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Controlled irradiation of TaOx memristive devices using a focused ion beam for modification of device properties

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- Brief Intro to Memristors
- Determine the size and location of conductive filaments
- Filament formation using ion beam irradiation
- Future work

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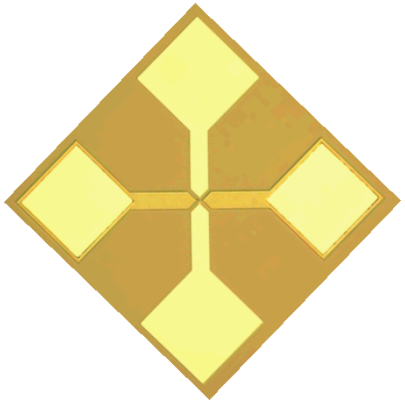
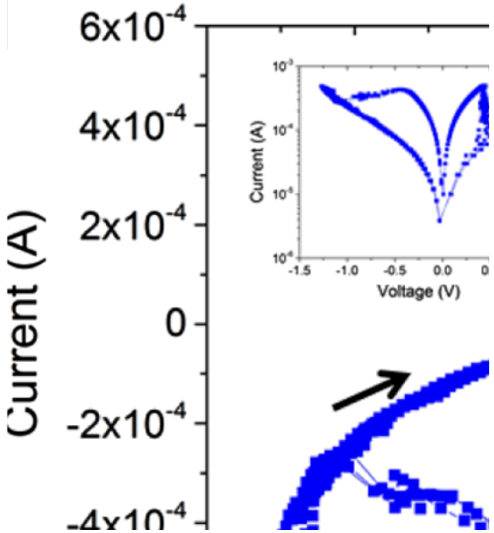
What is a Memristor?

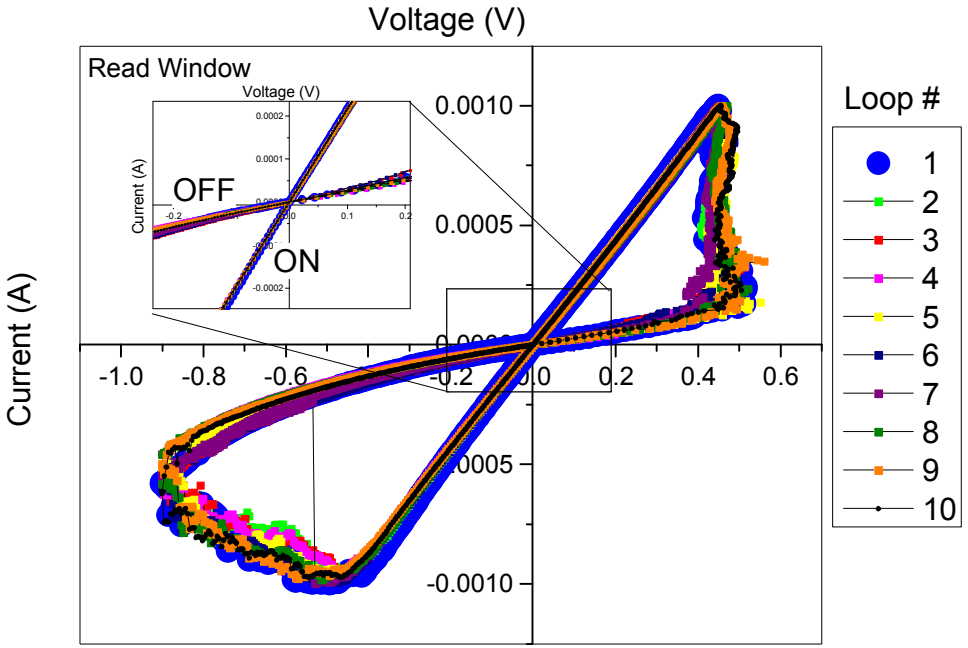
SNL and HP Fabrication



Device Stack



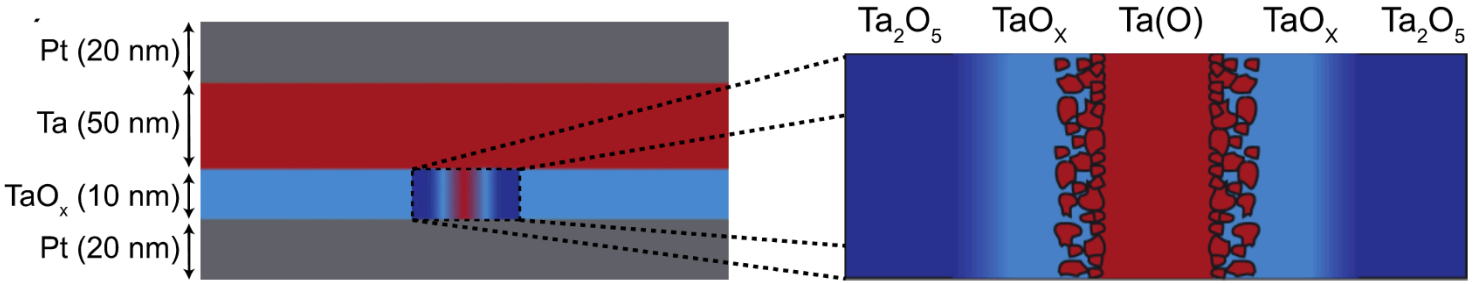
Hysteretic IV Curve



Hysteretic IV loop → Memory

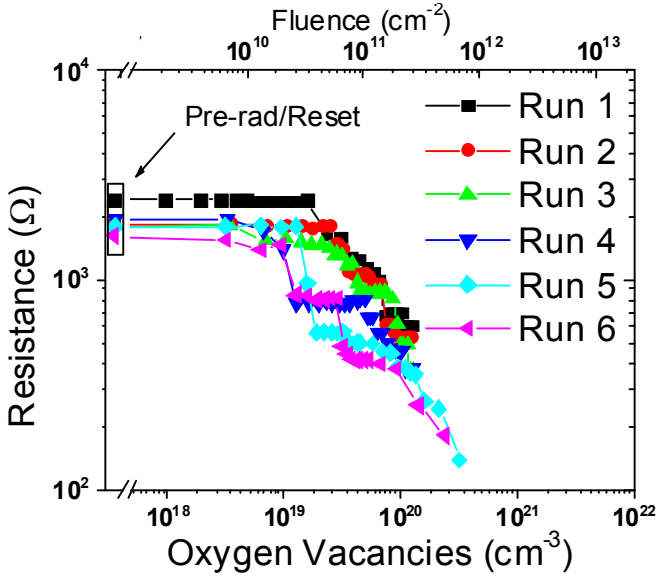
How do memristors work?

- Forming and switching mechanisms not fully understood
  - Formation of conductive channels
  - Conductivity dependent on concentration/motion of oxygen vacancies



Mickel, P. et. al., APL 102. 2013

  - Switching modulation of conductivity:
    - Electric field
    - Temperature gradients



Hughart, D. R. et. al., IEEE TNS 2014

Why are memristors important?

- Promising candidate to replace flash memory
  - ITRS roadmap
    - High speed, low voltage, high density, rad-hard

What is the problem?

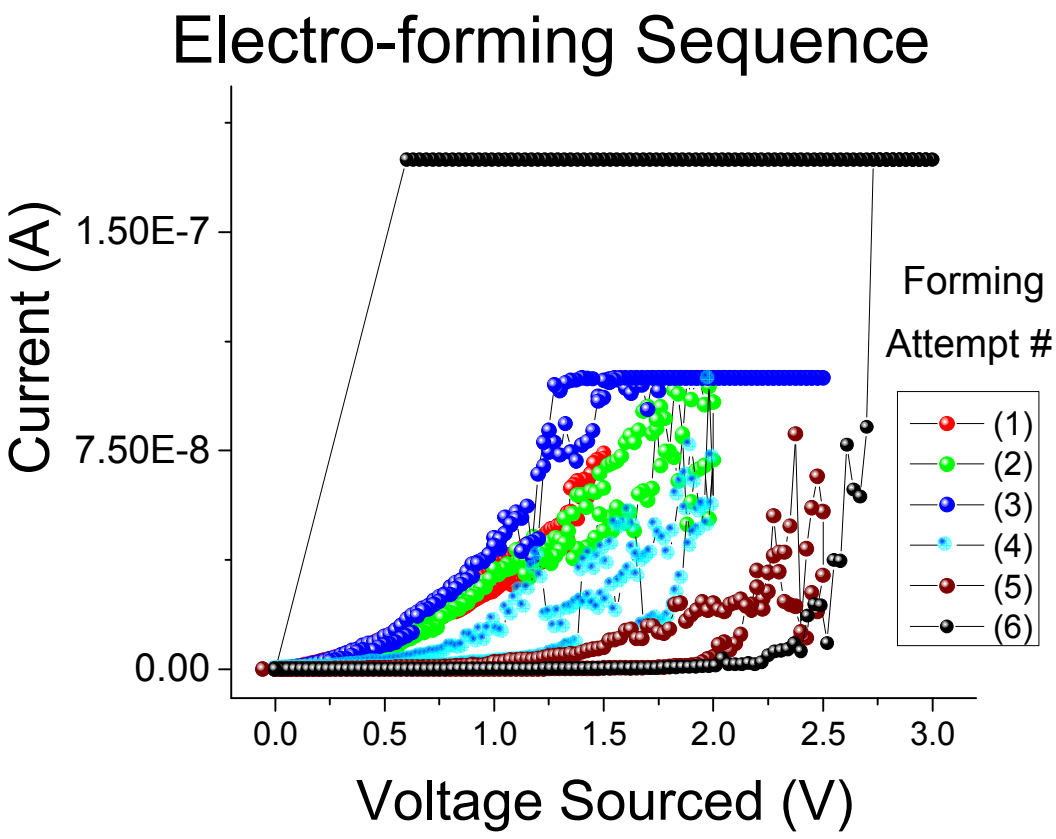
Breakdown of TaOx film during electroforming

Governs device characteristics

Random and uncontrolled

Impacting

- Device yield
- Device to device variation



TaOx film breakdown is a destructive process that governs device properties

Using Focused Ion Beams to Explore Memristors

- Determining the size and location of conductive filaments

- Filament formation using ion beam irradiation

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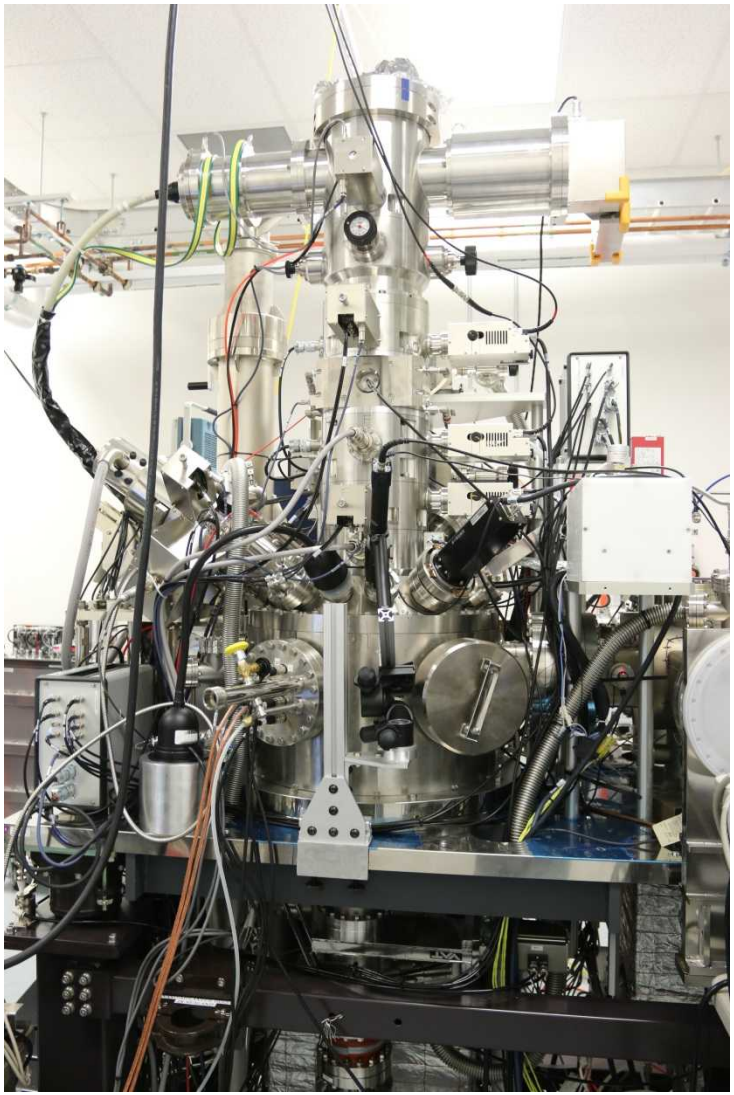
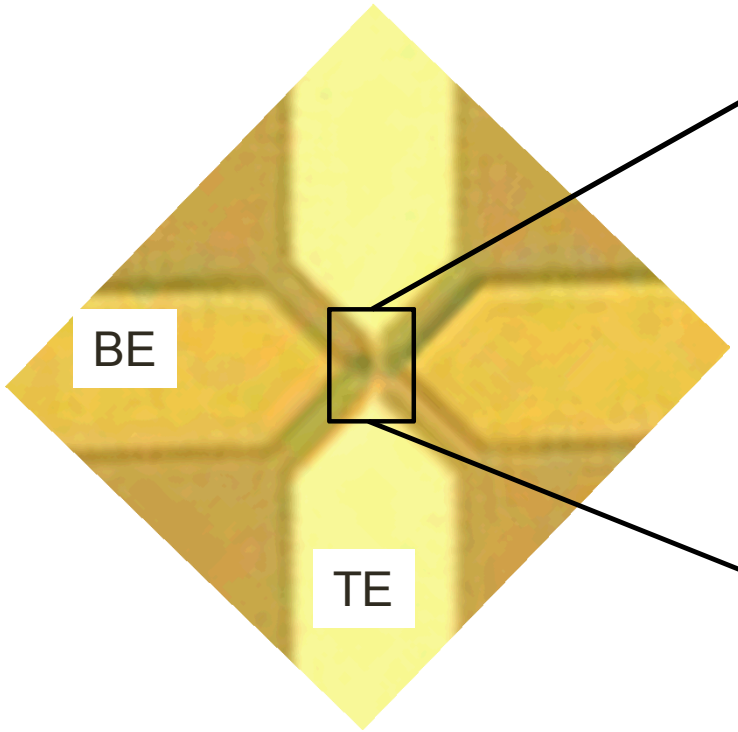
Investigation of device properties using ion beams, how?
→Nano-scale Ion Implantation

- SNL NanoImplanter (nI)
  - Variable Energy FIB
  - Fast Blanking and Chopping
    - Down to ~ 1 ion/pulse
  - Mass-Velocity (Wein) Filter
  - Liquid Metal Alloy Ion Source
    - Beam on target: 200 keV Si^{++} (<40 nm)
  - Direct write lithography platform
  - In-situ electrical probes



- X-Y targeted exposure
- Monitor device *in-situ*

Localization of Areas Sensitive to Irradiation



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FaceGrids → {{{0, 0, -1}, {{{-5, Black}, {5, Blac
FaceGridsStyle → Directive[Thick, Black, Dashed]
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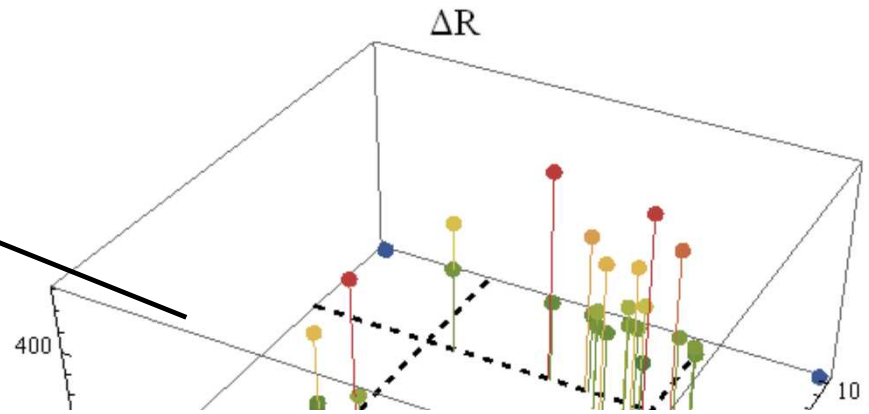
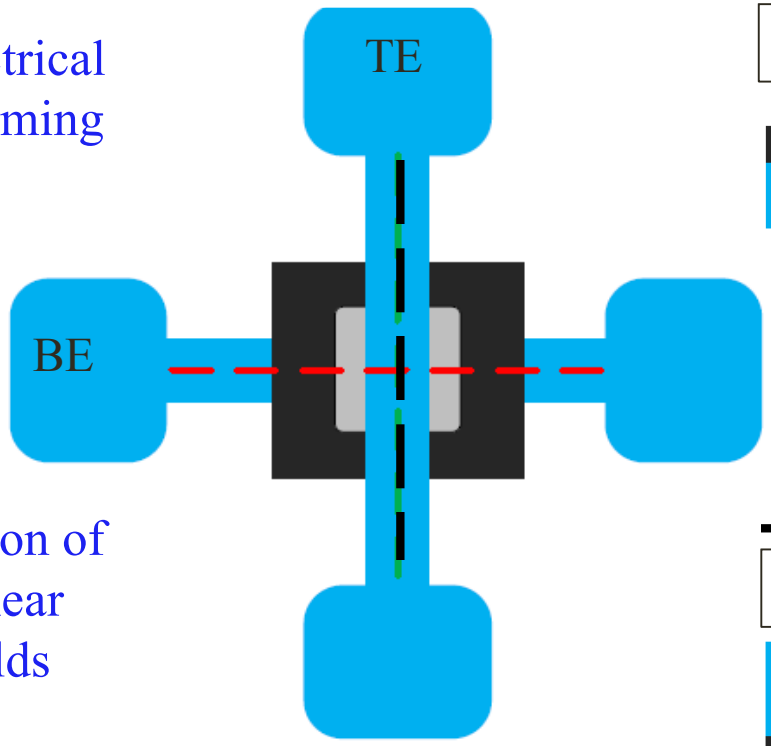


200keV Si ~30nm spot size

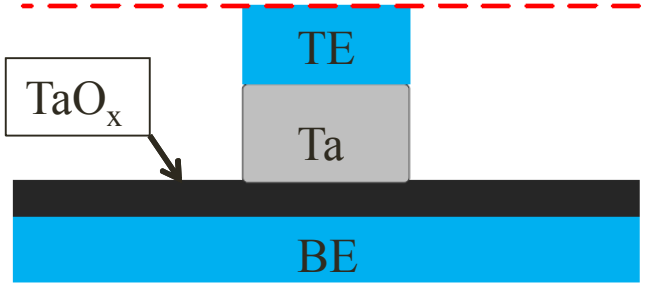
We have localized the conductive filaments to the upper and lower edges of the device

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

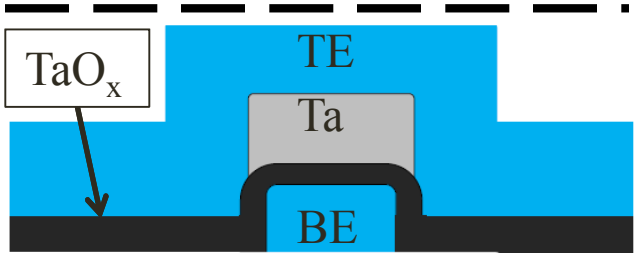
- Device under electrical tension during forming
- Preferential creation of oxygen vacancy near strong electric fields



Horizontal cross section



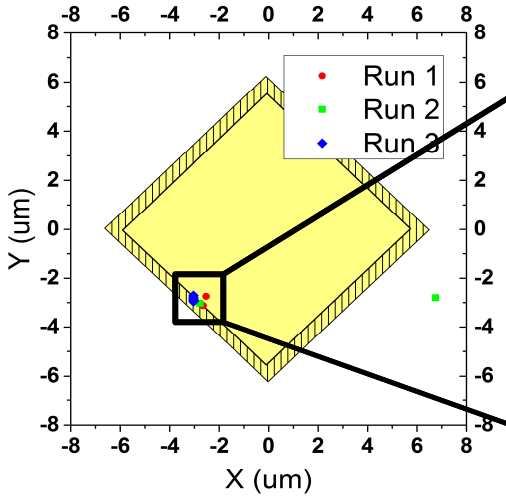
Vertical cross section

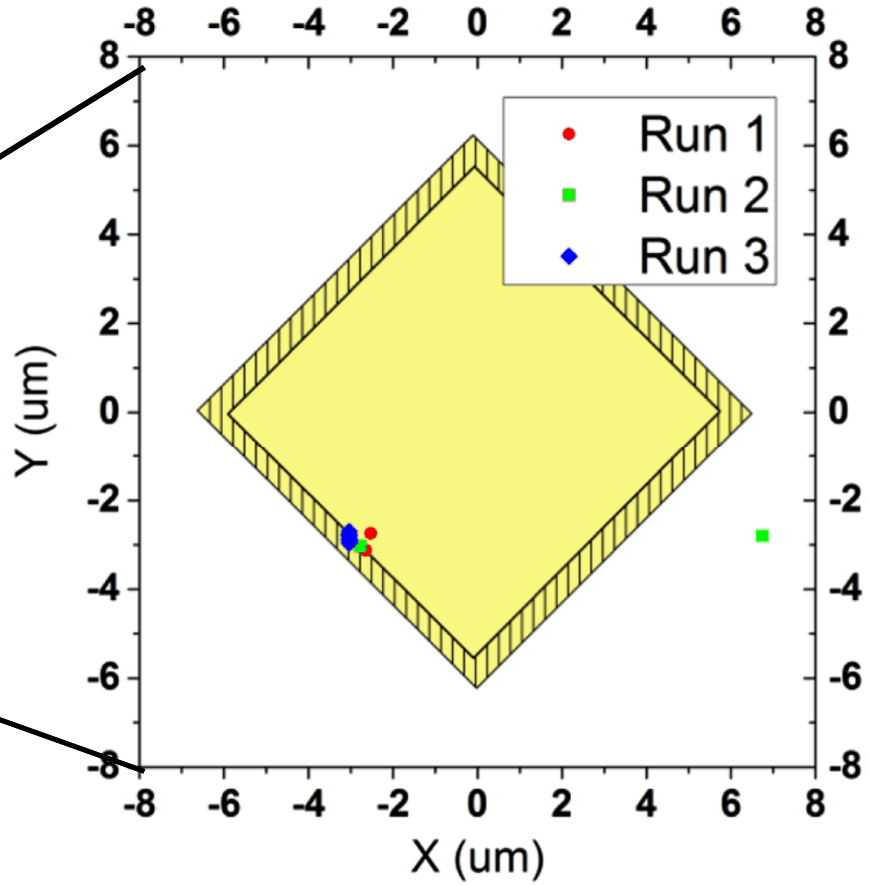


Located near regions of enhanced electric fields due to edge effects

Size of conductive filaments

- Determining the size of the sensitive regions





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

Estimated filament size is <300nm

Using Focused Ion Beams to Explore Memristors

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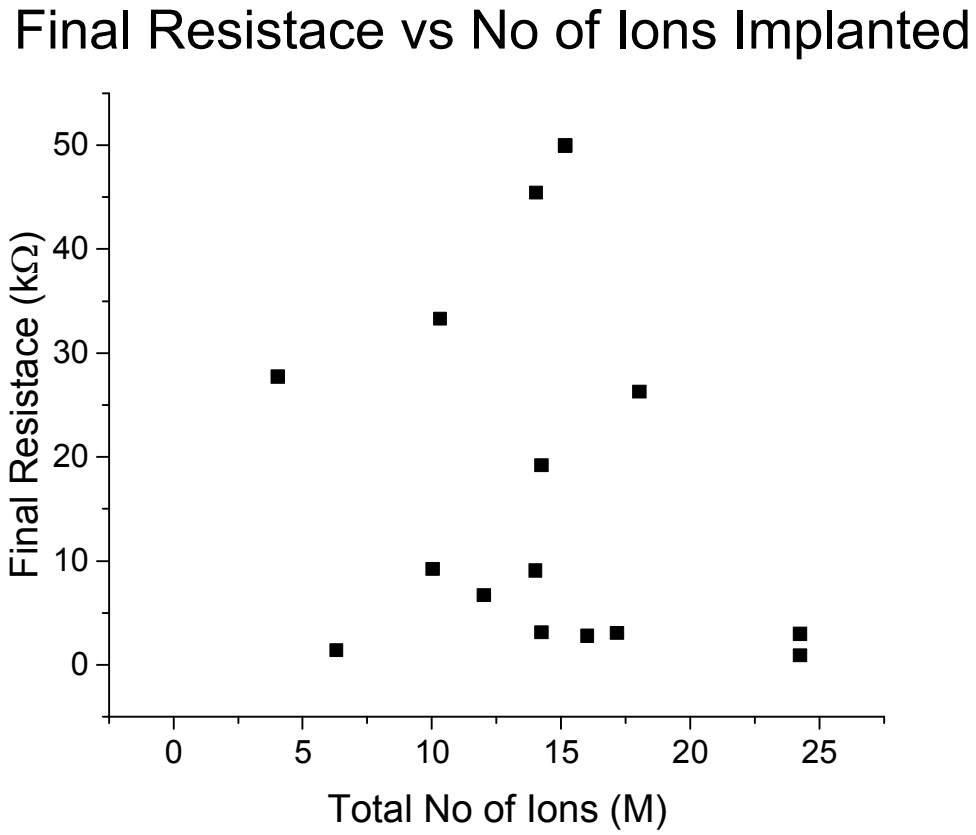
- Filament formation using ion beam irradiation

Seeding/Forming of filament using nl

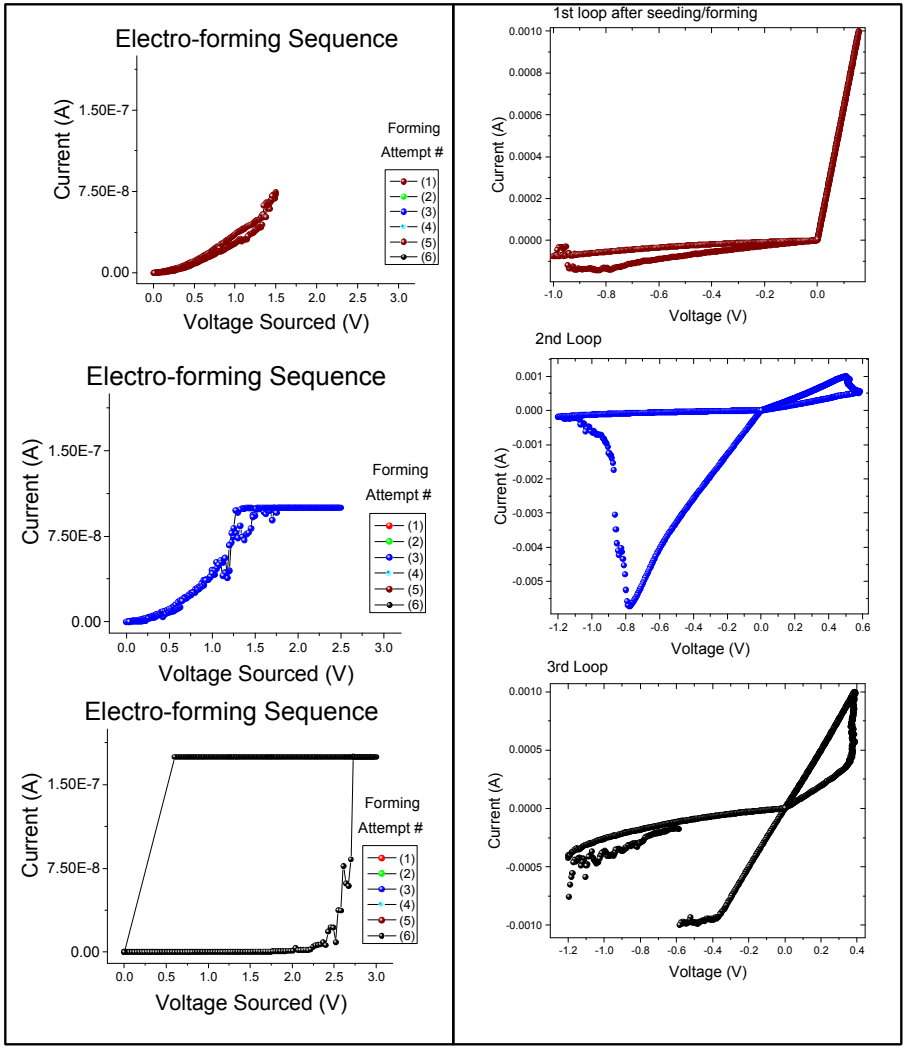
- Virgin device
- Initial Resistance > 500MΩ
- Monitor resistance
- count <number> of ions implanted
- Implant until R → kΩ

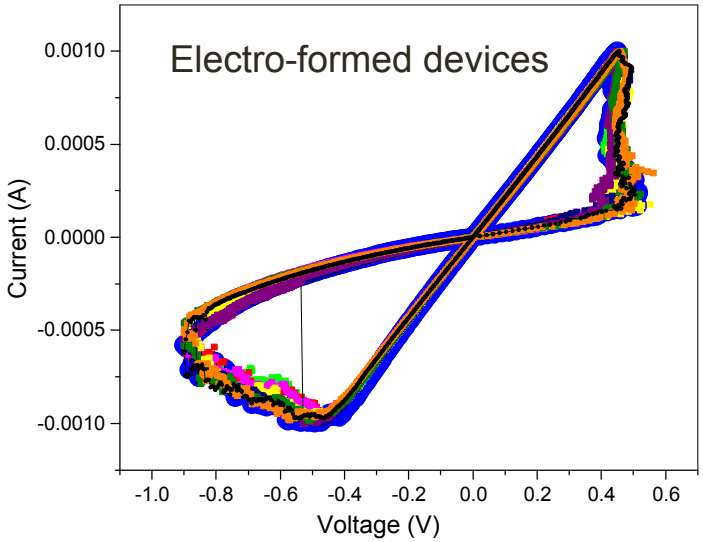
→ Look at change in forming characteristics

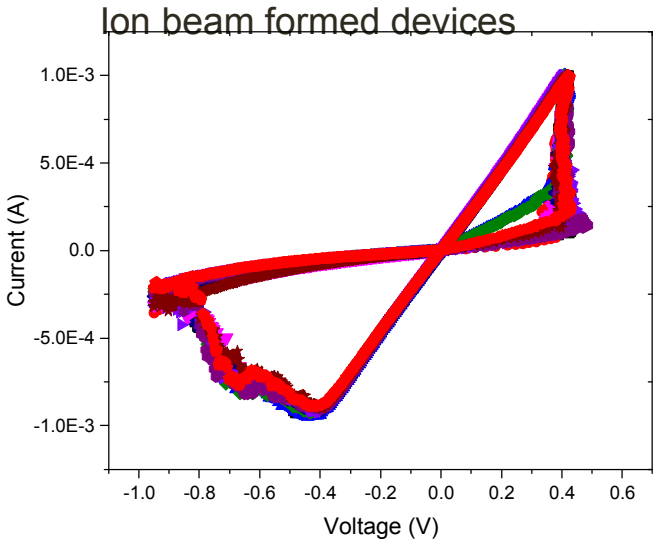


Large range of conditions still to explore

Electroforming vs ion beam forming/seeding







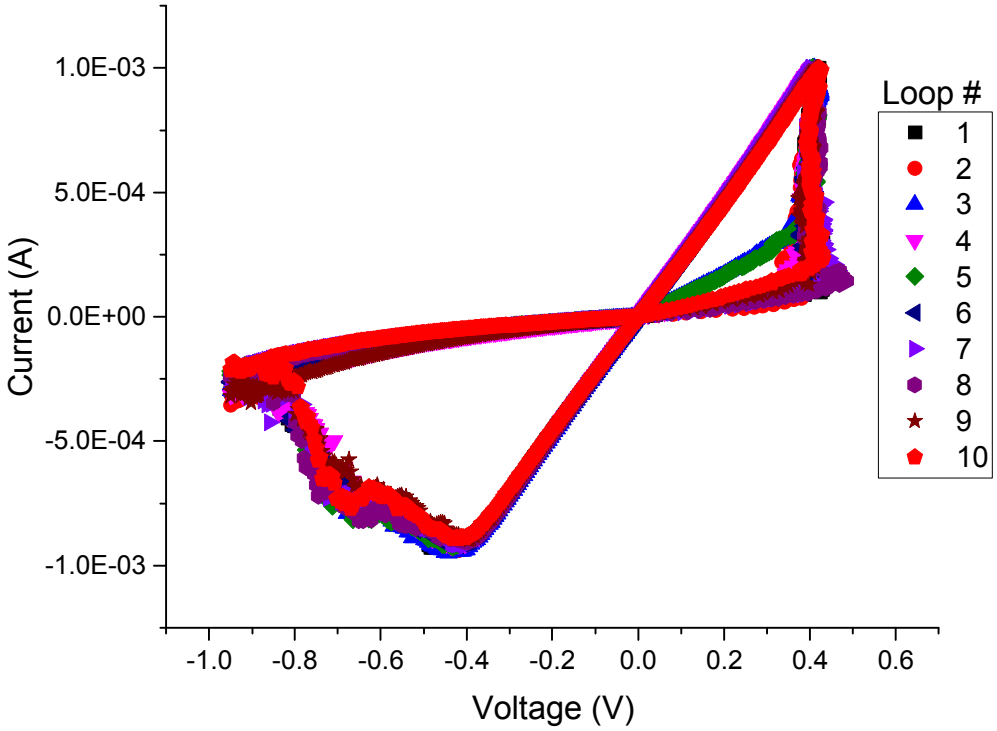
Forming markedly different!!

Hysteretic loops qualitatively identical

Ion beam forming/seeding

→ Forming by using ion implantation to modify TaOx film

Typical* forming process after ion beam seeding/forming:
1) Read (not really necessary), 2) looping



10 Identical loops

* 10 devices operational/10 devices measured

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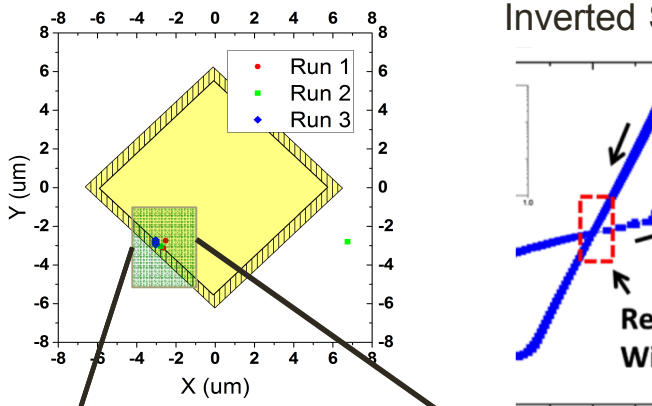
Conclusions

- Conductive filaments located at edges of device
  - Due to device topology and high fields
- Device Resistance Affected by Ion Implantation
  - Creation of O vacancies in TaOx film
- Measured areas sensitive to irradiation <300nm
- Formed/seeded devices using FIB
  - Improving yield, device uniformity

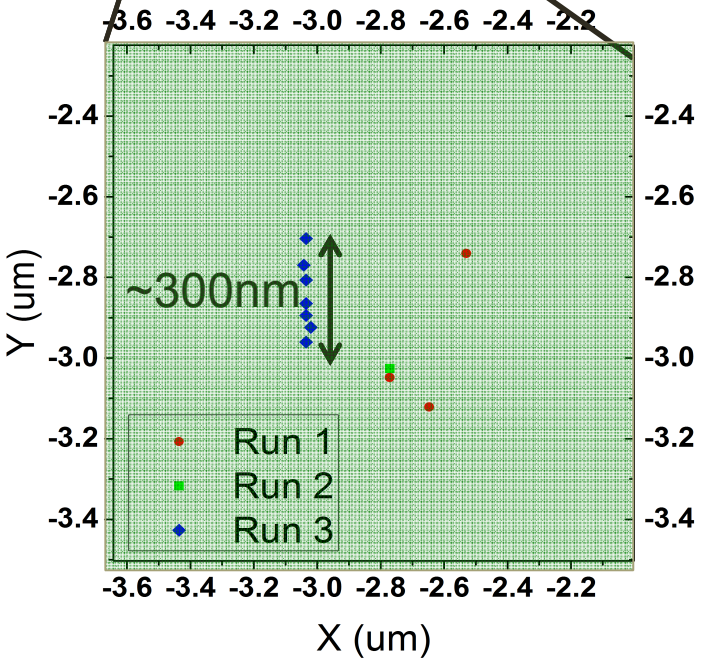
Future work

- Can we create devices with characteristics for low power operation
  - Using ion beam forming/seeding
  - Using a combination of ion beam and electroforming

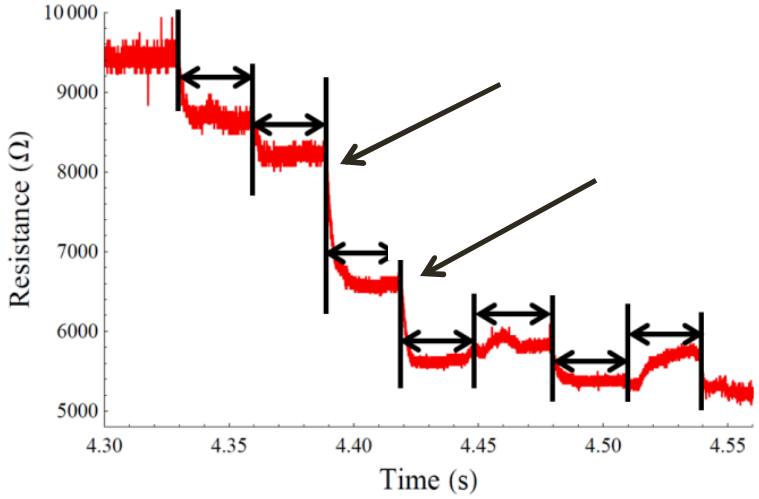
Determining the size of conductive filaments



Inverted Stack

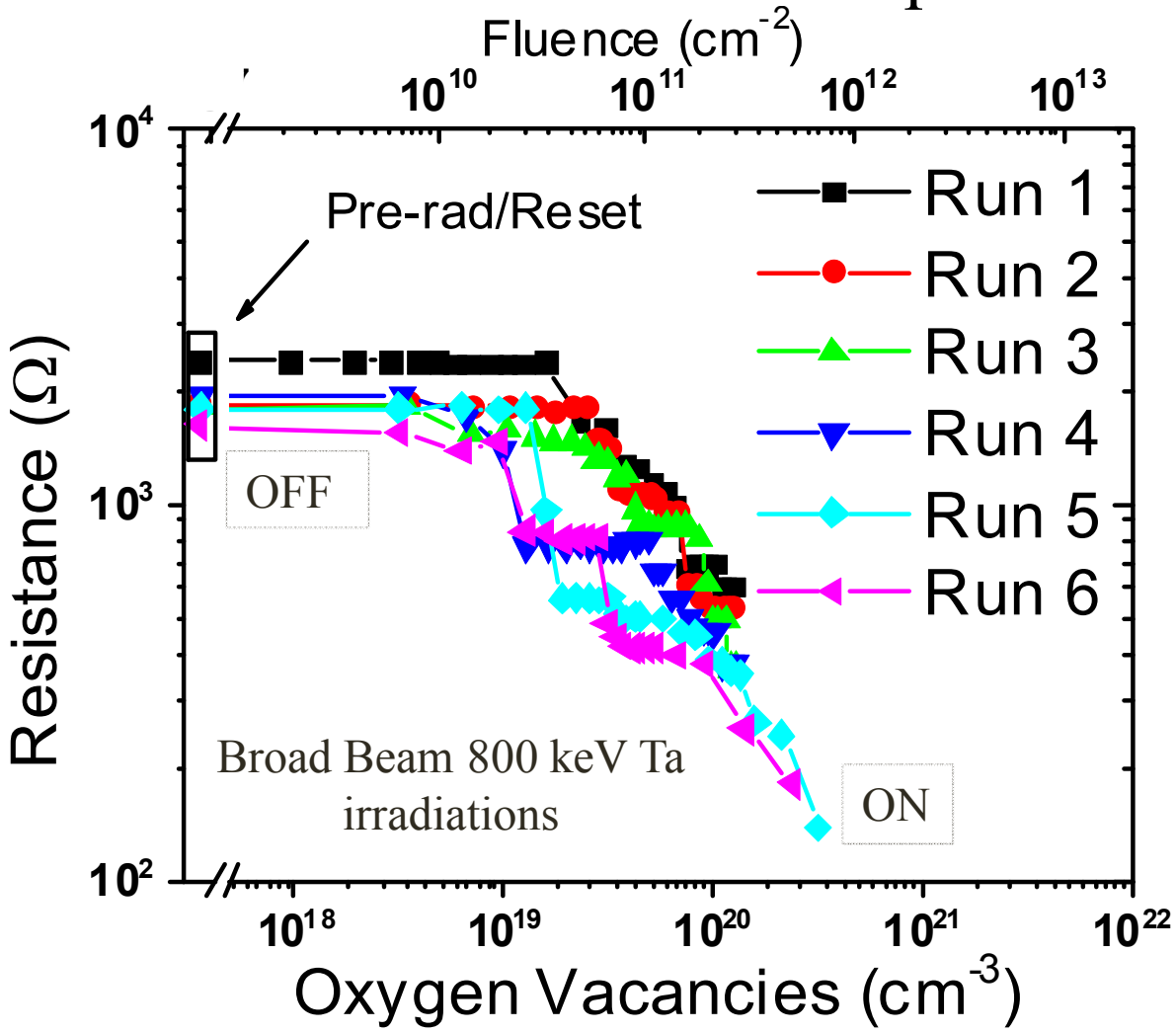


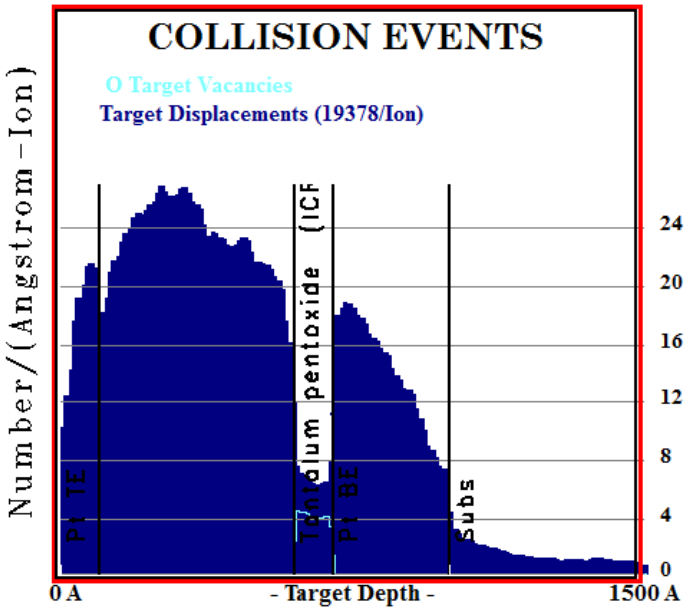
- Beam dynamics yield an apparent size for the conductive filament
  - 35nm spot size, ~60nm lateral straggle → beam will affect filament if within ~100nm
- However largest change observed when beam is on filament
  - ~2 beam spots →75nm



Possible to determine approximate size of conductive filaments

Memristor Rad-Hard to Displacement Damage





- Ta_2O_5 vs TaO_x
- Ta_2O_5 → TaO_x via ion beam irradiation
- Affecting conductivity

Hypothesis: Oxygen vacancy concentration ↑ device resistivity ↓

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- Forming and switching mechanisms not fully understood
  - Formation of conductive channels
  - Conductivity dependent on concentration/motion of oxygen vacancies
  - Switching modulation of conductivity:
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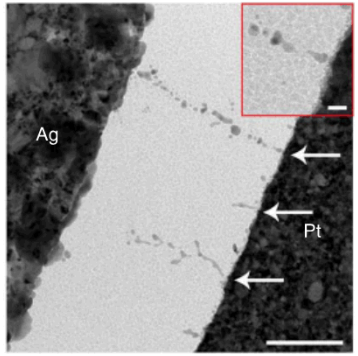
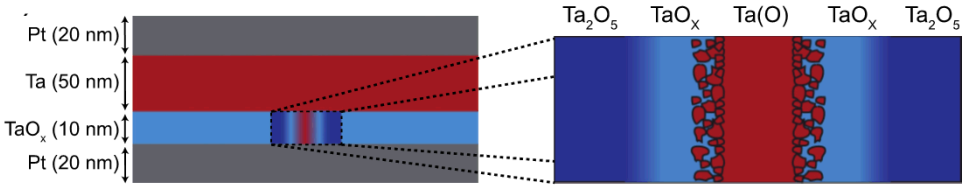
Filament formation in Pt/SiO2/Ag memristors

Yang et. al., Nat. Comms. 2012





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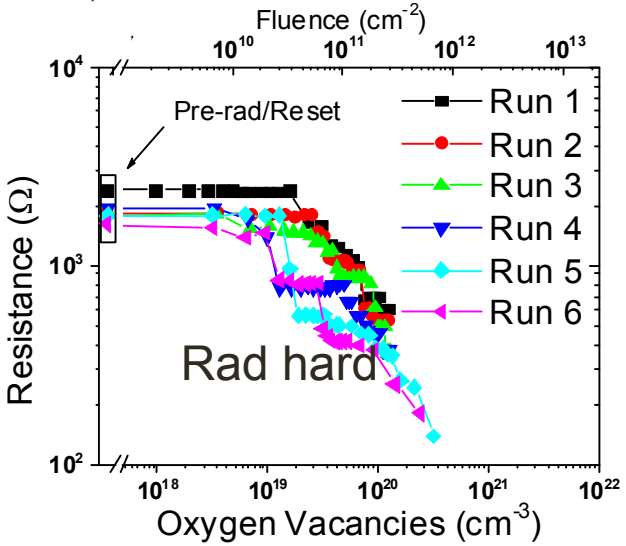

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