SAND2013-10822P

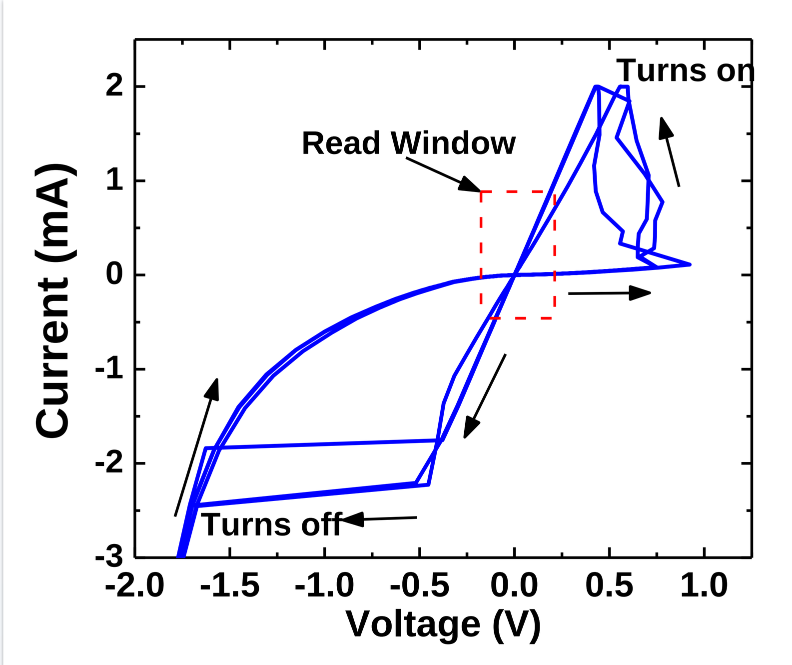
Displacement Damage and Ionization Effects in TaO_x and TiO_2 Memristors

D. R. Hughart, A. J. Lohn, P. R. Mickel, S. M. Dalton, P. E. Dodd,
M. R. Shaneyfelt, A. I. Silva, E. Bielejec, G. Vizkelethy, M. T. Marshall,
M. L. McLain, and M. J. Marinella

Sandia National Laboratories, Albuquerque, NM

Introduction

- Resistive or Redox RAM (ReRAM) is one of the most promising replacements for Flash, DRAM, and even SRAM memories [1]



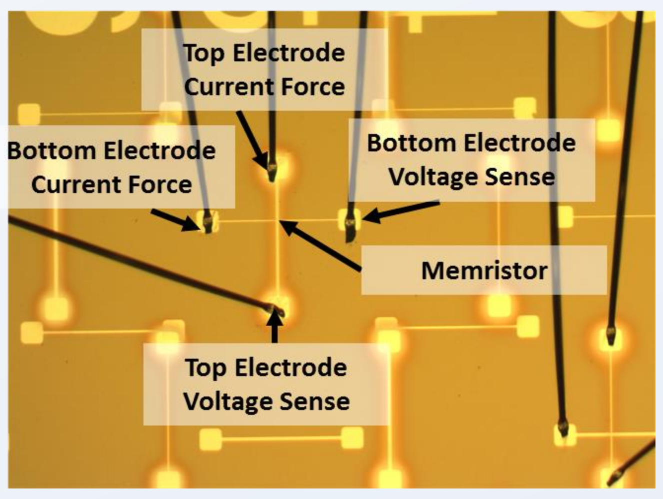
- Device operation
- Resistance changes due to a change in radius of a nanometer scale conducting filament composed of a higher density of oxygen vacancies [2],[3]
- The resistance state will change when current/voltage beyond a threshold is applied
- The resistance can be read at low voltages without changing the resistance

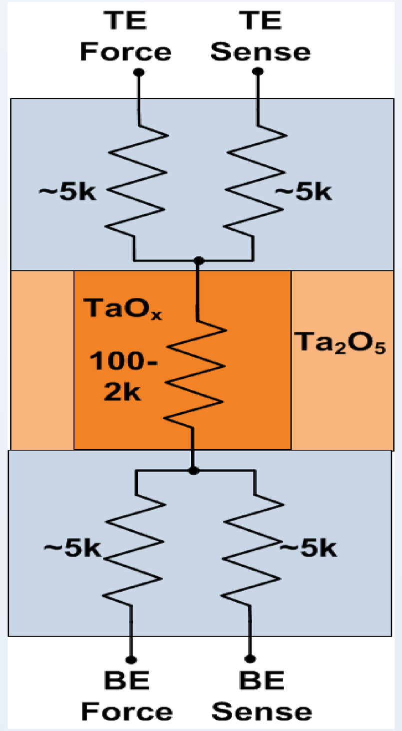
- This poster presents an investigation into displacement damage and ionization effects on TaOx and TiO_2 memristors using heavy ion and X-ray irradiation
- TaO_x and TiO_2 memristors both show high tolerance for displacement damage and ionization damage and are promising candidates for future radiation-hardened non-volatile memory applications.

Experimental Details

- Device Details
- Memristors are formed when two electrodes cross, one on the top and bottom of the material stack
- Four point measurement eliminates contact resistance

- Radiation Sources
- 800 keV Ta ions – Displacement damage
- 28 MeV Si ions – Mixed
- 10 keV x-rays – Ionization

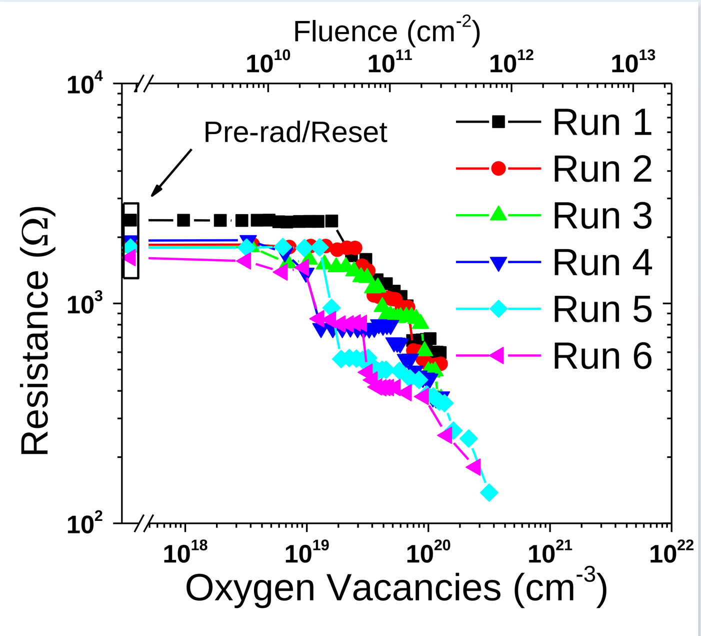


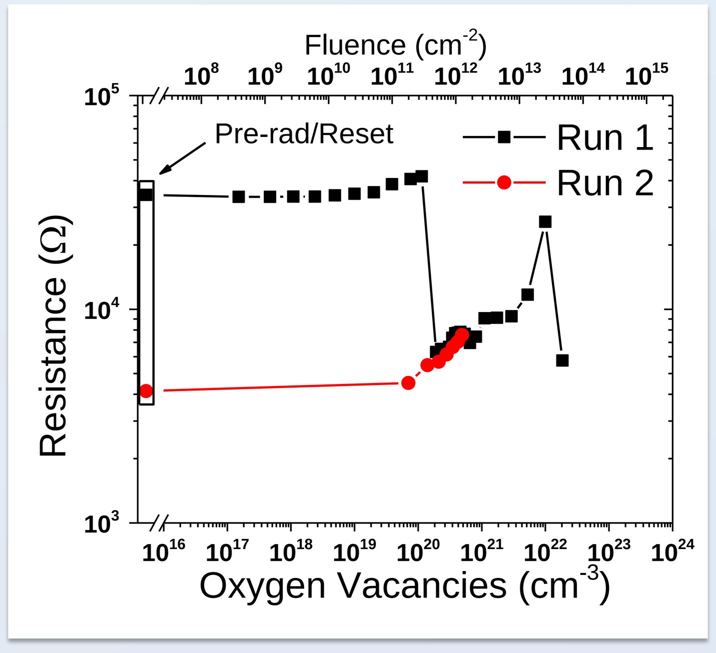


- Device Variation
- Devices were typically cycled 20-30 times prior to irradiation
- TaO_x devices selected showed <10% variation, TiO_2 <20%

800 keV Ta Ions

- TaO_x Response
- Gradual resistance degradation with increasing fluence due to displacement damage
- Average concentration of oxygen vacancies created calculated by SRIM [4]
- Decrease in R_{OFF} after reset and degradation at lower fluences during subsequent runs may indicate cumulative damage

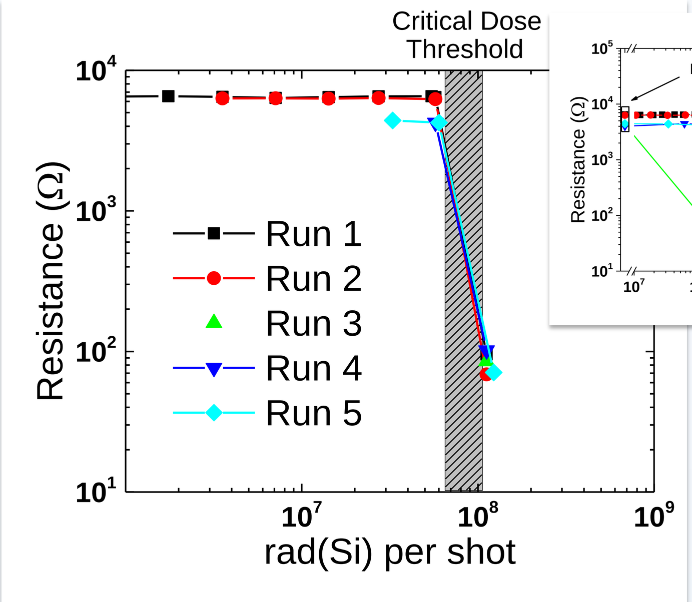


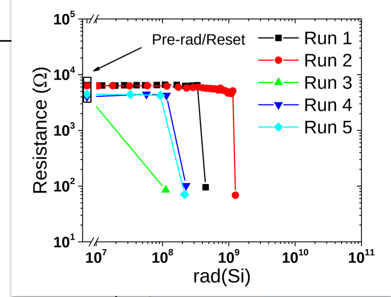


- TiO_2 Response
- Gradual increase in resistance with increasing fluence with inconsistent abrupt decreases
- Resistance decreases are inconsistent and do not approach on-state values

28 MeV Si Ions

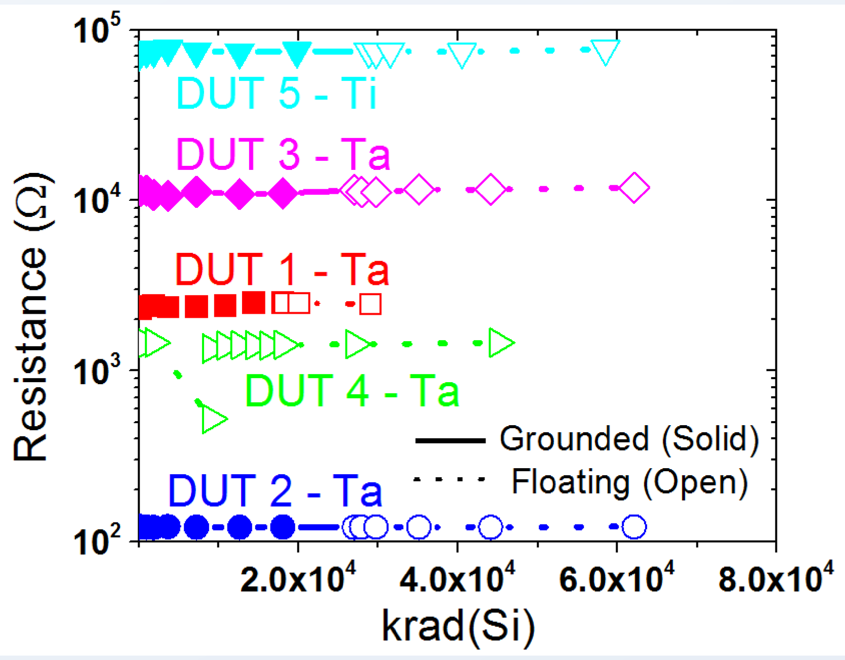
- TaO_x and TiO_2 Response
- TaO_x memristors switch to the on-state when a critical dose threshold is reached
- Applying small voltages prevents the switch
- Resistance changes are abrupt and consistent and little cumulative damage is observed
- TiO_2 memristors show a similar response but the critical dose threshold and resistance change are not as consistent
- Both ionization and displacement damage effects have been observed on a single TaO_x part





10 keV X-rays

- TaO_x and TiO_2 Response
- Devices exposed to doses up to 18 Mrad(Si) per step
- One TaO_x device set to the on-state, the rest were set to the off-state
- Some irradiations performed with pins shorted, others with pins floating
- Neither condition showed any change, except for a 7.2 Mrad(Si) step on DUT 4
- The change seen on DUT 4 was minor and not reproducible, even at higher doses



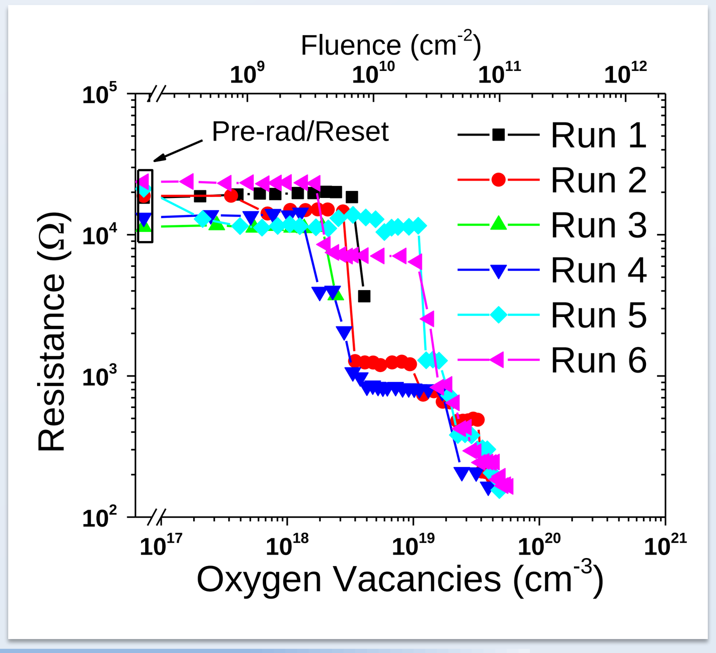
Post-Rad Behavior

TaOx Behavior

- A single reset may not remove all oxygen vacancies introduced by displacement damage
- Percolation paths may be easier to form during subsequent irradiations
- Multiple reset cycles may gradually return the conduction channel to its original state

TiO_2 Behavior

- Off-state resistance often degrades with repeated cycles after irradiation



Summary

- Radiation-induced resistance changes due to displacement damage and ionization effects have been identified in TaO_x and TiO_2 memristors
- Displacement damage tends to cause gradual resistance changes while ionization causes a large, abrupt change in resistance
- Applying small voltages appears to prevent ionization based resistance changes
- Displacement damage may cause cumulative damage in TaO_x devices that can be mitigated by resetting the part multiple times
- Displacement damage in TiO_2 causes less predictable effects and often results in post-irradiation instability in the off-state resistance
- Both technologies show little change in device characteristics until high fluences and doses are reached and show great promise for use in radiation-hardened non-volatile memory applications

References

[1] J. Hutchby and M. Garner, ITRS Future Memory Devices Workshop Summary, 2010.
[2] P. R. Mickel, et al., *Appl. Phys. Lett.*, 102, 223502 (2013)
[3] F. Miao, et al., *Adv. Mater.*, 2011, 23, pp. 5633-5640
[4] J. F. Ziegler, SRIM-2012 [Online]. Available: www.srim.org

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.