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Resistive Memory for Space Applications

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Outline

- Introduction
- Ionization and Displacement Damage
  - Separate and identify mechanisms
- Isolate conductive filament
  - Microbeam
  - Nanoimplanter

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
  - Promising initial radiation studies

- State of the art is rapidly advancing
  - Panasonic has a commercial product
  - HP plans DIMM by 2016, later "The Machine"

"Industry-leading low power operation (less than 4μW in low-speed active mode"

"High-speed rewriting, 5 times faster than conventional flash-based MCU"

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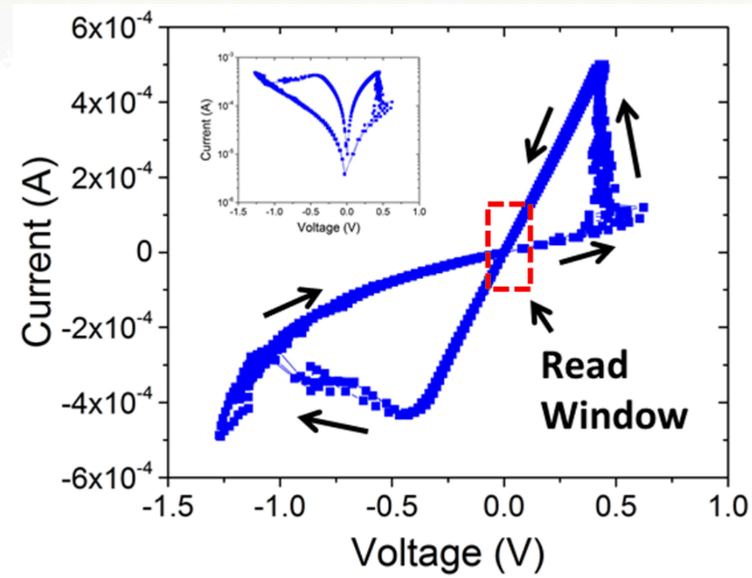
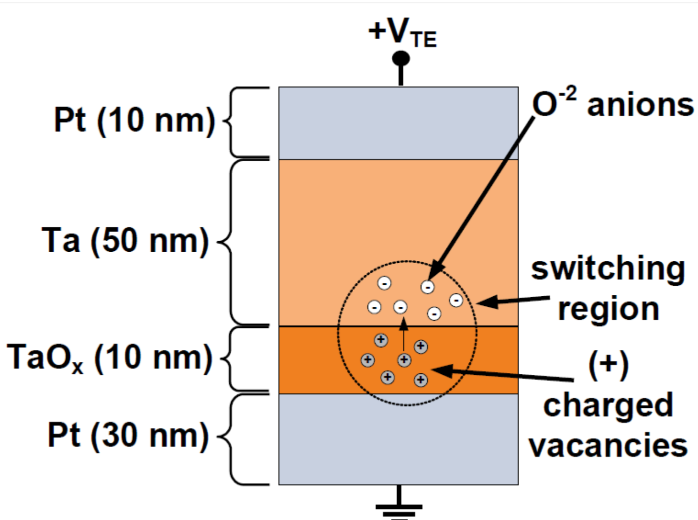
Memristor I-V Characteristics

- **Resistive RAM (ReRAM) stores state as a function of resistance**
- **Applied current and voltage can change resistance state**
  - **Hysteresis loop**
- **Low voltages can read state**





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

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Displacement Damage vs. Ionization

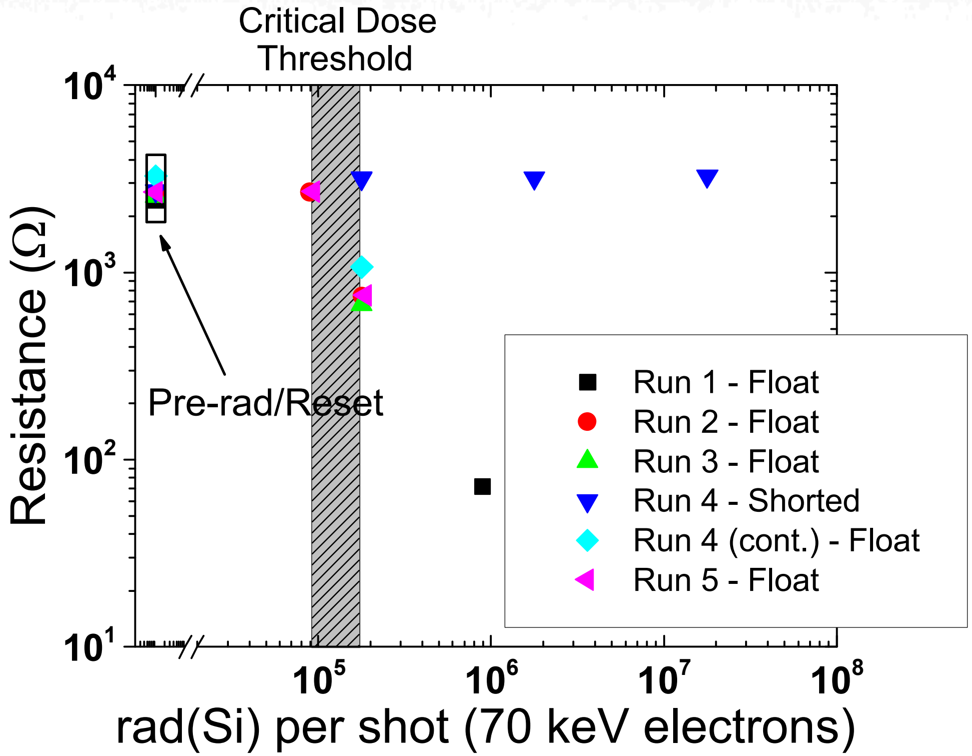
- **Different damage mechanisms investigated using various beams**

Displacement damage | **800 keV Ta** | **28 MeV Si** | **70 keV e^-** | **Ionization**

- **Different circuit configurations**
  - **Floating and shorted**

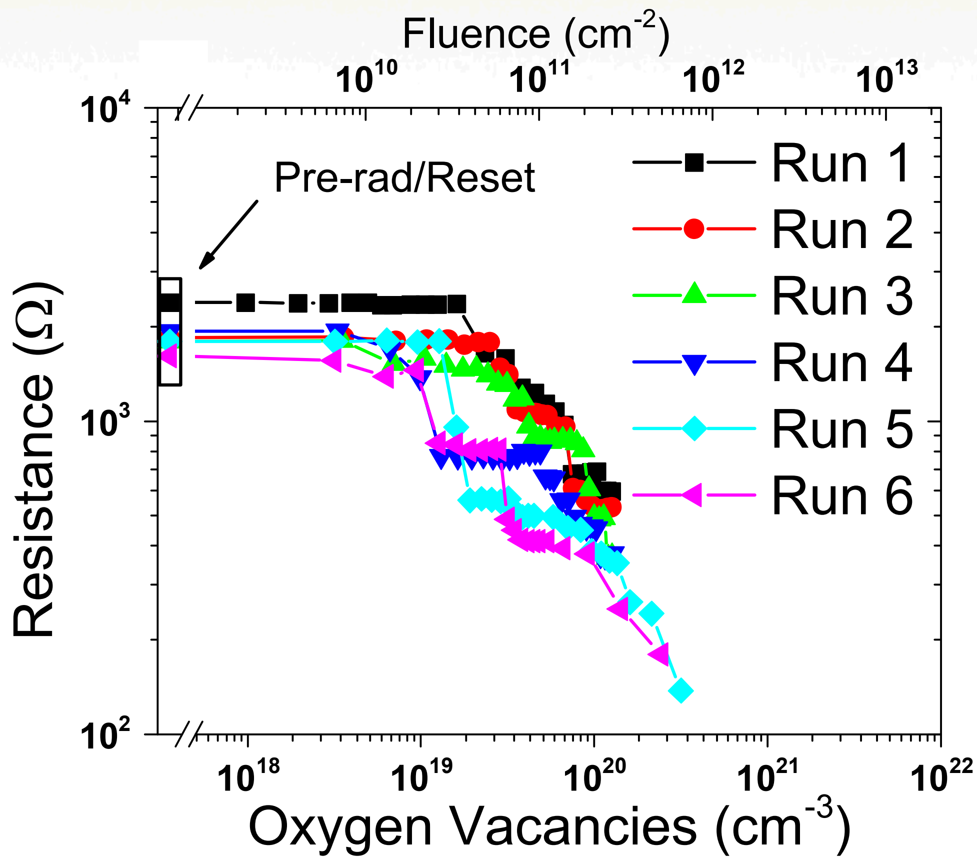
70 keV Electrons (Ionization) - TaO_x

- **Ionization**
  - Threshold 100-200 krad(Si) per shot
- When pins are **shorted** no changes occur for doses up to 18 Mrad(Si)
- Resistance change varies with dose per shot



Displacement Damage Effects

- 800 keV Ta
  - Gradual resistance degradation
- Creation of oxygen vacancies
  - Fluence > 10^{10} cm^{-2}
  - Vo > 10^{19} cm^{-3}
- Fluence for a single device
  - What size is the sensitive area?



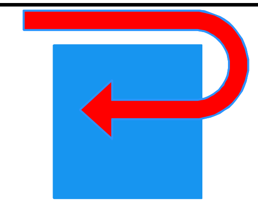
Ionization and Displacement Damage Initial Study Summary

- **Separate displacement damage and ionization effects**
  - Gradual resistance decrease above ~10^{19} cm^{-3} oxygen vacancies
  - Abrupt and consistent changes at rad(Si) per shot threshold
- **Potential mitigation strategies**
  - Displacement damage: Repeated cycling may restore degraded R_{OFF}
  - Ionization: Devices that aren't floating are less susceptible
  - If devices are floating often, apply small voltages periodically

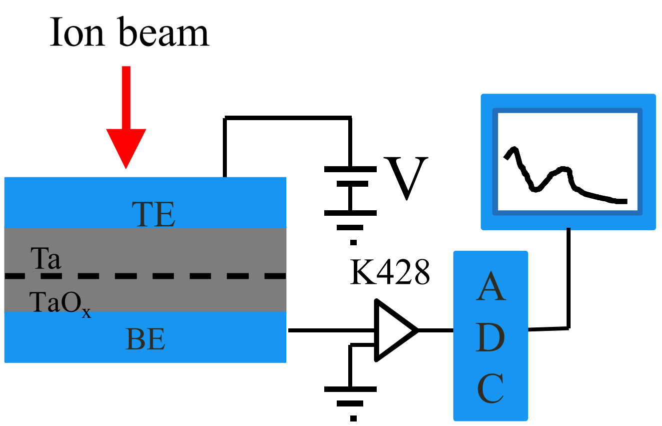
Microbeam Raster Scan

- **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)**

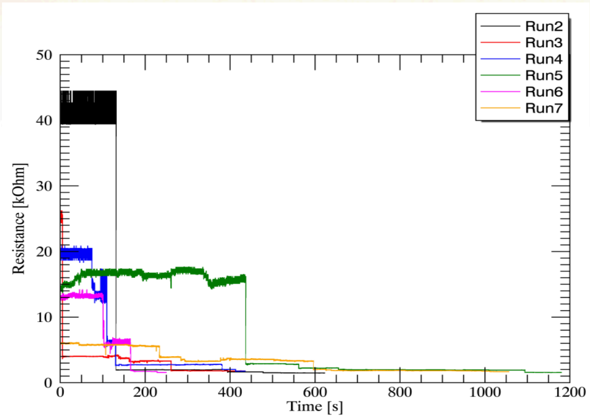
Scan Ion Beam over device

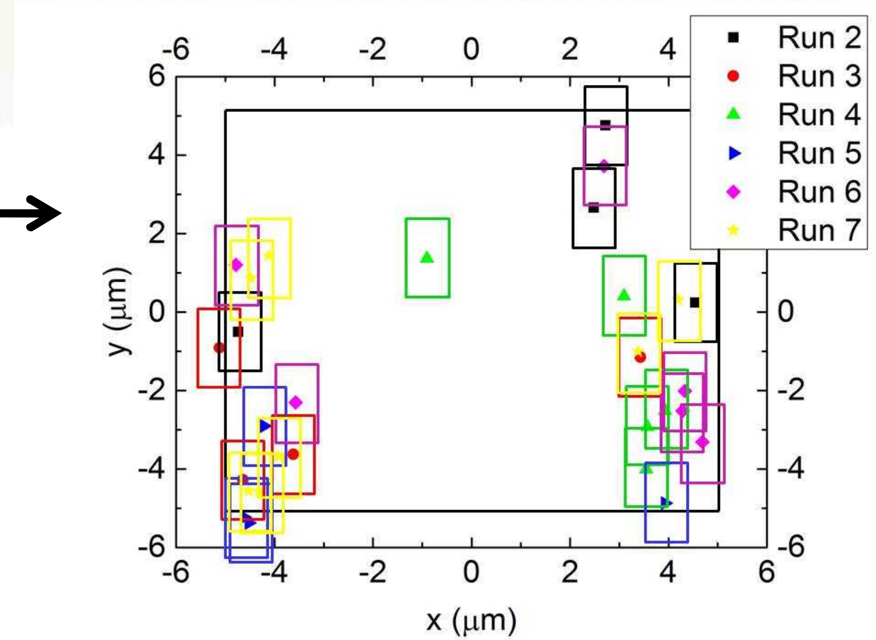


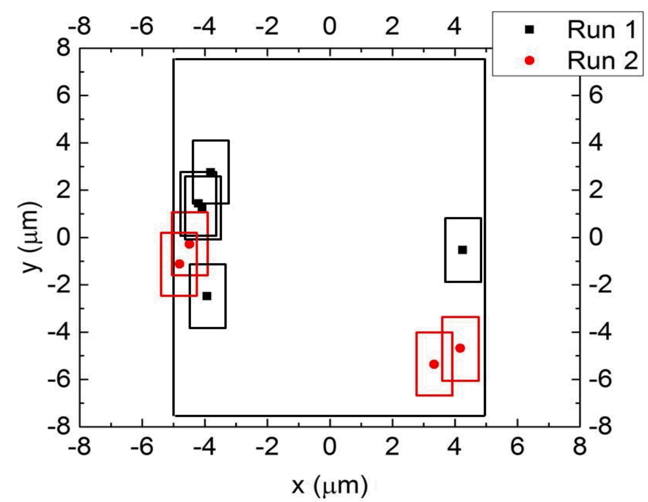
In-situ monitoring of resistance



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

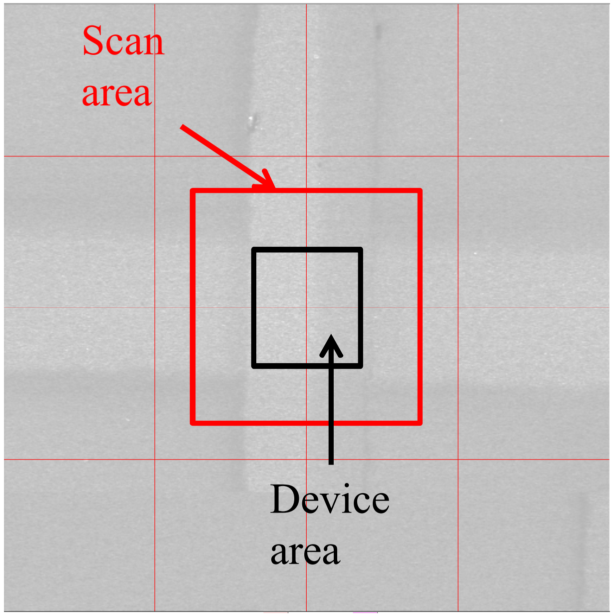
- Multiple distinct sensitive regions

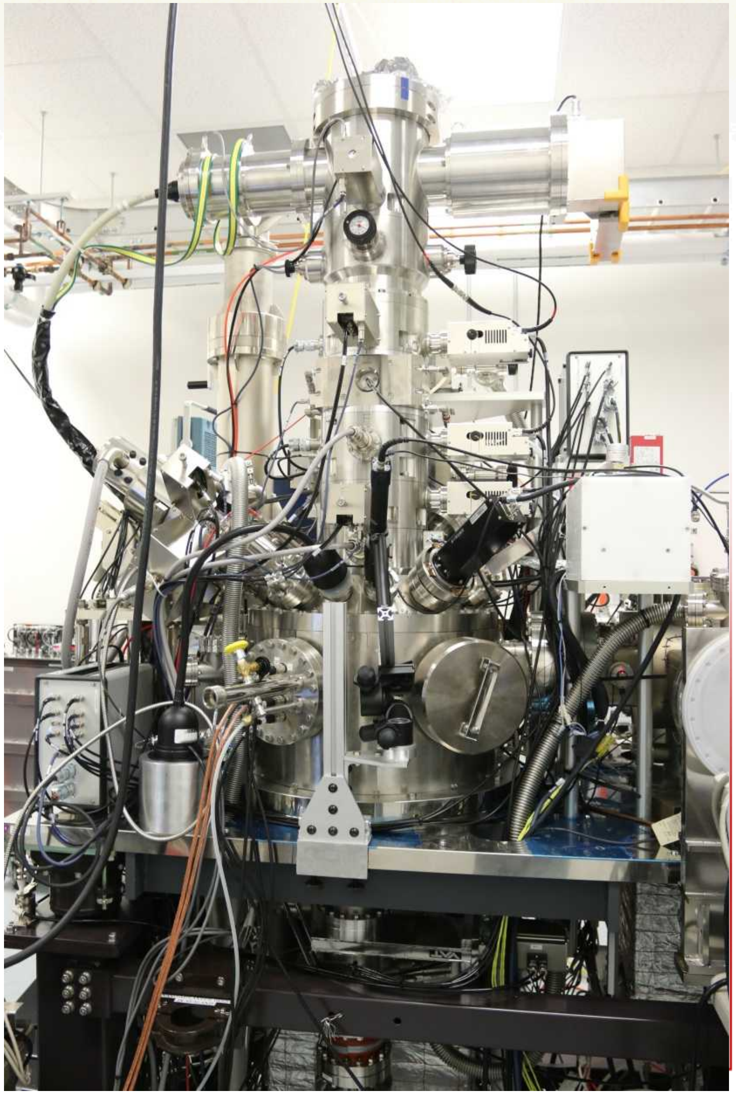
- Device is most sensitive on perimeter
  - Likely more defects on the perimeter
  - Appears insensitive in center of device
  - Sensitive area is not the entire oxide region

- Targeting likely not precise enough
  - Takes many scans to get changes
  - It sure would be great to have more precise targeting…

Nano-scale Ion Implantation

- **NanoImplanter (nI)**
- **15 µm by 15 µm scan area**
  - **200 keV Si++**
  - **Beam spot size ~40 nm**





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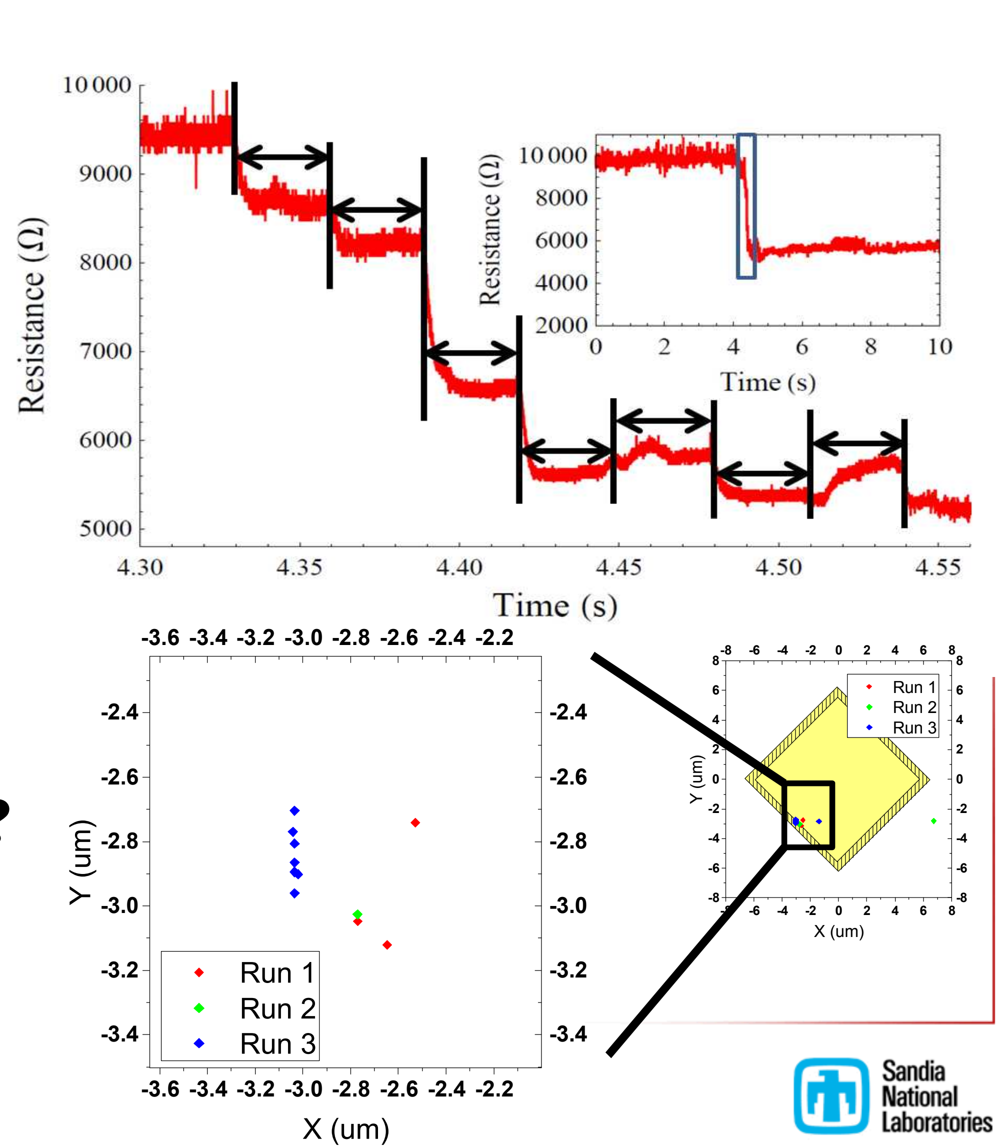
Size of a Sensitive Area

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



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Summary and Conclusions

- Characterized ionization and displacement damage sensitivity
- Spatially mapped multiple conduction paths, or potential conduction paths
  - Sensitive areas exist preferentially on the perimeter
  - Forming method and operating conditions may impact sensitive area
- Large portion of the active area is insensitive to displacement damage
  - Scaling implications
- Capability to locate and characterize sensitive regions with high precision

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