SAND2014-15687PE

Mapping of Radiation-Induced Resistance Changes and Multiple Conduction Channels in TaO_x Memristors

D. R. Hughart, J. L. Pacheco, A. J. Lohn, P. R. Mickel, P. E. Dodd, M. R. Shaneyfelt, E. Bielejec, G. Vizkelethy, B. L. Doyle, S. L. Wolfley, M. L. McLain, and M. J. Marinella

Sandia National Laboratories

This work was supported Sandia's Laboratory Directed Research and Development and the Defense Threat Reduction Agency

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

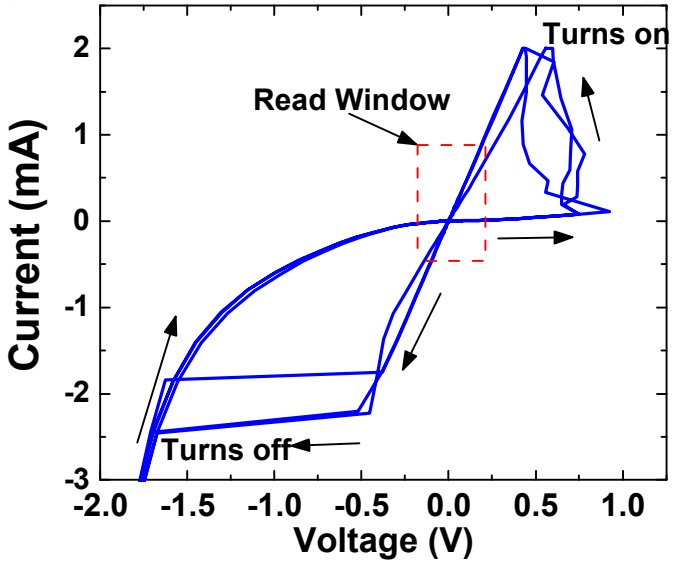
Why Memristors?

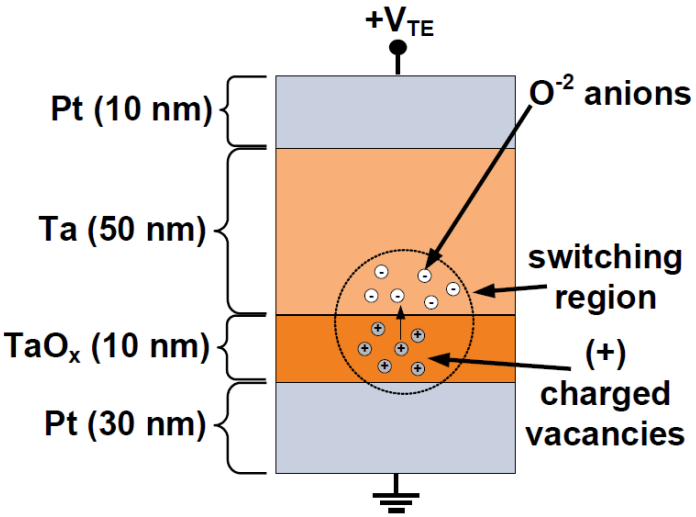
- Current nonvolatile memory (NVM) technologies like Flash are expected to be increasingly limited by scaling
- Resistive RAM (ReRAM) is a strong candidate to replace Flash with many promising performance metrics
  - Scalability, endurance, speed, low power
- State of the art is rapidly advancing
  - Panasonic has a commercial product PUT QUOTES IN
  - HP plans DIMM by 2016, later “The Machine”

Sandia National Laboratories

Memristor I-V Characteristics

- **Resistive RAM (ReRAM) is a memristor**
- **Applied current and voltage can change resistance state**
  - **Hysteresis loop**
- **Low voltages can read state**
  - **Read window**



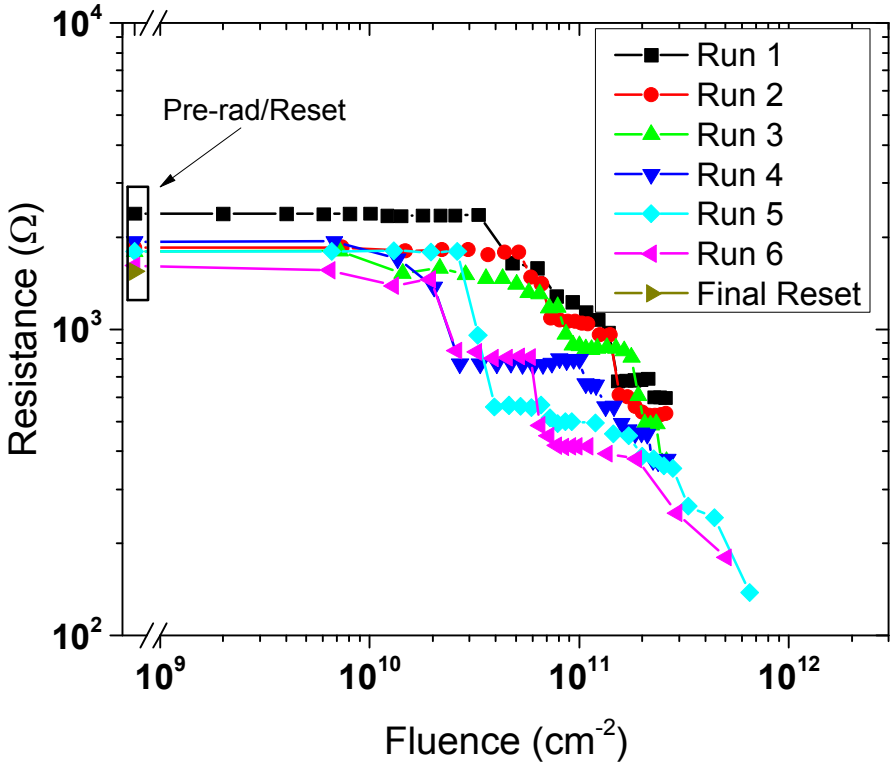


- **Resistive switching**
  - **Oxygen vacancies**
- **TaO_x**
  - **Oxygen anions**

Sandia National Laboratories

Displacement Damage Effects

- **800 keV Ta**
  - **Gradual resistance degradation**
- **Creation of oxygen vacancies**
  - **Fluence > 10^{10} cm^{-2}**
- **Fluence for a single device**
  - **What size is the sensitive area?**

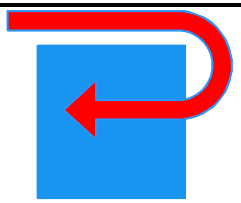


Sandia National Laboratories

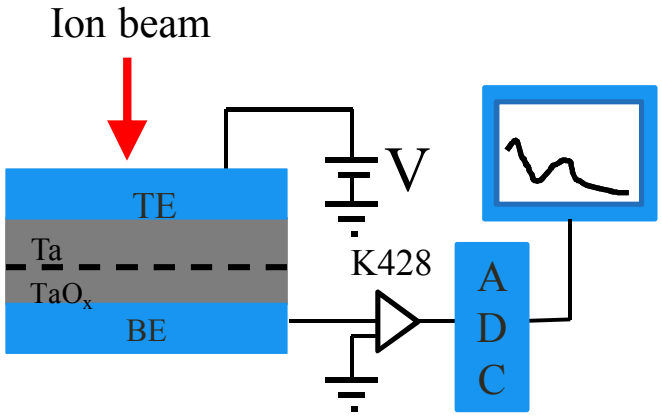
Microbeam Raster Scan

- **Target smaller regions of the oxide to look for sensitive regions**
  - **Spatial mapping of potential conduction channels**
- **800 keV Si beam rastered across the device**
  - **Targeted area ~1 µm x 2 µm (device is 10 µm x 10 µm)**
  - **Resistance recorded each time beam moves (50 mV)**

Scan Ion Beam over device

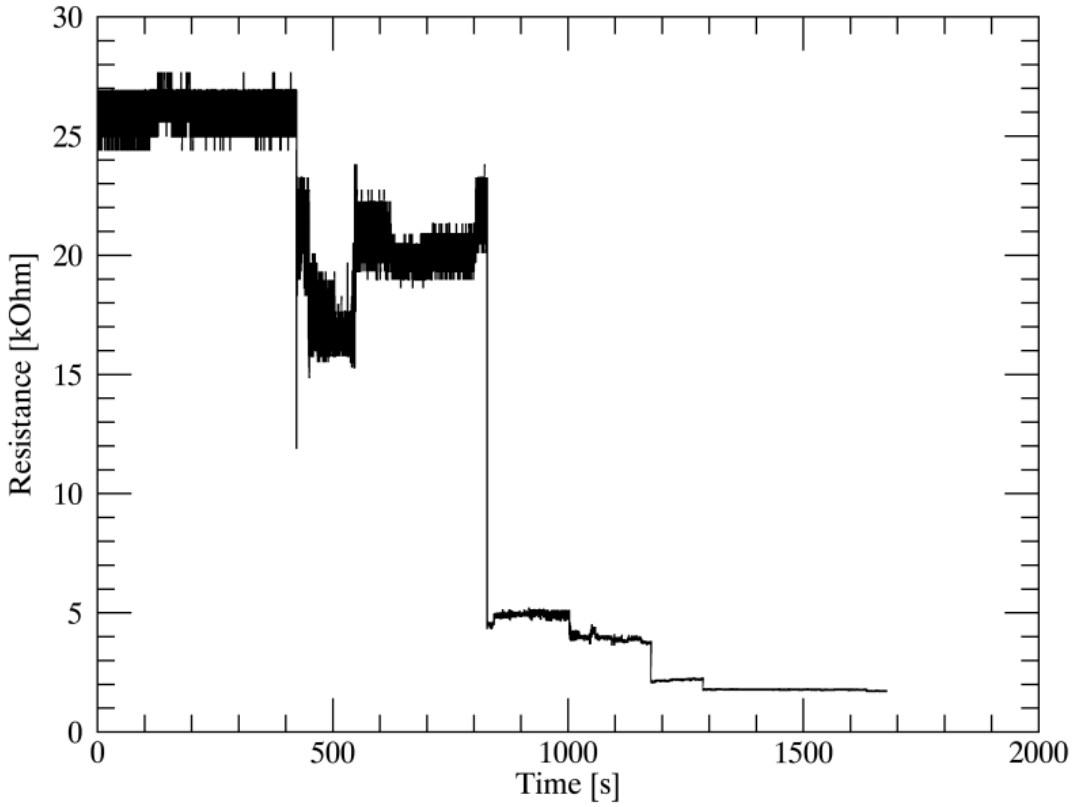


In-situ monitoring of resistance



Microbeam Data

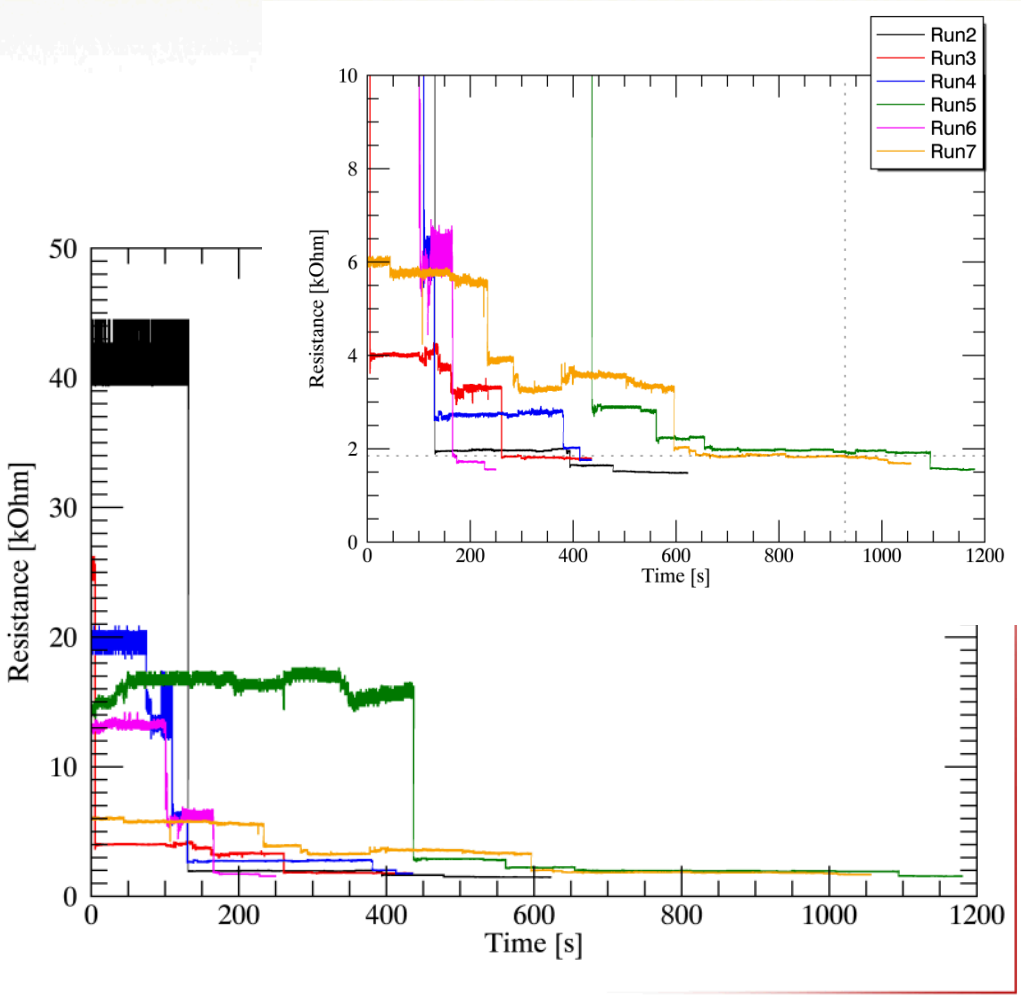
- 1 ion per spot on average
- Significant drops in resistance likely due to oxygen vacancy creation
- Two significant increases
  - Ion disrupts path of oxygen vacancies?



Sandia National Laboratories

Microbeam Data (cont.)

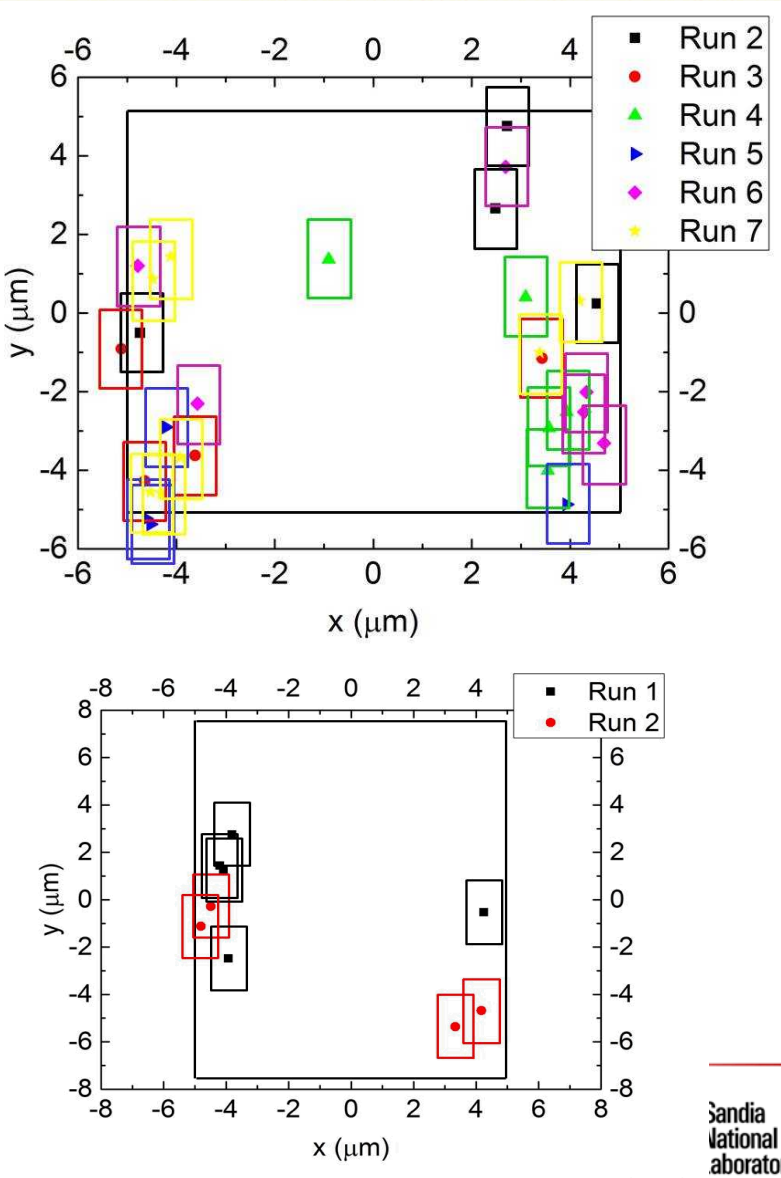
- Resistance generally degrades
  - Starting R_{OFF} degrades as well
  - Similar to previous results
- 10 to 40 scans
  - ~4 ions per spot
  - 5 or less changes
  - Imprecise targeting?
  - How many ions are hitting critical region?



Sandia National Laboratories

Spatial Mapping

- There are multiple distinct sensitive areas
- Changes in resistance tend to happen on the edges
  - More defects formed on perimeter during forming
  - Stronger electric field
- Beam targeted center with no effect



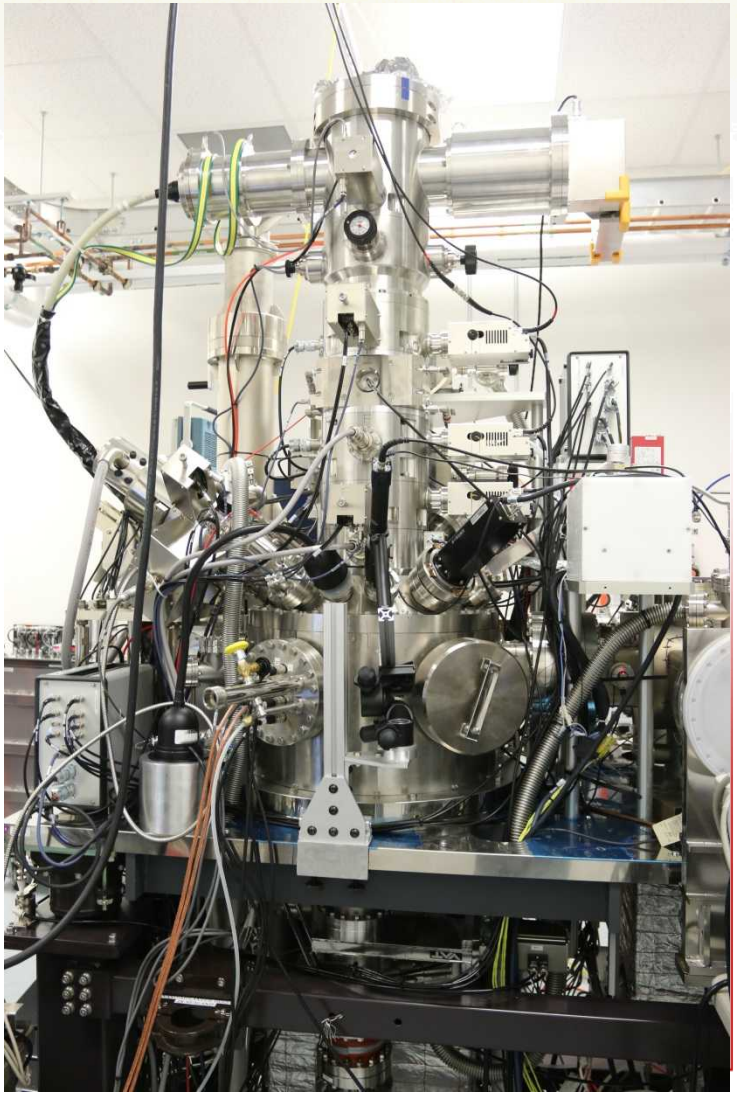
Microbeam Summary

- Multiple distinct sensitive regions
- Device is most sensitive on perimeter
  - Likely more defects on the perimeter
  - Appears insensitive in center of device
  - Sensitive area is not the entire oxide region
- Targeting likely not precise enough
  - Takes many scans to get changes
  - It sure would be great to have more precise targeting…

Sandia National Laboratories

Nano-scale Ion Implantation

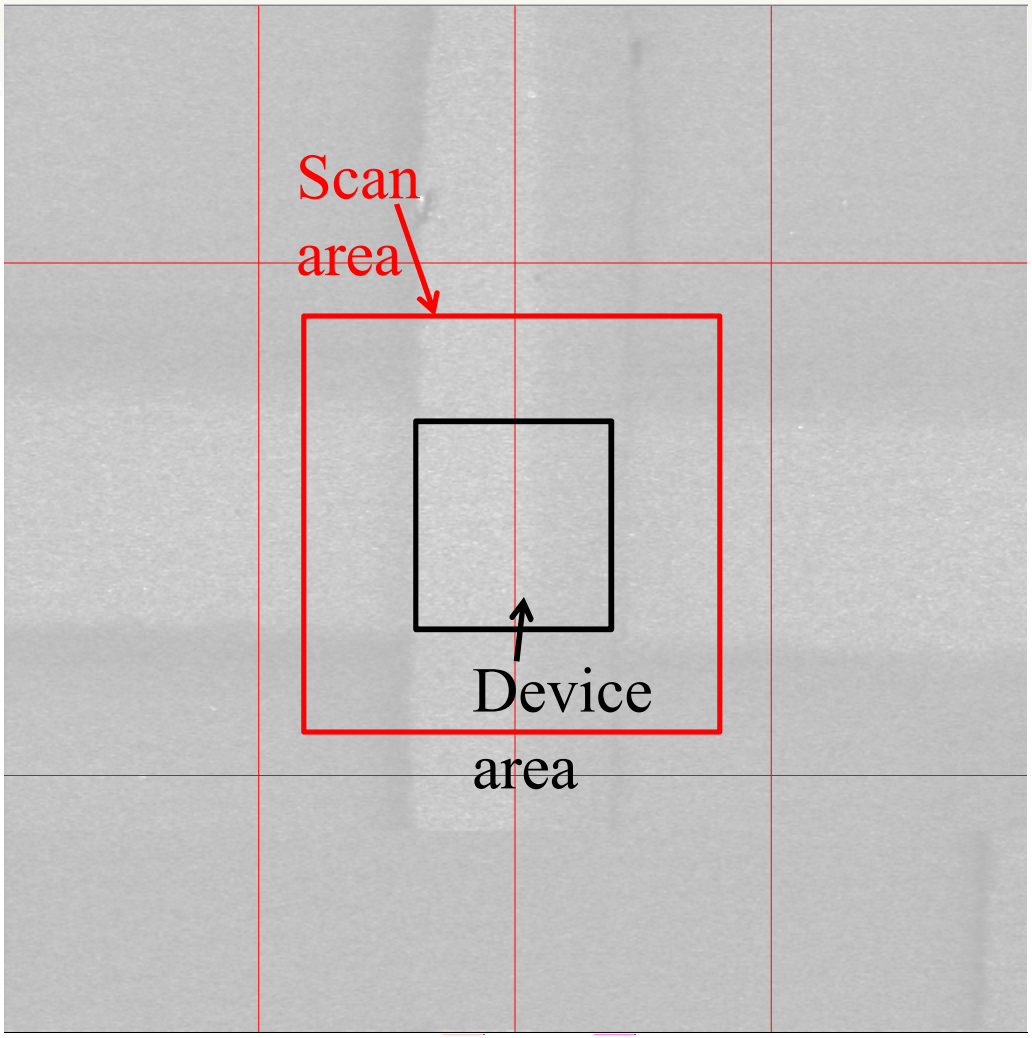
- **NanoImplanter (nI)**
  - **Variable Energy, 10-100 kV**
  - **Fast Blanking and Chopping → single ion!**
  - **Spot size on target**
    - ~10 nm, 100 keV Ga^{+}
    - ~24 nm, 200 keV Si^{++}
    - ~33 nm, 50 keV Sb^{+}
  - **Liquid Metal Alloy Ion Source (LMAIS)**
    - AuSiSb
    - CuPtP
    - and many more…
  - **Mass-Velocity Filter**



Sandia National Laboratories

Nanoimplanter Raster Scan

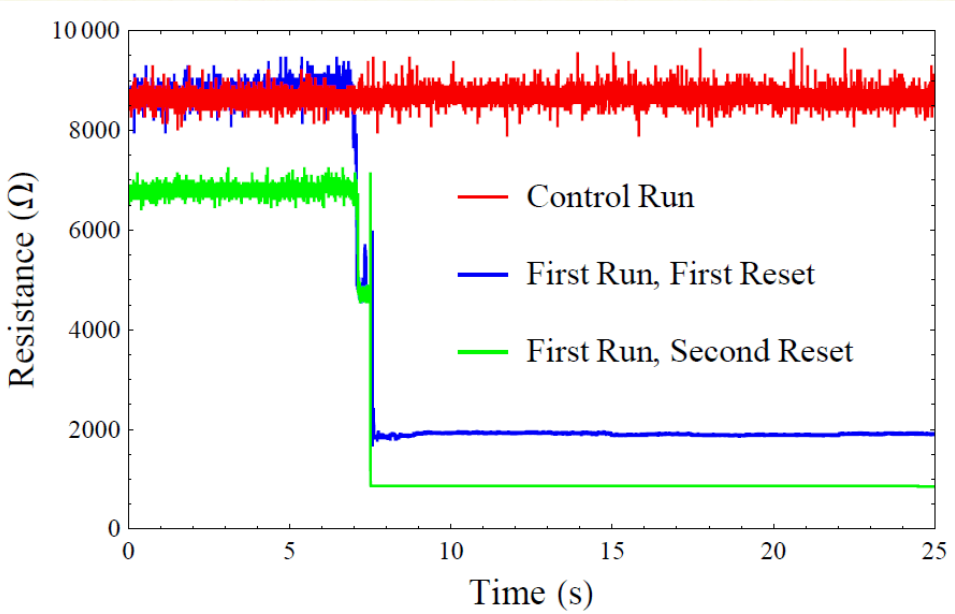
- **15 um by 15 m scan area**
  - **200 keV Si++**
  - **Beam current ~0.25 pA**
  - **Beam spot size ~40 nm**
  - **Step size 30nm**
  - **Dwell times ranging from 100 us down to 50 us**

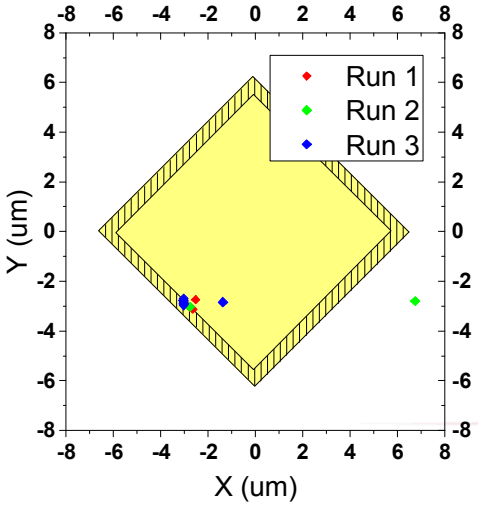


Sandia National Laboratories

nI Data

- **Resistance changes in consistent locations also observed using nI**
- **Control data taken with beam blanked**
- **Resistance changes occurred near edge**

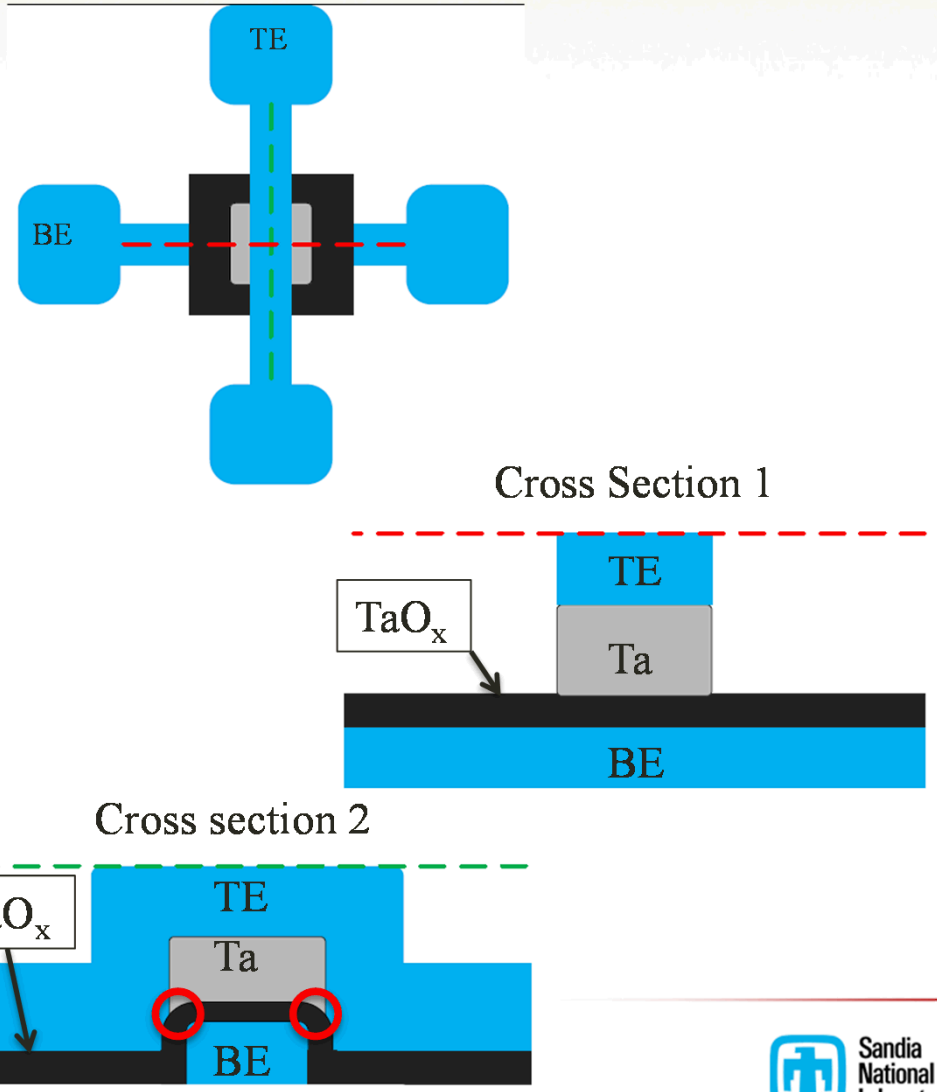




Sandia National Laboratories

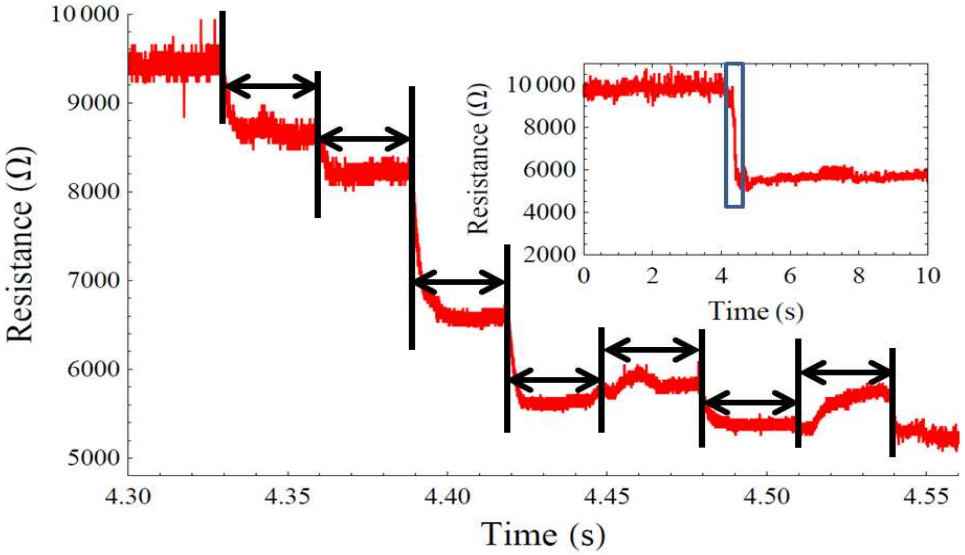
Edge Effects

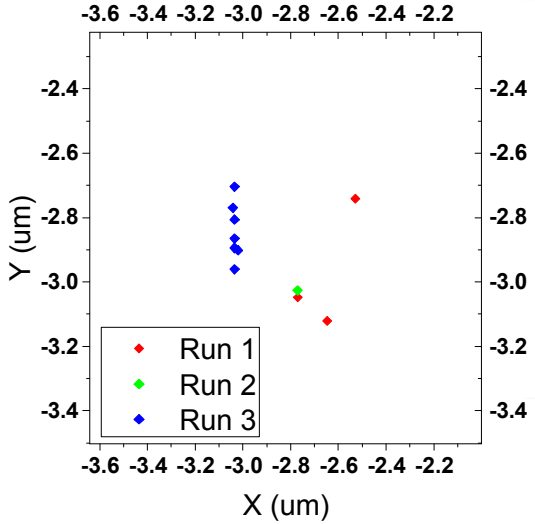
- **Edge of bottom electrode may have non-conformal oxide deposition at edge**
- **Electric fields may also be higher at edge**
- **Both factors may lead to higher concentration of defects during forming**



Size of a Sensitive Area

- Events equally spaced apart
  - 30 ms (one scan length)
  - Part of one region
- Estimate filament in Y
  - Symmetric in X?
- 240 nm
  - 120 nm critical region?
- Filament size affected by non-radiation factors
  - Operating conditions





Sandia National Laboratories

Summary and Conclusions

- **Spatially mapped multiple conduction paths, or potential conduction paths**
- **Large portion of the active area is insensitive to displacement damage**
  - **Scaling implications**
- **Capability to locate and characterize sensitive regions with high precision**

Sandia National Laboratories