SAND2013-5101C

Deposition Control and Depth Profiling in TaOx Memristors

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What are Memristors

Resistive Memory

- Flash has reached its limit
  - What's next?

Panasonic ideas for life

SAMSUNG

tsmc

hp invent

TOSHIBA Leading Innovation

imec

hynix

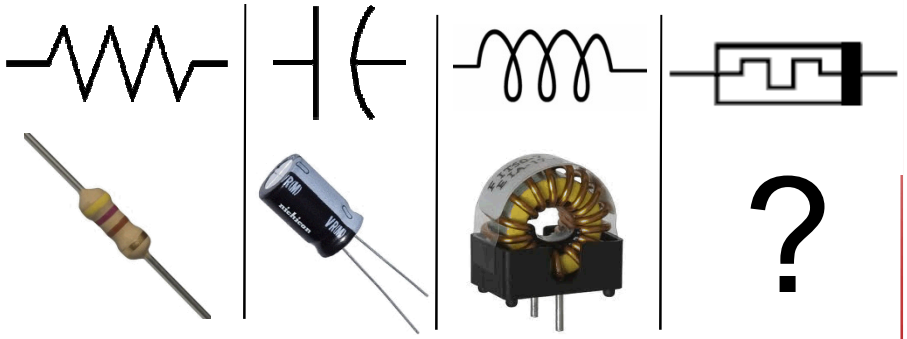
ELPIDA

Micron

SanDisk

Novel Circuit Element

- Leon Chua in the 70's
  - Resistor, Capacitor, Inductor, ?



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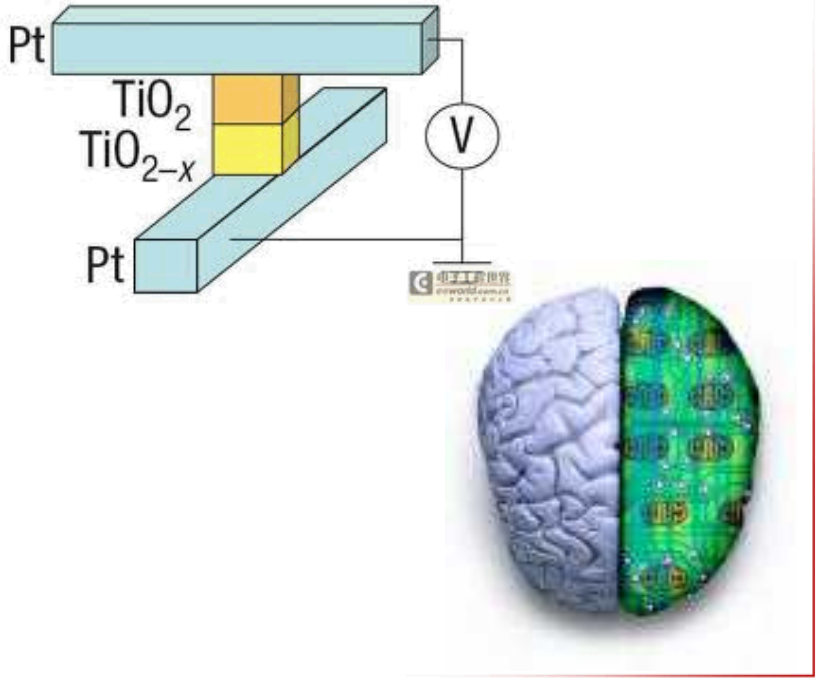
What are Memristors

Resistive Memory

- Performance in TaOx?
  - 30 nm (and shrinking)
  - Sub nanosecond switching
  - >10 year retention
  - ~10 pJ switching energy
  - CMOS compatible
  - Multi-level cell
  - 3D stackable
  - Simple architecture
- Remaining Issues?
  - Continued Scaling and Integration
  - Process Uniformity/Reproducibility
  - Forming Process
  - Nonlinearity

Novel Circuit Element

- HP in 2008 Showed One
  - Nanoscale TiO2 is a memristor



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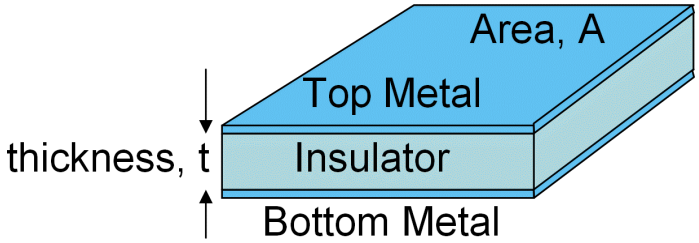
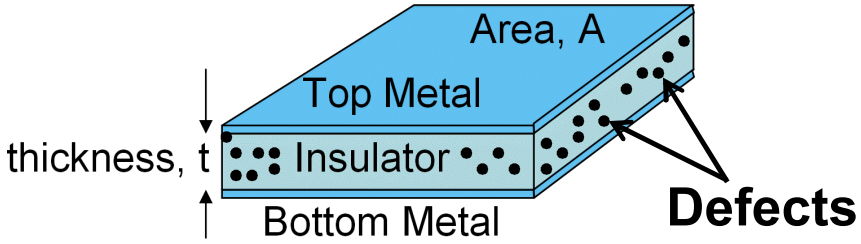
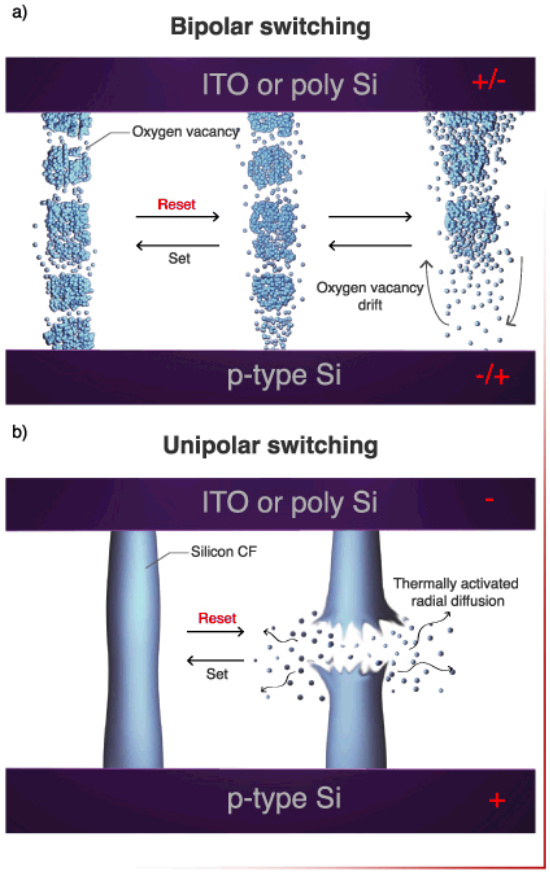
What are Memristors Really?

- A tantalum oxide metal-oxide-metal sandwich



- Good oxides are bad memristors





Adnan Mehonic *et al* 2012 *Nanotechnology* **23** 455201

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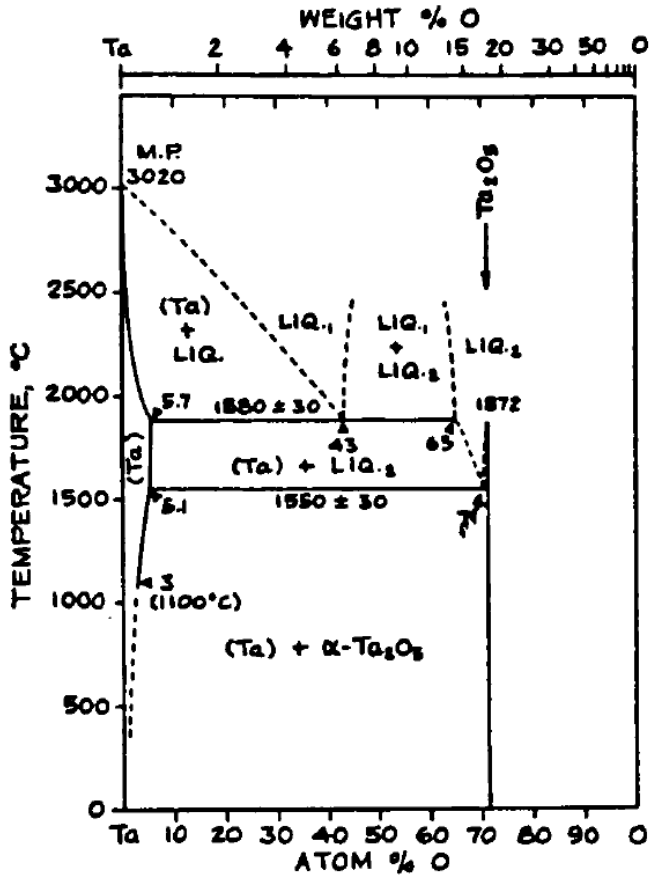
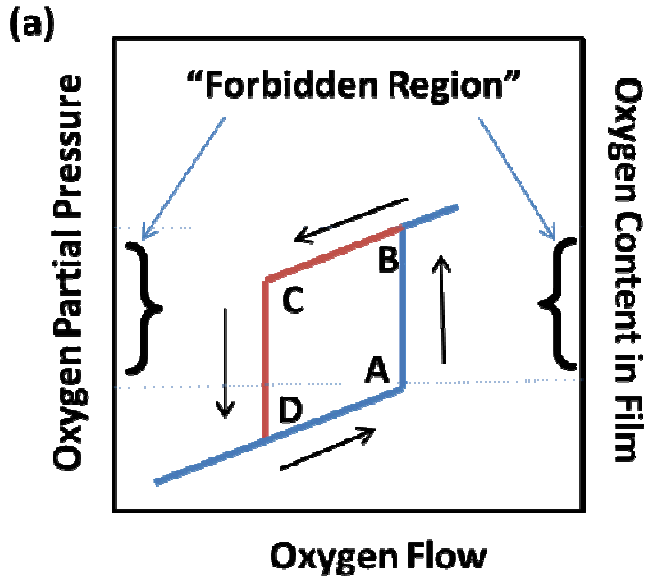
Making Bad Oxides is Hard

- Making bad oxides is harder than it sounds

- Tantalum Oxide wants to be either Ta or Ta_2O_5



- Sputtering wants to deposit Ta or Ta_2O_5



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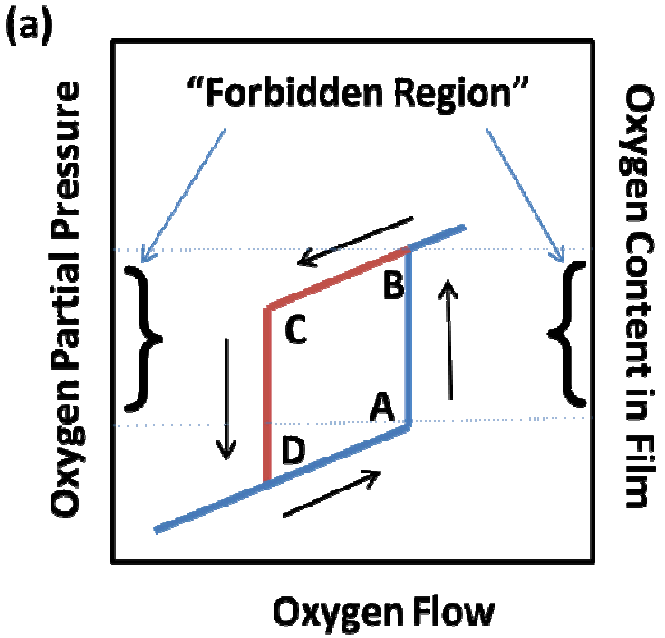
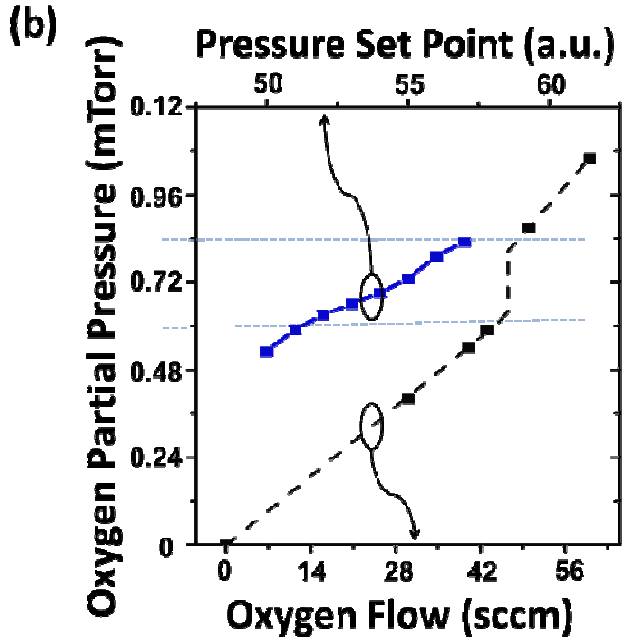
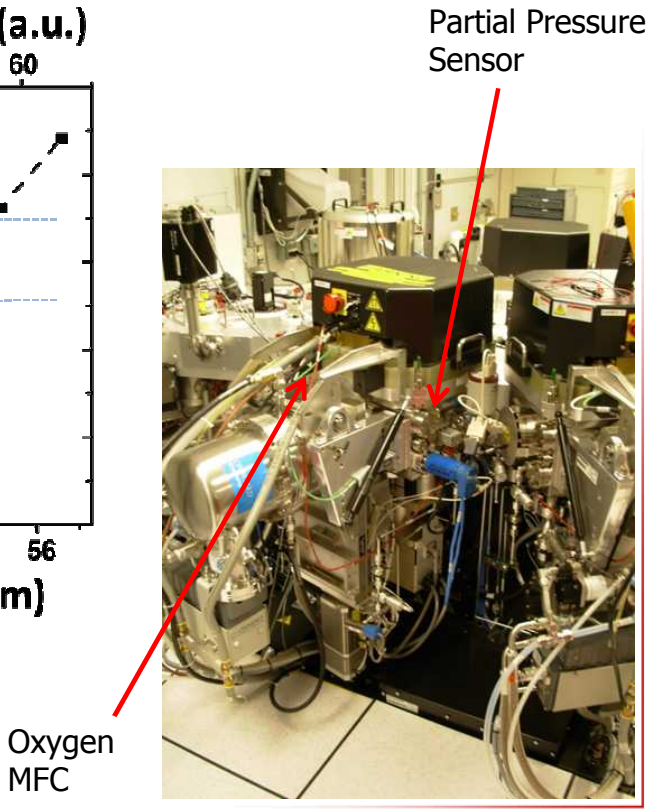
Making Bad Oxides is Hard

- But it can be done







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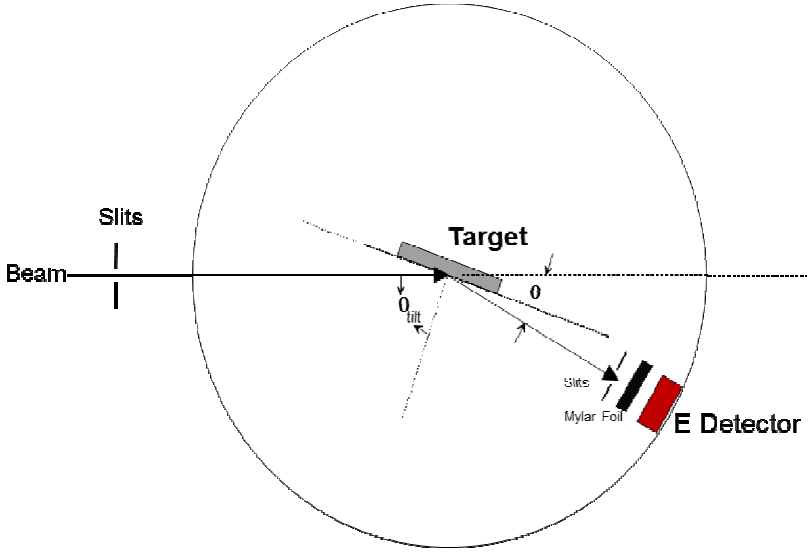
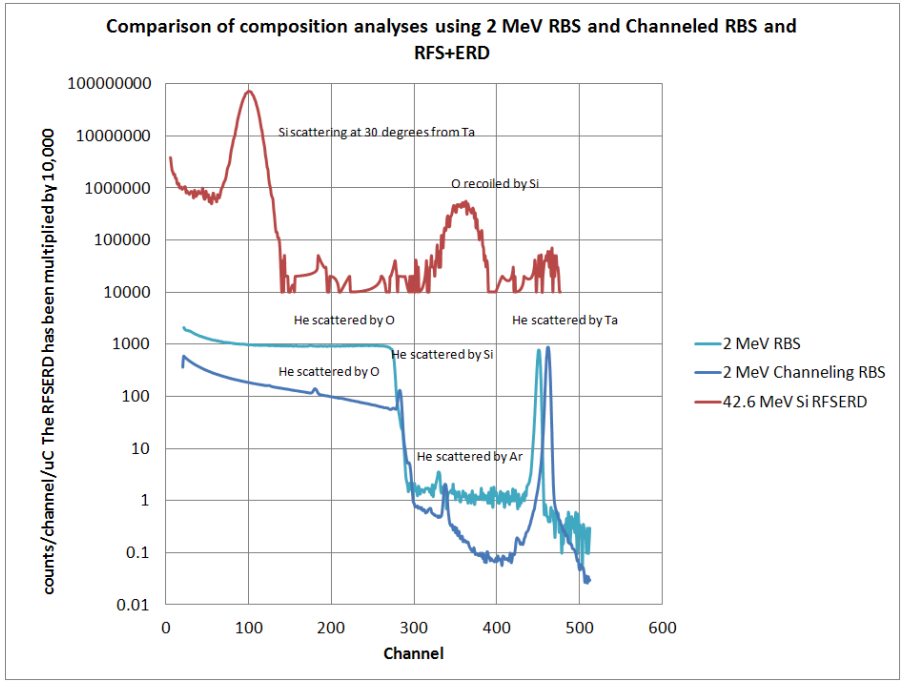
Calibrating Stoichiometry

- Measuring stoichiometry is challenging too

- Rutherford backscattering won't work!
- Developed a new characterization technique called RFSERD (Rutherford Forward Scattering and Elastic Recoil Detection).





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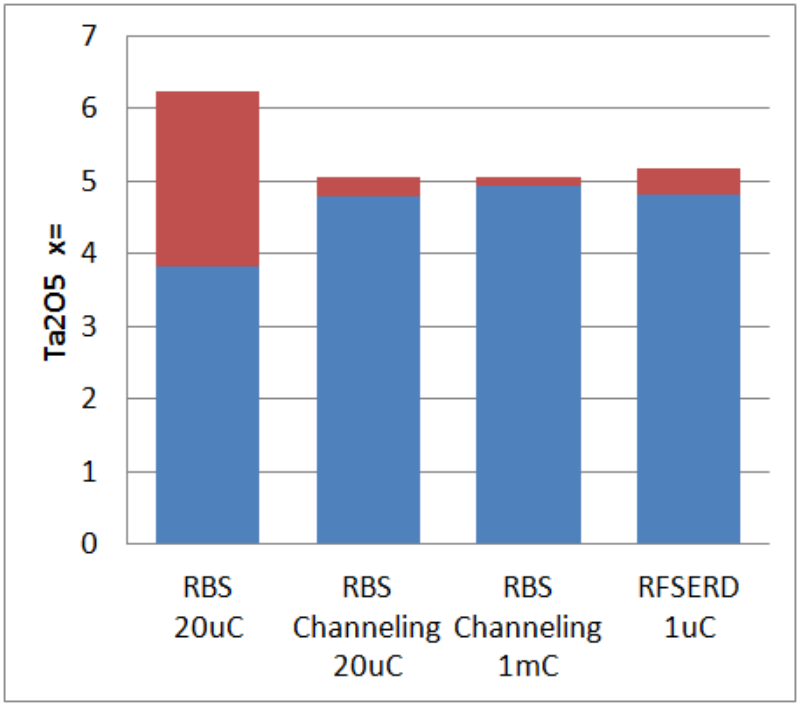

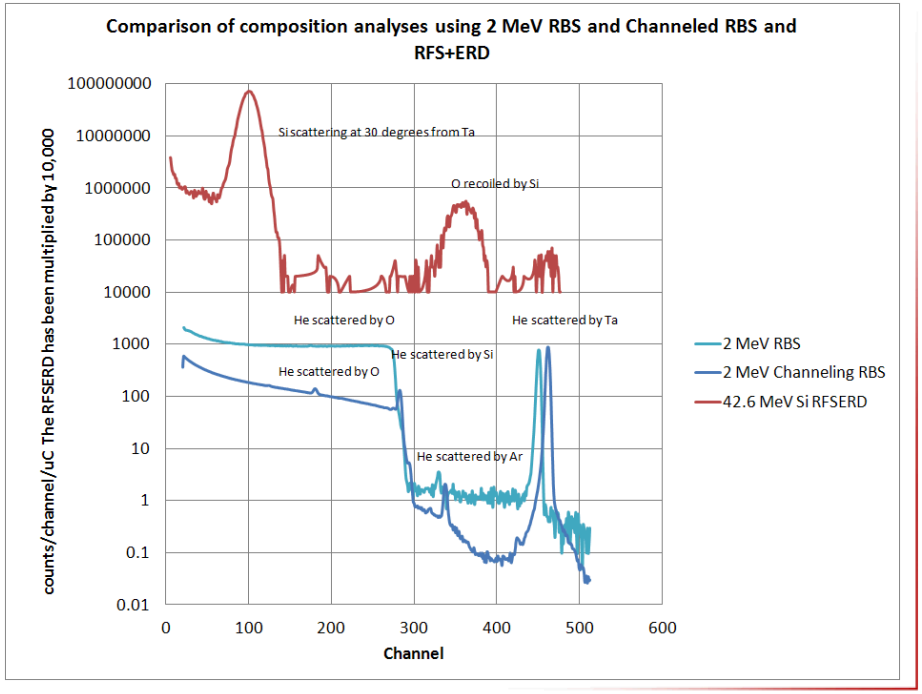

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HAXPES

- Measure stoichiometry at varying depths
- Gives chemical bonding state as well as stoichiometry

$$\lambda = E/\{E_p^2[\beta \ln(\gamma E) - (C/E) + (D/E^2)]\}$$

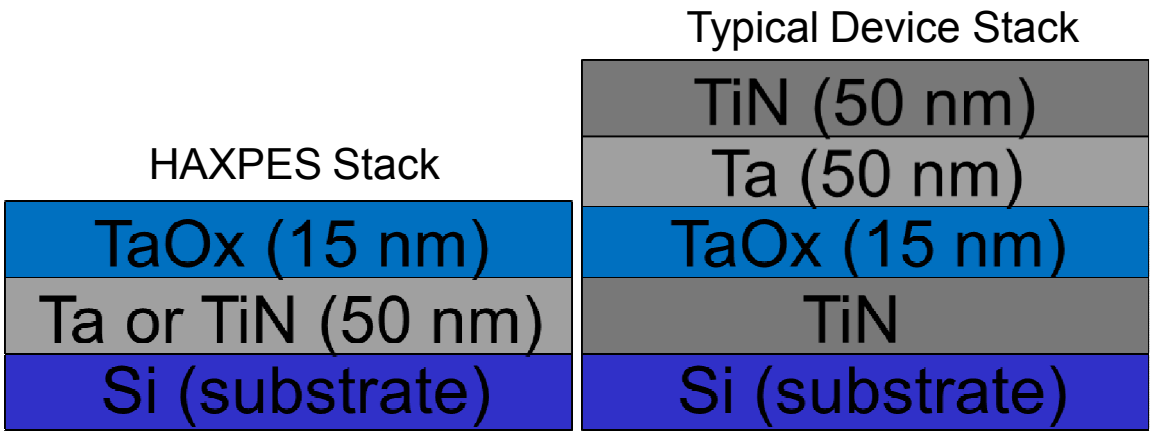
$$\beta = -0.0216 + 0.944/(E_p^2 + E_g^2)^{1/2} + 7.39 \times 10^{-4}\rho$$

$$\gamma = 0.191\rho^{-0.50}$$

$$C = 1.97 - 0.91U$$

$$D = 53.4 - 20.8U$$

$$U = N_v\rho/M$$



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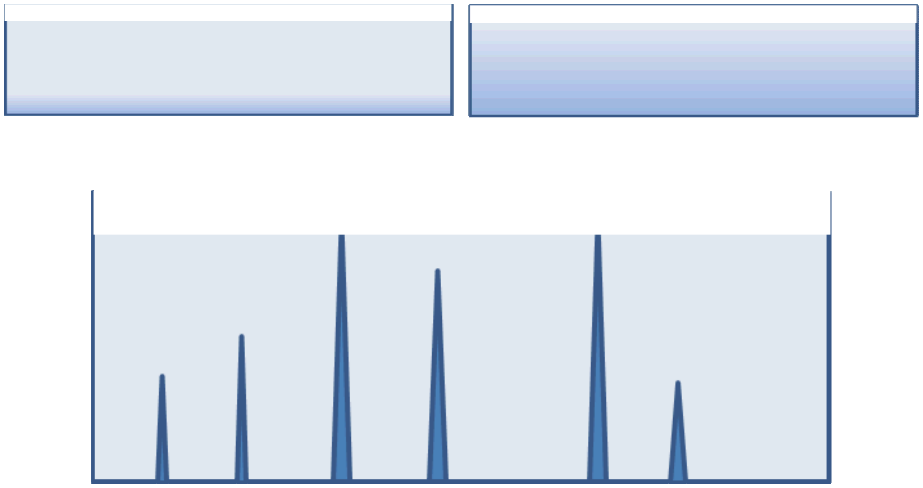
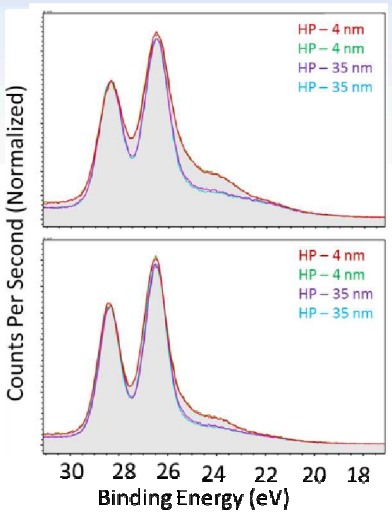
HAXPES

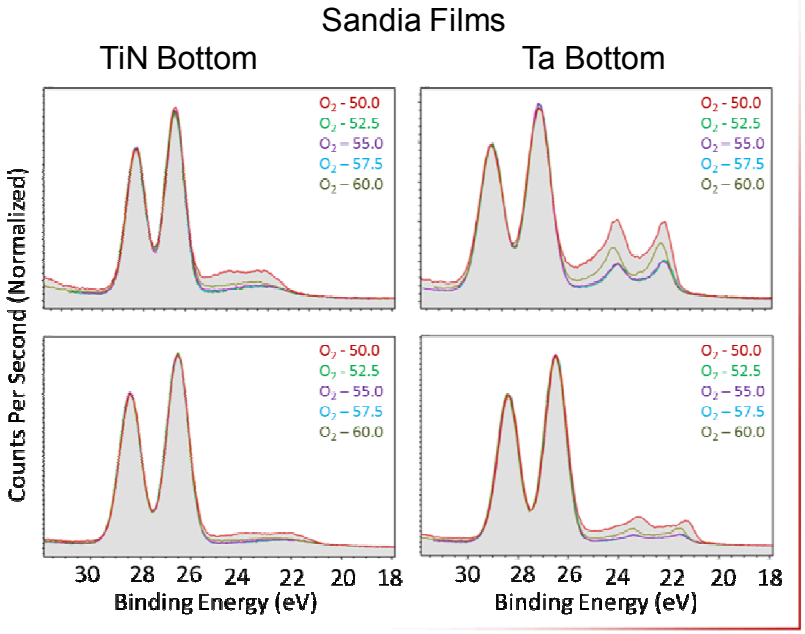
- Films made at Sandia are qualitatively different
- Depth and electrode dependence



Collaborator Films



Sandia Films



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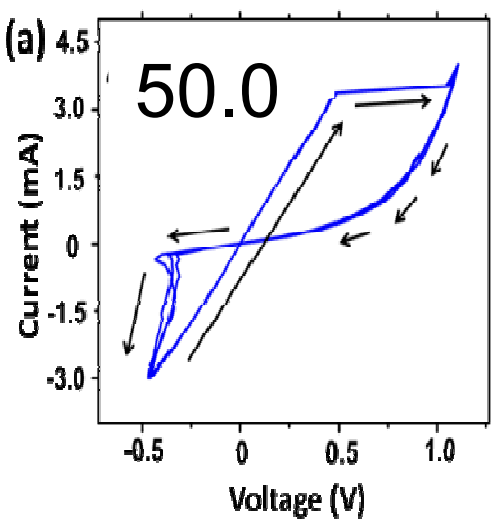
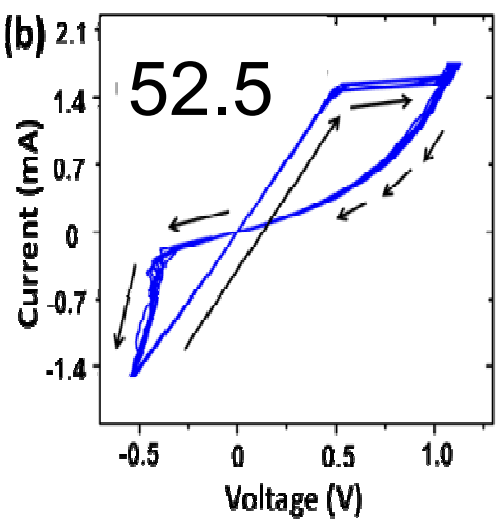
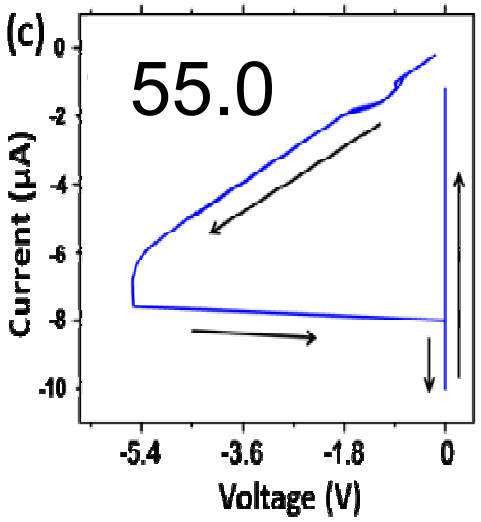
Sandia-Made Devices

- Low oxygen flows gave forming free, low yield
- High oxygen flows gave devices that shorted easily
- Middle results best
  - Forming free
  - High yield

Partial Pressure Set	x: Ta2Ox	Working Devices?
50.0	1.9 ± 0.5	Some
52.5	3.3 ± 0.5	Yes
55.0	4.2 ± 0.5	No
57.5	4.6 ± 0.5	No
60.0	5.0 ± 0.5	No







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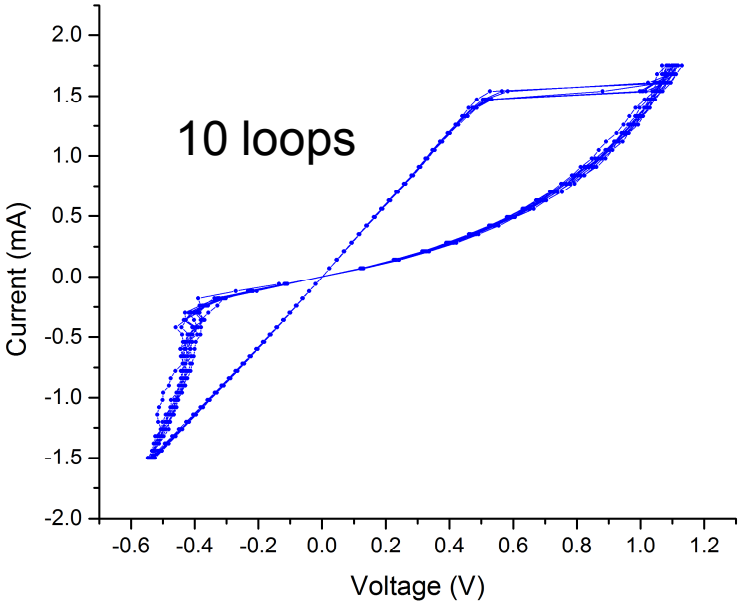

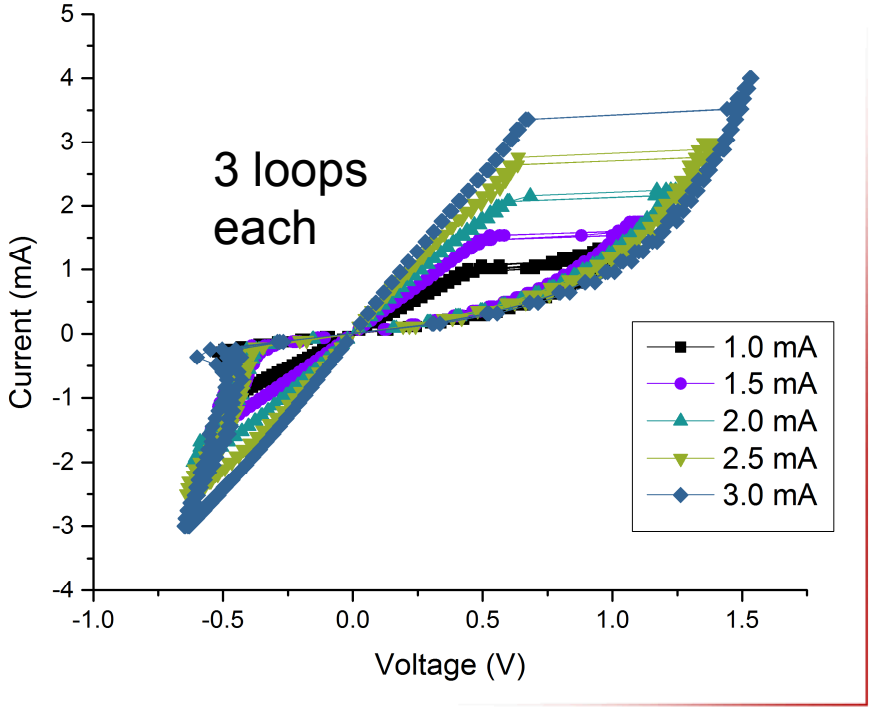

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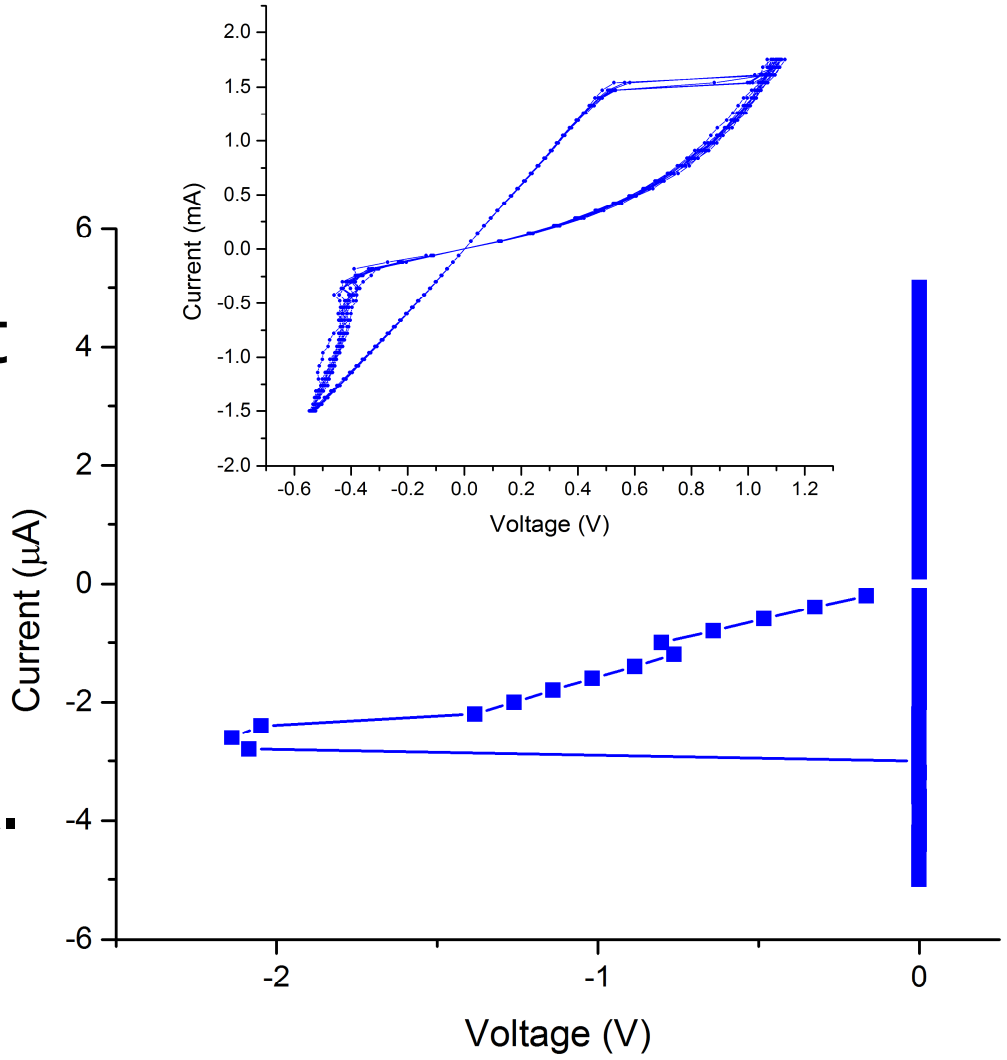
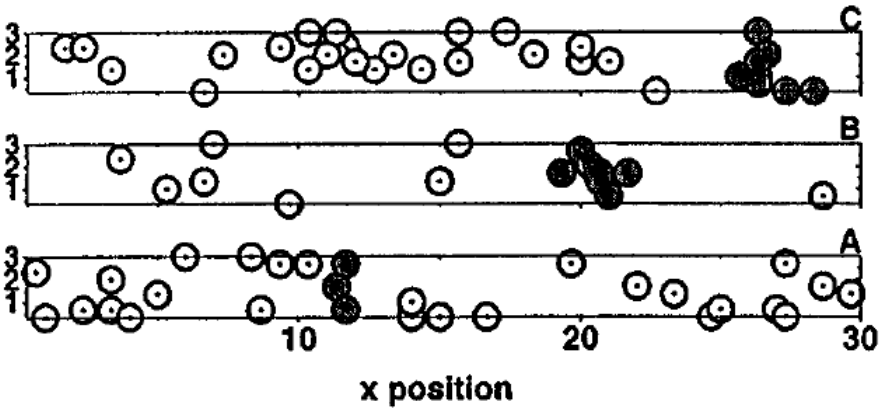
Annealing?

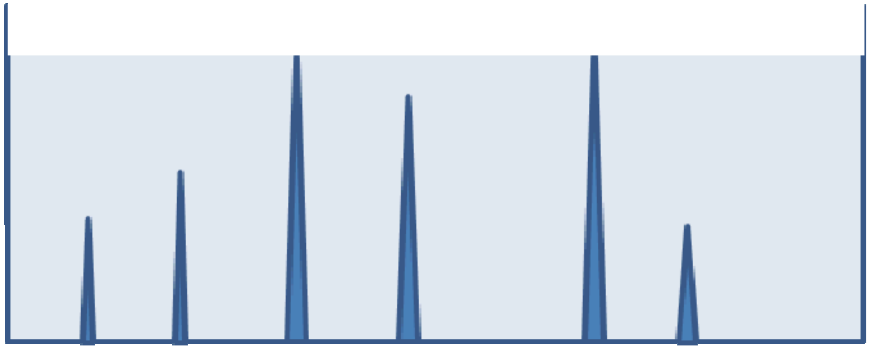
- Strange Reverse Forming Required
- Most likely the effect is some sort of anneal
- Possibly the filament is extended with negative feedback.



Possible Structure/Mechanism

- Possibly the OFF current anneals the device with negative feedback.
- Hard breakdown of thick oxides vs soft for thin





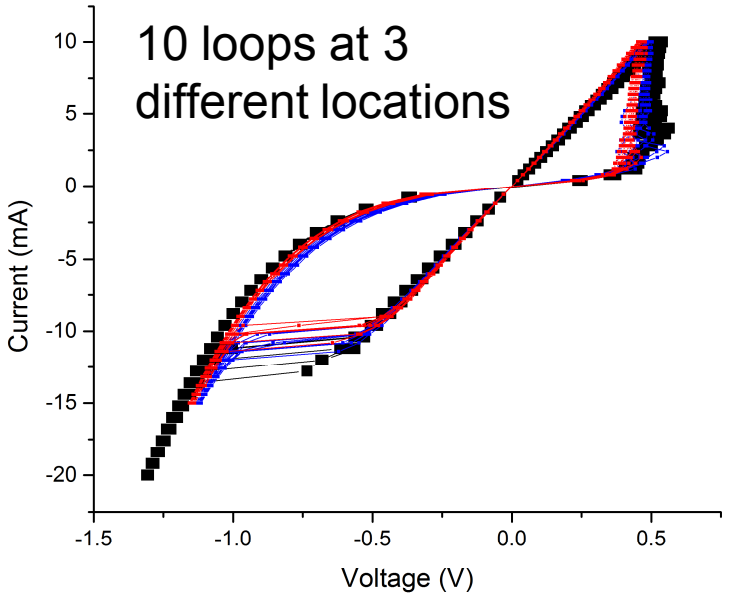
IEEE Trans. Elect. Dev. Vol 49, No. 2, Feb 2002

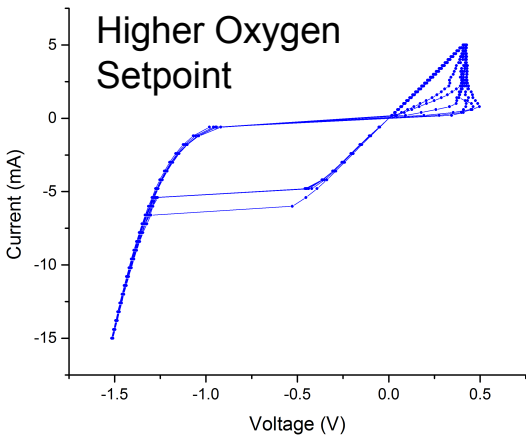
Summary

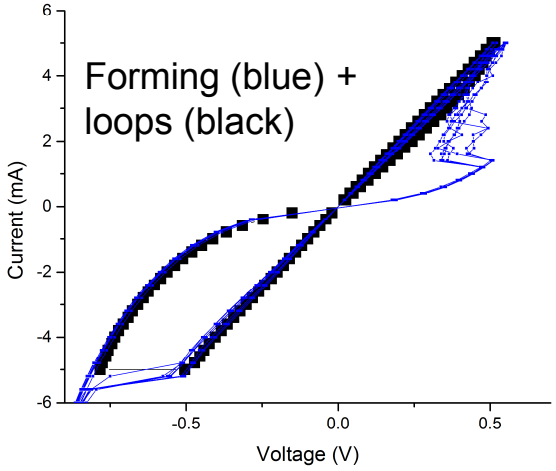
- We have developed a forming free memristor process
  - Process gives increased reproducibility
  - Papers to come soon
- We developed a new ion beam technique to characterize the films
- We learned about the chemical bonding and gradients in the films
- We are gaining insight into the forming and switching process

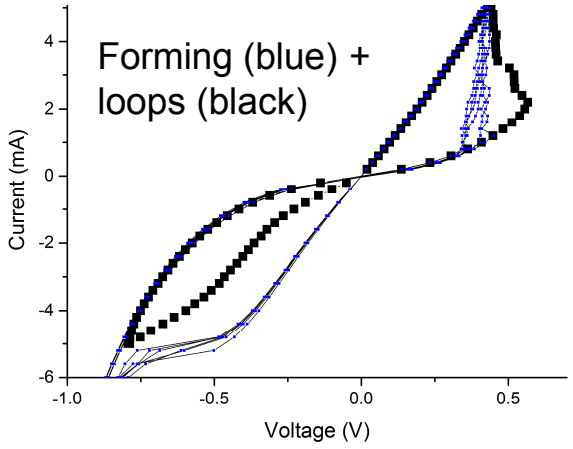
MicroFab Dot Caps

- Microfab Memristors
- Truly forming free
- Control On/Off ratio
- Consistency!
- Reproducibility?



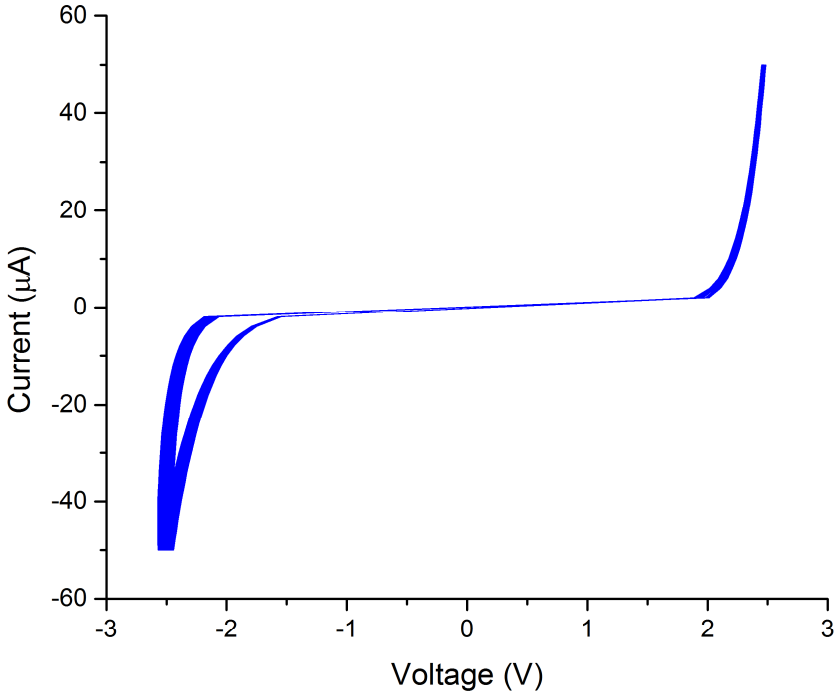


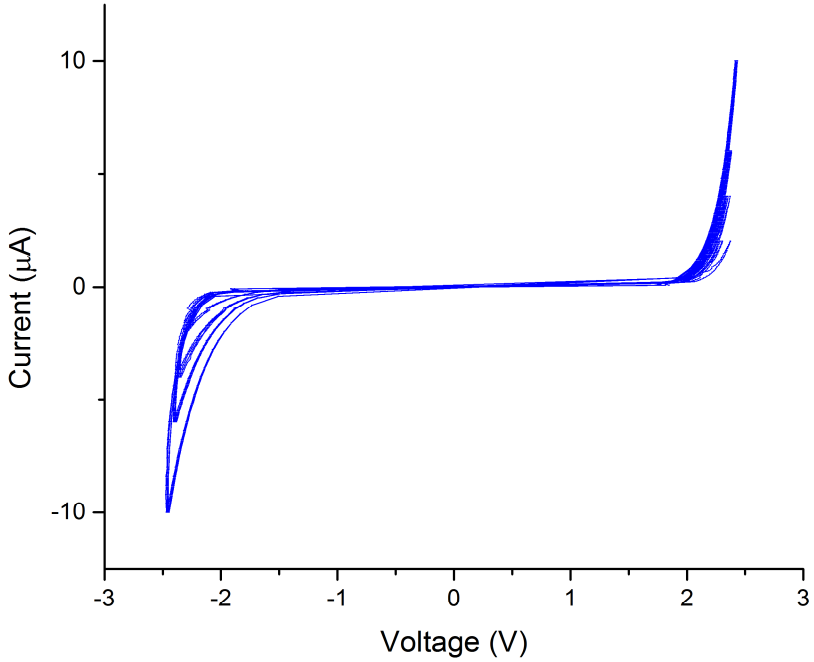




More MicroFab Dot Caps

- Highly Nonlinear
- High Resistance
- Forming Free
- Good Consistency





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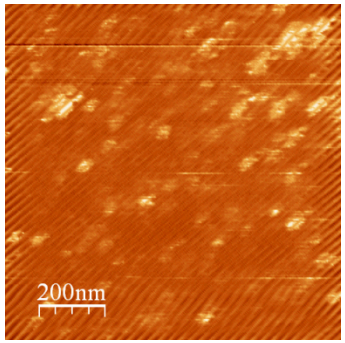
Hot Spot Mapping

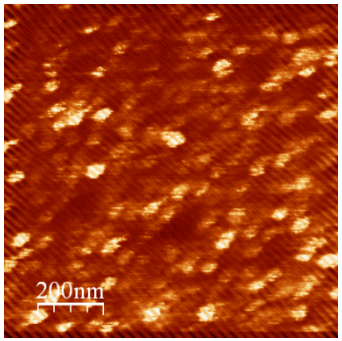
- Localized hot spots exist in the films suggesting the spire model is likely.

Vtip=2.4 V



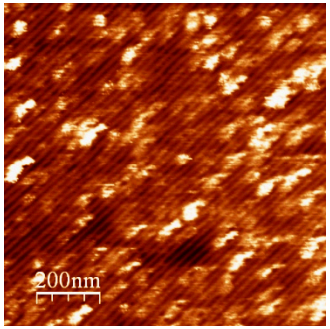
20120806_swh-16-38_TaOx-CAFM_0008

Vtip=2.6 V



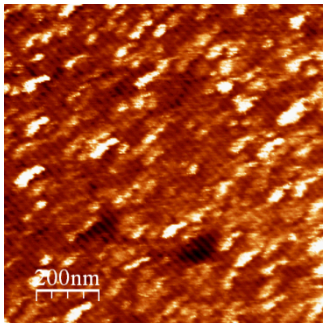
20120806_swh-16-38_TaOx-CAFM_0009

Vtip=2.8 V



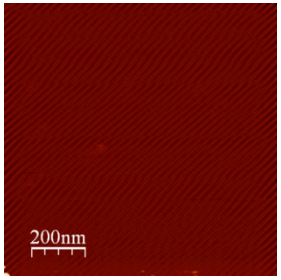
20120806_swh-16-38_TaOx-CAFM_0010

Vtip=3.0 V



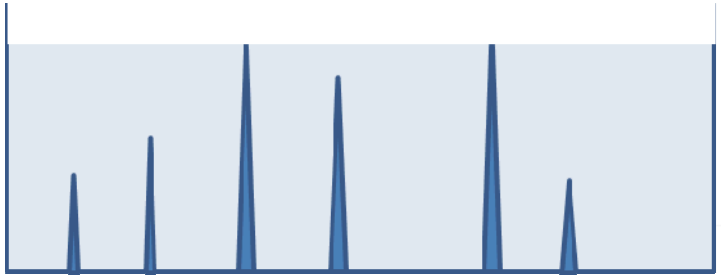
20120806_swh-16-38_TaOx-CAFM_0011

Vtip=2.0 V



20120806_swh-16-38_TaOx-CAFM_0012

Preamp Gain = 10^9 V/A
Same spot imaged with increasing tip voltage
Brighter colors indicate more conduction



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