Micro-Stereolithography: Physics and Technologies

Xiang Zhang

Department of Mechanical and Aerospace Engineering

University of California, Los Angeles

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (FROM - TO)
30-05-2001	Workshop Presentations	30-05-2001 to 01-06-2001

4. TITLE AND SUBTITLE
Micro-Stereolithography: Physics and Technologies
Unclassified

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Zhang, Xiang ;

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME AND ADDRESS
Department of Mechanical and Aerospace Engineering
University of California, Los Angeles
Los Angeles, CAxxxxx

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME AND ADDRESS
Office of Naval Research International Field Office
Office of Naval Research
Washington, DCxxxxx

10. SPONSOR/MONITOR'S ACRONYM(S)
11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
APUBLIC RELEASE
,

13. SUPPLEMENTARY NOTES
See Also ADM001348, Thermal Materials Workshop 2001, held in Cambridge, UK on May 30-June 1, 2001. Additional papers can be downloaded from: http://www-mech.eng.cam.ac.uk/onr/

14. ABSTRACT
? mSL principles and apparatus design ? Prototyping of polymeric and ceramic microstructures ? Experiment and modeling

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	Public Release	23	Fenster, Lynn lfenster@dtic.mil
Unclassified	Unclassified	Unclassified			19b. TELEPHONE NUMBER International Area Code Area Code Telephone Number 703767-9007 DSN 427-9007

Acknowledgement:

Students at my group:

Cheng Sun, Nick Fang, Xiaoning Jiang, Ming Xi,
Dongmin Wu, Zhiliang Wan

NSF CAREER award
ONR Young Investigator Award

Outline

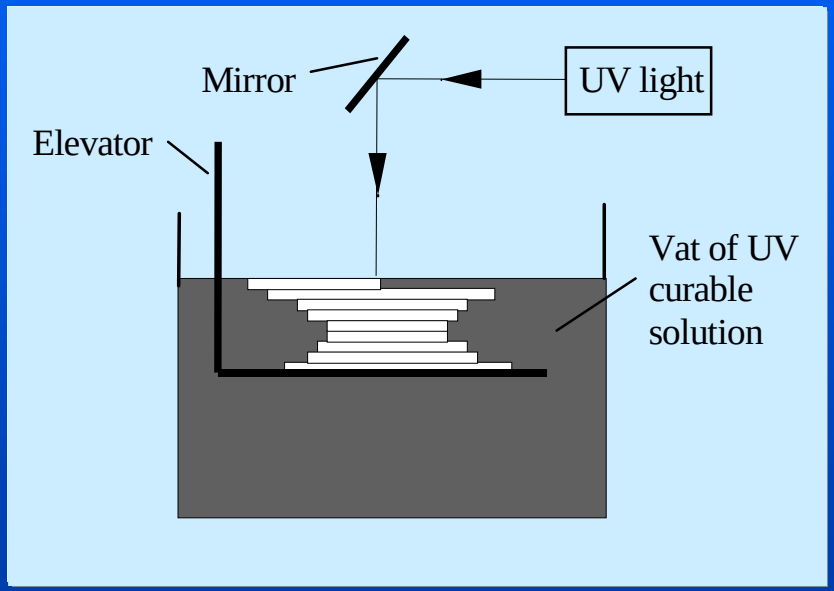
- Introduction
- Micro-Stereolithography (μSL)
  - μSL principles and apparatus design
  - Prototyping of polymeric and ceramic microstructures
  - Experiment and modeling
- Applications

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

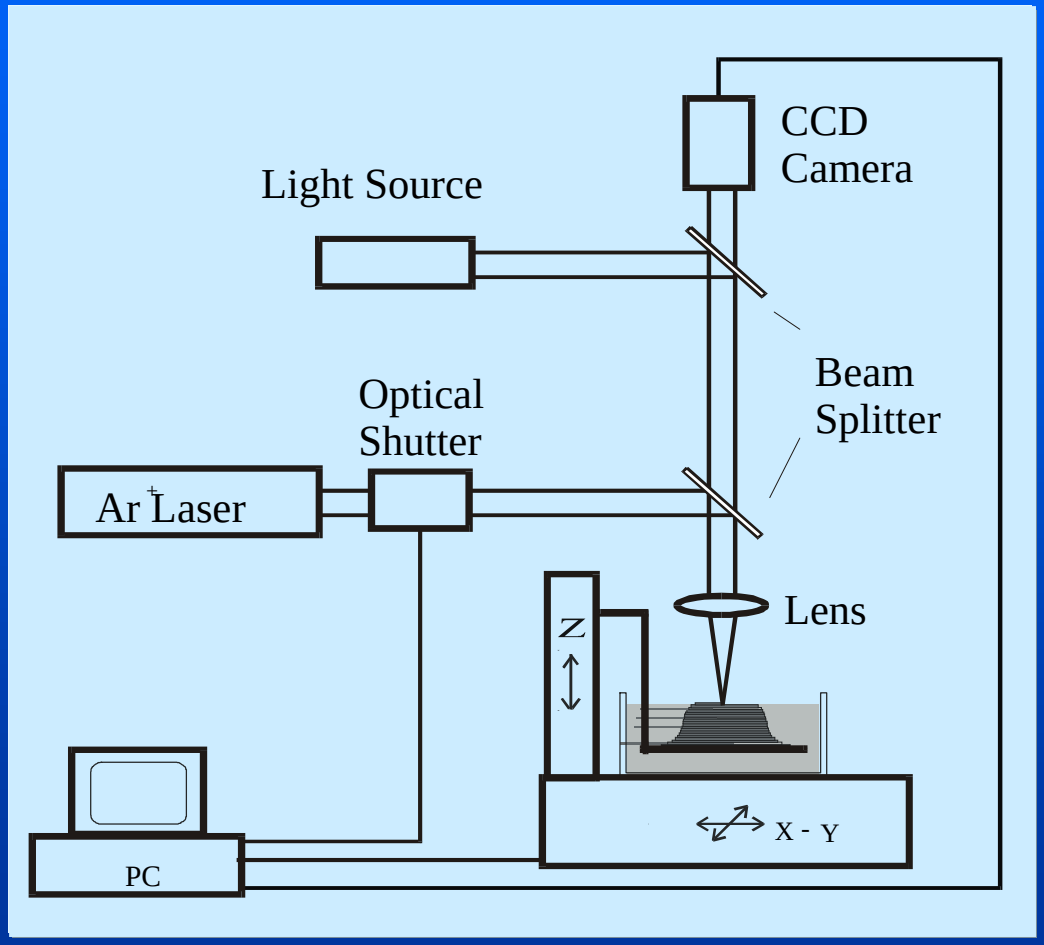
Micro-Stereolithography



(Ikuta, 1996)

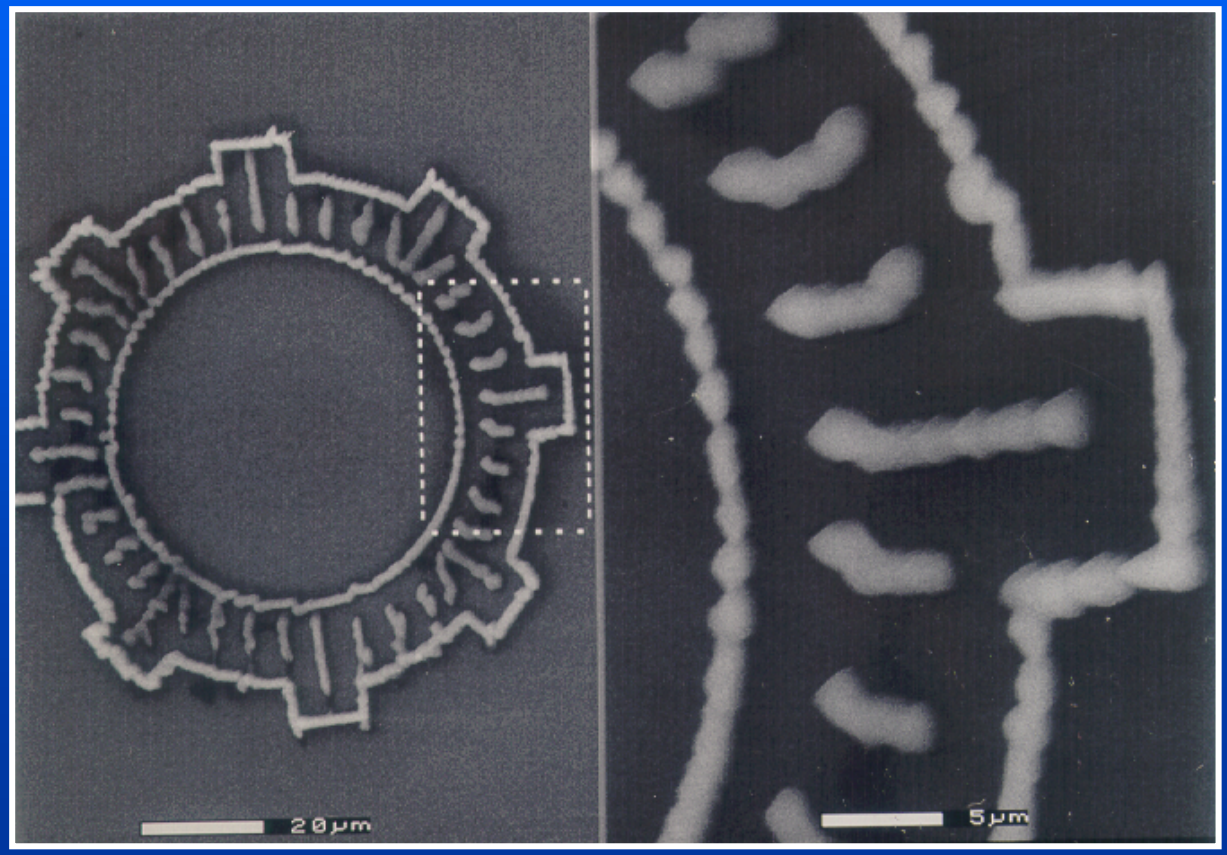
- UV laser micro photo-forming of 3D complex micro-parts
- A layer-by-layer additive process
- CAD design capability
- Incorporation of many functional materials

An Advanced Micro-Stereolithography Apparatus



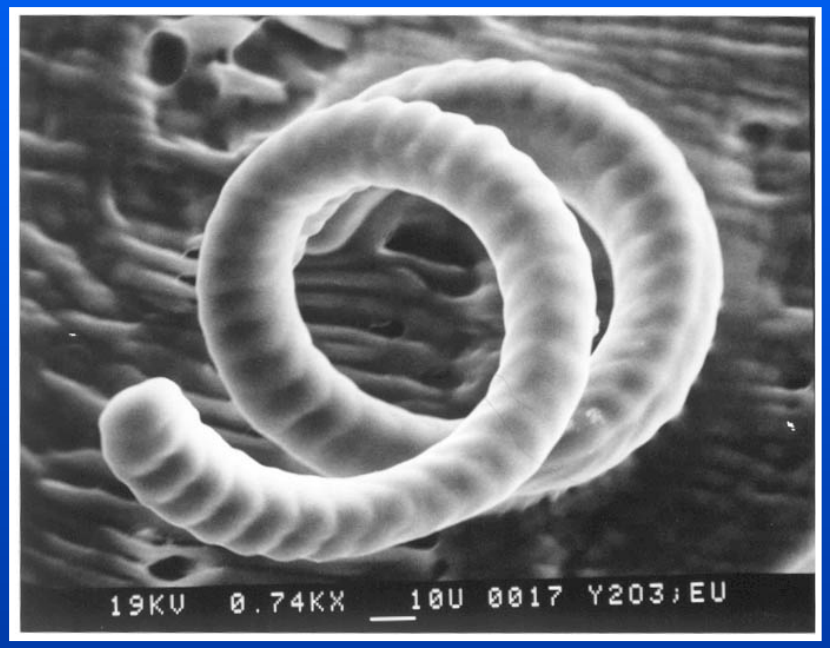
- Laser: λ=364 nm
- X-Y-Z stepper resolution: 0.5 μm
- UV beam spot: 1 μm

Test Pattern with 2 μm Line Width

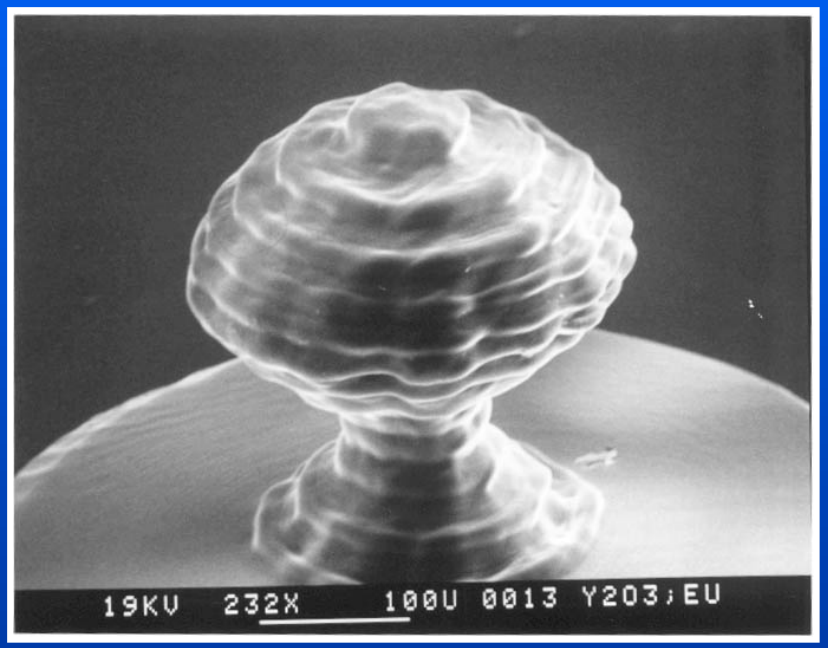


Micro-Stereolithography of 3D Complex Structures

- Micro-spring

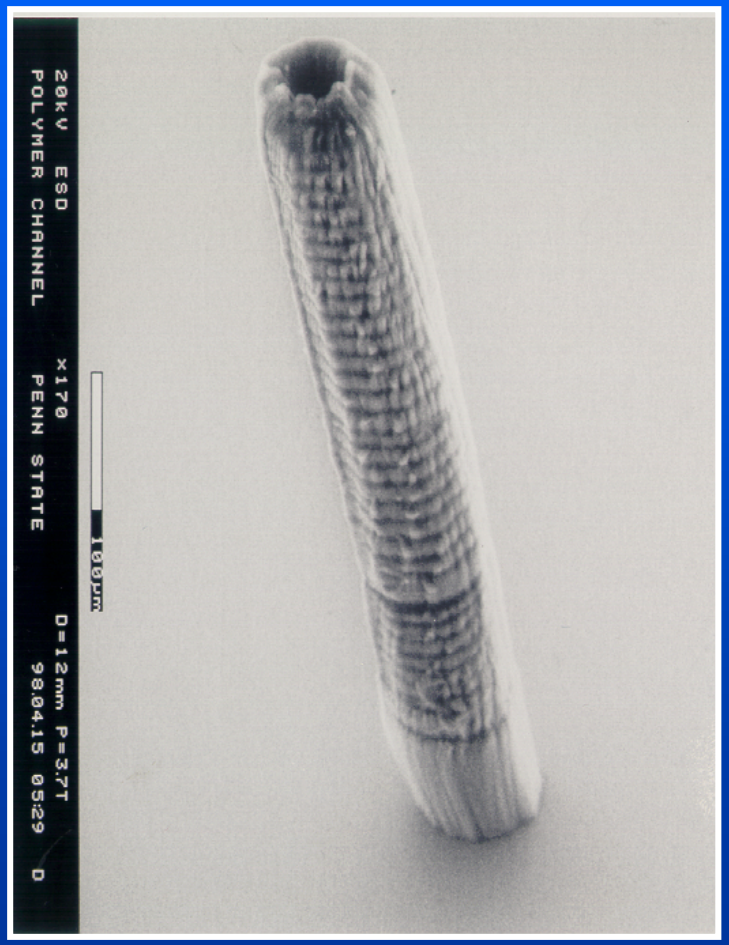


- Micro-mushroom



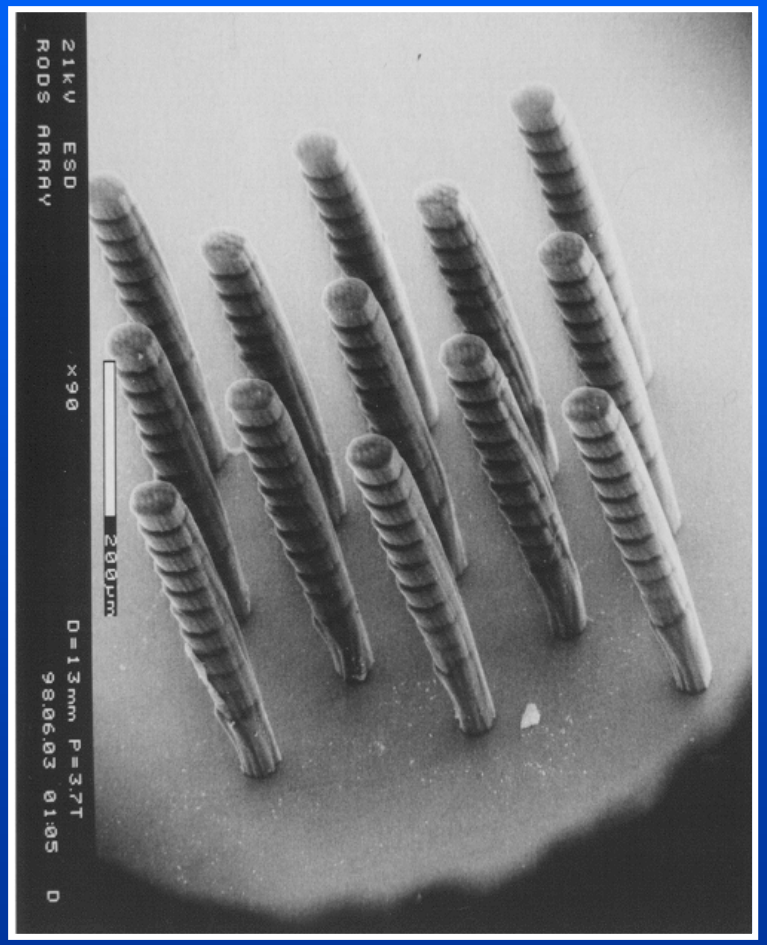
- **Micro-tube**

(50 μm inner diameter and 800 μm long)



- **Micro-rod Array**

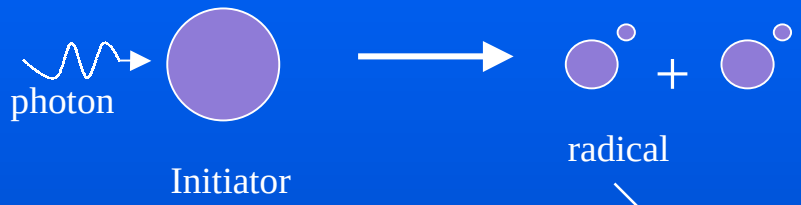
(50 μm diameter and 500 μm long)



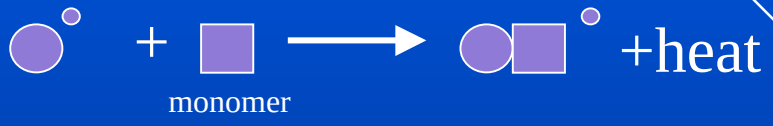
Simulation of Micro-Stereolithography of Polymer

Photopolymerization

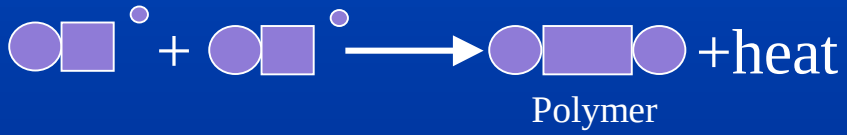
- **Initiation:**

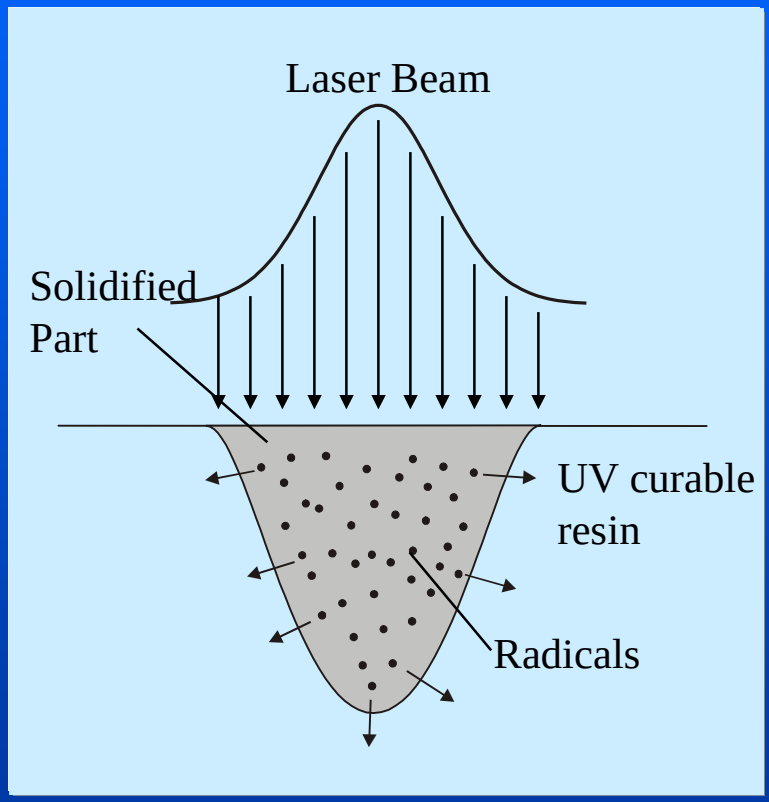


- **Propagation:**



- **Termination:**





Simulation Approach

- **Light absorption:**

$$\frac{dI}{dz} = -\varepsilon [S] I$$

- **Photoinitiation:**

$$\frac{d[S]}{dt} = -\psi\varepsilon [S] I$$

- **Diffusion of Radicals:**

$$\frac{d[R]}{dt} = D[\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial[R]}{\partial r}) + \frac{\partial^2[R]}{\partial z^2}) + \phi\varepsilon [S] I - k_t [R]^2$$

- **Polymerization Kinetics:**

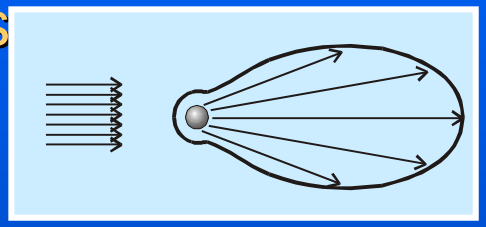
$$\frac{d[M]}{dt} = -k_p [R][M]$$

- **Heat Transfer:**

$$\rho C_p \frac{\partial T}{\partial t} = k[\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial T}{\partial r}) + \frac{\partial^2 T}{\partial z^2}] - k_p [R][M]\Delta H$$

Monte-Carlo Simulation of μSL of Ceramics

Single photon tracing processes



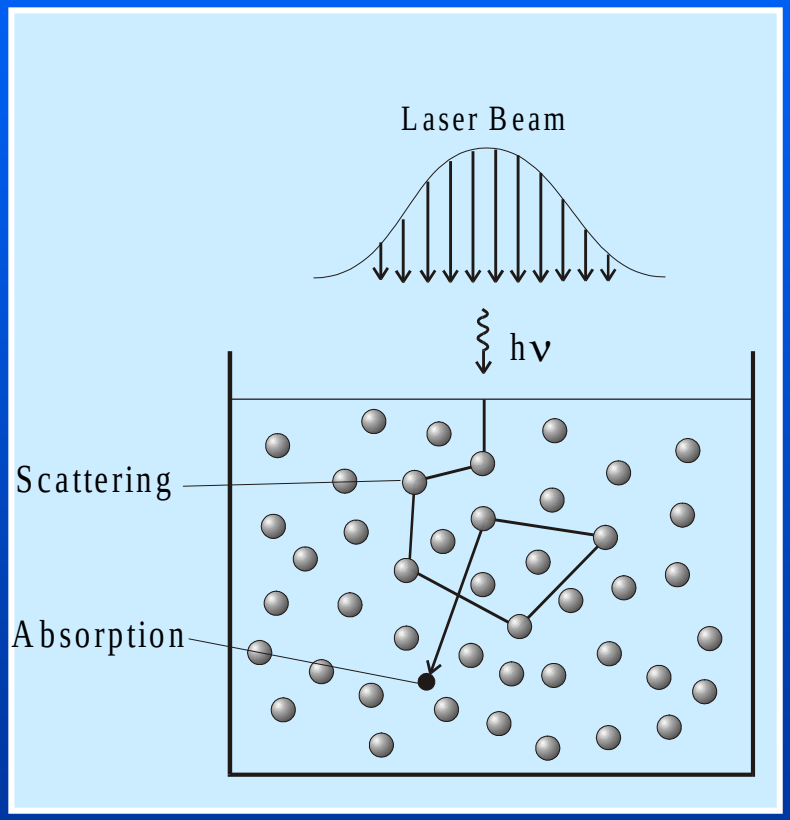
- Scattering
  - Mie theory
- Absorption during traveling
  - travel:

$$P = e^{-l/\lambda}, \lambda = \frac{4 \cdot r}{3 \cdot s}(MFP)$$

  - absorption:

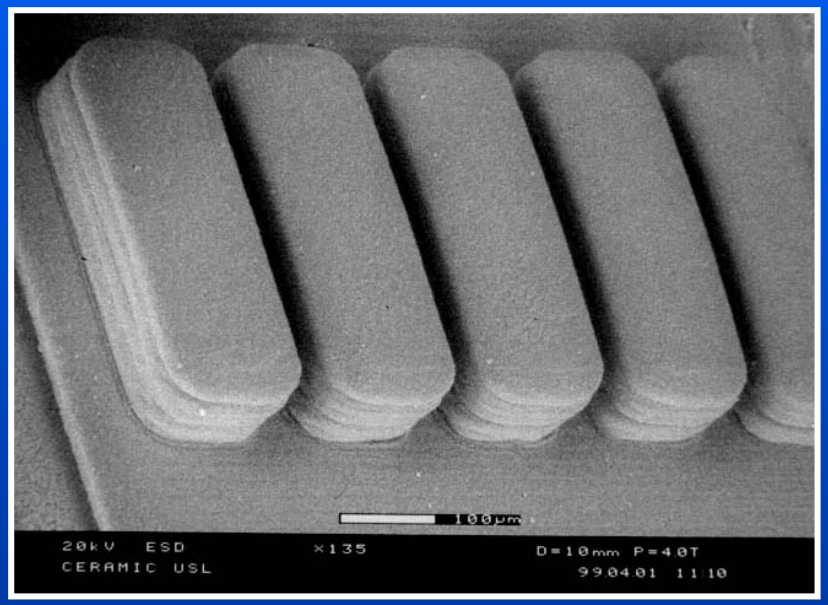
$$P_a = e^{-\varepsilon \cdot l}$$

- Photo polymerization

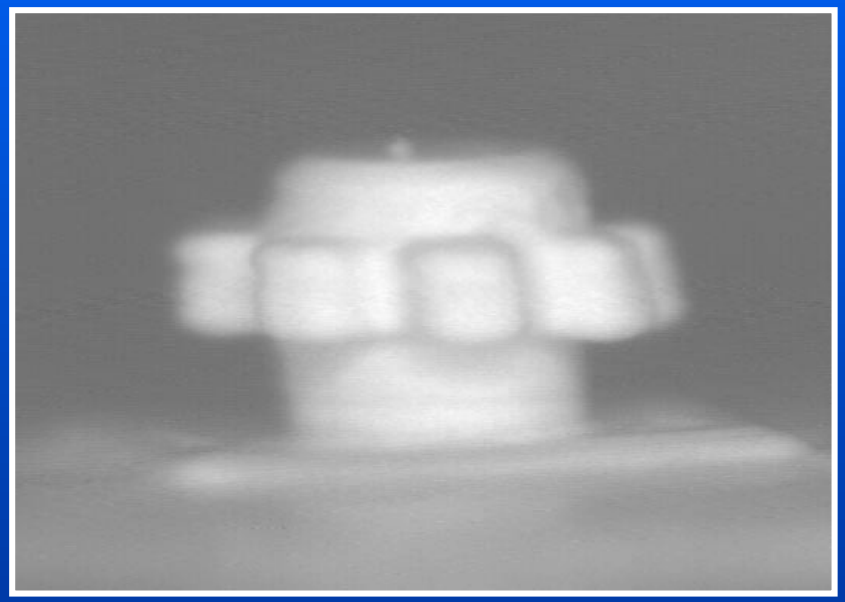


3D Ceramic μSL

30 μm Alumina Micro Channels

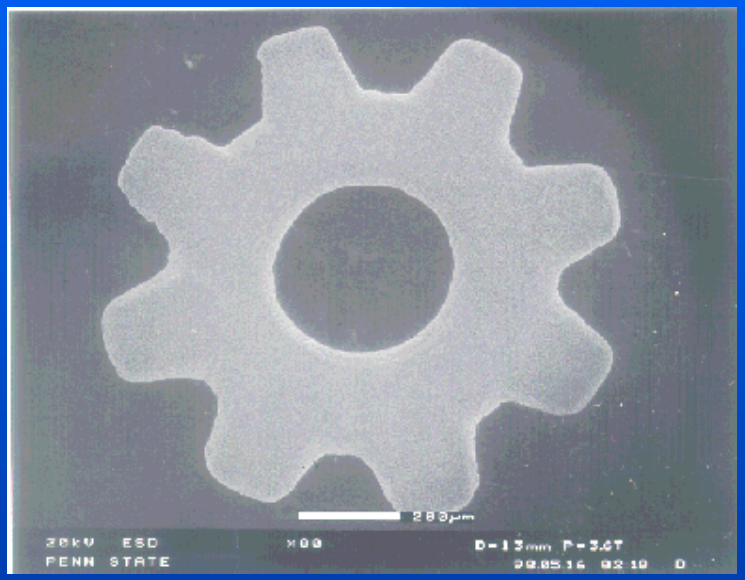


400 μm Alumina Micro Gear

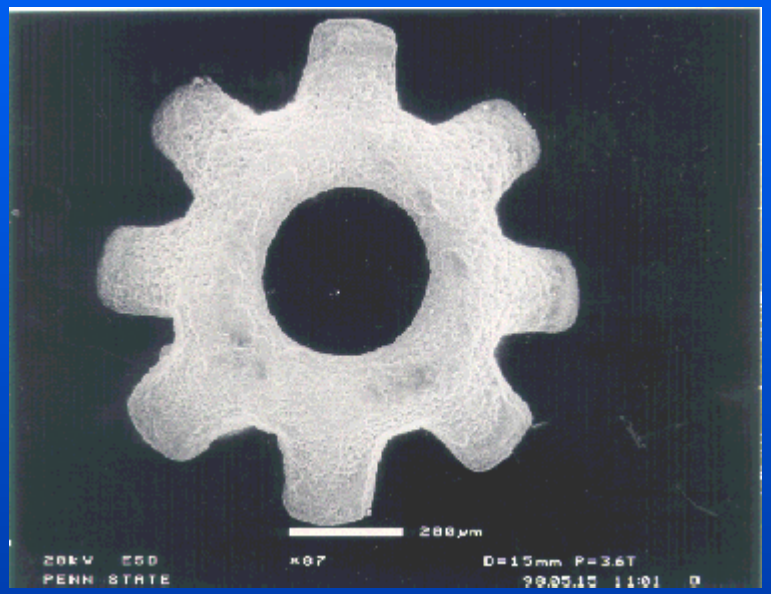


Micro-Stereolithography of Ceramic Structures

- Green Alumina Gear

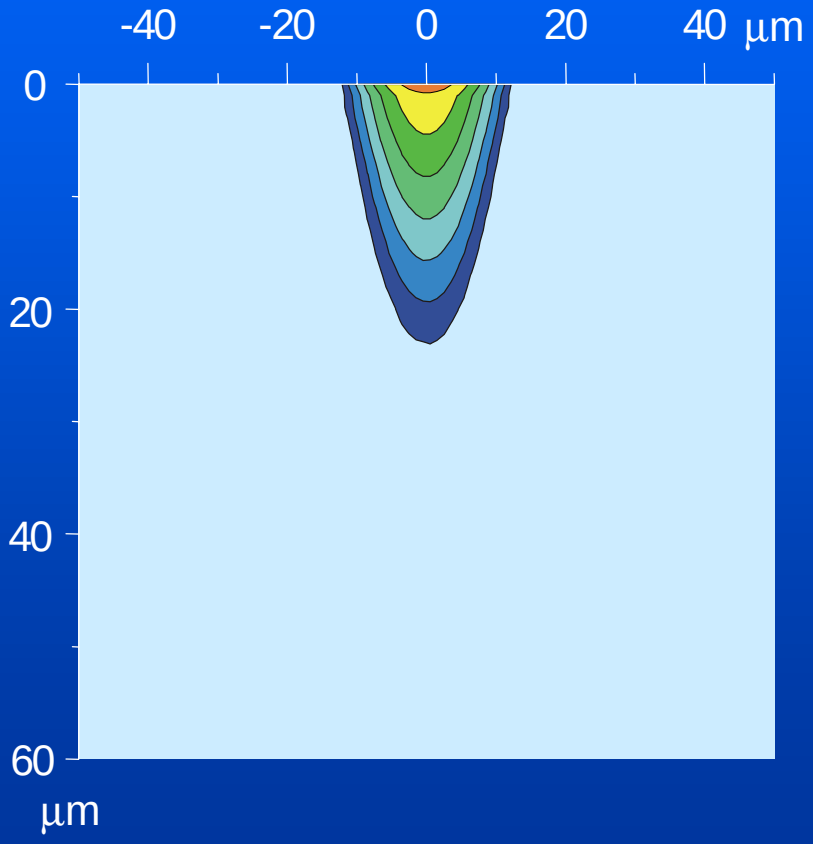


- Sintered Alumina Gear

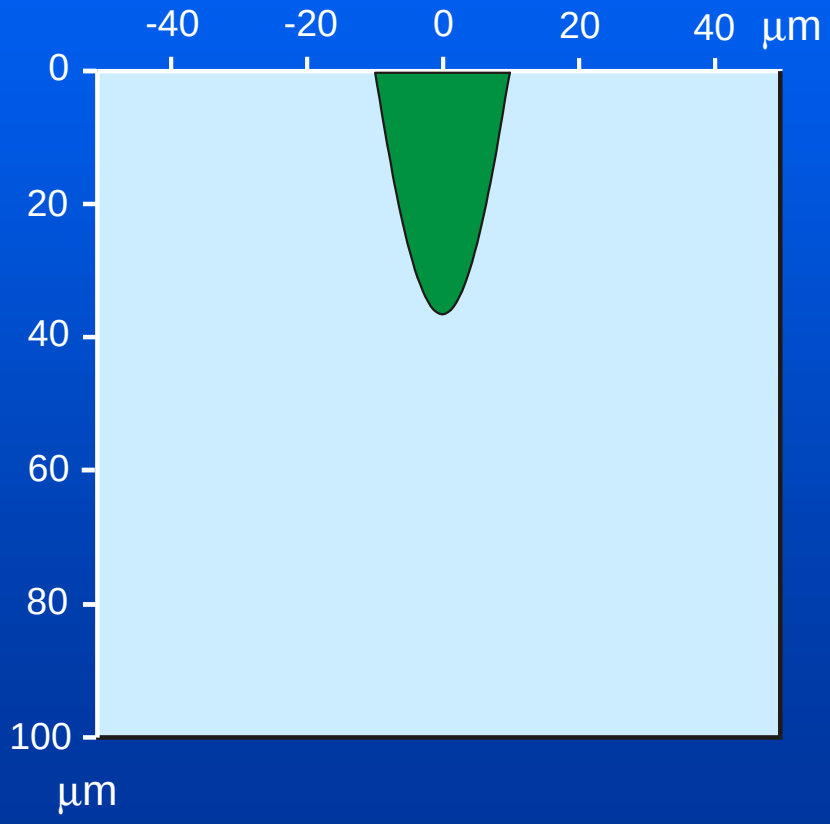


Sintered at 1400 °C and 3 hours
Shrinkage due to sintering: 5-16%

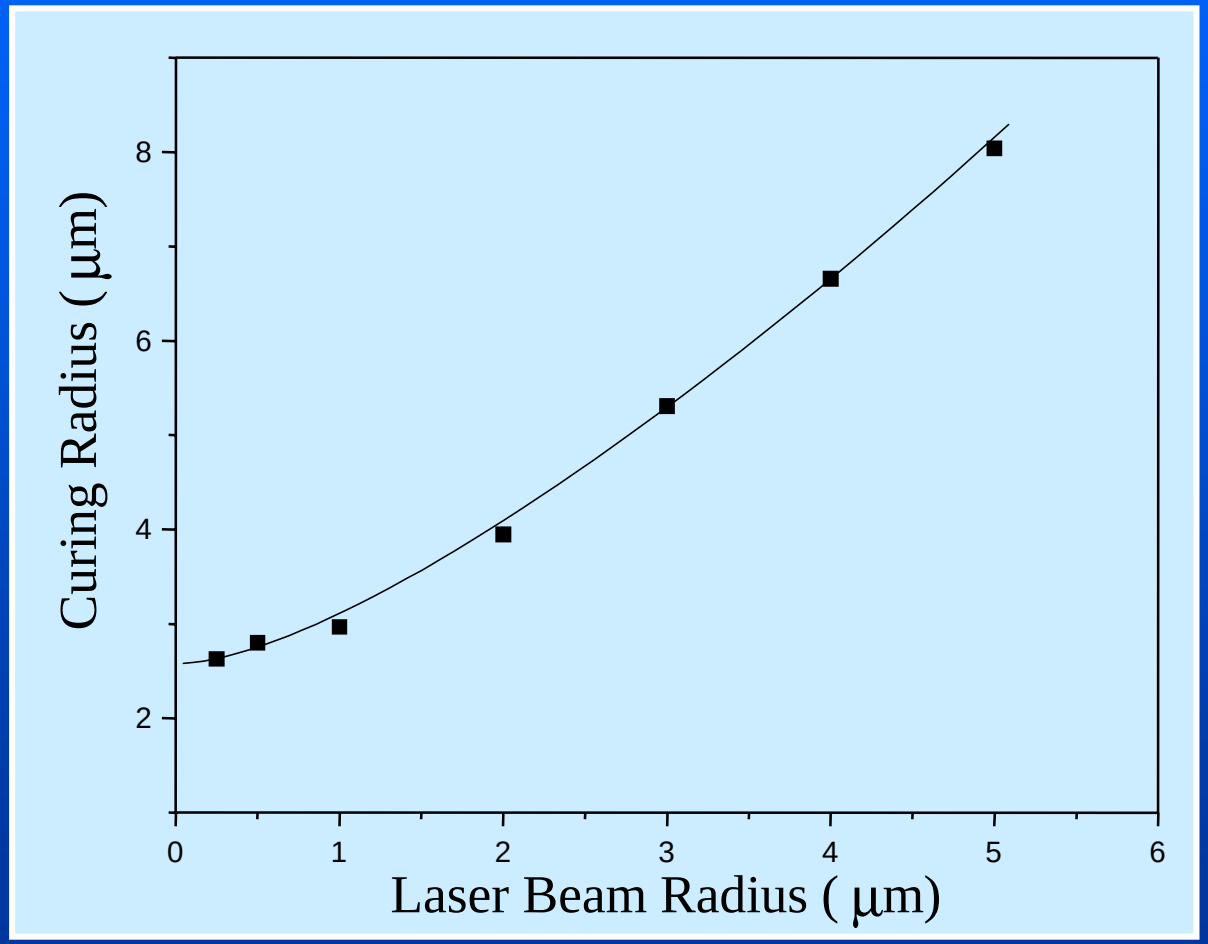
Light Scattering



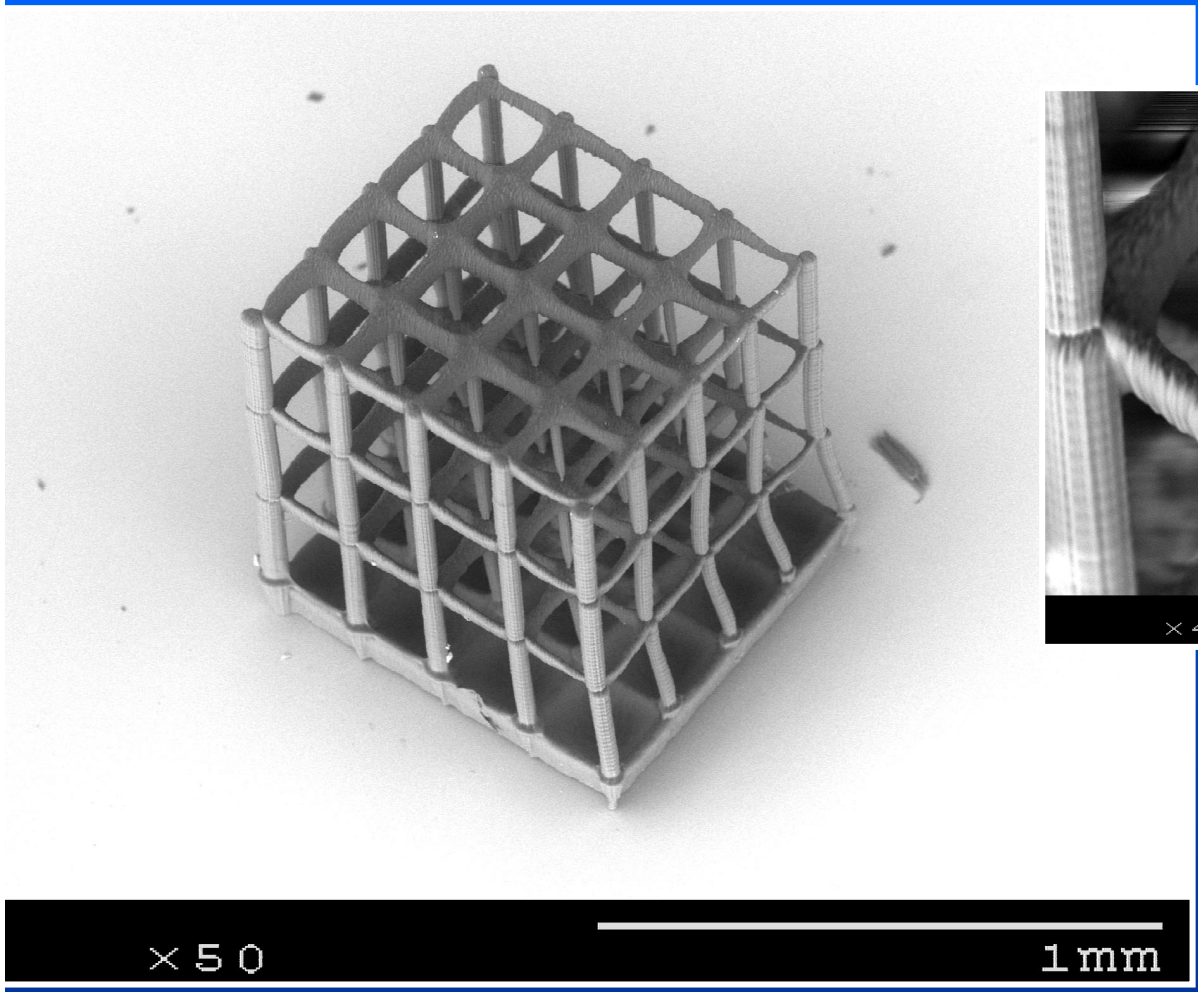
Polymerization

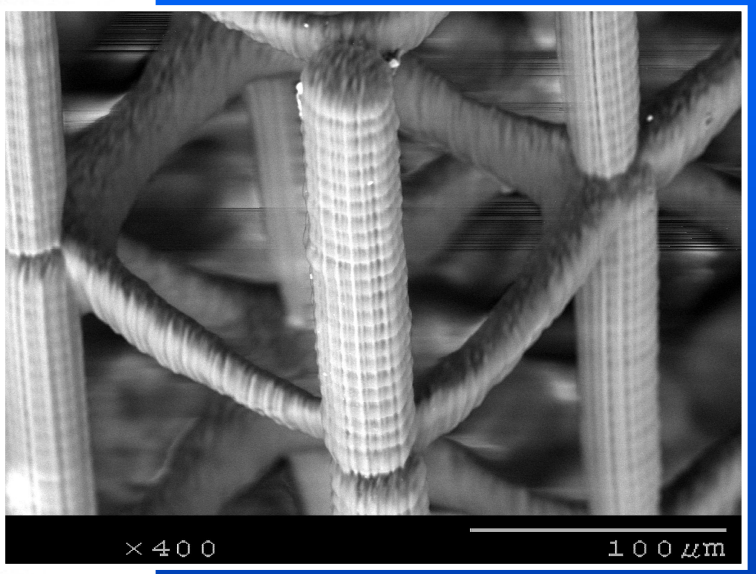


Lateral Resolution Limit in μSL of Ceramics

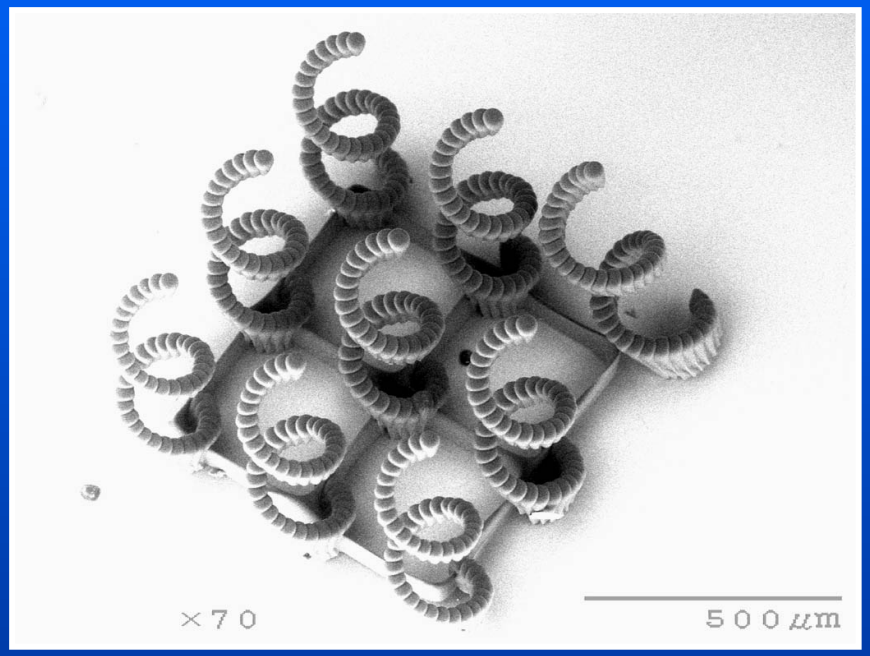


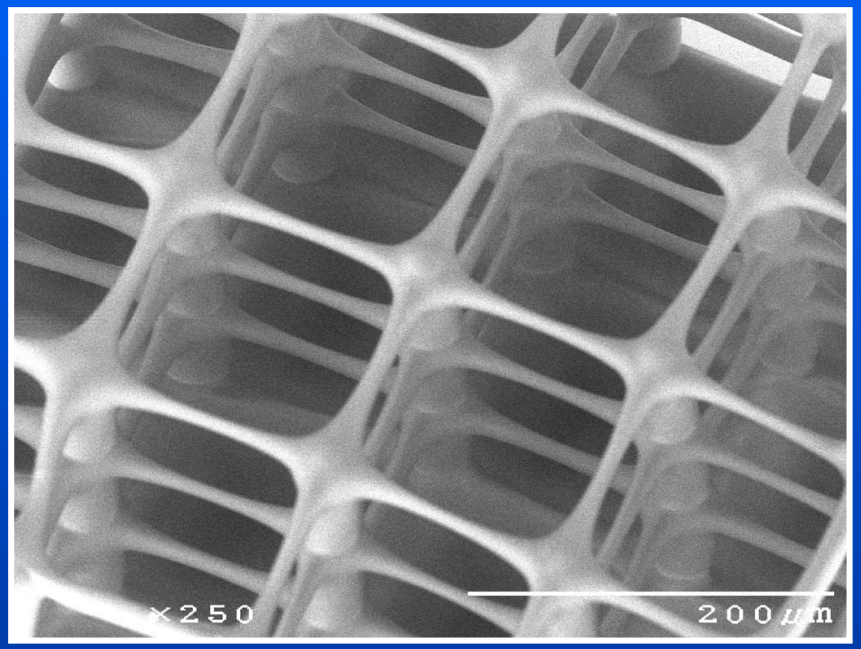
3D Matrix by DMD-μSL

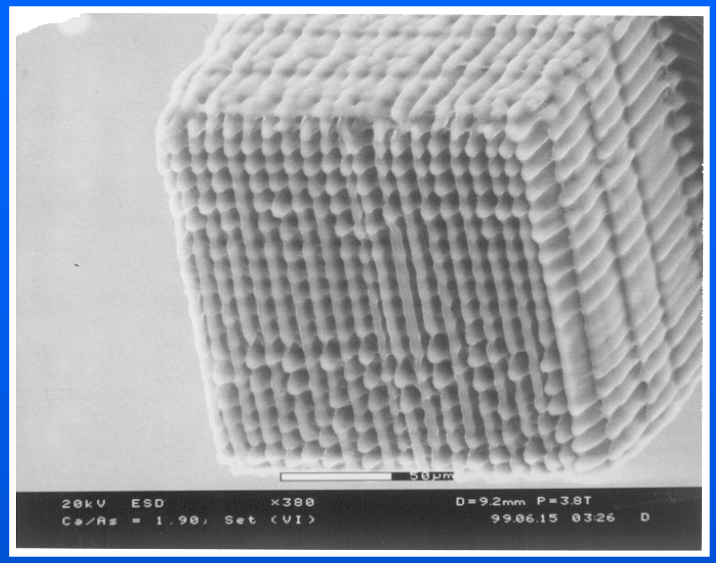




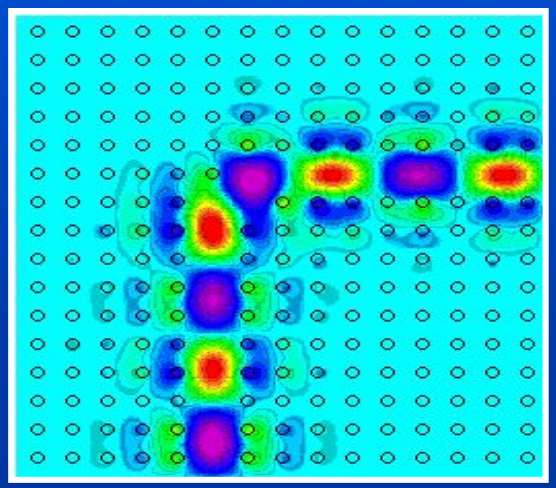
3D Coils Array and Micro-Matrix







(Zhang, 1999)



(Joannopoulos, 1996)

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-stereo-lithography (decide what type defects and where they localed, which is impossible in atomic scale defects in semiconductor)

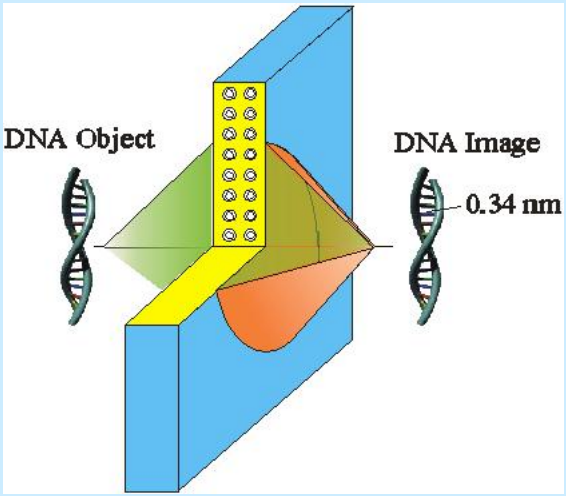
Applications

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

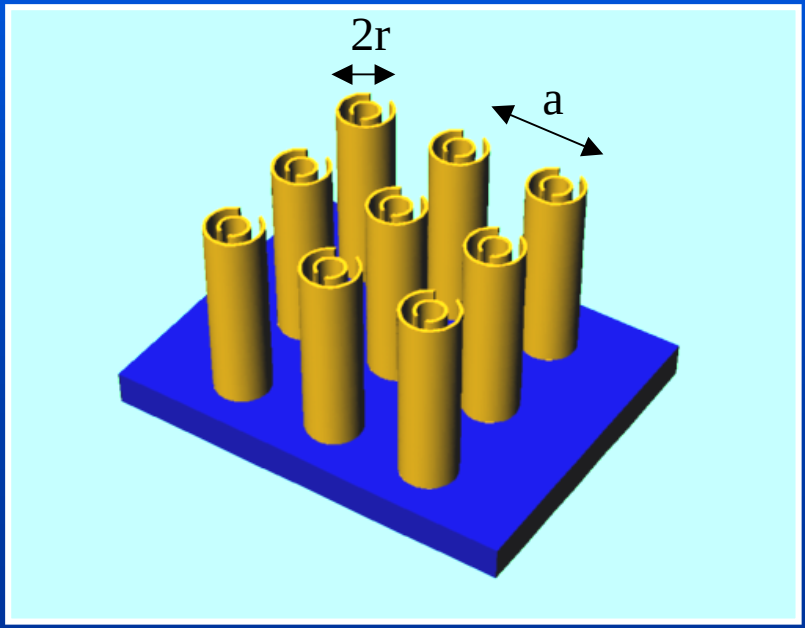
Artificial Materials With Unprecedented Properties

(Theoretical work of John Pendry, 2000)

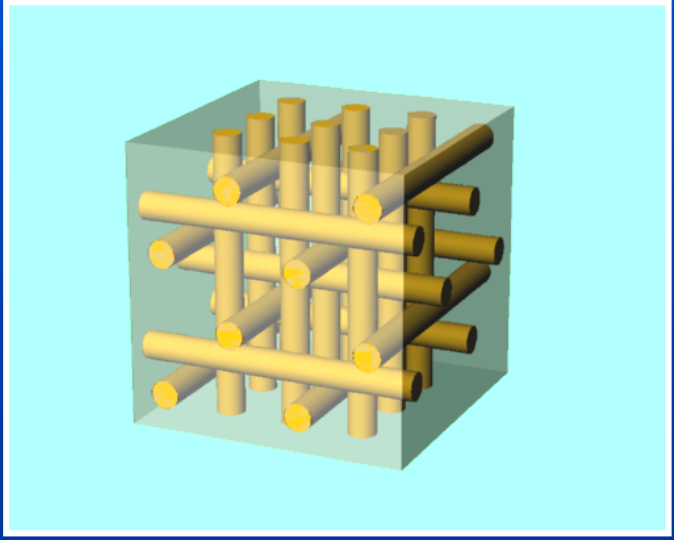
Super-lens



Artificial Magnetism at High *f*

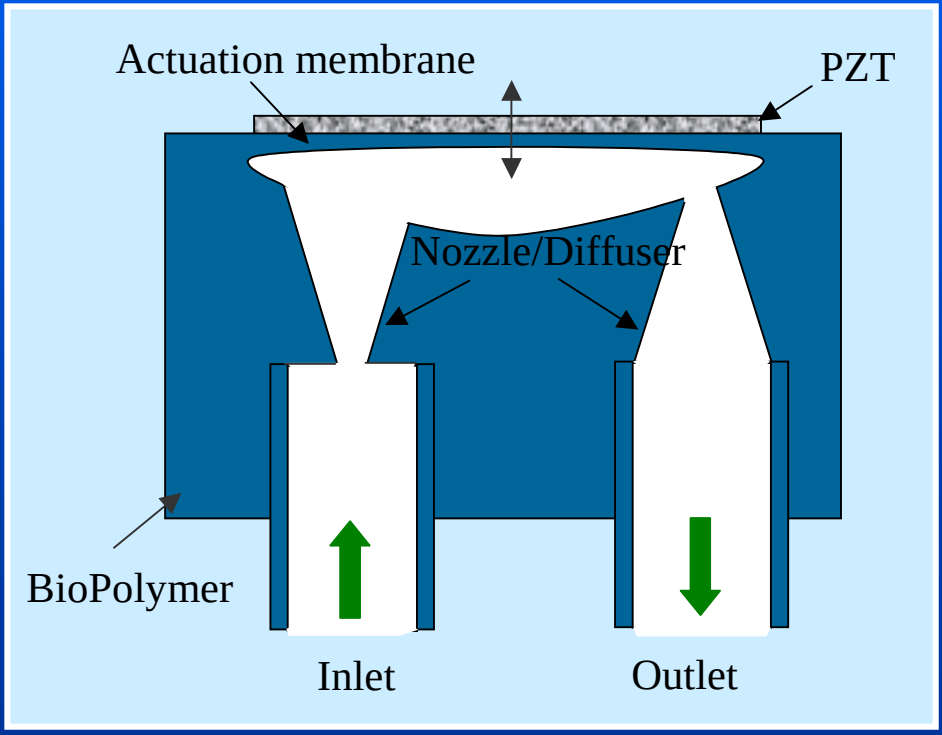


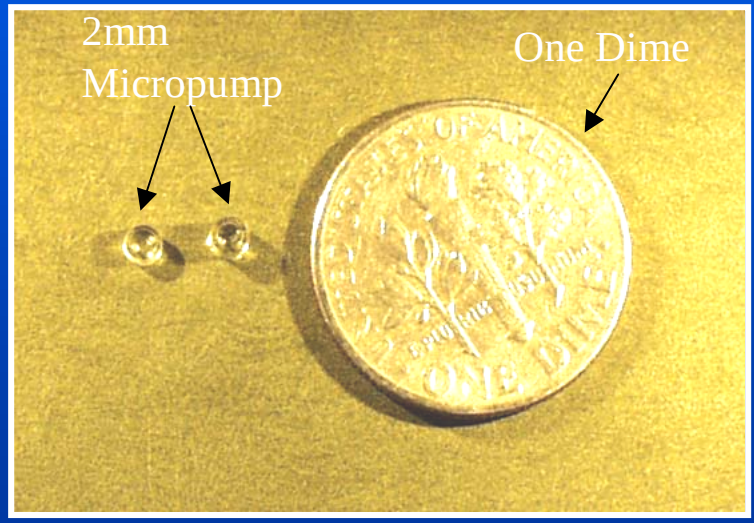
Artificial Plasma



3D Valveless Micropump

- Truly 3D cavity structure to optimize the design
- High reliability due to no movable valves
- A wide variety of materials (eg. Bio-polymer)



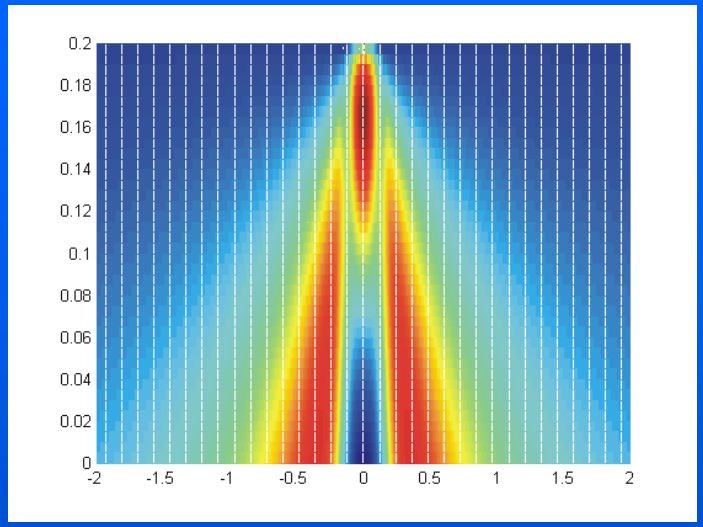


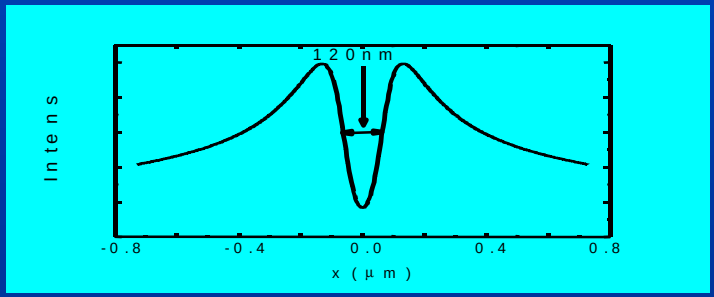
Near Field Optical nanolithography(NSOL)

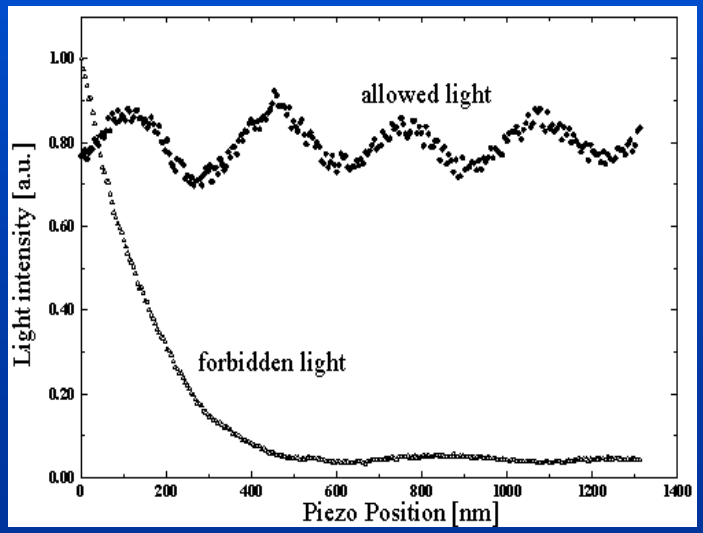
- Near field scanning optical microscopy (NSOM)- a proven technology to break the diffraction limit.

- 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.