Talk at TEQUIP Workshop, Dec. 2014

Research in MEMS, Dynamics, and Control Area

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Research

- MEMS: MicroElectroMechanicalSystems
  – Microstereolithography
  – Bulk lithography
- Dynamics and control:
  – Flexible linkage mechanisms
  – Flexible linkage robots
  – Ultra large deformation Inverted flexible pendulum
  – Mechanical timer dynamics

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Research

- MEMS: MicroElectroMechanicalSystems
  - Microstereolithography
  - Bulk lithography

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Suman Mashruwala Advance Microengineering Lab

Department of Mechanical Engineering,

Indian Institute of Technology Bombay

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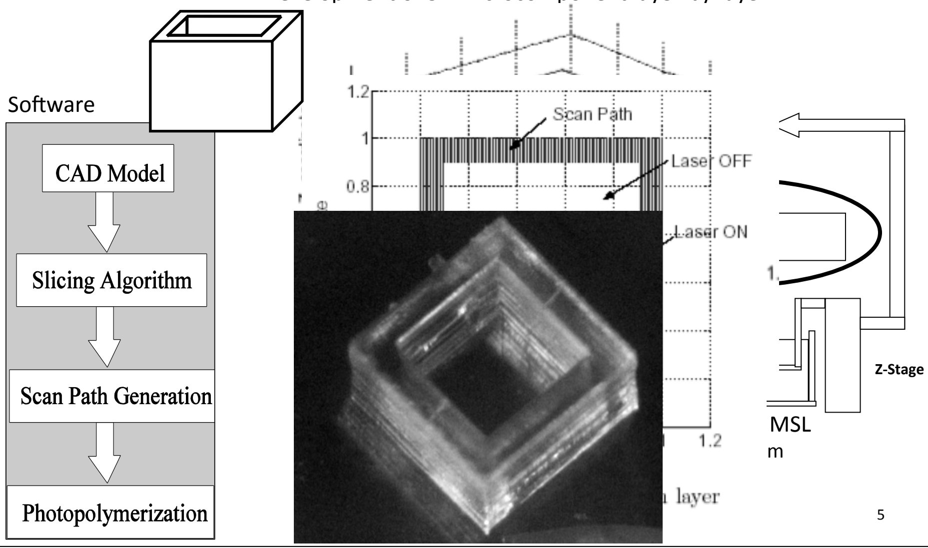
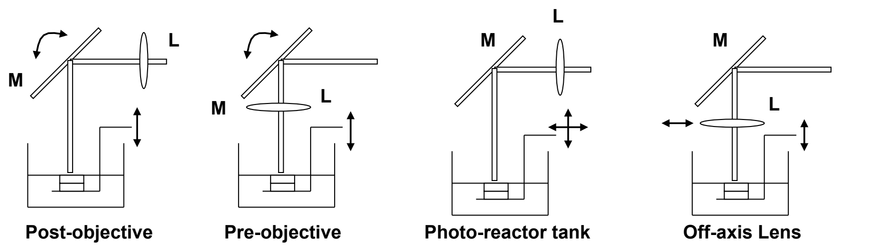
Microstereolithography

Development of 3D microcomponent layer-by-layer



Various Scanning Methods and Analysis



Proposed by our group*

•*Suhas Deshmukh, S. Dubey, P.S. Gandhi,* Microstereolithography systems”, *Proceedings of the SPIE Symposium on MOEMS-MEMS Micro & Nanofabrication, San Jose, CA USA, January 2006*

Suhas P. Deshmukh, and P.S. Gandhi, *“Optomechanical Scanning Systems for Microstereolithography {MSL): Analysis and Experimental Verification”*, Elsever Journal of Material Processing Technology. Vol 209, pp. 1275–1285, 2009.

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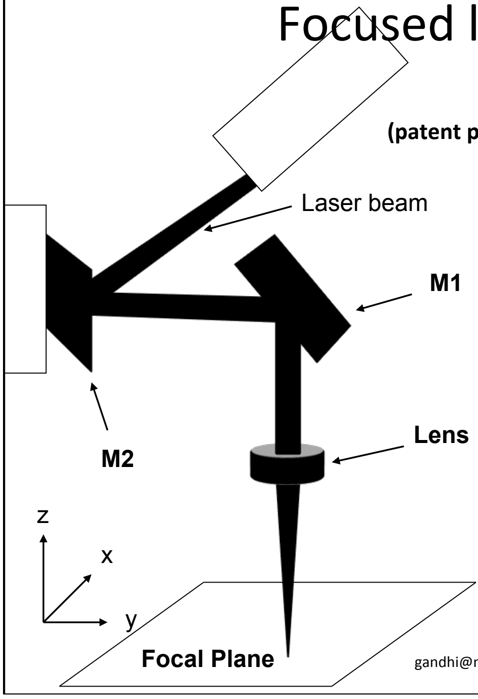
Focused laser spot scanning method

(patent pending No 1847/MUM/2007)



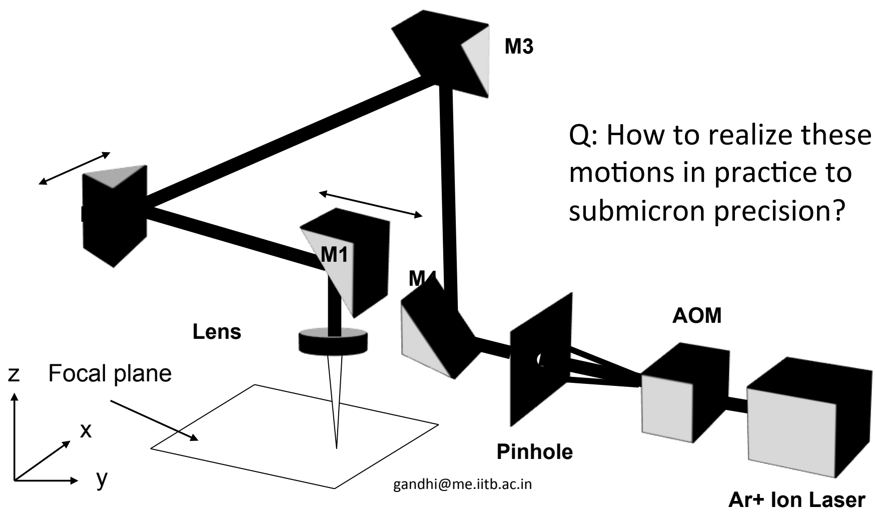
- Linear scanning of mirrors in the direction of the laser beam axis

ADVANTAGES:

☺ ***Uniform spot characteristics*** (i.e. constant spot size and uniform intensity profile)
☺ ***Virtually no limit on range***
☺ ***Improved resolution***
☺ ***Higher speeds possible***

Development of New Scanning MSL System

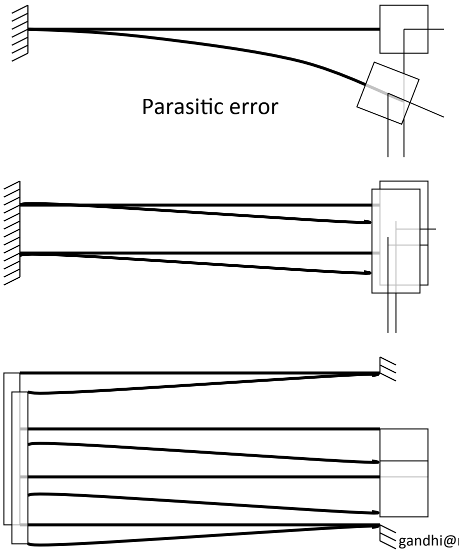
(Optical system)



Q: How to realize these motions in practice to submicron precision?

Flexure Mechanism

Concept



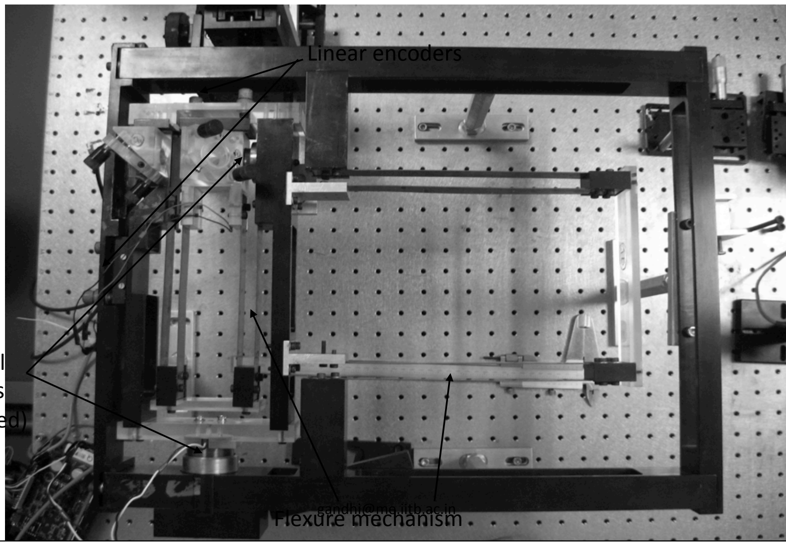
- To implement idea with nanometric scanning resolution innovative use of double parallelogram flexure mechanism and mechatronic system around it
- Advantages
  - No friction/hysteresis
  - High repeatability
- Used in Comb Drives

Flexure Mechanism via Assembly Route

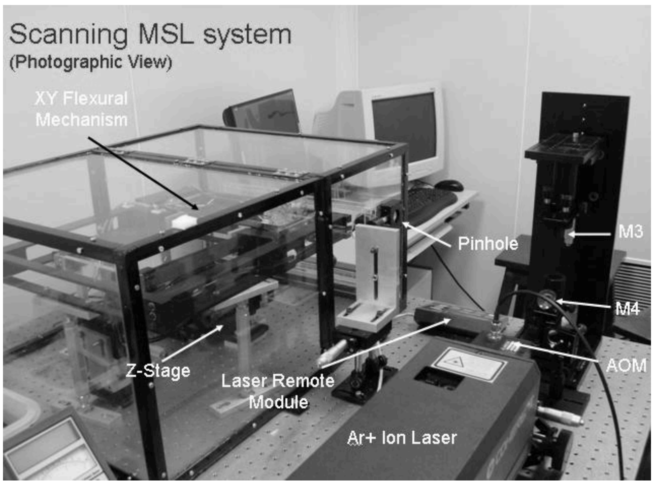
- Normally flexure mechanisms are fabricated using EDM or water cutting (macro scale) or etching (microscale in MEMS)
- Use of high fatigue strength materials (Cu-Be) not feasible and 3D mechanisms could not be fabricated
- Guidelines for developing flexure mechanisms by assembly way proposed recently and applied

Gandhi P.S., Soni Vaibhav, Sonawale Kaustubh, Patanwala Naved, "*Assembly Guidelines for Compact High Performance Meso Flexure Linkage Mechanisms*" in the proceedings of ASME Mechanical Engineering Congress and Expo, Nov 2011, Denver, Colorado, USA.
Prasanna Gandhi, Kaustubh Sonavale, Vaibhav Soni, Naved Patanwala and Arvind Bansode, "Design for Assembly Guidelines for High Performance Compliant Mechanisms," ASME Journal of Mechanical Design, Vol 124, pp 121006-1 to 121006-10, Dec 2012 (DOI: 10.1115/1.4007928).

Flexure mechanism for xy scanning

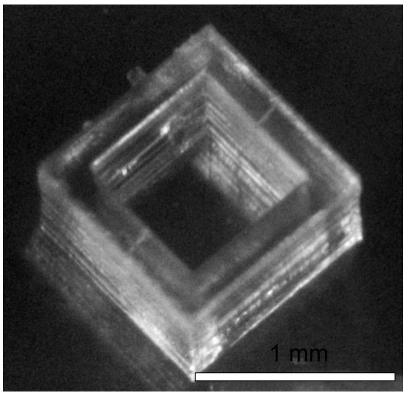


Complete system

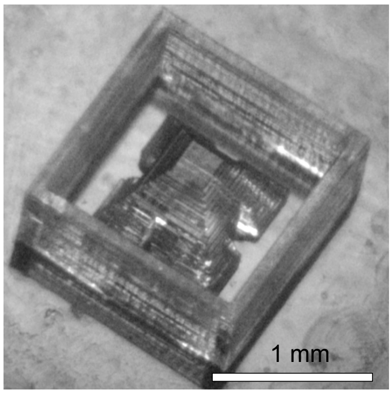


Prasanna Gandhi, Suhas Deshmukh, Rahul Ramtekkar, Kiran Bhole and Alem Baraki, “On-Axis Linear Focussed Spot Scanning Microstereolithography System: Optomechatronic Design, Analysis, and Development,” Journal of Advanced Manufacturing Systems, Vol. 2, No. 1, pp 43-68, 2013. (DOI: 10.1142/S0219686713500030)

Fabrication of Multilayered Micro-Structures



Square tank with 1mm outer size 800 µm inner size wall thickness of 200µm Height of 500µm 10 layers

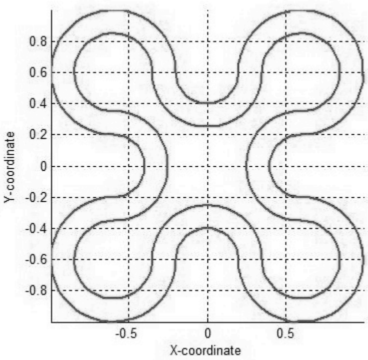


Pyramid with 1mm size fabricated inside a tank of size 1.6mm Height of the structure is 750µm 15 layers

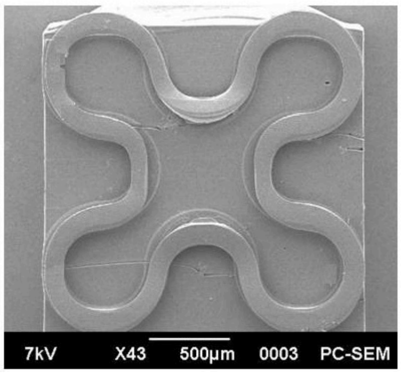
Fabricated components (cont…)

Clover

- Component with complicated curved features
  - ✓ Maximum size = 2mmx2mm, wall thickness = 150µm
  - ✓ Number of layer = 4, fabrication time = 1.30hrs.



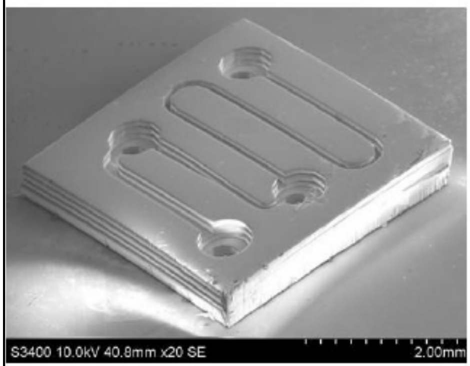
Contours of sliced model

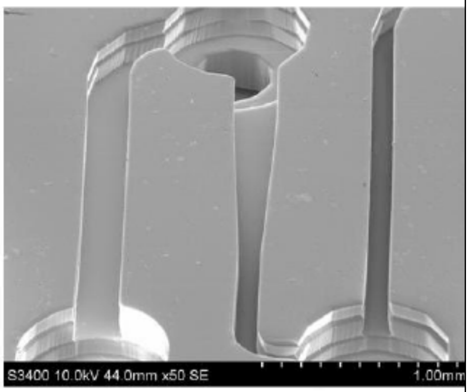


SEM image

3D High Aspect Ratio Microchannels

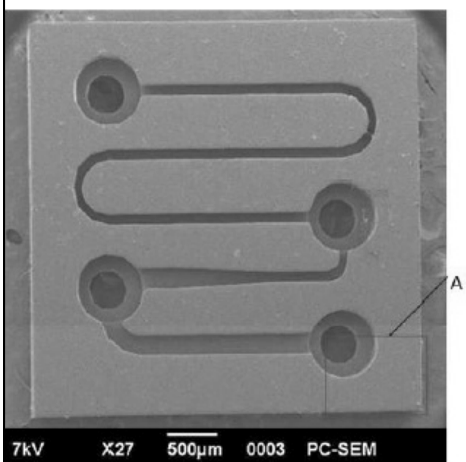
1mm

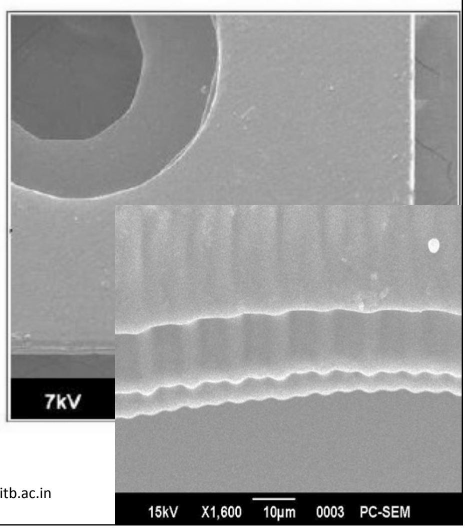




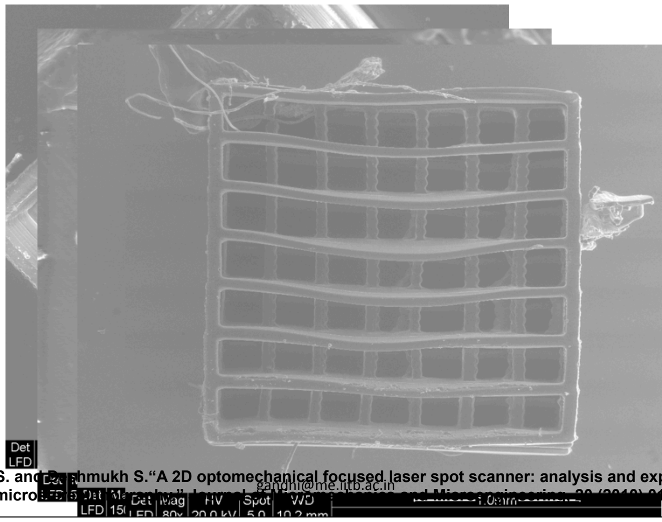
High aspect ratio microchannels

Microchannels Smooth Boundaries

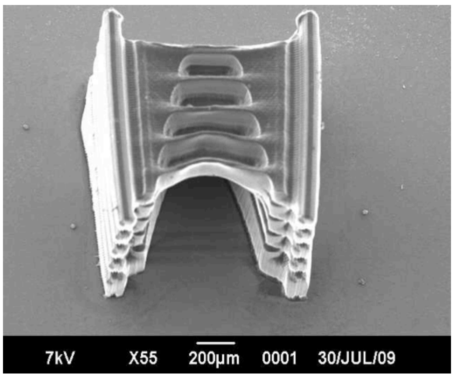


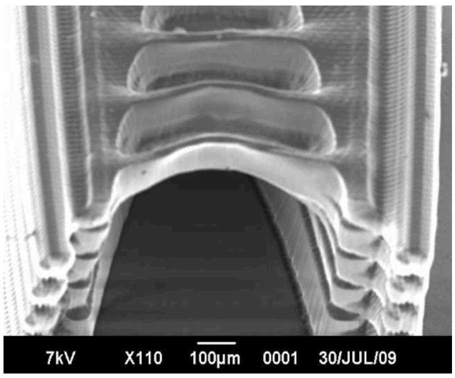


More Fabricated Microstructures using Proposed Way

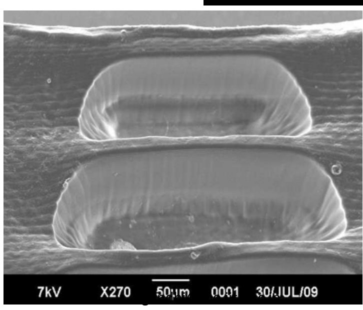


* Gandhi P.S. and Deshmukh S.“A 2D optomechanical focused laser spot scanner: analysis and experimental results for microstereolithography,” Journal of Micromechanics and Microengineering, 20 (2010) 015035.



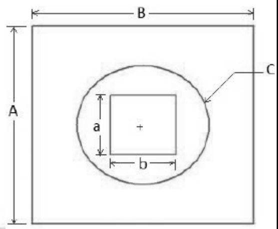


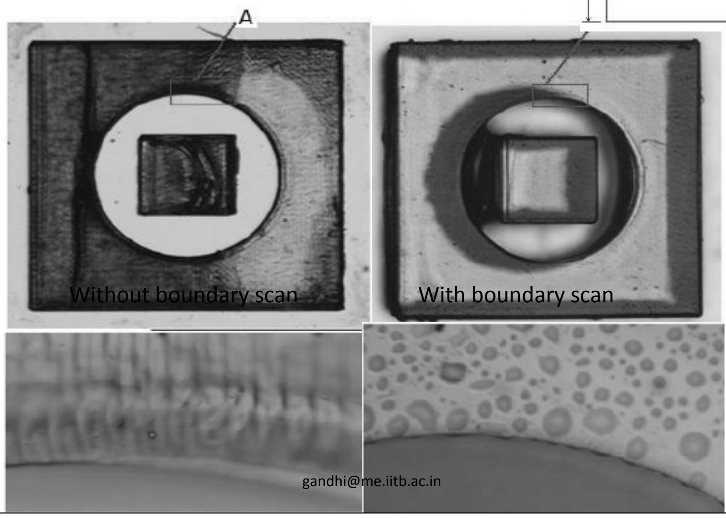
OVERHANG STRUCTURE



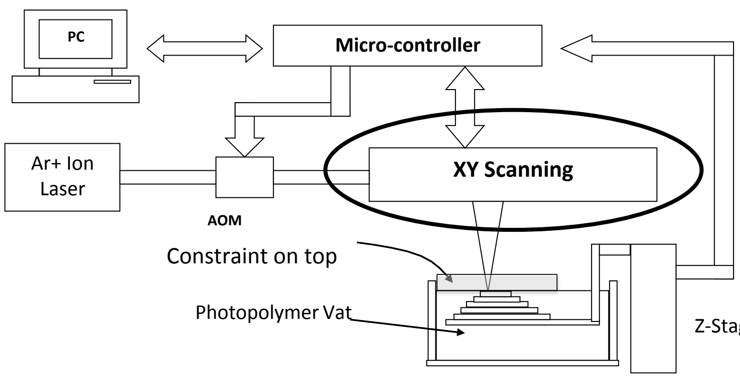
OVERHANG STRUCTURE (MAGNIFIED IMAGE)

Boundary scanning



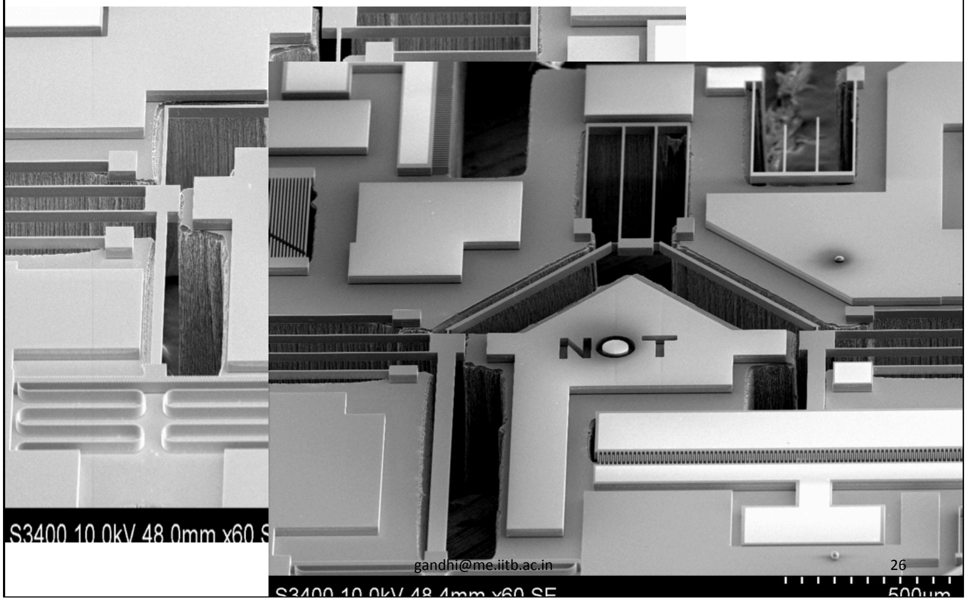


Constrained Surface Microstereolithography



Schematic of Constrained Surface Microstereolithography

Microflexural GATEs : NOT, OR

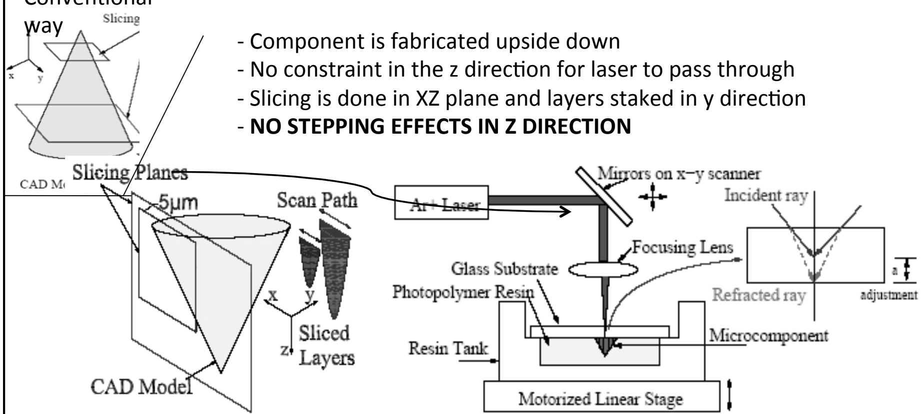


`Bulk Lithography': Novel 3D Microfabrication Process

Basic Concept

Conventional way

- Component is fabricated upside down
- No constraint in the z direction for laser to pass through
- Slicing is done in XZ plane and layers staked in y direction
- **NO STEPPING EFFECTS IN Z DIRECTION**



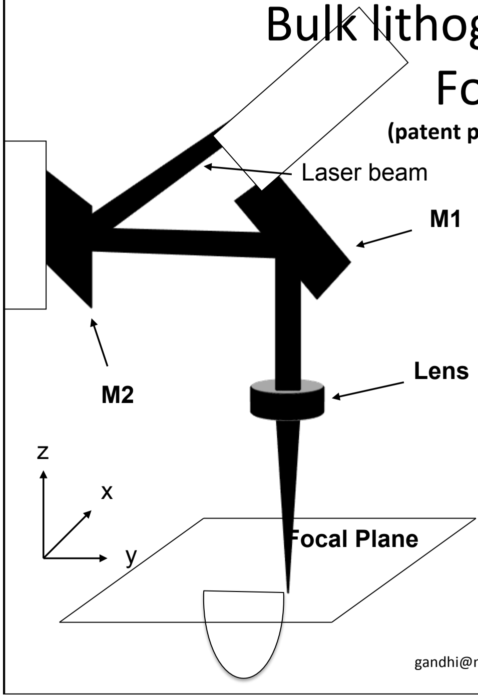
A. CAD model slicing strategy in 'Bulk Lithography'

B. Schematic diagram of proposed 'Bulk Lithography'.

• Bhole Kiran, " *Microfabrication using 'Bulk Lithography,'* in the proceedings of ASME •Mechanical Engineering Congress and Expo, Nov 2011, Denver, Colorado, USA.

Bulk lithography: Scanner for Focused Spot

(patent pending No 1847/MUM/2007)



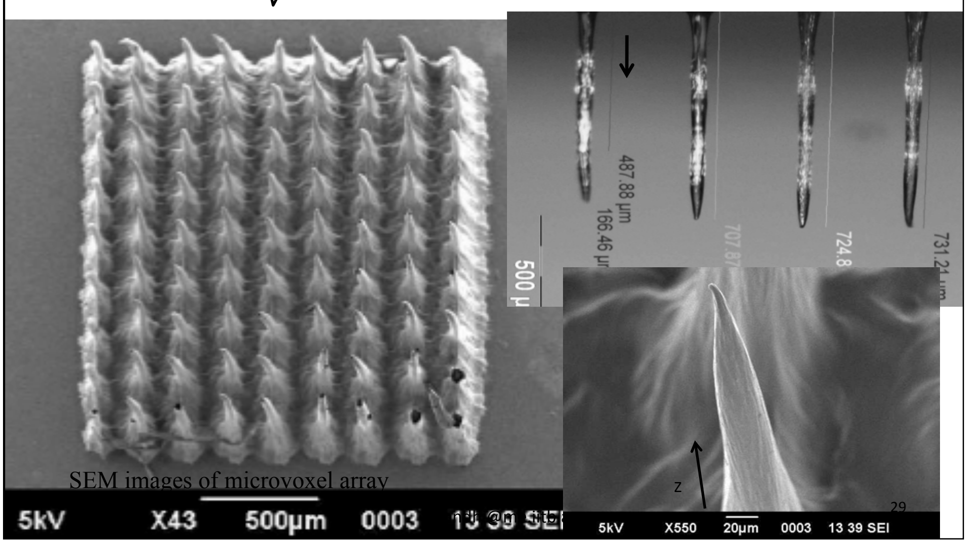
- Linear scanning of mirrors in the direction of the laser beam axis

ADVANTAGES:

☺ ***Uniform spot characteristics*** (i.e. constant spot size and uniform intensity profile)
☺ ***Virtually no limit on range***
☺ ***Improved resolution***
☺ ***Higher speeds possible***

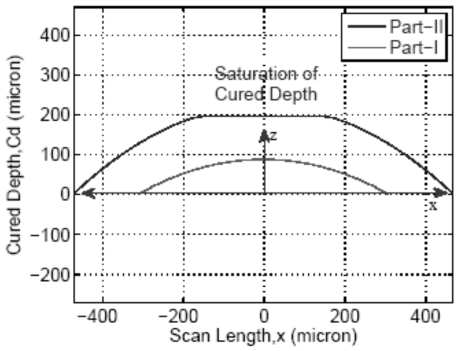
Q: How deep can we go??

Experimental Results: Cured Depth

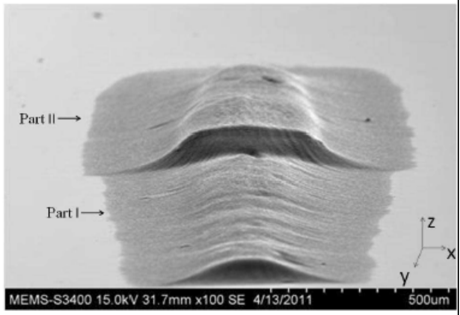


SEM images of microvoxel array

Fabrication of microstructures: Bulk lithography

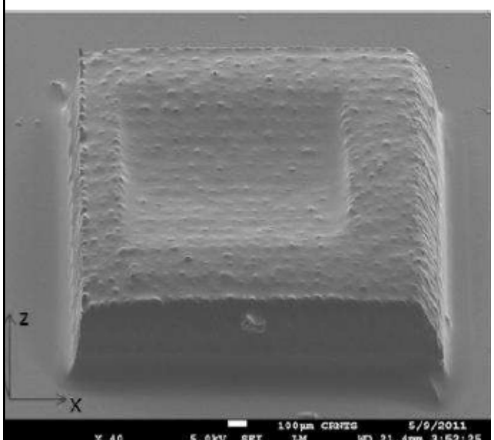


Curing depth variation along scan length.



Varying depth test structure using 'Bulk Lithography'.

Fabrication of microstructures: Bulk lithography



Observations

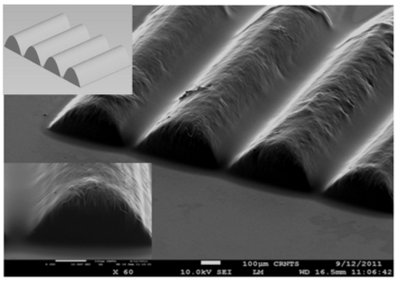
•
fabrication for micromirror

• Surface roughness because of scattering of light due to refractive index variation

• Possible to create fresnel lenses in similar manner

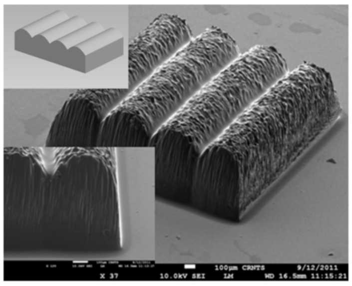
Fabrication of Test Microstructures : 'Bulk Lithography'

Fabrication predefine texture



Microstructure corresponding to regime I

Fabrication of rough surfaces



Microstructure corresponding to regime II and III

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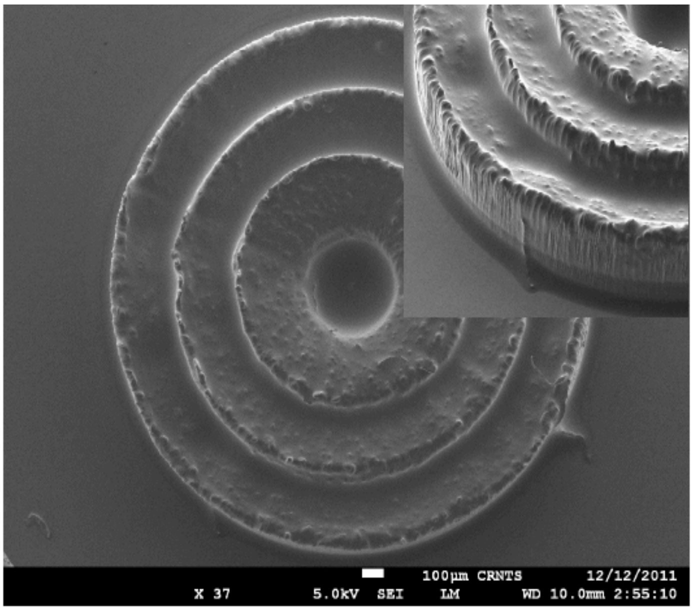

Test structure using 'Bulk Lithography' using radial scan.

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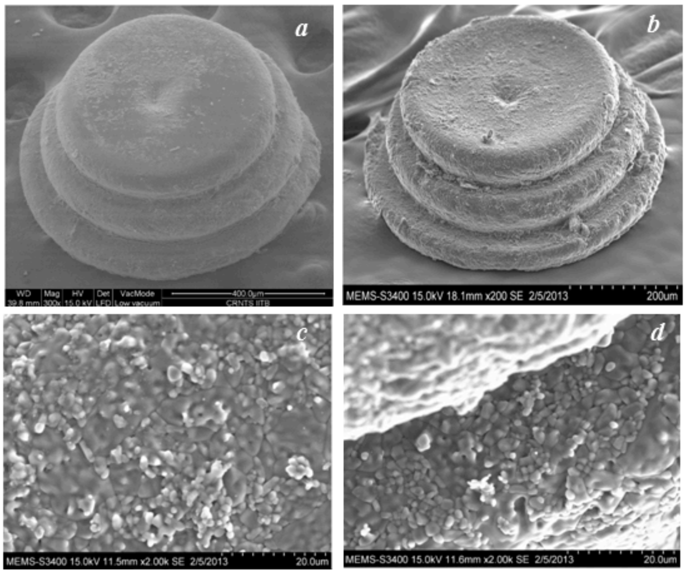
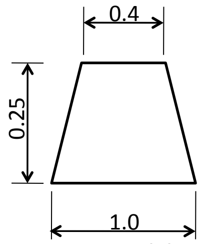
Ceramic MSL





CAD model

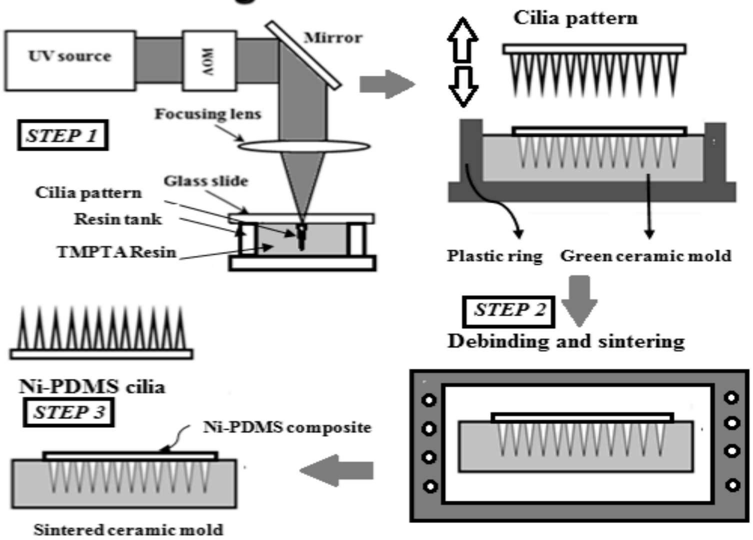
Power : 2mW
Scanning speed : 1.2 mm/sec
Layer thickness : 50 microns

(a)
(b)
(c)
(d)

layers

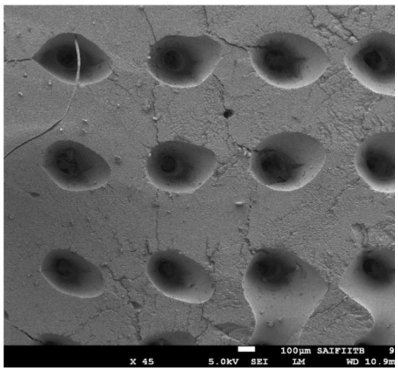
SEM images of part of the nozzle fabricated from constrained surface technique

Biomemtic Cilia using Ceramic Moulding

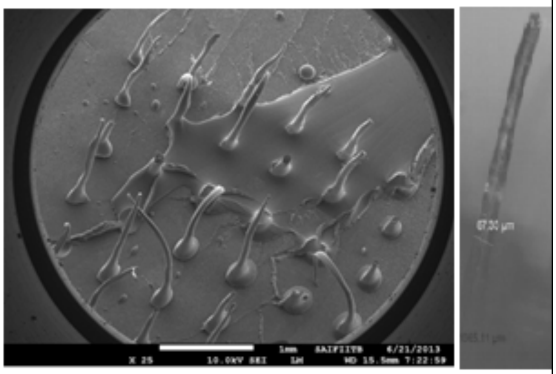


Biomemtic Cilia using Ceramic Moulding

High aspect ratio



SEM image of sintered ceramic mold showing holes by cilia pattern



SEM image of Ni-PDMS composite cilia (inset: Microscopic image of single cilium)

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Research

- Dynamics and control:
  - Slosh of liquid in tank
  - Flexible linkage mechanisms
  - Flexible linkage robots
  - Ultra large deformation Inverted flexible pendulum
  - Mechanical timer dynamics

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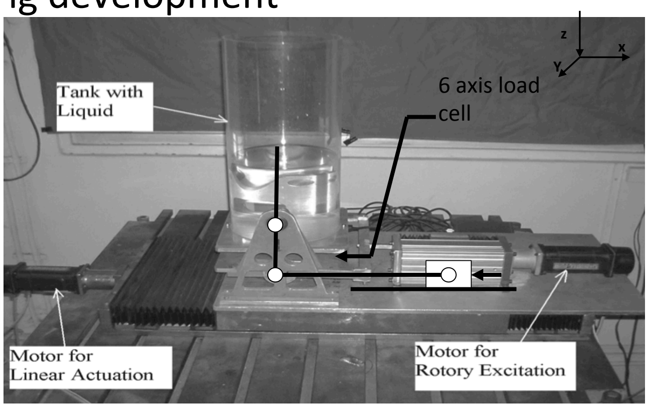
Slosh dynamics and control

- Importance
- Novel slosh rig development



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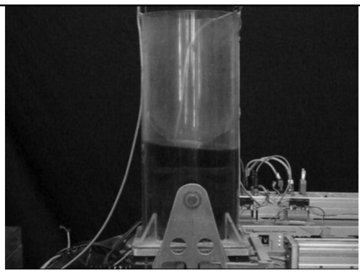
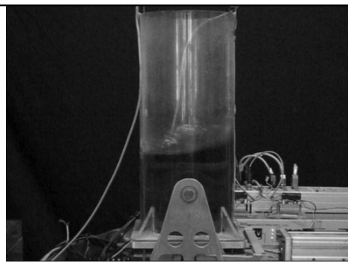
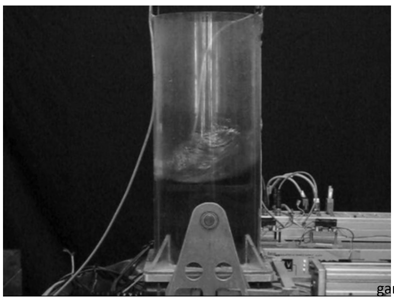


Lateral Slosh (only Linear excitation)
Linear amplitude = 2 mm
Linear frequency = 1.8 Hz



Small rotary Slosh + resonance near natural frequency (only Linear excitation)
Linear amplitude = 2 mm
Linear frequency = 2 Hz



Continuous Rotary Slosh
(only Linear excitation)
Linear amplitude = 2 mm
Linear frequency = 2.2 Hz
(All experiments for h/d=1)

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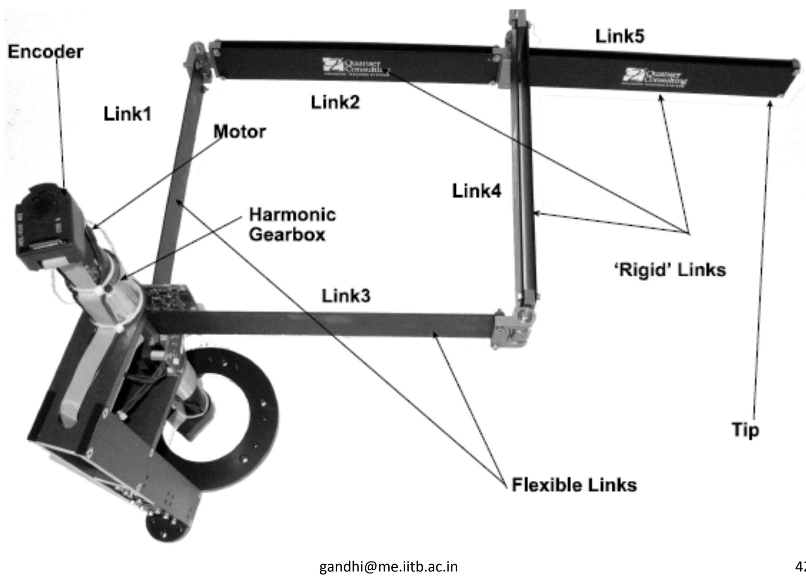
Slosh dynamics and control

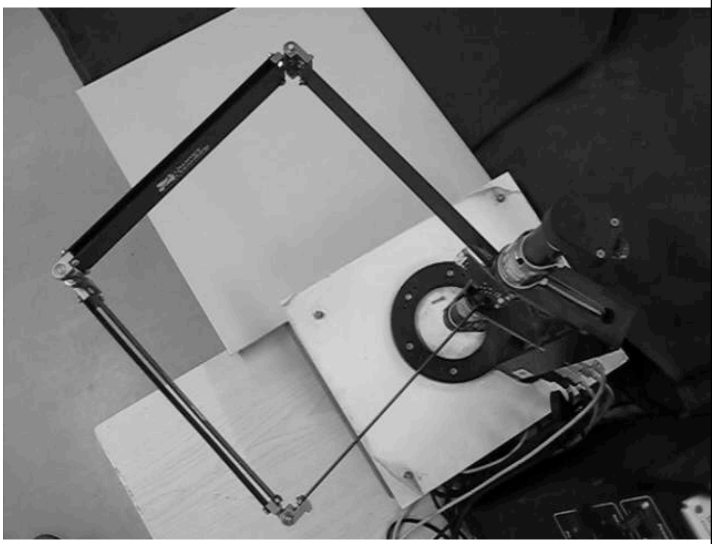
- Slosh modeling is carried out with pendulum model analogy
- Various parameter identification strategies developed and transferred to ISRO
- ISRO based on our pilot design built a similar 2DOF rig at VSSC and currently using algorithms transferred for identification of parameters used in mission simulation and control
- Various control strategies have been developed

Parallel Five Bar Manipulator



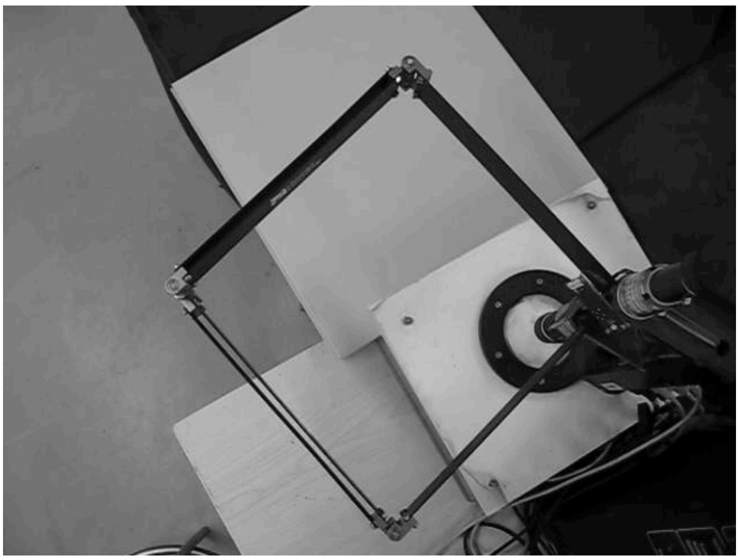
Parallel Five Bar Manipulator

- Without control

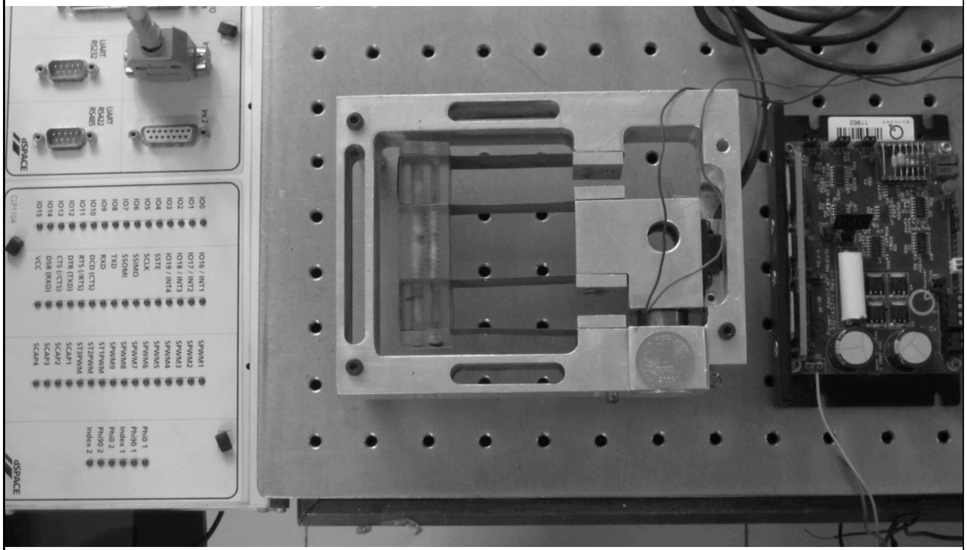


Parallel Five Bar Manipulator

- With control

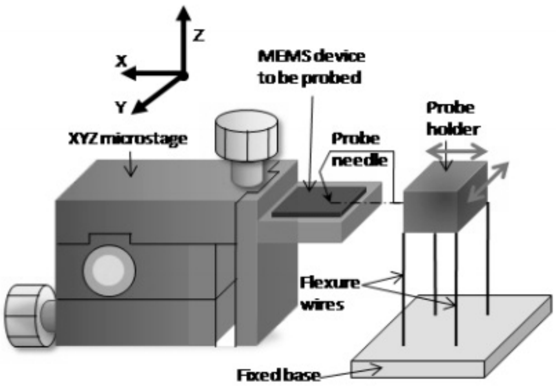


Double parallelogram flexue mechanism



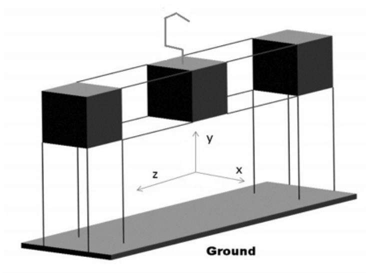
Mechanical Probe Station for MEMS

- Probe module-1



Small parasitic error

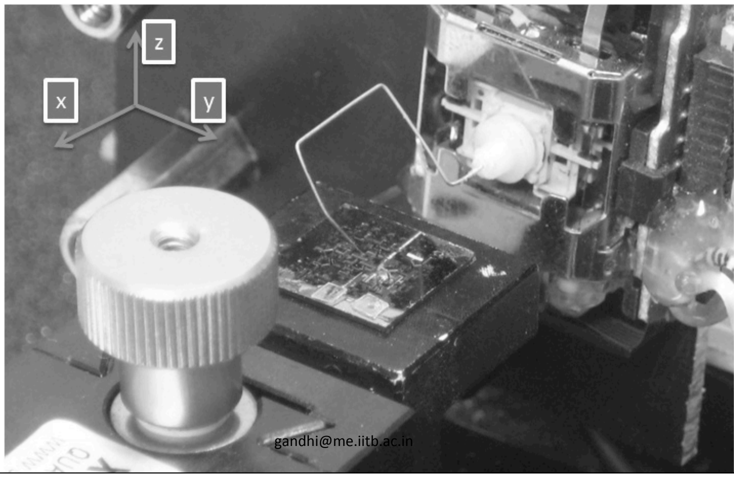
Alternative Design



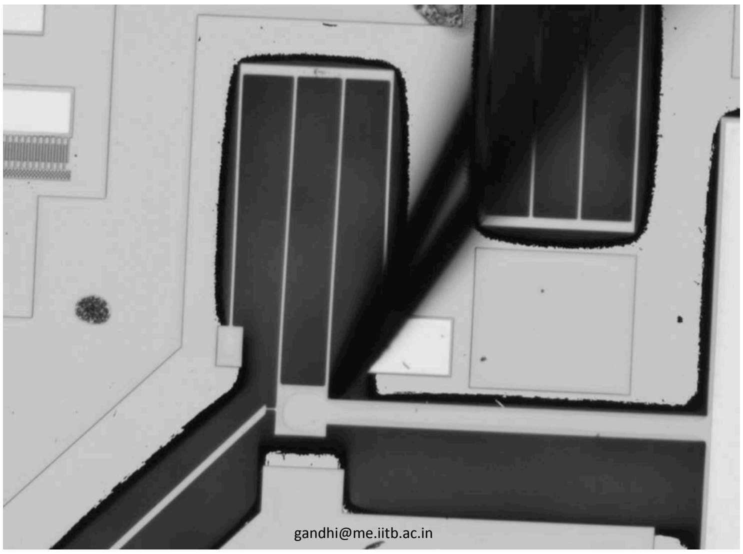
Avoids parasitic error while Moving in vertical direction

Mechanical Probe Station for MEMS

- Actually fabricated mechanism using CDROM



Case study : Probing of mechanical NOT Gate



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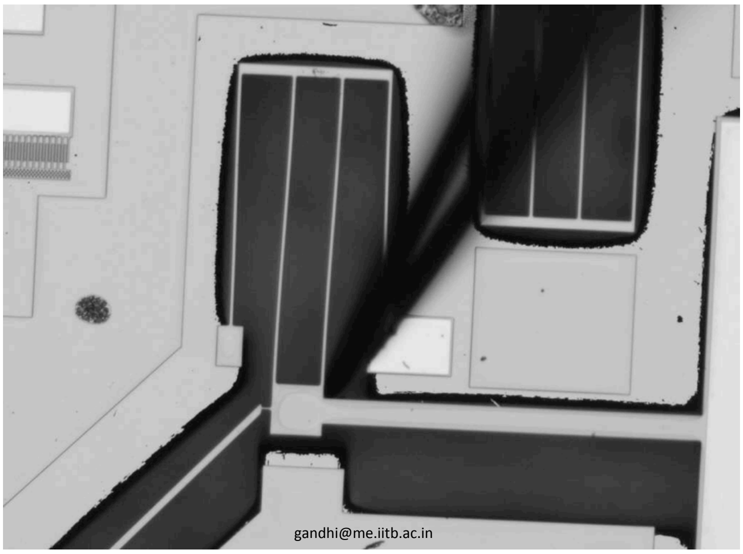
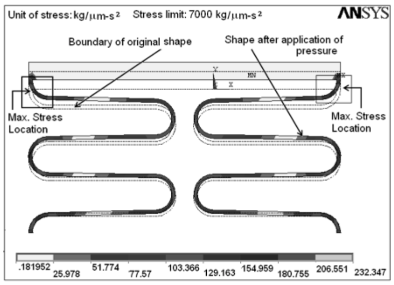
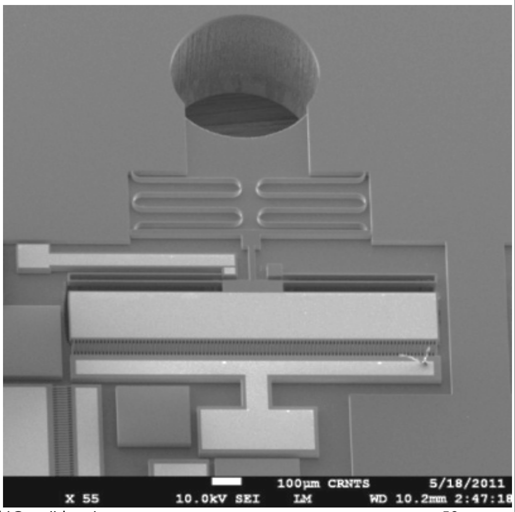


Pneumatic microactuator





Displacement amplifying flexure mechanism

Flexure mechanism for RCM

Inverted flexible pendulum system

- Ultra large deformations