A Non Volatile MEMS Switch for Harsh Environment Memory Applications

CAVENDISH KINETICS

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Talk outline

- **Introduction to Cavendish Kinetics**
  - NanoMech™ technology
- **MEMS cantilever memory switch**
- **The cavity**
- **Harsh environment rocker memory design**
  - Harsh memory temperature performance
- **Harsh memory radiation performance**
- **Other applications**
- **Conclusion**

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Cavendish Kinetics
Building MEMS Electronics

- **Mission: Enable our Customer to Deliver Breakthrough Products**
  - *How:* Enable integration of devices and sensors with CMOS
  - *Results:* Lower cost, lower power and smaller size
  - *Means:* Standard semiconductor processing technology

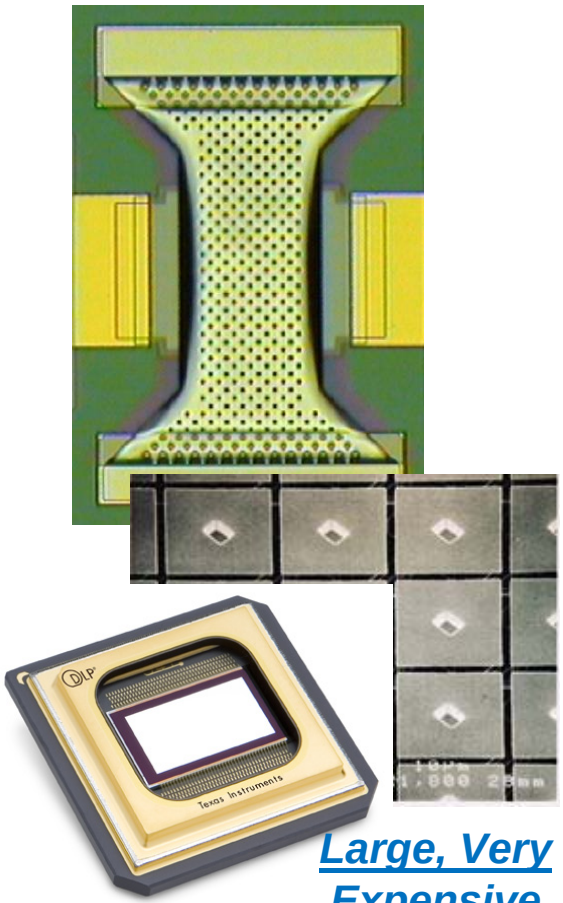
- **NanoMech™ Technology Platform – 3rd Generation MEMS**
  - Fully integrated into the back end process flow
  - No unique equipment or materials or packaging
  - Capability of delivering multiple applications on the same IC

- **NanoMech™ Memory**
  - Volatile and Non-Volatile Switch Technology
  - Demonstrated Extreme Harsh Operation

Evolution of MEMS Technology

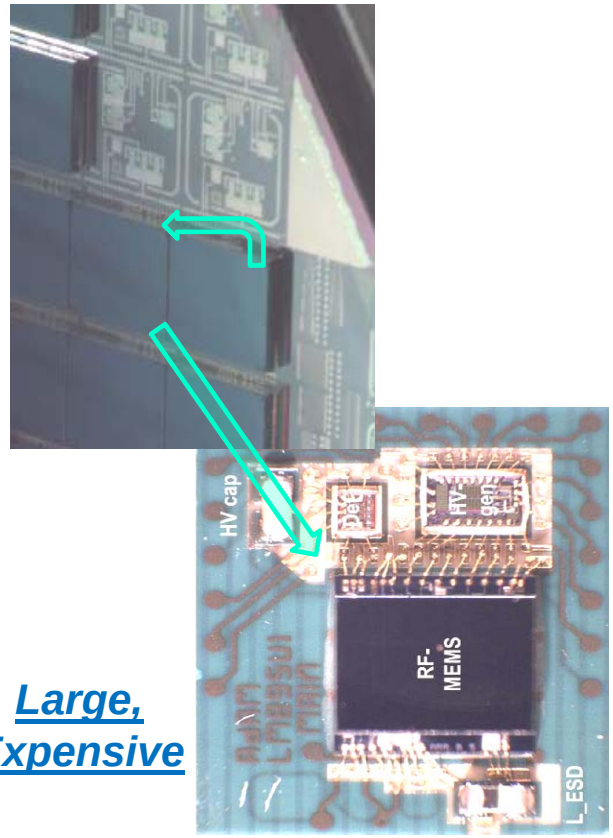
3 Generations of Evolution

Gen1: Build / Assemble



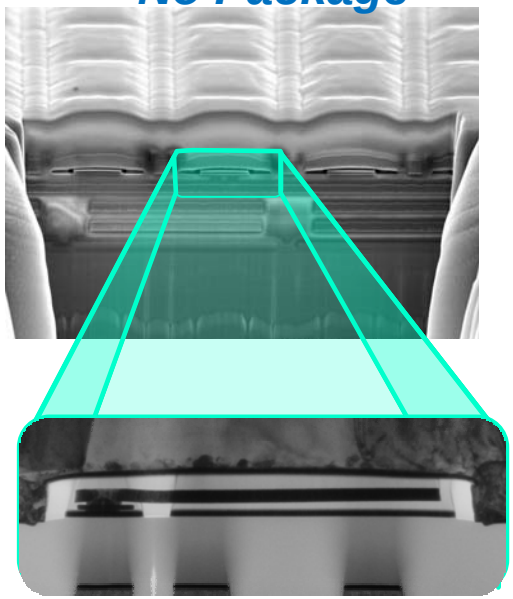
Large, Very Expensive

Gen2: Package in Package



Large, Expensive

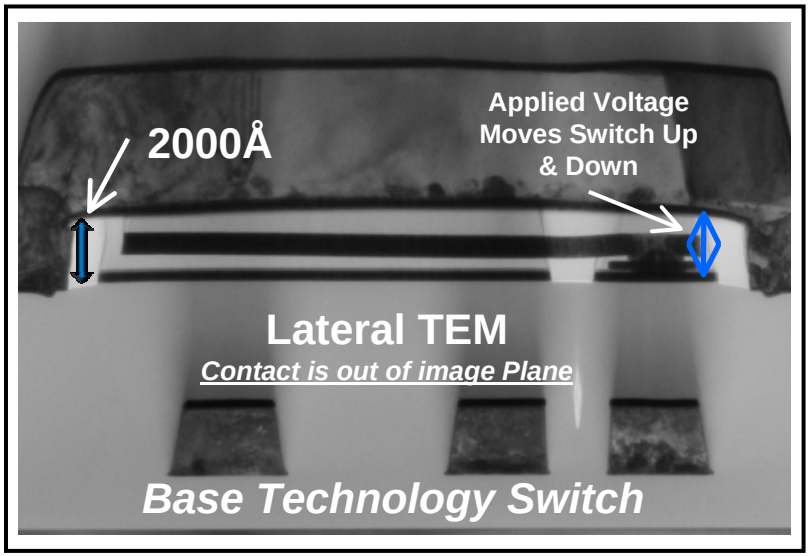
Gen3: Fully Integrated No Package



Small, Integrated, Low Cost Scale-able

Gen3 Enables MEMS Performance, But Delivers CMOS Size and Costs

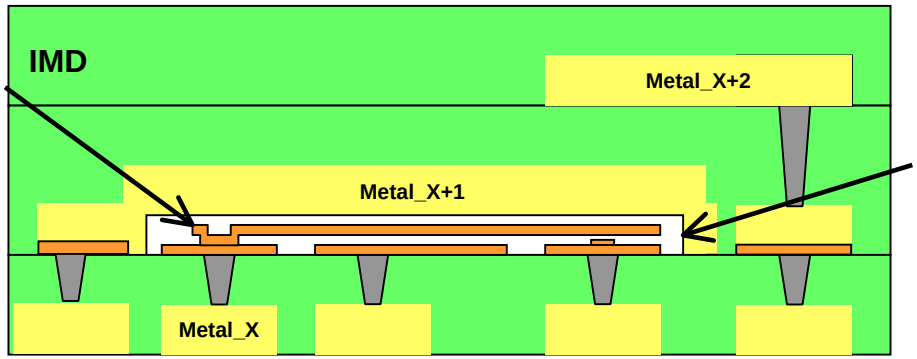
Core Technology: 3rd Gen MEMS



- **CMOS Compatible, Packaging Free MEMS platform**
- **Uses only Standard CMOS interconnect Process Technology**
- **Mechanical Platform (MEMS) is capable of producing a wide variety of applications**

MEMS Technology

- *Metal Based MEMS*
- *Cantilever*
- *NZRF Cantilever*
- *Many Operate as One*



Cavity

- *Package Free MEMS*
- *Non Contaminating*
- *CMOS Processes*
- *Planarized Interconnect*
- *Controlled Release Design*
- *Electrically Active Roof*
- *Roof: Metal or Dielectric*
- *Via Electrical Connections*

Integrates into Standard Flow

Both Integrated together into Standard CMOS

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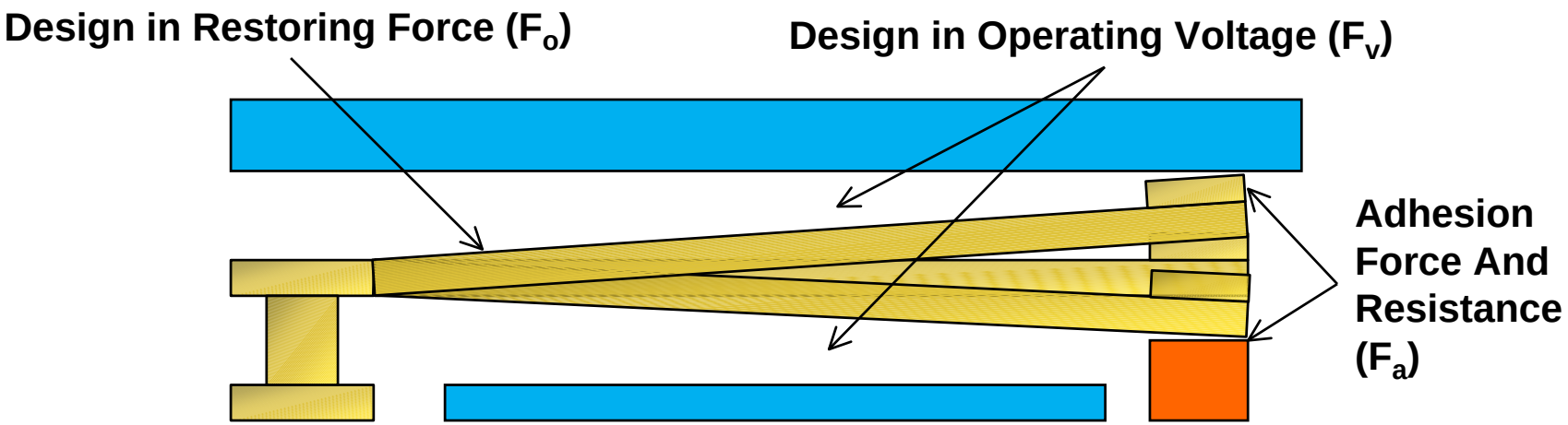
Anatomy of a CK Switch

Utilize Stiction



Design Attributes

Nonvolatile: $F_o < F_a, F_v$ **Volatile: $F_a < F_o < F_v$** **Sensor: $F_a = F_o < F_v$**

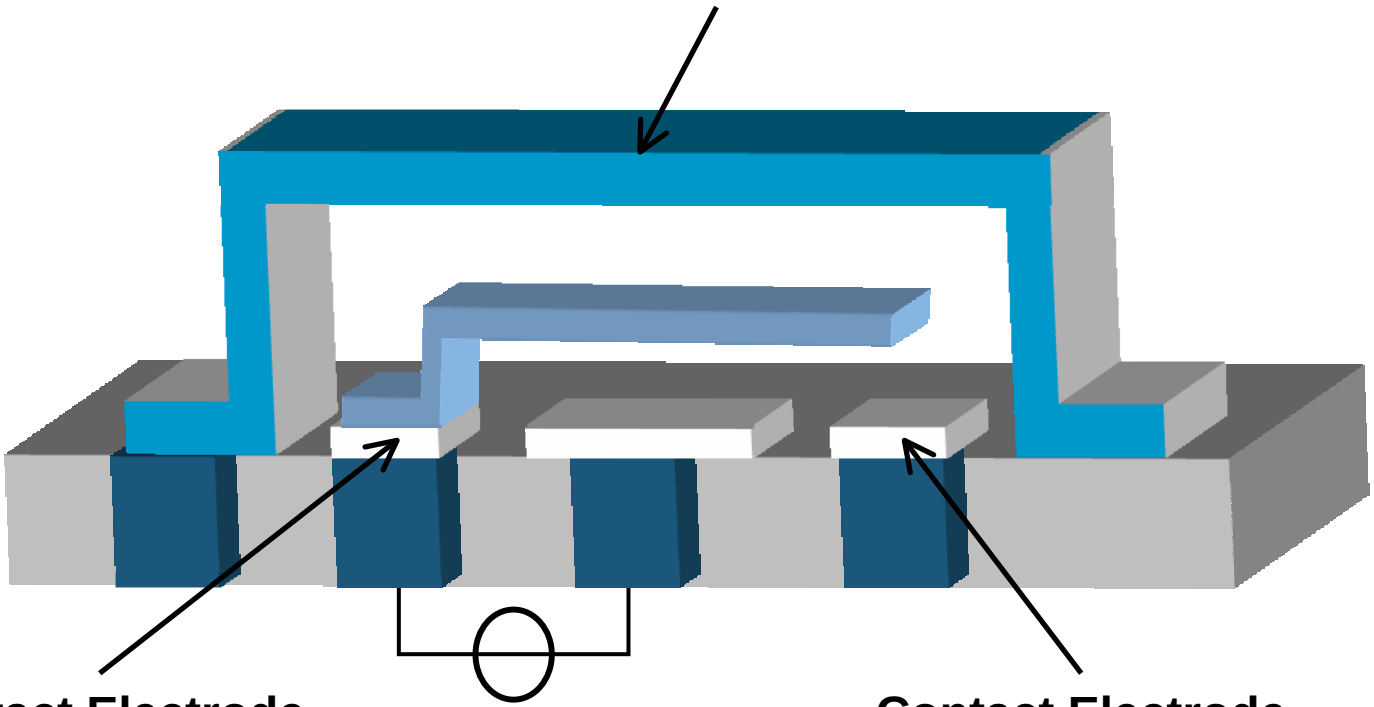
Key features

- ✓ Can tune the restoring force without a process change
- ✓ Can tune for volatile or non-volatile behavior
- ✓ Digital sensing (contact either open or closed)
- ✓ Native or higher voltage programming as required
- ✓ High Endurance contact cycles demonstrated
- ✓ Fast response time in the sub 100 nanosecond range
- ✓ Environmental Superiority: Operates -150ºC to 300ºC and Radiation Hard
- ✓ Natural frequencies in the 75Mhz range

Simple Concept, Broad Applications

Traditional Style Cantilever

Technology has Ability to Utilize Roof as Electrode



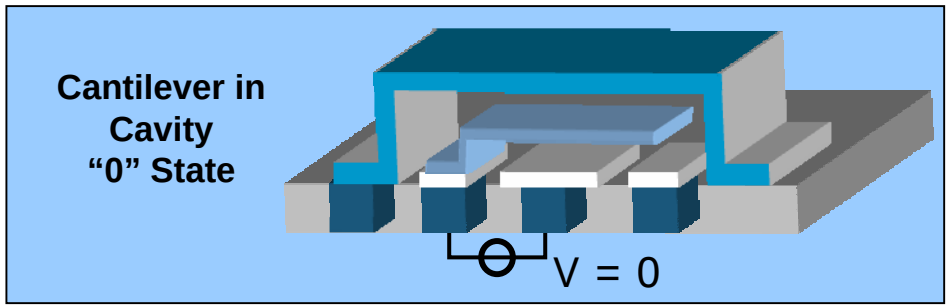
Contact Electrode

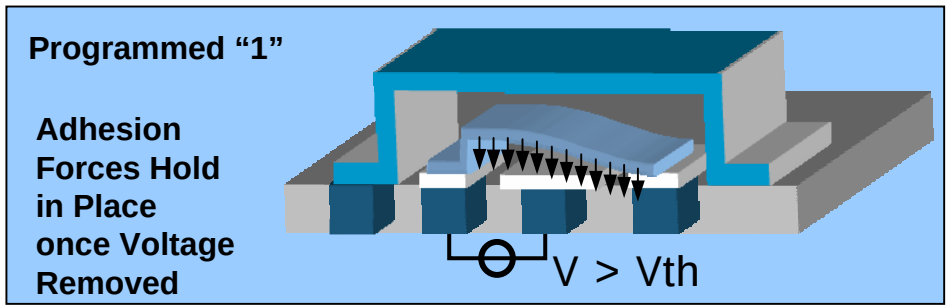
Control Voltage

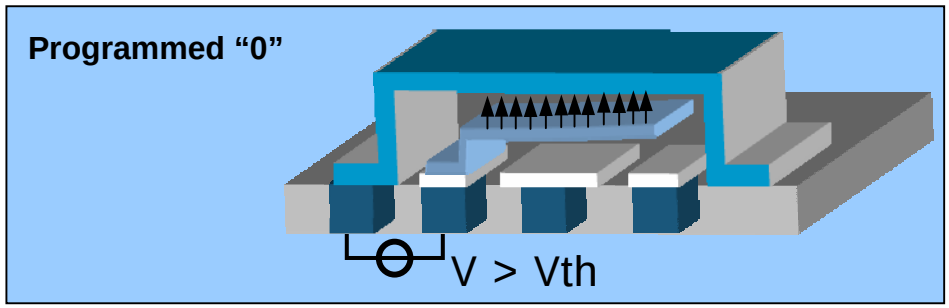
Contact Electrode

Pull In Electrode

Cantilever uses adhesion to make NVM

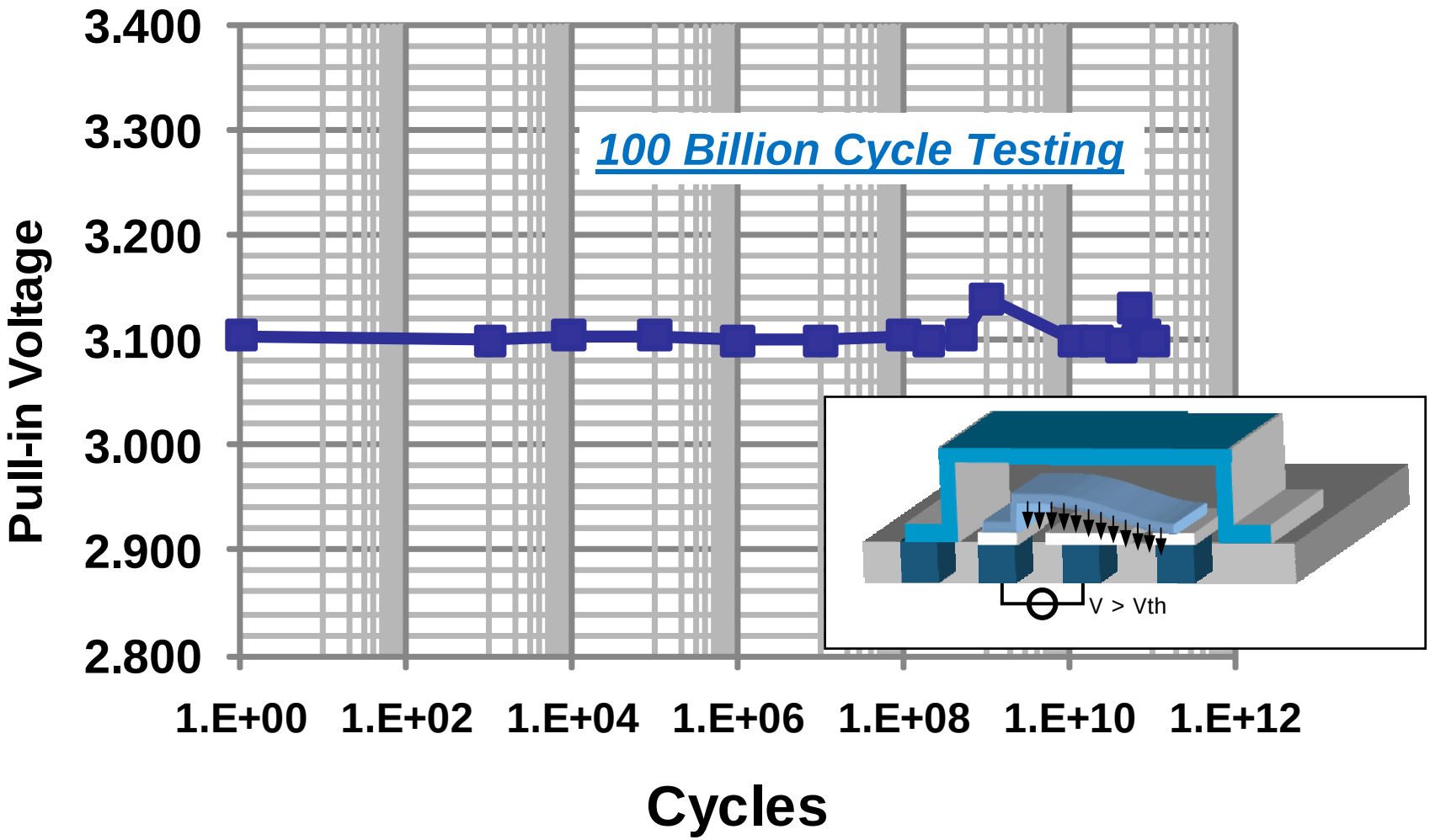






Material System Fatigue

Completed on Traditional Cantilever



No Demonstration of Fatigue in Material System

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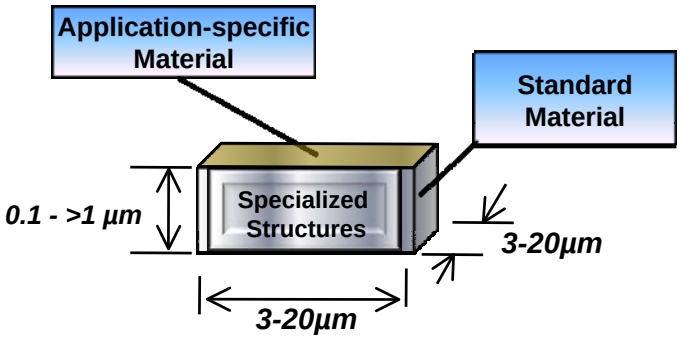
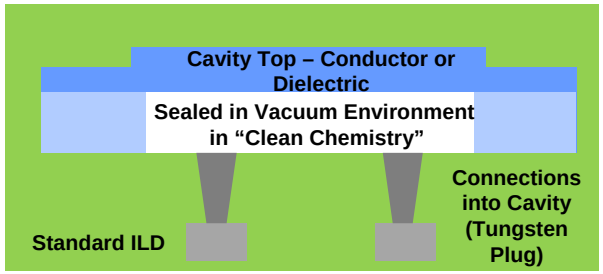
NanoMech Technology
Each Device is in Own Cavity

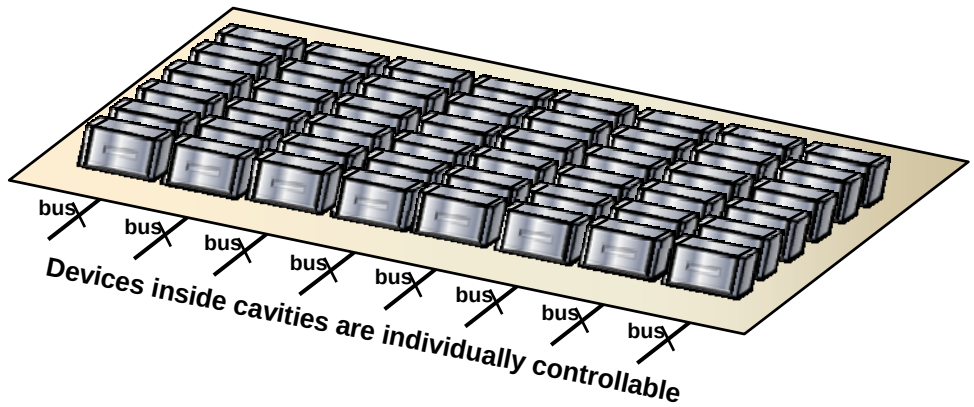
***Each* component is sealed in a cavity**





Sealed cavities used individually or built into arrays

Can combine multiple devices in single cavity



- **Characteristics:**
  - **High isolation & high density**
  - **Standard fab materials and processes**
  - **Sealing during production lowers cost**
  - **Variable cavity and array sizes to fit applications**
  - **Connections through Lower Metals, and Metal Roof**
  - **Demonstrated WLR Performance of Cavity and Device**
    - **Temp Cycle, High Temp Storage, Thermal Shock, Unbiased Autoclave**

Robust Cavity and Robust Architecture

Wafer Level Reliability

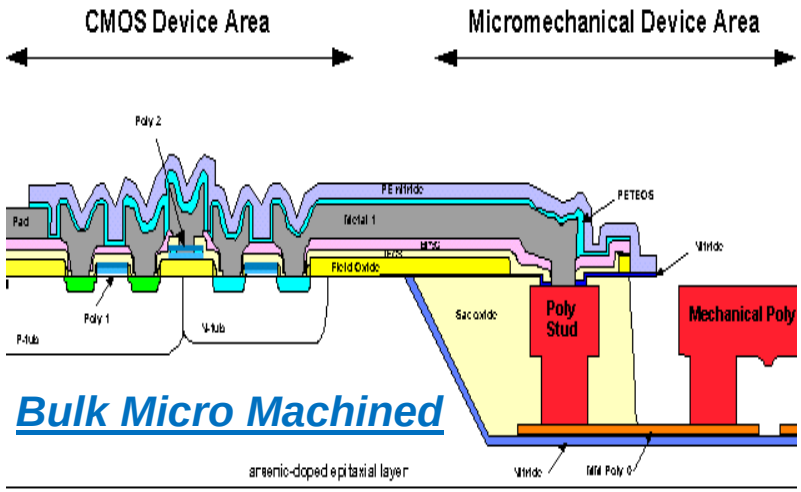
Performance of Cavity & Structure

Test	Conditions	Release	Status
7-alloy (**7A**)	Cycle from 25°C to 400°C to 25°C, N2 purge, 50 min. dwell	7 cycles	❖ Only minor parametric drifts over cycles
Thermal Cycling (**TC**)	Air-air Cycling, -65°C to 150°C	100 cycles	❖Only minor parametric drifts over cycles
High Temperature Storage (**HTS**)	T=*250°C*, N2 purge, storage, interim tests every 150 hours	1000 hours	❖Only minor parametric drifts over time
Thermal Shock (**TSK**)	Liquid-liquid Shock, -55°C to 150°C, wafer sample	100 cycles	❖Only minor parametric drifts over cycles
Unbiased Autoclave (**UA**)	T=125°C, 100% RH, 2 atm pressure	96 hours	❖Only minor parametric drifts over time

- *Wafer Level Tests of Integrated MEMS Technology*
- *Minor < 5% Shift (7Alloy), Typically < 2% all Others*

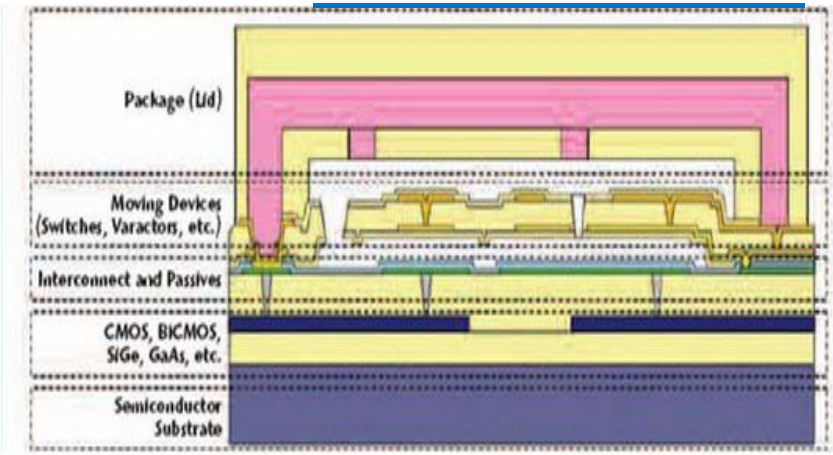
Environmental stress tests confirmed no issues for: (1) *Sealed Cavity*; (2) MEMS *membrane* and *anchor*; (3) *metallization* and *vias*

NanoMech™ vs.
Existing MEMS Technology

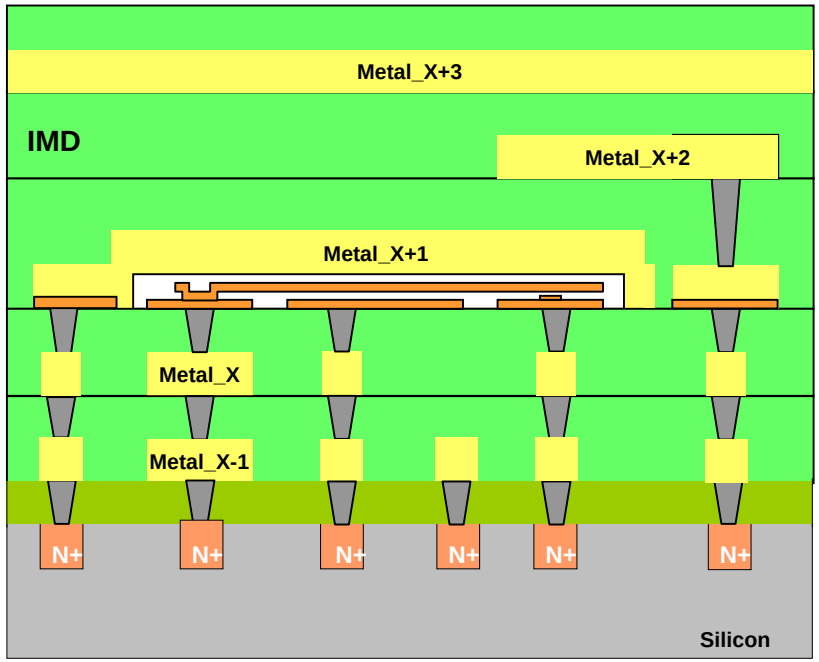


Bulk Micro Machined

Surface Micro Machined



Integrated into metal stack of any IC using standard equipment and materials

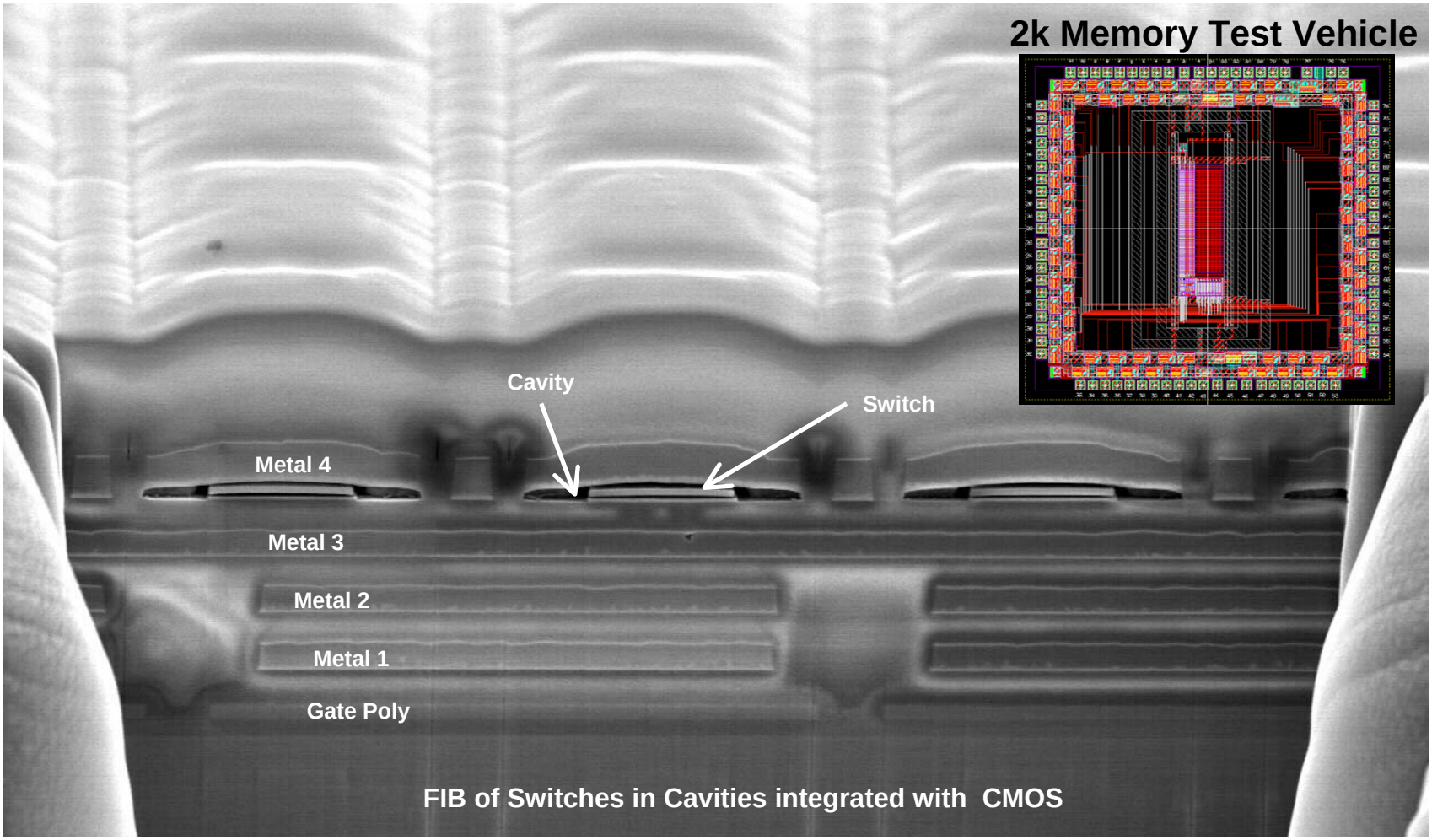


Built into Existing CMOS

Traditional Approach vs. NanoMech Technology

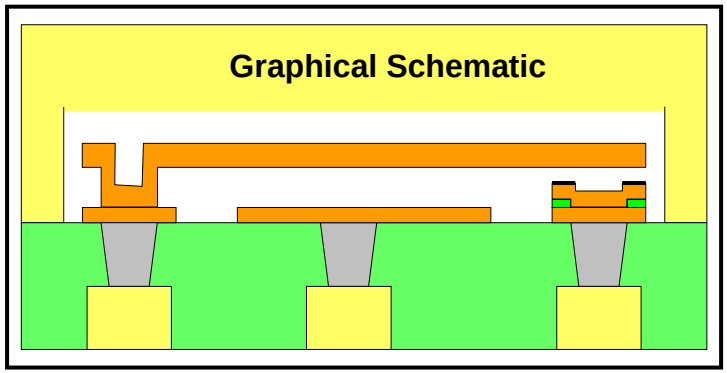
Cavity Embedded in CMOS

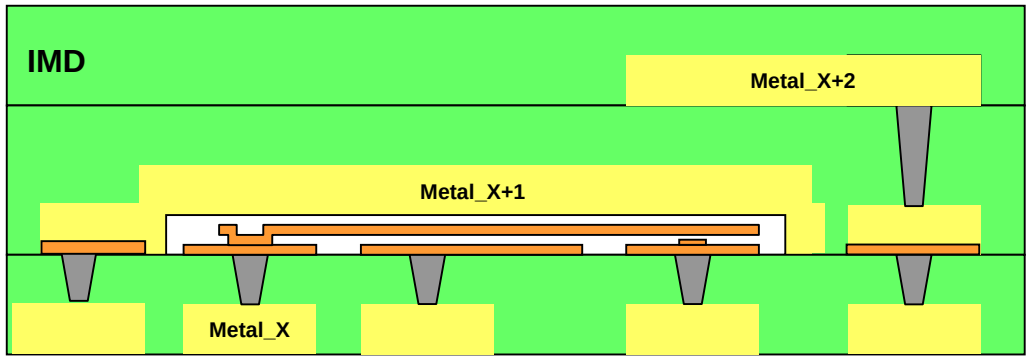
Array of Cavities with Switches on 4LM CMOS



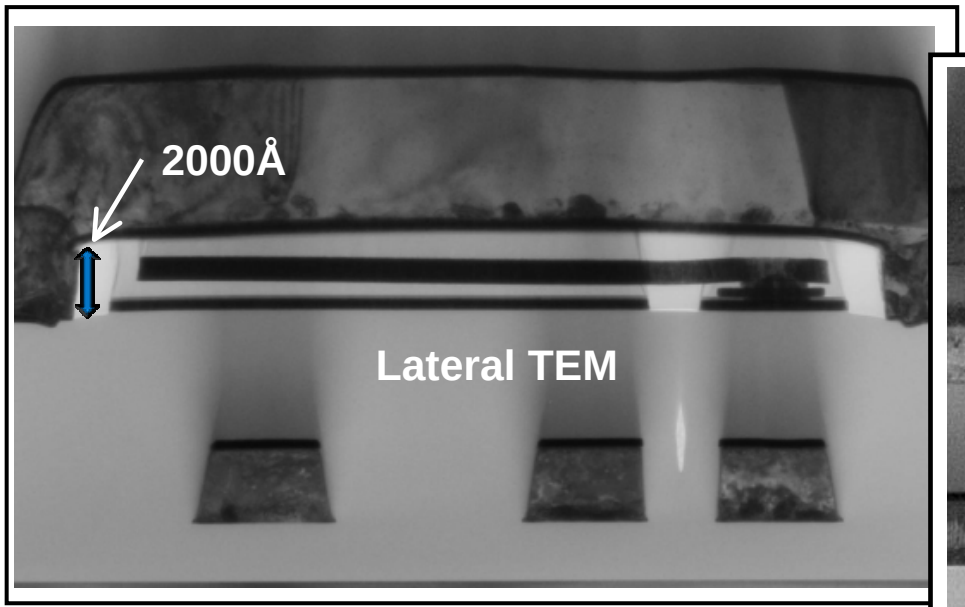
NanoMech Switch Fully Integrated into Interconnect

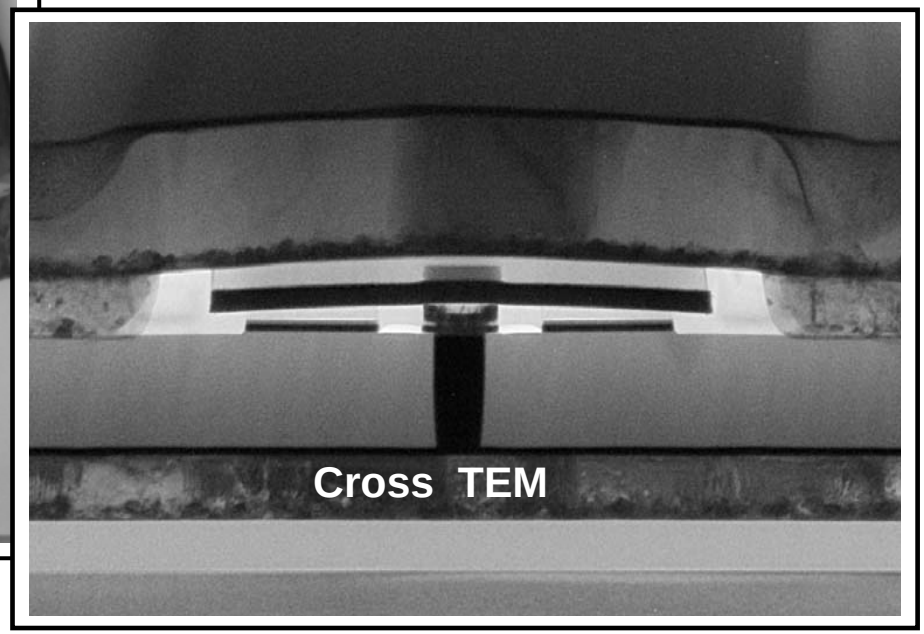
Device Integrated into Chip





Integrates into Standard Flow





Integrated into Standard CMOS, No Unique Packaging

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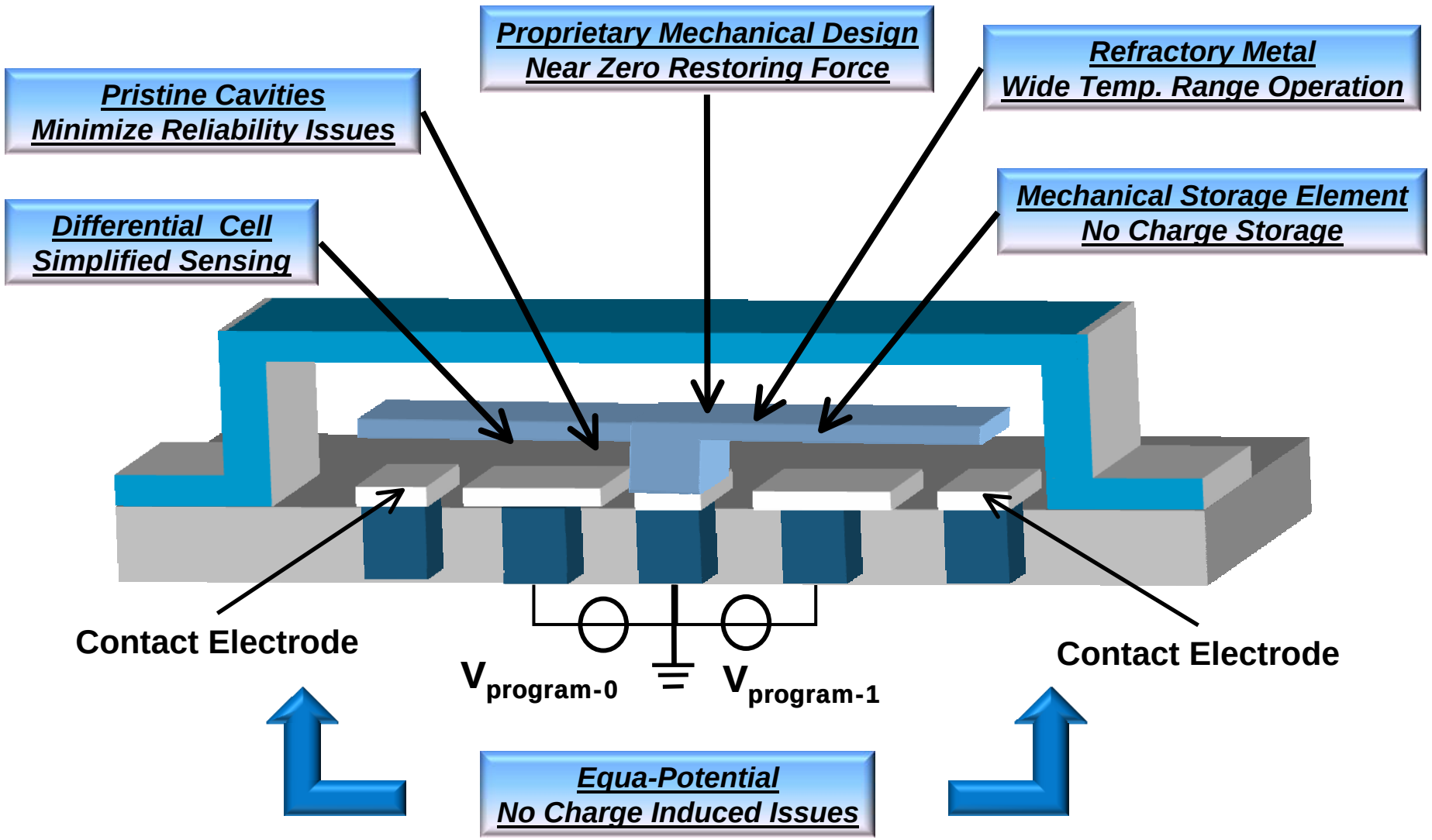
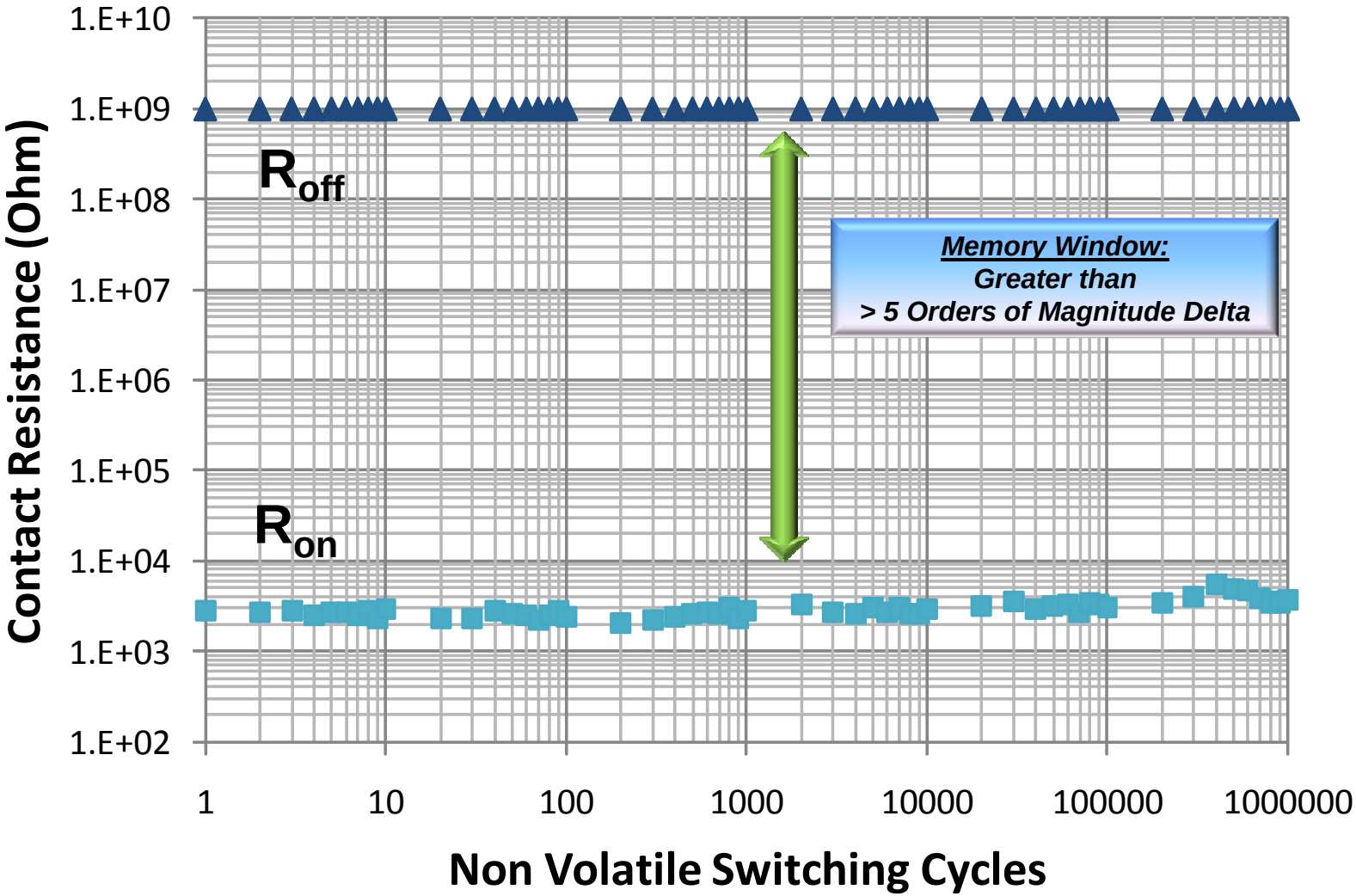
Elements of Non Volatile Switch
Harsh Environment Operation



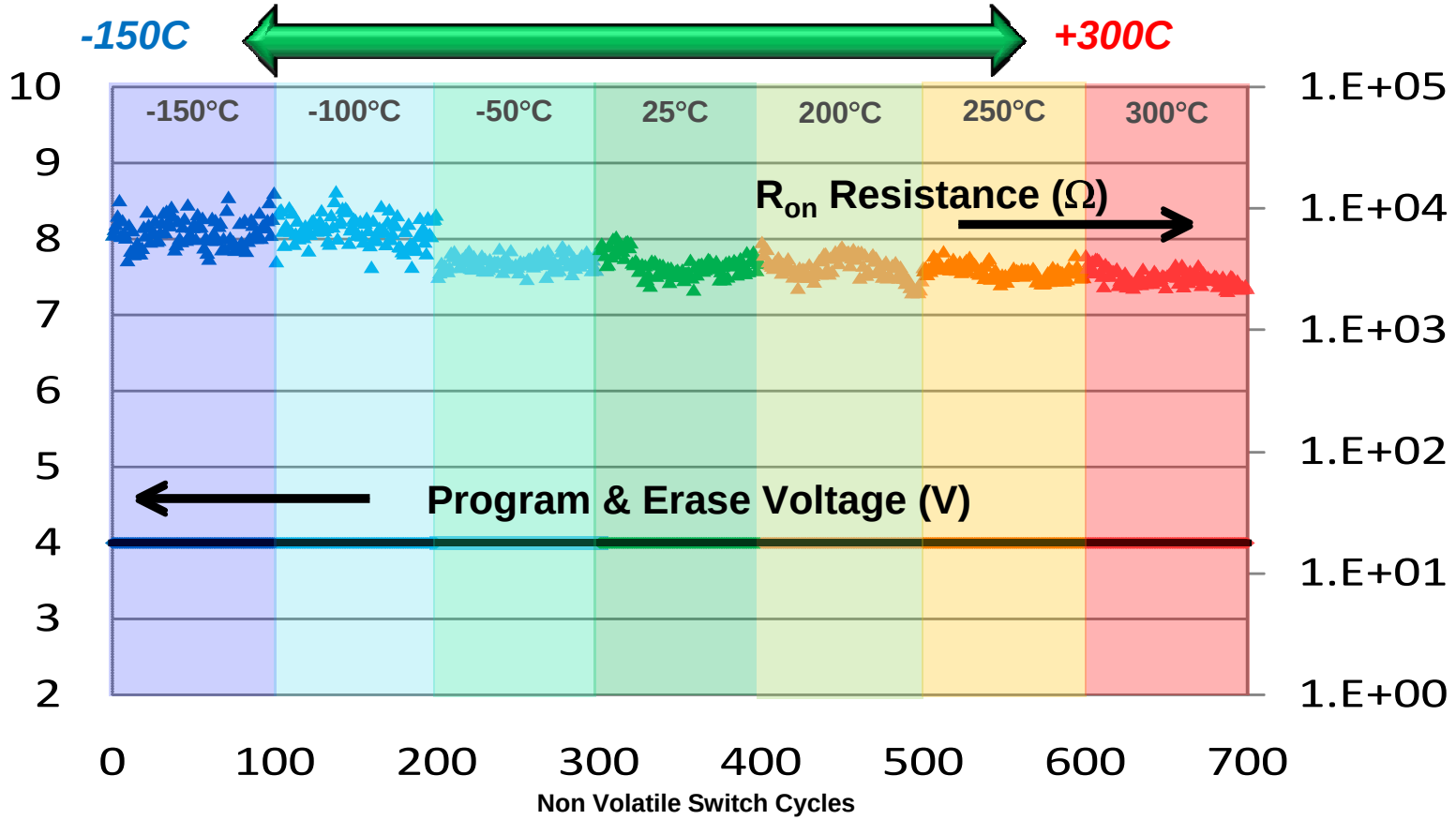
Extended Life Operation

Harsh Design



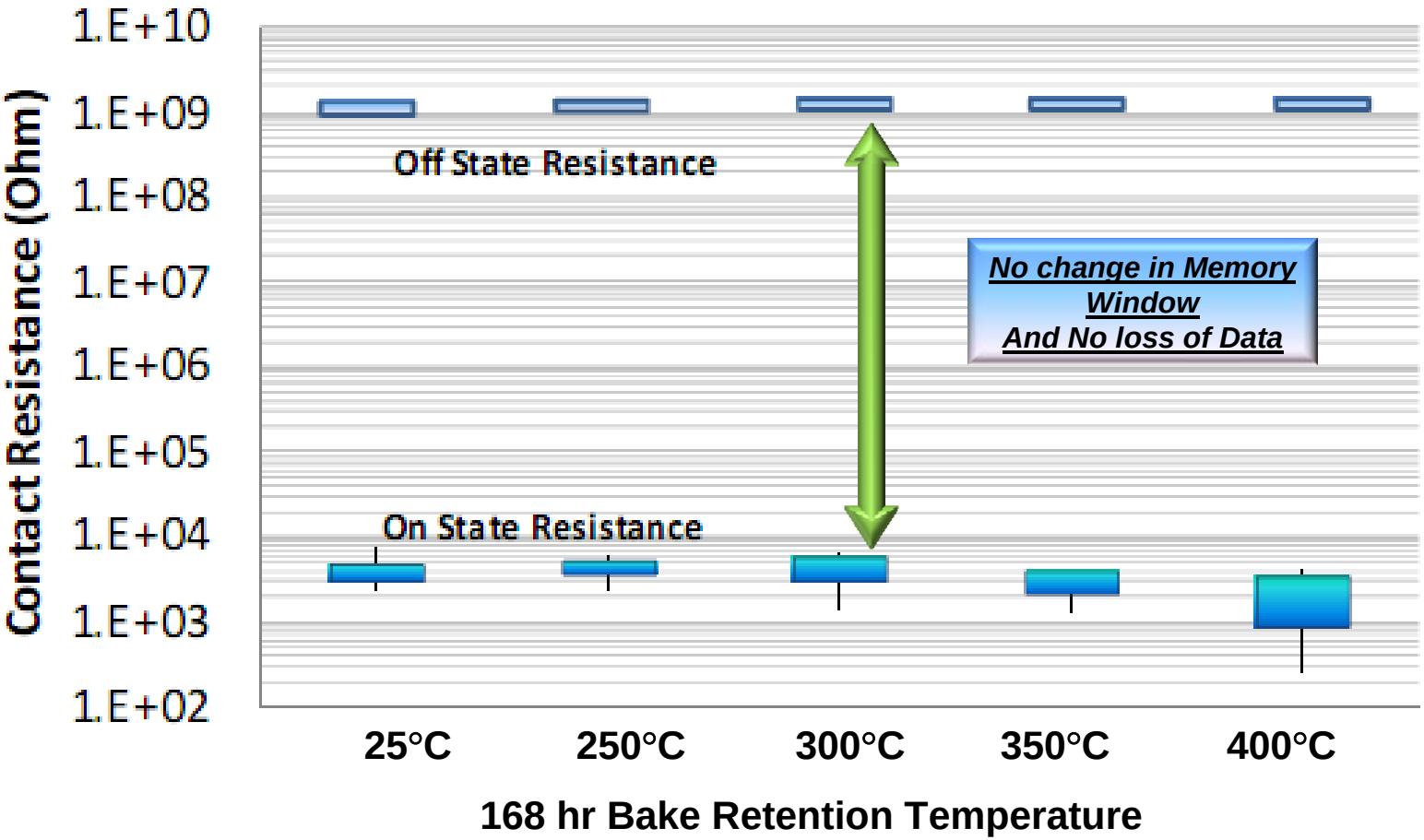
Temperature Performance

Harsh Design



Core Technology – Robust and Very Stable

Data retention and memory window
(168hr Bake Retention)



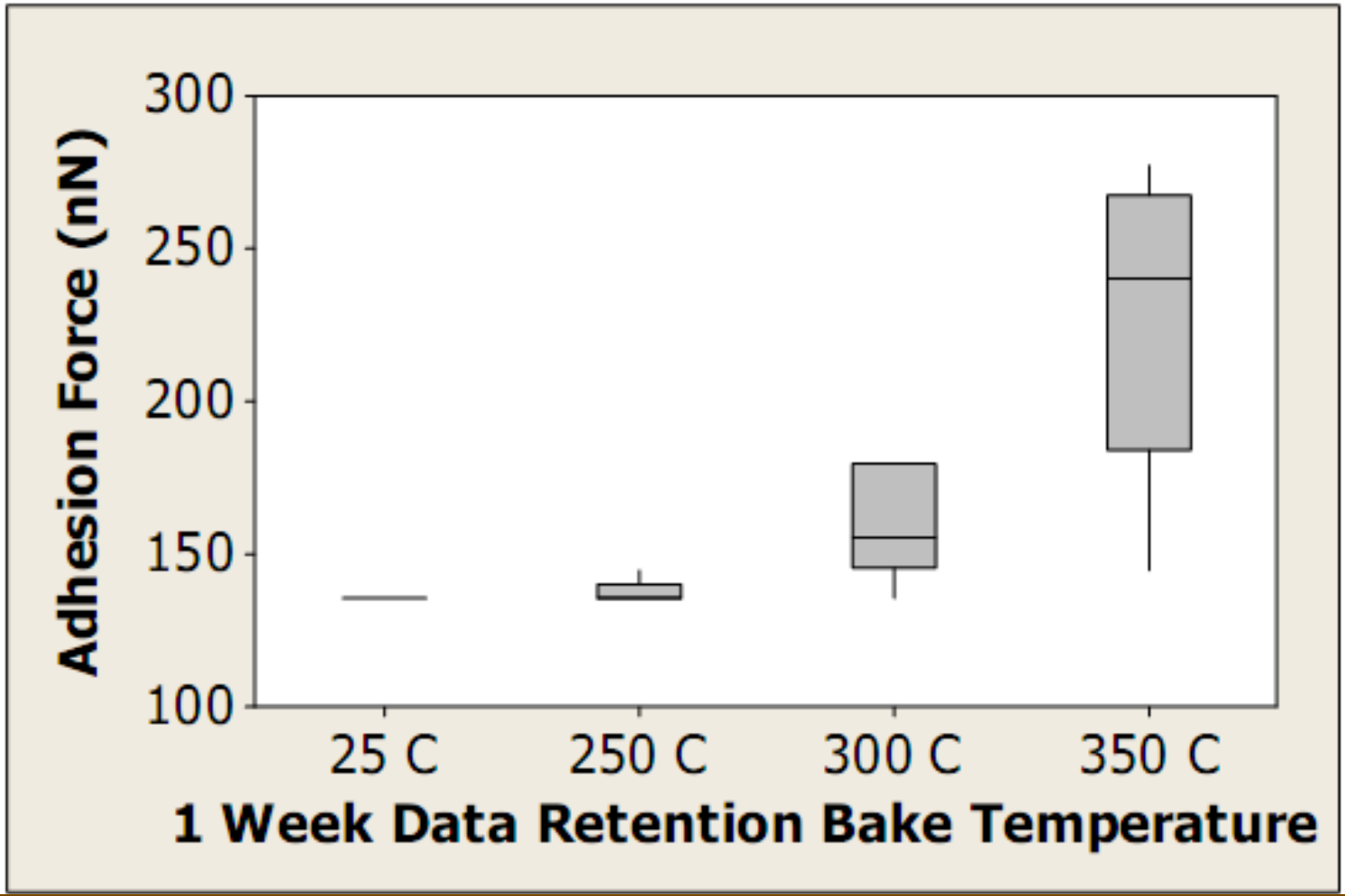
Adhesion grows at 350°C and Greater

Failure Mode

- **The only failure mode observed is increase in stiction between the cantilever and contact interface, primarily at higher operating temperature.**

- **This implies that the bit may fail as:**
  - failure to erase or
  - failure to re-program, but
  - never any loss of data

Adhesion Force of Metal Contacts
vs. 168 hr Bake Retention Temperature



Test data showed, once cycled after temperature, adhesion force was as original 25°C value

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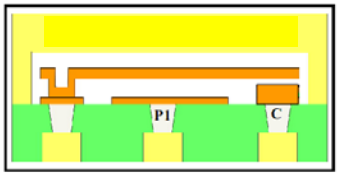
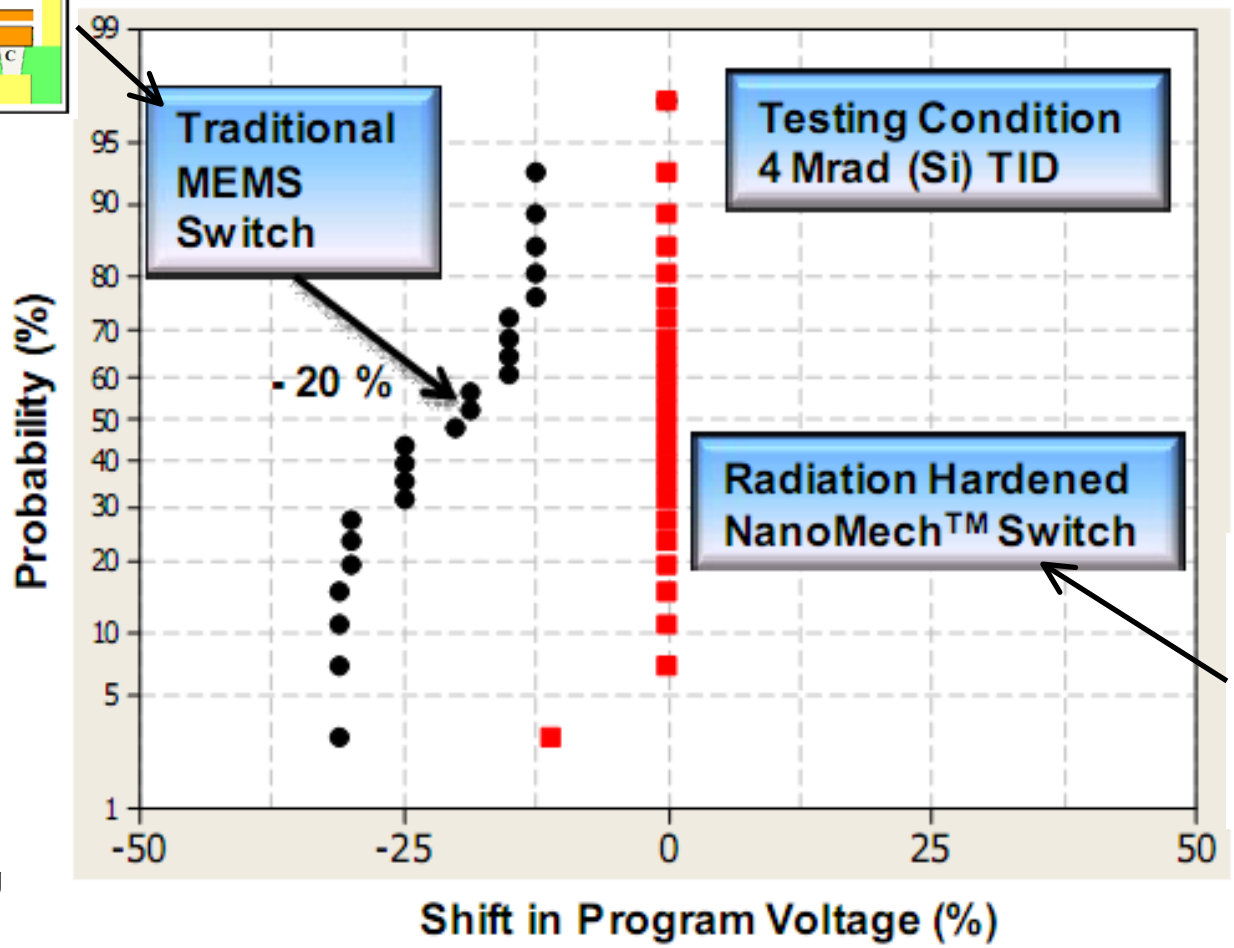
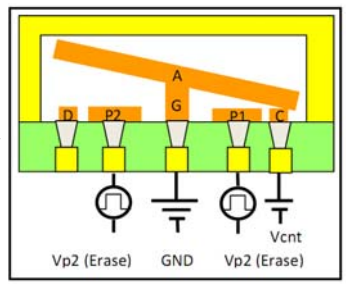
Effect of Radiation on Device

Standard cantilever vs. Harsh Env. Design







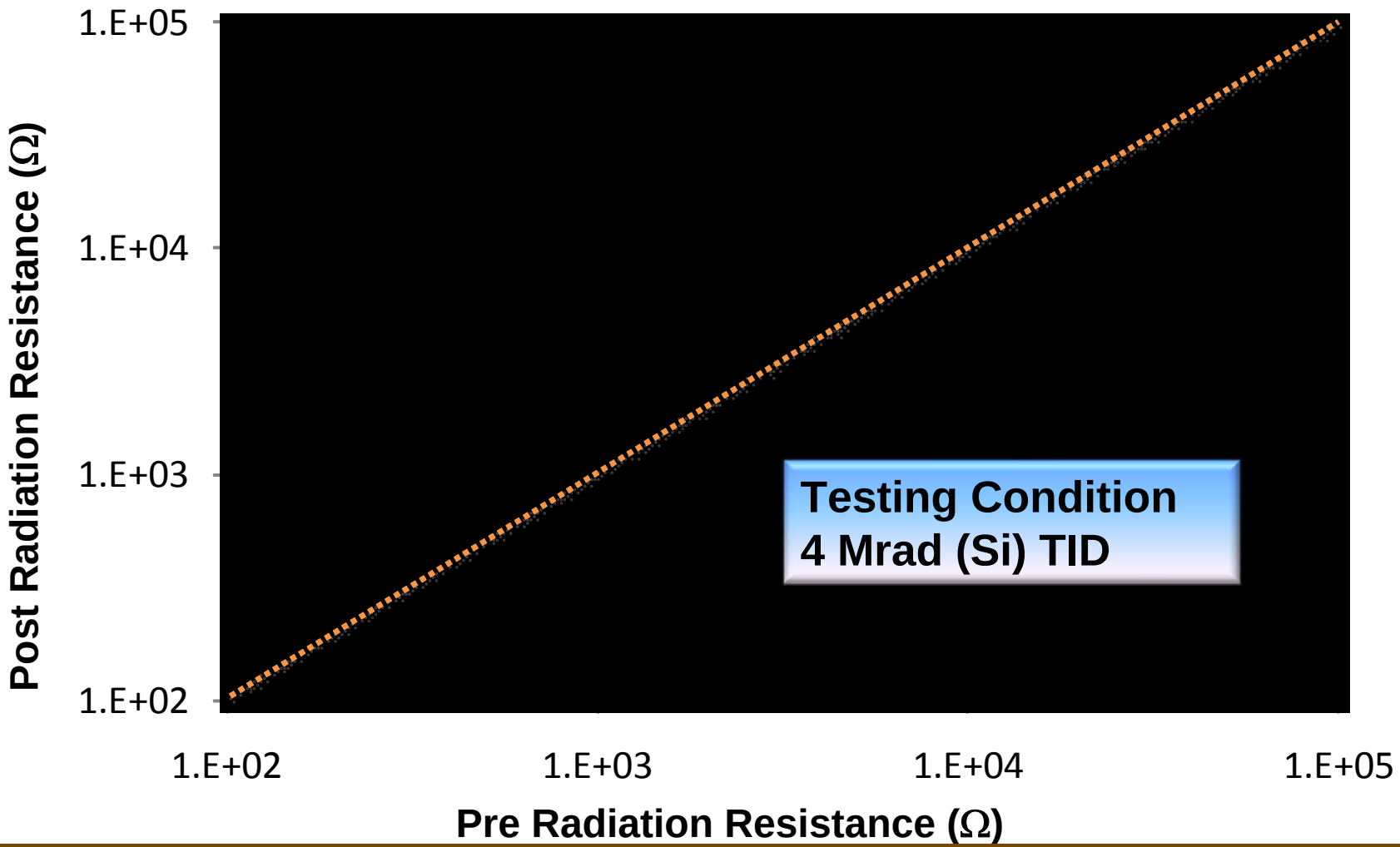
Test Details:

- **4Mrad TID (Si)**
- **Cobalt 60**
- **389 Minutes**
- **5.5 cm Spacing**

Radiation has no impact on Harsh Environment Design
But does Impact Traditional cantilever

Radiation Hardness

Harsh Design Performance



No impact on Resistance due to Radiation

NanoMech™ Specs For Non Volatile Memory

Parameters	Specifications
Operating Voltage	Native voltage (eg. 1.8V to 5 V)
Write Current	Electrostatic device; baseline CMOS current
Standby Power	Non-volatile memory; baseline CMOS power
Write Time	< 200 ns
Read Time (NDRO)	< 20 ns
R_{on} versus R_{off} Range	Five orders of magnitude
Endurance	>1 Million Cycles
Retention	>10 years (power off)
Operating Temperature Range	-150°C to + 300°C
Storage Temperature	-200°C to + 350°C
Shock Survival	>> 50,000 G
Total Dose Hardness	> 4 x 10^6 rad (Si)

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NanoMech Applications

Electrical Componets

- ***Non-Volatile Switches***
- Integrated RF Components
  - *Programmable Variable Capacitors*
  - Low Impedance Switches
  - Programmable Filters
  - Integrated Resonators
  - Phase Shifters
- Metal Logic
- I/V Switch in Interconnect
  - Signal routing
  - Power switching

Other Applications of Technology

- Display
  - Pico Projector, Light Modulator
- Focal Plane Array
- CMUT
  - Ultrasonic sensors
- Inertial Measurement Sensors
  - Drop sensor
  - Accelerometer
- MEMS needing 3rd Gen Packaging

Wide Range of Applications that Can be Enabled

Conclusions

- **Cavendish Kinetics has developed a robust, low voltage, non-volatile memory using standard CMOS interconnect processing**
- **ROCKER tested for 1 million switches, cantilever tested to 100 billion switches**
  - No sign of performance degradation
- **Could also be embedded in the back end of other material systems such as Bipolar, GaAs, GaN, SiC etc**
- **Reliability was demonstrated from -150 ºC to +300 ºC**
  - Extendable based upon MEM Design
- **Non-volatile memory reliability was also demonstrated under radiation doses of 4Mrad (TID (Si))**