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NANO AND MICRO SYSTEMS ACTIVITIES

Presentation to the MDL visiting Committee

By

HARISH MANOHARA
Jet Propulsion Laboratory, California Institute of Technology

November 7th, 2012

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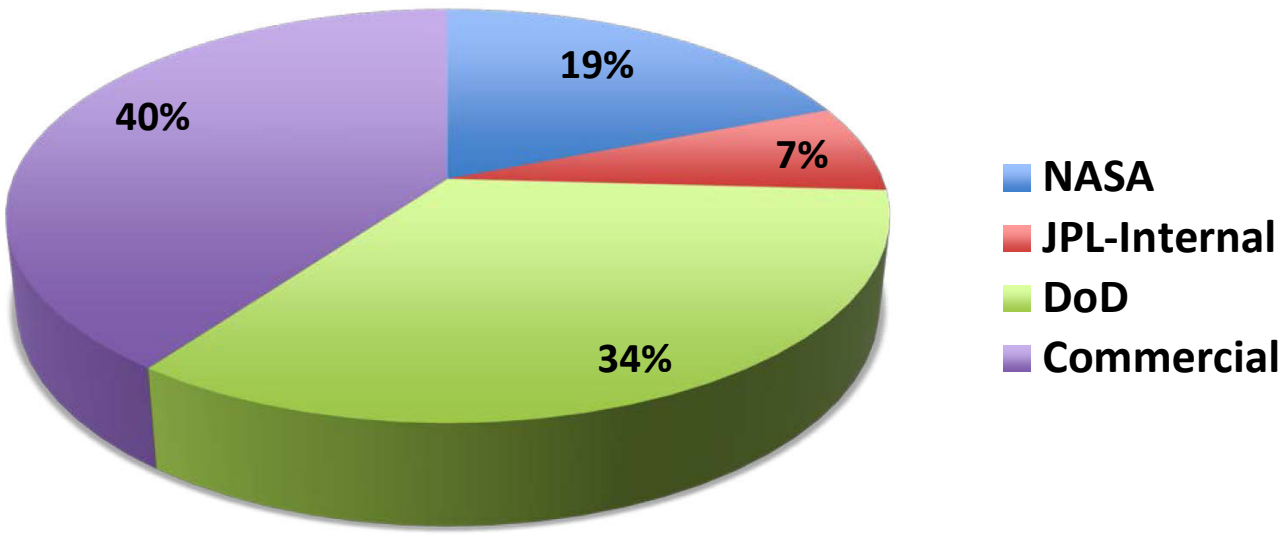
OVERVIEW

The focus of this group is to develop ***miniature smart systems*** that are capable of operating in targeted environments (harsh/extreme, biological, etc.) primarily in support of ***space exploration.***

- Predominantly a technology development group that is highly ***entrepreneurial***.
- Other than NASA funds, the group has been very successful in attracting funds from multiple non-NASA entities.
  - *In such cases technologies developed are dual- or multi-use in nature serving both NASA and non-NASA customers.*
- Expertise areas: *Carbon nanotubes, MEMS, Micromachining & Microassembly*
- Uniqueness: *Merge nano and microtechnologies with monolithic/hybrid microassembly to produce microsystems for space (concept to prototype).*

DIVERSE FUNDING BASE

FY12



The Group

PROJECTS

NASA

- *Damage detection sensors for self-healing nanomaterials*
- *RF-Powered Aqueous Extractor-on-a-Chip Instrument for Identification of Chemical Signatures of Life*
- *Fabrication Process Development for Light Deformable Mirrors*

JPL

- *Micro-Scale Sample Processing Instrument for Lunar, Mars, and NEO In Situ and Sample Return Missions*
- *Center Academic Partnership (CAP) development funds: Harsh environment nano-micro systems*

Reimbursable (Commercial and Defense)

- *High current density CNT cathodes for 220 GHz TWT sources*
- *Slit-Beam Electron Sources Using Gate Integrated Field Emission Carbon Nanotube Arrays*
- *Development of smart endoscopic surgical instruments for skull base surgery*
- *CNT-based high temperature electronics (active and passive components)-Phase 1*
- *Navigation grade integrated micro-gyroscopes*
- *Timing and Inertial Measurement Unit*
- *Micro Rate Integrating Gyroscope*
- *Portable mass spectrometer with disposable mass analyzer*
- *MEMS Based North Orienting System*
- *MEMS Based Sensor for Gun Tubes*
- *High Vacuum Package for MEMS Inertial Sensors*

TECHNOLOGY HIGHLIGHTS

DISTRIBUTED CAPACITOR (DISC) SENSOR FOR SAMPLE VERIFICATION

- Applicable to *robotic sample return missions*
- Need exists to verify mission success- Did we collect the sample? Did we collect enough?
- Past sample return missions DID NOT have sample verification capability.
- MEMS technology adapted to measure sample mass to high accuracy
- Targeted for Lunar and primitive body sample return missions

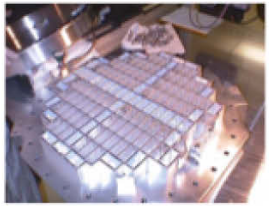
Human Missions:
Sample collected and verified by astronauts

Apollo mission sample collection case (1969-1972)

Unmanned Robotic Missions:
Sample quantity verified only after return to Earth

Russian *Luna-24* sample collector (Launched 1976)

JAXA's *Hayabusa* re-entry vehicle (Launched 2003)

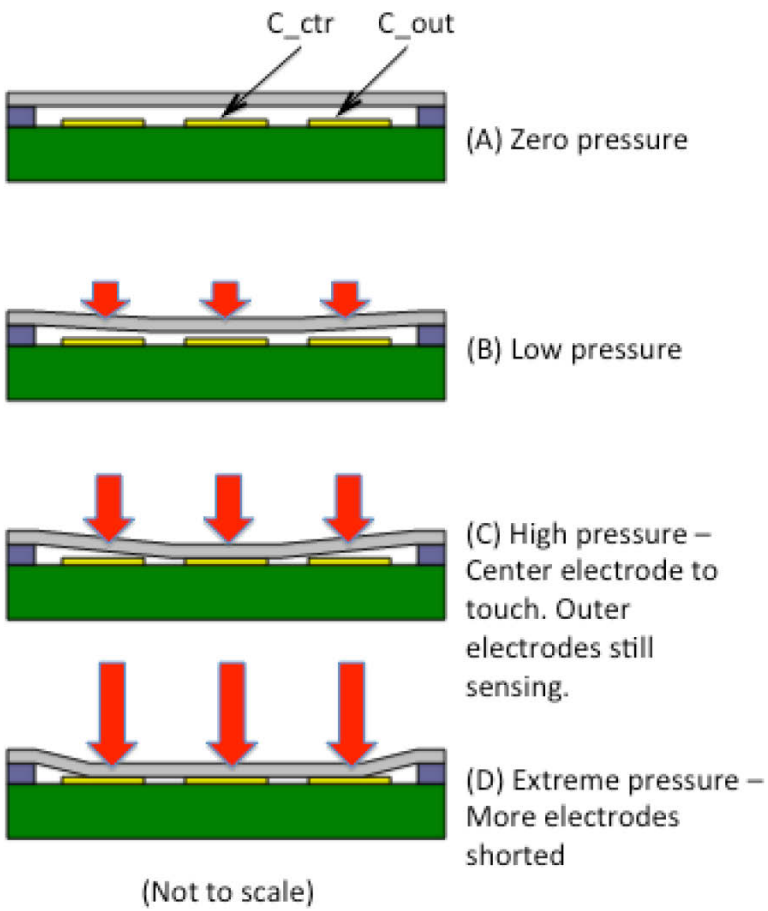


Stardust Aerogel sample collector (Launched 1999)

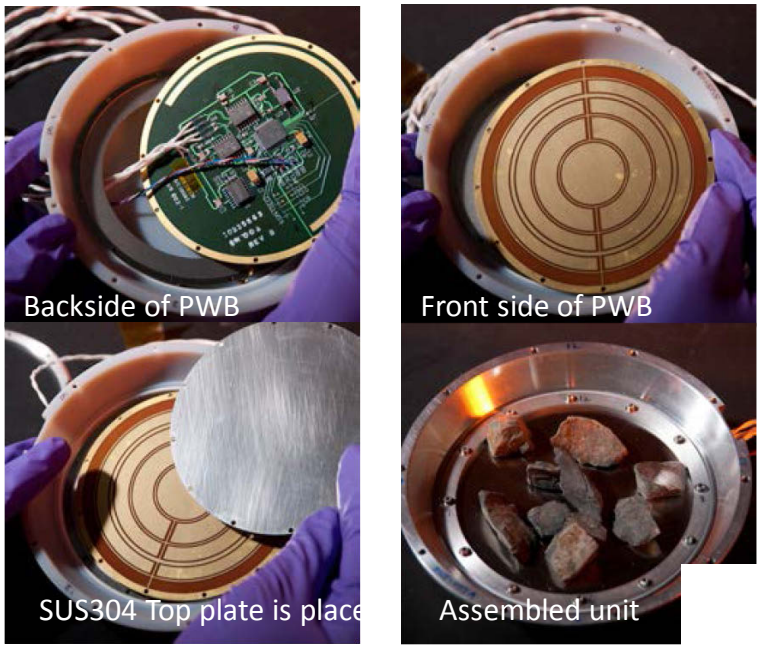
Genesis solar wind particles collector (Launched 2001)

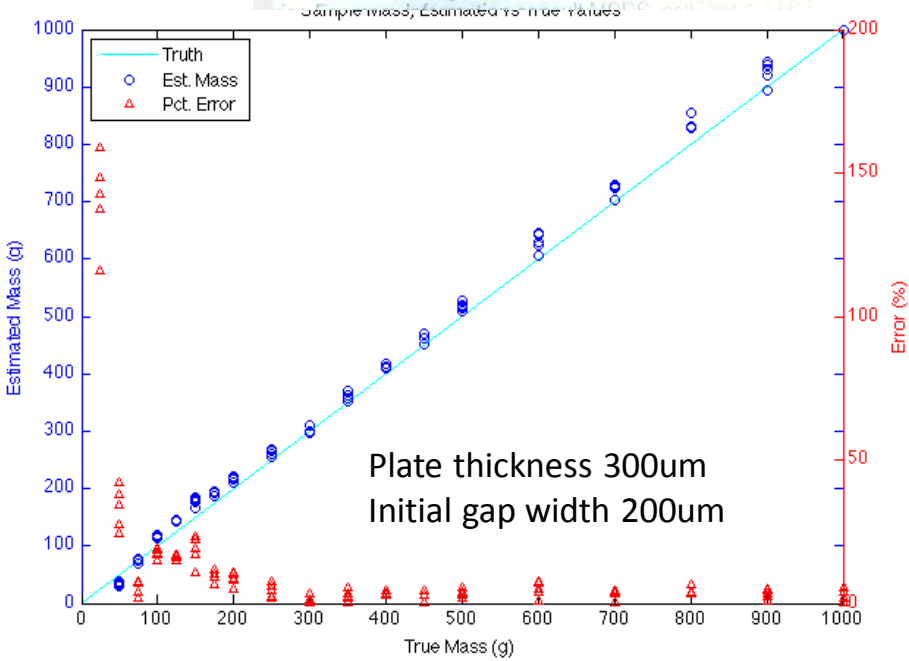
DISC SENSOR FOR LUNAR SAMPLE RETURN

- Contamination issues
  - *Even small contamination could impact isotopic age determination.*
  - *All surfaces that may come in contact with the sample must be made with cleared materials- stainless steel SS304 and aluminum AL6061.*
- Harsh environment
  - *Survival temperature, -95C to +60C on moon.*
- Measurement accuracy / range
  - *Measure 50g ±10g in lunar gravity.*
  - *Range 1000 g~3000 g.*
- Robustness
  - *Launch and EDL shock tolerance (**vibration 10-60 g's**)*



DISC SENSOR FOR LUNAR SAMPLE RETURN





- Sensitivity depends on plate thickness and initial gap width: typ. 0.1~1pF/gram
- Calibration with rock sample showed good statistical accuracy.
- ***Applying variations of this principle for primitive body sample return missions***

BLACK SILICON ABSORBERS FOR IMAGING SPECTROMETERS

Surface textured silicon (i.e. black silicon) absorbs stray light that can degrade image quality in spectrometry and radiometry instruments.

- *Integrated with spectrometry components (for eg., entrance slits)*
- *Currently being used in flight projects.*
- *JPL developed technology in collaboration with Caltech facilities (Kavli Nanoscience Institute), and JPL flight spectrometry group*

Unique Aspects:

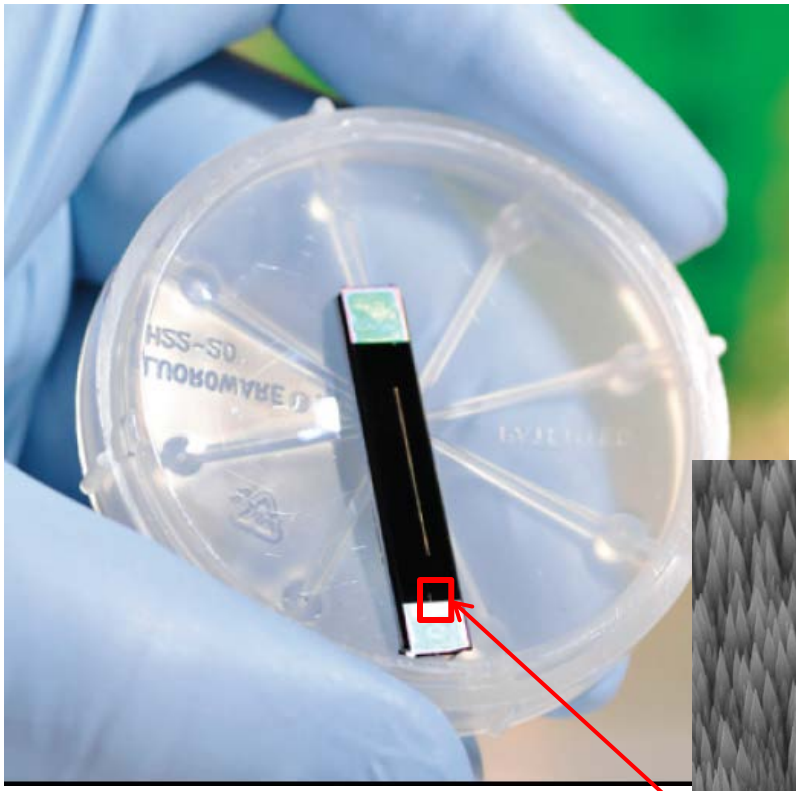
- *Cryo-etch process is repeatable, with regions to be blackened definable with lithographic precision*
- *Black silicon surface is compatible with subsequent wet processing*
- *Process parameters can be adjusted for control over average height and spacing of needles, which determine absorption at non-normal incidence*
- *Spectral absorption can be adjusted by altering doping level of Si*
- *Inorganic and exhibits zero outgassing*

Competition:

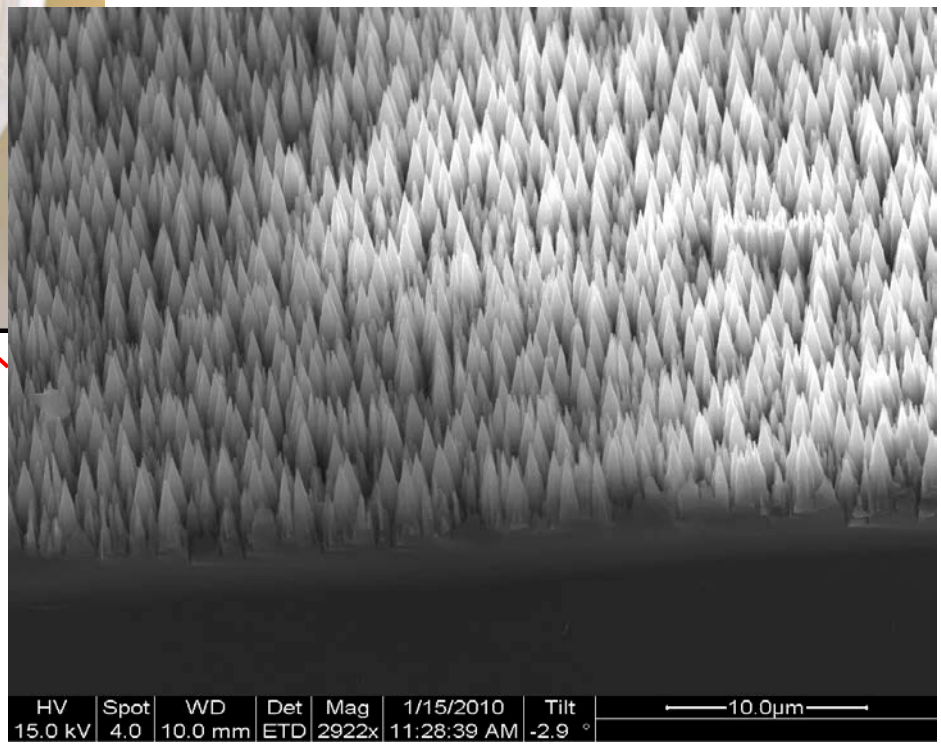
- *Blackening via deposition processes (e.g. CNTs, black paint) suffer from adhesion issues*
- *Minimal control over Si doping level, height and spacing of needles in laser blackening processes*

Flight projects: HyTES, AVARIS, UCIS, HyspIRI, MaRS2, PRISM, NEON

BLACK SILICON ABSORBERS FOR IMAGING SPECTROMETERS



Silicon / silicon nitride slit for the fast imaging spectrometer for the coastal ecosystem exploration (PRISM)



Electron micrograph of cryo-etched black silicon.

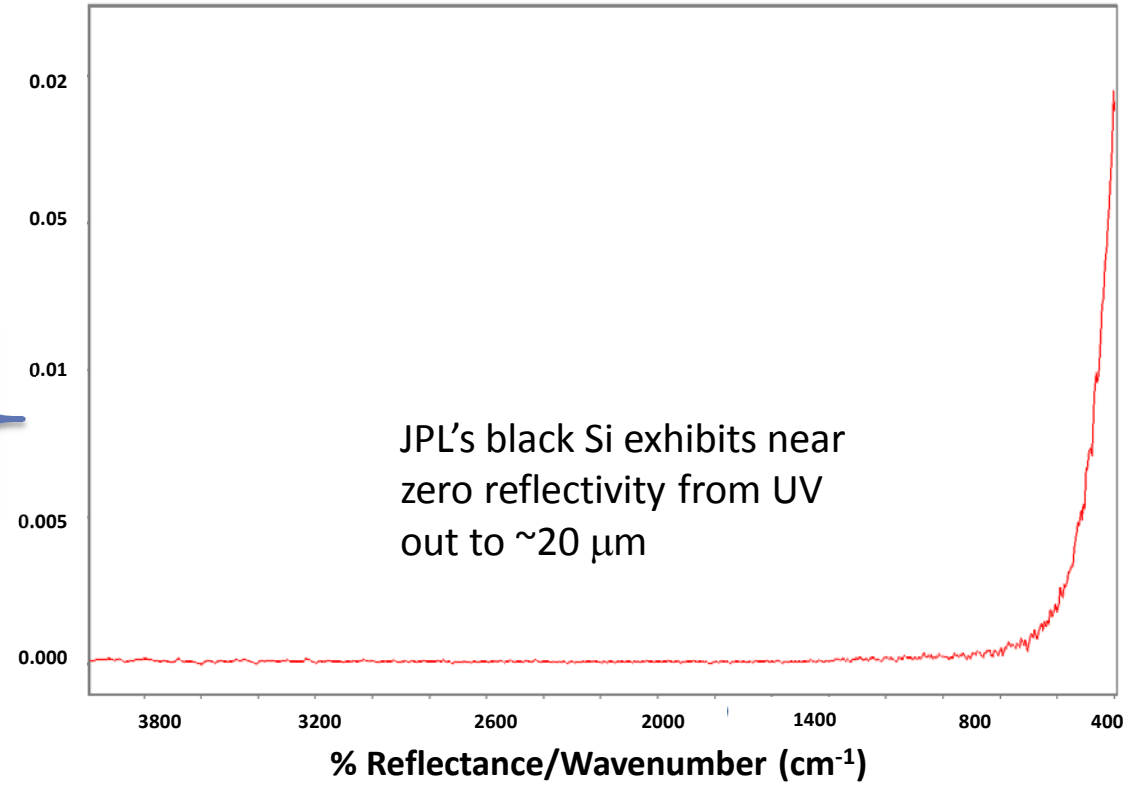
BLACK SILICON ABSORBERS FOR IMAGING SPECTROMETERS

	Acktar Metal Velvet™	CNT[1]	Black Si
350-750 nm	2.5%	1-2%	<1%
750-2500 nm	2.5-6%	1-2%	<1%

Comparison of % reflectance of state-of-the-art materials. Black Si is shown to be a better anti-reflective surface than other known materials.

[1] Mizuno et al., "A black body absorber from vertically aligned single-walled carbon nanotubes", *Proceedings of National Academy of Sciences*, April 2009

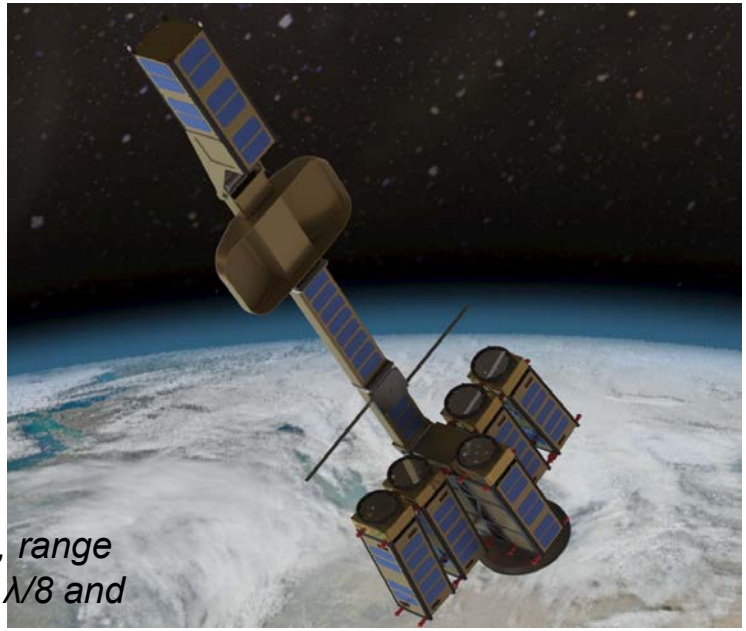
Reflectivity data for highly doped black silicon



DEFORMABLE MEMBRANE MIRRORS FOR AUTONOMOUS RECONFIGURABLE SPACE TELESCOPES

Development of deformable membrane mirrors for small satellite-based space telescope technology that is auto-reconfigurable in space.

- *Piezoelectric PVDF polymer actuates deformable mirror built on ultra-low CTE Al/Ti bi-lattice.*
- *A primary payload of Caltech's AAReST CubeSat mission targeted to launch in 2015.*
- *Close collaboration between Caltech faculty (Pellegrino and Daraio), students and NAMS group engineers*



AAReST CubeSat 2015

Unique Aspects:

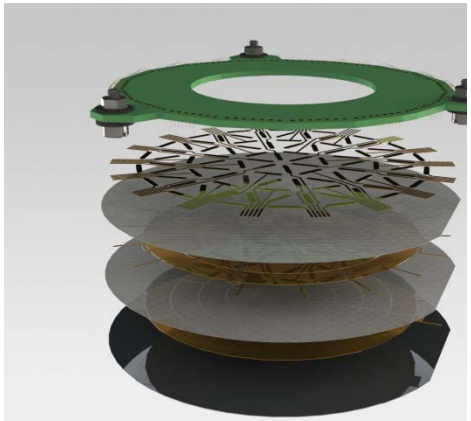
- *Multi-cube sat based*
- *Mirrors use polymer actuators (PVDF)*
- *Will achieve r.m.s shape error of 1λ, λ~633nm, range of actuation travel ±10 μm, travel resolution of λ/8 and radius of curvature ~2.5 m.*
- *Employs a unique bi-metallic lattice to even out the temperature induced mirror distortions*

Competition:

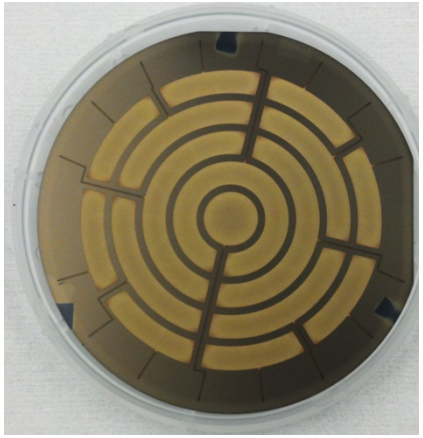
- *Highly mature development using PMN actuators*
- *Difficulty in scalability (manual assembly) as opposed wafer-scale monolithic fabrication process*
- *Expensive*

DEFORMABLE MEMBRANE MIRRORS- STRUCTURE, PERFORMANCE CHARACTERISTICS

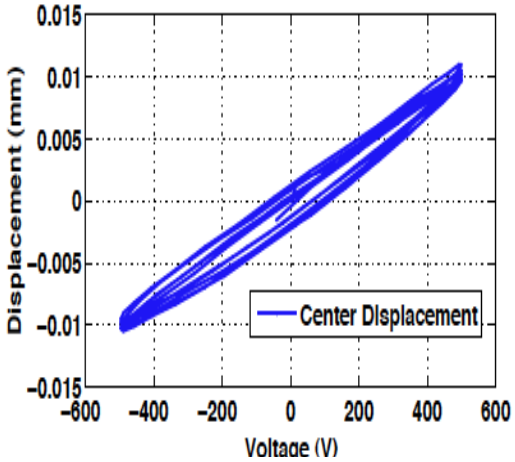
Fabricated active mirror with 16-segment actuation regions



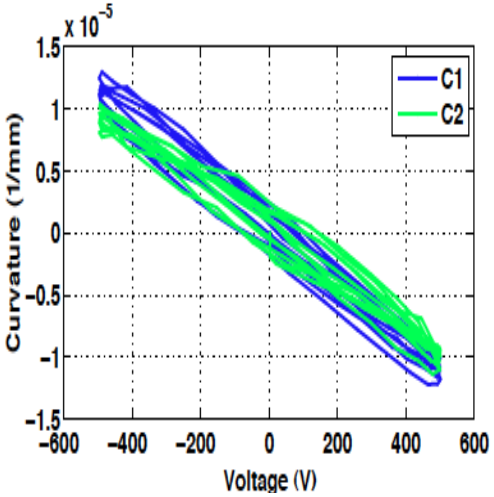
Simplified film stack geomet



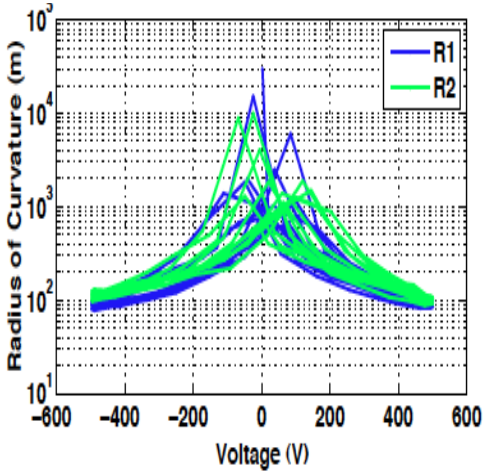
Photograph of a finished sili membrane mirror (reflective surface on opposite side)



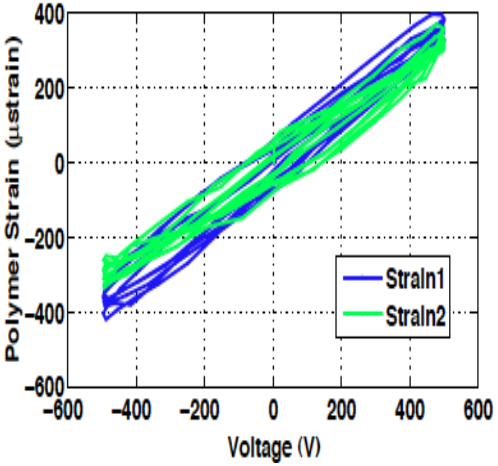
Peak-to-valley deflection of mirror



Surface curvatures and twist



Corresponding radii of curvatures



Estimated piezo strain in the polymer layer

DEFORMABLE MEMBRANE MIRROR ACTUATION
A MOVIE

TECHNOLOGIES- LICENSED OR IN PROCESS

1. *Stereo imaging miniature endoscope with single imaging chip and conjugated multi-bandpass filters.*
2. *High Performance, Wide Field of View, Fast Relative Aperture (f/n) Endoscope Objective Lenses for Space-Constrained Applications*
3. *Programmable Spectral Source and Design Tool for 3D Imaging using Complementary Bandpass Filters*
4. *Multi-angle rear-viewing endoscope and method of operation thereof*
5. *High temperature capacitors using silicon micromachining and carbon nanotubes*
6. *Thermionic Power Cell to Harness Heat Energies for Venus and Geothermal Applications*
7. *New double-SOI process to fabricate gated high-performance CNT cathode*
8. *High current density field emitters based on carbon nanotube bundle arrays*
9. *Vacuum packaged CNT diodes and triodes (in preparation)*
10. *Disc resonator gyroscope fabrication process requiring no bonding alignment*
11. *Integral resonator gyroscope*
12. *Resonant vibratory device having high quality factor and methods of fabricating same*

SUMMARY

- MDL resources and the support structure have been exceedingly helpful in delivering critical components to the sponsors and expand our group's business base.

- MDL as a facility is playing key role in attracting commercial customers to NAMS group technologies.

- Equipment Needs

  - *Fused Silica Etcher (for MEMS gyro project, but will be useful for multiple projects)*

  - *Solder Reflow Bonding system (for vacuum packaging of microcomponents; multi-projects use)*

  - *Silicon Cryoetching System (for high aspect ratio structures with smooth sidewalls and black Si)*

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ACKNOWLEDGMENTS

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with National Aeronautics and Space Administration (NASA). The reported projects are supported by different sponsoring agencies.