SAND2007-4525C

Advanced Concepts

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration under contract
DE-AC04-94AL85000.

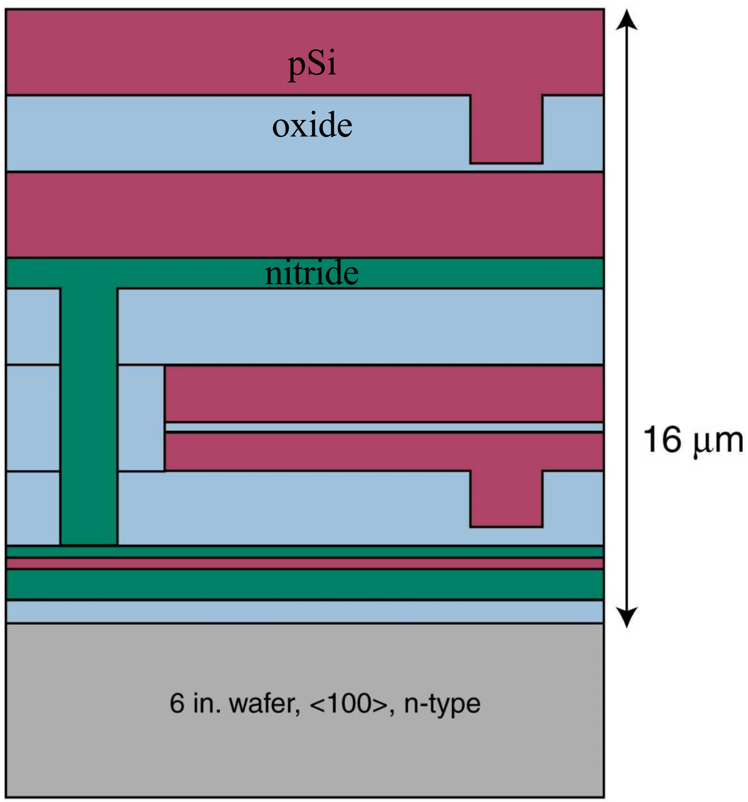
Advanced Concepts

- Modified process flows for specific applications
  - sensors, resonators, BioMEMS, etc.
- SwIFT
  - Microtransfection device
  - DEP gate
- SFET – MEMS integrated electronics
- Waveguides
- Molded Tungsten
- Aluminum Nitride (resonators)
- Retinal Implant
- Actuated Neural Electrodes

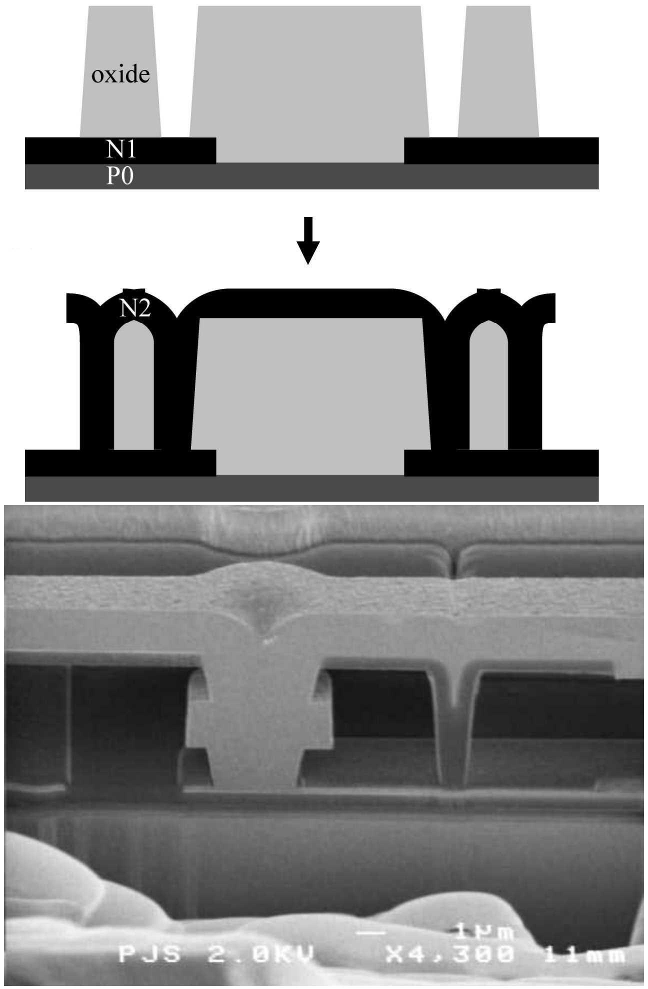
SWIFT

SWIFT

SwIFT ™ (Surface Micromachining with Integrated microFluidic Technology)
sacrificial layers of SiO_2, five layers of doped pSi, ~ 200 nm resolution, three layers of Si_xN_y



Fluidic channel fabrication:



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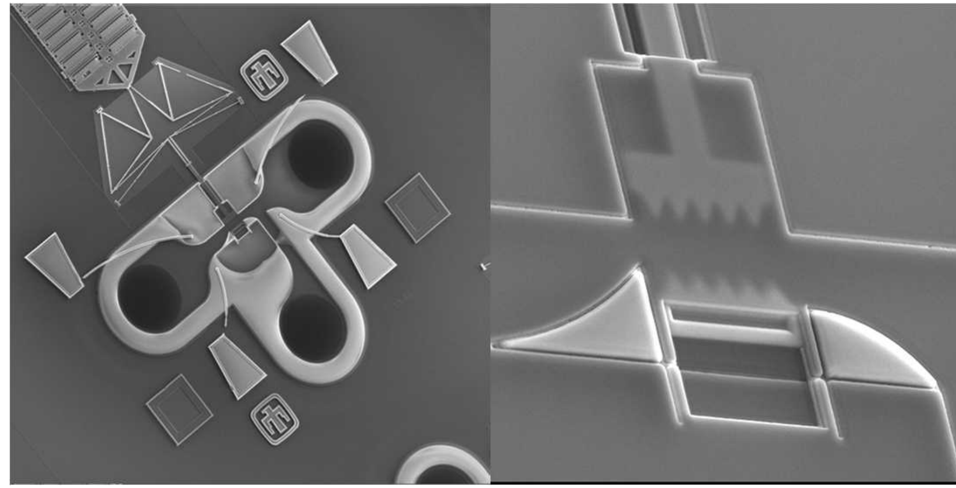
Micro Fluidics with SWIFT

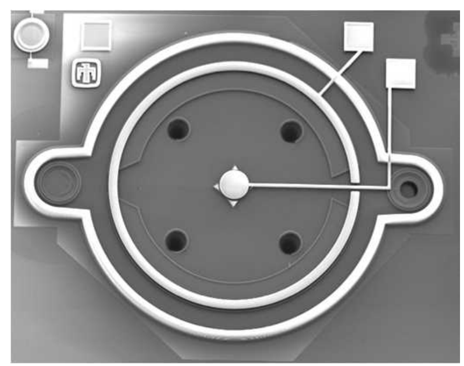
Low stress silicon nitride layers allow the creation of complex microfluidic structures and enclosed cavities with optical access



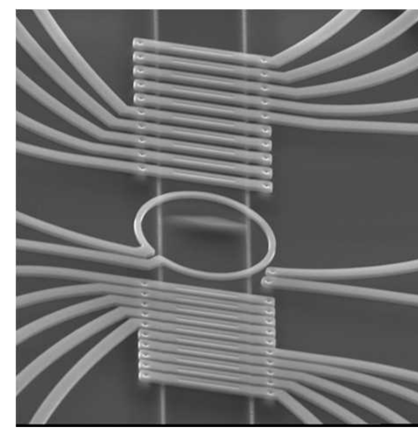
Cellular manipulation

Potential Applications

- -Drug Delivery
- -Bio Sensors
- -Cellular Manipulation
- -Gene Chips
- -Cell Based Assays
- -Environmental Monitoring
- -micro Fluidic mixing/transport

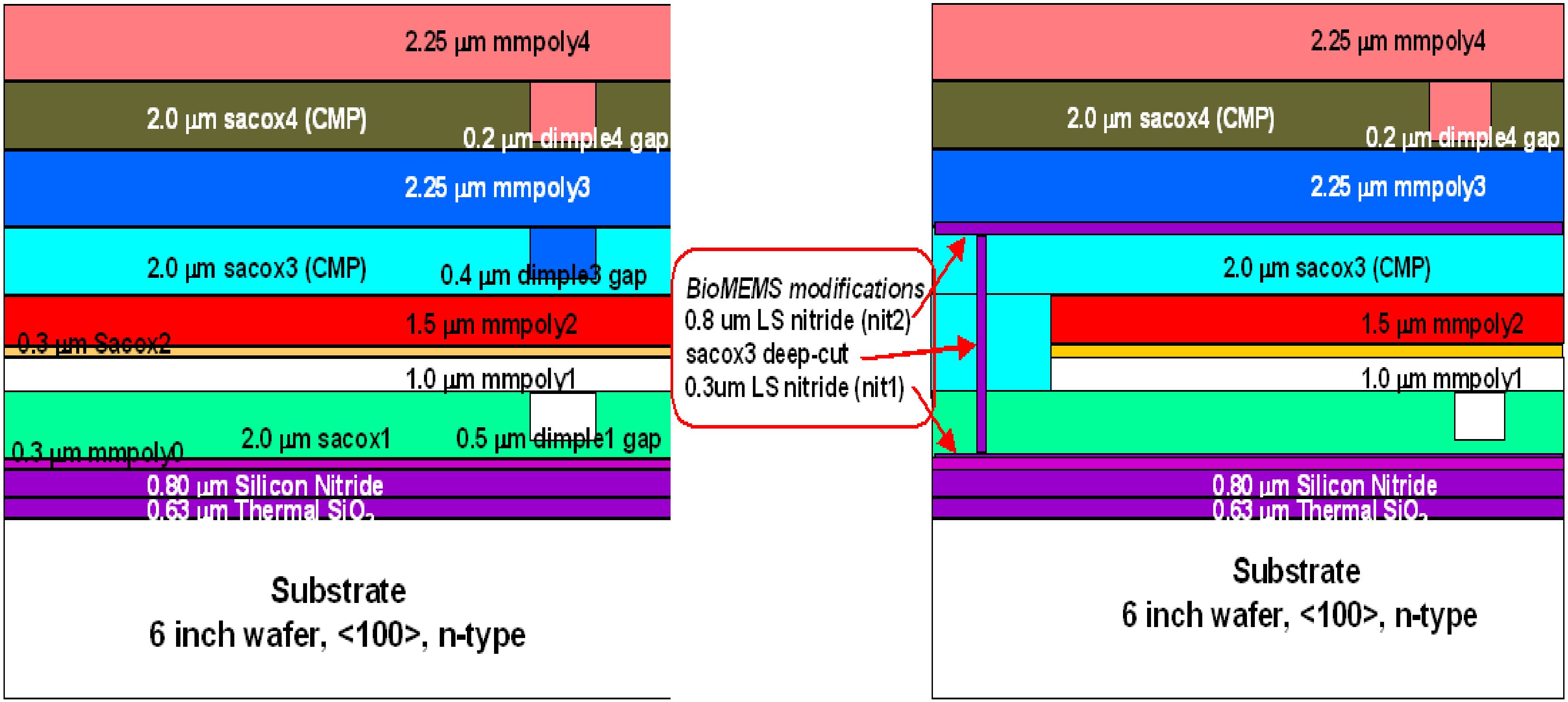


Pumps



Channels

Film Stack SUMMiT Comparison



Standard SUMMiT V™ (left) and SWIFT™ (right) Process layers.

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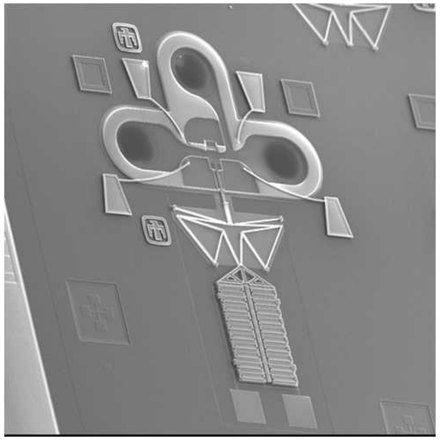
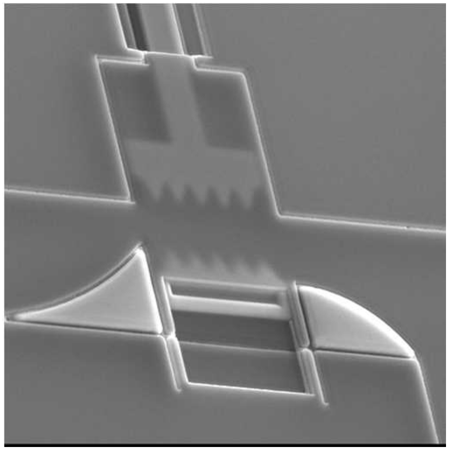
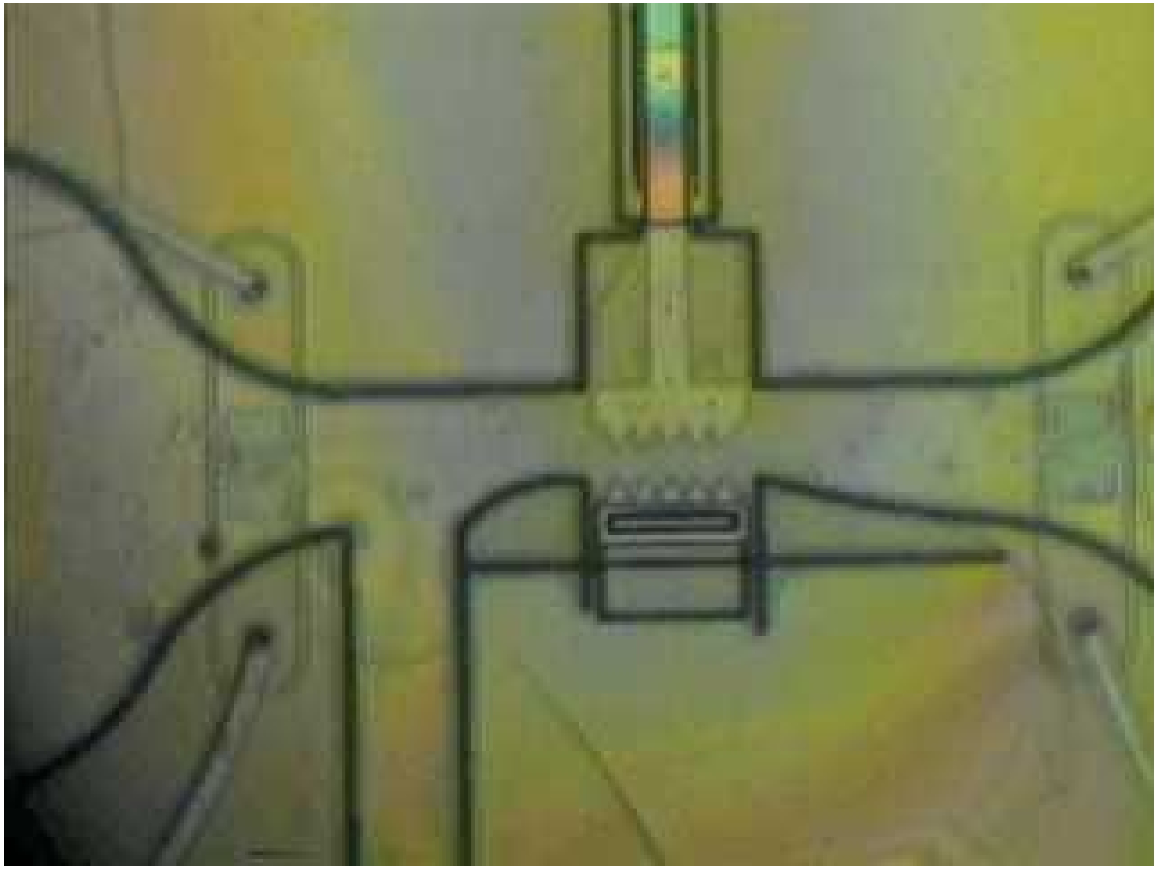
Mechanical Cell Lysis Device - Example

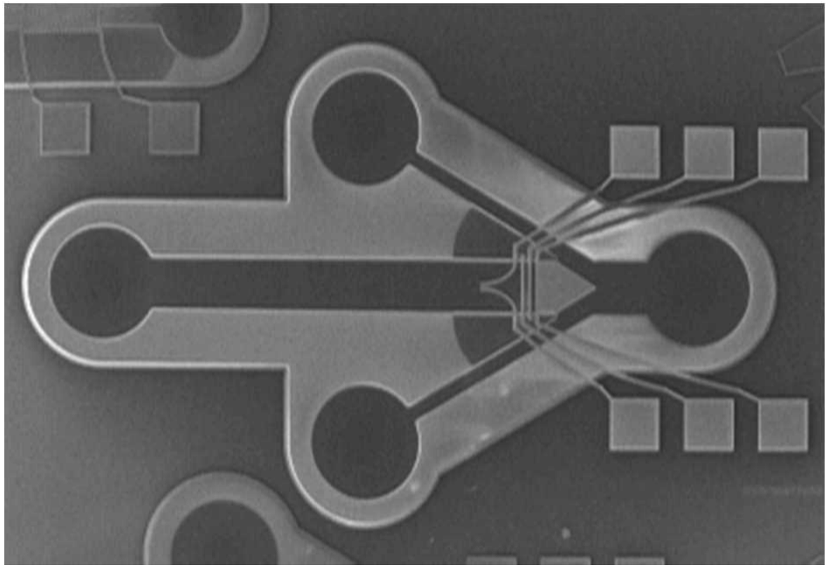






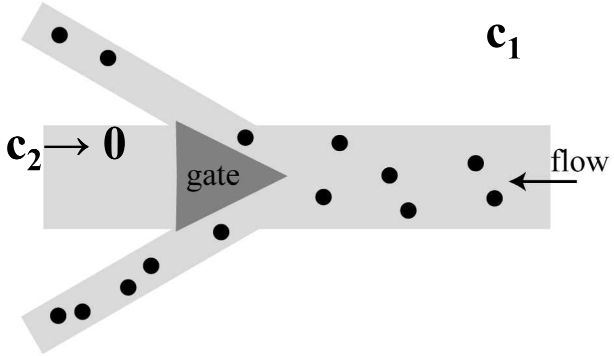
Continuous Flow DEP Device - Example

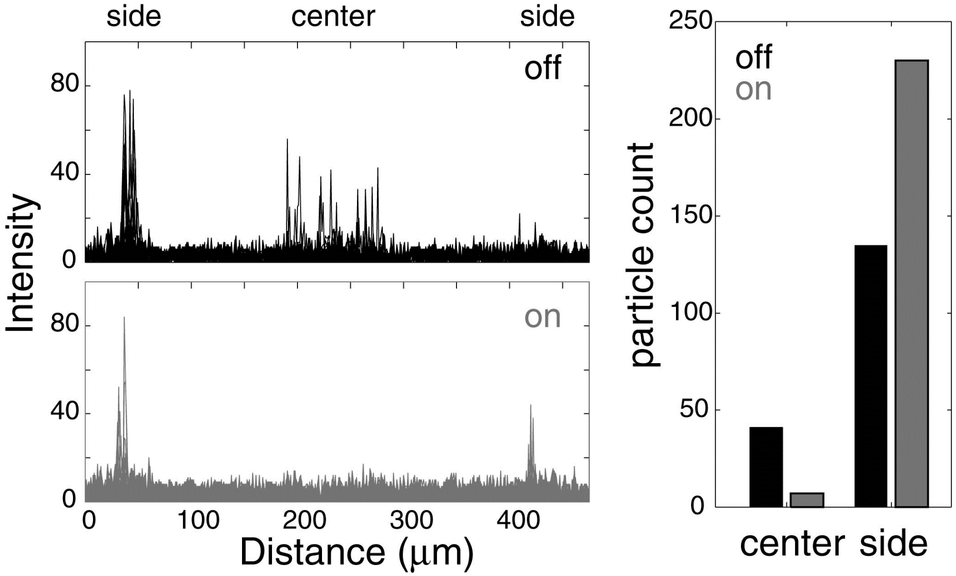
Particle preconcentration (pDEP) and binary valving (nDEP) in a multi-port microfluidic device



Electrodes can be precisely positioned within insulating silicon nitride channels. This allows such applications as on-chip integrated EKP (Electro-Kinetic Pumps) and electrochemical sensors.

Device with a bifurcating dual microelectrode DEP gate





1 µm latex particles, 20 nL/min (velocity ~450 µm/s)

James, et al., J. Micromech Microeng 2006, vol. 16, pg. 1909.

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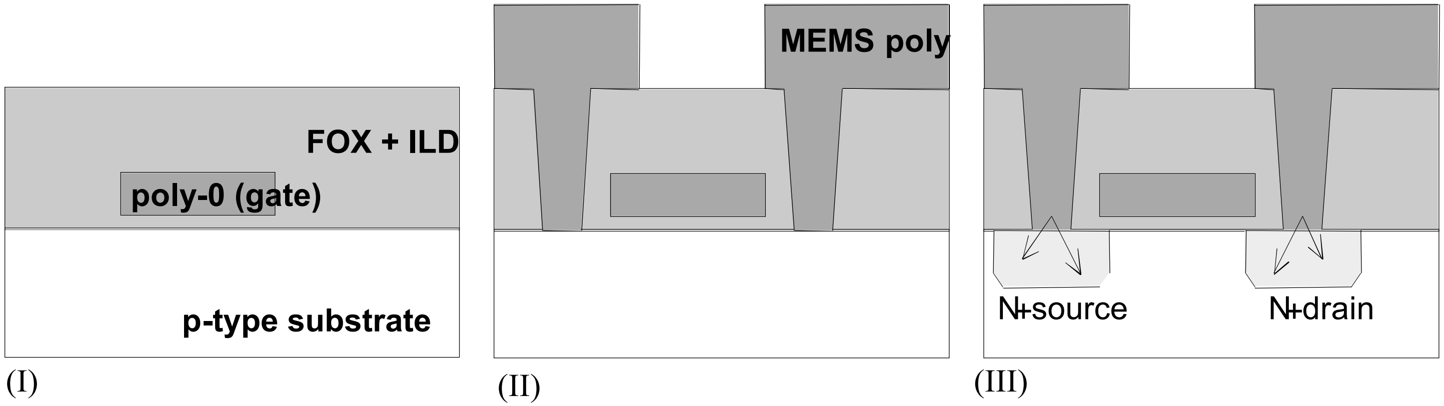
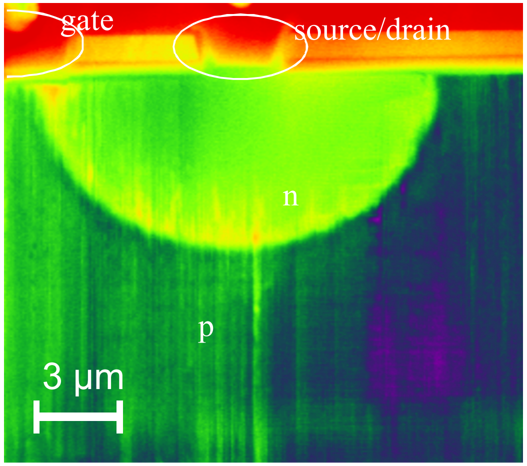
SFET

Integration of Active Devices (SFET)



General process flow for generating the on-chip electronics (SFETs–SUMMiT^{TM} FETs). Contact openings are filled with in-situ doped LPCVD poly, which serves as the source/drain dopant source. These process steps are only slightly different from the MEMS-only flow.



Cross-sectional AFM/SCM (scanning capacitance microscopy) image of a source/drain diffusion and gate region of the sFET. (measurement and image courtesy of Dr. Craig Nakakura, Sandia National Labs).

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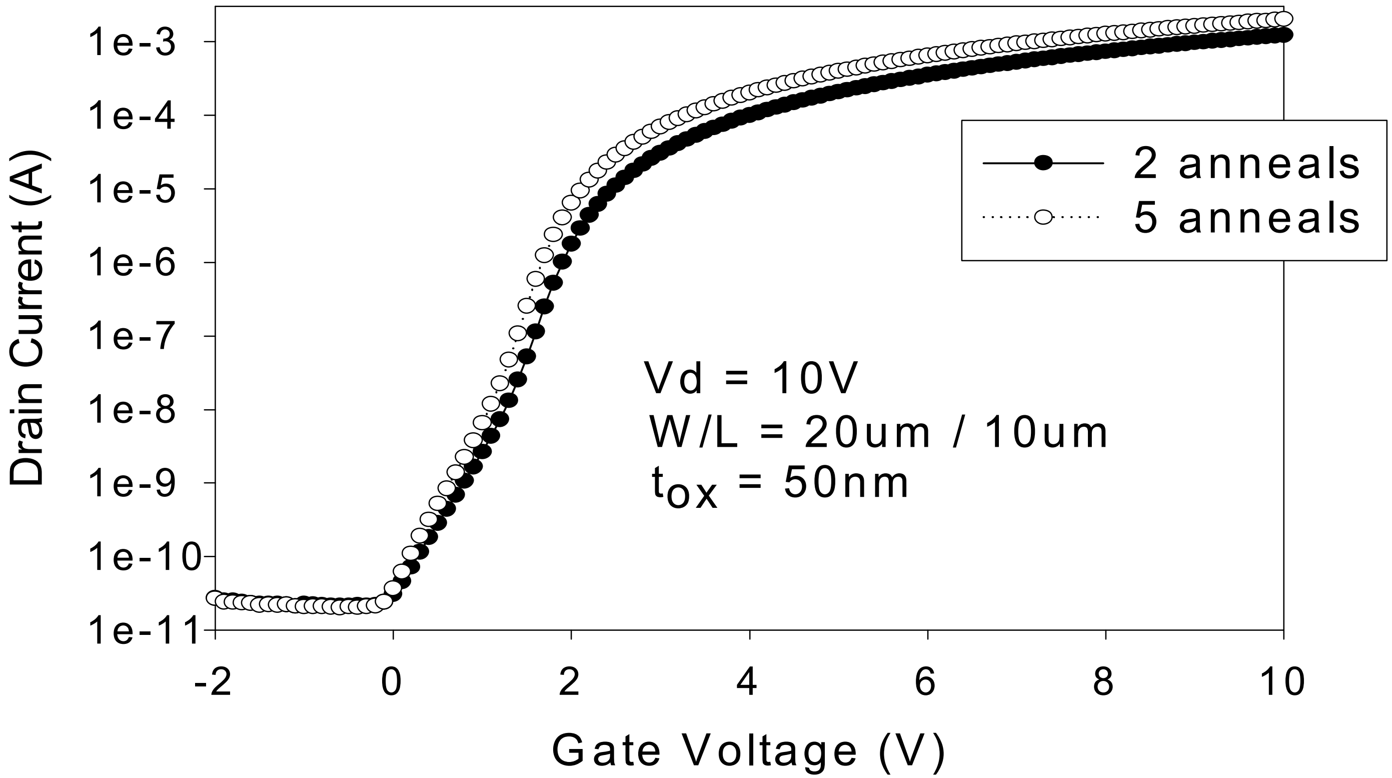
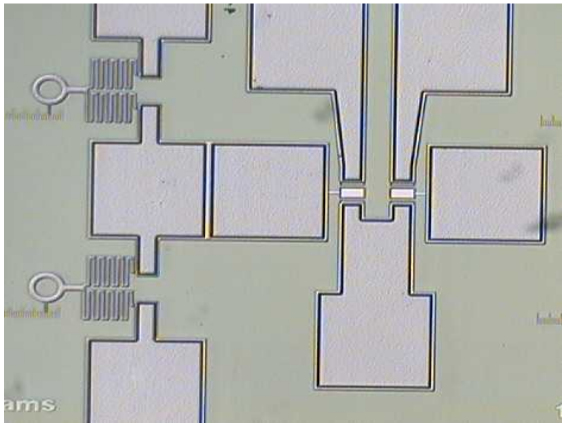
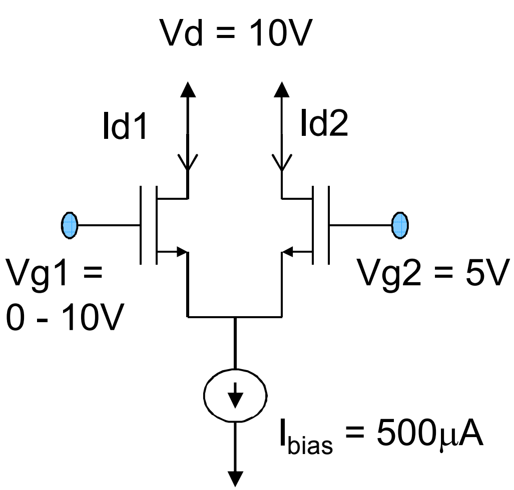
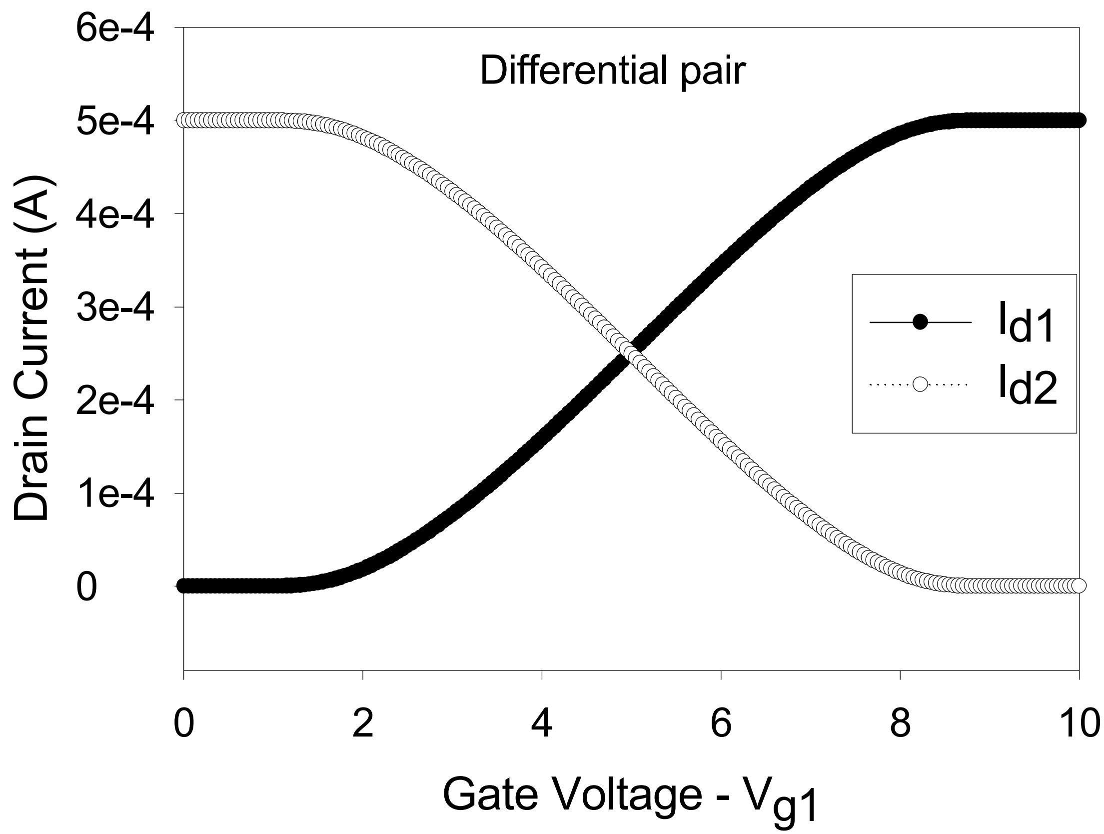
Integration of Active Devices (SFET)



Differential pair (input stage for amplification)







⇒ 10 mV/pC sensitivity

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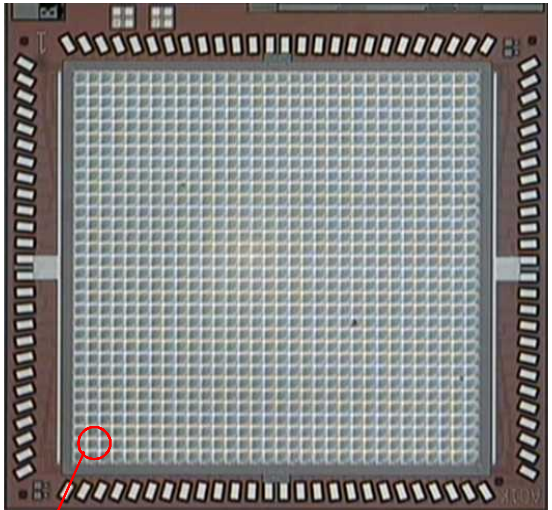
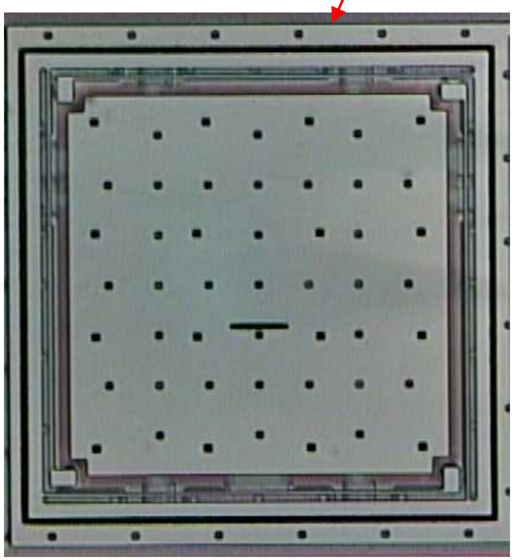
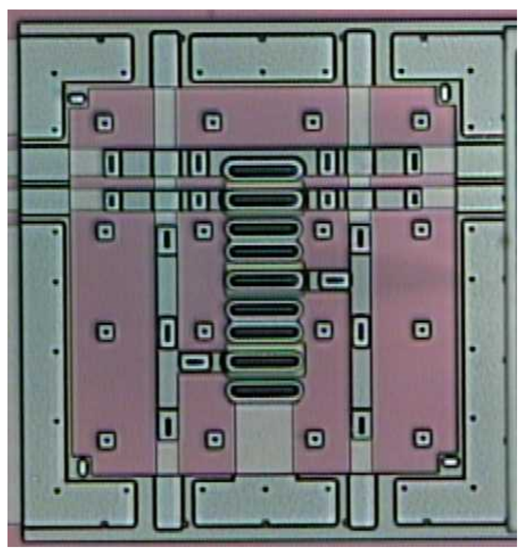
Signal Routing (column-row addressing, mirror array)

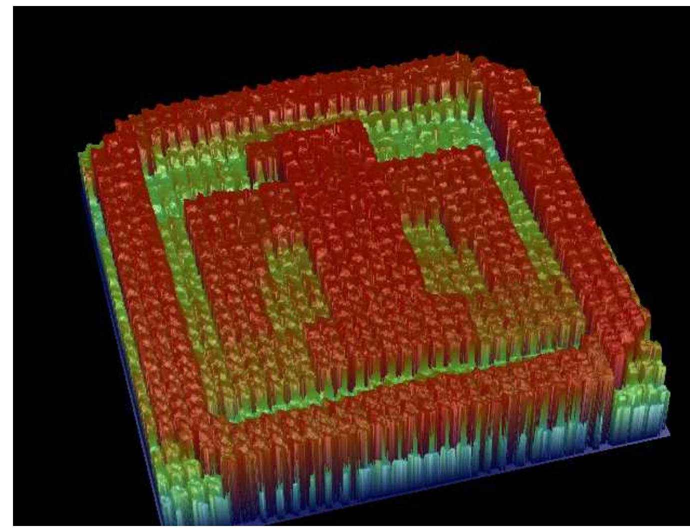
1024 (32x32) piston mirror array







switching circuitry below mirror



W. Cowan, 01742

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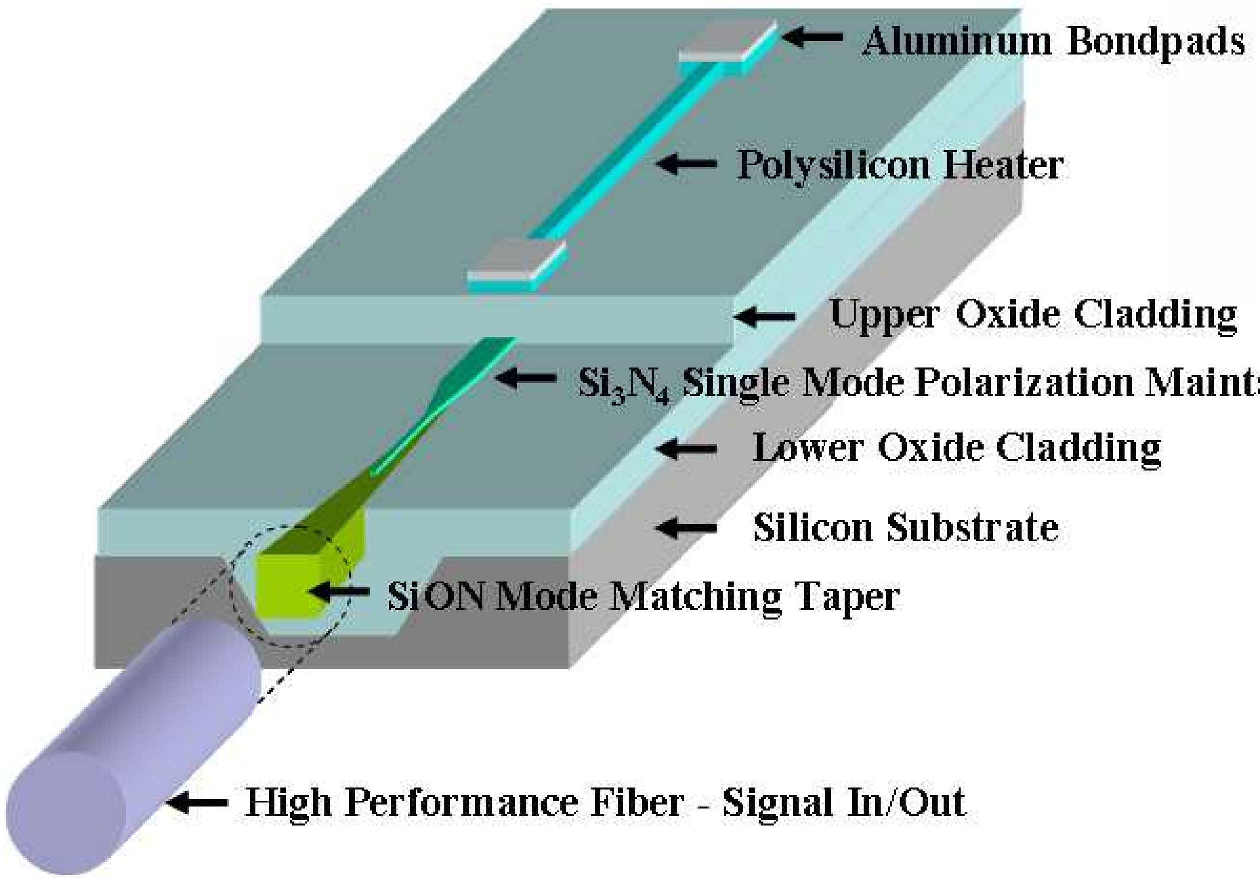
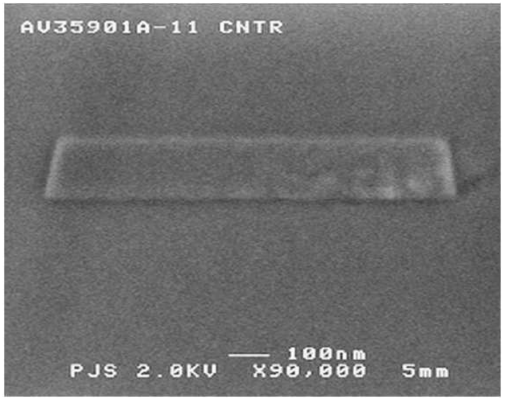
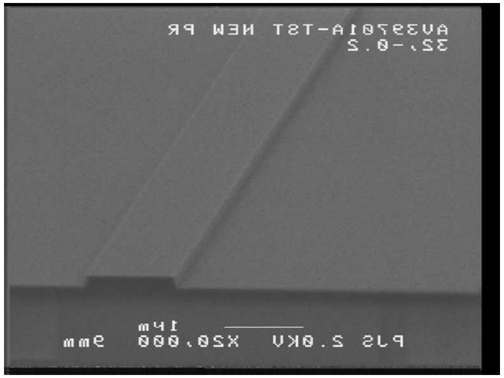
Waveguides

Waveguide Technology







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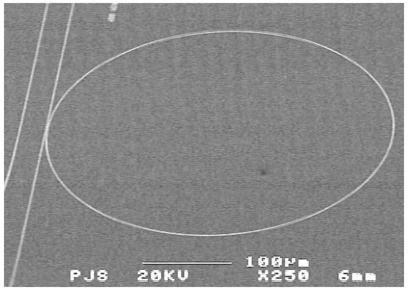
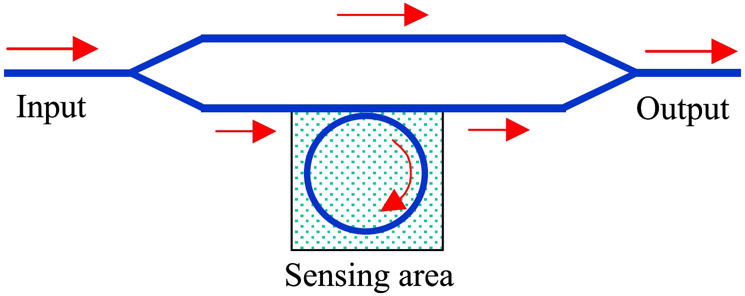
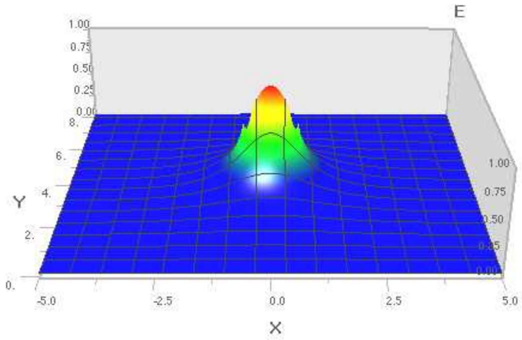
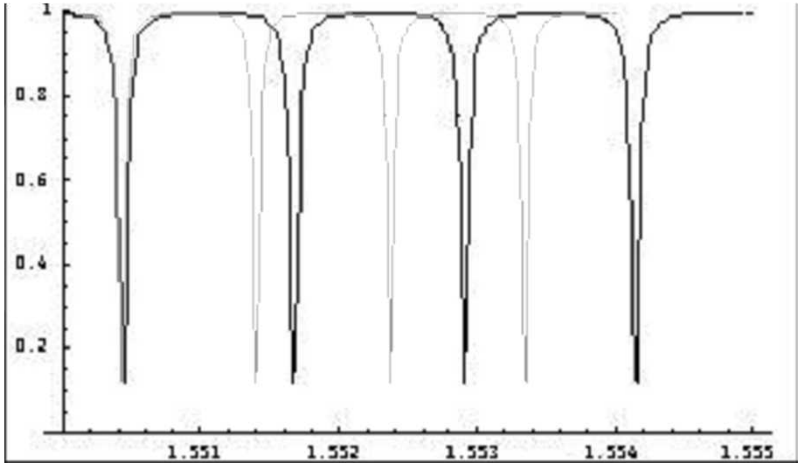
Waveguides as Sensors

- Integrated Photonic Circuits
- Chemical sensing
- Optical filters and resonators for wavelength-sensitive signal processing.









Mode index

Specimen is attached to the top thin cladding of the ring, the mode index of the waveguide ring will change in a predictive way for various substances.

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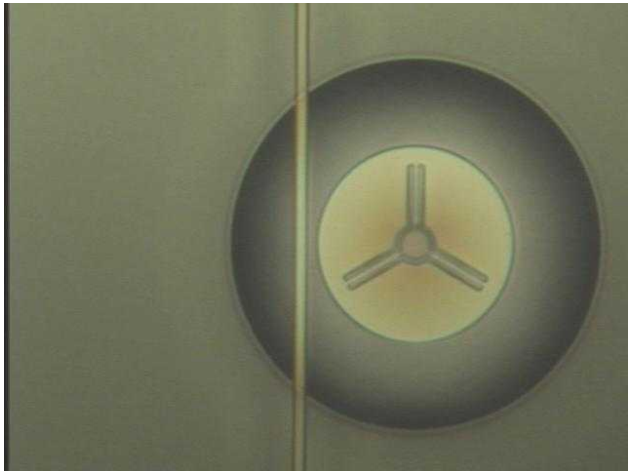
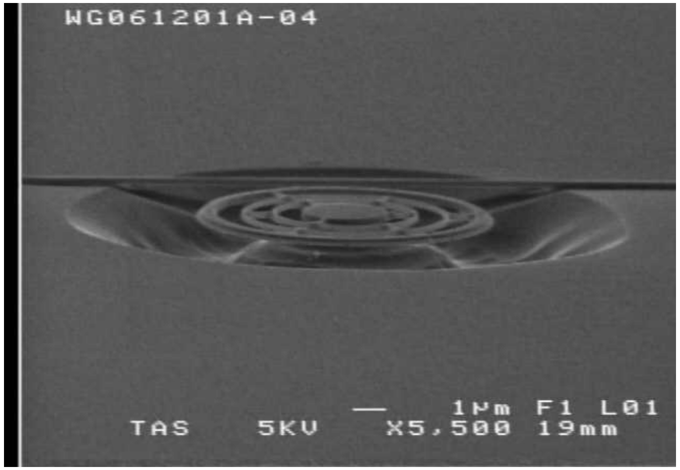
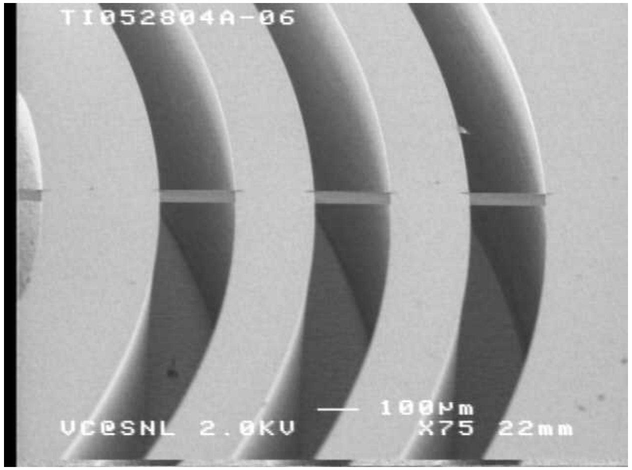
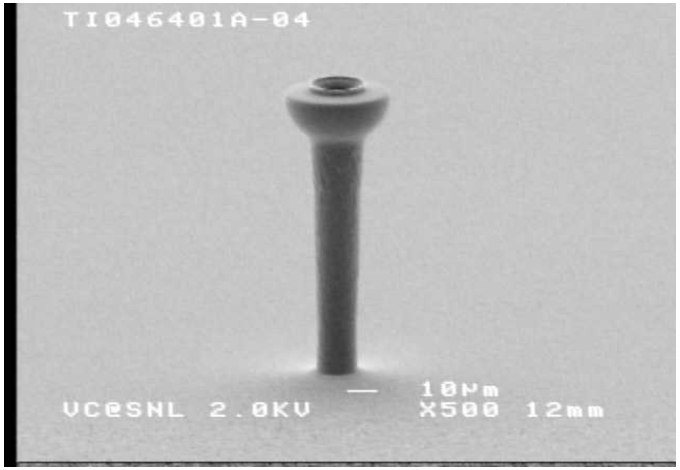
Interesting Geometries









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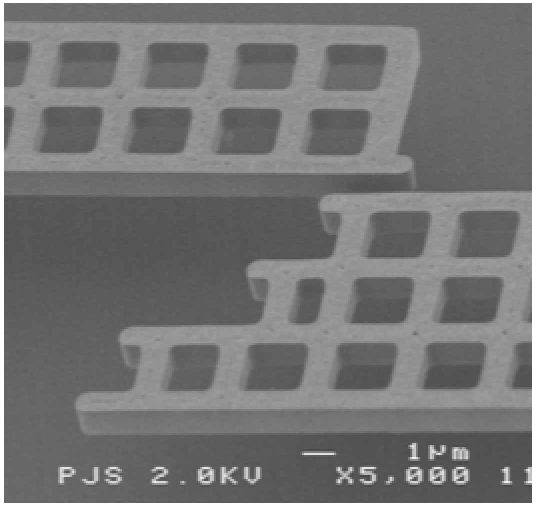
Molded Tungsten

Molded Tungsten (MolTun™)

Molded tungsten technology uses a tungsten damascene process for the fabrication of complex structures.

- Pattern etched into sacrificial oxide film.
- Tungsten is deposited by chemical vapor deposition.
- Excess tungsten is removed by CMP.
- Process repeats, such that subsequent films anchor to previous pattern.
- Sacrificial oxide is removed when structure is complete.



Molded tungsten latching relay

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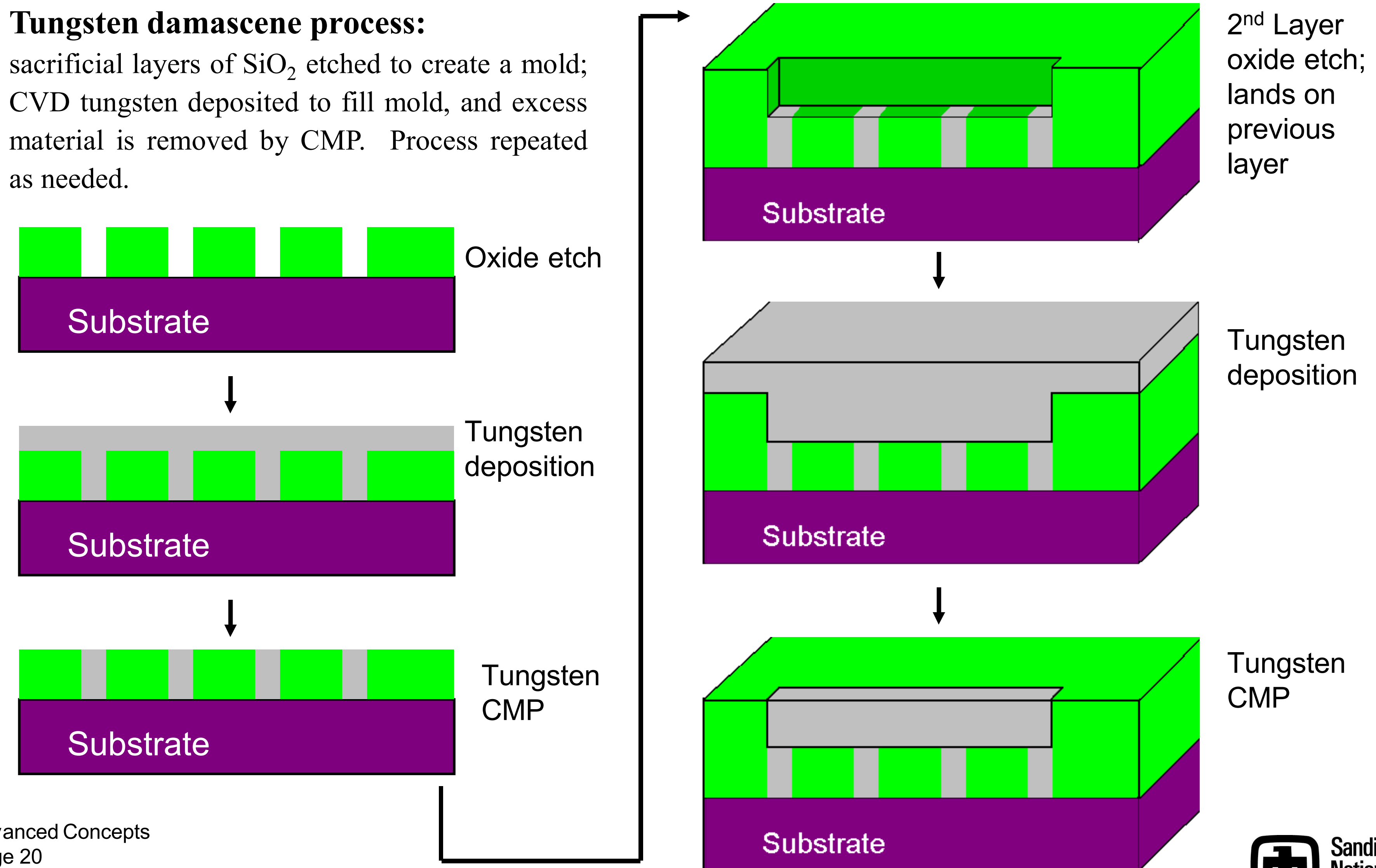
Molded Tungsten Processing

Tungsten damascene process:
sacrificial layers of SiO_2 etched to create a mold; CVD tungsten deposited to fill mold, and excess material is removed by CMP. Process repeated as needed.



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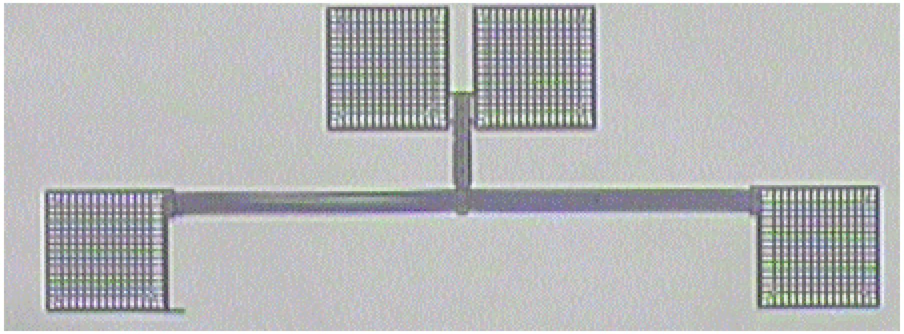
Constraints & Applications

An arbitrary number of layers can be patterned, but…

- Tungsten is tensile; design must accommodate film stress (or may exploit it).
- Individual feature width cannot be chosen arbitrarily – determined by tungsten film thickness.
- Sacrificial oxide is compressive; total film stress must be considered for manufacturability.

Potential Applications:

- -Photonic crystals
  - -Wavelength-specific reflectors & filters
  - -Waveguides
  - -Actuators/Sensors
- -High temperature applications
- -Corrosive environments
- -RF applications



Molded tungsten thermal actuators

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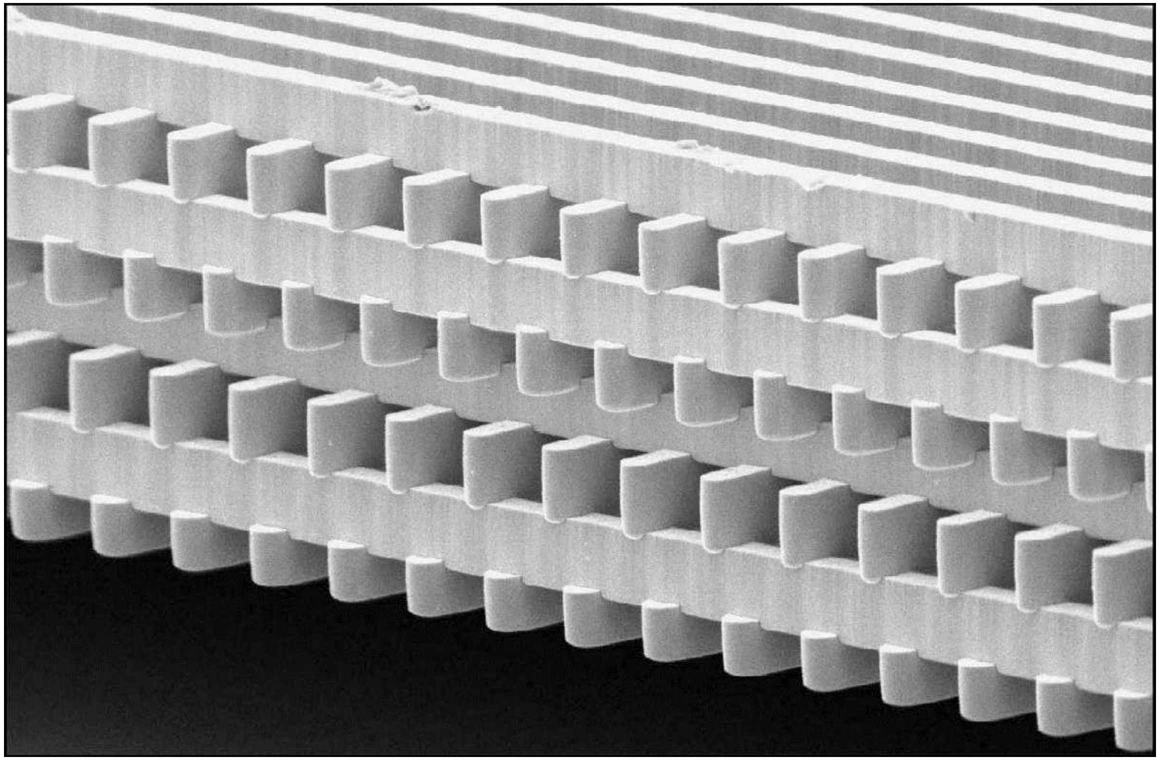
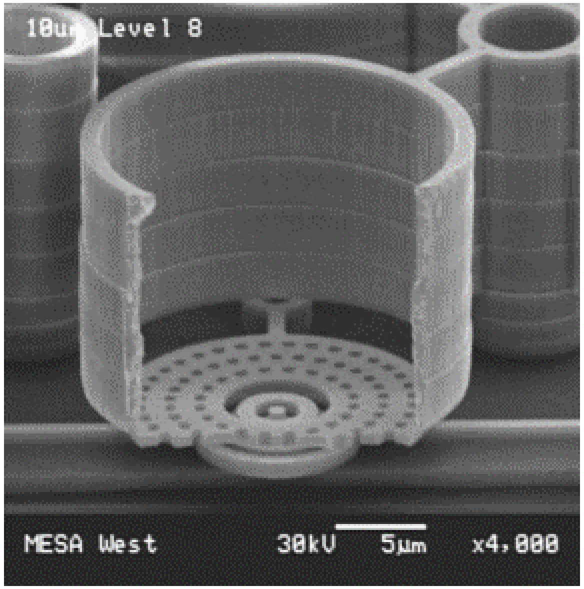
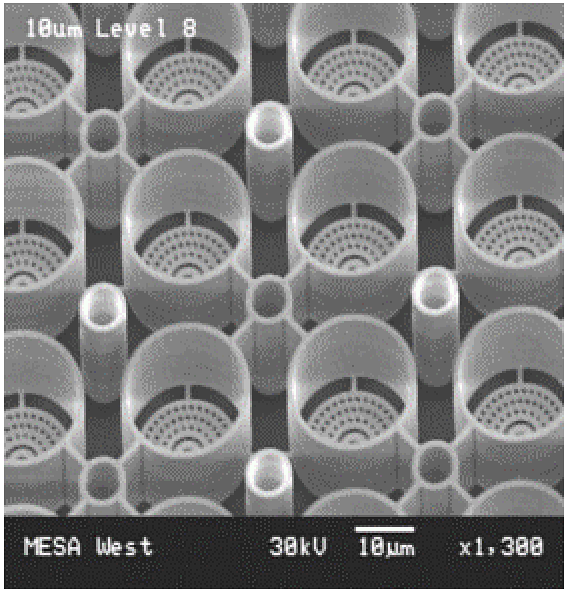
Photonic Crystal - Example



8-Layer tungsten photonic crystal (4-layer periodicity)

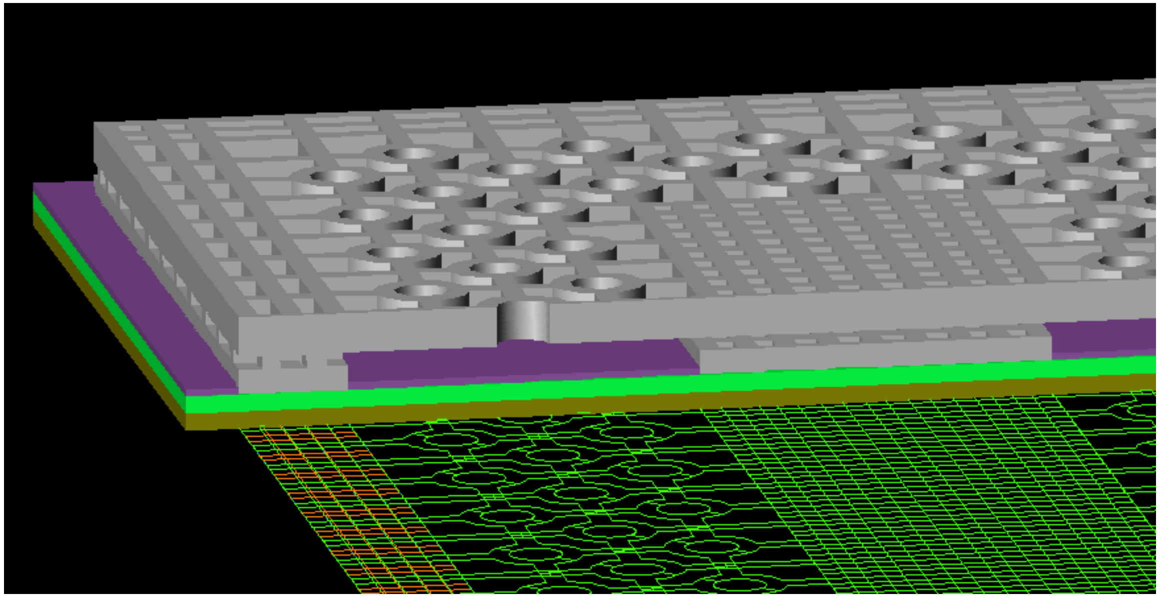
Mass Analyzer - Example





Mass analyzer, prior to upper electrode fabrication

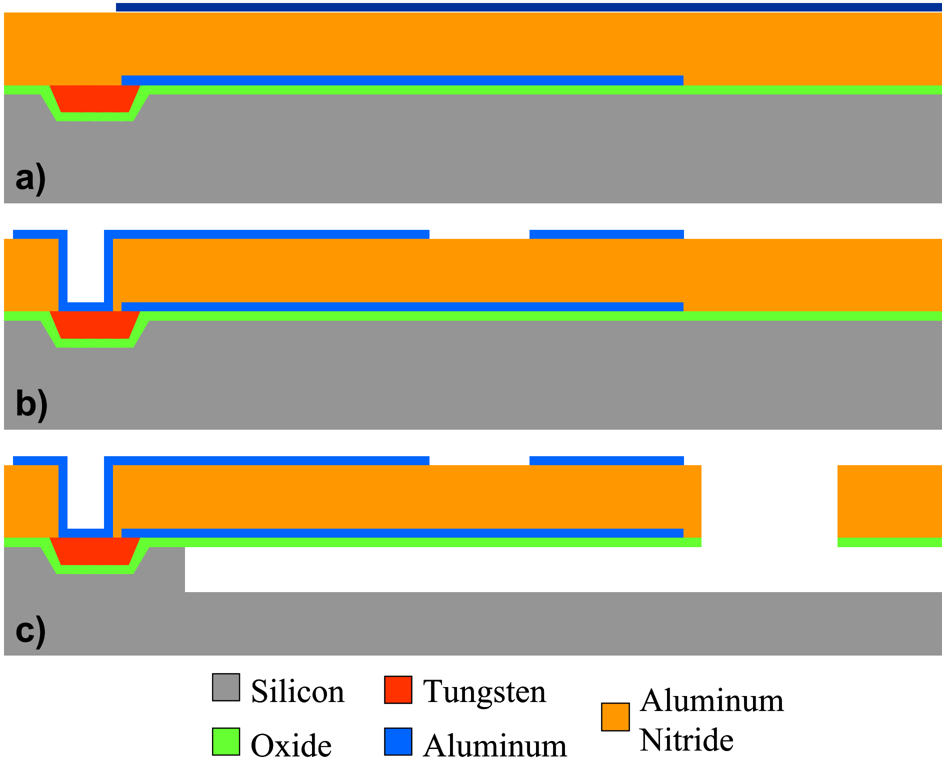
Parallel Plate Sensor -- Example



3-Layer parallel plate sensor (AutoCAD rendering)

Aluminum Nitride

Aluminum Nitride (AlN) MEMS

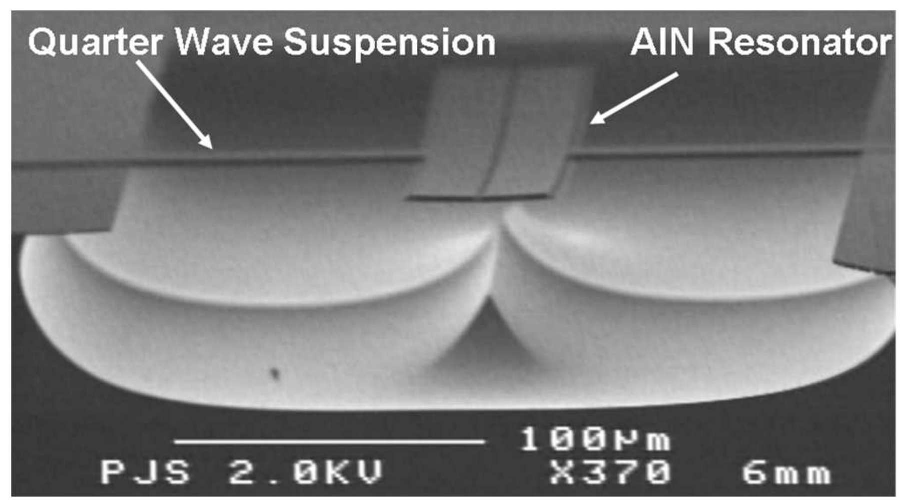


Process Description

- 5 Levels
- Post-CMOS Compatible (T_{max} = *350 C*)
- Highly C-Axis Oriented
- Dry Si Release (No Stiction)

Material Advantages

- Piezoelectric transduction
- Linear transduction mechanism
- Higher displacement for a given voltage
- No bias voltage
- Transduction efficacy dependent on orientation



20 MHz AlN MEMS Oscillator Reference

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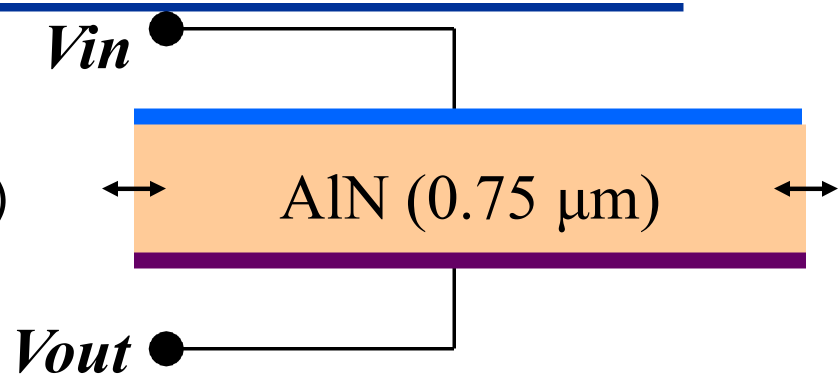
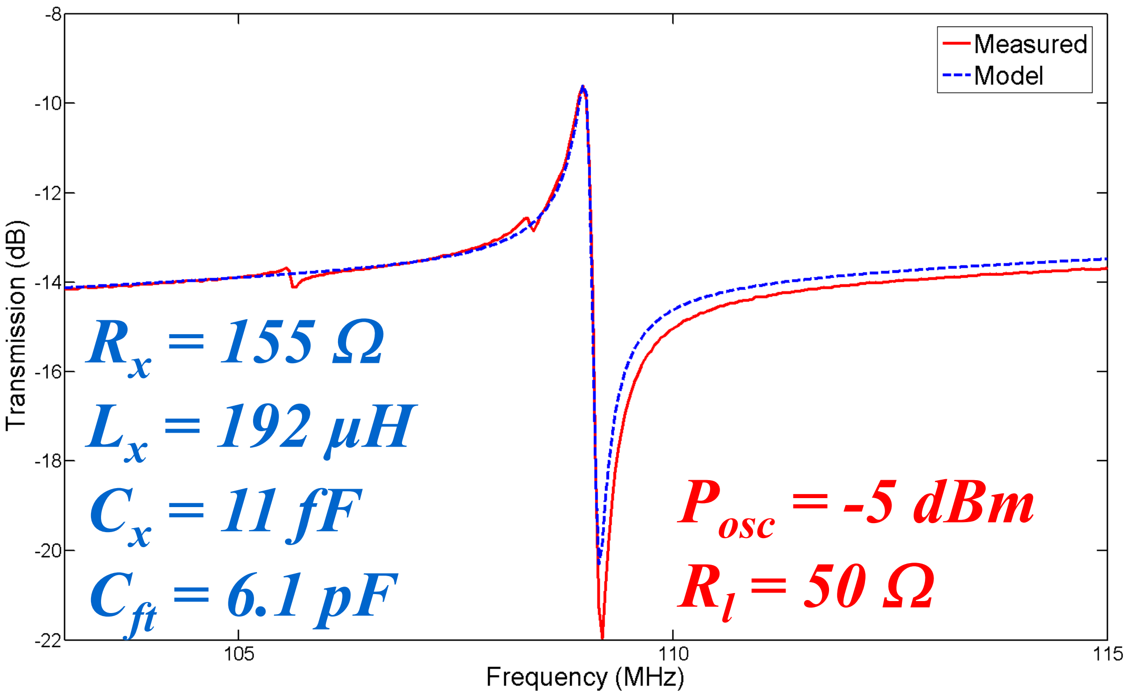
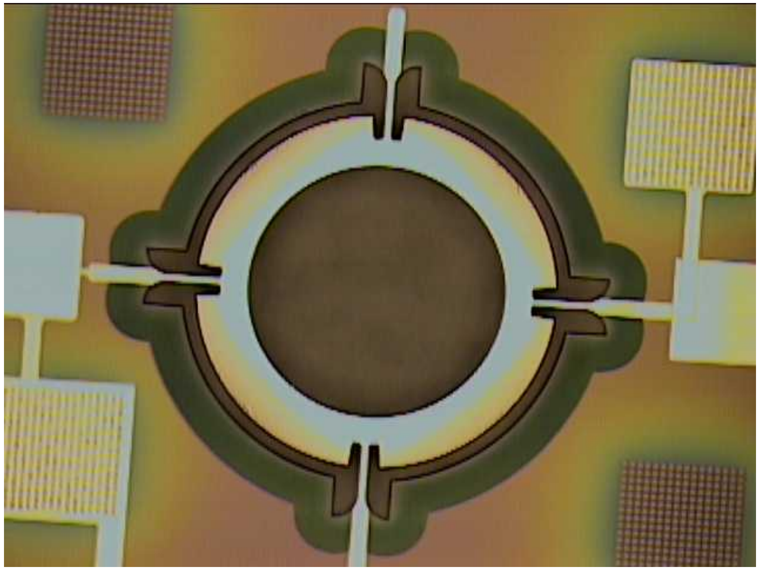
Aluminum Nitride Resonators and Filters

Applications

- RF/IF Filters and Filter Banks
- Resonant Sensors (Inertial, Chemical, Bio)
- Oscillators
- Explosives Characterization

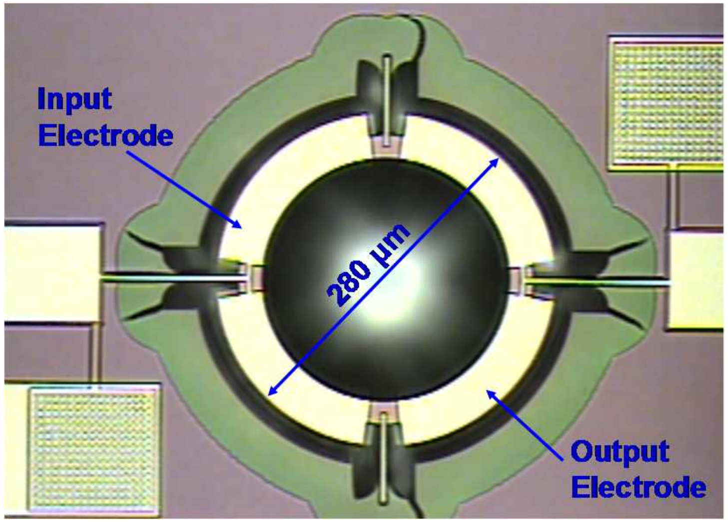


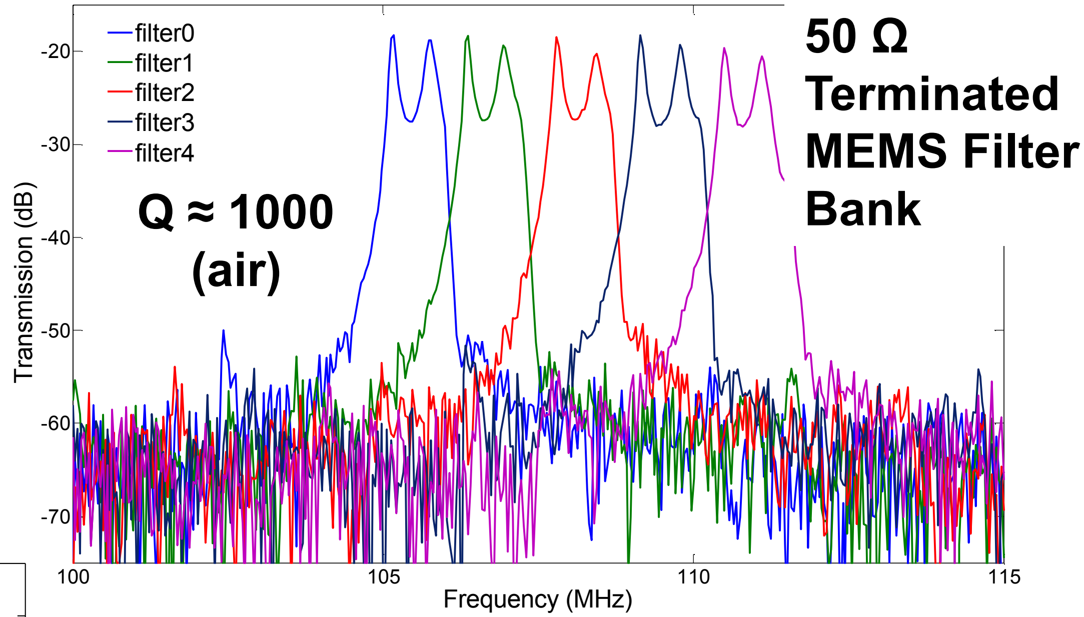


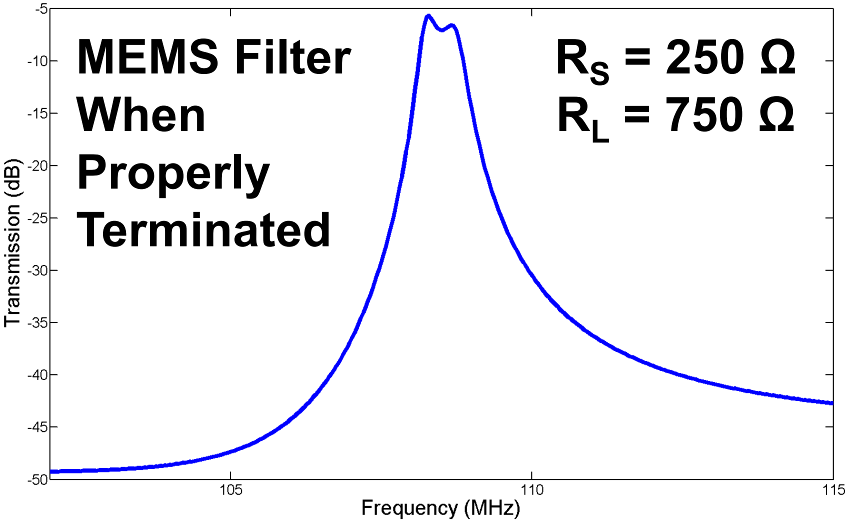


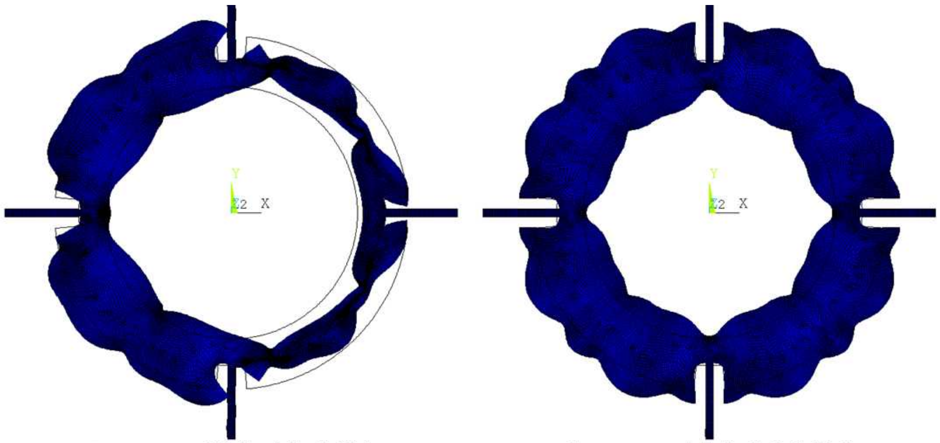
110 MHz AlN Ring Resonators

Dual Mode MEMS Filter Bank - Example





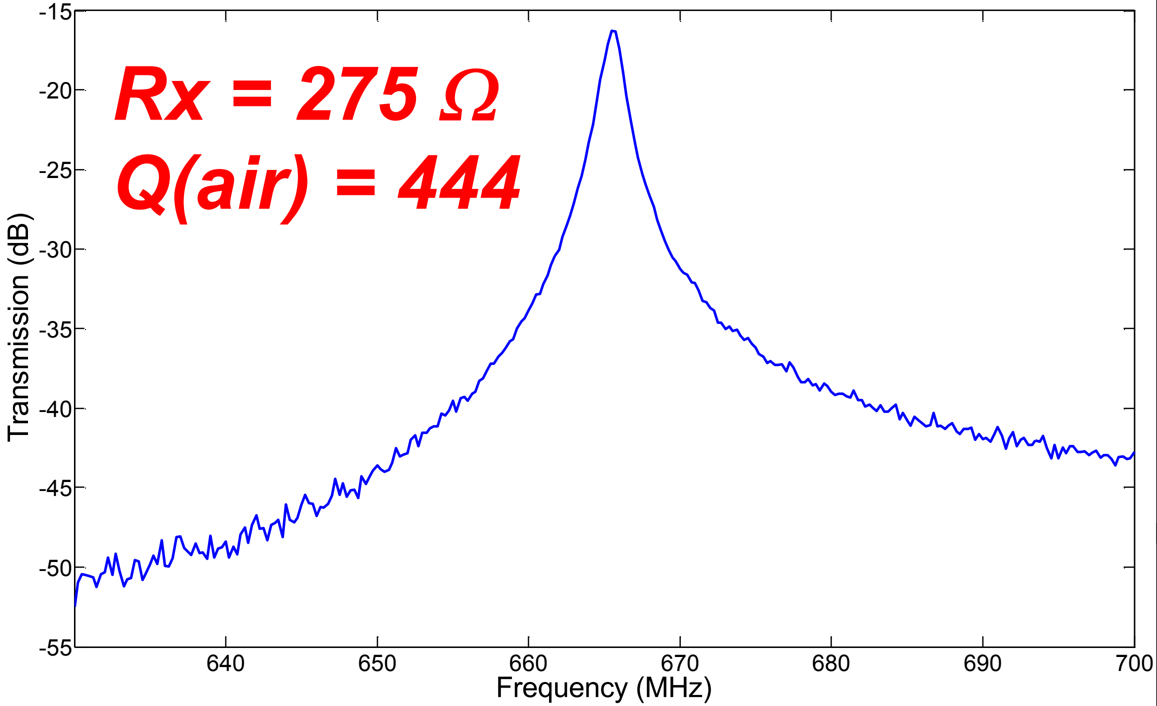


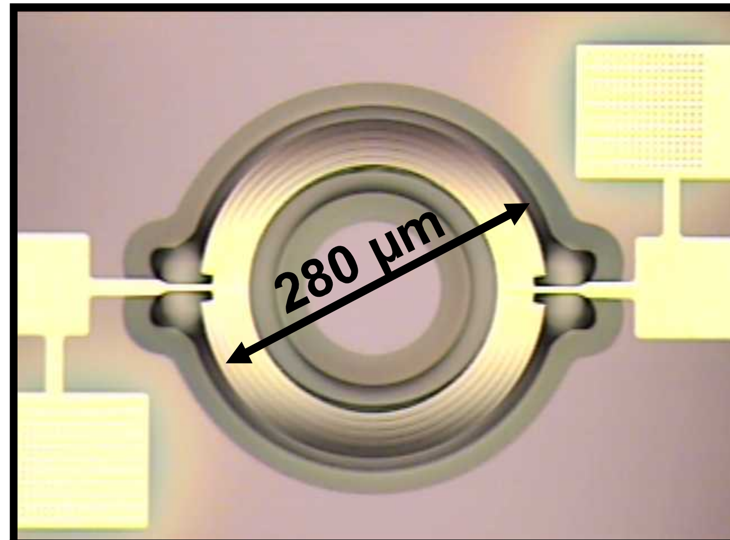


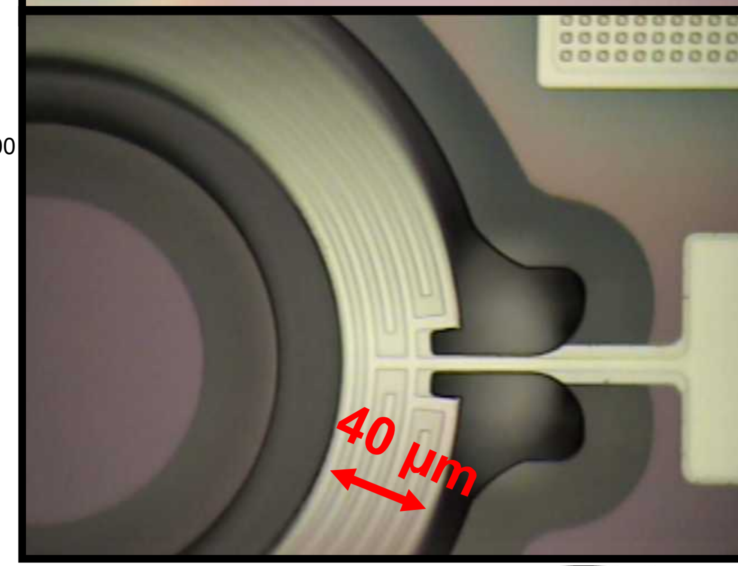
f_{mode1}= 108.18 MHz f_{mode2}= 108.66 MHz

Mode Shapes Making up the Dual Mode Filter

AlN MEMS Resonator (665 MHz) - Example







(Top Right) 665 MHz AlN MEMS Resonator

(Bottom Right) Interdigitated electrodes selectively drive/sense 6th Harmonic

(Top Left) Measured resonator response

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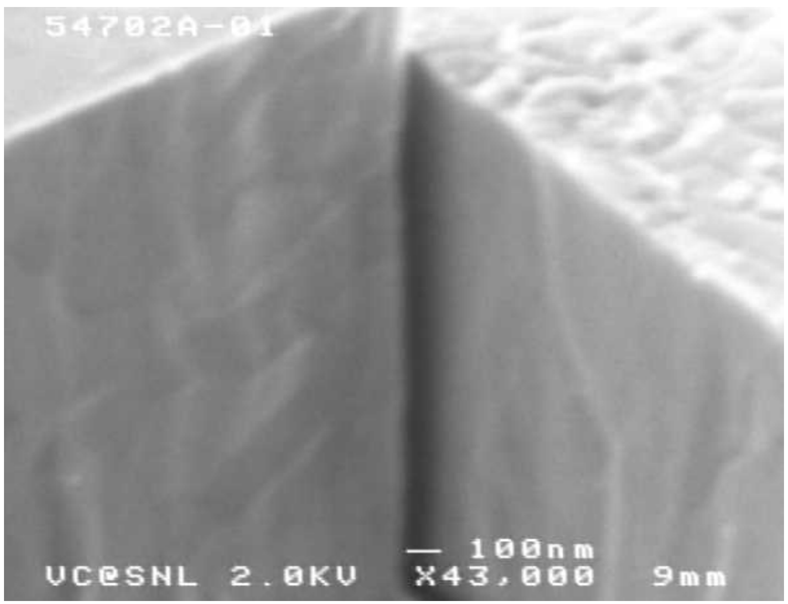
Narrow Gap Silicon

Narrow-Gap PolySi MEMS



Poly-Poly Spacing
= 100 nm

Advantages

- Narrow Gaps (< 75 nm)
- Actuator Force ≈ $(1/gap)^2$
- Resonator Impedance ≈ gap^4
- Lower Voltages
- PolySi is low stress
- PolySi is High-Q (10^5)

Process Description

- 8 Levels
- < 75 nm Poly-Poly Gaps
- Low Res. Al Interconnect
- Wet Oxide Release

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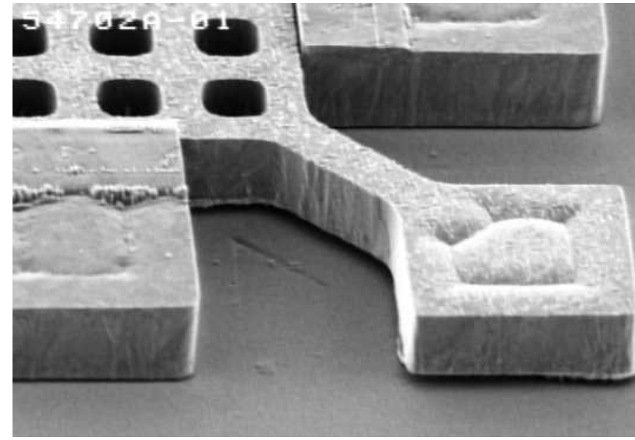
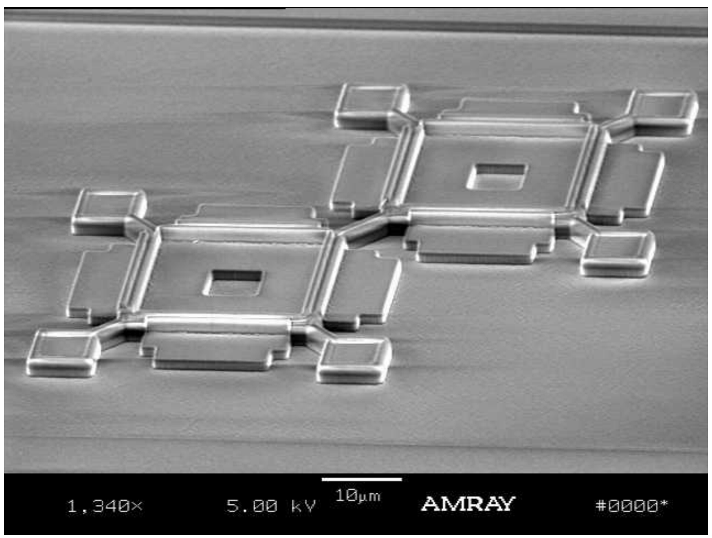
Narrow-Gap PolySi Resonators and Filters

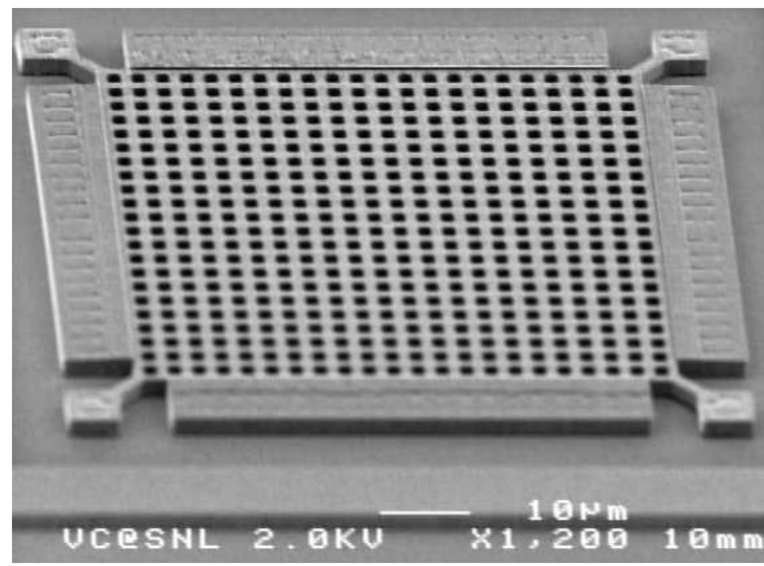
Applications

- Oscillators (Quartz Crystal Replacement)
- IF Filters
- Mechanical Memories
- Resonant Sensors





Mechanically Coupled PolySi MEMS Filter



Poly Si MEMS Resonator

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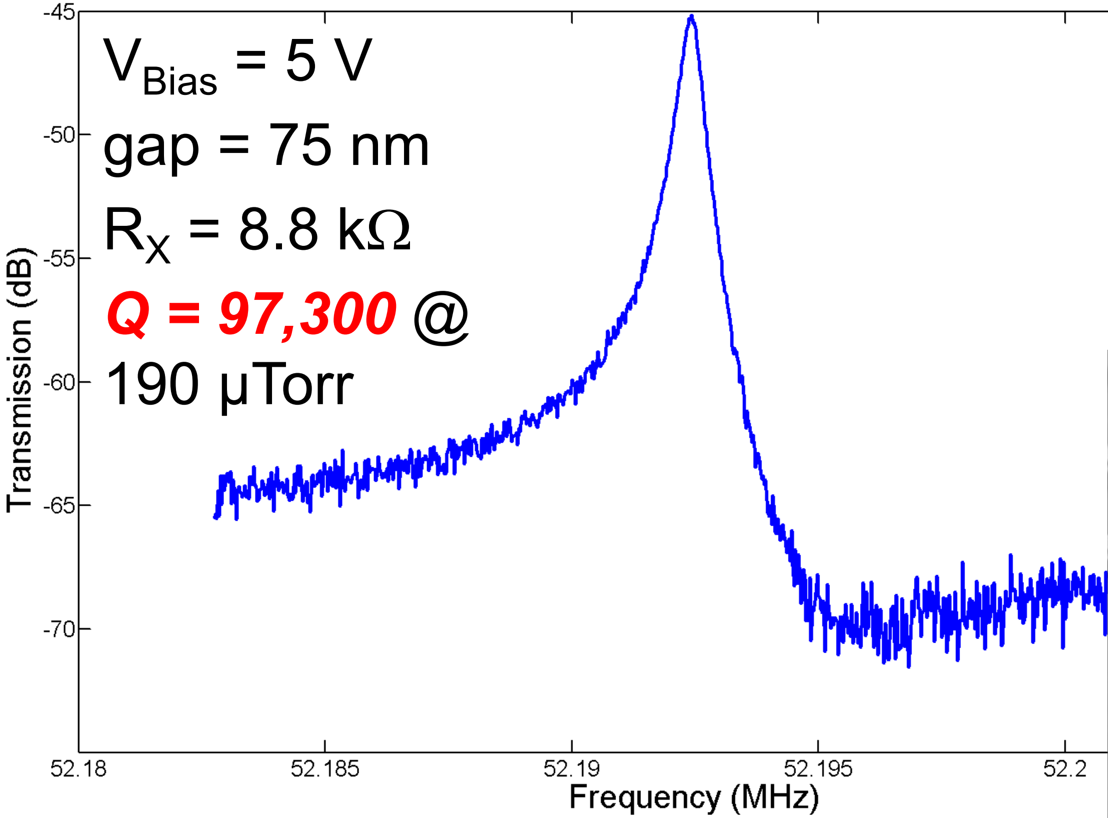
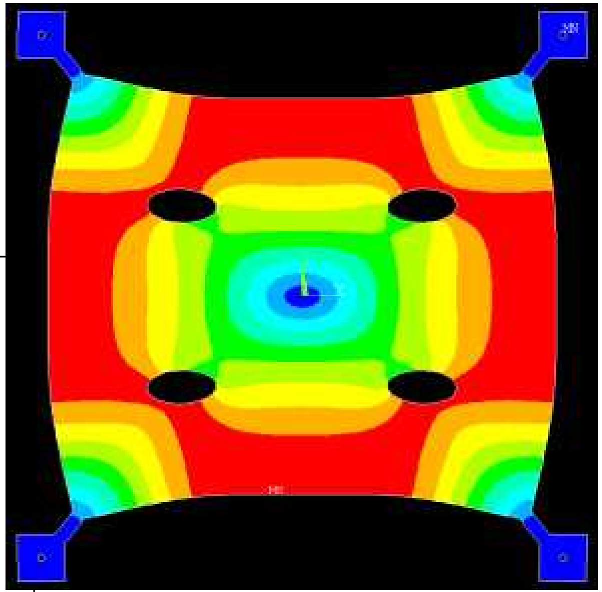
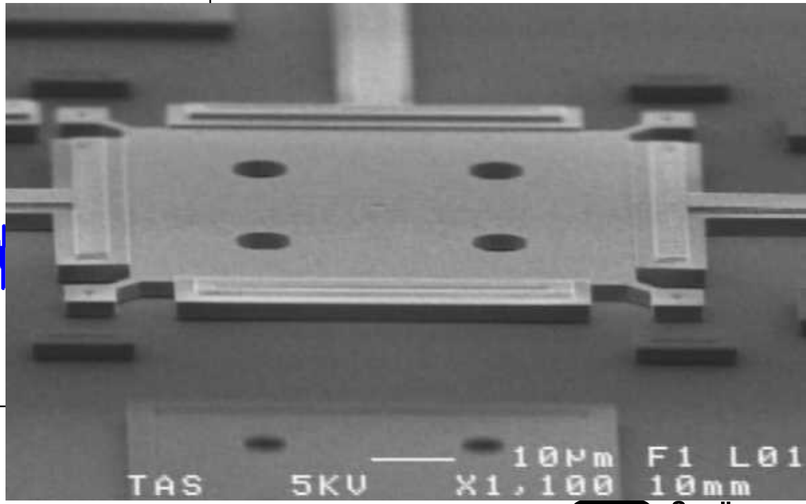
Lame’ Mode Resonator - Example

(Right) Lame’ Mode Resonator and Mode Shape

(Left) Measured Transmission of Lame’ Resonator







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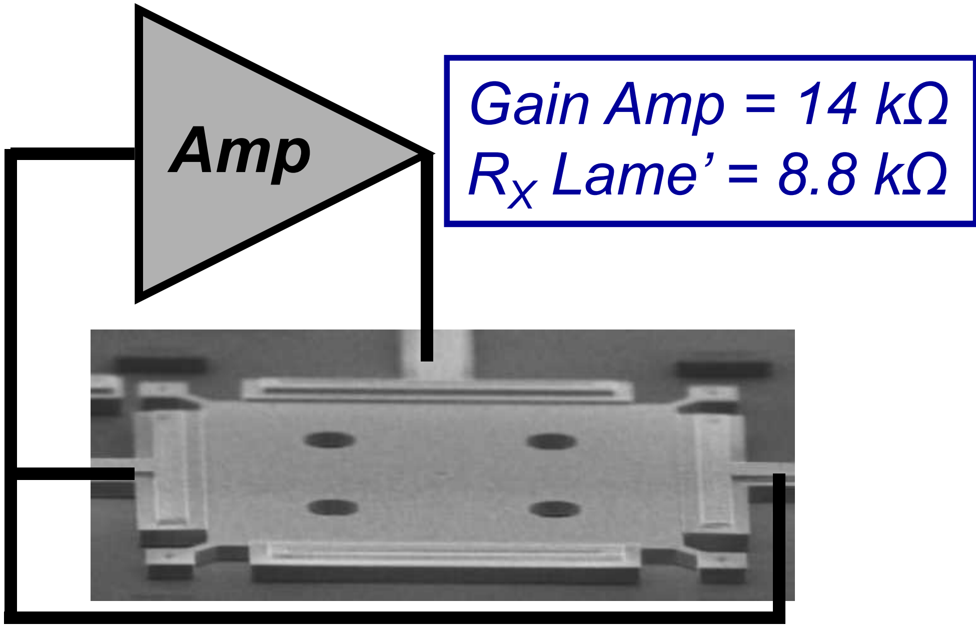
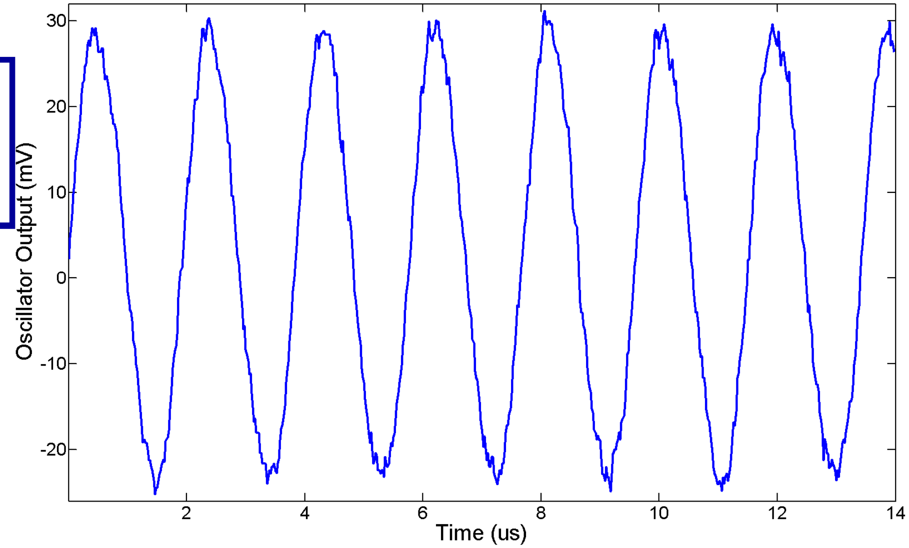
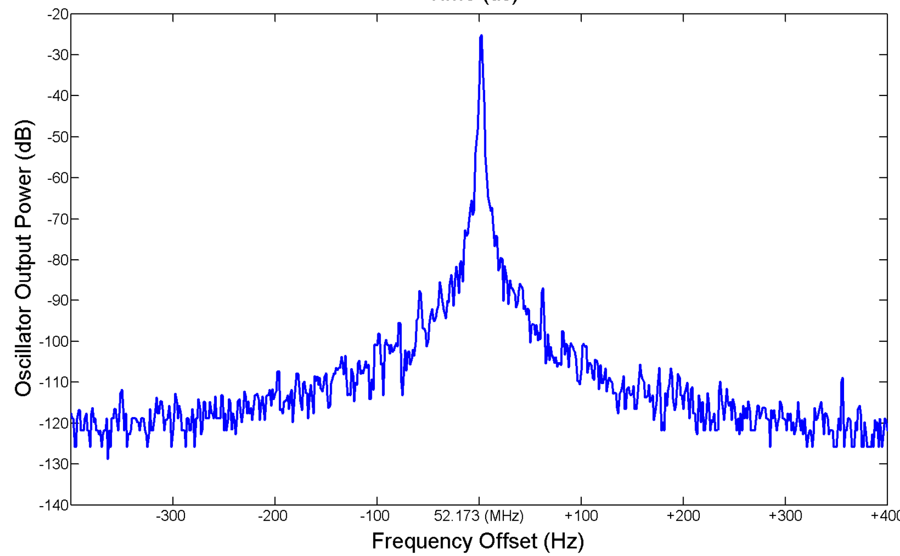
Lame' Oscillator (52 MHz) - Example







(Top Left) MEMS Oscillator Schematic

(Top Right) 52 MHz Oscillator Output

(Bottom Right) Oscillator Output Spectrum

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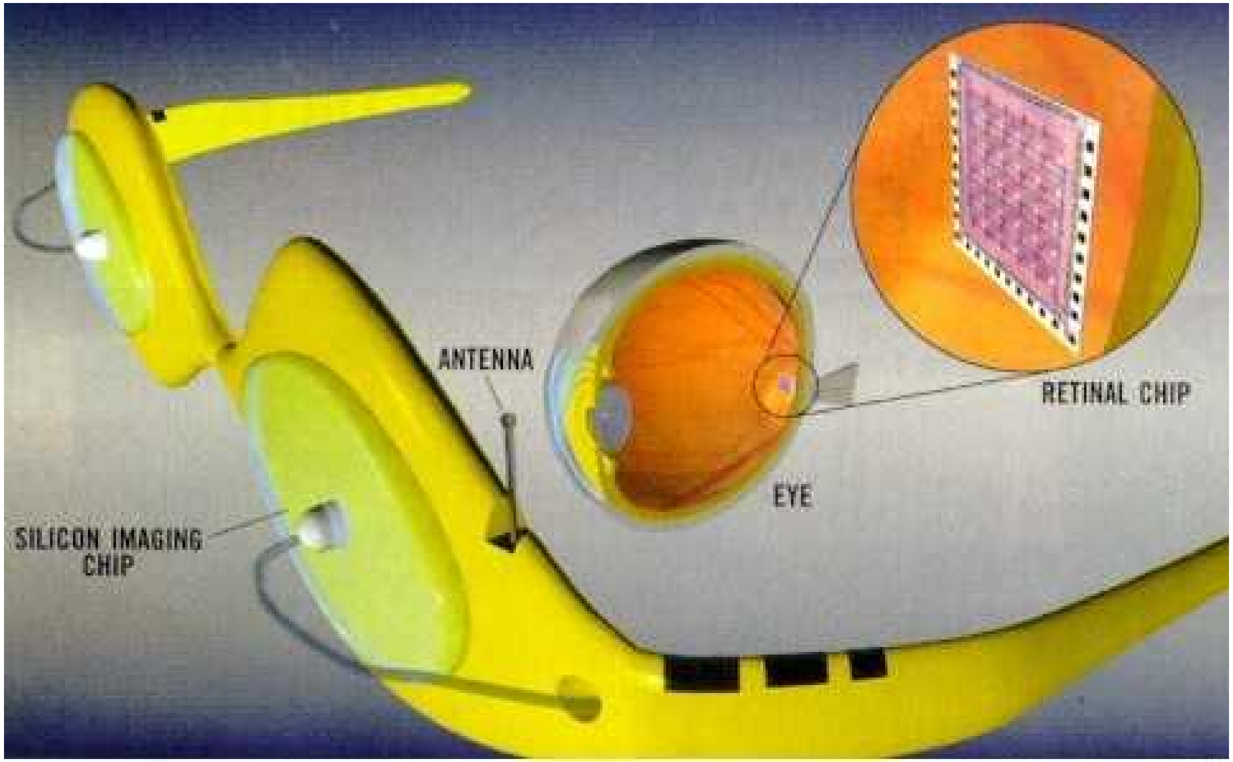
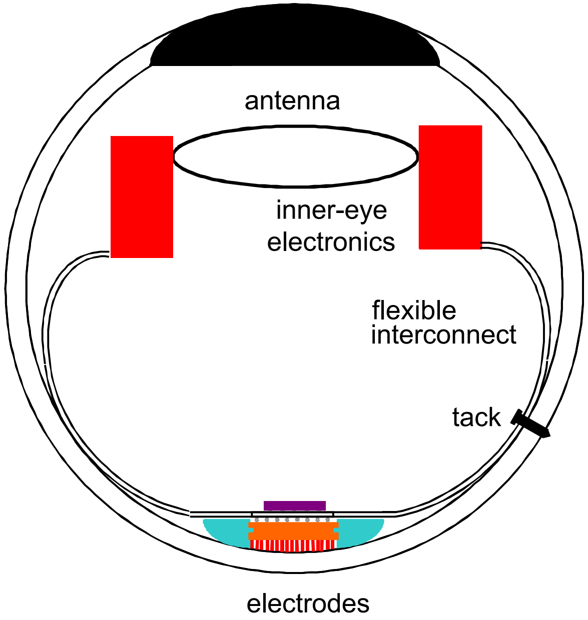
Retinal Implant

DOE Artificial Retina Project





(PI : Mark Humayun, M.D. Ph.D. , USC/DEI)

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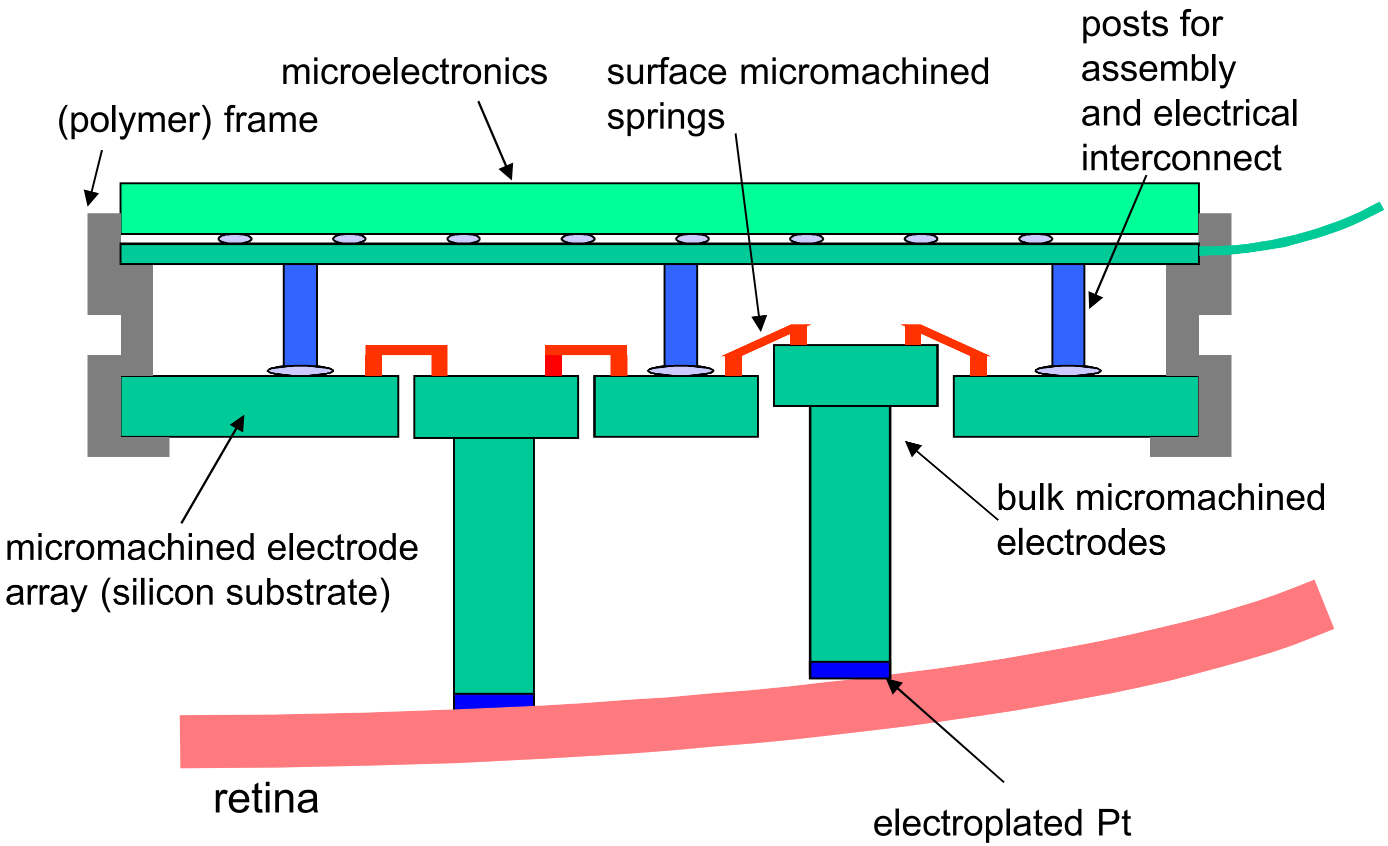
Conformable Electrode Array



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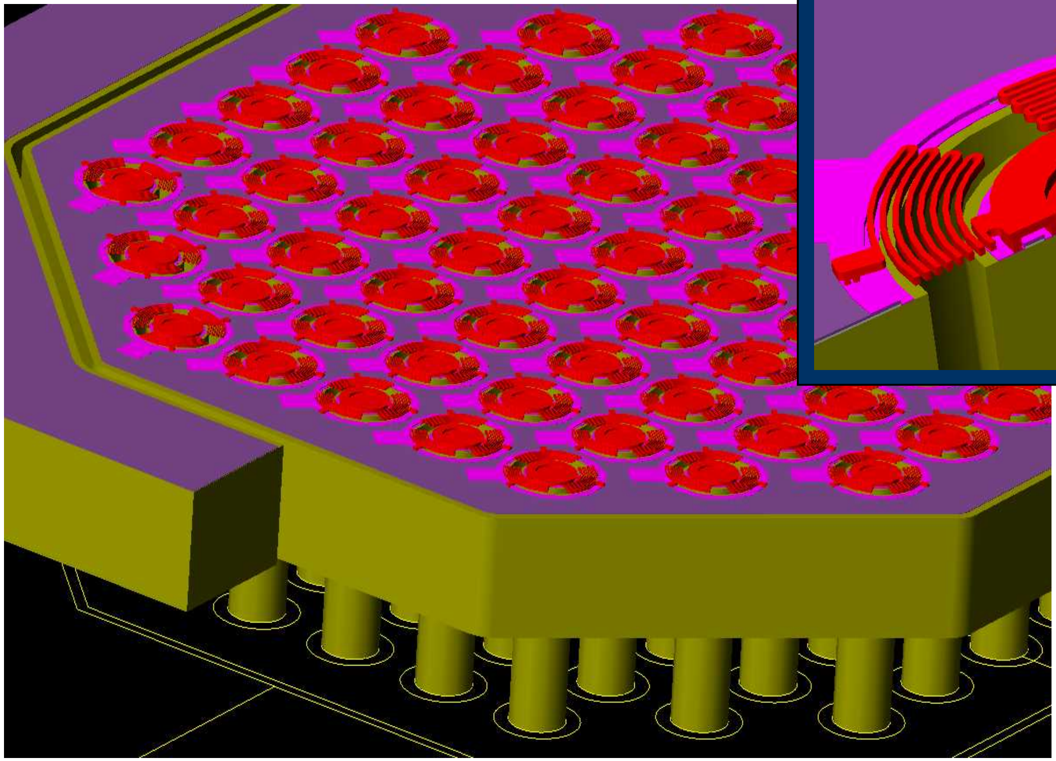
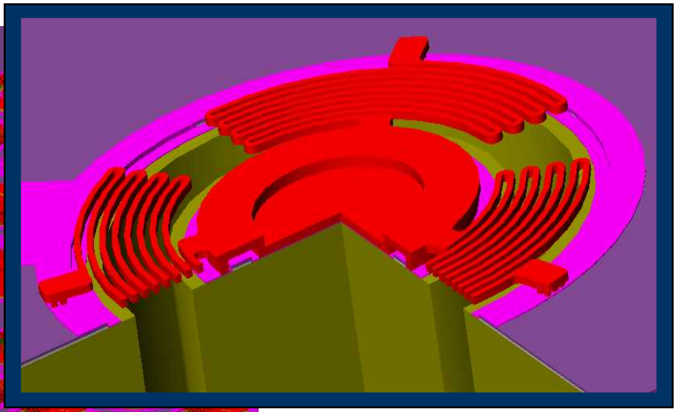
Hexagonal and octagonal arrays





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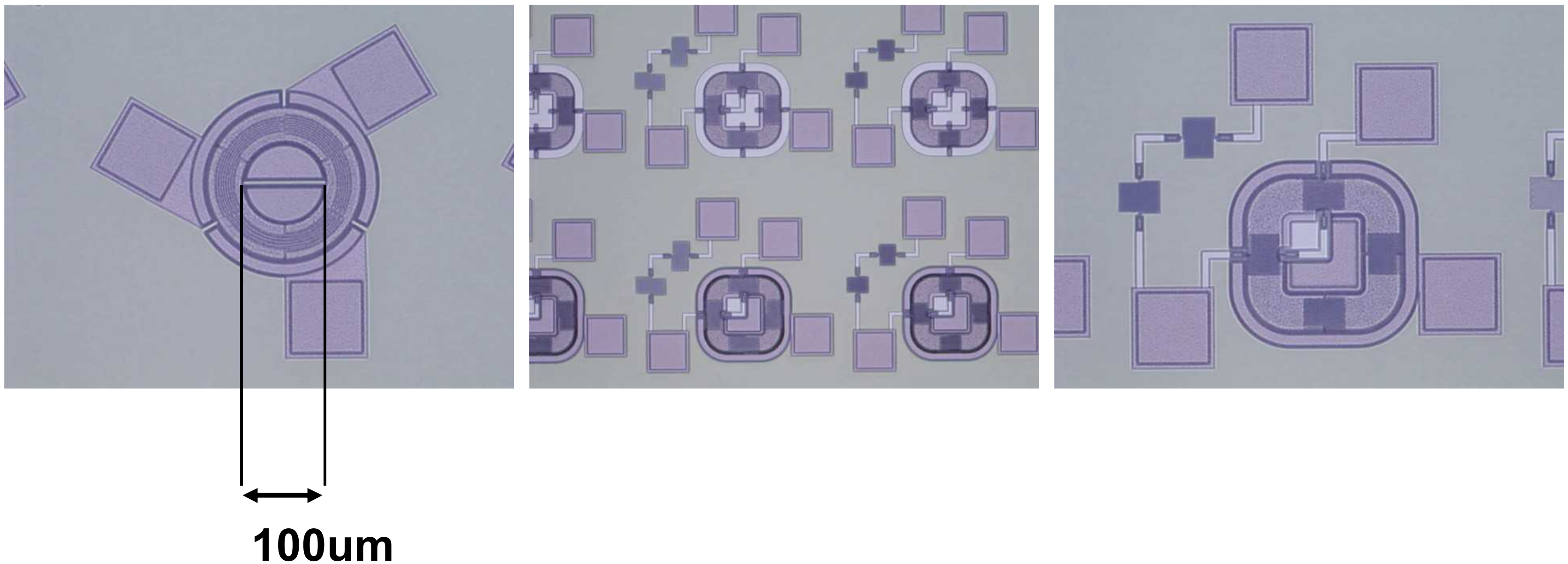
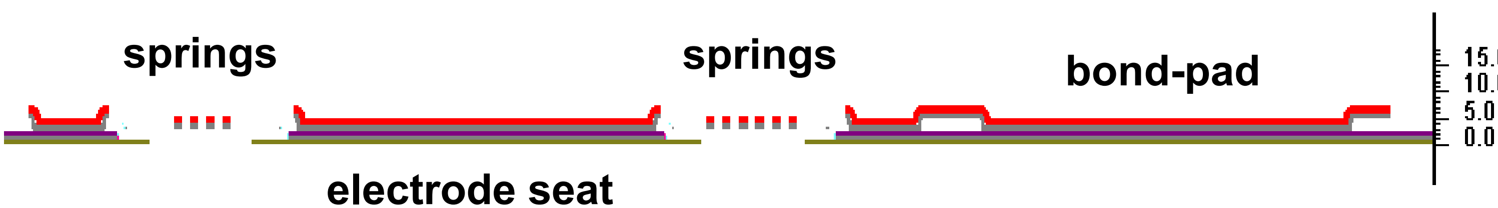
Fabrication

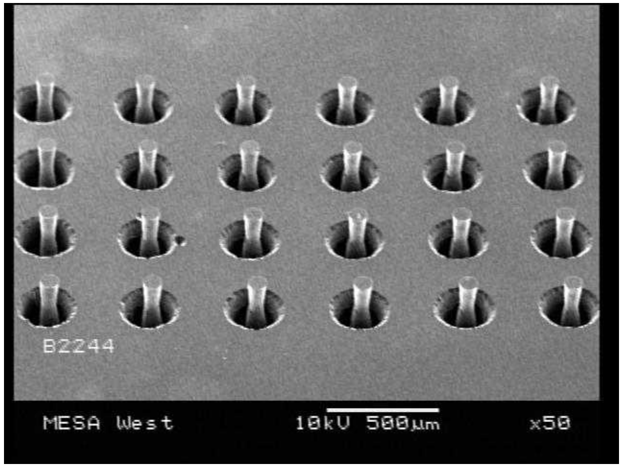
- **Surface micromachined features**

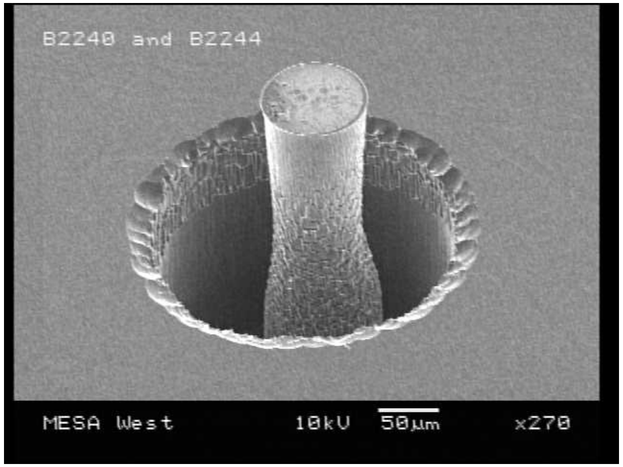


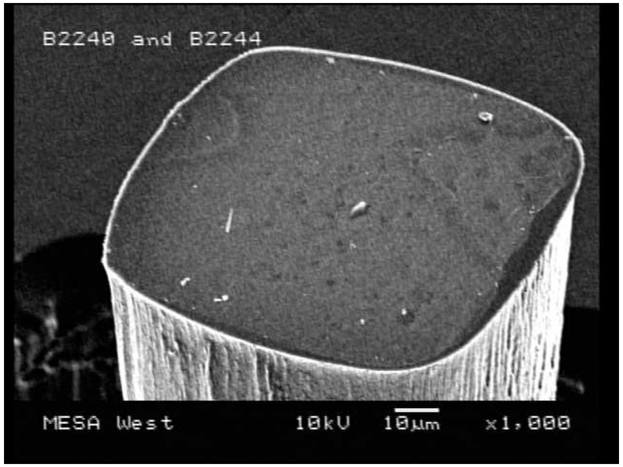


Fabrication

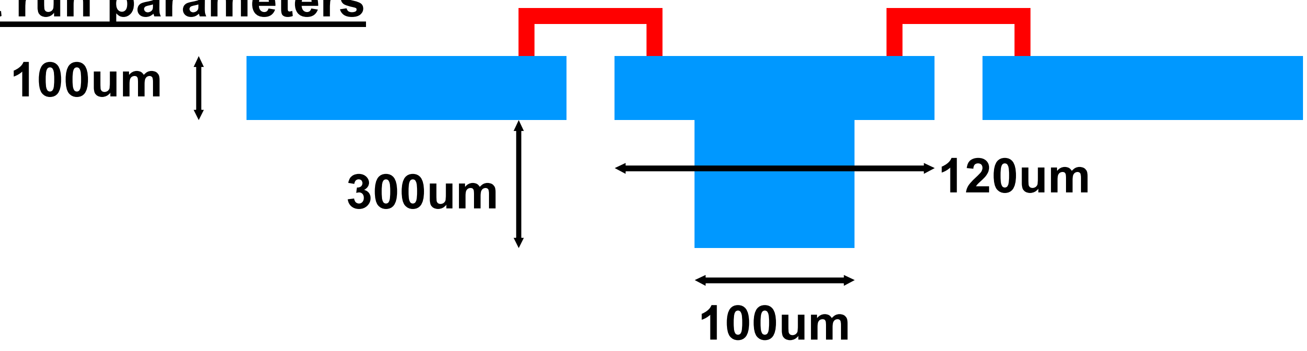
- **Bulk micromachined features**







First run parameters



Randy Shul

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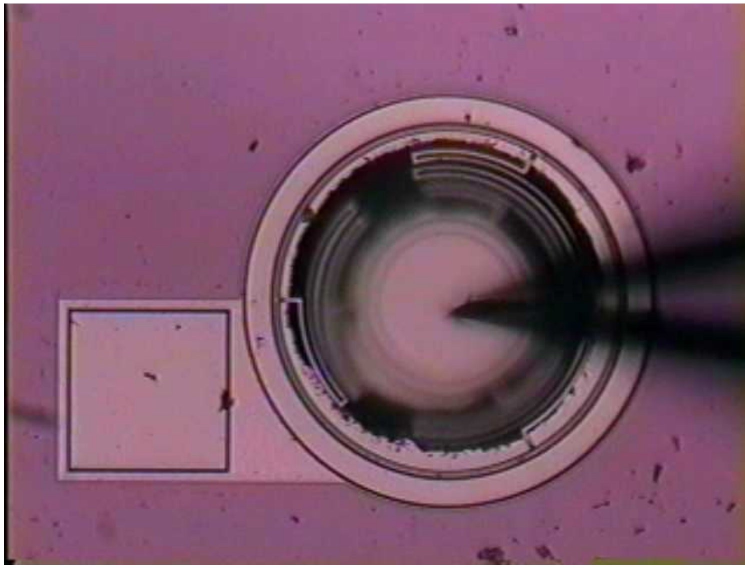
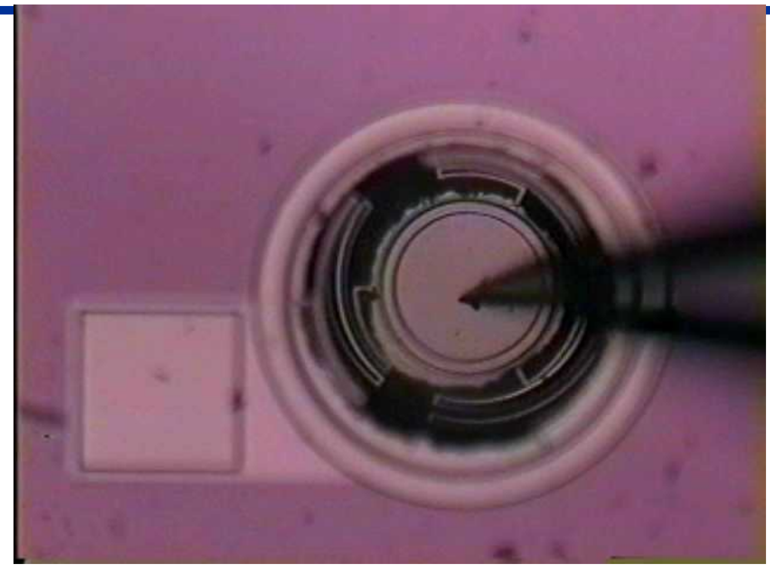
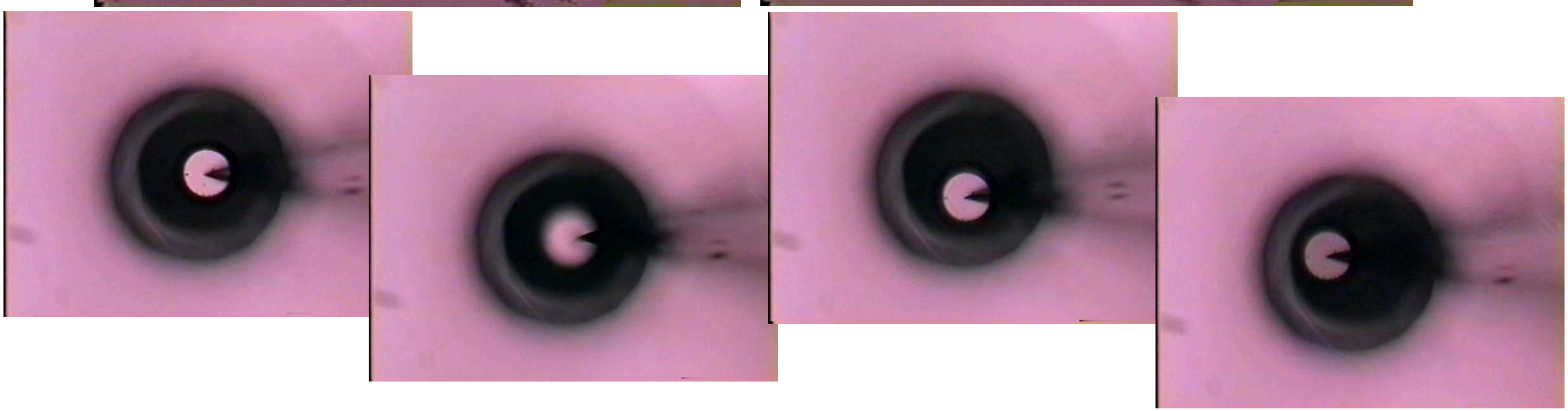
Electrodes



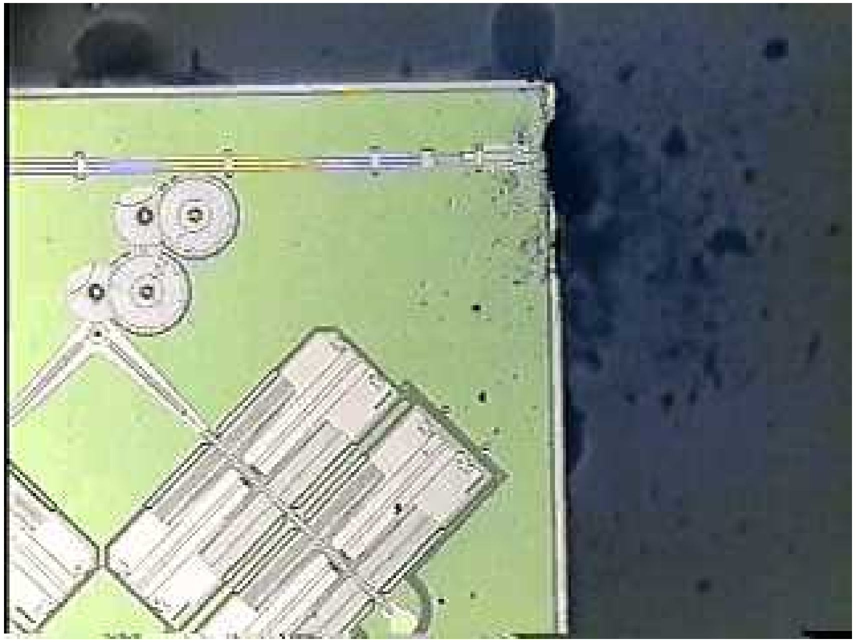


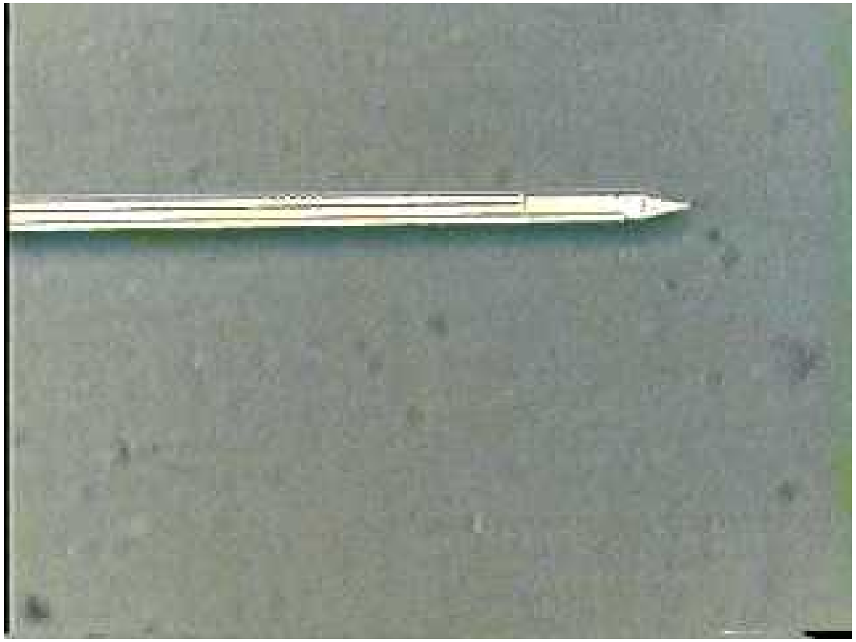


Actuated Neural Electrodes

co-PI: Jit Muthuswamy, ASU

- **First design fabricated – tested**
- **Second design in animal testing (higher force, longer displacement, different actuator)**





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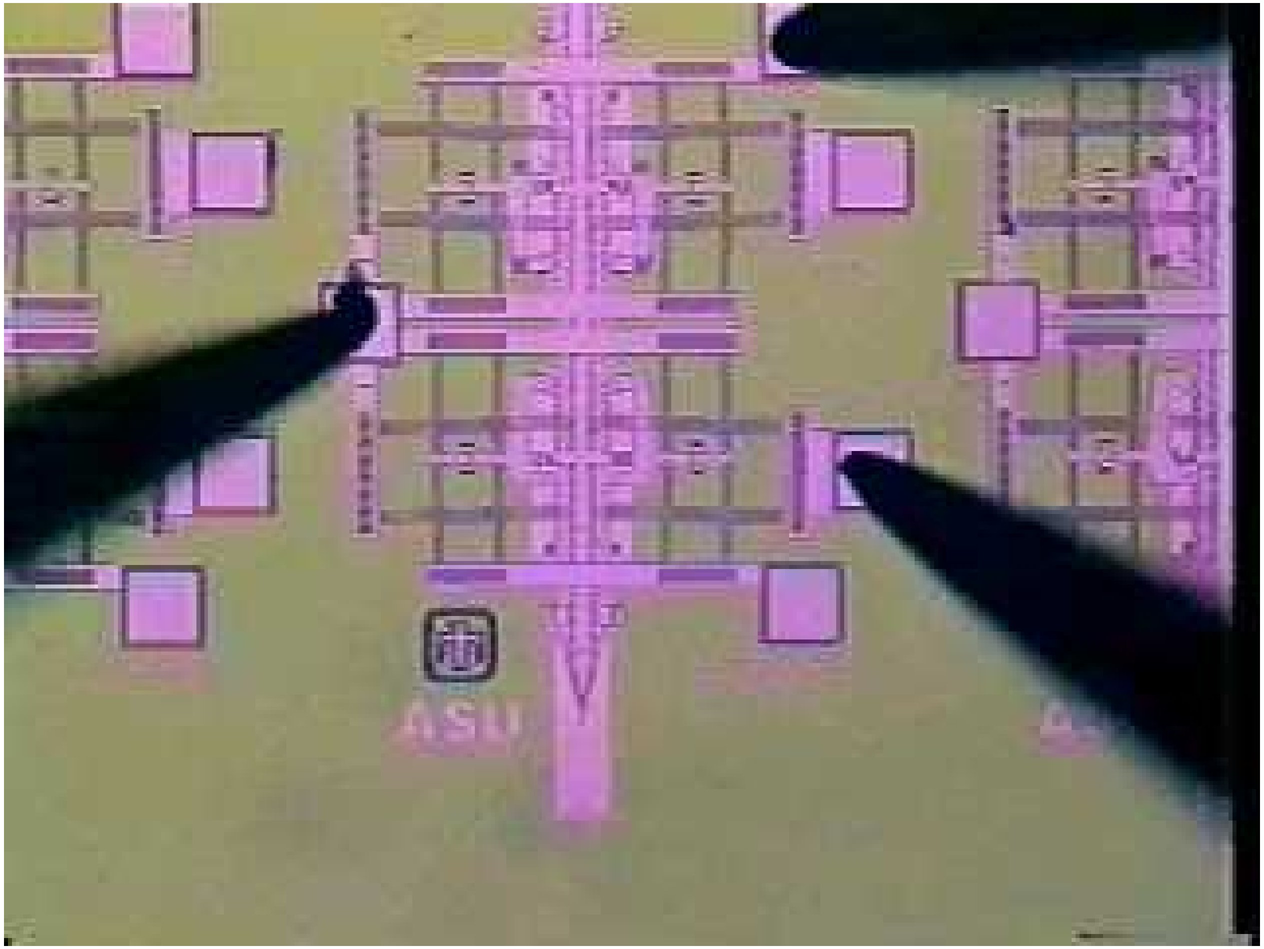
Second Design



Conclusions

- **Integration of microfluidics, electrodes, mechanical manipulation and optical components will produce the *ultimate system on a chip* – this is only useful when integration enables a unique function or form factor that is not possible otherwise.**

- **Our technology development efforts are aimed at integrating maximum functionality in a microsystems component – as well as providing the crucial link to nano-scale systems.**

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