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Determining the Location and Size of Conductive Filaments in TaOx Memristive Devices Using Focused Ion Beam Irradiation

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Outline

- Introduction to memristors
- Briefly cover previous results indicating rad-hard to displacement damage
- Localization and size of conductive filaments results using:
    - μ-beam at SNL Tandem Accelerator
    - SNL Nano-Implanter
- Future experiments

Memristor Devices

- A promising candidate to replace flash memory (ITRS roadmap)

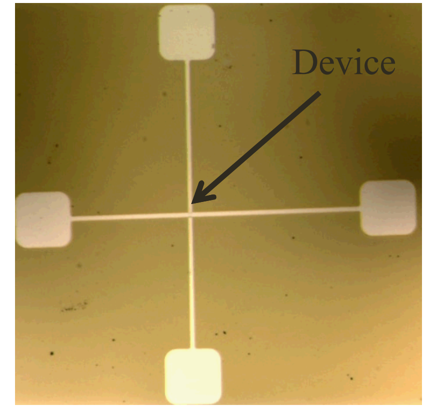
  -High speed, low voltage, high density, rad-hard

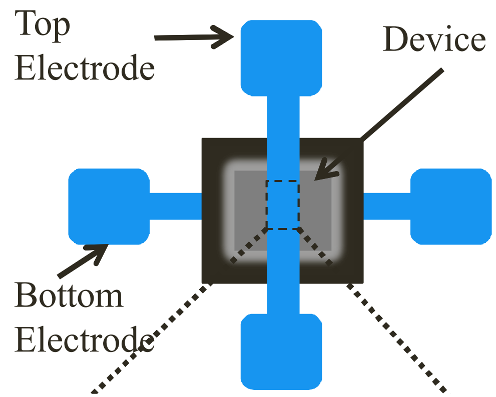
- Forming and switching mechanisms not fully understood

  -Formation of conductive channels

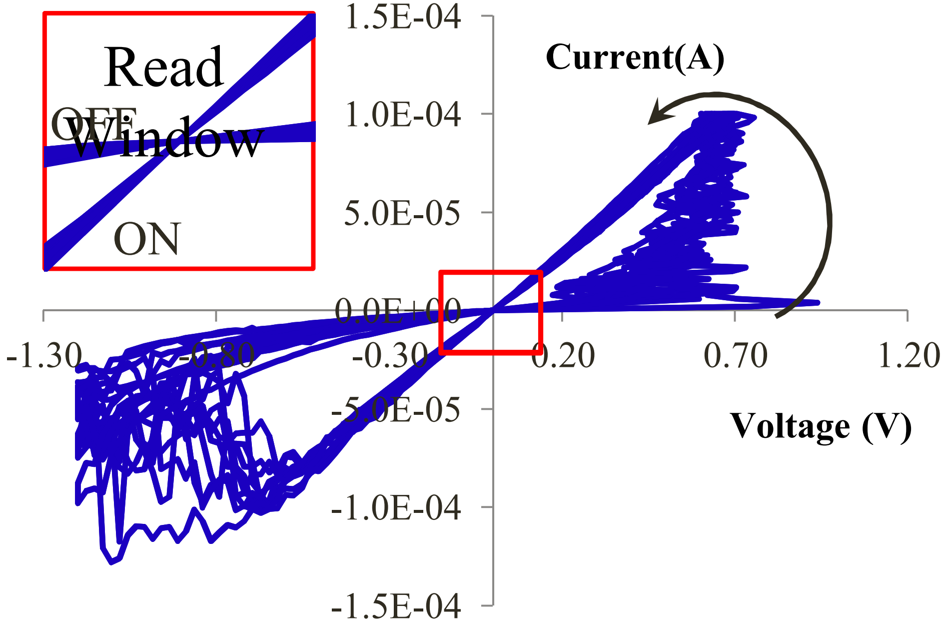
  -Dependent on oxygen vacancy motion and concentration

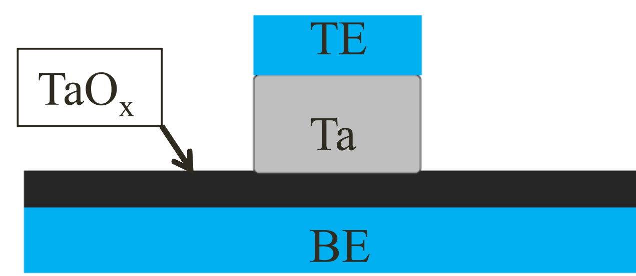
HP "Dog-Bone" Construction



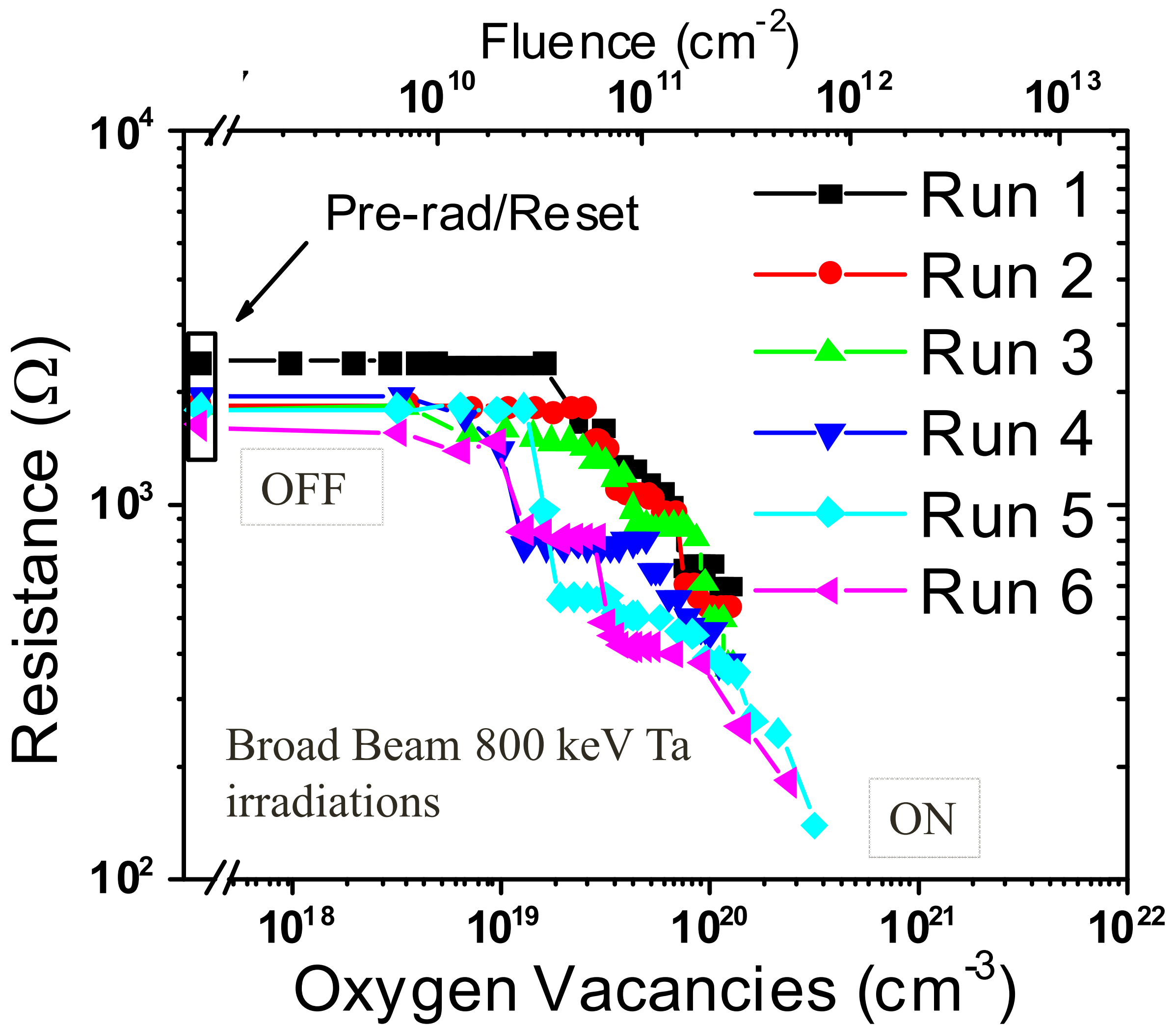


Hysteretic IV Curve



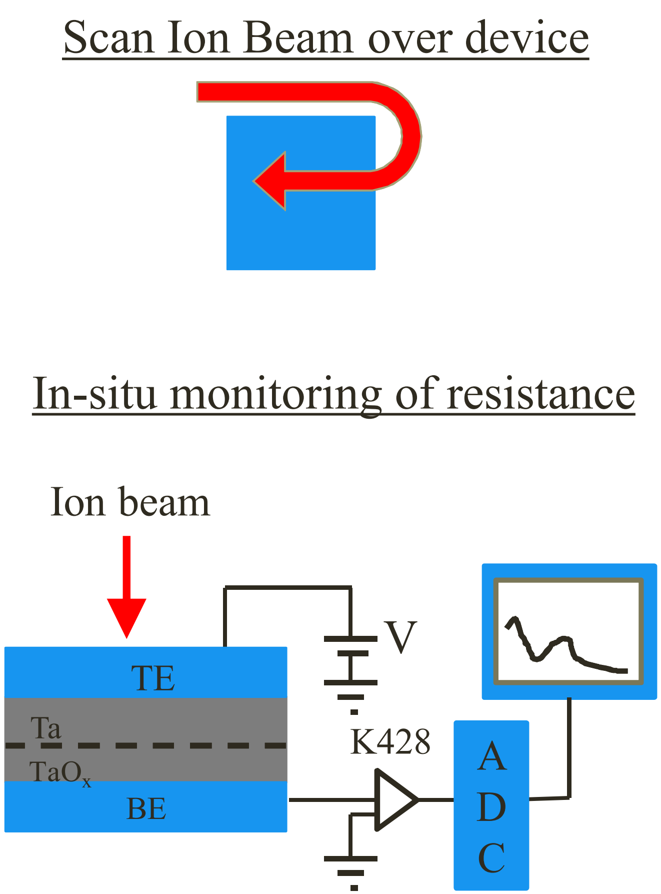


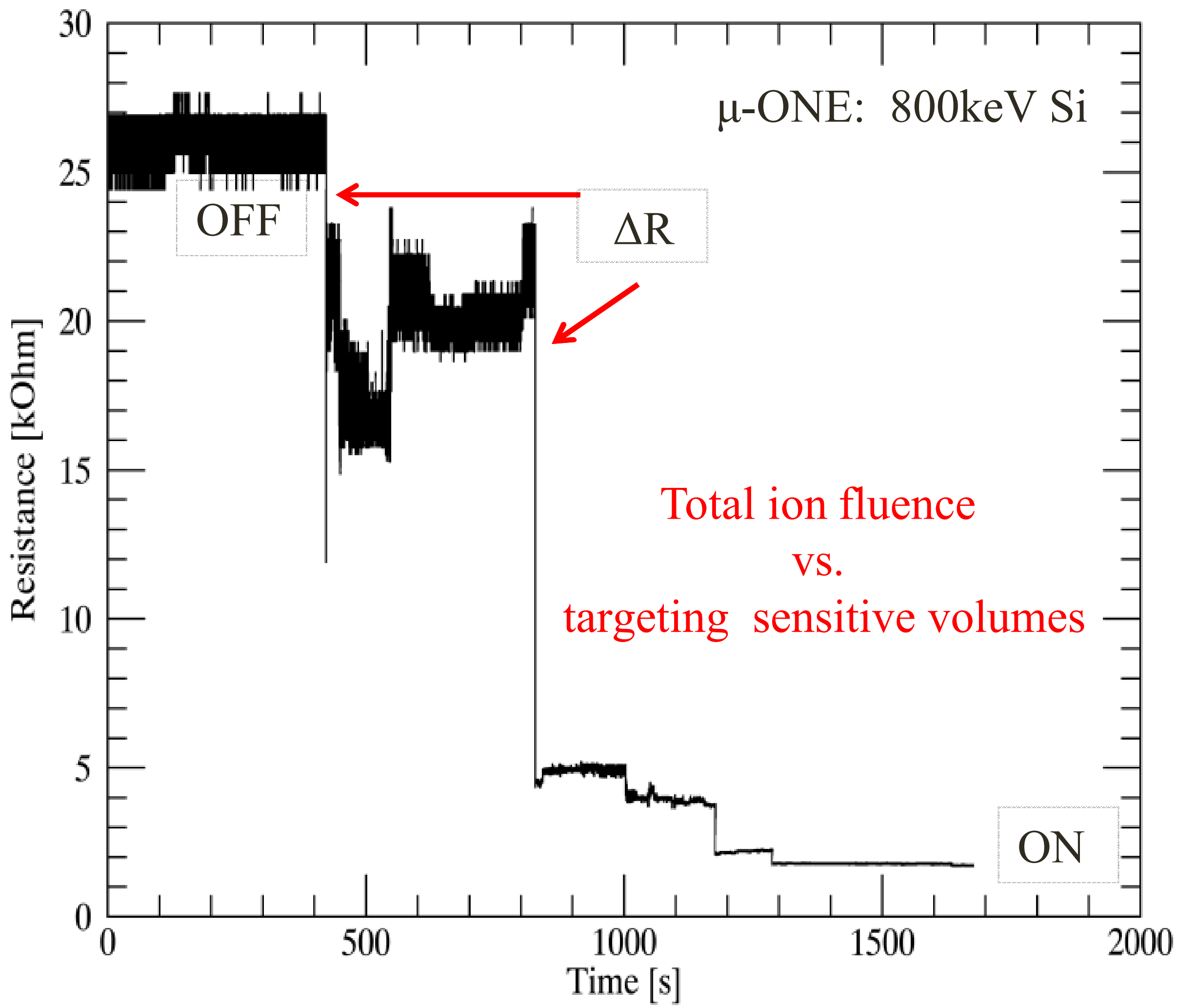
Memristor Rad-Hard to Displacement Damage



Hypothesis: Oxygen vacancy concentration ↑ device resistivity ↓

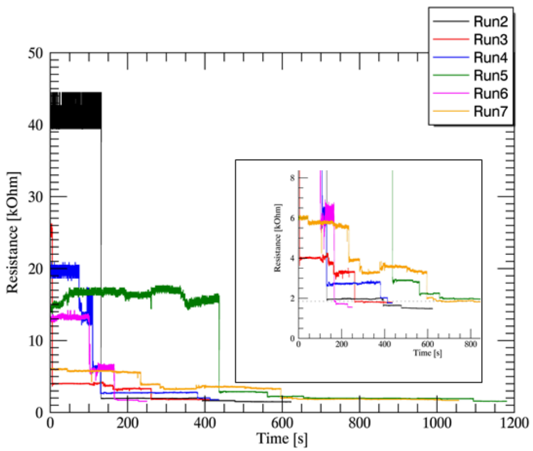
Sensitive Area Irradiation: μ-beam raster scan



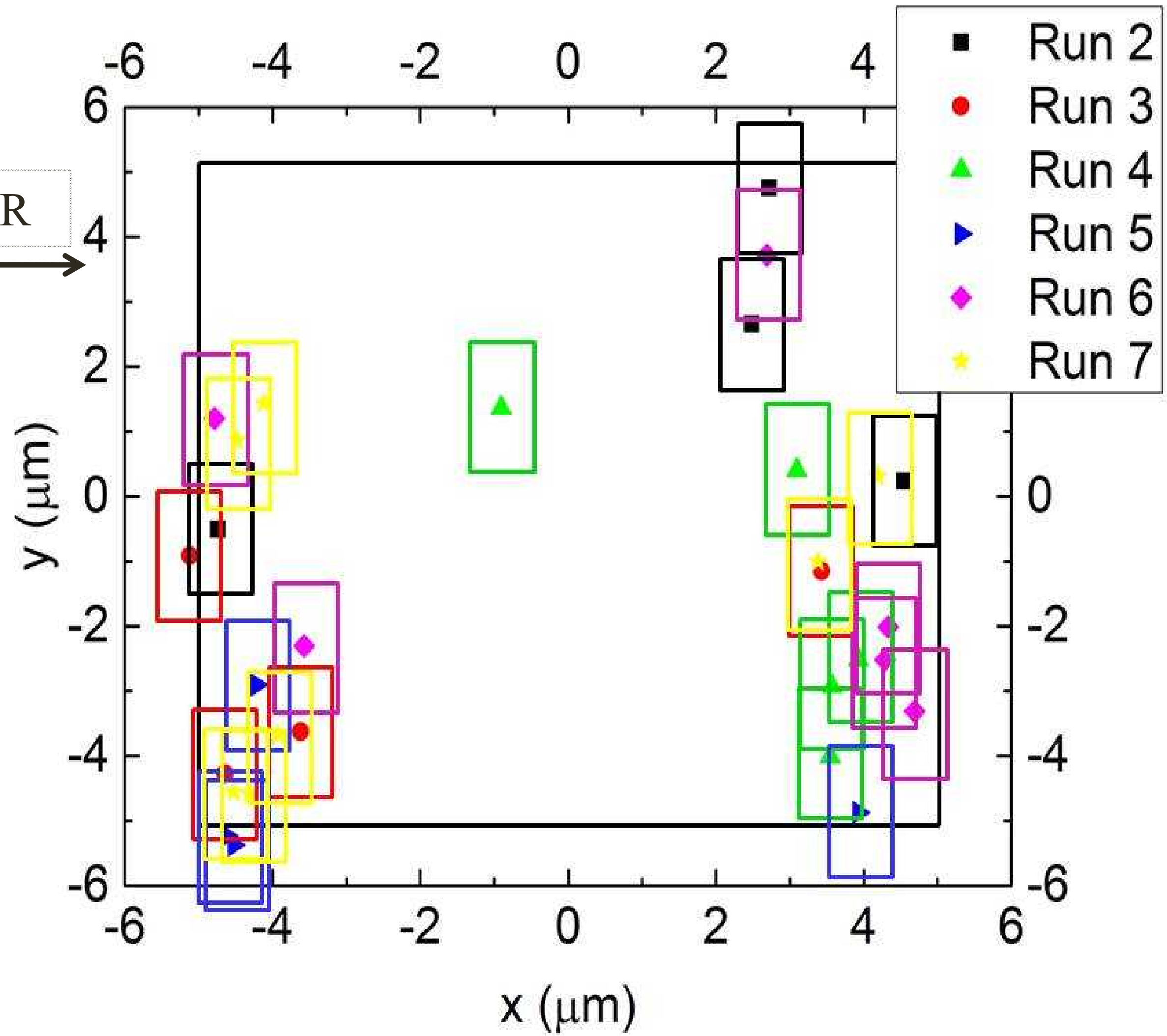


We believe the OFF-to-ON switching due to single ion strikes near a sensitive location

ΔR Mapping: Conductive Filament Localization



ΔR

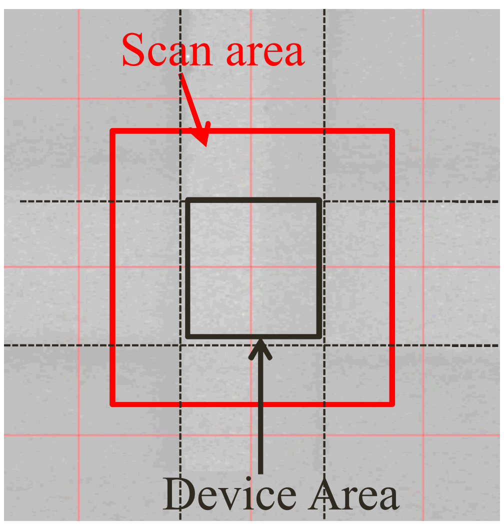


- Displacement damage-sensitive areas at perimeter of device.
- oxygen vacancies near conductive filaments…

Conductive filaments predominately at edges of device

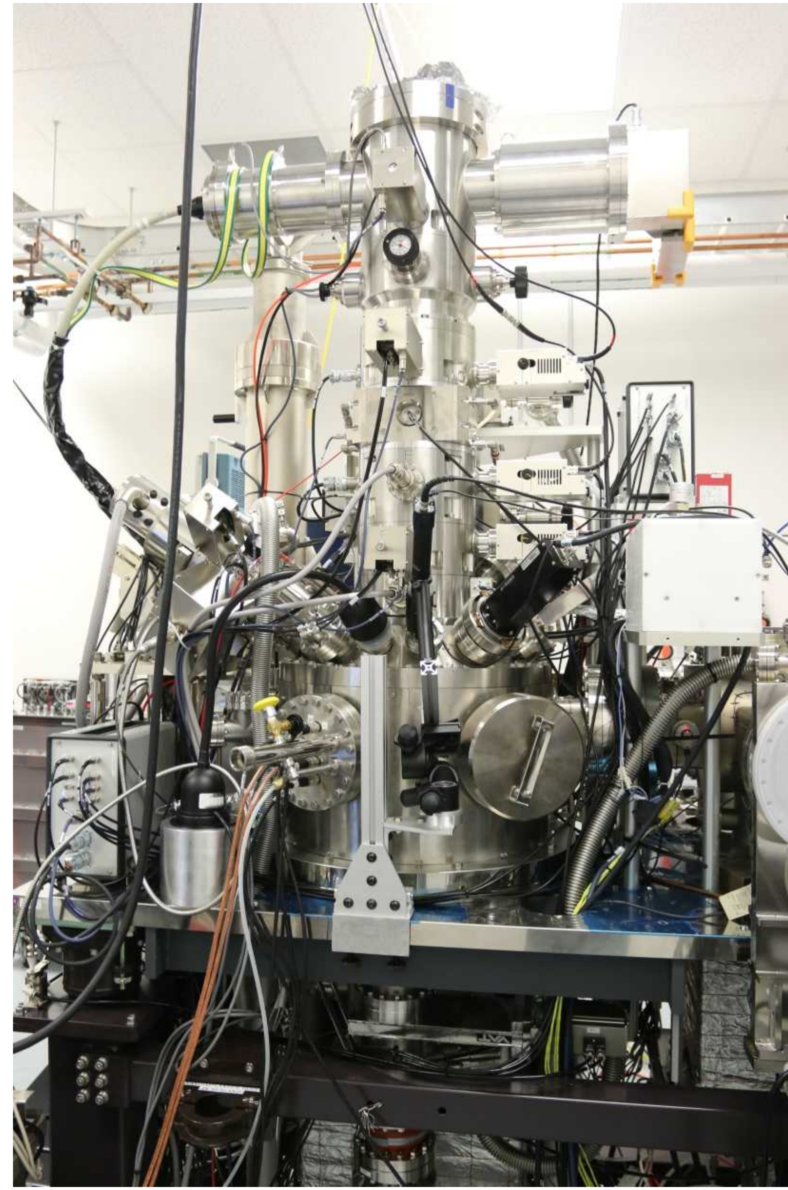
How to improve resolution?
→Nano-scale Ion Implantation

- SNL NanoImplanter (nI)
  - Variable Accelerating Potential: 10-100 kV
  - Fast Blanking and Chopping
    - Down to ~ 1 ion/pulse
  - Mass-Velocity Filter
  - Liquid Metal Alloy Ion Source
    - AuSiSb
    - Beam on target: 200 keV Si^{++} (<40 nm)

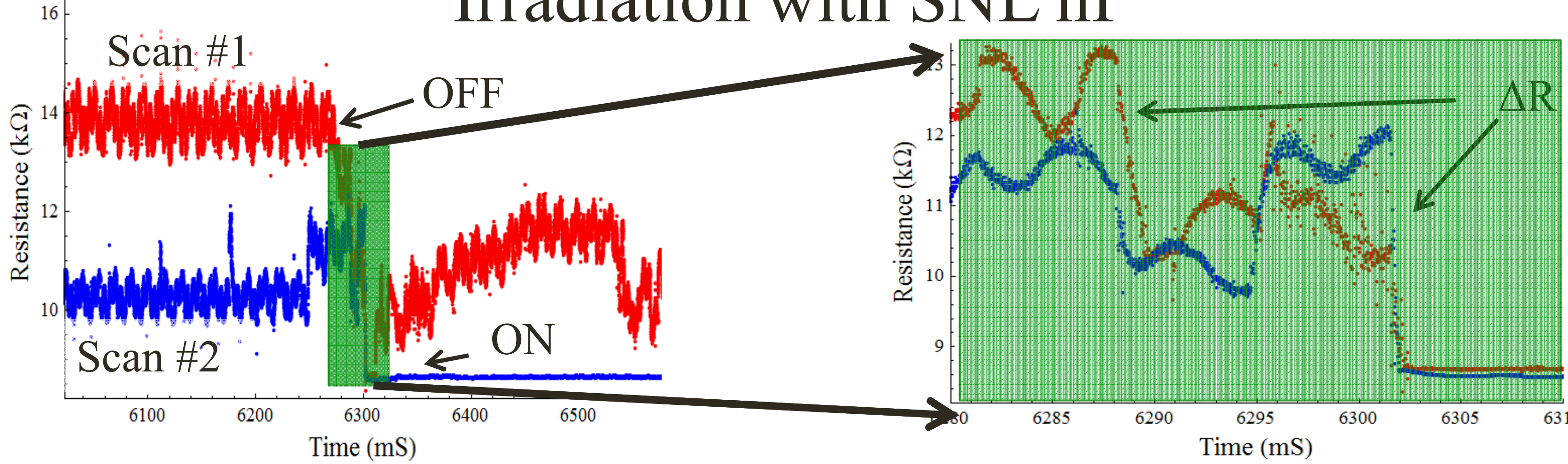


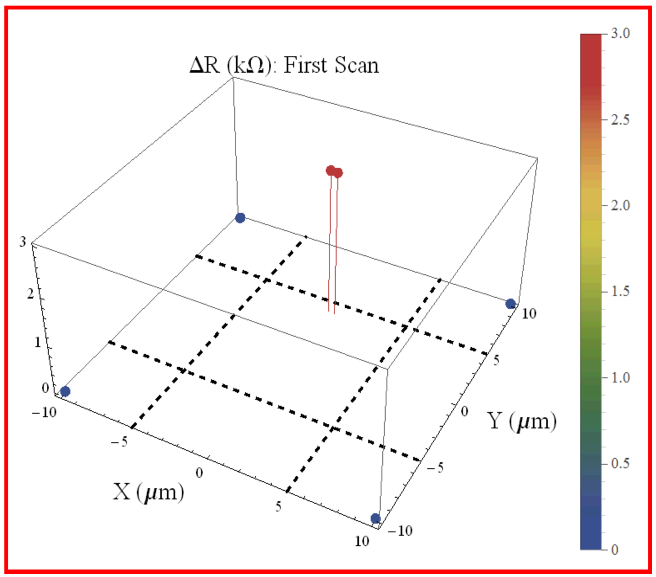
X-Y raster scan

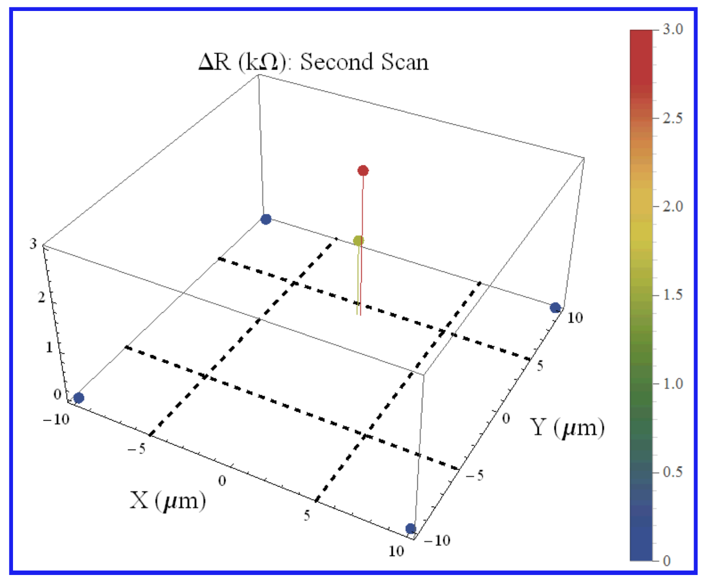
Die 2 Device 7
10 um x 10 um



Localization of Areas Sensitive to Irradiation with SNL nI

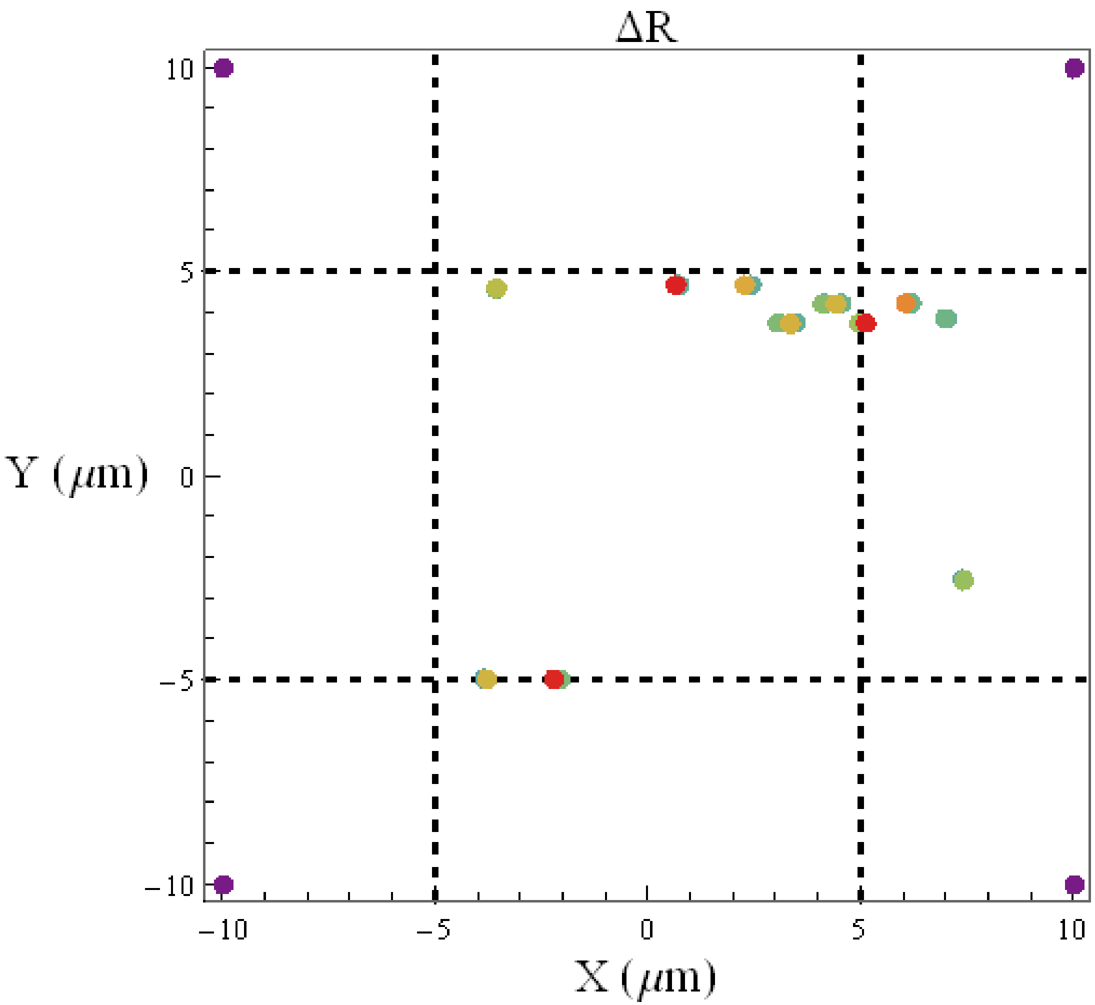






Localization of the conductive channels?

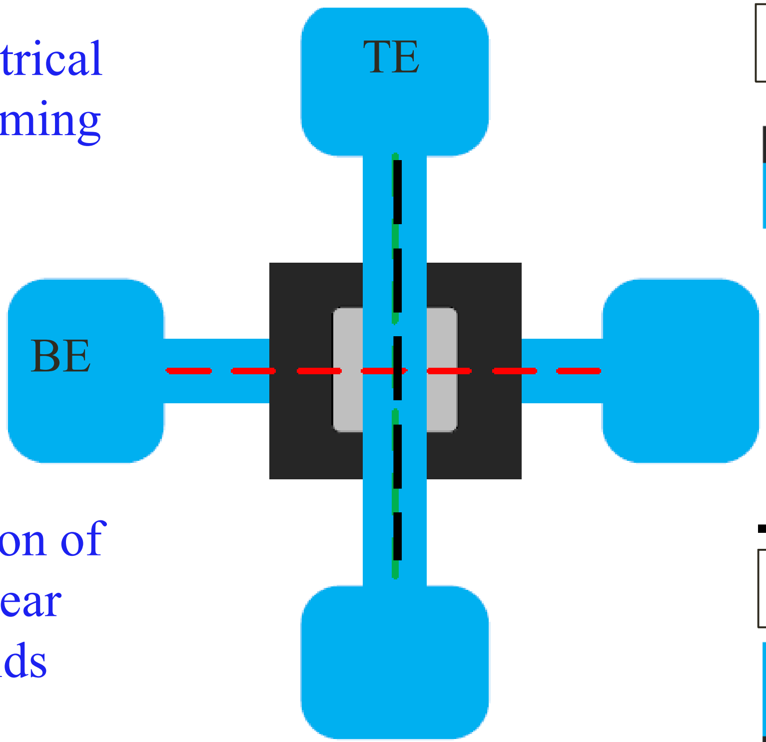
Localization of Areas Sensitive to Irradiation with SNL nI



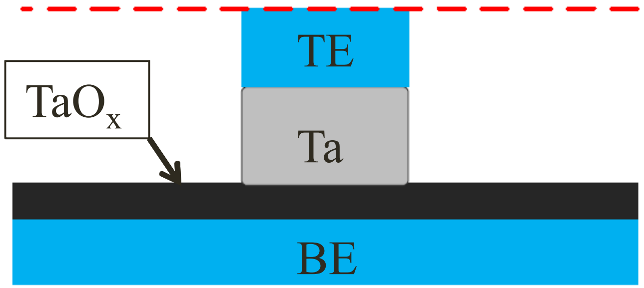
We have localized the conductive filaments to the upper and lower edges of the device

Why do the channels form on the edges of the device?

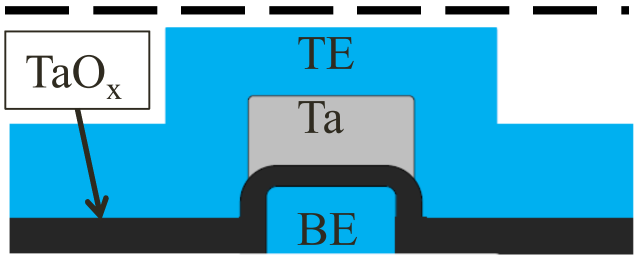
- Device under electrical tension during forming



Horizontal cross section



Vertical cross section

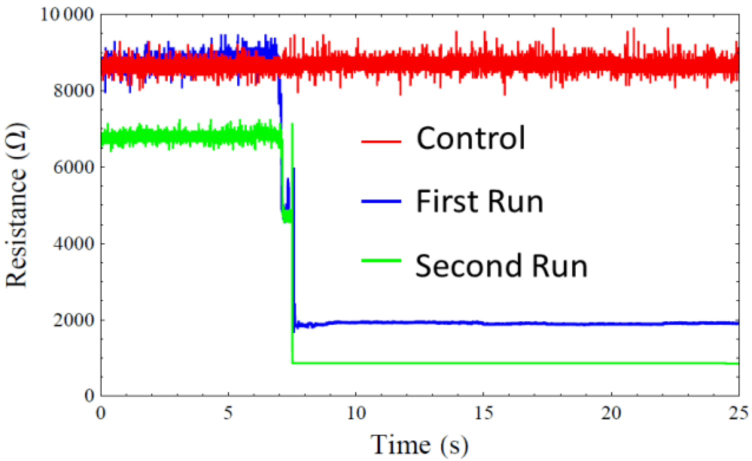


- Preferential creation of oxygen vacancy near strong electric fields

Located near regions of enhanced electric fields due to edge effects

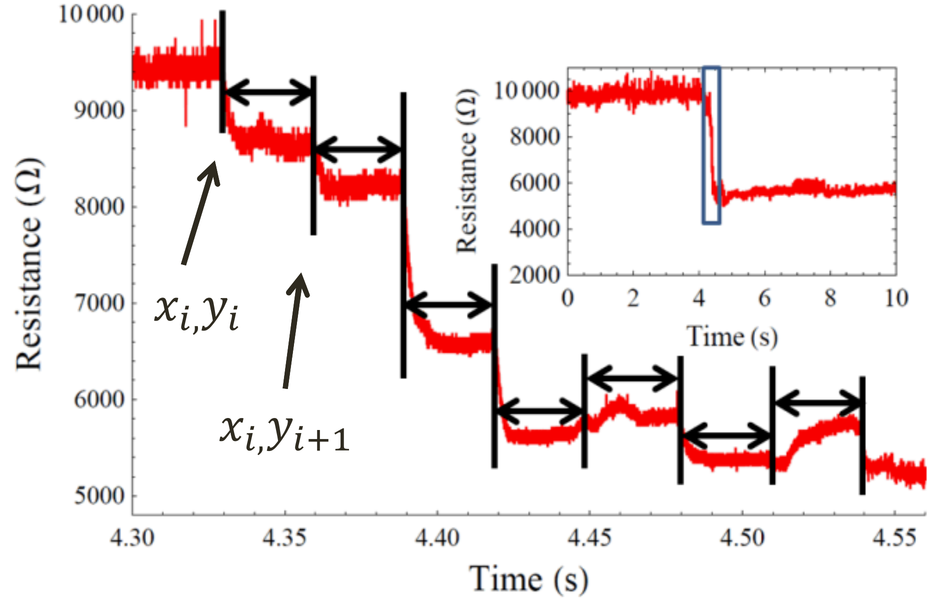
Determining the size of conductive filaments

- Raster X- Y- Scan
- Reset device after each scan
- Resistance changes at the same time
  - ➢ Corresponds to same location



- Only particular regions are sensitive to irradiation
  - ➢ Near conductive filaments

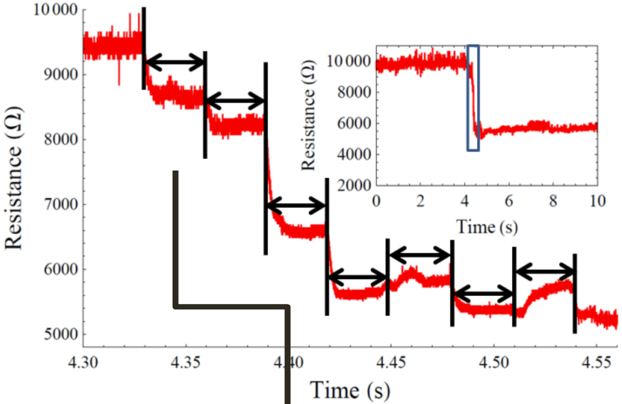
- Determine the size of the region sensitive to irradiation

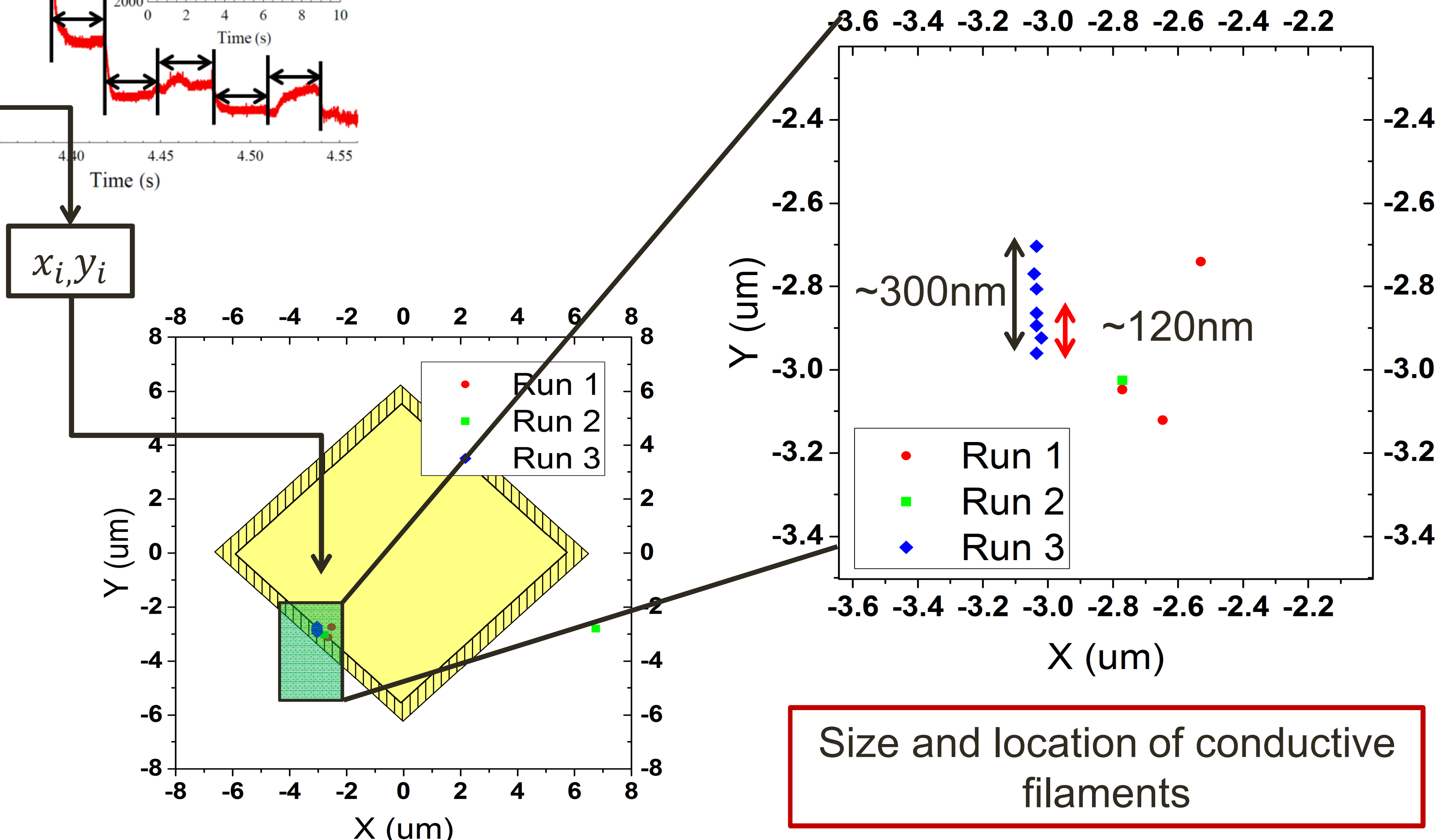


Determine the size and location of the sensitive regions with a single scan

Determining the size of conductive filaments

- Focus on changes that result in resistance decrease

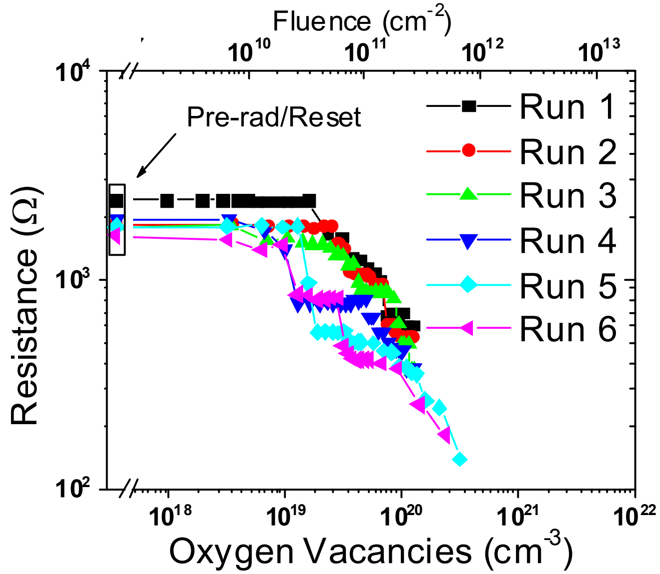


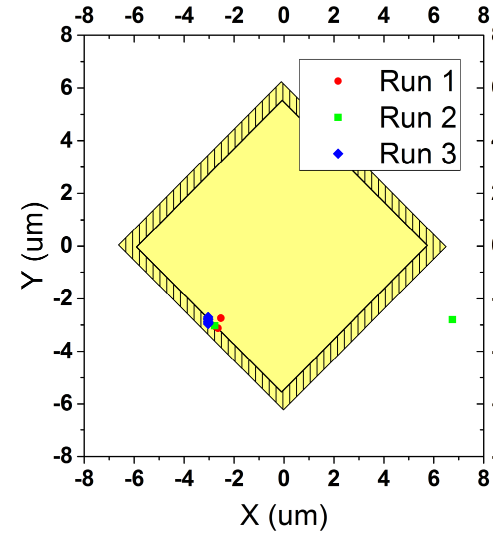


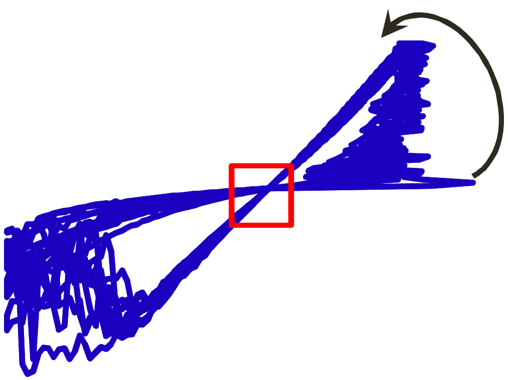
Size and location of conductive filaments

Experimental outlook: toward device uniformity

- Variability between devices is problematic
- →Possible path to improve device uniformity

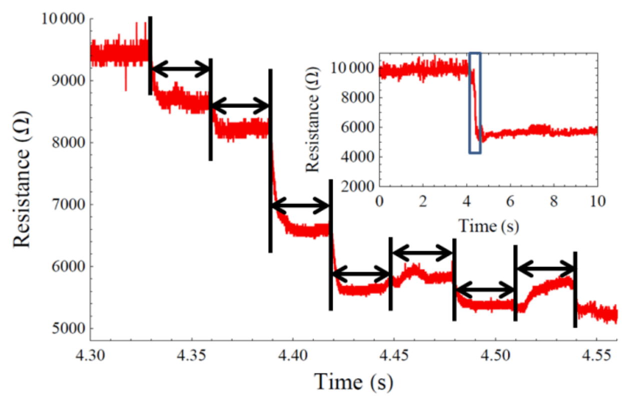






1) Monitor Resistance

2) Modulate resistance via ion implantation/conductive channel modification



→ Achieve device characteristics necessary for operation within the architecture to be employed

Conclusions and Future Experiments

- Conductive filaments located near the upper and lower edges of the devices

→ Formed in regions of high electric fields

- Able to determine the size and location of the conductive filaments

Deterministic modification of the conductive filaments using ion beam irradiation

Filament characteristics are highly non-uniform but can be tuned using ion beam irradiation to potentially create homogeneous and reliable devices