MEMS: Fabrication:

Microstereolithography

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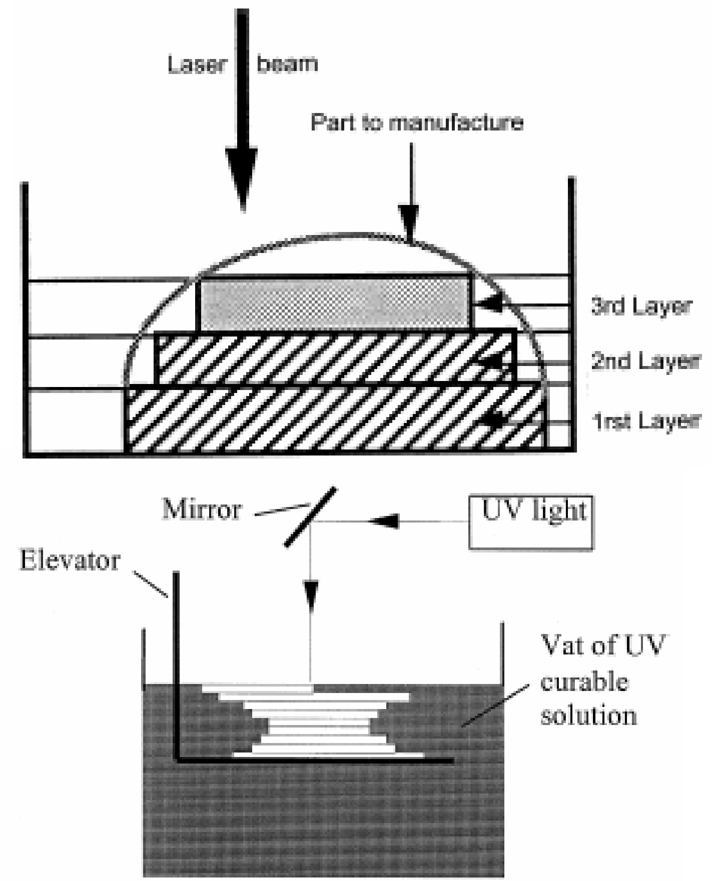
Recap

- Optical characterization
- Previous classes on fabrication
    - VLSI based methods
        - Patterning
        - Etching
        - Deposition
    - EDM
    - ECM
    - Laser machining

Today's Class

- Microstereolithography
    - Advantages
    - Fundamentals of laser optics
    - Methods
        - Projection method
        - Scanning method
    - Some fundamentals of polymerization

What is Microstereolithography?



- Novel microfabrication process for fabricating high aspect ratio and complex 3D microstructures.
- Evolved from the rapid prototyping industry.
- UV laser beam scanned on a photopolymerizable resin.
- Curing of the resin layer by layer.
- Stacking of all the layers.

Motivation

Need for Microstereolithography

MEMS – Worldwide Research attention

- Requirement of current actuating and sensing mechanisms to be of complex 3D shapes.
- Incorporation of a wide range of materials

Limitations of Conventional processes :

- Inability to manufacture high aspect ratio and complex 3D microstructures.
- Few semiconductors and other materials processed by current VLSI-based machining processes for MEMS.

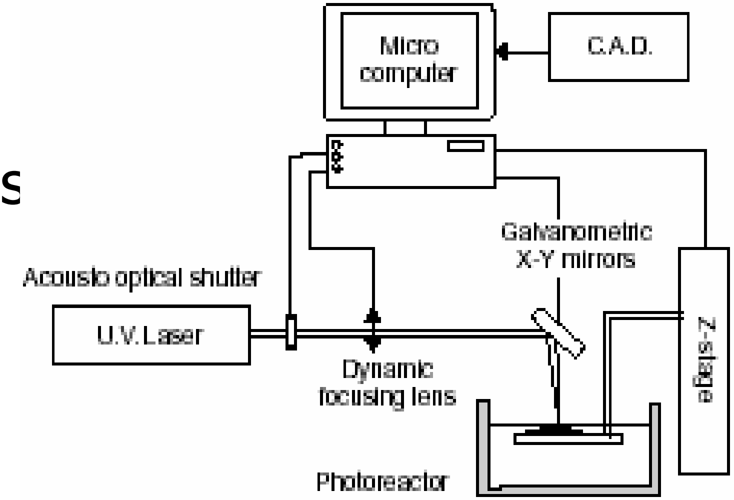
Microstereolithography

Process Types

- Scanning method:
  - Scan one layer by focused laser beam and then the next layer
- Dynamic mask method:
  - Expose the layer to be built at a time
  - Change the mask dynamically
  - Expose the next layer

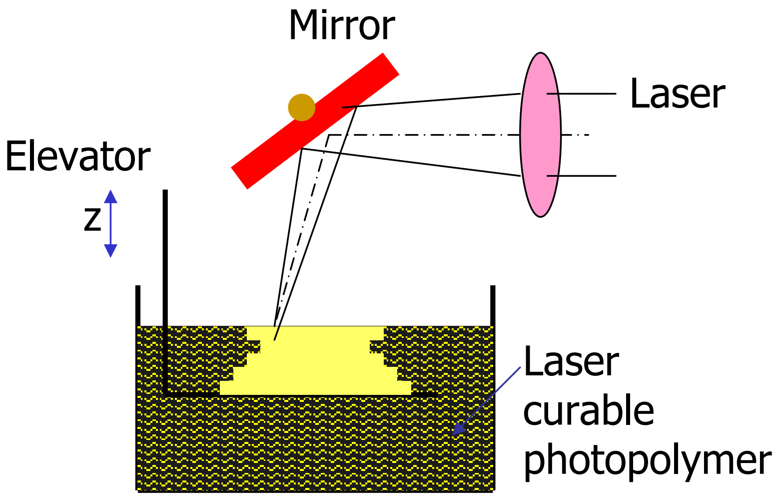
Scanning Method

- **Classical msl**
  - Focusing by a dynamic lens
  - Use of galvanometric mirrors
  - Theoretical best point of focus not intersecting the resin surface.
- **Free surface technique**
  - All optical parts fixed
  - X-Y-Z motorized translation stage
  - Thickness control of deposited liquid layer difficult

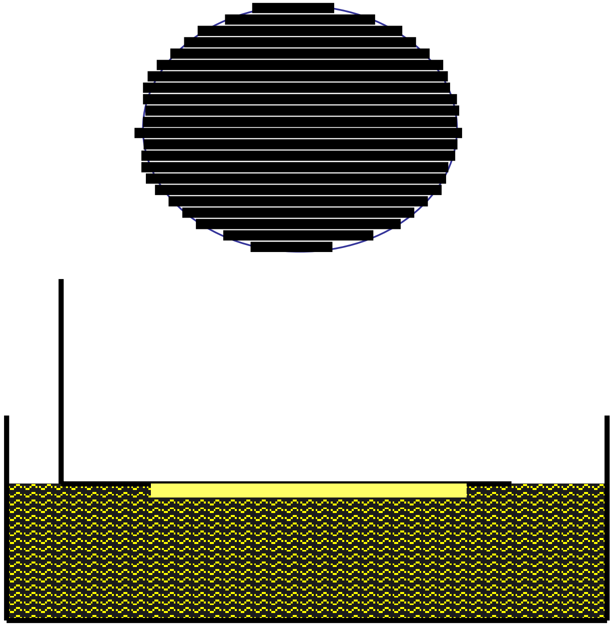


Scanning Method

- Schematic diagram



Vector Scan



Scanning Method

Issues

- Factors affecting resolution of components:
  - Laser intensity
  - Motion and quality of the beam
  - Photopolymer/ monomer used
  - Focusing
  - Exposure
- In case of ceramic materials process of laser sintering is used

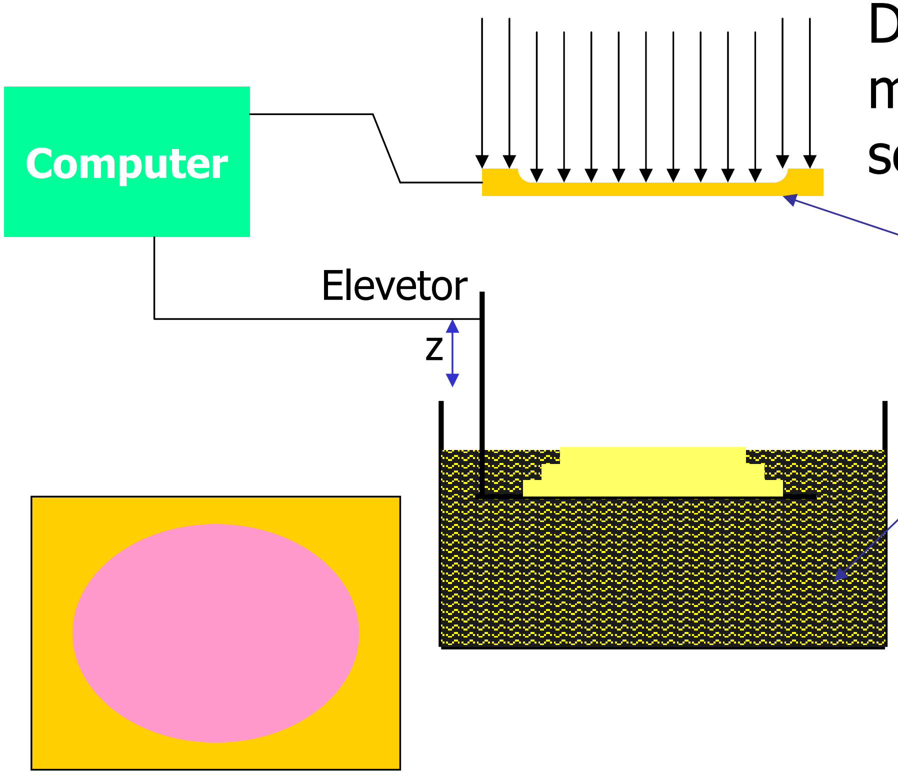
Scanning Method

Variations

1. Fixed optics, move liquid tank for xy scanning
2. Various ways for scanning
    - Rotating galvano-scanning mirrors
    - Linearly moving mirrors
    - Raster scan vs vector scan

Microstereolithography

Dynamic mask process

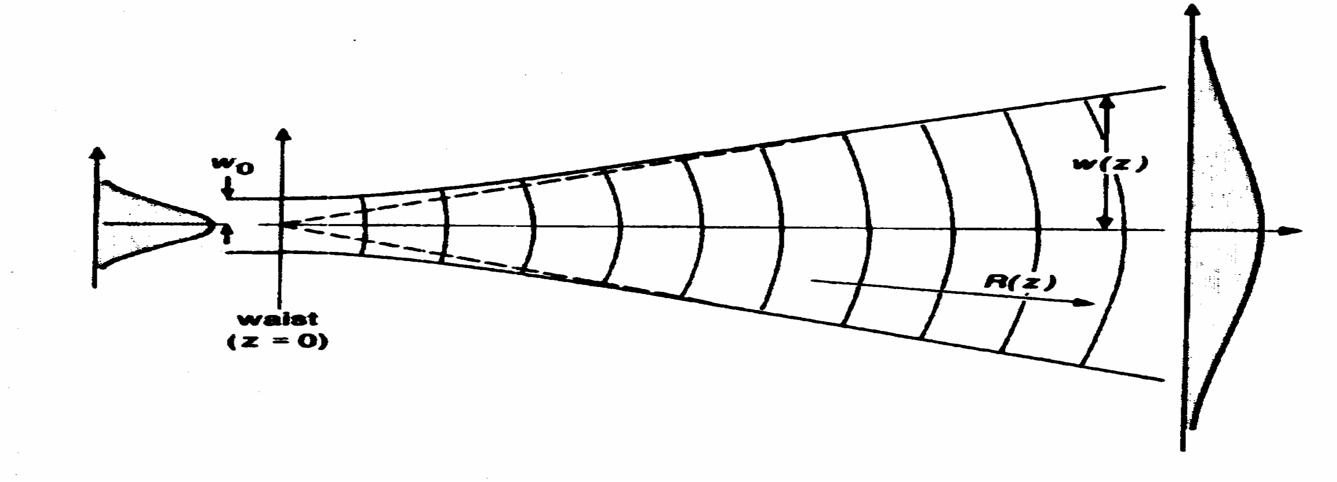


Dynamically changing mask according to the section to be exposed

Dynamic Mask

Laser curable photopolymer

Fundamentals of Laser Beam



Gaussian Beams

Beam waist at z = 0, where the spot size is w_0.

Expansion to w = w(z) with distance z away from the laser.

The beam radius of curvature, $R(z)$, also increases with distance far away.

Fundamentals of Laser Beam

Expressions for spot size, radius of curvature,

$$w(z) = w_0\sqrt{1+\left(z/z_R\right)^2}$$

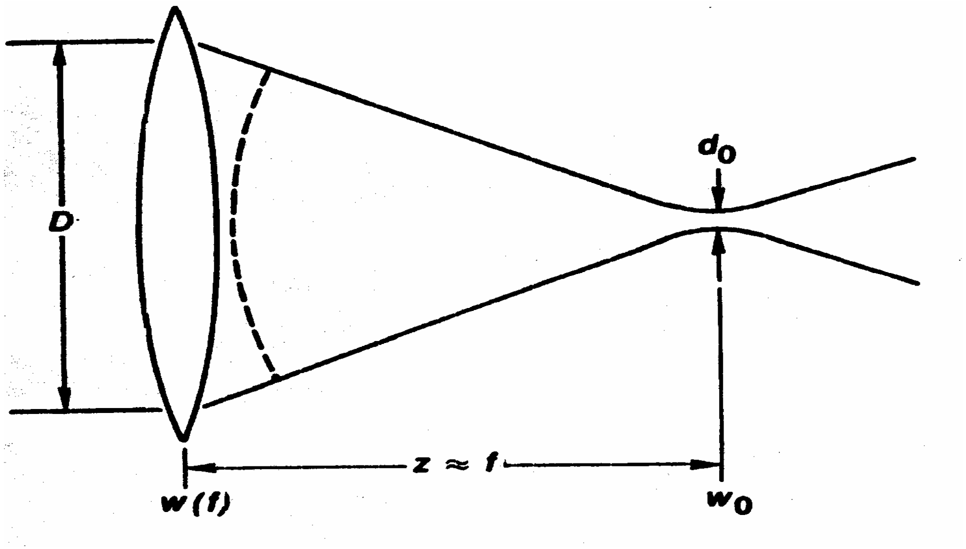
$$R\left(z\right) = z + z_R^2/z$$

where z_R is the Rayleigh Range (the distance over which the beam remains about the same diameter), and it's given by:

$$z_R \equiv \pi w_0^{\;2}/\lambda$$

Fundamentals of Laser Beam

Gaussian Beam Focusing



Airy Disk formula for spot size:

$$d = 2.44\lambda(F/D)$$

System Details

Typical System Components

- Laser
- Beam delivery system
- Computer controlled precision stages and a CAD design tool
- Process monitoring system with a CCD camera.
- UV curable resin – HDDA (1,6 – Hexanediol diacrylate)

Laser

- UV Lamps
- He-Cd Laser
- Argon Ion Laser

Typical specifications :

Name of the supplier : Coherent Inc.

Product model : Innova 300 Series (I-304) (Ar$^+$ Laser)

Multiline UV wavelengths : 333.4nm to 363.8nm

Power : 200mW

Diameter (@ 1/e^2 points) in mm : 1.5mm

Divergence (full angle) in mrad : 0.5

UV- curable Resin

Desired Properties:-

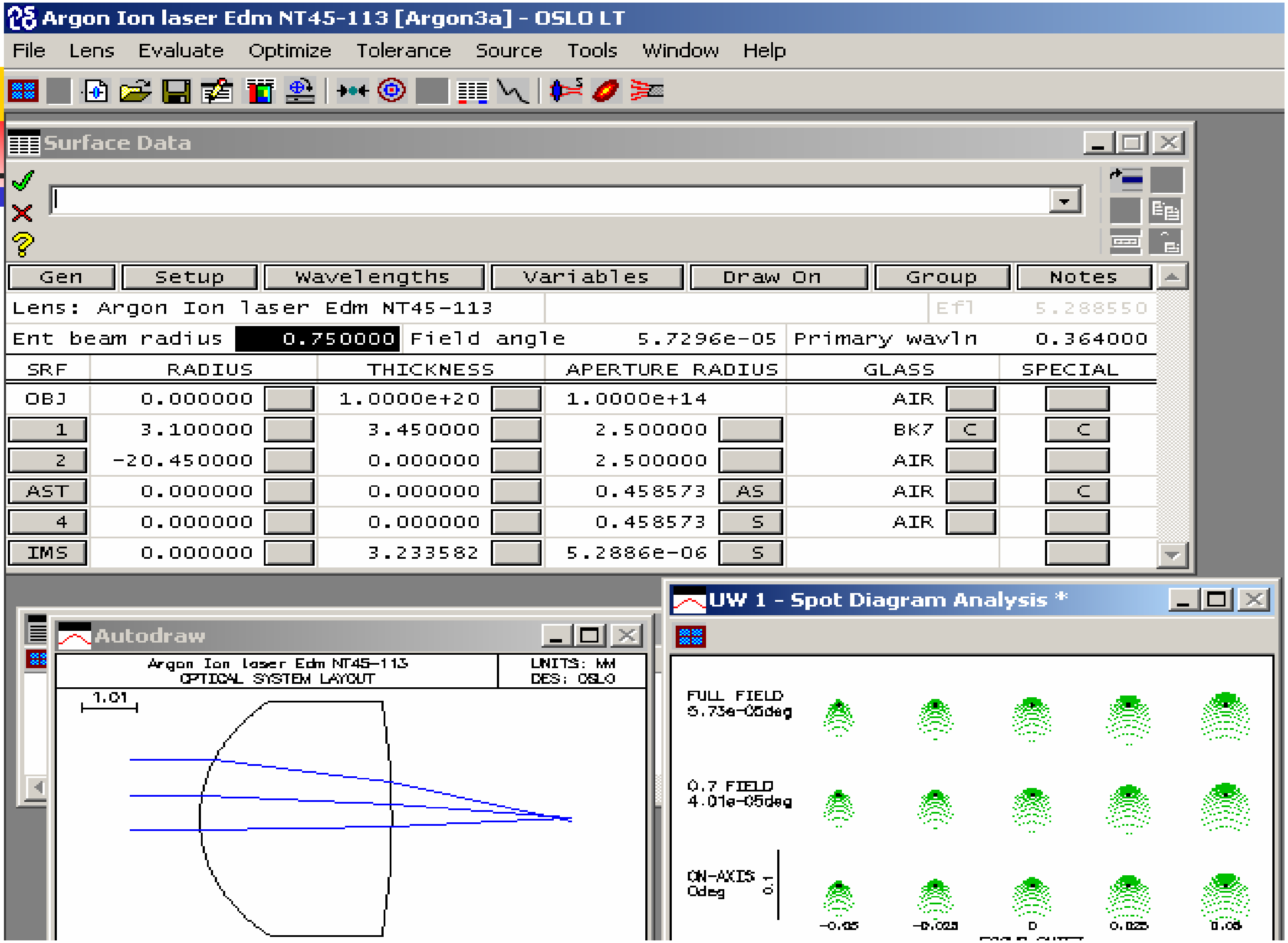
- Photosensitivity at the operating wavelength
- Low viscosity to produce a smooth surface
- High curing speed
- Low shrinkage during polymerization
- High absorption for low penetration of light.

Types of Resins

1) Epoxy Resins
2) Acrylate resins

HDDA (1,6 – Hexanediol diacrylate) with 4% by wt. photoinitiator

Spot characterization using Oslo



Argon Ion laser Edm NT45-113 [Argon3a] - OSLO LT

Lens: Argon Ion laser Edm NT45-113

Efl 5.288550

Ent beam radius 0.750000

Field angle 5.7296e-05

Primary wavln 0.364000

SRF	RADIUS	THICKNESS	APERTURE RADIUS		GLASS		SPECIAL
OBJ	0.000000	1.0000e+20	1.0000e+14		AIR		
1	3.100000	3.450000	2.500000		BK7	C	C
2	-20.450000	0.000000	2.500000		AIR		
AST	0.000000	0.000000	0.458573	AS	AIR		C
4	0.000000	0.000000	0.458573	S	AIR		
IMS	0.000000	3.233582	5.2886e-06	S			

Mathematical Modeling

- Laser exposure along the X-Axis defined as

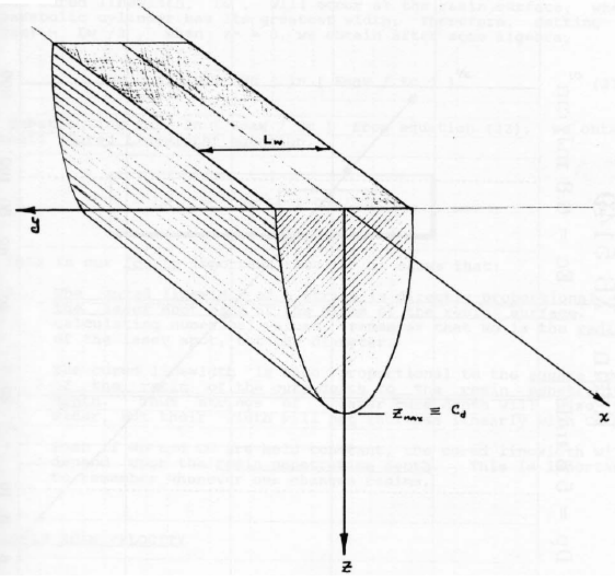
$$E(y,z) = \sqrt{\frac{2}{\Pi}}\left(\frac{P}{W_0 V_s}\right) e^{\left(\frac{-2y^2}{W_0^2}\right)} e^{-\left(\frac{z}{D_p}\right)}$$

- Curing depth working equation :

$$C_d = D_p \ln\left(\frac{E_{max}}{E_c}\right)$$

- Cured Line width:

$$L_w = \sqrt{2} W_0 \left(\ln\left(\frac{E_{max}}{E_c}\right)\right)^{0.5}$$



Mathematical Modeling

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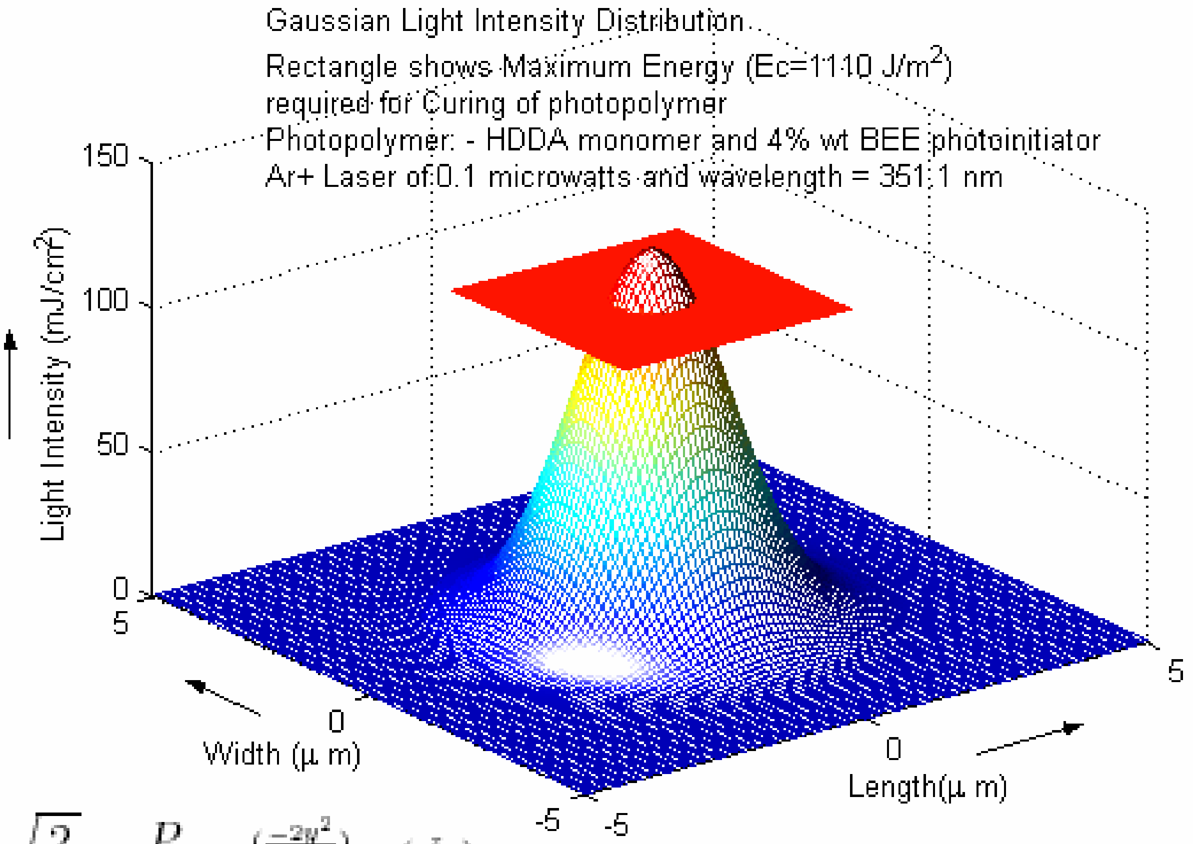

$$E(y,z) = \sqrt{\frac{2}{\Pi}}\left(\frac{P}{W_0 V_s}\right)e^{\left(\frac{-2y^2}{W_0^2}\right)}e^{-\left(\frac{z}{D_p}\right)}$$

Microstereolithography

Limitations

- Smooth 3D surfaces difficult to produce; stepping effects will always be present
- Mass production of several components is another challenge
- Extremely small features difficult to produce

Conclusions

- Microstereolithography: process details
- Mainly a process for true 3D structures of polymer and ceramic materials
- Limitation about the size of the feature

- Any suggestions to improve

  E-beam with z-stage movement

Mathematical Modeling

$$E(y,z) = \int H(x,y,z)\,dx / V_s \approx \frac{e^{\frac{-z}{D_P}}}{V_s} \sum H(x,y,0) \triangle x$$

- Exposure (Energy per unit area)

$$LSF(y) = \int_{-\infty}^{+\infty} H(x,y)\,dx$$

- Line Spread Function (LSF)

$$E(y,z) = \frac{a LSF(y) e^{\frac{-z}{D_P}}}{V_s}$$

- Modified expression for exposure:

$$z^* = D_P \ln\left(\frac{a\, LSF(y^*)}{V_s E_c}\right)$$