Talk at TEQUIP Workshop, Dec. 2014

Research in MEMS, Dynamics, and Control Area

Prasanna S Gandhi
Professor
Department of Mechanical Engineering
IIT Bombay

gandhi@me.iitb.ac.in

Research

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

gandhi@me.iitb.ac.in
Research

- MEMS: MicroElectroMechanicalSystems
  - Microstereolithography
  - Bulk lithography

Suman Mashruwala Advance Microengineering Lab

Department of Mechanical Engineering, Indian Institute of Technology Bombay
Microstereolithography

Development of 3D microcomponent layer-by-layer

Various Scanning Methods and Analysis

- Post-objective
- Pre-objective
- Photo-reactor tank
- Off-axis Lens

Proposed by our group*


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

• 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

Flexure mechanism for xy scanning

Complete system

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...)

- Component with complicated curved features
  - Maximum size = 2mmx2mm, wall thickness = 150μm
  - Number of layer = 4, fabrication time = 1.30hrs.
3D High Aspect Ratio Microchannels

High aspect ratio microchannels

gandhi@me.iitb.ac.in

Microchannels Smooth Boundaries

Microchannels Smooth Boundaries

gandhi@me.iitb.ac.in
More Fabricated Microstructures using Proposed Way

* Gandhi P.S. and Deshmukh S. "A 2D optomechanical focused laser spot scanner: analysis and experimental results for micro-

OVERHANG STRUCTURE

OVERHANG STRUCTURE (MAGNIFIED IMAGE)
Boundary scanning

Without boundary scan  
With boundary scan

Constrained Surface Microstereolithography

Schematic of Constrained Surface Microstereolithography
Microflexural GATEs : NOT, OR

'Bulk Lithography': Novel 3D Microfabrication Process

Basic Concept

- 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’.
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

Experimental Results: Cured Depth

Q: How deep can we go??

SEM images of microvoxel array

5kV  X43  50μm  0003  13.39 SE1

5kV  X550  20μm  0003  13.39 SE1
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
- Fabrication of rough surfaces

Fabrication of Test Microstructures:

- Microstructure corresponding to regime I
- Microstructure corresponding to regime II and III

Test structure using ‘Bulk Lithography’ using radial scan.

Contact: gandhi@me.iitb.ac.in
SEM images of part of the nozzle fabricated from constrained surface technique

(a) as fabricated
(b) sintered part
(c) grain boundary
d) two different layers

CAD model

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

Biomemetic Cilia using Ceramic Moulding

STEP 1
UV source
Focusing lens
Glass slide
Tempo Resin

STEP 2
Plastic ring
Green ceramic mold
Debonding and sintering

STEP 3
Ni-PDMS cilia
Ni-PDMS composite
Sintered ceramic mold

gandhi@me.iitb.ac.in
Biomimetic 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)

gandhi@me.iitb.ac.in

Research

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

gandhi@me.iitb.ac.in
Slosh dynamics and control

• Importance
• Novel slosh rig development

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)
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

• Without control

Parallel Five Bar Manipulator

• With control
Double parallelogram flexue mechanism

Mechanical Probe Station for MEMS

• Probe module-1

Small parasitic error

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
Case study: Probing of mechanical NOT Gate

Pneumatic microactuator
Displacement amplifying flexure mechanism

Flexure mechanism for RCM
Inverted flexible pendulum system

• Ultra large deformations