Micro-Stereolithography: Physics and Technologies

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mSL principles and apparatus design
Prototyping of polymeric and ceramic microstructures
Experiment and modeling

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Outline

- Introduction

- Micro-Stereolithography (µSL)
  - µSL principles and apparatus design
  - Prototyping of polymeric and ceramic microstructures
  - Experiment and modeling

- Applications
Background

- Future high Performance MEMS requires:
  - 3D complex micro-structures
  - Incorporating with a broader spectrum of materials (Smart materials, functional polymer, and magnetic alloys)

- However, current silicon IC fabrication can not provide an effective solution.

- Other efforts:
  - X-ray LIGA: high aspect ratio 2.5D, but not true 3D
  - Micro-mechanical machining: complex 3D, but very slow and severe tool wear
  - EFAB, 3D, need many masks needed and limited to metal
A New Approach—Scale Down Rapid Prototyping Technologies

Micro-Stereolithography

- UV laser micro photo-forming of 3D complex micro-parts
- A layer-by-layer additive process
- CAD design capability
- Incorporation of many functional materials

(Ikuta, 1996)
An Advanced Micro-Stereolithography Apparatus

- Laser: $\lambda = 364$ nm
- X-Y-Z stepper resolution: 0.5 $\mu$m
- UV beam spot: 1 $\mu$m
Test Pattern with 2 μm Line Width
Micro-Stereolithography of 3D Complex Structures

- Micro-spring
- Micro-mushroom
- **Micro-tube**
  (50 µm inner diameter and 800 µm long)

- **Micro-rod Array**
  (50 µm diameter and 500 µm long)
Simulation of Micro-Stereolithography of Polymer

Photopolymerization

• **Initiation:**
  
  Photon \(\rightarrow\) Initiator \(\rightarrow\) Radical

  Initiator + Heat

• **Propagation:**

  Radical + Monomer \(\rightarrow\) Polymer + Heat

• **Termination:**

  Polymer + Polymer \(\rightarrow\) Solidified Part

  Laser Beam

  UV curable resin

  Radicals
Simulation Approach

- **Light absorption:**
  \[
  \frac{dI}{dz} = - \varepsilon [S] I
  \]

- **Photoinitiation:**
  \[
  \frac{d}[S]}{dt} = - \psi \varepsilon [S] I
  \]

- **Diffusion of Radicals:**
  \[
  \frac{d[R]}{dt} = D \left[ \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial [R]}{\partial r} \right) + \frac{\partial^2 [R]}{\partial z^2} \right] + \phi \varepsilon [S] I - k_t [R]^2
  \]

- **Polymerization Kinetics:**
  \[
  \frac{d[M]}{dt} = - k_p [R][M]
  \]

- **Heat Transfer:**
  \[
  \rho C_p \frac{\partial T}{\partial t} = k \left[ \frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial T}{\partial r} \right) + \frac{\partial^2 T}{\partial z^2} \right] - k_p [R][M] \Delta H
  \]
Monte-Carlo Simulation of µSL of Ceramics

Single photon tracing processes:

- Scattering
  - Mie theory

- Absorption during traveling
  - travel: $P = e^{-1/\lambda}$, $\lambda = \frac{4 \cdot r}{3 \cdot s}$ (MFP)
  - absorption: $P_a = e^{-s}$

- Photo polymerization
3D Ceramic μSL

30 μm Alumina Micro Channels  400 μm Alumina Micro Gear
Micro-Stereolithography of Ceramic Structures

- Green Alumina Gear
- Sintered Alumina Gear

Sintered at 1400 °C and 3 hours
Shrinkage due to sintering: 5-16%
Lateral Resolution Limit in µSL of Ceramics

![Graph showing the relationship between Curing Radius (µm) and Laser Beam Radius (µm). The graph displays a positive correlation between the two variables, with the Curing Radius increasing as the Laser Beam Radius increases.]
3D Matrix by DMD-µSL
3D Coils Array and Micro-Matrix
3D Photonic Band-gap Crystals

- Transmit/forbid light beam of selected wavelength (12 dB)

- Defects are pre-designed by CAD and embedded into the PBG by micro-stereolithography (decide what type defects and where they localed, which is impossible in atomic scale defects in semiconductor)

Applications

- Loss-free optical fiber
- High efficiency visible –IR bandpass filter/waveguide
- Resonant cavity in solid state laser

(Joannopoulos, 1996)

(Zhang, 1999)
Artificial Materials With Unprecedented Properties
(Theoretical work of John Pendry, 2000)

Artificial Magnetism at High $f$

Super-lens

Artificial Plasma
**3D Valveless Micropump**

- Truly 3D cavity structure to optimize the design
- High reliability due to no movable valves
- A wide variety of materials (e.g., Bio-polymer)
Near Field Optical nanolithography (NSOL)

- Near field scanning optical microscopy (NSOM)- a proven technology to break the diffraction limit.
- 2D nanopatterning with NSOM demonstrated features with ~100nm lateral resolution
- Computer simulation propose that NSOM has the potential in 3D nanolithography
Conclusions

- Scanning micro-stereolithography has been developed

- Micro-stereolithography of complex 3D micro-structures has been demonstrated; For the first time, μSL of ceramic micro-structures has been succeeded

- Theoretical Simulation of micro-stereolithography shows good agreements with preliminary experimental results

- The unique 3D techniques enable exciting applications in photonics, bioMEMS and possibly novel thermally engineered materials.