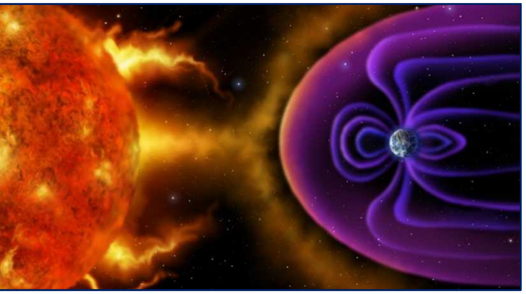
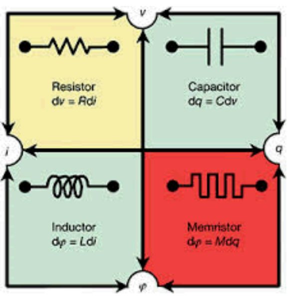
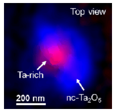
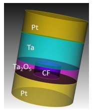
SAND2017-10609C

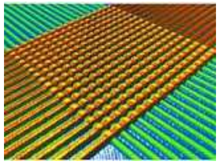
Temperature Effects on the Total Ionizing Dose Response of TaO_x-based Memristive Bit Cells











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Sandia National Laboratories

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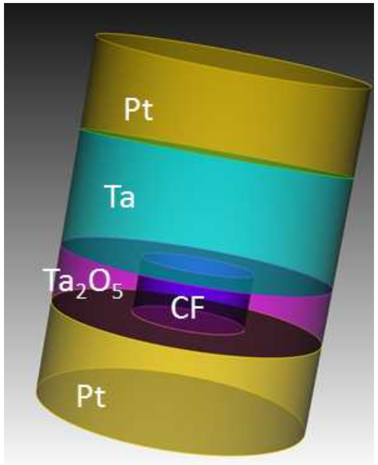
RADECS 2017
CERN, Geneva

Why Do We Care About Memristors?

- **Push to develop a storage class memory technology to replace SRAM, DRAM, and Flash as silicon hits scaling limits**
- **ITRS has identified Resistive RAM (also known as redox, RRAM, memristive, or ReRAM) as one of the more promising future memory technologies**
- **Memristors are the storage elements**
  - **Metal Oxide: Bipolar Filamentary (valence change)**
  - **Electrochemical Metallization Bridge (CBRAM)**
  - **Metal Oxide: Unipolar Filamentary**
  - **Metal Oxide: Non-filamentary**



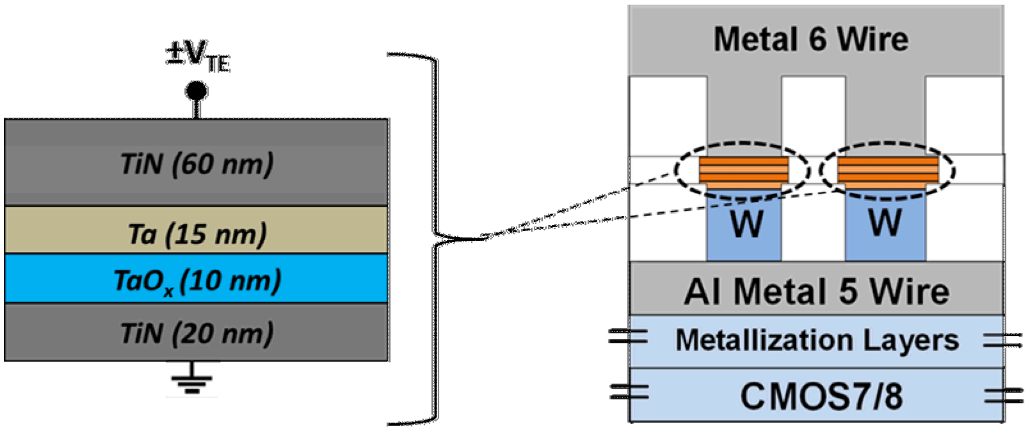
Memristors switch between low and high resistance states

ReRAM one of the more promising future memory technologies

Motivation

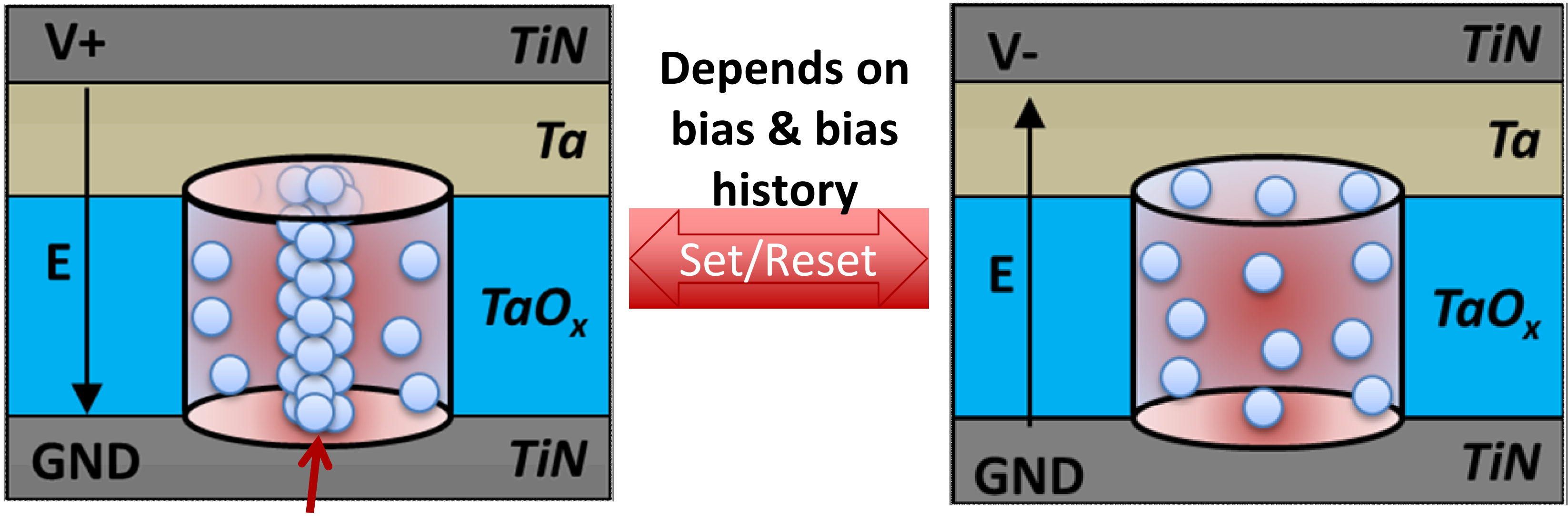
- **COTS NVM technologies are commonly used to store mission critical information in systems designed for harsh environments**
  - **Surrounding CMOS circuitry often radiation sensitive**
- **Discovering a rad-tolerant memristor would allow devices to be inserted into the metallization layers of a rad-hard CMOS process**
- **Need to assess the combined effects of temperature and total ionizing dose (TID) on memristive technologies**

Baseline for memristor integration within a CMOS process



Many applications have TID and temperature requirements

How a TaO_x Memristor Works

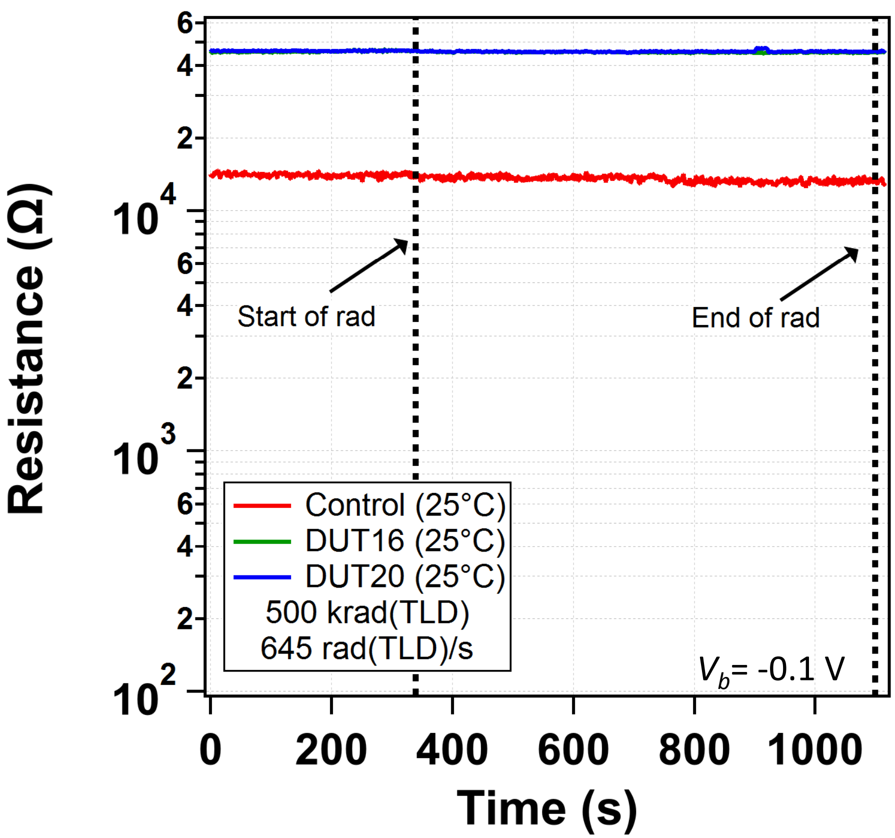


Filament formation in insulator
Low resistance on-state

No filament
High resistance off-state

- Memristors are two terminal metal-insulator-metal devices characterized by a low resistance on-state and a high resistance off-state
- Switching mechanism involves redox reactions and transport of oxygen anions
  - Electric and thermal fields cause dissociation and transport of oxygen anions, leaving behind positively charged oxygen vacancies
- Processes lead to formation of Ta-rich conducting filaments

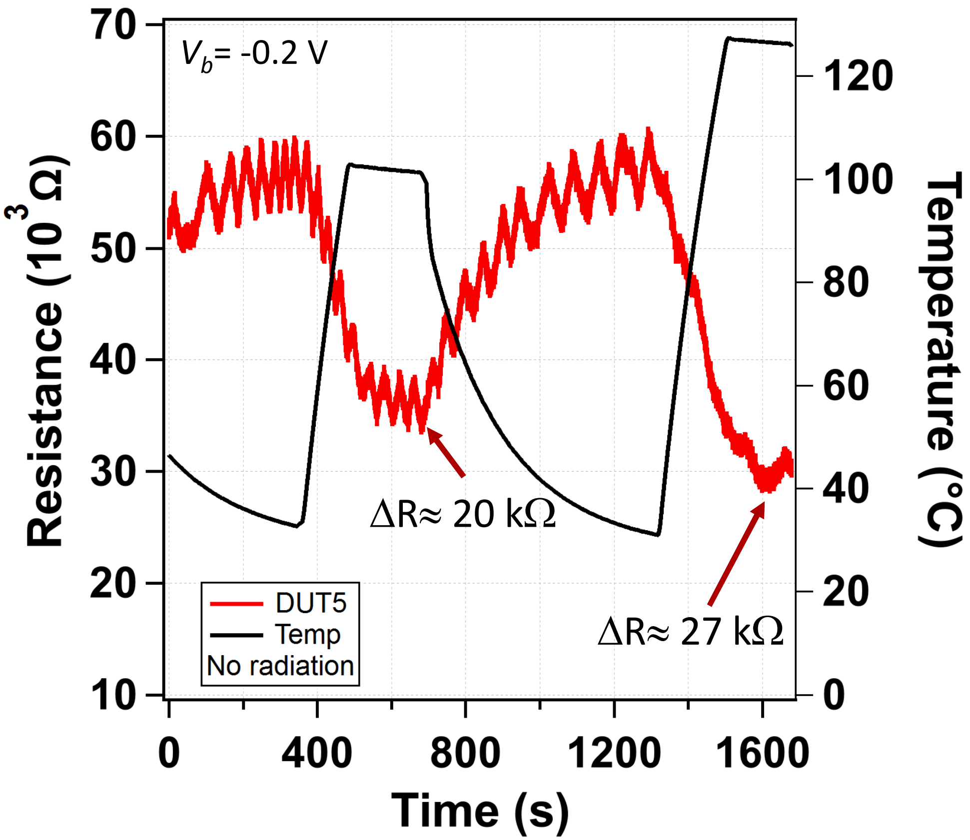
Experimental Details



- **Investigated the combined effects of temperature and TID using a decay photon source**
- **Devices typically reset to the off-state prior to radiation**
- **Device resistance actively measured during step-stress irradiations up to ~500 krad(TLD)**
- **Temperature varied between 5 °C and 125 °C**
- **Performed hysteresis sweeps before and after set of radiation exposures**

Negligible resistance shifts observed during ambient TID exposures

Temperature Effects



- **Temperature ramped from ambient to ~100 °C, back to ambient, and then to ~125 °C**
- **Resistance has an inverse relationship with temperature when device in off-state**
- **Resistance returns to original level once temperature reaches ambient**
- **Negligible resistance shifts observed in devices set to the on-state**

Device resistance has an inverse relationship with temperature when device in high resistance off-state

Model for Temperature Dependence

Elevated temperatures will increase the mobility of ions and probability of thermally-activated hopping, thus reducing the resistance of the memristive layer

Activation Energy

$$R(T) = \beta T^n \exp\left(\frac{E_a}{k_B T}\right)$$

Temperature

Resistance described by thermal activation law for small polaron mobility

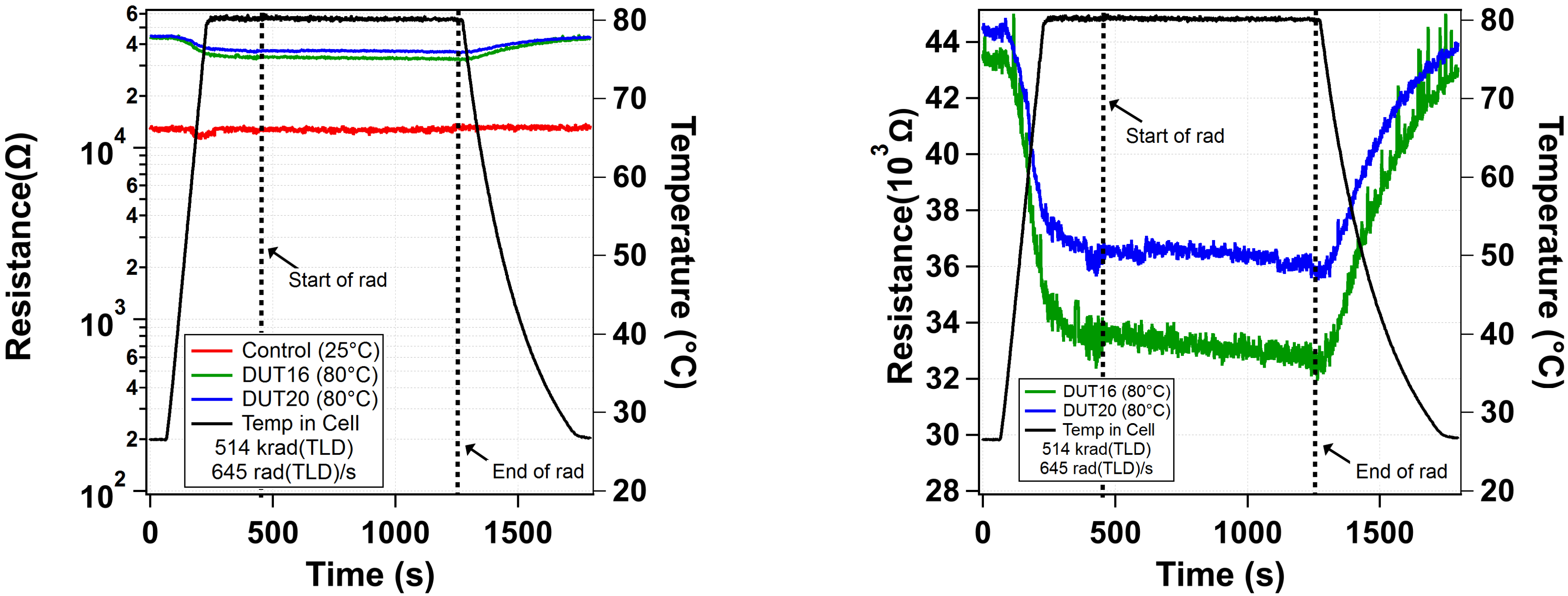
$$\frac{R_{post}}{R_{pre}} \propto \exp\left(\frac{E_a}{k_B T_{Post}} - \frac{E_a}{k_B T_{Pre}}\right)$$

Relationship holds assuming low applied bias

$$R_{post} \propto R_{pre} \cdot \exp\left(\frac{E_a}{k_B T_{Post}} - \frac{E_a}{k_B T_{Pre}}\right)$$

(after Alexandrov, APL 2011)

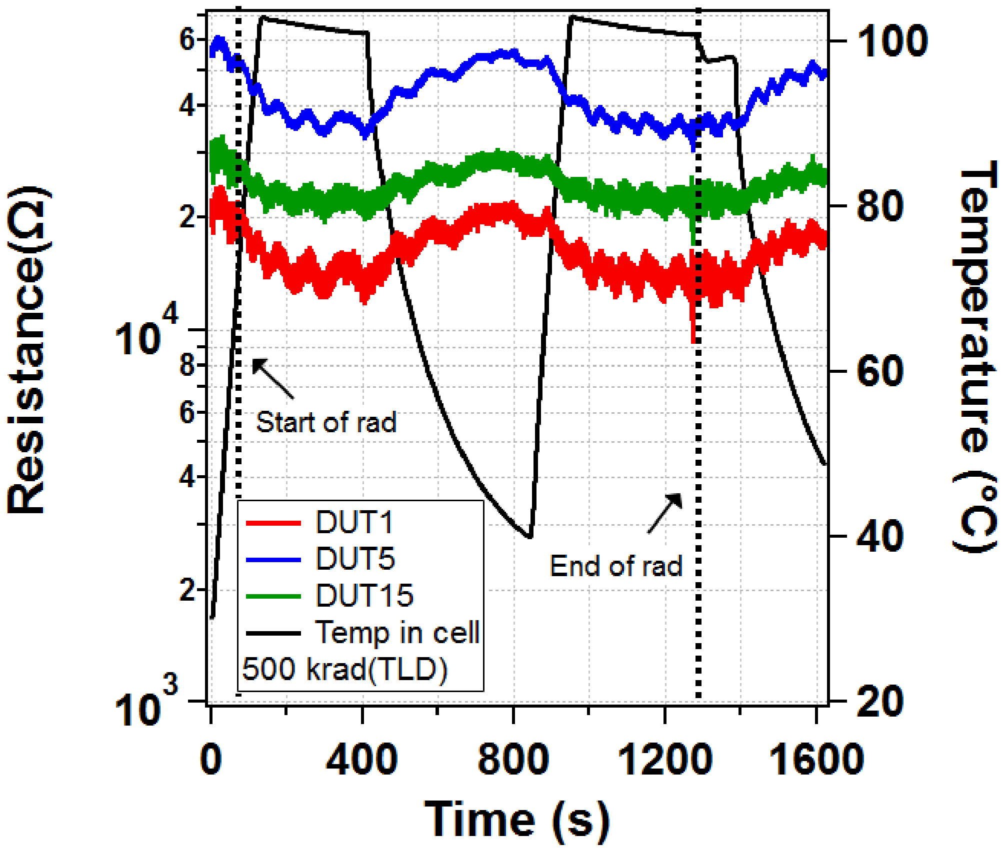
Combined Environment (80 °C)



- Control is located in the instrumentation area (no resistance shifts)
- Radiation starts after temperature is increased to 80 °C
- During irradiation, the resistance continued to gradually decrease

TID susceptibility does not increase at elevated temperatures

Combined Environment (100 °C)



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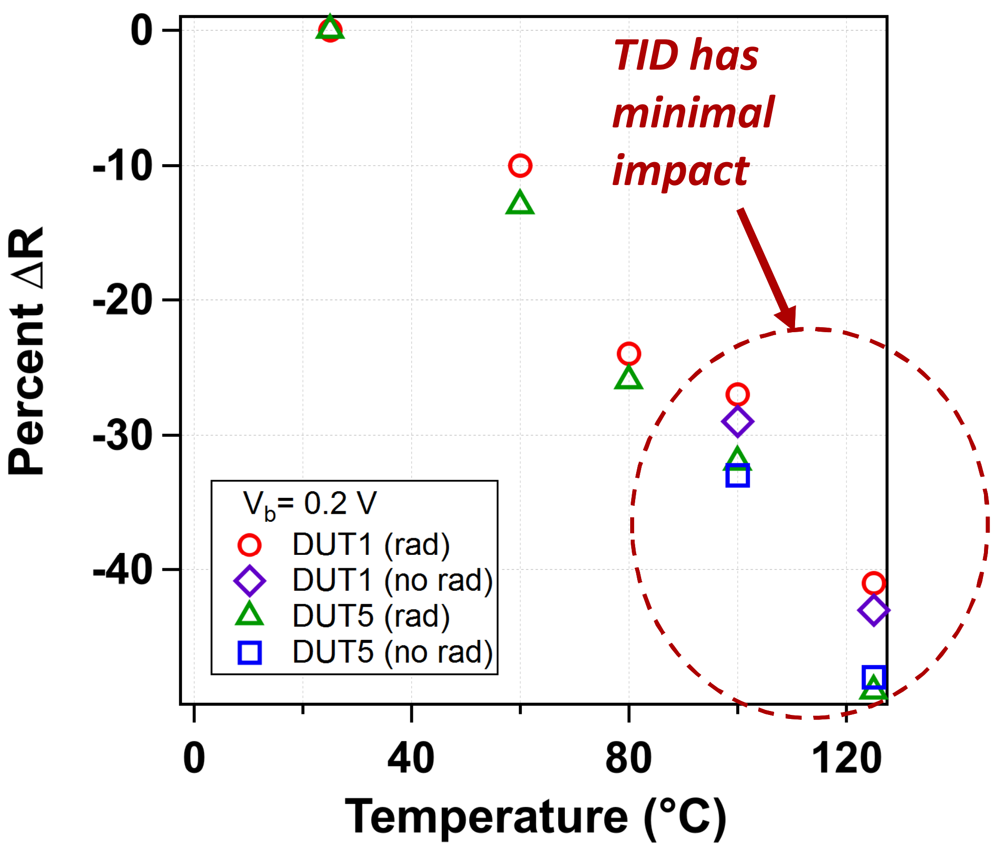
Resistance shifts dominated by temperature fluctuations

Percent Change in Resistance



- **Percent change in resistance:**

$$\%\ \Delta R = \frac{R_{post} - R_{pre}}{R_{pre}} \times 100$$

- **Negative percent values indicate decrease in resistance**
- **Data suggest that only temperature changed the resistance of the device**
- **Devices still functional after cumulative dose levels greater than 3 Mrad(TLD)**

Percent change in resistance close to 50% at 125 °C

Summary

- The TID response of TaO_x memristive bit cells was characterized as a function of temperature using a decay photon source
- Devices in the high resistance off-state exhibited decreases in resistance when the temperature was increased
- An increased susceptibility to ionizing dose at elevated (or lower) temperatures was not observed
- Important since many space and industrial applications will require not only radiation hardened circuits but also circuits that can operate over extreme temperature ranges