Sandia National Laboratories SUMMiT V™ MEMS Process

Mature Technology with an Exciting Future

March 8, 2012

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**MEMS Integration Engineer
Senior Member of Technical Staff**

Microsystems Engineering Sciences and Applications (MESA) Facility
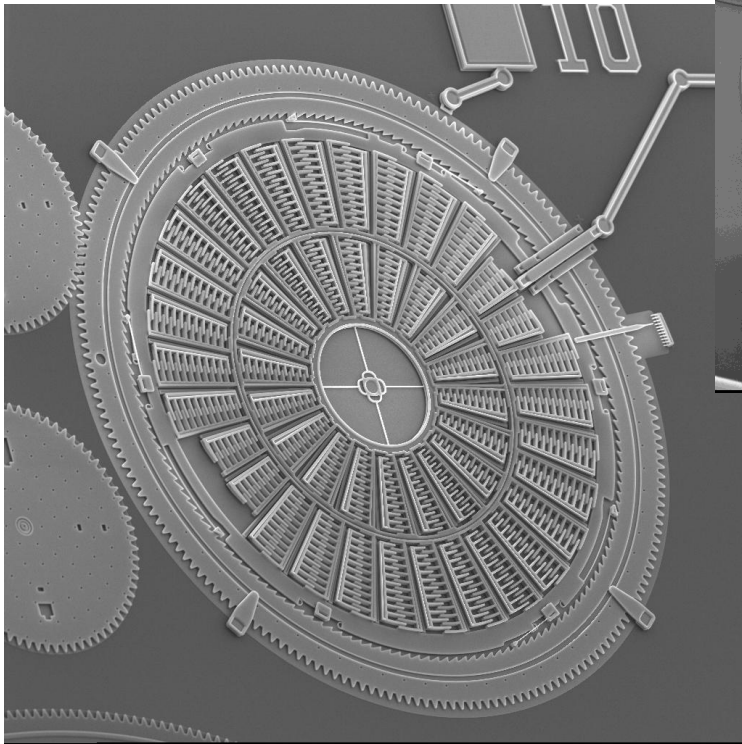
The SiFab at the MESA facility is a 150mm silicon wafer research and production facility for CMOS, MEMS, PV, and other microscale semiconductor products. The facility is a class-1 cleanroom with a highly trained production staff operating 24 hours, 5 days per week.
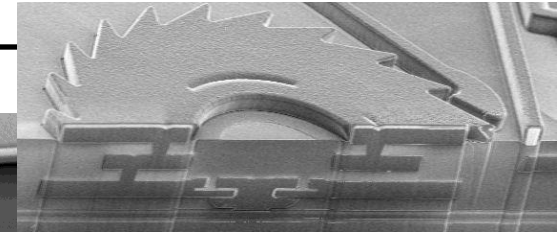

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SUMMiT™ Process:
Sandia Ultra-planar, Multi-level MEMS Technology
Early Applications

Torsional Rotational Actuator

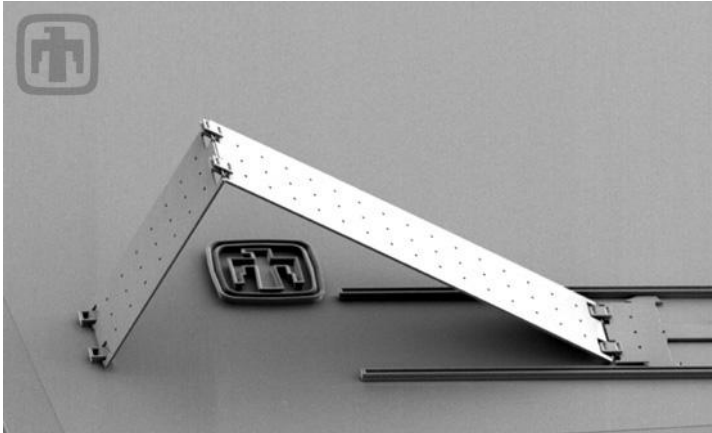Cross-Section of a Pin Joint Gear Hub
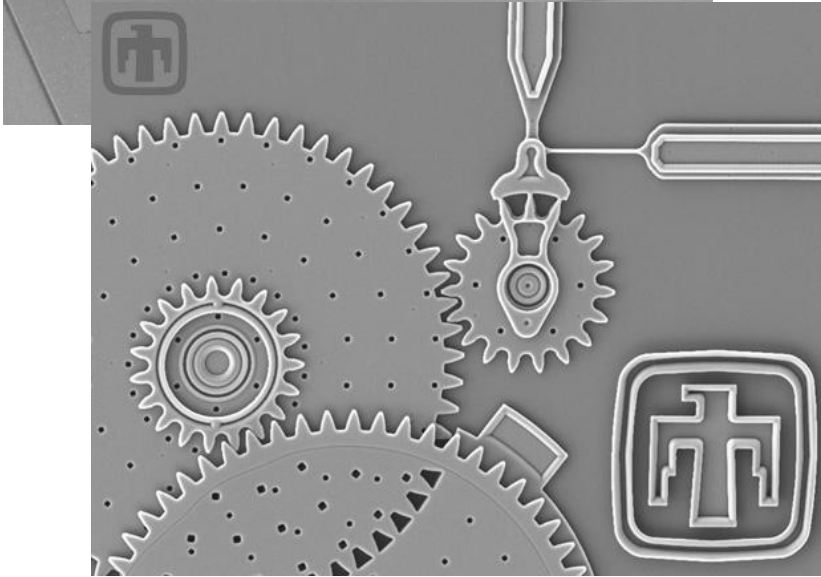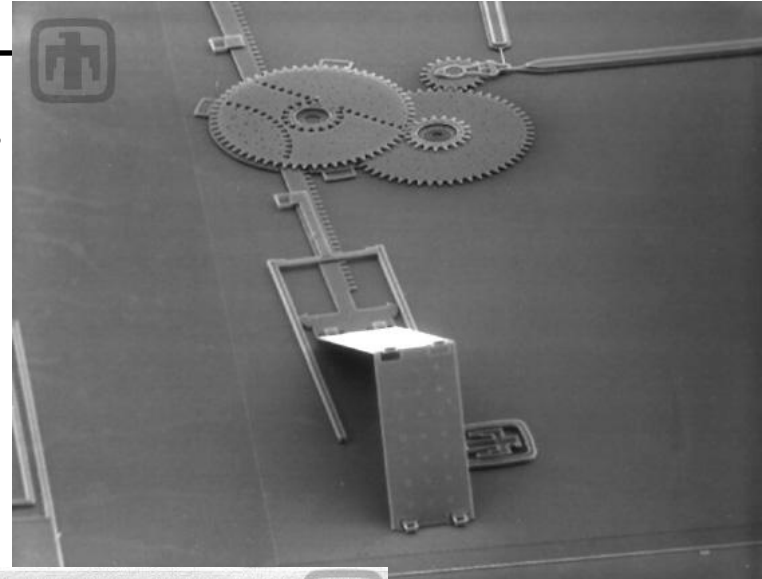
Double Ratchet Actuator

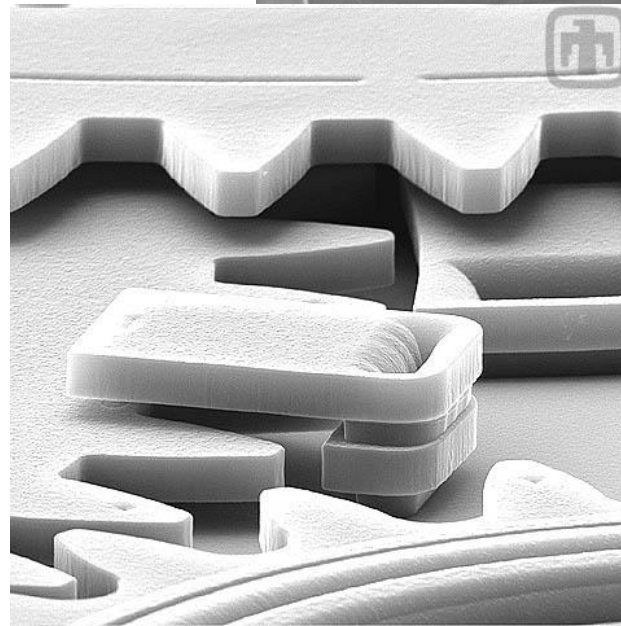Sandia National Laboratories

SUMMiT™ Process:
Sandia Ultra-planar, Multi-level MEMS Technology
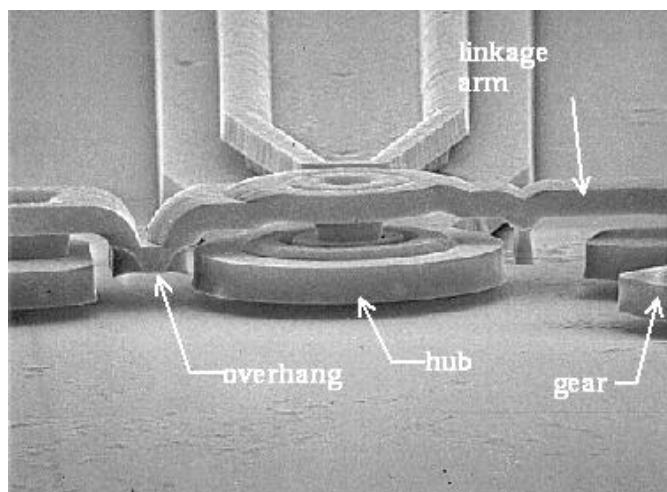## Early Applications

Hinged Pop-Up Mirrors

Gear Assemblies
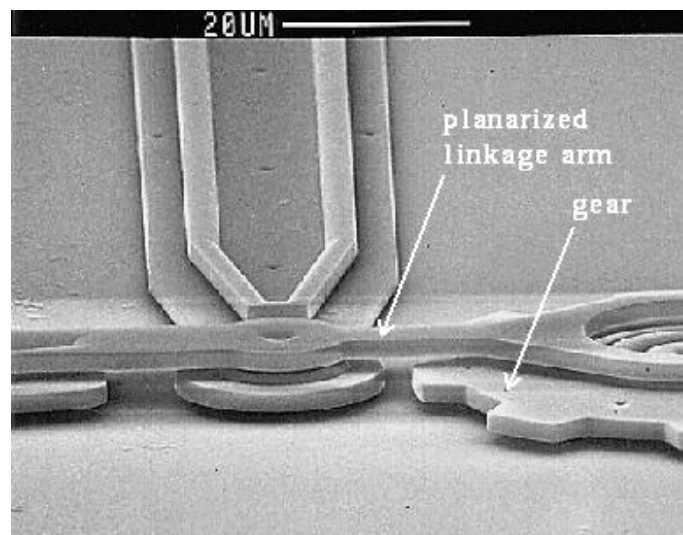
SUMMiT V™ Process Layers

0.7 μm PTNMETAL

2.25 μm MMPOLY4

2.0 μm SACOX4

0.2 μm Dimple4 backfill

2.25 μm MMPOLY3

2.0 μm SACOX3

0.4 μm Dimple3 backfill

1.5 μm MMPOLY2

0.3 μm SACOX2

1.0 μm MMPOLY1

2.0 μm SACOX1

0.5 μm Dimple1 gap

0.3 μm MMPOLY0

0.80 μm Silicon Nitride

0.63 μm Thermal Oxide

Substrate
6 inch wafer, <100>, n-type

** All Polysilicon is doped with Phosphorus
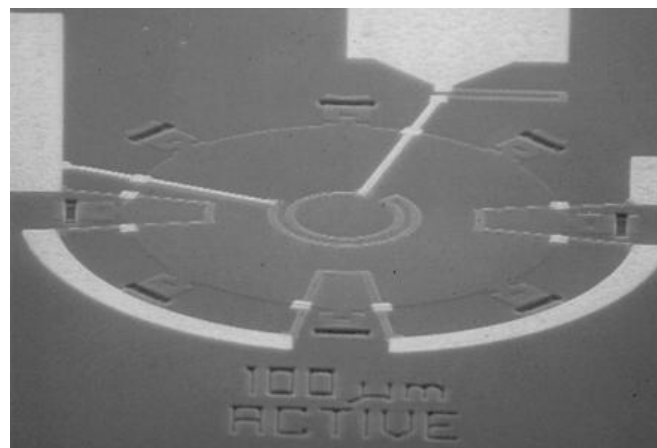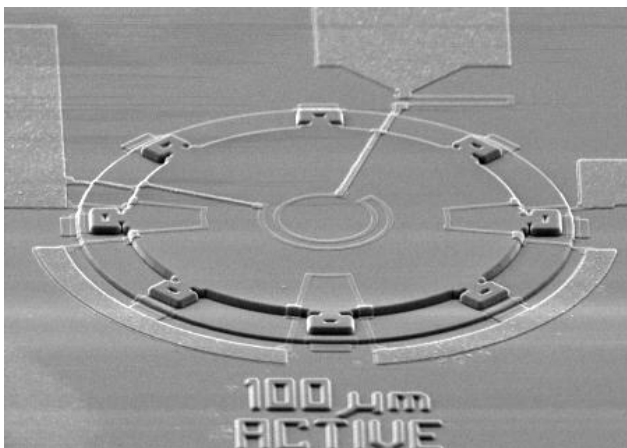
CMP Process Comparison
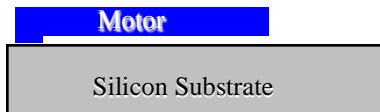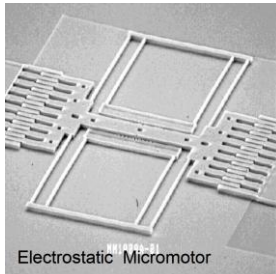
Non-planar Process

Planarized Process

Pressure Sensor

Planarization Enabled a New Generation of Micromachines

2*-Level

Electrostatic Micromotor

Motor

Silicon Substrate

■ Polysilicon Level #1

Sensors

* First Poly level is a ground plane

3-Level

Gear   Bearing   Motor

Silicon Substrate

■ Polysilicon Level #1
■ Polysilicon Level #2

Advanced Sensors / Simple Actuators

4-Level

Drive Linkages
Bearing   Motor
Gear

Silicon Substrate   Pin Joints

■ Polysilicon Level #1
■ Polysilicon Level #2
■ Polysilicon Level #3

Advanced Actuators

5-Level

Drive Linkages
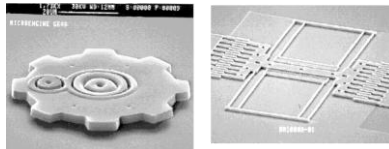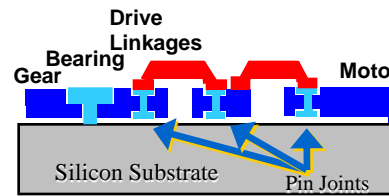Bearing   Motor
Gear

Moveable Plate

Silicon Substrate

■ Polysilicon Level #1
■ Polysilicon Level #2
■ Polysilicon Level #3
■ Polysilicon Level #4

Complex Systems

Competing technologies can be limited to only two poly levels

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Active MEMS Polysilicon Microvalve for a Micro-Gas-Analyzer

Boss with
Electrode Beneath

Spring

FIB Cut through
Stop Ring

Flow Exit
Holes

Thru Wafer Etch
Under Bosch Center

Upward-Movement Stop

Figure 8: Active Valve SEM image

FIB cut SEM through valve stop

MGA

Sandia
National
Laboratories

Check Valve
Fabricated Using SUMMiT V™ Based Processes
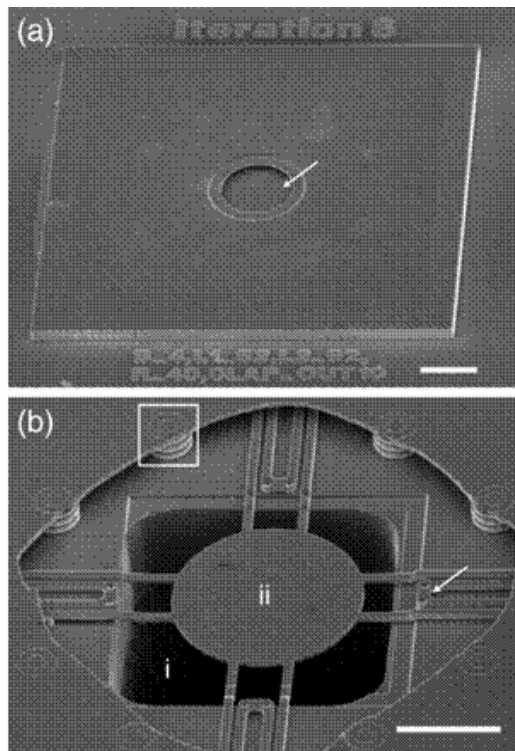
Passive MEMS Disk-in-Cage Poppet Microvalves

Figure 6: (a) SEM micrograph of an offset check-valve showing the outlet (arrow). (b) Valve with the cover removed to expose the valve inlet (i), body (boss) (ii), and springs. A lid anchor (box) and spring anchor (arrow) are noted. Scale bars = 50 μm.

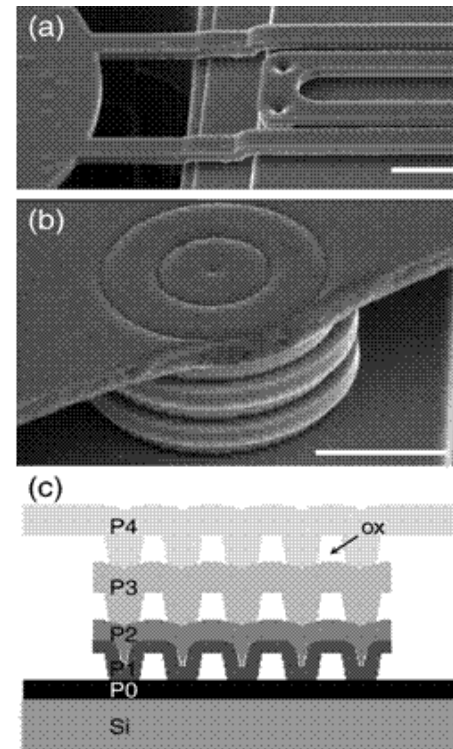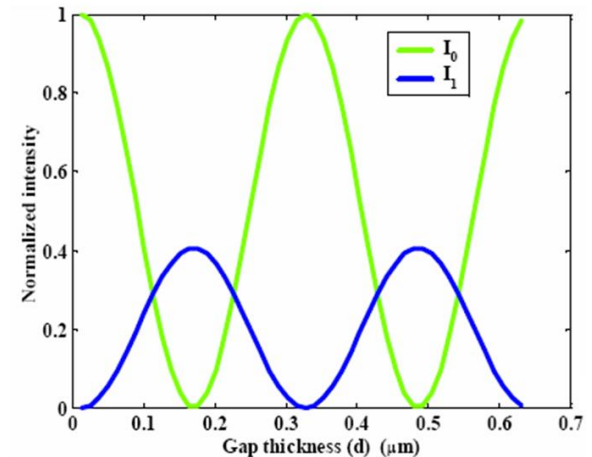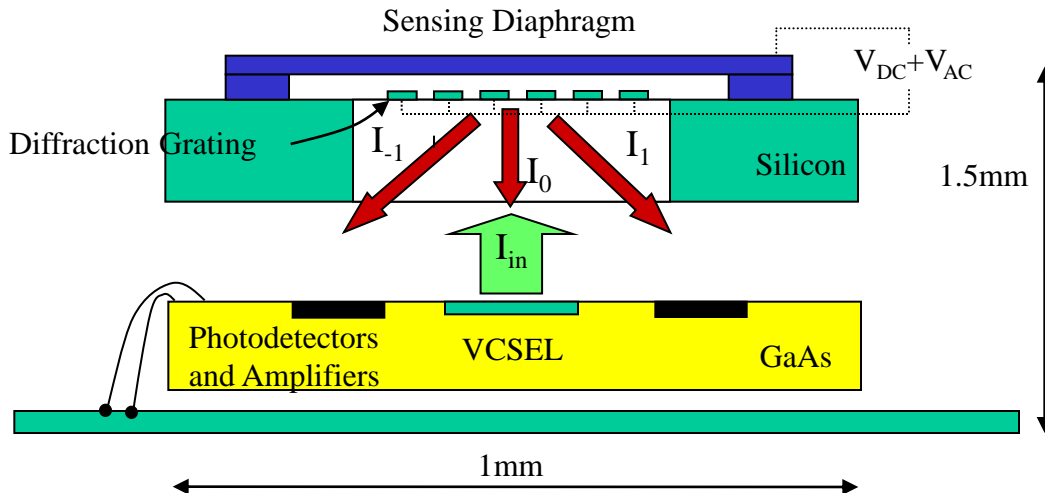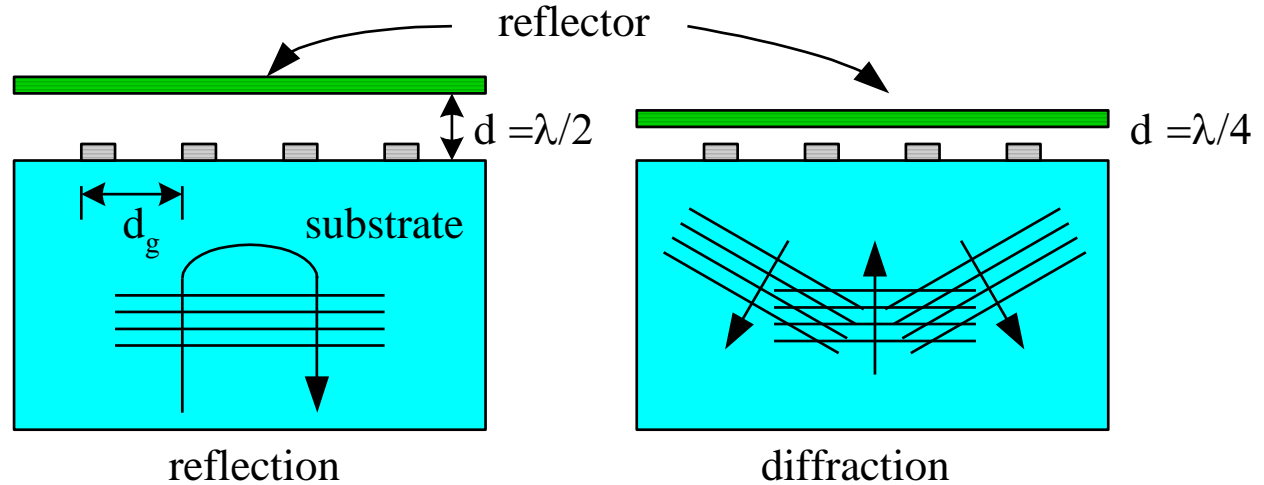

Figure 7: (a) Close-up of the spring anchor. Scale bar = 10 μm. (b) SEM micrograph of a lid anchor (box). Scale bar = 10 μm. (c) Schematic of the cross-section through the lid anchor showing the five polysilicon layers and trapped oxide (ox).

Optical Diffraction Microphone

Optical Measurement of Displacement

reflector

$d = \lambda/2$

$d = \lambda/4$

d_g

substrate

- Reflector displacement changes intensity of diffracted orders
- Excellent motion detector
- Very good optical modulator

reflection

diffraction

Sensing Diaphragm

$V_{DC} + V_{AC}$

Diffraction Grating

I_{-1}

I_0

I_1

Silicon

1.5mm

I_{in}

Photodetectors and Amplifiers

VCSEL

GaAs

1mm

Normalized intensity

I_0

I_1

Gap thickness (d) (μm)

Optical Diffraction Microphone Design

Gold Coating

0.5 to 2.0 mm

200 um

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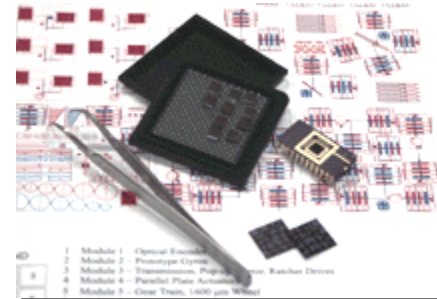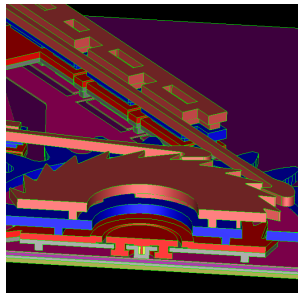# SAMPLES™: _Sandia's Agile MEMS Prototyping, Layout Tools, Education, and Services_
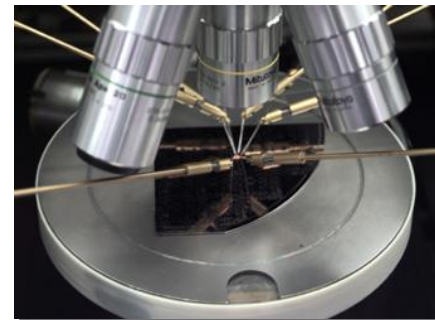

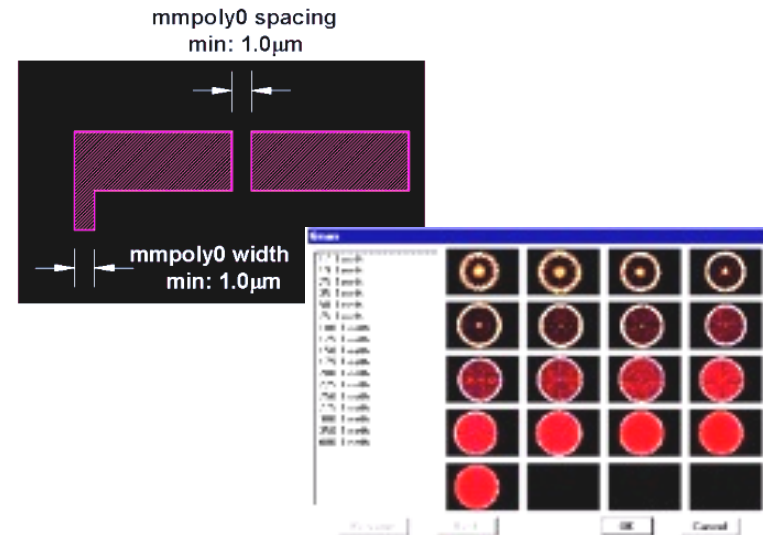**Education**

Prototype Fabrication

Design Tools

Services

The SAMPLES™ Program Offers Ready, Comprehensive Access to SUMMiT V™ Technology:

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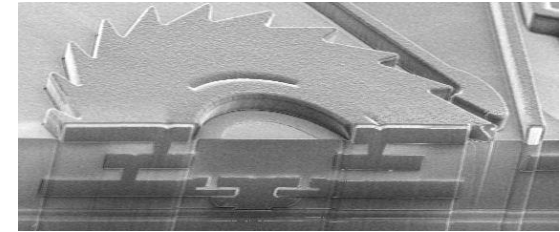# SAMPLES: Design Layout & Visualization Tools

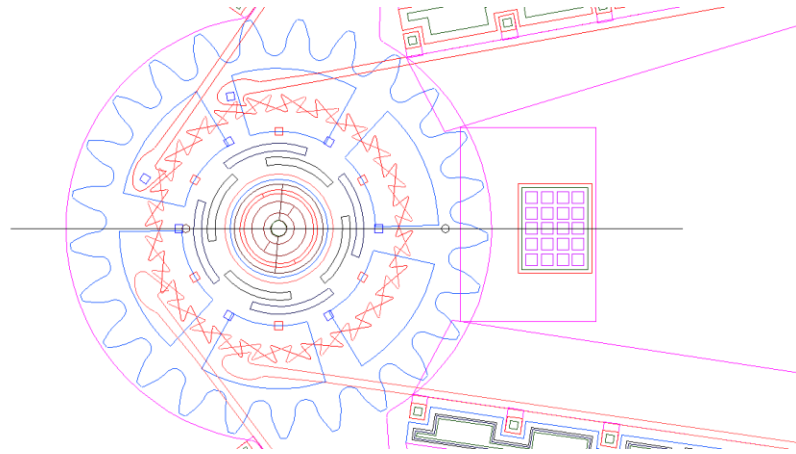- **Specific to SUMMiT V™ technology**

- **Integrated into AutoCAD environment**

- **Comprehensive suite of design tools**

  – **Advanced MEMS Design Tools software**

  – **Standard Components Library**

  – **Design Rule Checker**

  – **2D Process Visualizer, 3D Visualizer Tools Software**

  – **3D Modeler**

mmpoly0 spacing
min: 1.0μm

mmpoly0 width
min: 1.0μm

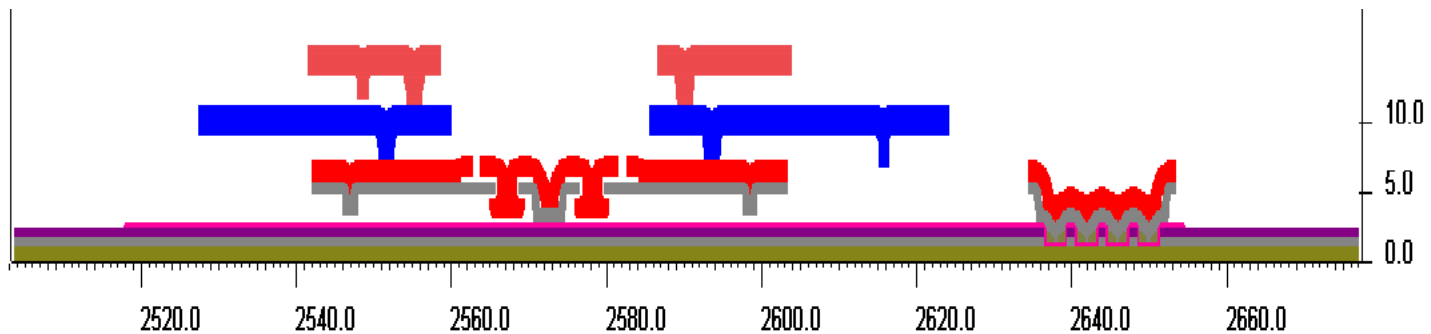Sandia National Laboratories

SUMMiT™ Process Cross-sections: Released Structure (Double Ratchet)

SEM perspective view of fabricated device

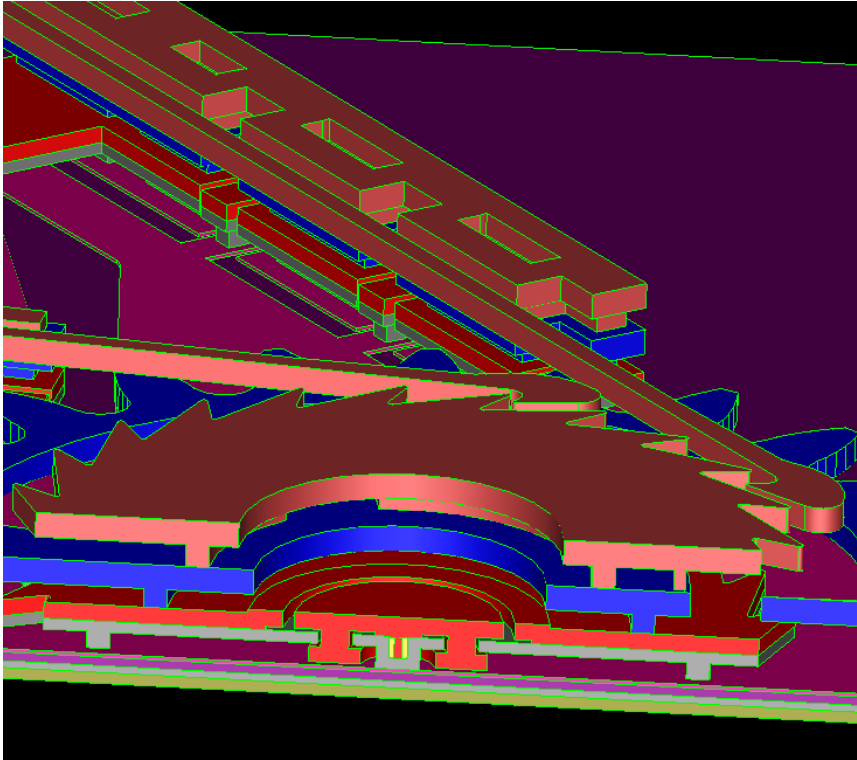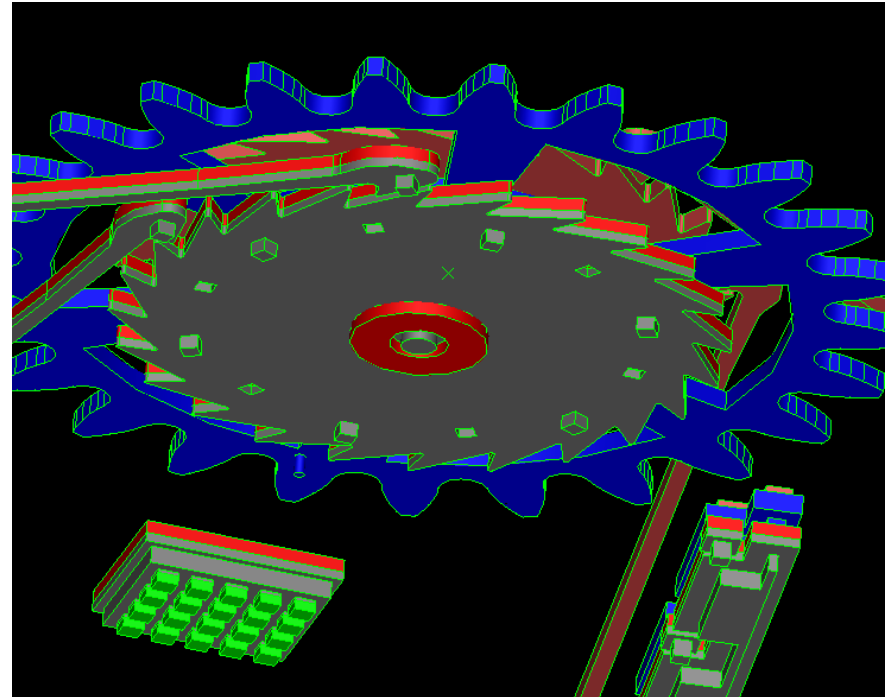**FIB cross-section of fabricated device**

2D Visualizer Tool

Sandia National Laboratories

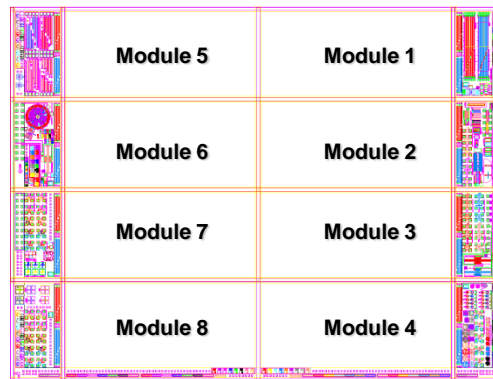# SUMMiT V™ Process Cross-sections: Double Ratchet
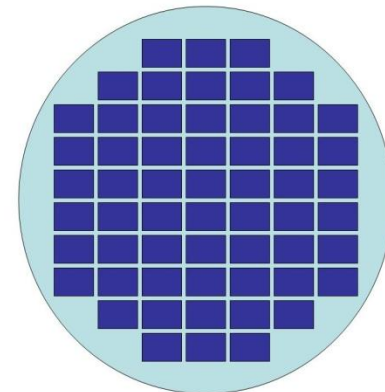
3D Visualizer Tool

Using the SAMPLES™ Program to Prototype with SUMMiT V™ Technology

SAMPLES™ modules are fabricated with the SUMMiT V™ Process

- **Reticle size: 16500 μ X 12400 μ**

- **Diagnostic devices help characterize fab process**

- **Customer receives approximately 200 unreleased die**

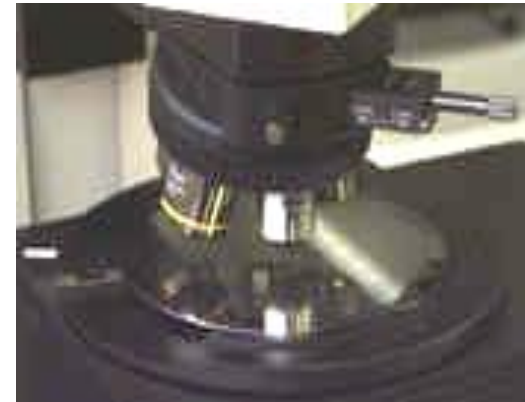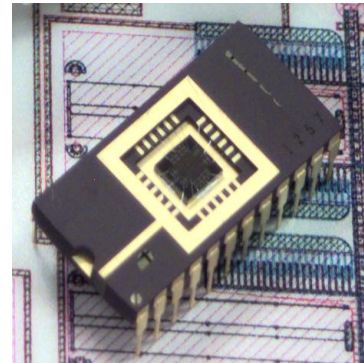- **Fabrication cost is shared among customers, $17.2K per module**

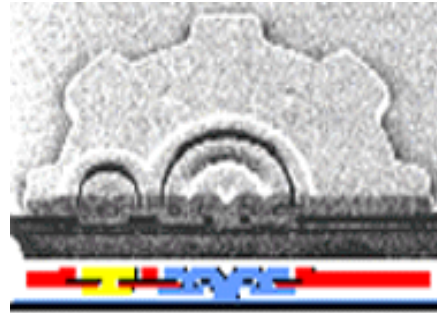| Module 5 | Module 1 |
Module 6	Module 2
Module 7	Module 3
Module 8	Module 4

2820 μ X 6340 μ modules

~ 58 die per wafer

SAMPLES: Additional Services Available

- **Design Reviews**
- **Metallization**
- **Back-end processing**
- **Packaging**
- **Reliability characterization**
- **Failure Analysis**
- **Testing**
- **Individual specialized agreements**
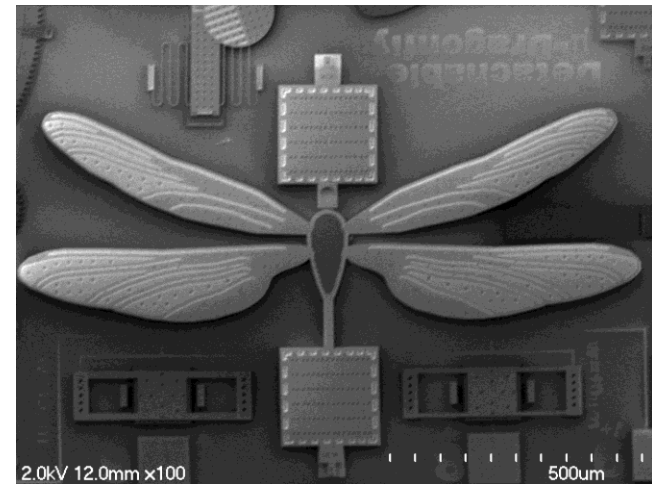- **Alternative processing available on a case by case basis**

Sandia's MEMS University Alliance (UA): Leveraging the SAMPLES™ program

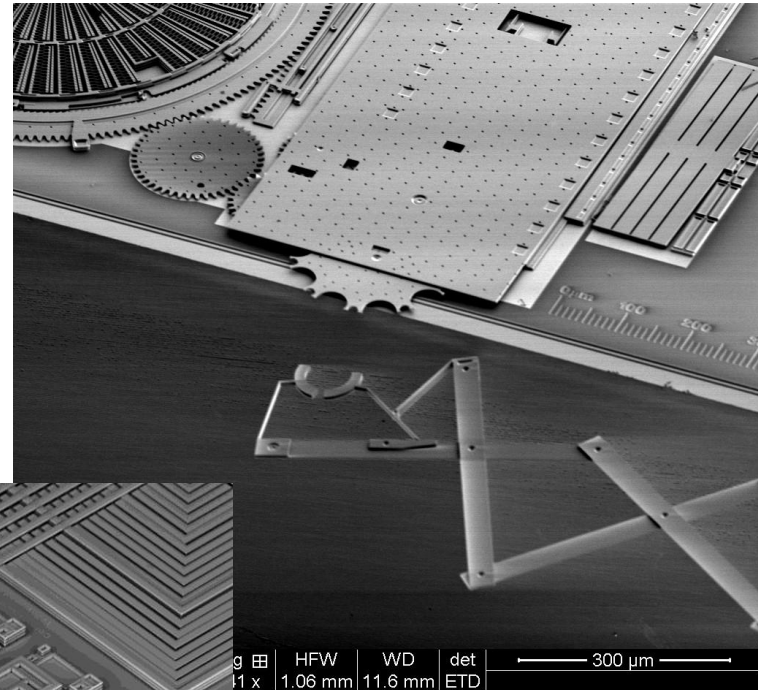## Highlights of the University Alliance License:

- **Site license for SUMMiT V™ Design and Visualization Tools**
  - For use in lab or classroom by course participants (1-50 students)
- **Training and technical support for a University POC to become a "Superuser"**
- **Opportunity to participate in the annual design contest**
- **MEMS parts for use in teaching**

One-time License Fee of $5000

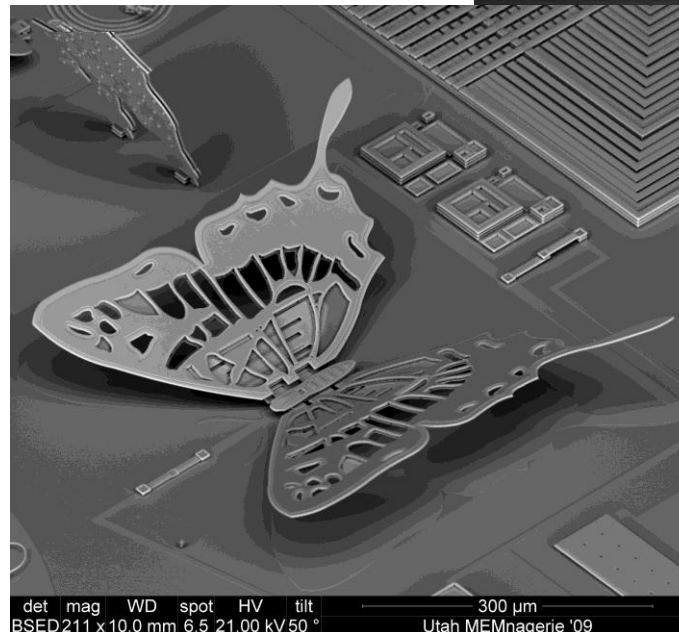Sandia National Laboratories

University Alliance Design Competition

Texas Tech

University of Utah

Useful Web Links

- **Sandia National Laboratories MicroElectroMechanical Systems (MEMS)**

  http://www.mems.sandia.gov/

- **Sandia National Laboratories University Alliance (UA) Program**

  http://www.mems.sandia.gov/ua/index.html

- **University Alliance – Design Competition**

  http://www.mems.sandia.gov/ua/contest.html

- **University Alliance – Member Resources**

  http://www.mems.sandia.gov/ua/resources.html

- **Sandia National Laboratories SAMPLES Program**

  http://www.mems.sandia.gov/samples/index.html