SAND2007-4368P

Sandia MEMS Technologies Overview

Dr. Keith Ortiz, Manager
MEMS Technologies, Department 1749
Sandia National Laboratories

Presented to Lockheed Martin Space Systems Company
Advanced Technology Center
Palo Alto, CA

July 10, 2007

LOCKHEED MARTIN

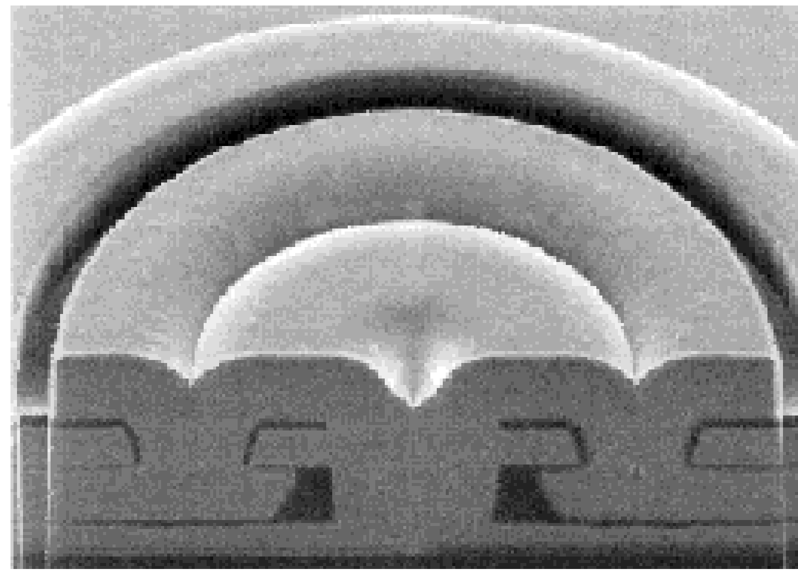
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

About This Presentation

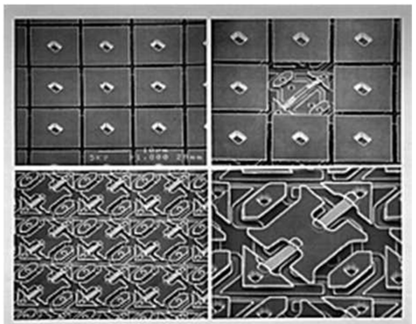
- **Sandia has the world's finest capability for microelectromechanical system (MEMS) process development, design exploration, and prototyping**
- **The purpose of this presentation is:**
  - To familiarize you with Sandia's MEMS technologies
  - To stimulate your imagination about the potential of MEMS
- **Outline**
  - Brief Description of MEMS today
  - Explain Sandia's Baseline MEMS Process: Summit V™
  - Describe Further Capabilities
  - Suggest Future Directions

Sandia MEMS Technologies Overview: Outline

- **Brief Description of MEMS**
- Explain Sandia's Baseline MEMS Process: Summit V™
- Describe Further Capabilities
- Suggest Future Directions

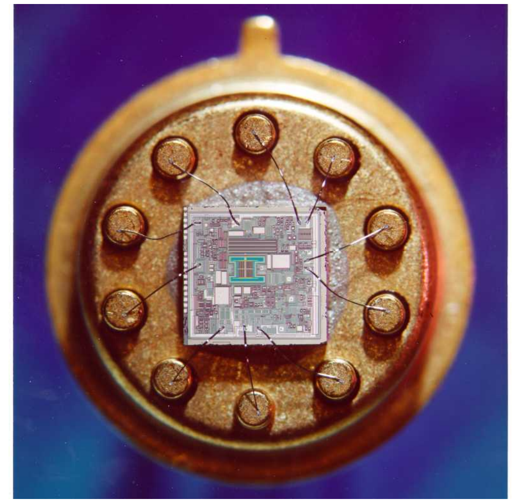


Commercial applications of MEMS are taking off!

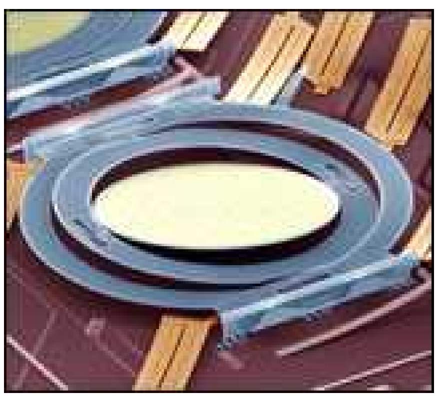


Digital Mirror Device
Texas Instruments

Ink Jet Cartridge
Hewlett Packard

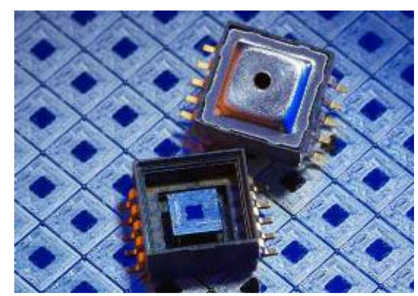


Accelerometer
Analog Devices



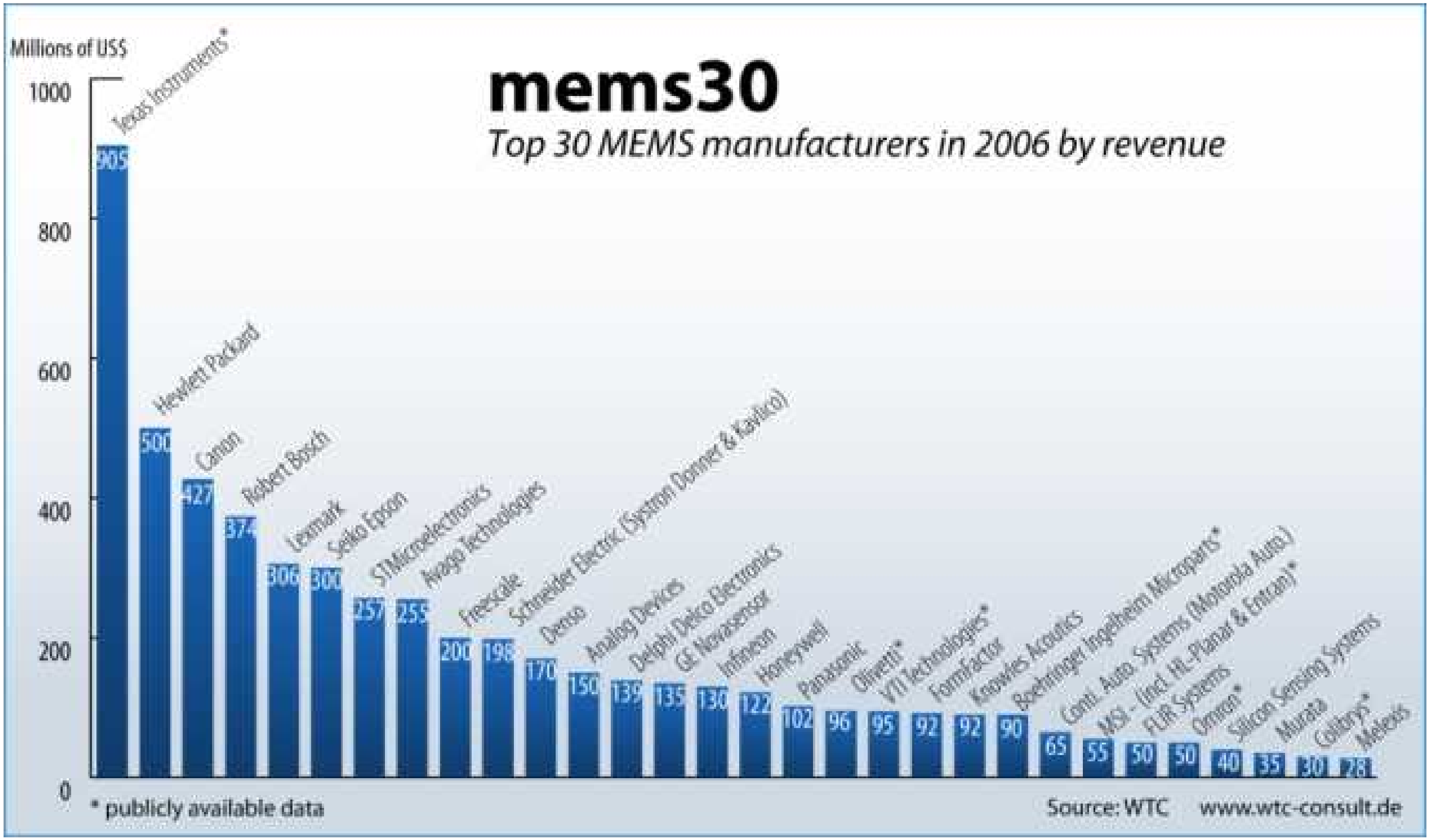
Micromirror switch
Lucent Technologies

Coming Soon:
- Microphones
- RF Switches
- Oscillators, Filters
- Microfluidics
- Biotechnology
- Nanotechnology



Pressure Sensor
Bosch MEMS

Top MEMS Manufacturers in 2006



http://www.memsinvestorjournal.com/2007/04/ranking_of_top_.html#more

LOCKHEED MARTIN

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Fundamental Process Steps

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

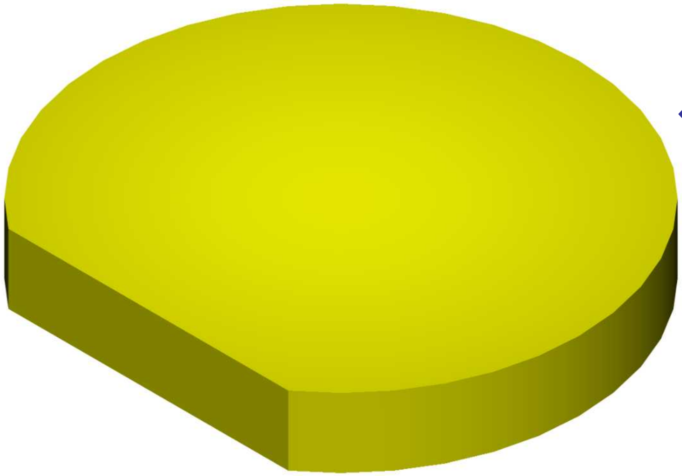
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Deposition | **Lithography** | **Etching**

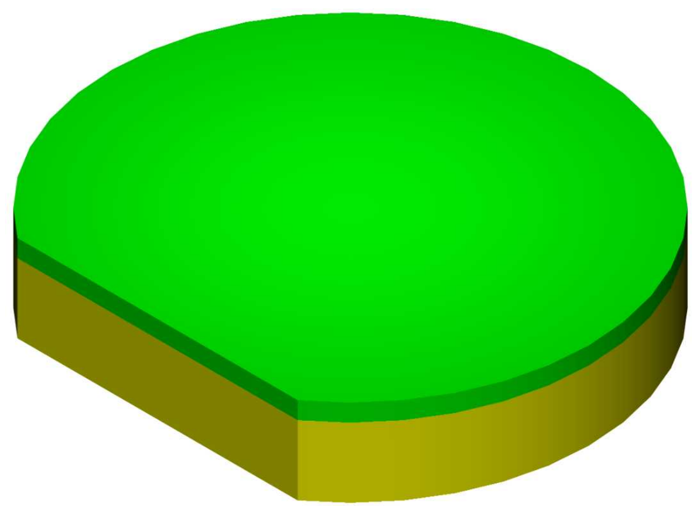
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Example One Layer Process (1)

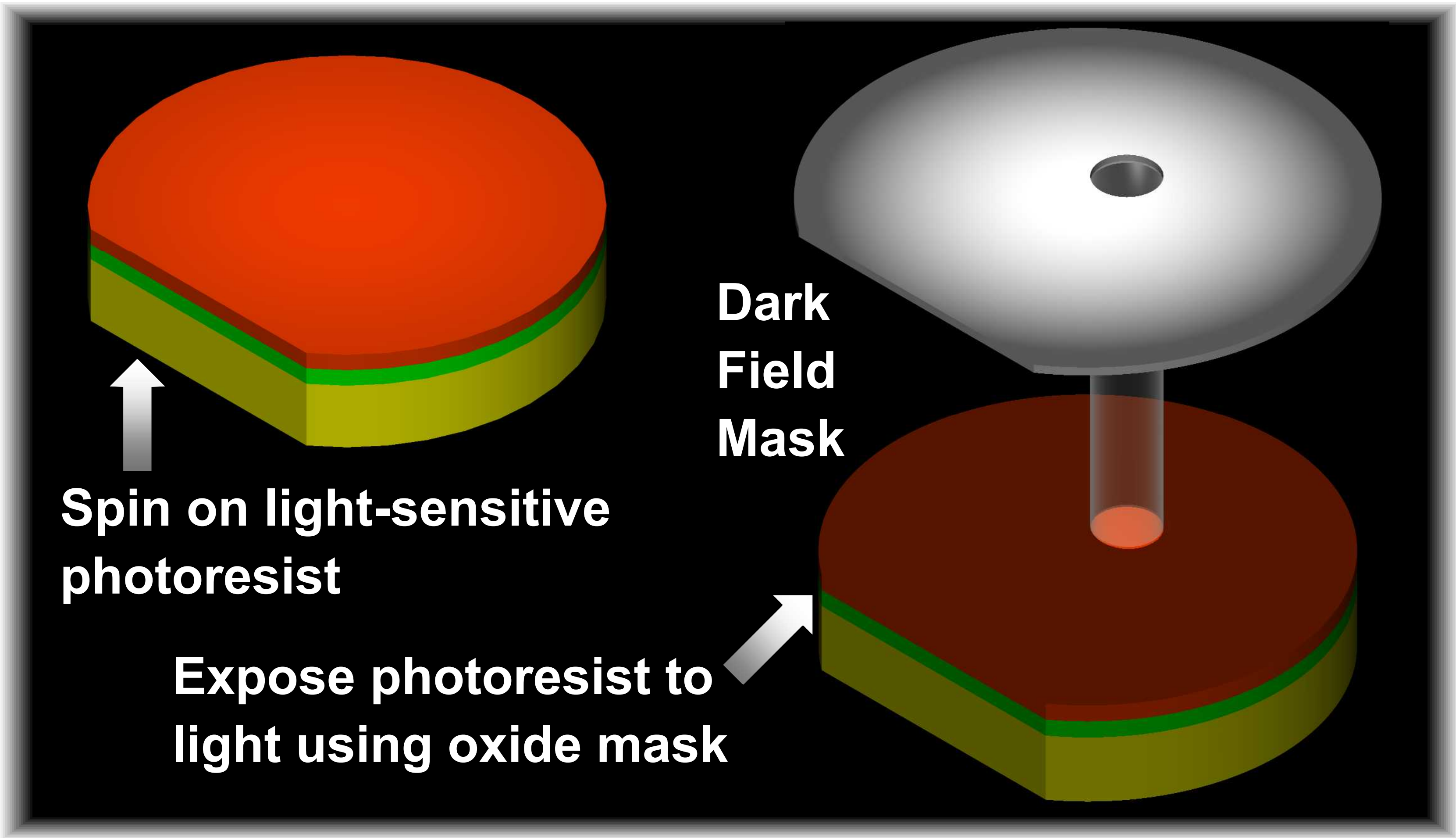


Start with single-crystal silicon wafer

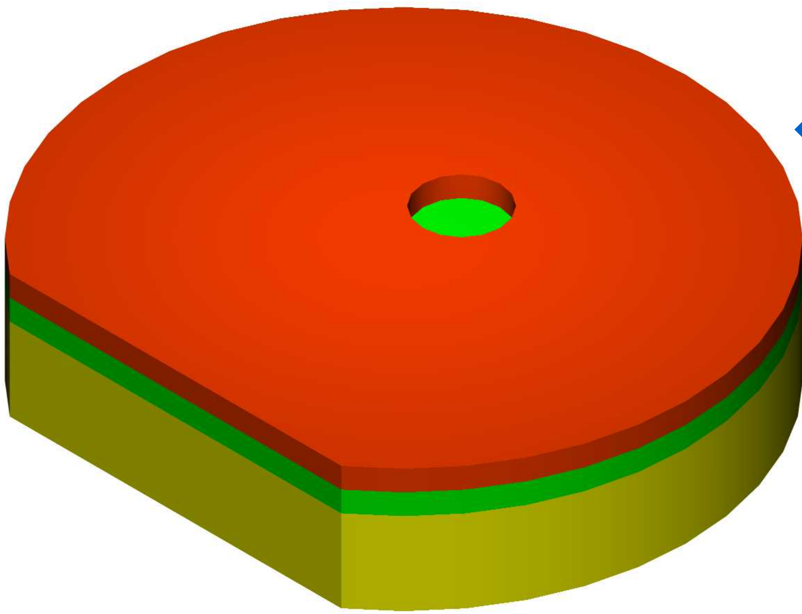
Deposit layer of sacrificial oxide



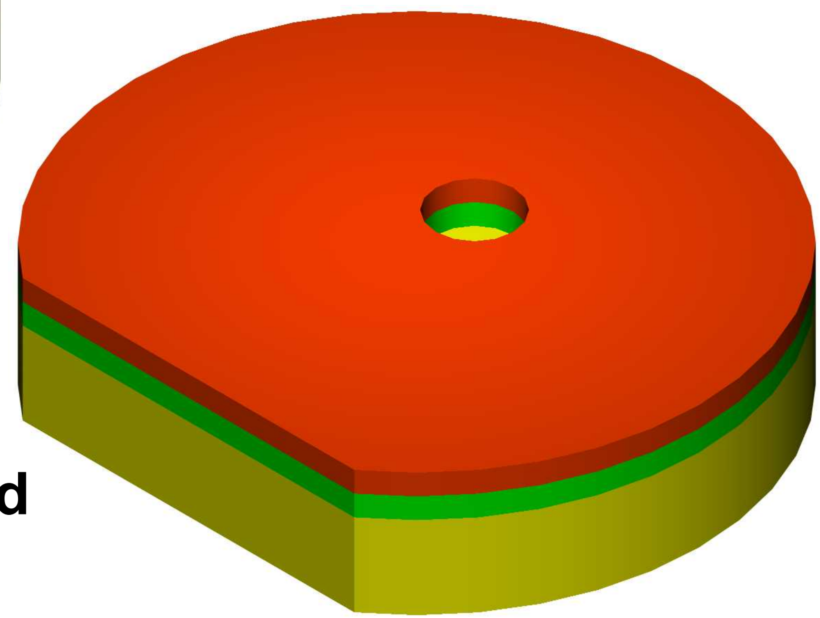
Example One Layer Process (2)



Example One Layer Process (3)

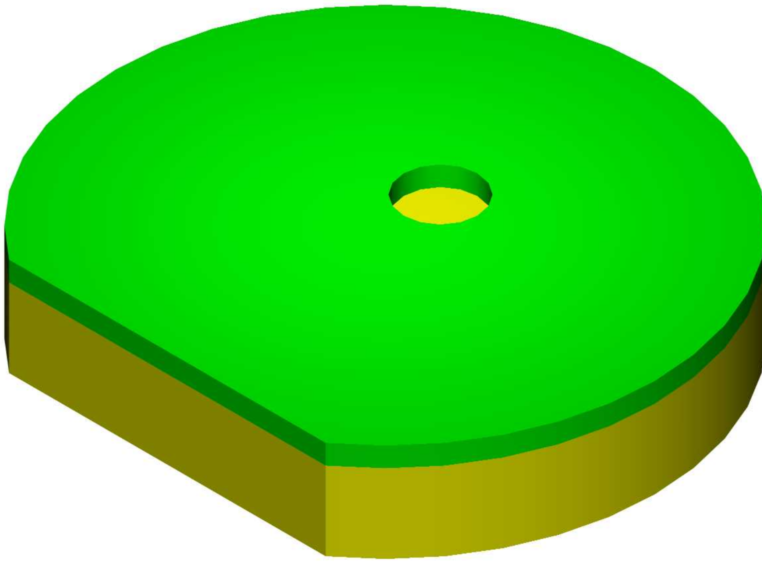


Develop photoresist

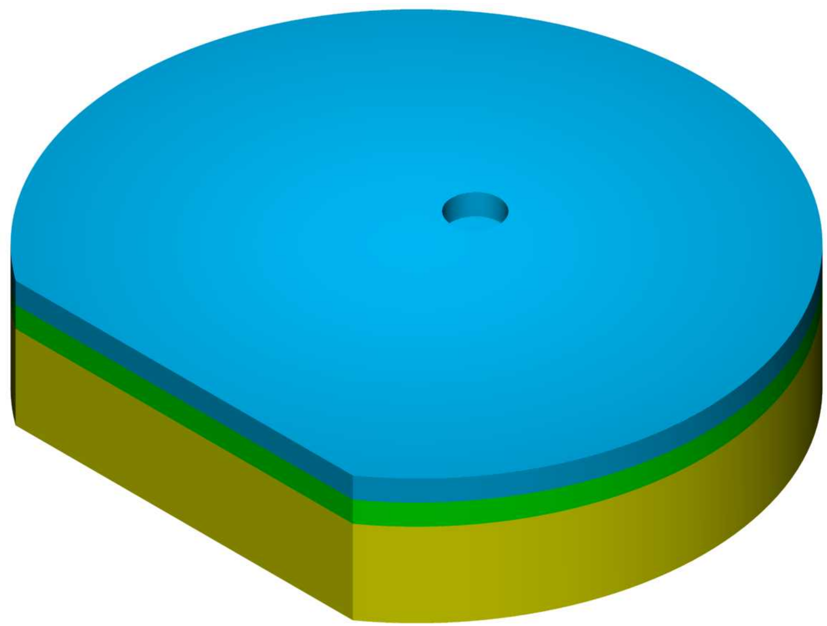


Etch away
oxide <u>not</u> protected
by photoresist

Example One Layer Process (4)

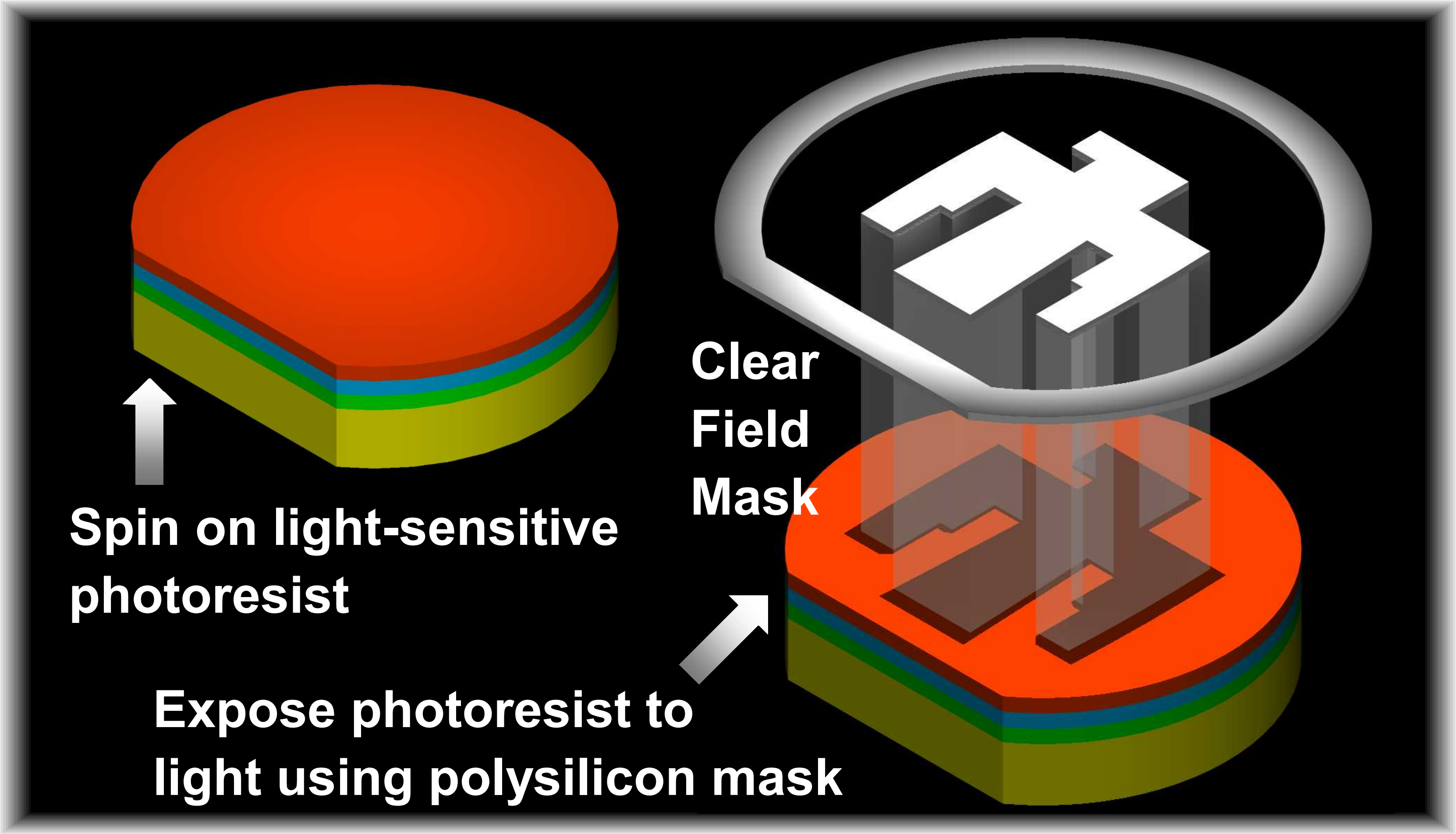


Strip off photoresist

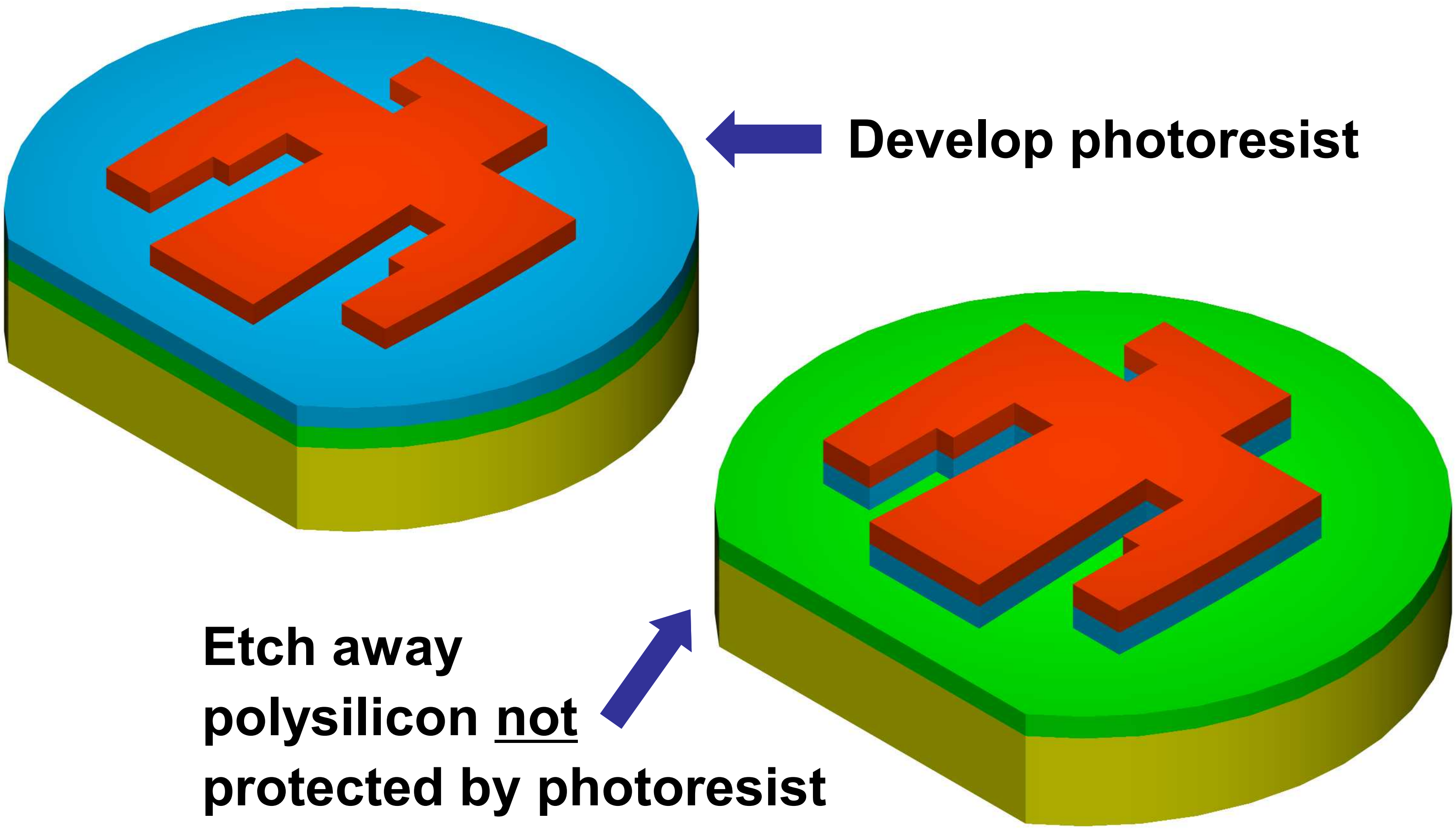


Deposit conformal layer of polysilicon

Example One Layer Process (5)



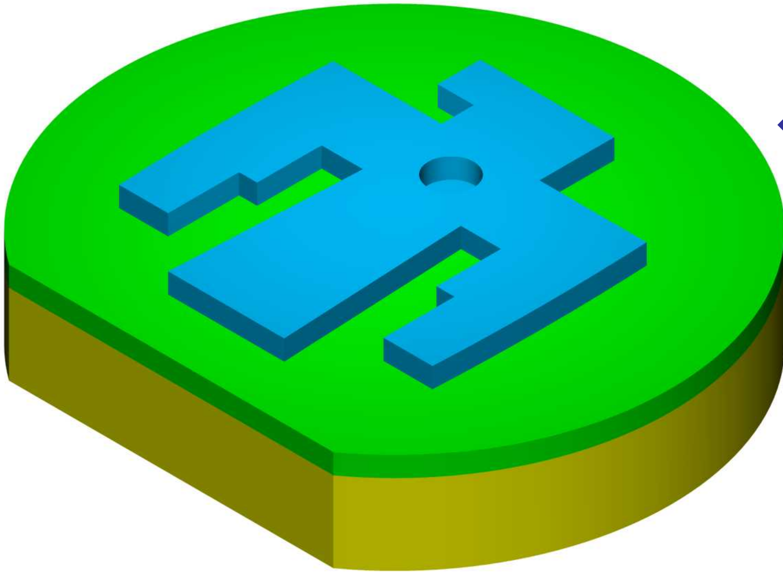
Example One Layer Process (6)



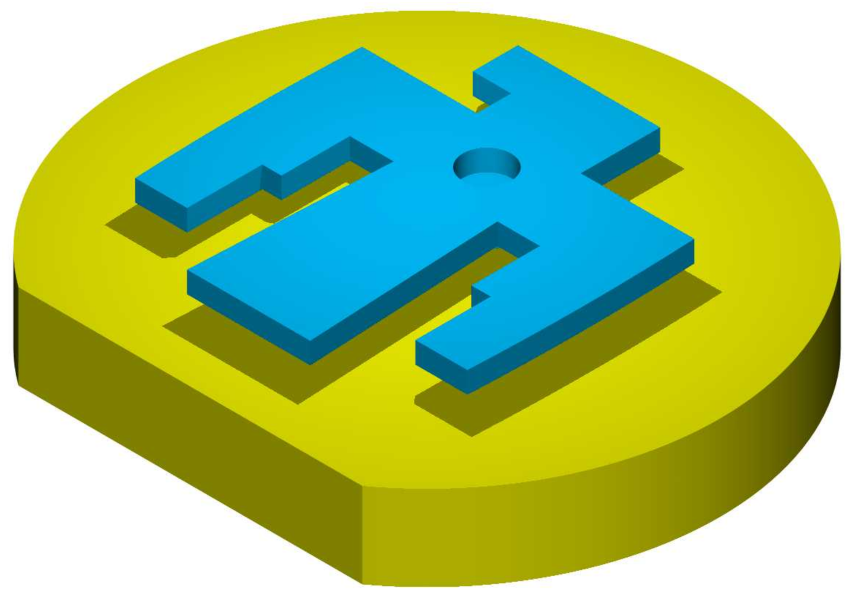
Develop photoresist

Etch away polysilicon <u>not</u> protected by photoresist

Example One Layer Process (7)



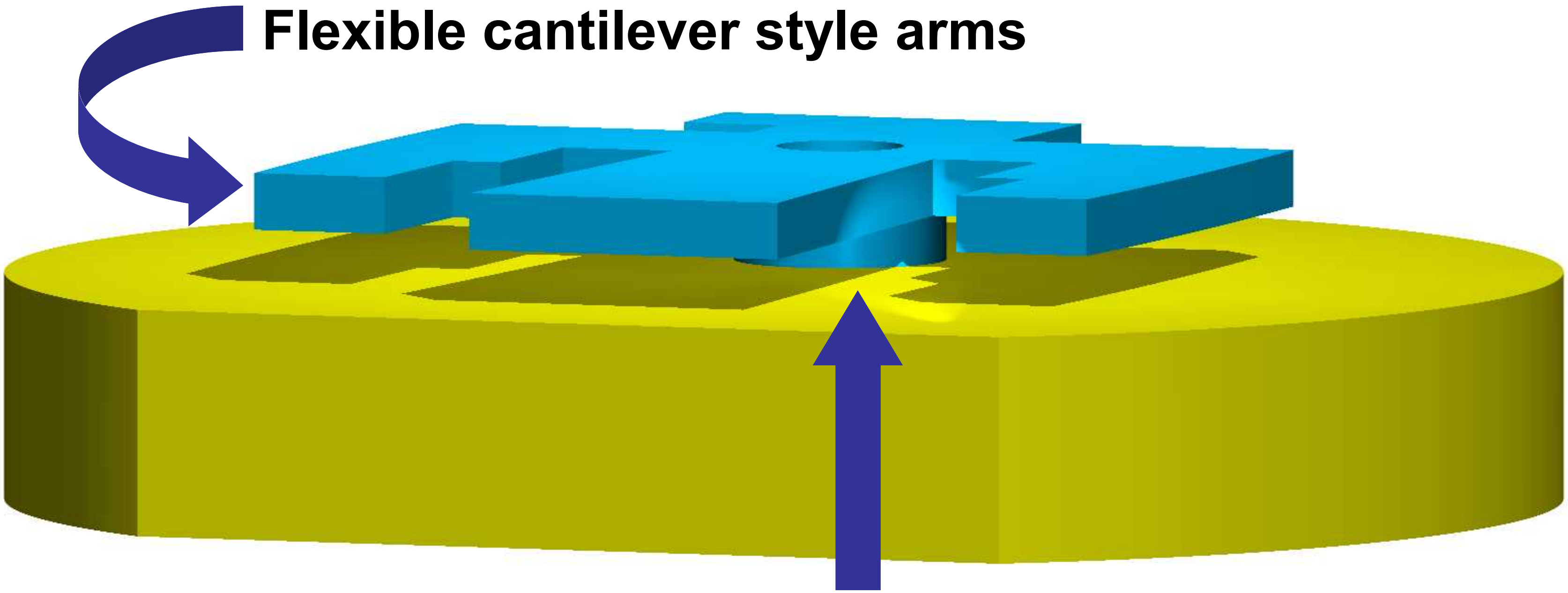
Strip off photoresist



Etch away sacrificial oxide to complete

Example One Layer Process (Final Product)

Flexible cantilever style arms



Hole in oxide created anchor post

Bulk Micromachining

Wet Etch Pressure Sensors for Automobile Tire Inflation

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Surface Micromachining

Three-level, Multi-User MEMS Process (MUMPS™)

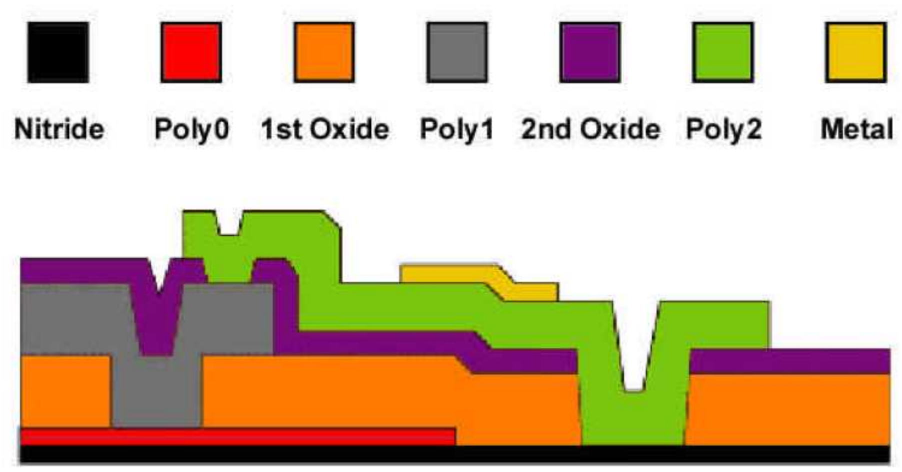


Figure 1.1. Cross sectional view showing all 7 layers of the MUMPs™ process (not to scale).

MUMPs Design Handbook, Revision 5.0, Cronos Integrated Microsystems

Note: Poly0 is a ground plane required to prevent electrostatic attraction between structures and underlying substrate

Example: UCLA Micro Optics, 1996

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

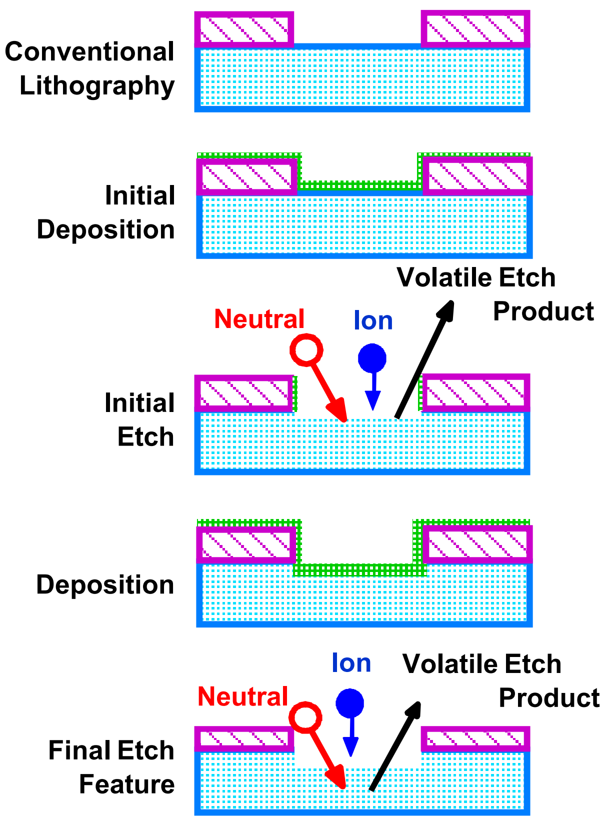
Laser, 3 Fresnel lenses, beam splitter, 45 degree mirror

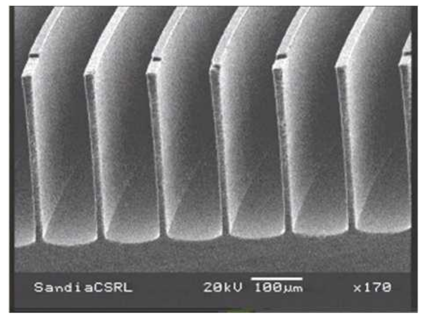
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

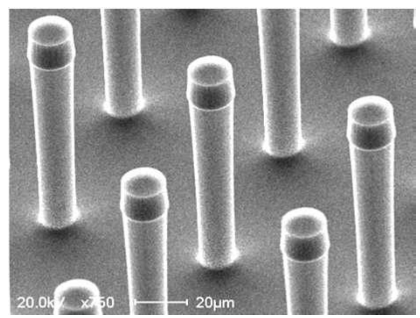
Deep Reactive Ion Micromachining

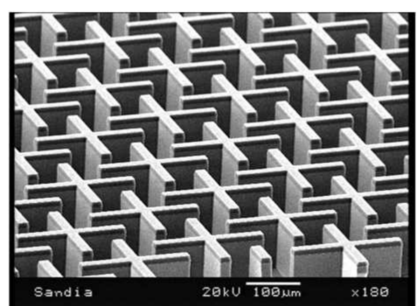
Bosch Etching (~1994)

Basic Process









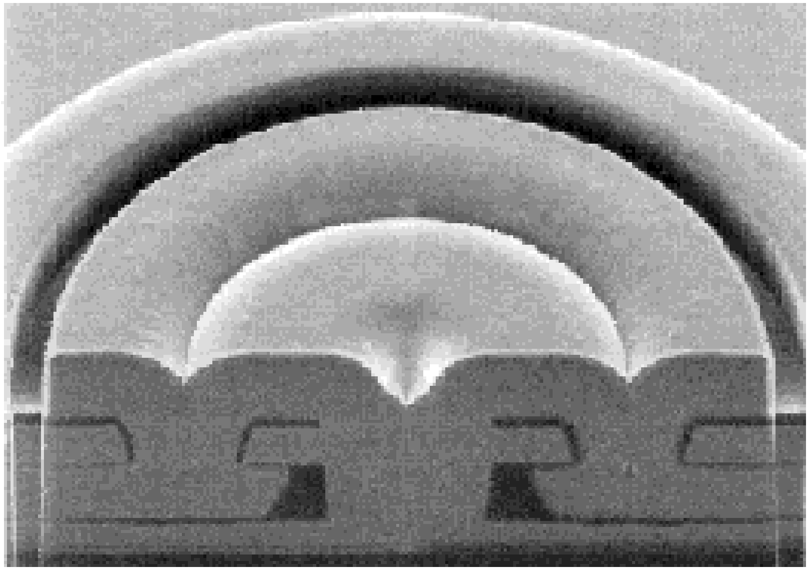
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

LOCKHEED MARTIN

Sandia MEMS Technologies Overview: Outline

- Brief Description of MEMS
- **Explain Sandia's Baseline MEMS Process: Summit V™**
- Describe Further Capabilities
- Suggest Future Directions



LOCKHEED MARTIN

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Motivation: Complex Mechanical Devices

Demanding additional levels and control of topography

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

LOCKHEED MARTIN

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Example: Six gear train

In-plane stability provided by flat guide plates on top of shafts

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

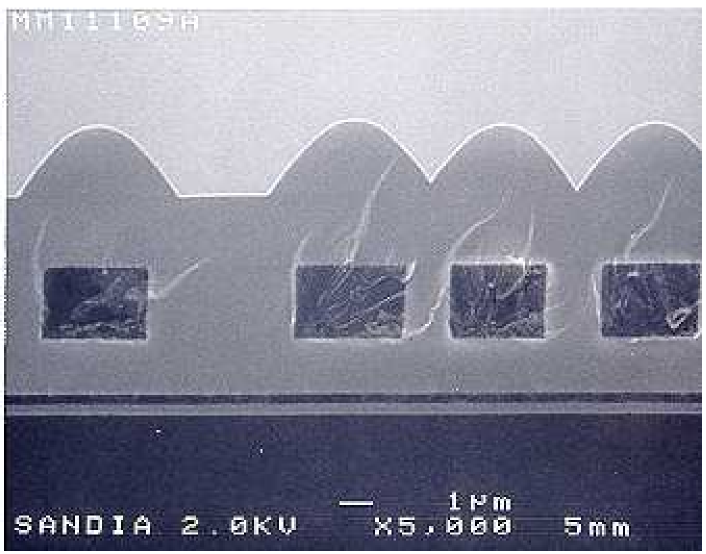
QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

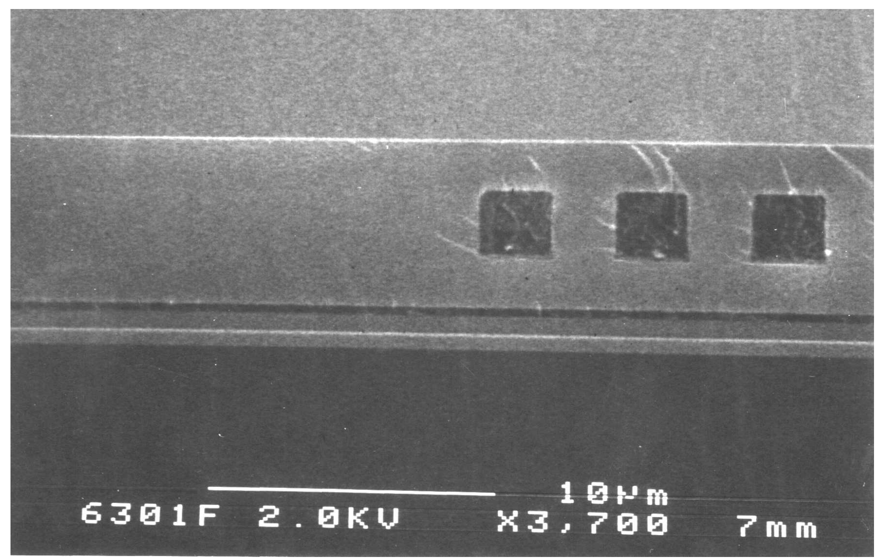
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Sandia's baseline technology is SUMMiT V™

Sandia Ultraplanar Multilayer MEMS Technology

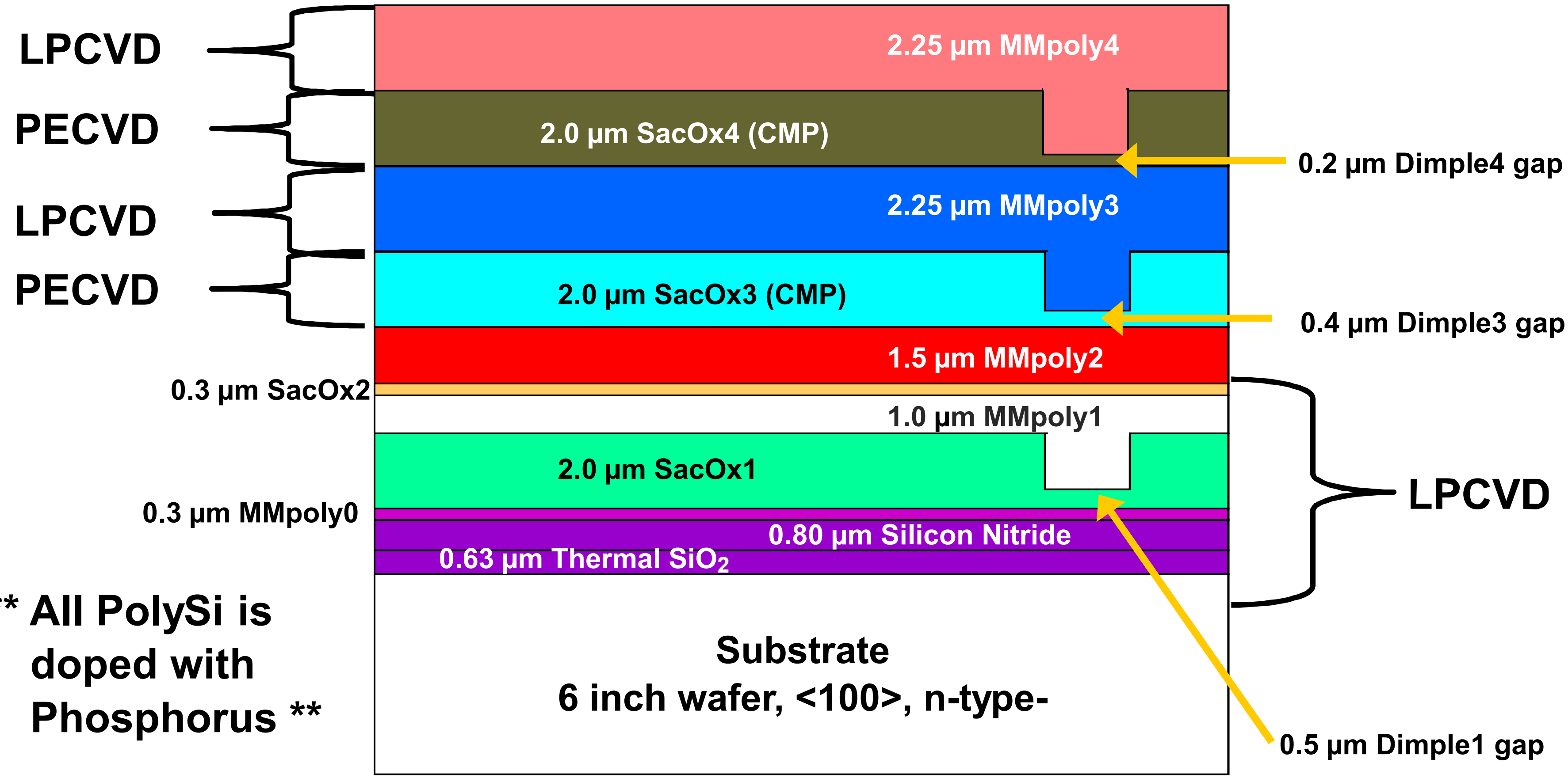
- **Five Layers of Polysilicon**
- **Chemical-Mechanical Polishing (CMP)**
  - SacOx3 and SacOx4
- **Annealing to Reduce Residual Stresses**





LOCKHEED MARTIN

SUMMiT V™ Layers

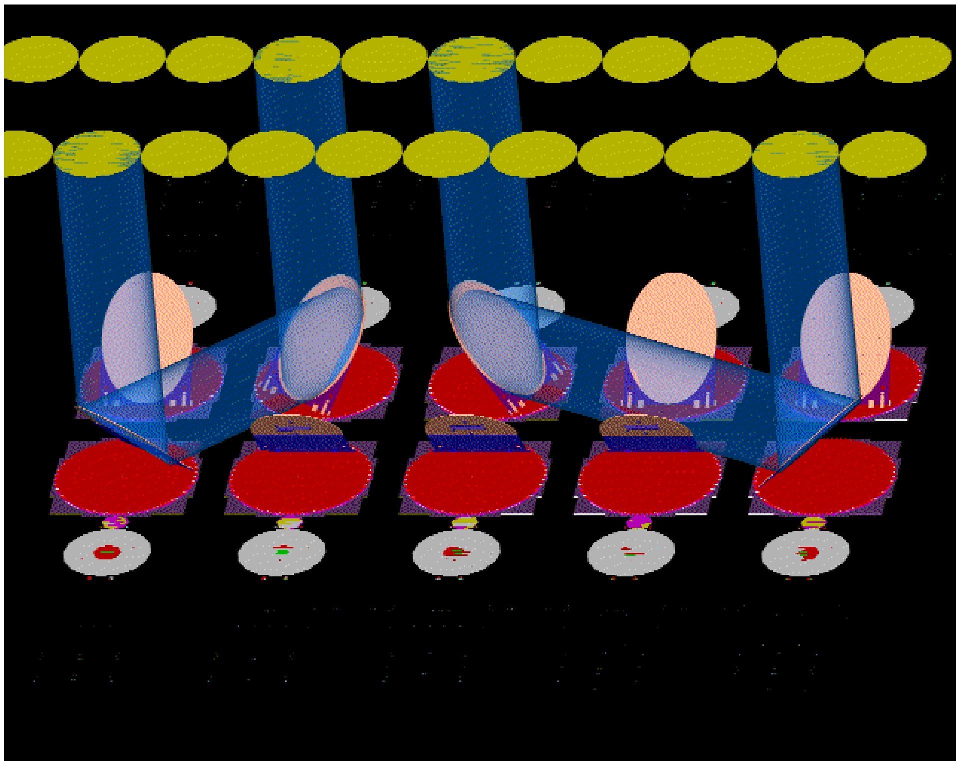


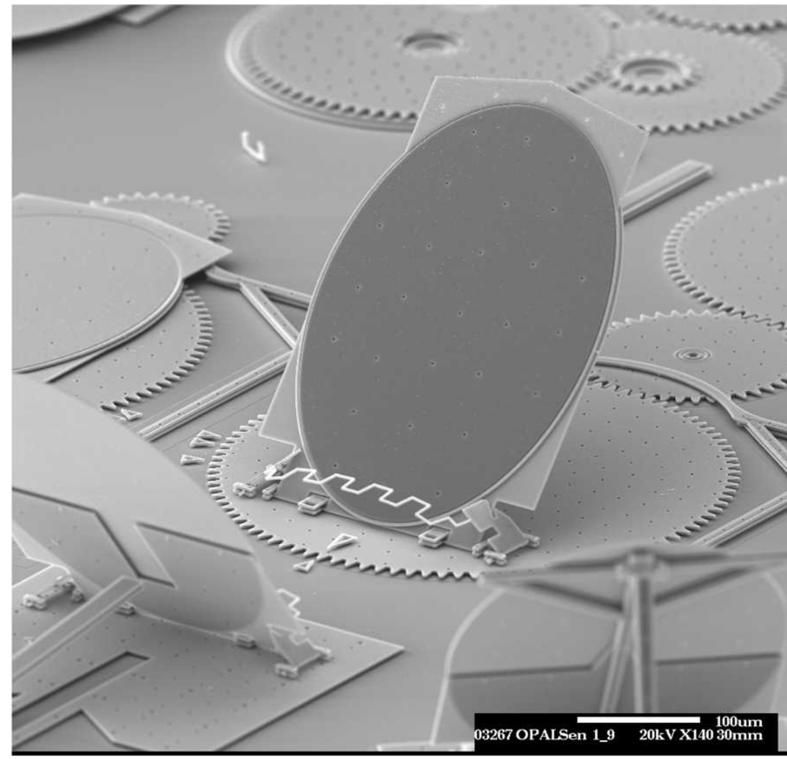
** All PolySi is doped with Phosphorus **

LOCKHEED MARTIN

Optical Programmable Array Logic (OPAL)

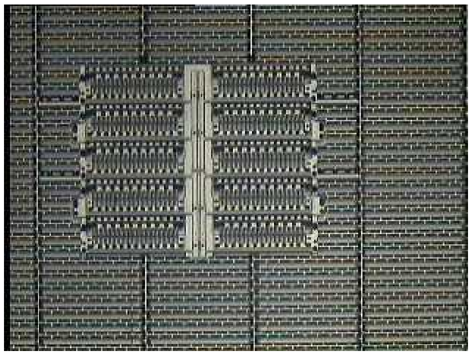
A Lockheed Martin Shared Vision Project





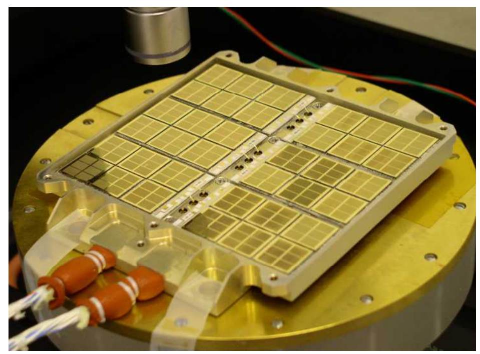
mSatellite MEMS Variable Emittance Louvers

2007 Lockheed Martin NOVA Award

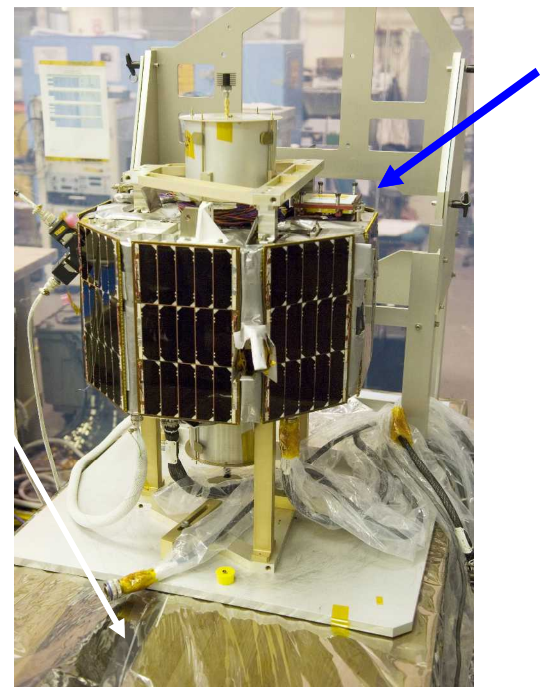


2592 SUMMiT V™ die
with Buried Interconnects

4”x4” Johns Hopkins/APL
Experimental Thermal
Regulator



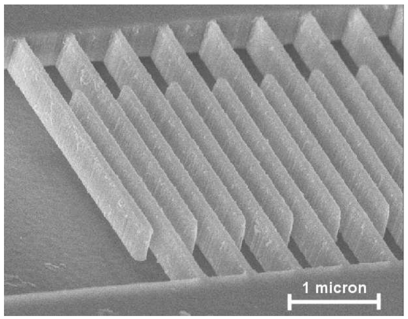
3 NASA/Goodard
ST5 Microsats
Launched 3/22/06

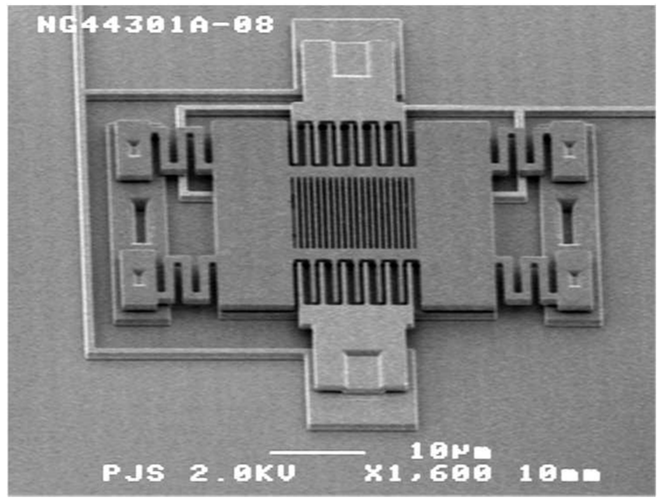


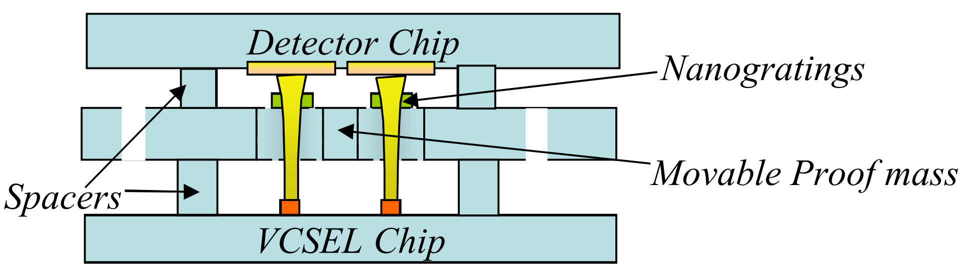
Experimental satellites
monitor space weather

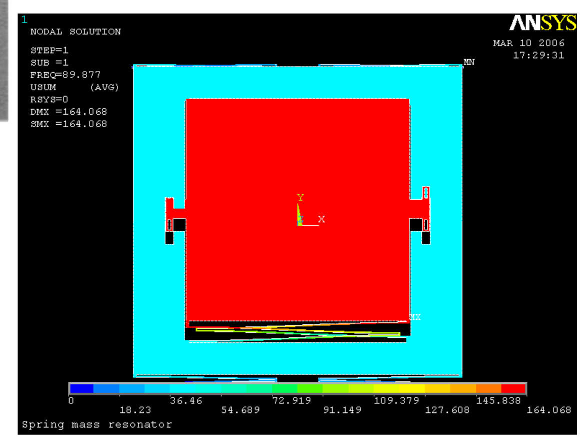
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Nanophotonic Gratings to Measure Nano-G Accelerations





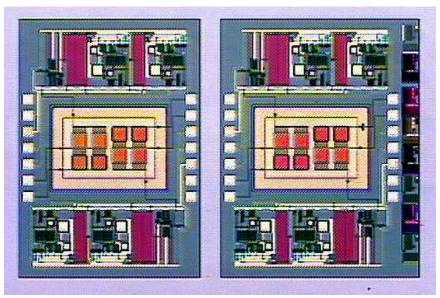




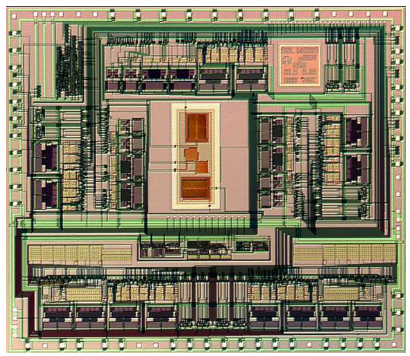
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Reliability Concerns Increase With Complexity

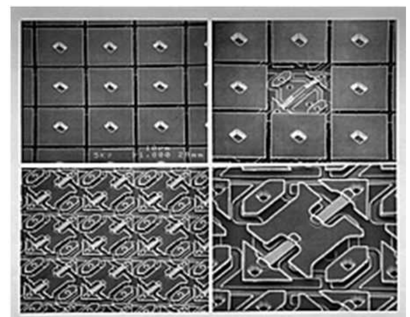
Class I
• No Moving Parts
e.g., Pressure Sensors



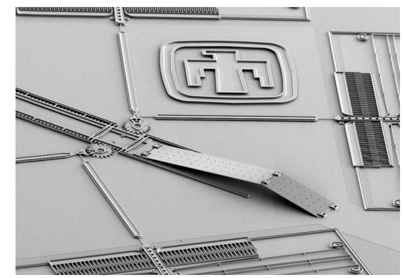
Class II
• Moving Parts
e.g., Accelerometers



Class III
• Moving Parts
• Impacting Surfaces
e.g., Tilting Mirrors



Class IV
• Moving Parts
• Impacting Surfaces
• Rubbing Surfaces
e.g., Gears

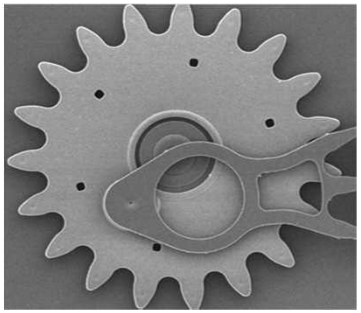


QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

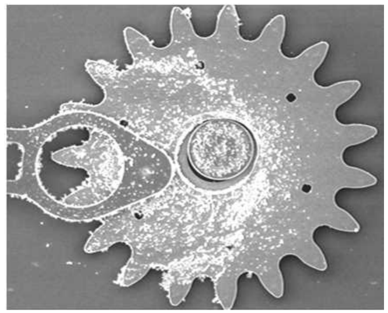
LOCKHEED MARTIN

Example Reliability Issues

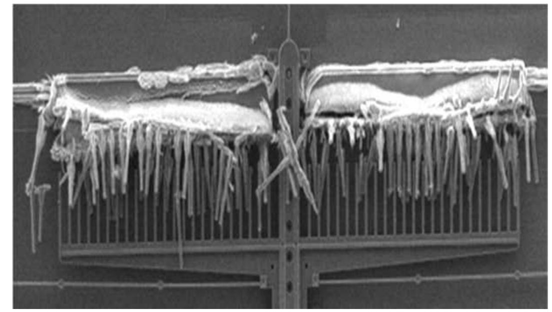
Silicon oxide wear debris



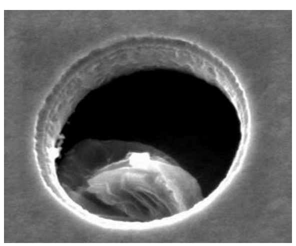
612,000 cycles
31% RH



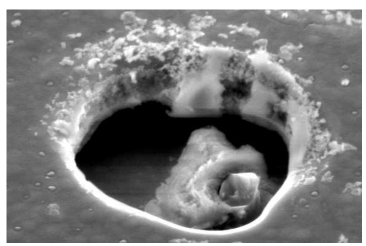
600,000 cycles
1.8% RH



Electrostatic Comb Drives
Anodic oxidation - 100V
+ 65% RH25° C, 10 days

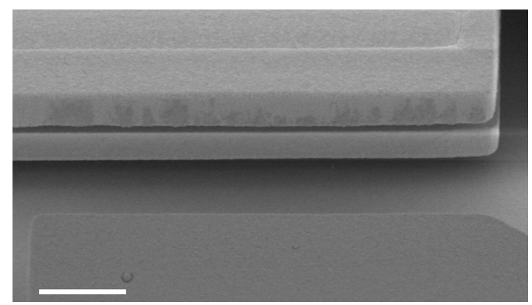


Unstressed Hole



Stressed Hole

Linkage arm pin joint under accelerated conditions

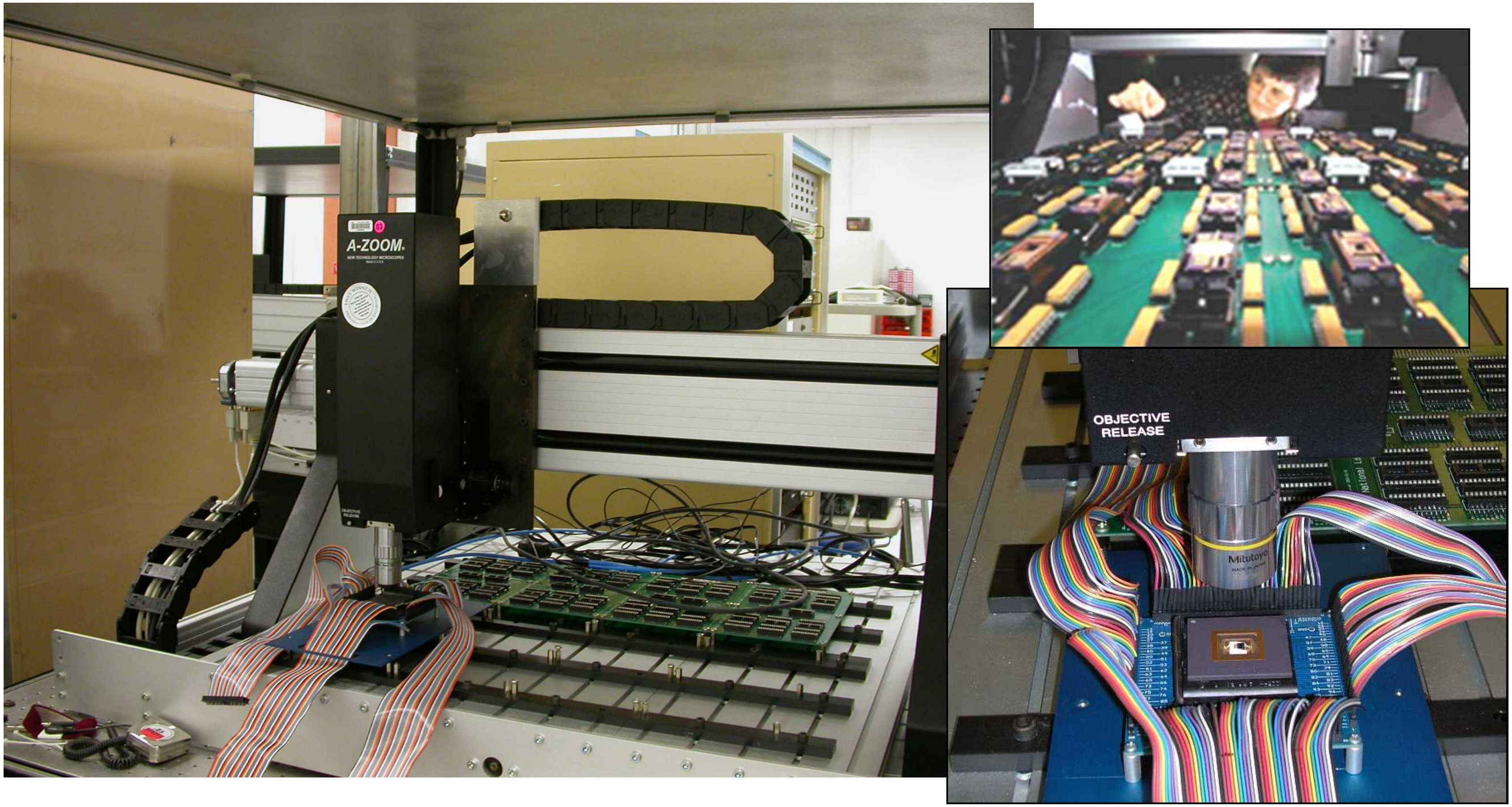


Electrical relay fails due to high resistance from friction polymer buildup on the contacts

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

SHiMMeR

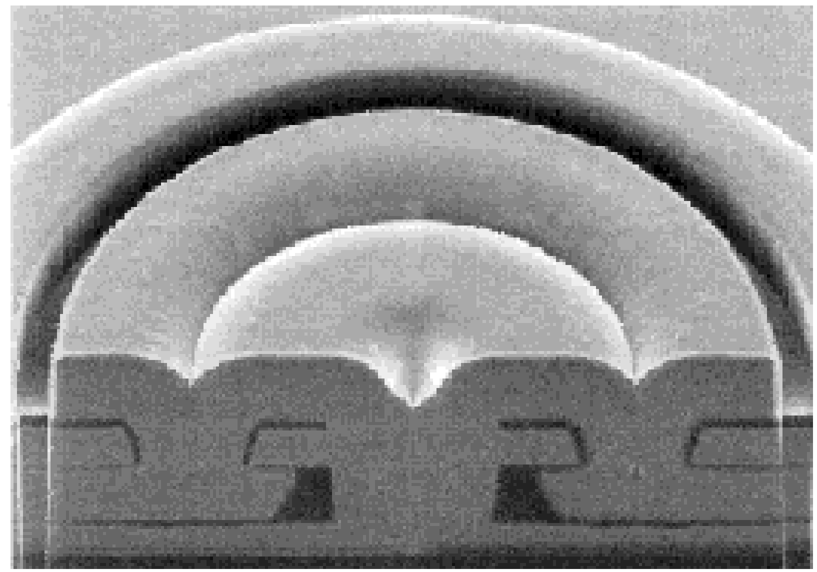
Sandia High M MEMS Reliability



QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

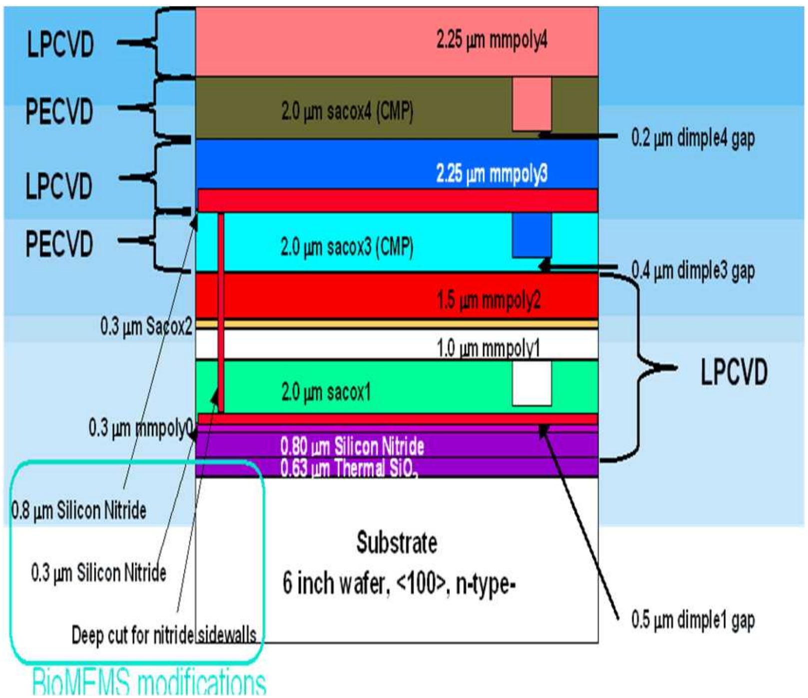
Sandia MEMS Technologies Overview: Outline

- Brief Description of MEMS
- Explain Sandia's Baseline MEMS Process: Summit V™
- **Describe Further Capabilities**
- Suggest Future Directions



Microfluidics: SWIFT™

SUMMiT V With Integrated Fluid Technologies



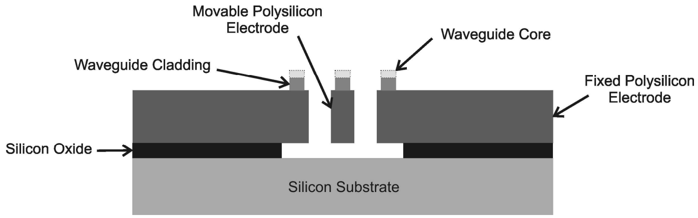
QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

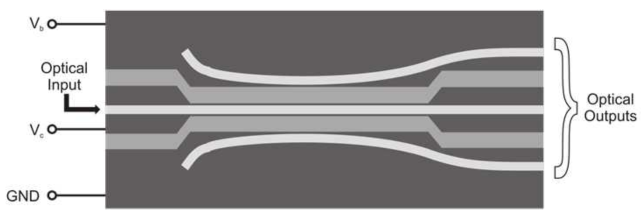
Optically transparent silicon nitride layers

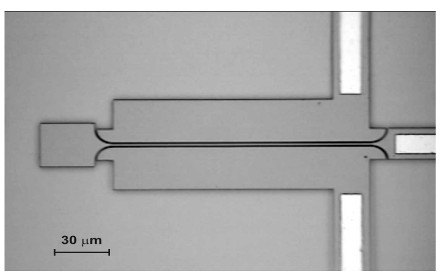
Optical Waveguides

Optically Transparent Silicon Nitride

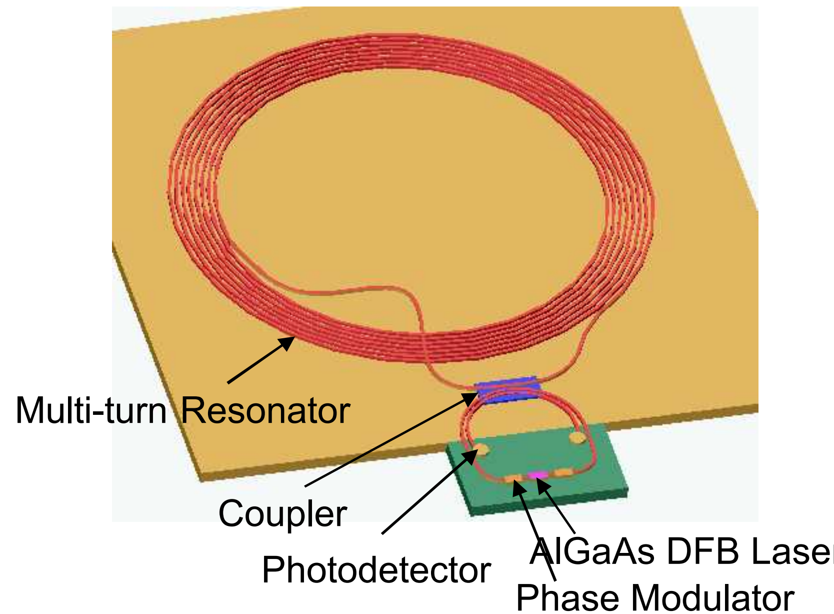
Evanescent Coupling Switch







Resonant Micro Optical Gyroscope

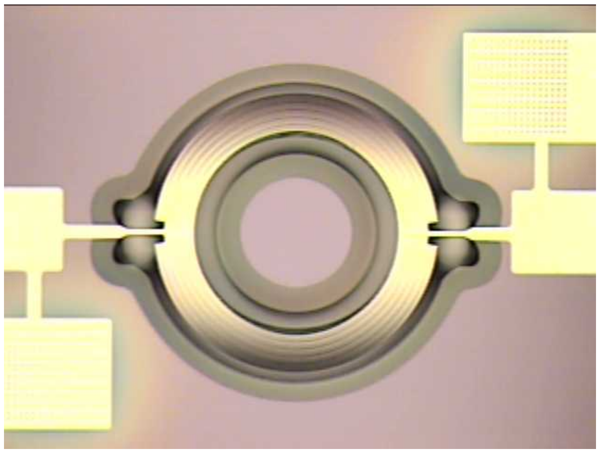


LOCKHEED MARTIN

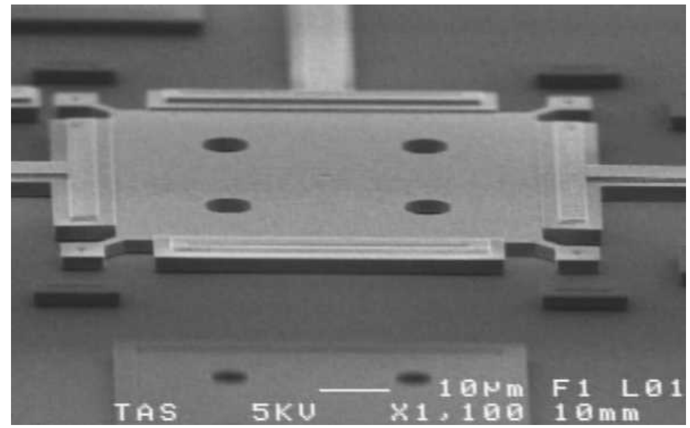
QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Post-CMOS Compatible Resonators

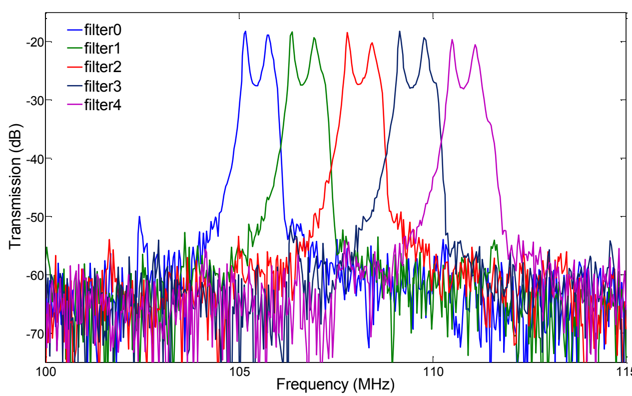
Polysilicon and Aluminum Nitride



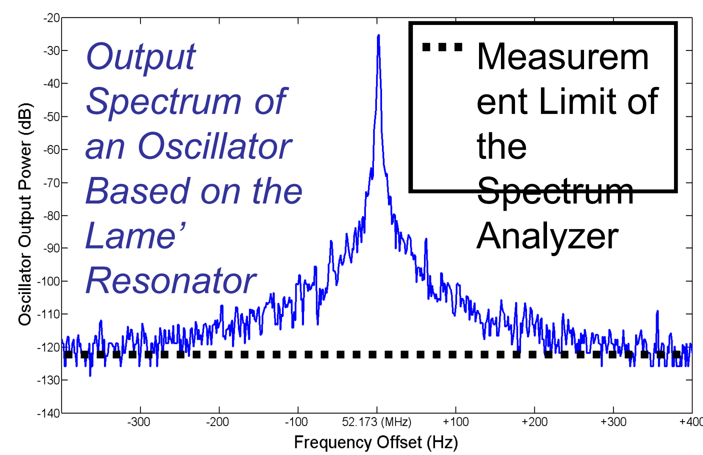
Aluminum Nitirde Resonator



Polysilicon Oscillator



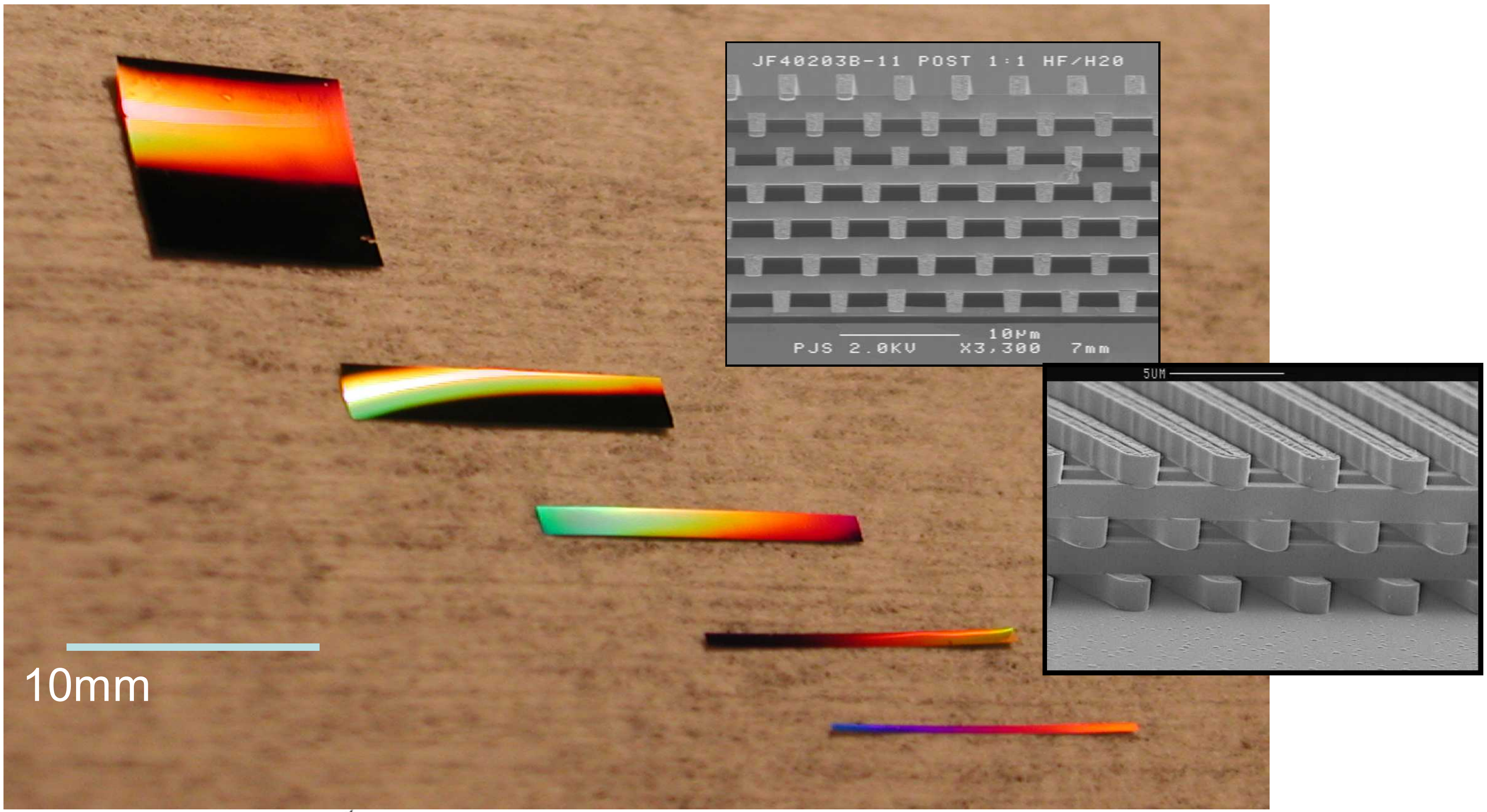
Measured Response of a 5-Element Dual Mode Filter Bank with 50 Ω Termination



LOCKHEED MARTIN

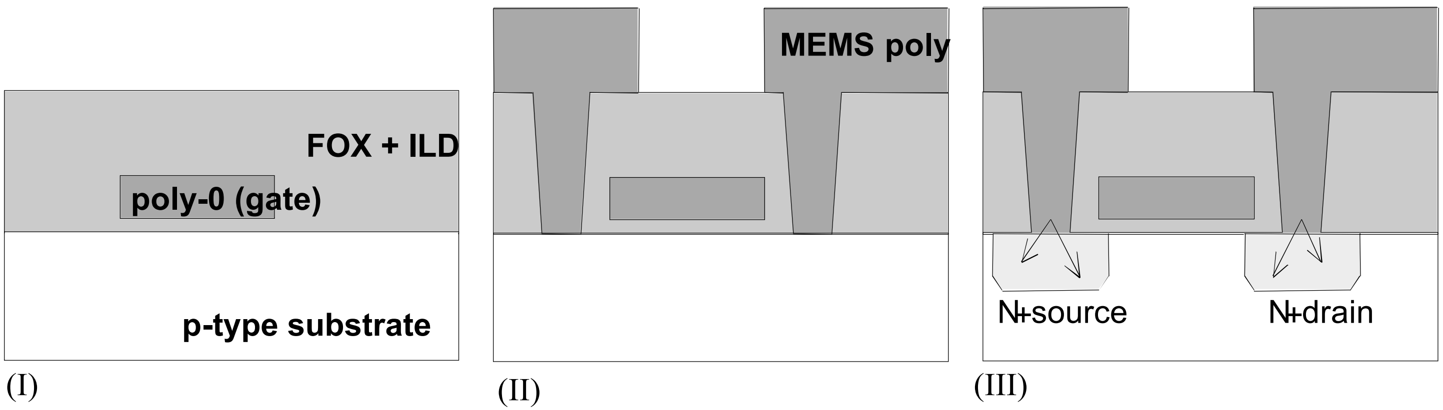
Molded Tungsten Technologies

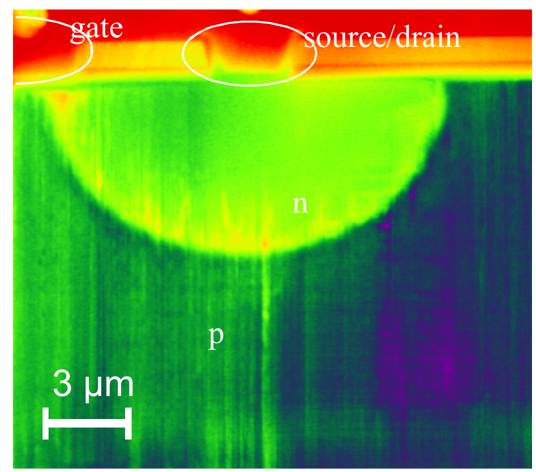
Tungsten molded in silicon dioxide layers



Integration of Active Devices

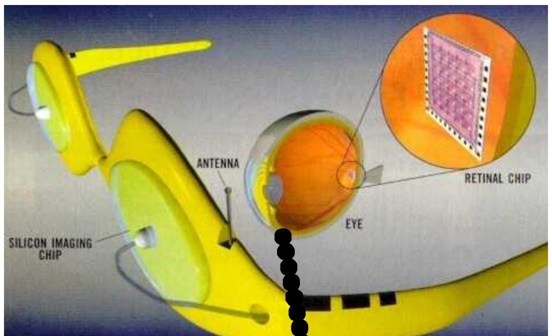
SUMMiT Field Effect Transistors (SFET)

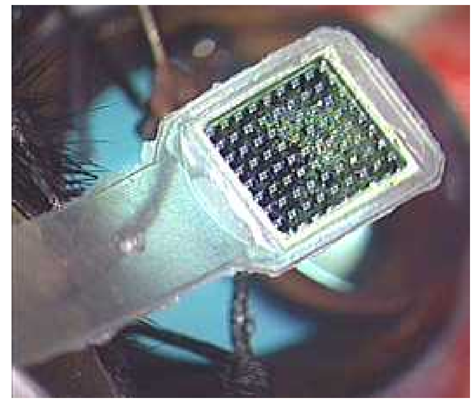


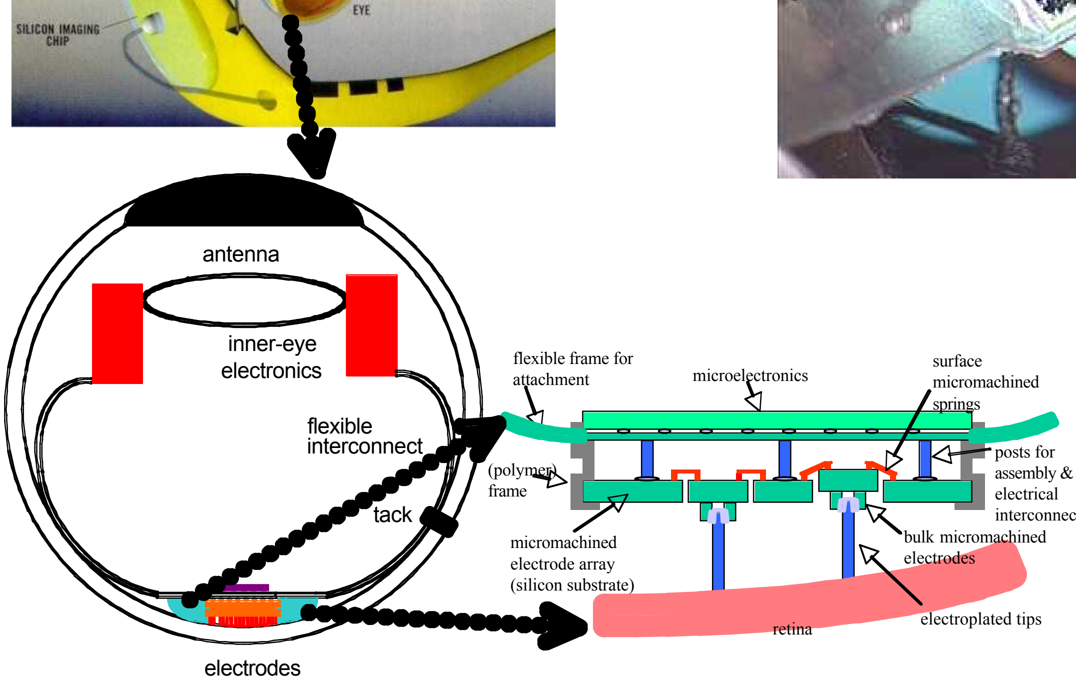


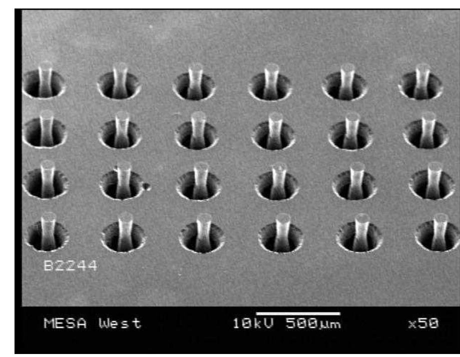
Packaging Electrodes for a Retinal Implant

Electrical stimulation of retinal neurons after light sensitive cells (photoreceptors) are lost







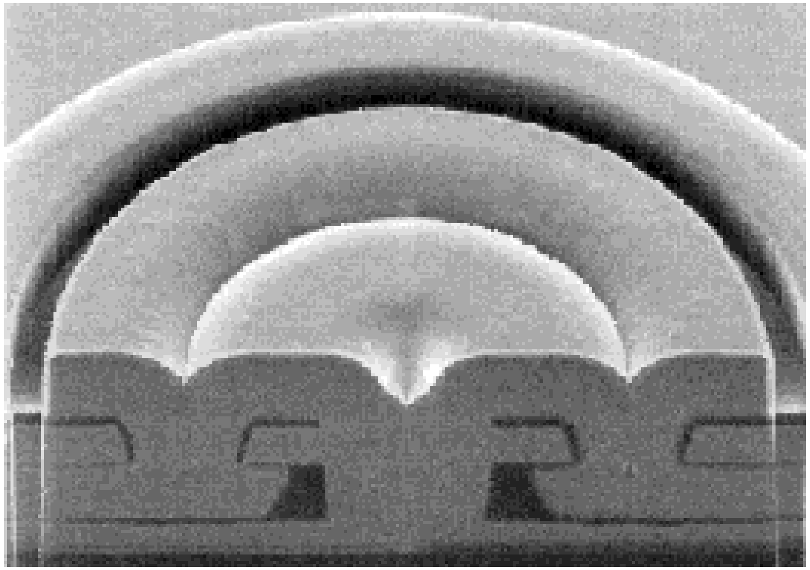


LOCKHEED MARTIN

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Sandia MEMS Technologies Overview: Outline

- Brief Description of MEMS
- Explain Sandia's Baseline MEMS Process: Summit V™
- Describe Further Capabilities
- **Suggest Future Directions**



Challenges

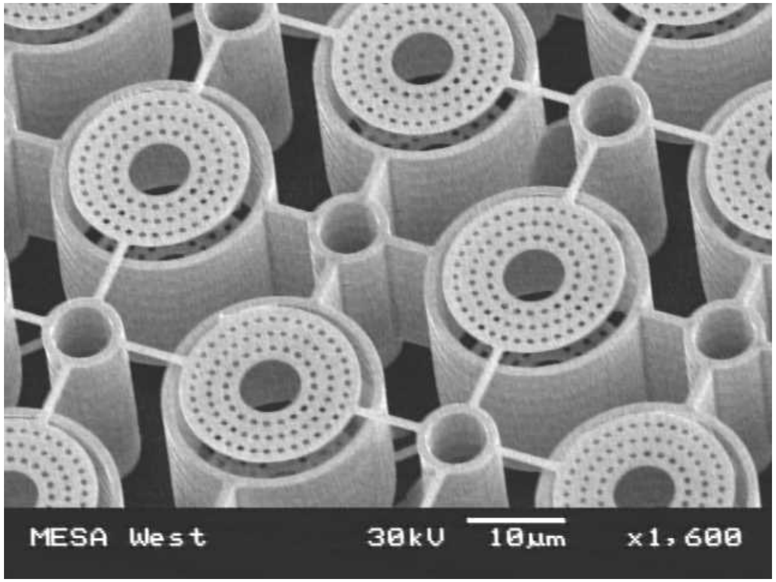
- **Metalization**
  - Reflectance
  - Electrical Contacts
- **Integration**
  - CMOS Process Limitations
  - Mixed MEMS Technologies
- **Packaging**
  - Cost
  - Interaction with MEMS

LOCKHEED MARTIN

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Opportunities

- Make Existing Things Smaller
- Work at Micro Scales
- Reduce Manufacturing Cost
- Create Arrays
- Integrate



Molded tungsten array of ion traps for mass spectroscopy

Contact Information

Keith Ortiz
Keith.Ortiz@sandia.gov
(505) 844-2072

www.mems.sandia.gov

Sandia National Laboratories

LOCKHEED MARTIN