Fundamental Study of Metal/Oxide/Metal Memristor Physics and Device Optimization

Sandia National Laboratories

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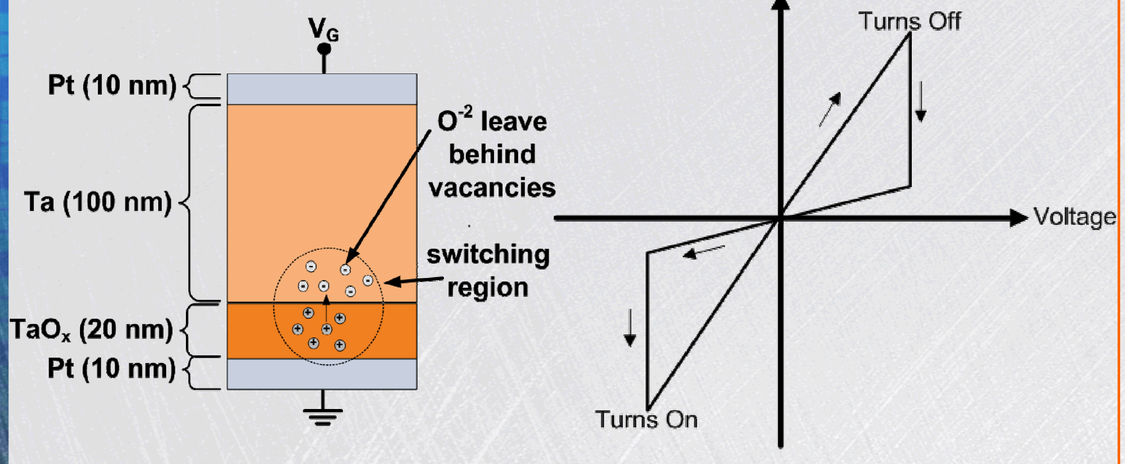
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Early Career R&D Program

Problem

- **The Memristor or Resistive/Redox RAM (RRAM) is one of the most promising replacements for Flash, DRAM, and even SRAM memories**
- **Poor physical understanding of switching action has limited the use of this technology**
- **Problem: Insufficient understanding of switching mechanism**
- **Current working theories:**
  - **Conductivity modulated by O^{-2} anion migration**
  - **Filament formation**
  - **Donor or electron hopping models**



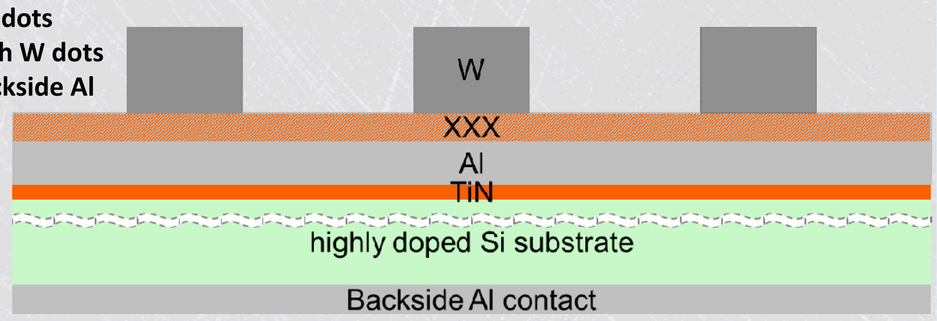
Approach

- **Project Plan: Make memristors and use electrical characterization and modeling to understand switching**
- **Focus on transition metal oxide (TMO) memristors**
- **Initial major risk – fabricating inexpensive but stable, working memristors**
- **Fabrication Approach: Two methods of device fabrication**

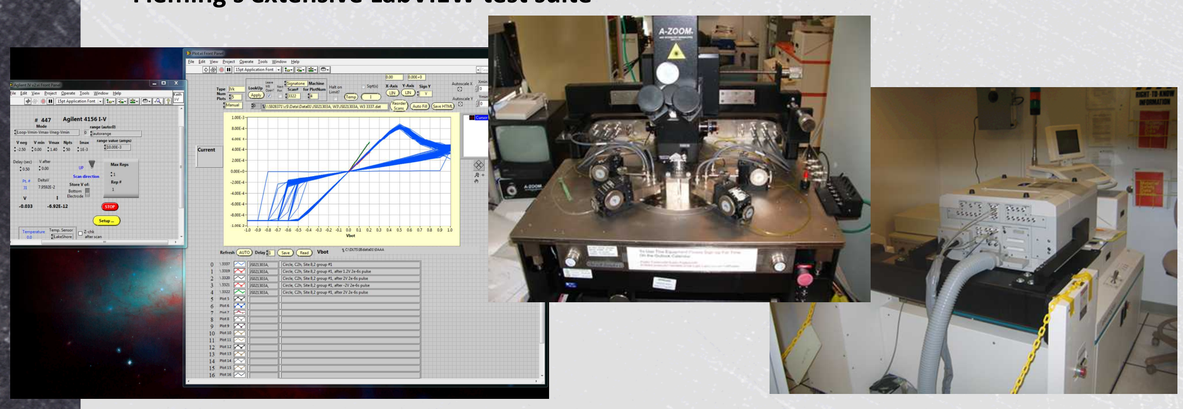
1. **Sol-gel ZnO deposition on TMO substrate**
2. **Simple MESAFab flow to create metal/oxide/metal capacitors**

MESAFab Flow

1. **Dep blanket TiN/Al**
2. **Deposit metal oxide (XXX)**
3. **Dep top ~7k W**
4. **Pattern dots**
5. **Wet etch W dots**
6. **Dep backside Al**



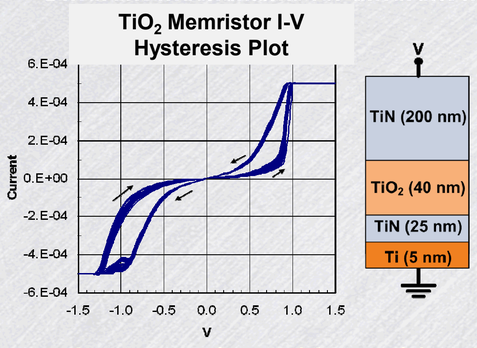
- **Electrical Characterization Approach: Match a Common Insulator Conduction Mechanism**
- **Examples: Ohmic, Ionic, Tunneling, Frenkel-Poole, Schottky Emission**
- **2 Main Factors:**
  1. **Current – Voltage Relationship**
  2. **Current – Temperature Relationship**
- **Make use of 1748 rad-hard CMOS/advance device parametric test lab and Robert Fleming's extensive LabVIEW test suite**

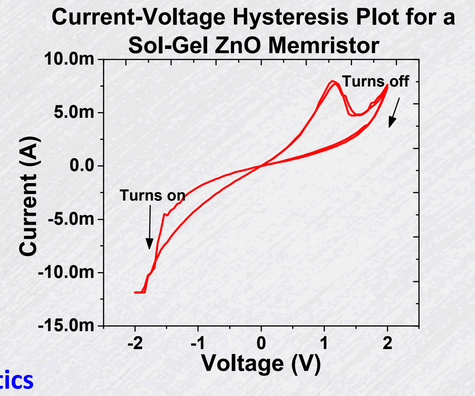


Results

Each fabrication approach resulted in working devices:

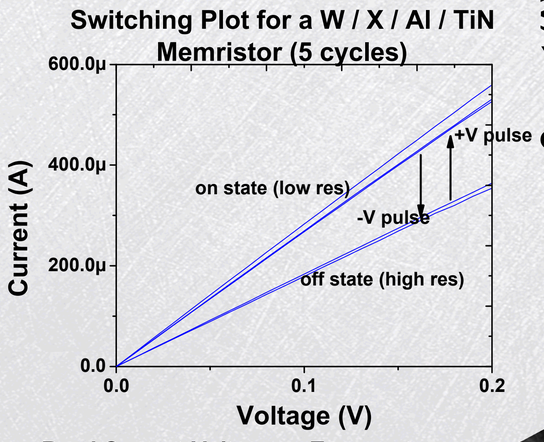
- **Chemistry lab: Sol-gel ZnO demonstrated (TiO_2 possible also)**
- **Fab: TiO_2, WO, and a new, promising material demonstrated, TaOx samples from HP and in progress in uFab**
- **Variety of electrical characteristics for on and off I-V curves**
- **Different mechanisms for different materials?**

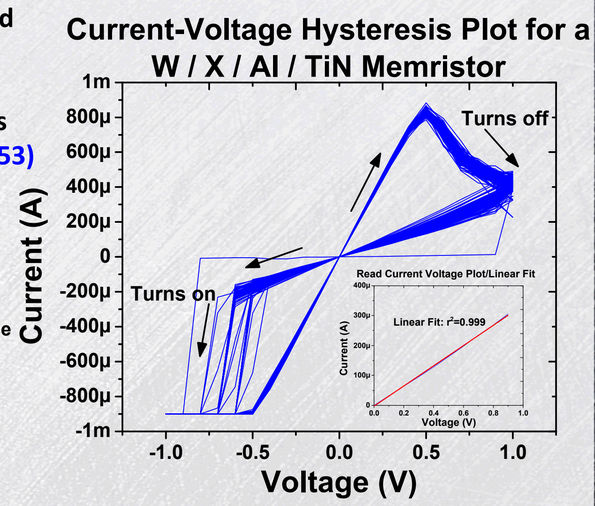


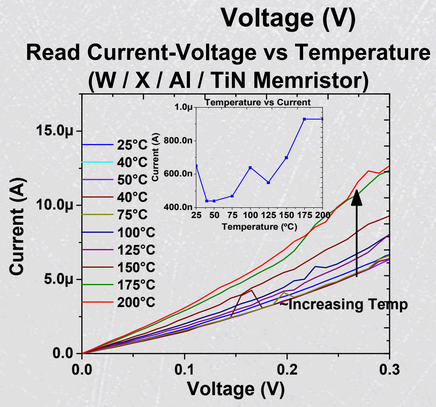


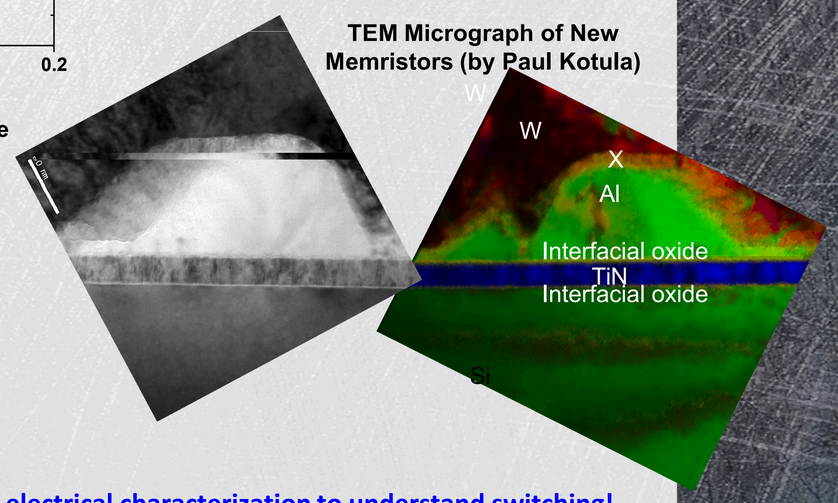
Invented new memristor with promising characteristics

- **150 cycles, on/off pulsing demonstrated**
- **Highly linear I-V – Ohmic conduction?**
- **High on/off ratio possible**
- **New material questions current models**
- **TA submitted for new material (SD 12053)**









Need a combination of physical and electrical characterization to understand switching!

- **New NTM LDRD has been proposed and accepted to study physics of memristor switching**

Significance

- **Sandia has gained the ability to fabricate memristors from a number of materials**
- **A new memristor has been invented (SD 12053)**
- **Electrical modeling reveals different likely mechanisms for different materials**
- **Need a combination of physical and electrical characterization to understand switching!**
- **Memristors represent a new technology with major potential in numerous applications**
  - **Flash, DRAM, SRAM replacement, rad-hard memory, neuromorphic systems, and national security applications**
- **Two new follow-on LDRDs have been Funded for FY12 to continue and expand this work:**
  - **NTM LDRD to study physics of switching in TaOx memristors**
  - **Cyber security LDRD**
  - **One of the disruptive memory technologies for the Exascale Grand Challenge**
- **Other activities initiated by this work:**
  - **CRADA with Industrial Research Lab**
  - **Two external funded projects and major proposals**
  - **Collaborations initiated – Arizona State University, Boston University, and Industrial Partners**

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