Array of four windowless silicon-drift energy-dispersive x-ray spectrometers (0.7sr)
  - 0.8Å STEM resolution at 200kV
  - 1.2Å STEM resolution at 80kV
  - Other detectors, STEM (4), CCD (3), EFTEM/EELS

## FEI Titan G2 80-200 ChemiSTEM-P



- The Memristor or Resistive/Redox RAM (RRAM) is one of the most promising replacements for Flash, DRAM, and even SRAM memories
- Poor physical understanding of switching action has limited the use of this technology
- Problem: Insufficient understanding of switching mechanism
- Current working theories:

- Conductivity modulated by  $O^{2-}$  anion migration
- Filament formation
- Donor or electron hopping models



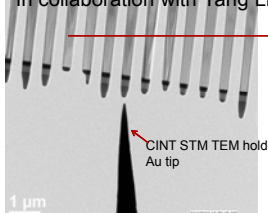
## Characterization Plan

- Initially HP fabricated materials
- First SNL materials currently being fabricated
- AC-STEM *ex situ* and CINT *in situ* observations
- HAADF, BF, EDS, and EELS spectral imaging, multivariate statistical analysis
- Current development:
  - EELS stoichiometry measurements
  - Structural/chemical imaging
  - In situ actuation followed by high-resolution microanalysis

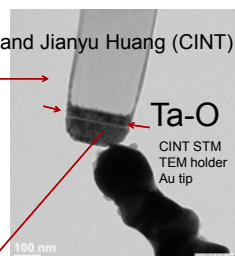
## Conclusions

- Preliminary experiments are promising.
  - *In situ* measurements
  - Next step better current limiting and demonstrating switching
- Microanalysis development
  - New AC-STEM online for 1.5 mo.
  - Already high-resolution x-ray microanalysis and EELS measurements, structural imaging
  - EELS core-loss spectroscopy
    - O-K and Ta-M stoichiometry
    - Valence state
    - Localized to the sub-nm scale

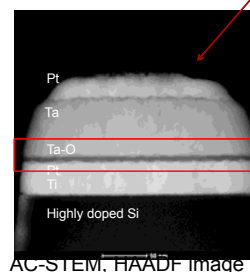
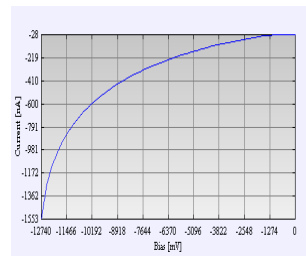
In collaboration with Yang Liu and Jianyu Huang (CINT)



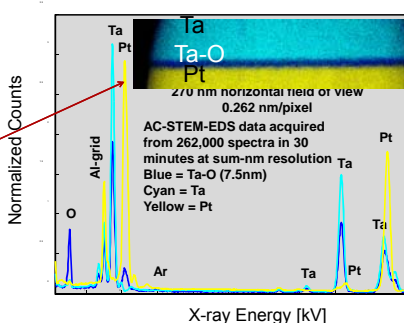
FIB-prepared comb structure



Electrical actuation of single element

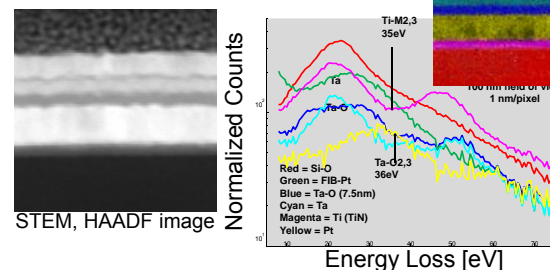


AC-STEM, HAADF image



X-ray Energy [keV]

## EELS Low-loss spectral image (AXSIA analysis)



Energy Loss [eV]

Preliminary EELS measurements demonstrate unbiased characterization of the memristor structure