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Novel Materials for MEMS

Dr. James J. Allen
MEMS Technologies, Department 1749
Sandia National Laboratories

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MEMs for Defense an Security Applications
McLean, VA
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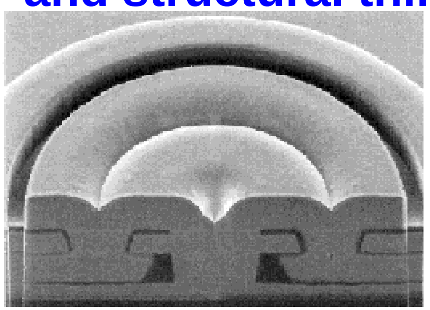
This talk is to introduce you to some novel materials for MEMS

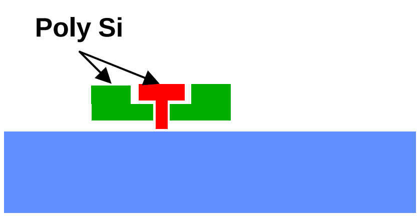
- Audience's interest is to understand
  - The motivation for novel materials
  - Potential applications
  - Technical challenges
- Outline
  - Review conventional MEMS material systems
  - Novel materials enhancing performance (SOI, SiC, PZT)
  - Novel materials integrating with compatible materials (AlN, GaAs, SFET)
  - Novel materials developing new capabilities (molded metals)
- This will result in appreciation of future directions and potential opportunities

3 Major Categories MEMS Fabrication

Surface Micromachining

2D assembled structures formed by deposition and etching of sacrificial and structural thin films.

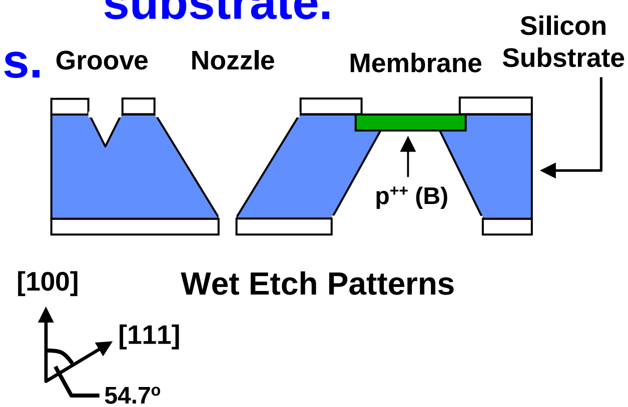




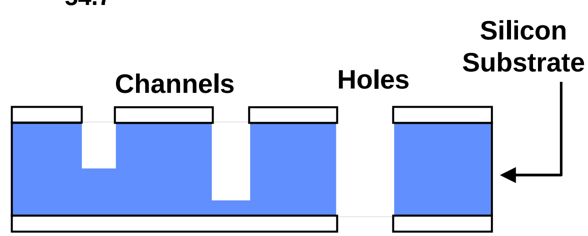
Silicon Substrate

Bulk Micromachining

3D structures formed by wet and/or dry etching of silicon substrate.



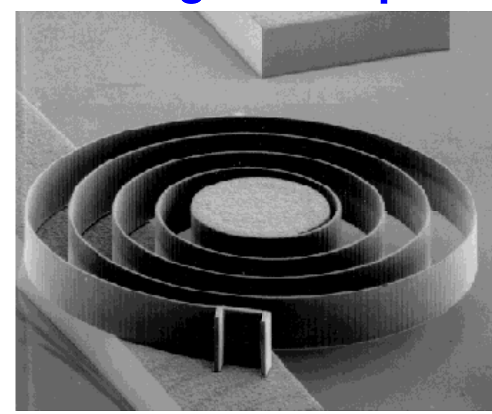
Wet Etch Patterns

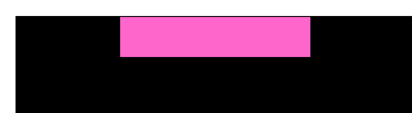


Dry Etch Patterns

LIGA

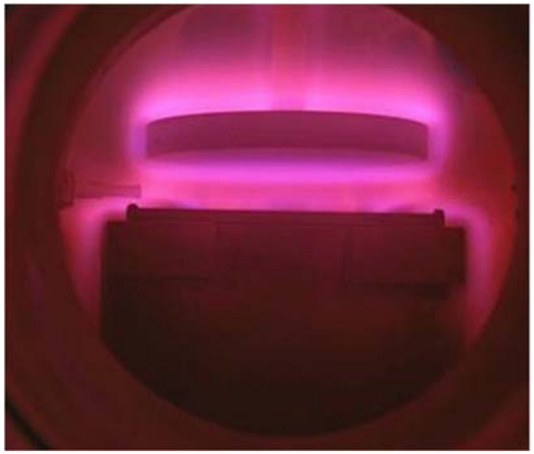
High aspect ratio structures formed by mold fabrication, followed by injection molding/electroplating



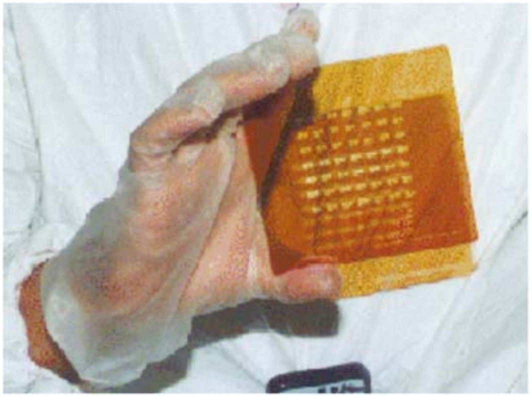


Mold

MEMS technology is derived from standard CMOS technologies

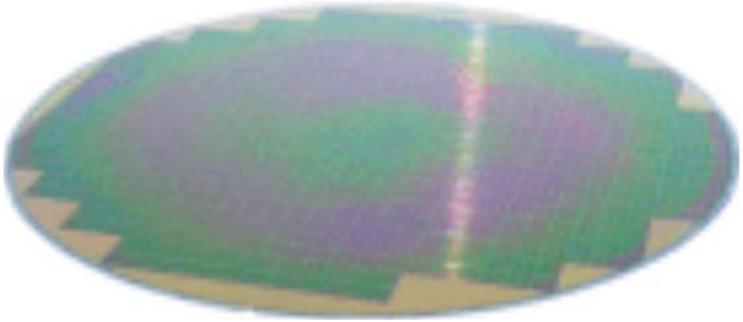


Deposition



Lithography

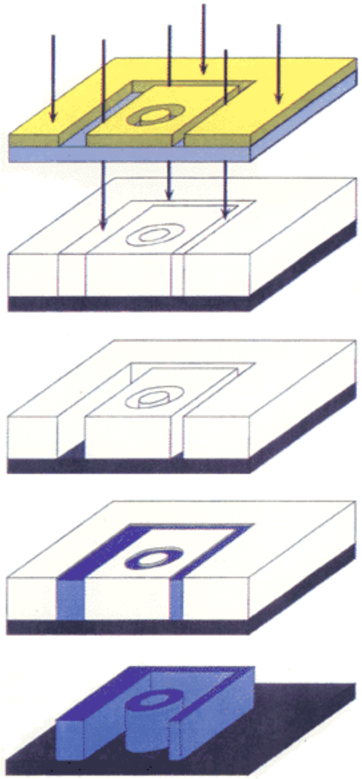
Etching

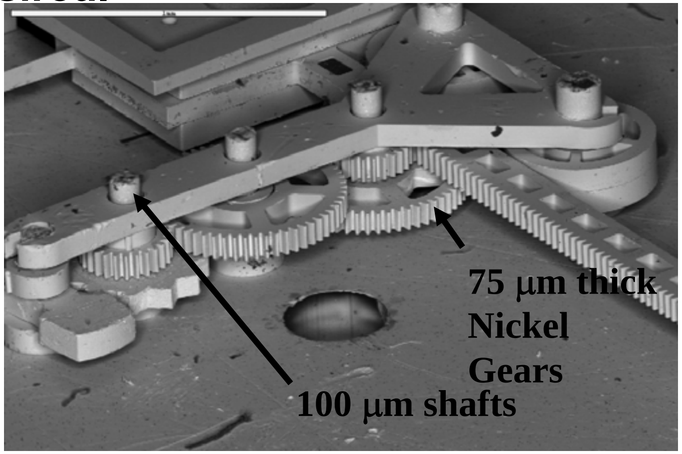


Standard MEMS processes are based on the CMOS material system

LIGA Processing Steps

- X-rays from a synchrotron are incident on a mask pattered with high Z absorbers.
- X-rays are used to expose a pattern in PMMA, normally supported on a metallized substrate.
- The PMMA is chemically developed create a high aspect ratio, parallel wall mold.
- A metal or alloy is electroplated in the PMMA mold to create a metal micropart.
- The PMMA is dissolved leaving a three dimensional metal micropart. This micropart can be separated from the base plate if desired.

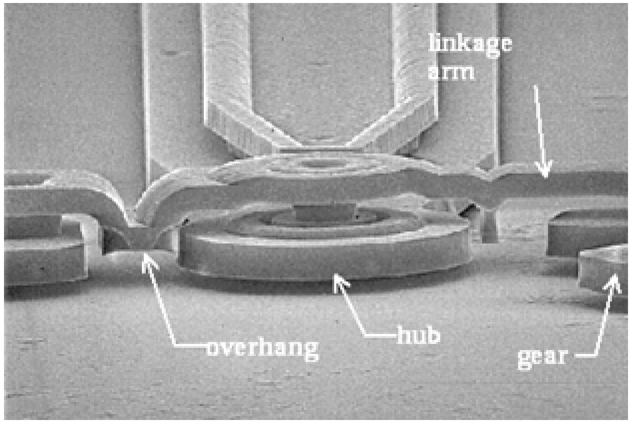




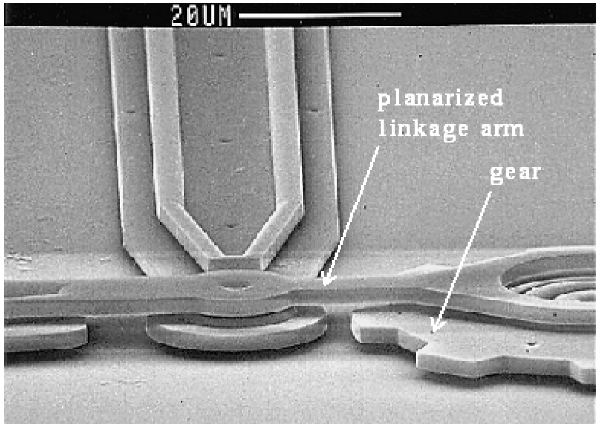
* PMMA - polymethylmethacrylate

MEMS Technology
Surface Micromachining

Chemical Mechanical Polishing used in SUMMiT™



a) Example of a conformable Layer



b) Example of topography removed by Chemical Mechanical Polishing

Table 1. Example Surface Micromachining Technologies Material Systems

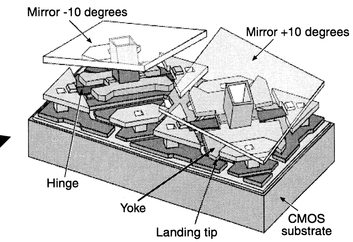
Structural	Sacrificial	Release	Application
polySi	SiO_2	HF	SUMMiT V™
SiN	polySi	XeF_2	GLV™
Al	resist	plasma etch	TI DMD™
SiC	PolySi	XeF_2	MUSIC™

Note: SUMMiT™ - Sandia Ultra-planar, Multi-level MEMS Technology
GLV™ - Grating Light Valve (Silicon Light Machines)
DMD™ - Digital Mirror Device (Texas Instruments)
MUSIC™ - Multi User Silicon Carbide (FLX micro)

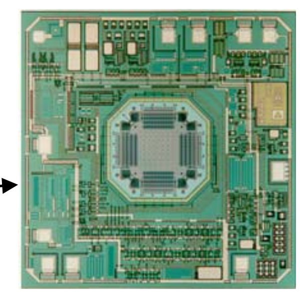
Integration of Electronics and MEMS Technology (IMEMS)

- **Issues for Integration of μelectronics & MEMS**
  - **Large vertical topologies**
  - ***High Temperature Anneals***
- ***Strategies for IMEMS processes***
  - ***Microelectronics First*****: (ex. TI DMD™)**

Digital Micromirror Device
Texas Instruments

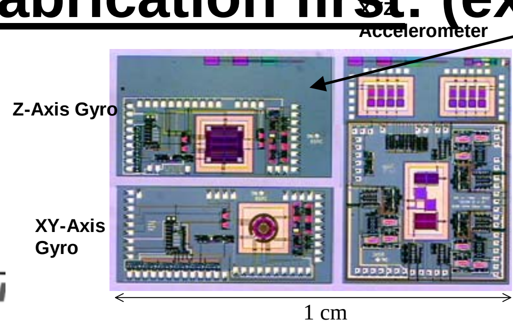


  - ***Interleave the Microelectronics and MEMS fabrication:*** **(ex. Analog Devices ADXL)**



Analog Devices ADXL Accelerometer

  - **MEMS fabrication first: (ex. Sandia IMEMS Process)**



Fabricated: Sandia National Laboratories

Designed: University of California, Berkeley Sensor & Actuator Center

OR --- Integration via Packaging

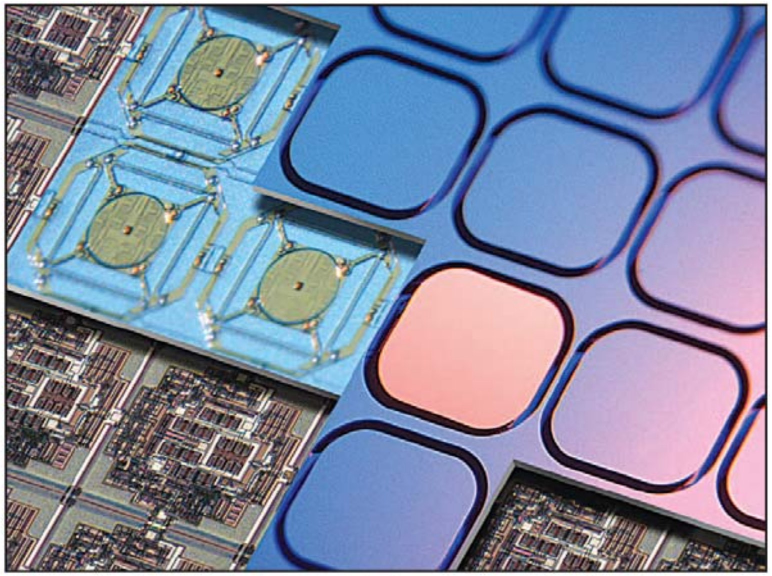
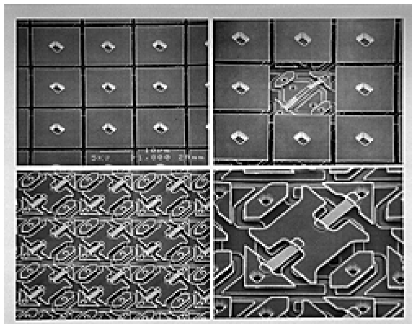


Fig. 3. An electrostatically actuated micromirror array for photonic cross connects was fabricated with a vertical MEMS-IC wafer integration process. (Courtesy of Transparent Networks.)

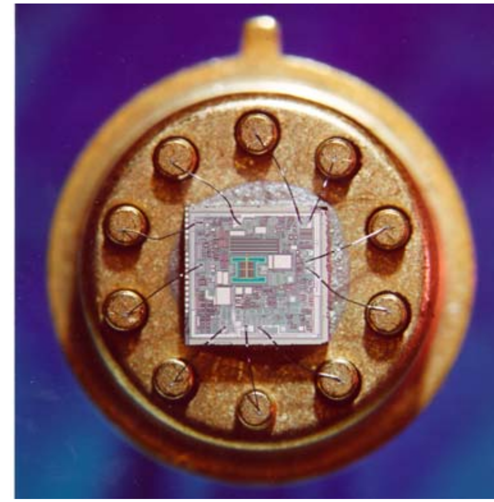
J. Bryzek, A. Blannery, D. Skumik, Integrating Microelectromechanical Systems with Integrated Circuits, IEEE Instrumentation & Measurement Magazine, June 2004.

MEMS Applications Abound

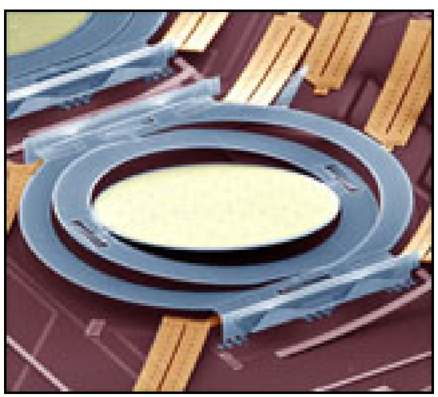


Digital Mirror Device
Texas Instruments

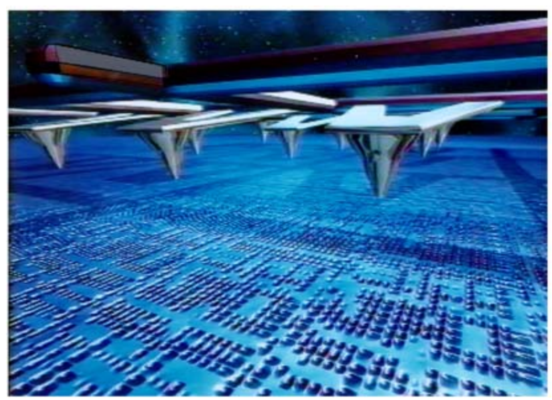
Ink Jet Cartridge
Hewlett Packard



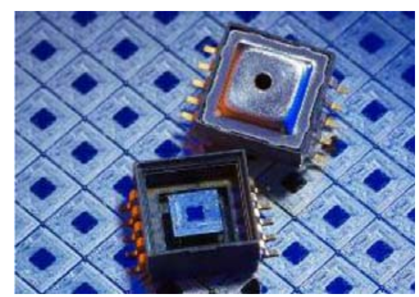
Accelerometer
Analog Devices



Micromirror switch
Lucent Technologies



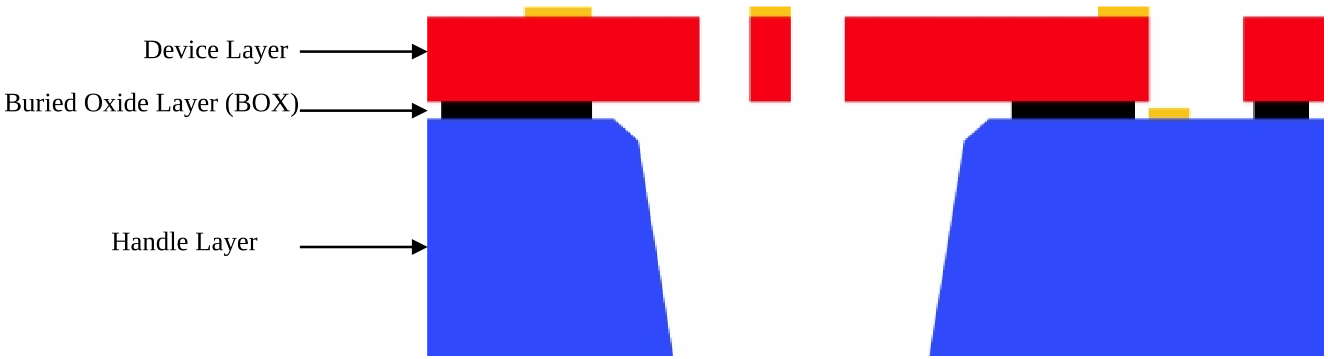
Data Storage
IBM Research



Pressure Sensor
Bosch MEMS

Silicon on Insulator (SOI)

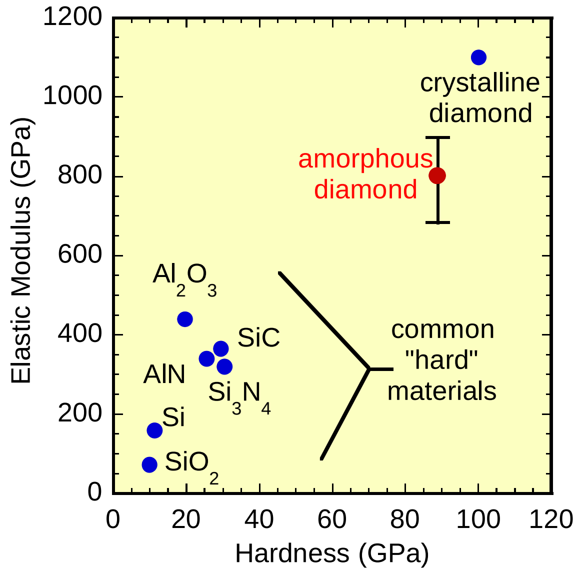
Thicker, more robust structures



Cross sectional view showing all layers of the SOI-MUMPs™ process (not to scale)
SOIMUMPs Design Handbook, Revision 4.0, MEMSCAP

- **Applications:** sensors, actuators
- **Challenges:** uniform etching

Harsh Environment Materials



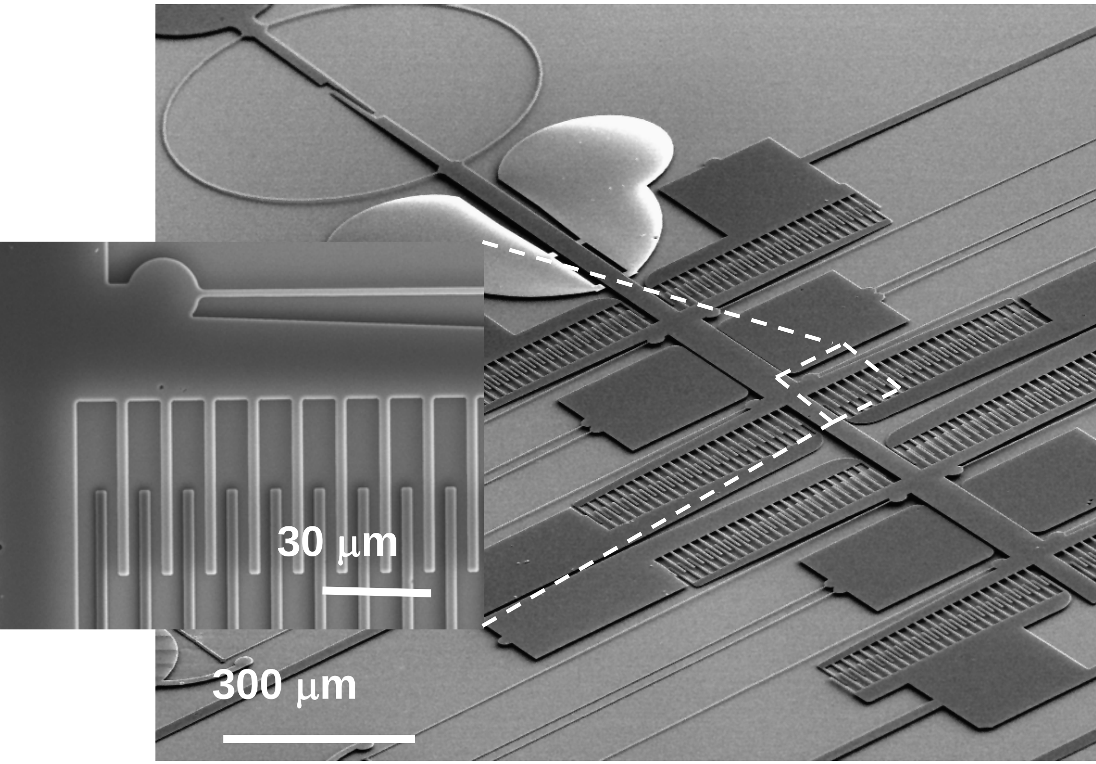
* Silicon Carbide

* Amorphous Diamond

Property	3C-SiC	Diamond	Si
Young's Modulus E (GPa)	448	800	160
Melting Point (°C)	2830 (*sublimation*)	1400 (*phase change*)	1415
Hardness (Kg/mm^2)	2840	7000	850
Wear Resistance	9.15	10.0	<<1

- **Applications:** high-temperatures or aggressive environments
- **Challenges:** Not fully mature technology

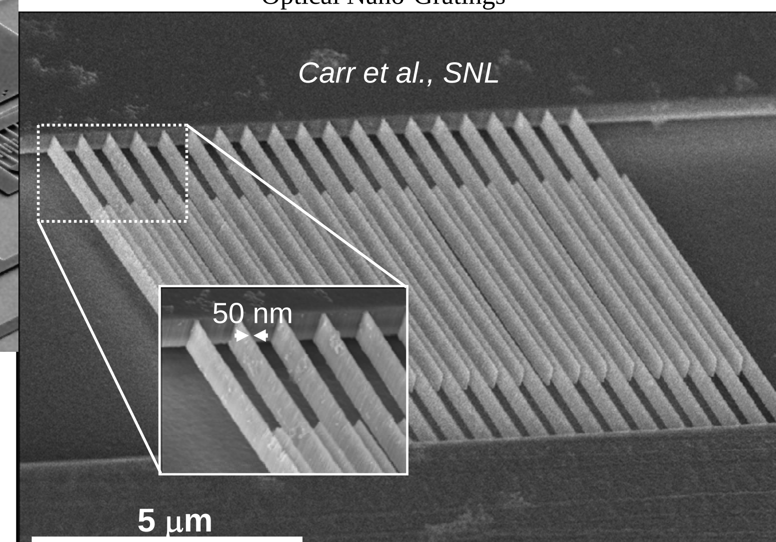
Amorphous diamond MEMS and Low Temperature processing



All room temperature process!

Should enable MEMS on existing electronics!

Optical Nano-Gratings



Silicon Carbide

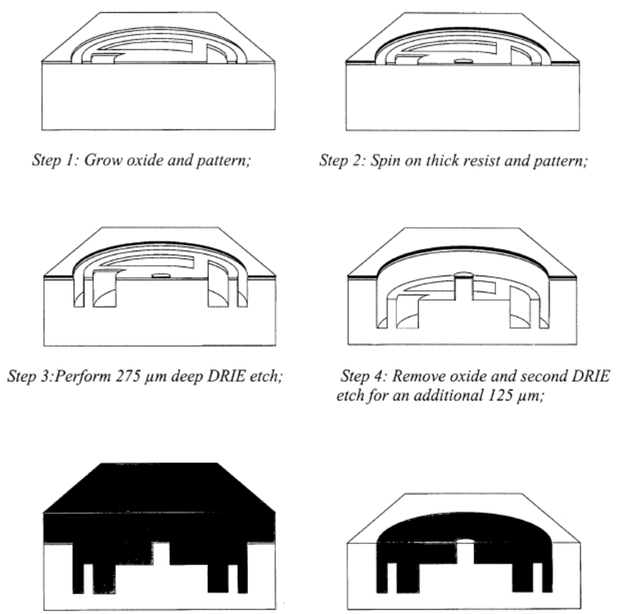


Fig. 1. Cross-sectional schematics of the SiC fuel atomizer fabrication process [26].

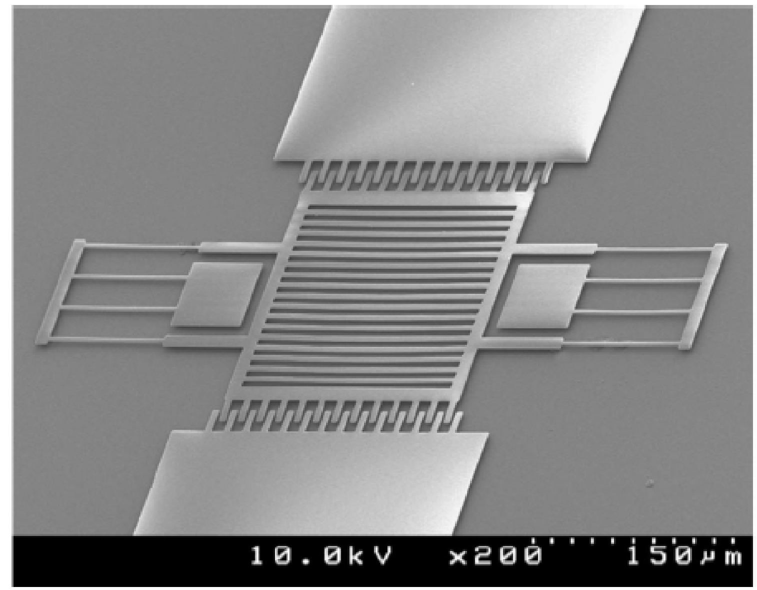


Fig. 7. SEM micrograph of a SiC lateral resonant structure fabricated using micromolding [31].

M. Mehregany, C. Zorman, SiC MEMS: Opportunities and challenges for applications in harsh environments.

Established Process MUSiC (www.flxmicro.com)

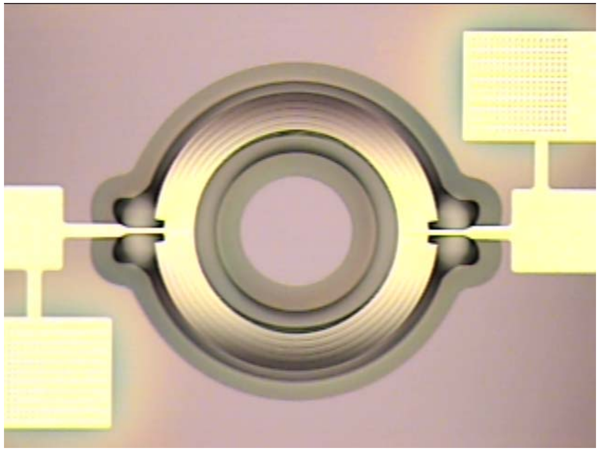
Low Voltage Actuation

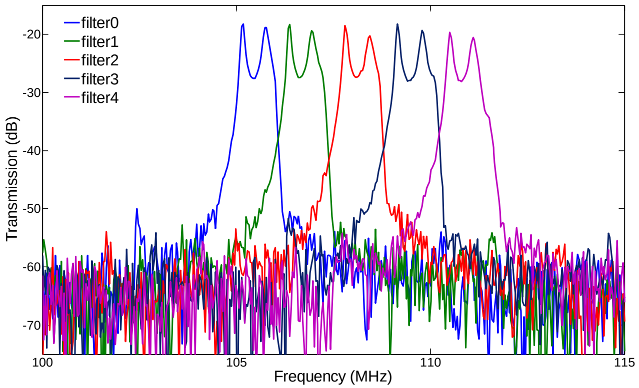
- **Lead Zirconate Titanate (PZT)**
  - **piezo-electric effect**
- **Shape Memory alloys (Ni-Ti)**
  - **phase Transition**

- **Applications:** actuators, sensors
- **Challenges:** Thin Film Fabrication, Integration

Aluminum nitride (AlN)

Simple, post-CMOS compatible MEMS with complex transistors



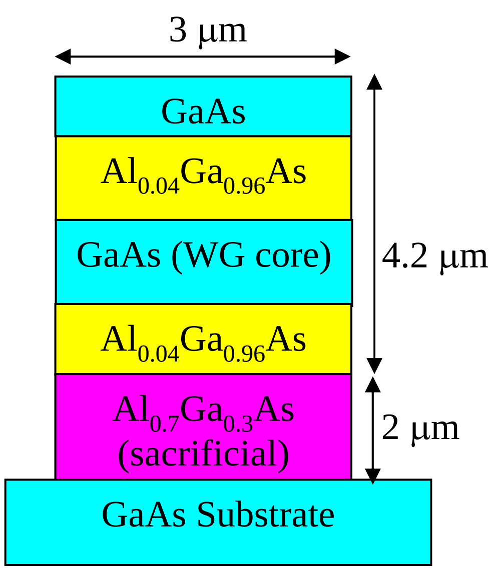


Measured Response of a 5-Element Dual Mode Filter Bank with 50 Ω Termination

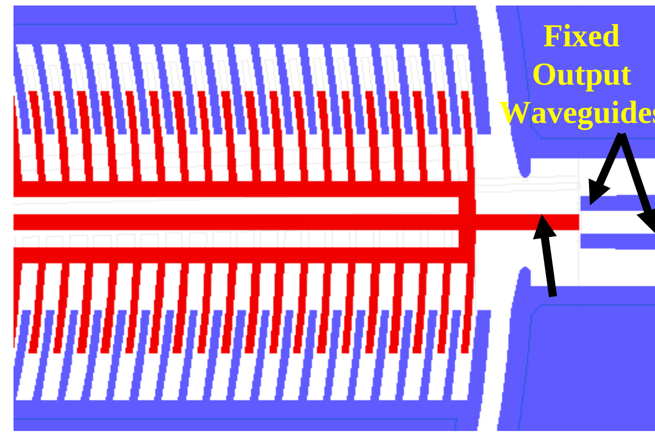
- **Applications:** RF filters, clocks
- **Challenges:**

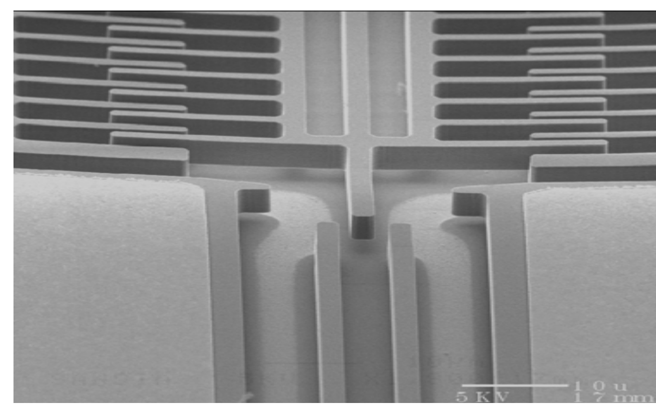
Galium Arsenide (GaAs)

Simple MEMS with complex optoelectronics



Cantilever
cross section

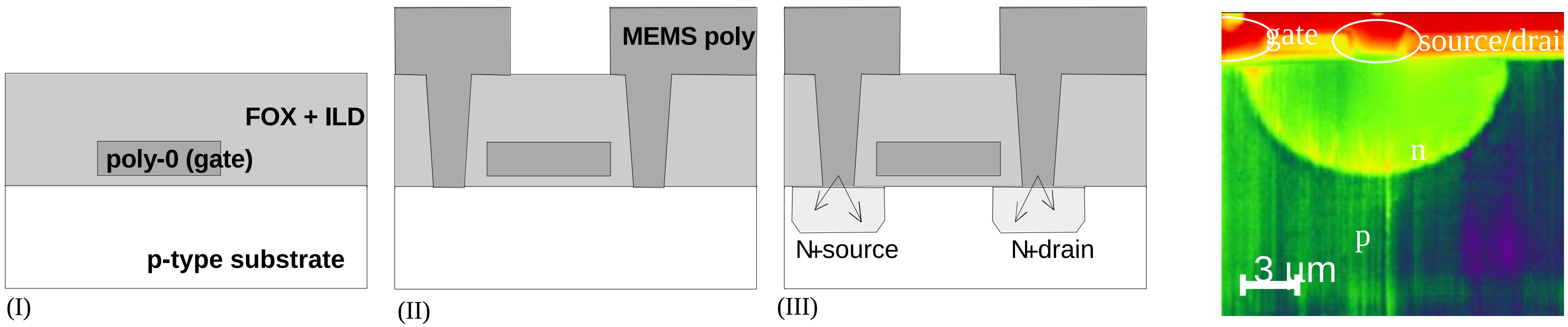


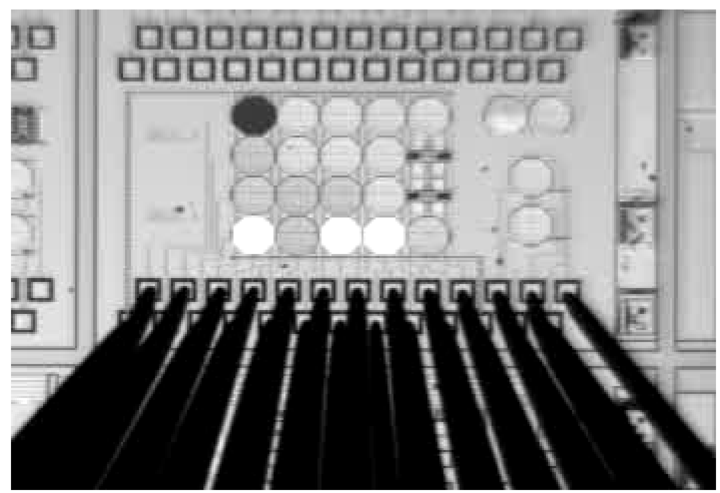


- **Applications:** on-chip signal routing
- **Challenges:**

SUMMiT Field Effect Transistors (SFET)

Complex MEMS with simple transistors

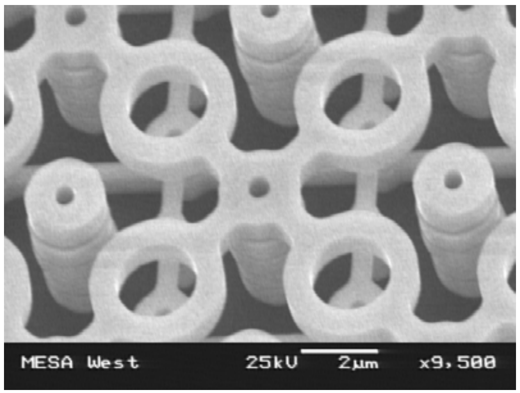




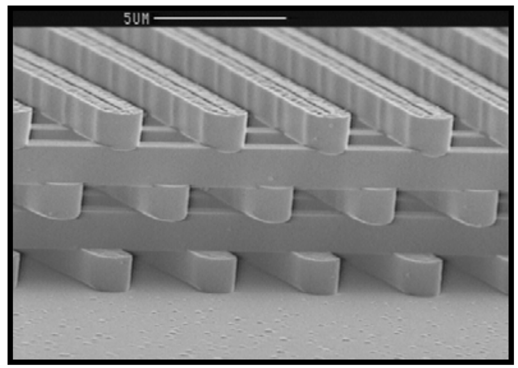
- **Applications:** addressing
- **Challenges:**

Molded Technologies

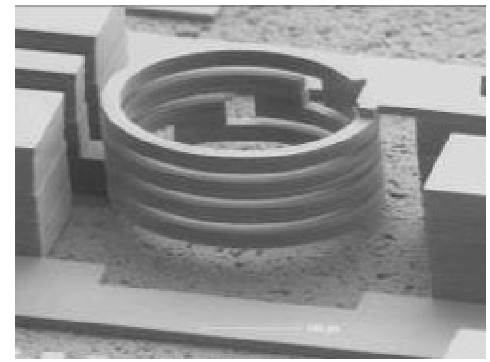
Innovative applications



Ion Trap



Photonic Lattice



Inductor

- **Applications:**
- **Challenges:**

Metal MEMS Technology

EFAB Technology (www.microfabrica.com)

- variety of materials
- 10’s of levels

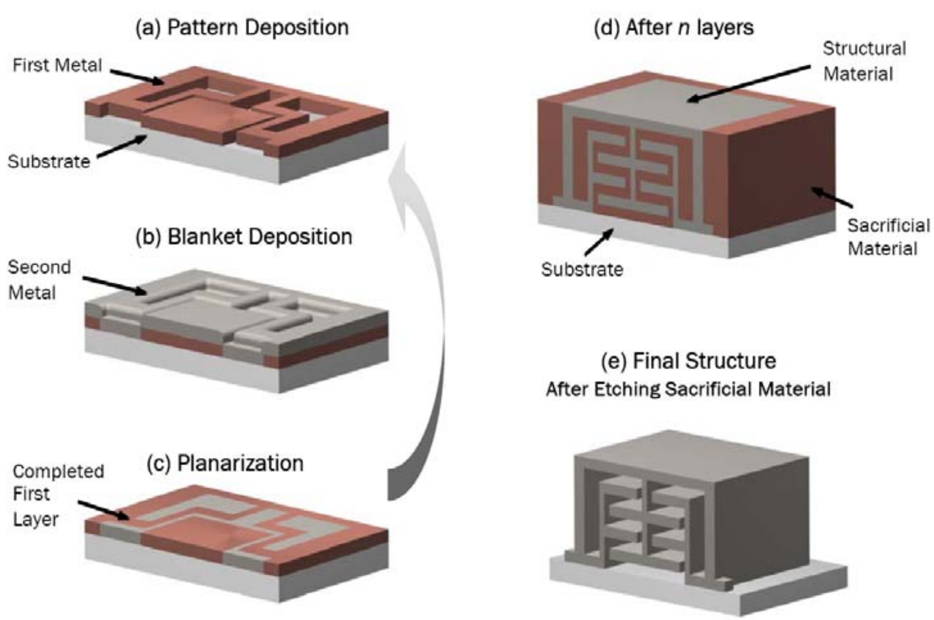
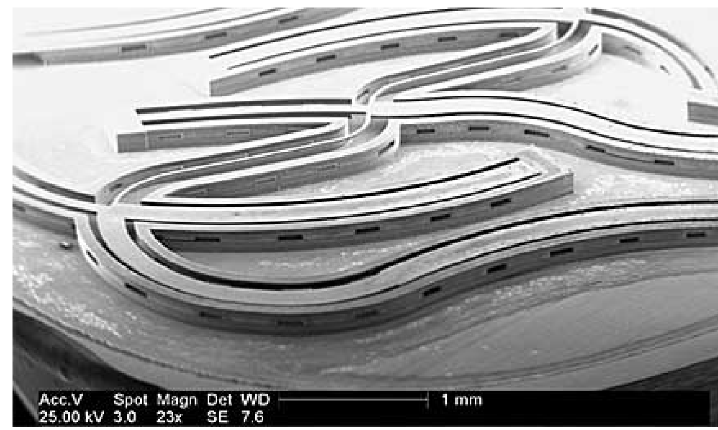


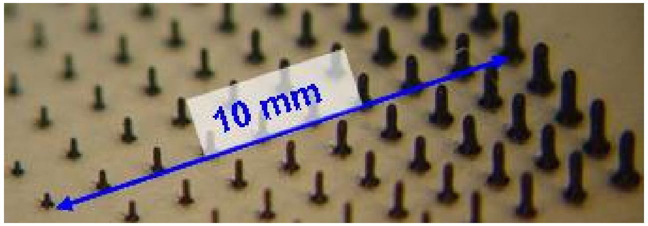
Figure 2.1 EFAB™ Process Overview

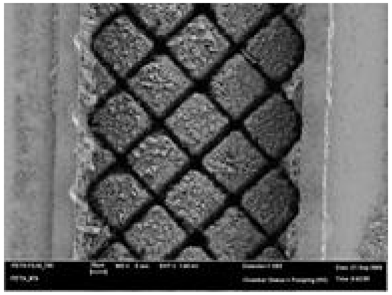


Three Dimensional Micromachined Integrated Coax for a Ka Band Filter

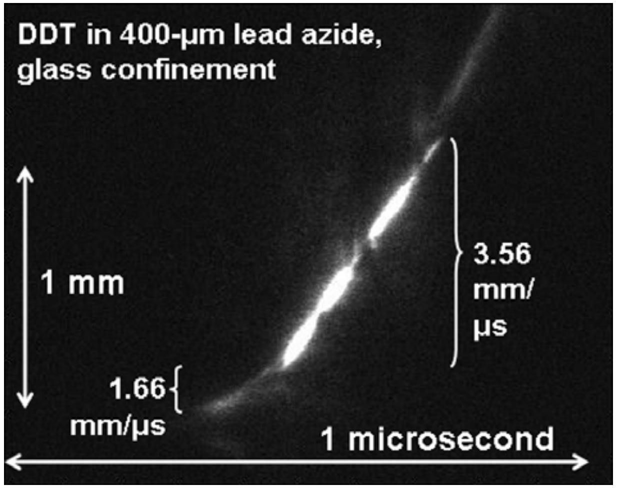
Energetic Materials

- Deposition
  - Fluid based deposition
  - Vapor deposition
- Patterning
  - Photolithographic
  - fs Laser





Patterns in 300-micron wide channels by fs laser micromachining (top) and plasma etching (bottom).



- Applications: Locomotion/propulsion
- Challenges:

Multilayer Dielectric Mirrors

- **High Reflectivity required for optics for heat dissipation and optics requirements.**
- **Single layer mirrors coating of Si, Au, Al, Ag are used but are not sufficiently reflective <100 nm**

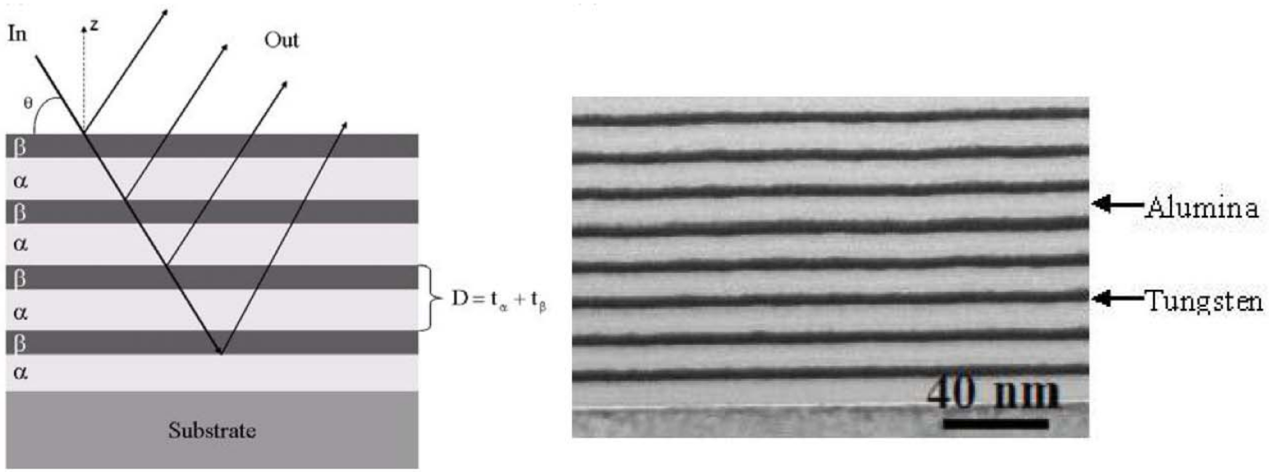
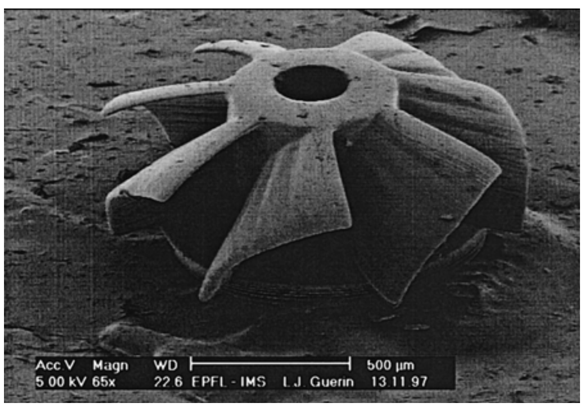


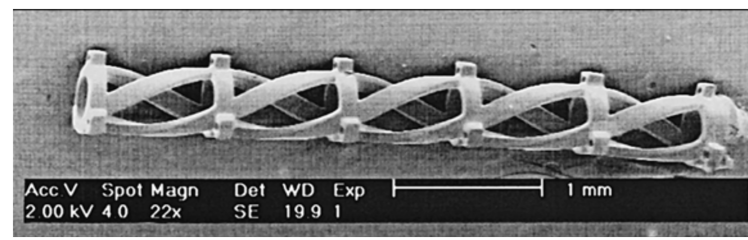
Figure 2: (a) Illustration of multilayer mirror structure, (b) TEM image[29] of the cross section of an Al_2O_3/W multilayer stack on a bulk substrate.

M. Tripp, et. al., Multilayer coating method for s-ray reflectivity enhancement of polysilicon micro-mirrors at 1.54 A wavelength, Proc. of SPIE, vol5720, 2005.

SU-8

- EPON SU-8 (Shell Chemical)
  - Thick epoxy-photoplastic hi aspect ratio resist
  - plastic parts, molds, electroplated metal molds





True 3-D Parts!

A. Bertsch, H. Lorenz, P. Renaud, 3D microfabrication by combining microsterolithography and thick resist UV lithography, Sensor & Actuators 73, pp 14-23, 1999

Materials for Electrical Contact

- **This is an issue for MEMS because**
  - **sticksion/adhesion**
  - **resistance degradation**

! Actuators 73 (1999) 138–143

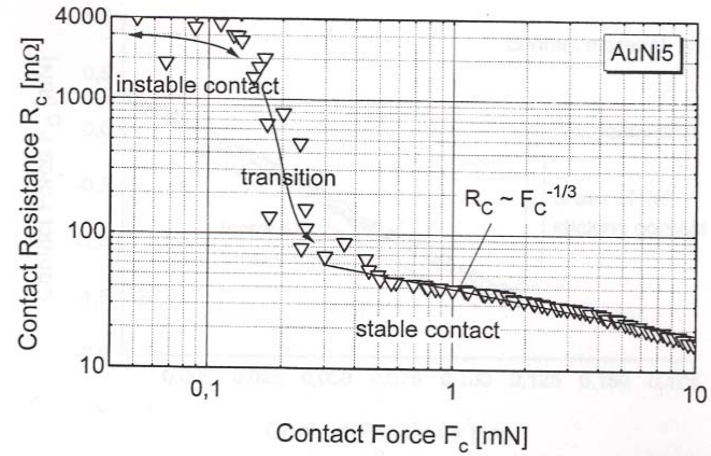


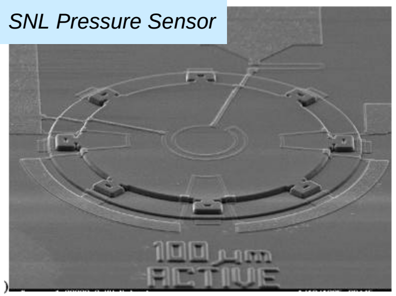
Fig. 4. $R_c - F_c$ characteristics of closing AuNi5 contacts: unstable contact at very low force, transition to lower resistance and the domain of stable contact with the measured resistance force characteristic compared to theoretical relationship according to Holm's model, from Ref. [6].

Taxonomy of MEMS devices

Class I

No Moving parts

SNL Pressure Sensor



Pressure Sensors
Inkjet Print Heads
Strain Gauge

Class II

Moving Parts, No Rubbing or Impacting Surfaces

RF Oscillator

Image courtesy of SI Time

Gyros
Accelerometers
FBAR
(Film Bulk Acoustic Resonator)
RF Oscillators

Class III

Moving Parts, Impacting Surfaces

TI DMD Pixels

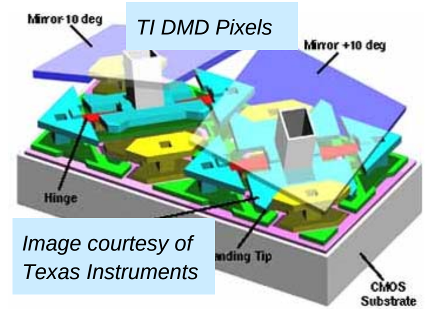


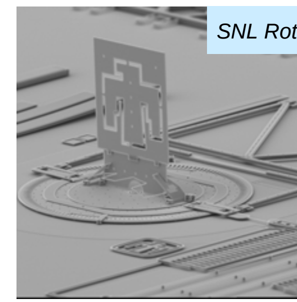
Image courtesy of Texas Instruments

Texas Inst. DLP
Accel. with stops
RF Switch
Adaptive Optics
Optical Switch

Class IV

Moving Parts, Impacting and Rubbing Surfaces

SNL Rotary Mirror

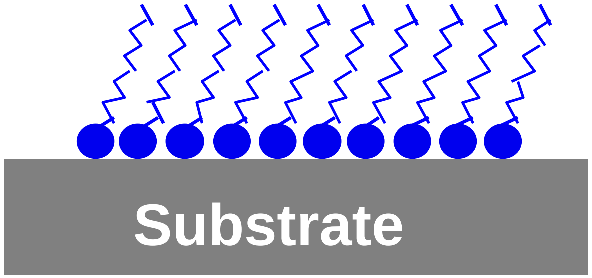


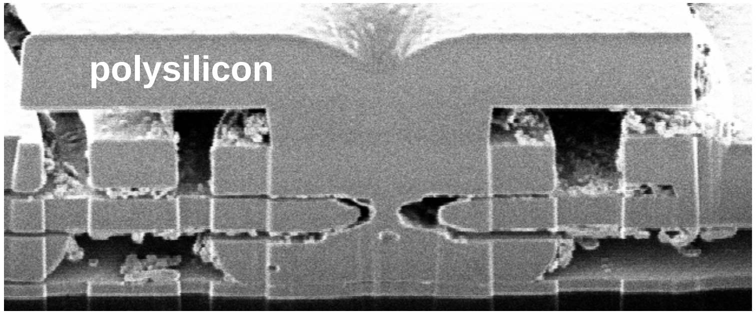
Optical Switches
Shutters
Scanners
Locks
Discriminators

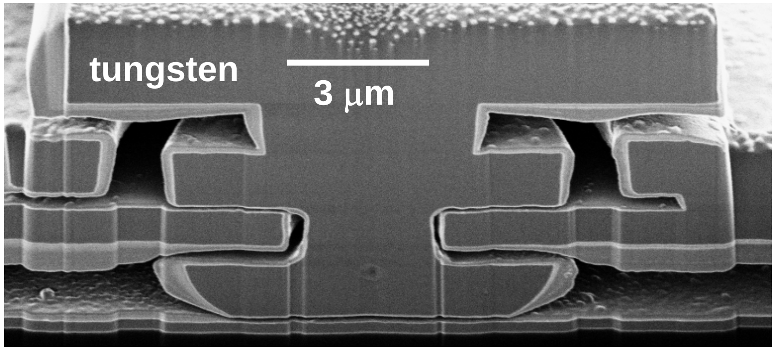
Materials to Combat Wear

- Use of Vapor-Deposited Self-Assembled Monolayer (VSAM) coatings reduce stiction after release

FOTAS
$C_8F_{13}H_4Si(CH_3CH_3N)_3$







- Selective Tungsten

What about CNT or Nano?

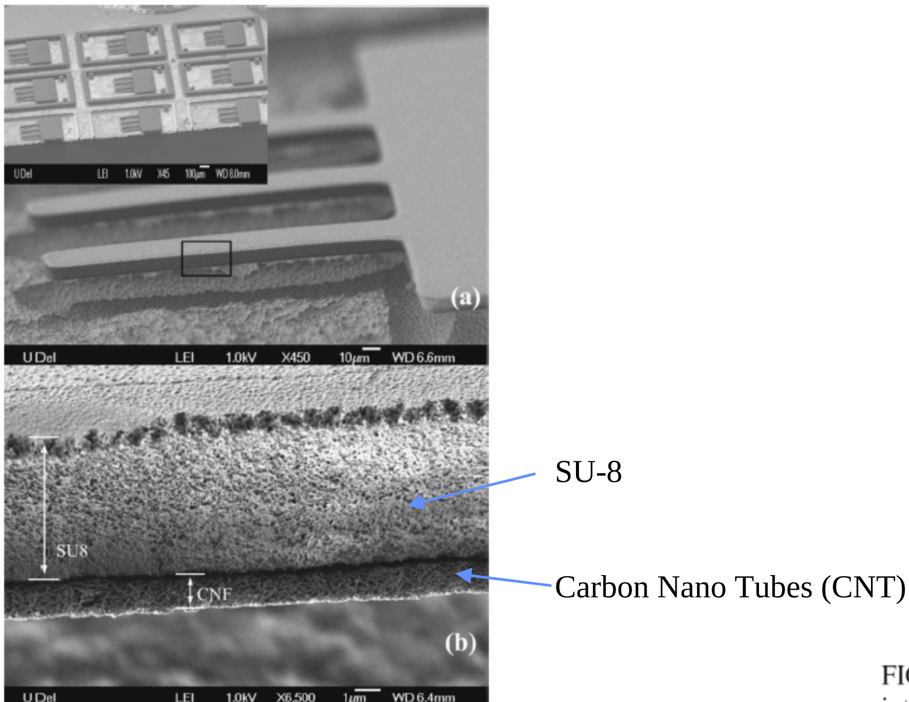


FIG. 3. (a) SEM image of released CNF/SU8 actuators. Insert: SEM imag of a 3×3×3 actuator arrays. (b) SEM image of the squared region in (ε showing the bilayer cross section of the actuator.

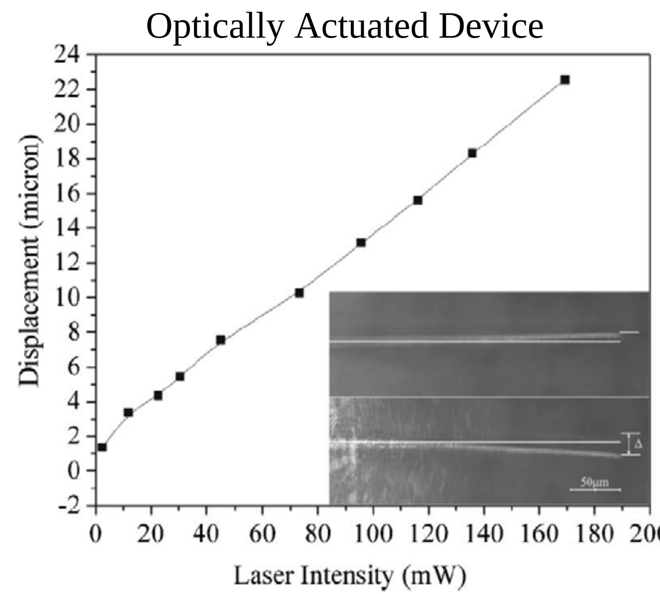


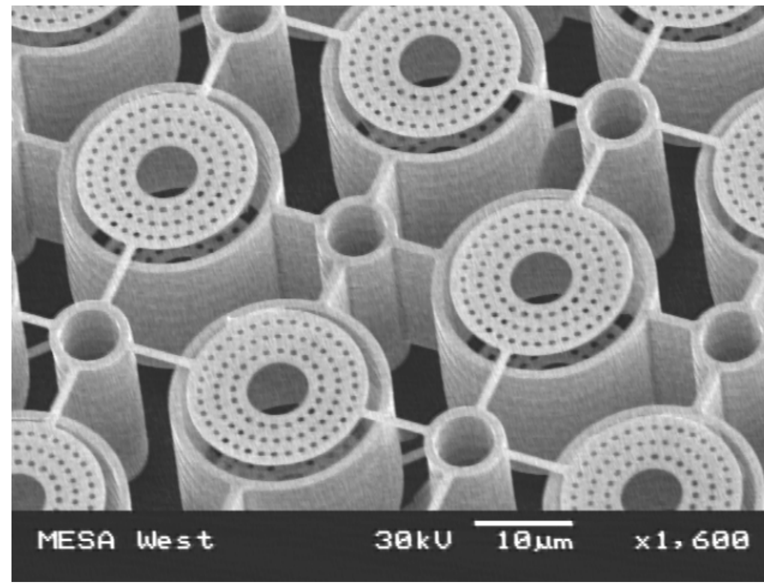
FIG. 4. The displacement of the CNF/SU8 actuator as a function of the laser intensity. Insert: Cross-sectional view of actuation under laser light stimulus. Straight lines were drawn for eye guidance.

S. Lu, B. Panchapakesan, Nanotube micro-optomechanical actuators, Appl. Phys. Lett, Vol. 88, 2006.

Optically Actuated Device?

Opportunities

- Enable new applications
- Enhance performance
- Higher levels of Integration
- Create Arrays
- Reduce Manufacturing Cost
- Enable work at Micro-Nano Scales



Molded tungsten array of ion traps for mass spectroscopy

Contact Information

James J. Allen
jjallen@sandia.gov
(505) 844-6764

www.mems.sandia.gov