Outline

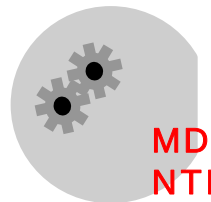
1 Introduction

2 Basic IC fabrication processes

3 Fabrication techniques for MEMS

4 Applications

5 Mechanics issues on MEMS



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3. Fabrication Techniques for MEMS

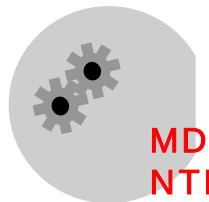
3.1 Bulk micromachining

3.2 Surface micromachining

3.3 LIGA process

3.4 Hybrid micromachining

3.5 Thick micromachined structures



3.3 LIGA Process

- **LIGA is the abbreviation of three German words:**
  - + **Li**thographie (lithography in English)
  - + **G**alvanoformung (electroplating)
  - + **A**bformung (moulding)

- **The primary advantage of LIGA process is its capability to make large aspect ratio structures (can be up to 1000 μm thick while only several micron wide), however the shape of the structures remain flexible (can be gears, nozzle, etc.)**

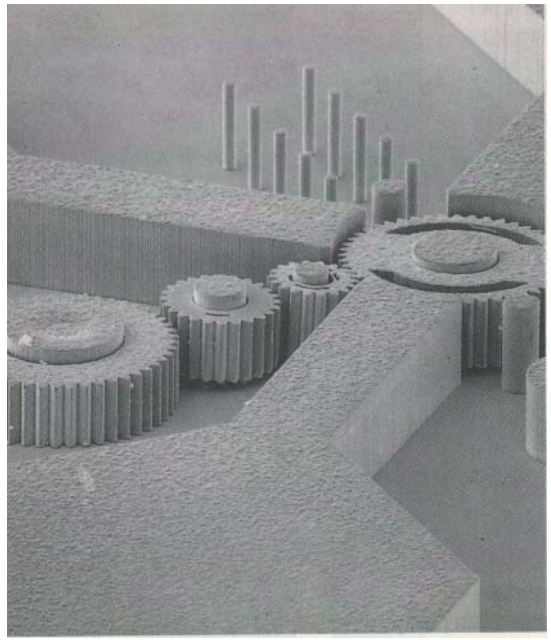
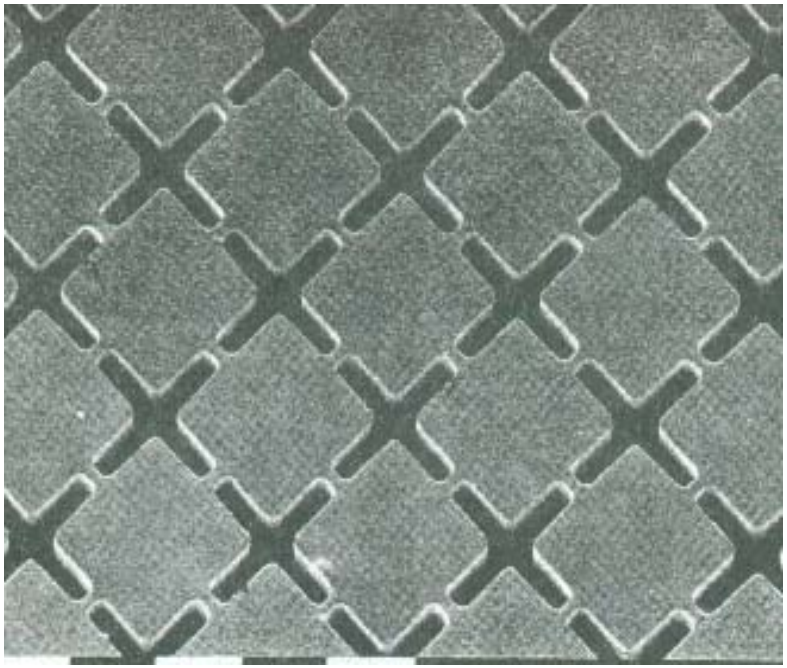
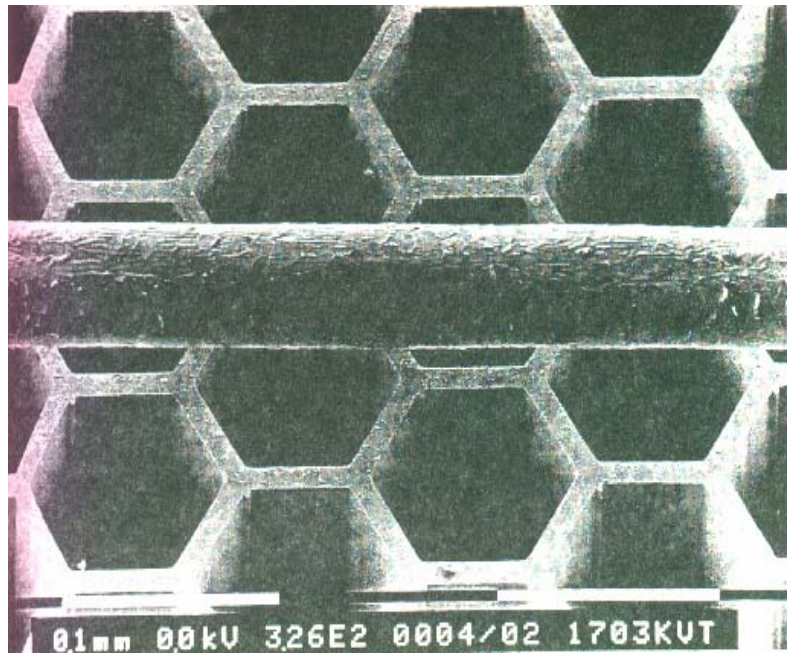


Figure source: J. Bryzek, K. Petersen, and W. McCulley IEEE Spectrum, 1994





W. Menz, Microsystem Technology for Engineers Intensive Course, 1994.

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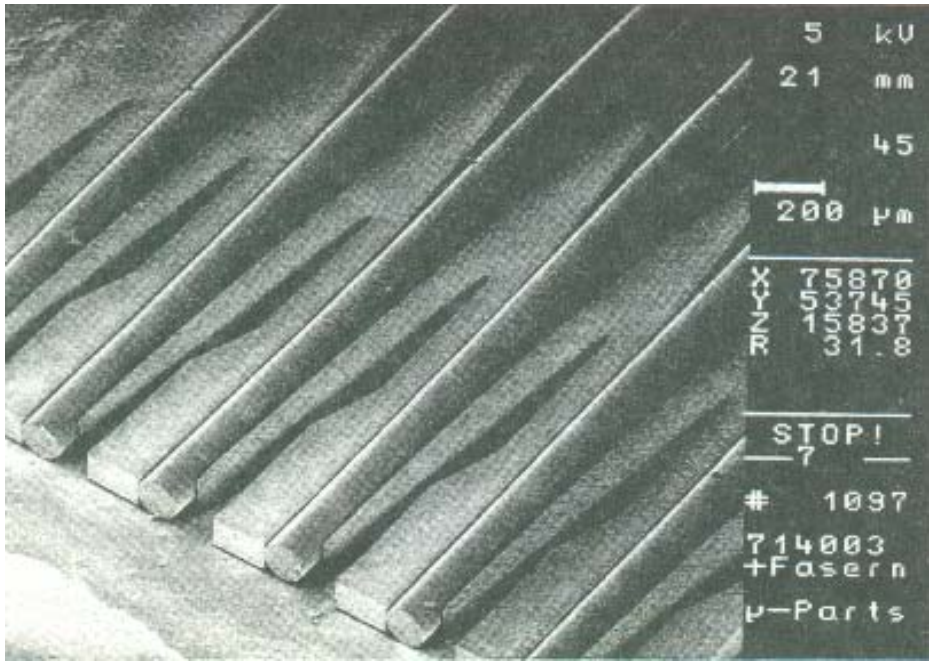

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- **The LIGA process can also be applied to make movable structures and stepped structures by adding the concept of sacrificial layer and multiple mask process**

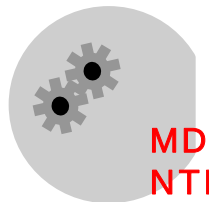
- **The deep lithography process can be done by sources other than X-ray, thus the LIGA process can be achieved through other techniques (LIGA-like)**

- **In this section, three parts will be included in the discussion**

  + LIGA by deep X-ray lithography

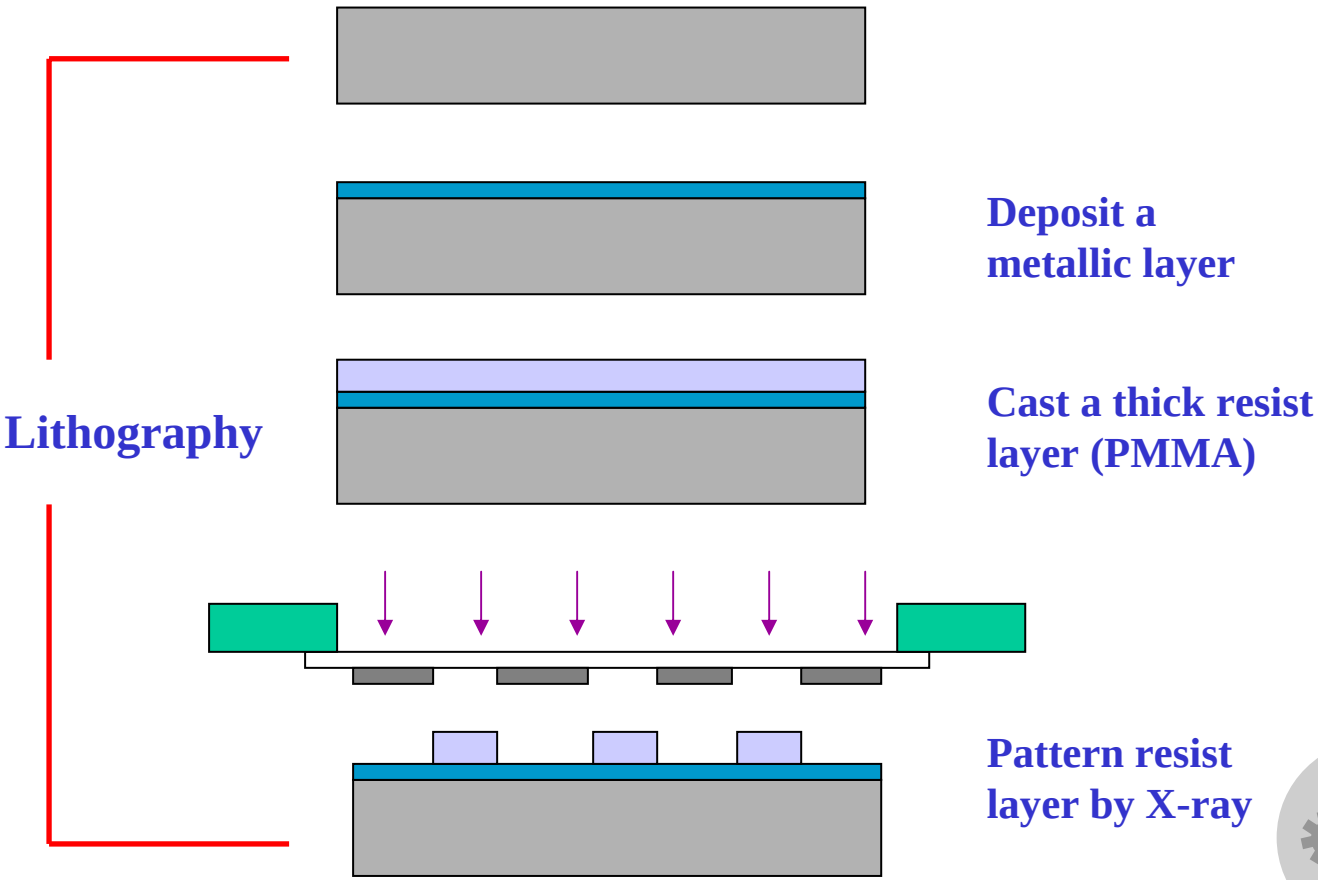
  + SLIGA and Stepped LIGA

  + Other deep lithography techniques (LIGA-like)

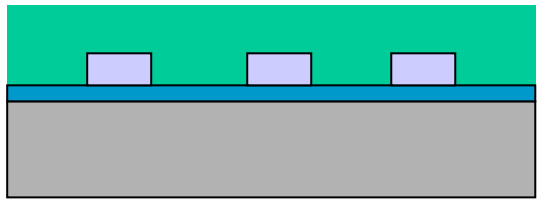


3.3.1 LIGA by deep X-ray lithography

- **Typical fabrication processes**



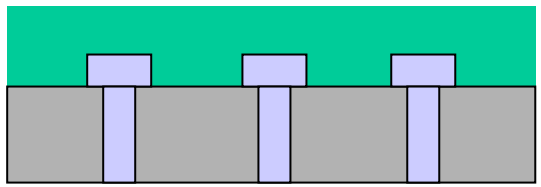
Electroplating



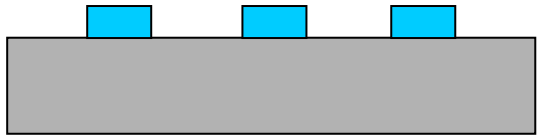
Electroplating the mold insert

Molding

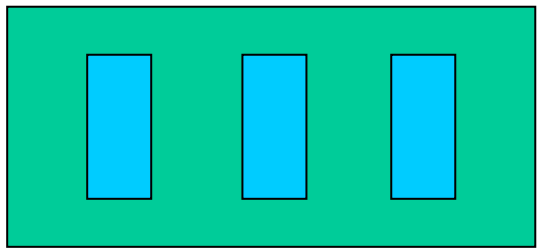
Mold insert

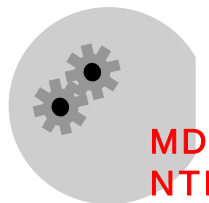


Use the mold insert to form multiple plating base by injection molding



Remove the mold insert





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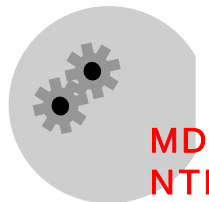
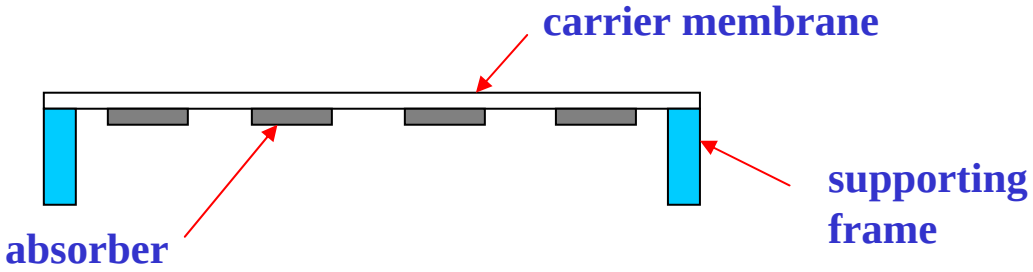
Lithography

- There are three major difference between deep X-ray and UV lithography
  - + The PR is much thicker than that of silicon micromachining
  - + The PR material is different
  - + The mask for UV light is different with that for X-ray
- Advantages of the X-ray lithography
  - + High intensity
  - + Excellent parallelism
- Disadvantages of the X-ray lithography
  - + Cost
  - + X-ray mask is very difficult to make

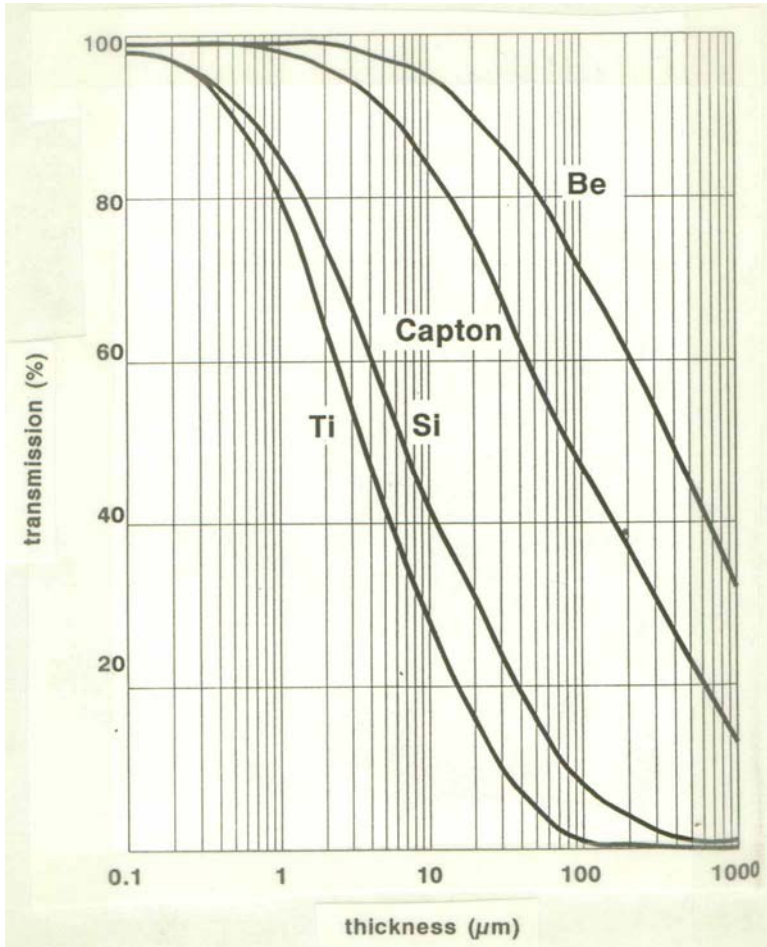


Mask



- The X-ray mask contains three parts, (1) absorber, (2) carrier membrane, and (3) supporting frame
- The requirements to obtain a better contrast between the transparent and opaque region on the mask are,
  - + For **absorber**: (1) high atomic weight material (such as Gold), and (2) as thick as possible
  - + For **carrier membrane**: (1) low atomic weight material, and (2) as thin as possible
- The residual stresses of the absorber has to be as small as possible in order to (1) have a better adhesion between the absorber and the membrane, and (2) prevent the distortion of the mask pattern

- An ideal material for carrier membrane is ***Be***, however it is toxic
- ***Ti*** is also a proper material for carrier membrane
- ***Au*** is the most common material for absorber
- X-ray transmission (%) vary with film thickness for different material



W. Menz, Microsystem Technology for Engineers Intensive Course, 1994.

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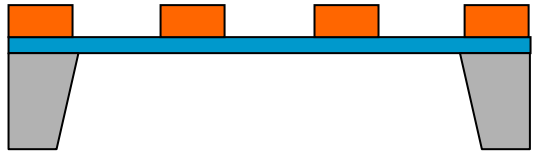
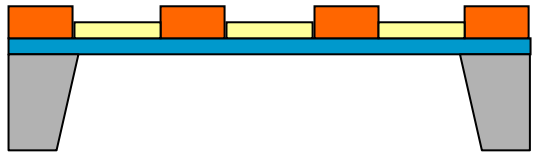
- **Fabrication of the X-ray mask**

Sputter the material for carrier membrane



PR is patterned by UV lithography

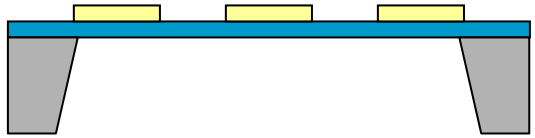
Backside etch Si to form the membrane



Electroplating absorber layer for X-ray

2~3um

Spin coat PR



Remove PR and complete the intermediate mask

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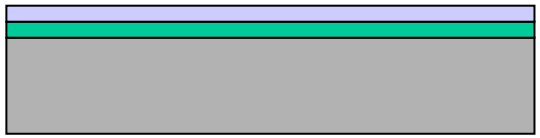
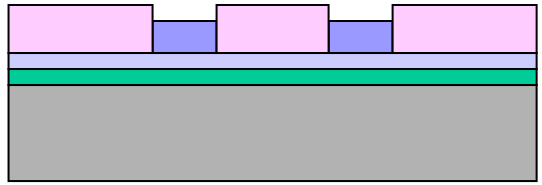
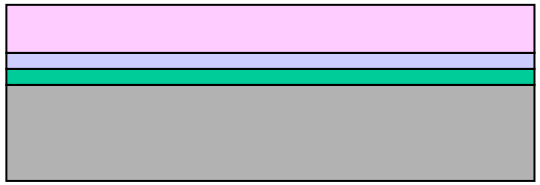


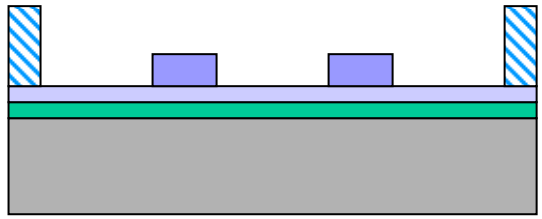
Sputter the material for carrier membrane and separation layer



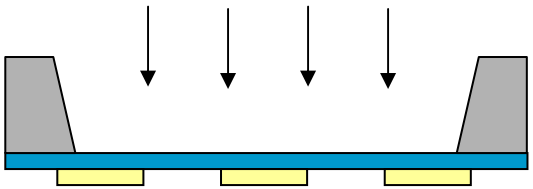
Electroplating absorber layer for X-ray



Cast thick PR onto the membrane

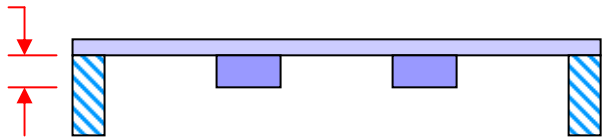


Remove PR and bond with supporting frame

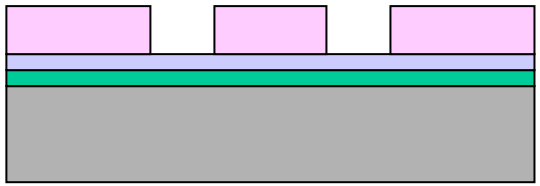


X-ray **intermediate mask**

15~20um



Complete the **working mask** after separate with substrate



PR is patterned by X-ray lithography

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Photoresist

- PMMA (poly-methyl methacrylate) is the most common photoresist for X-ray lithography
- PMMA is coated on the substrate by casting or gluing (not spinning) since its thickness can even reach 1000 μm

  + Commercial equipment used to coat thick film is available now

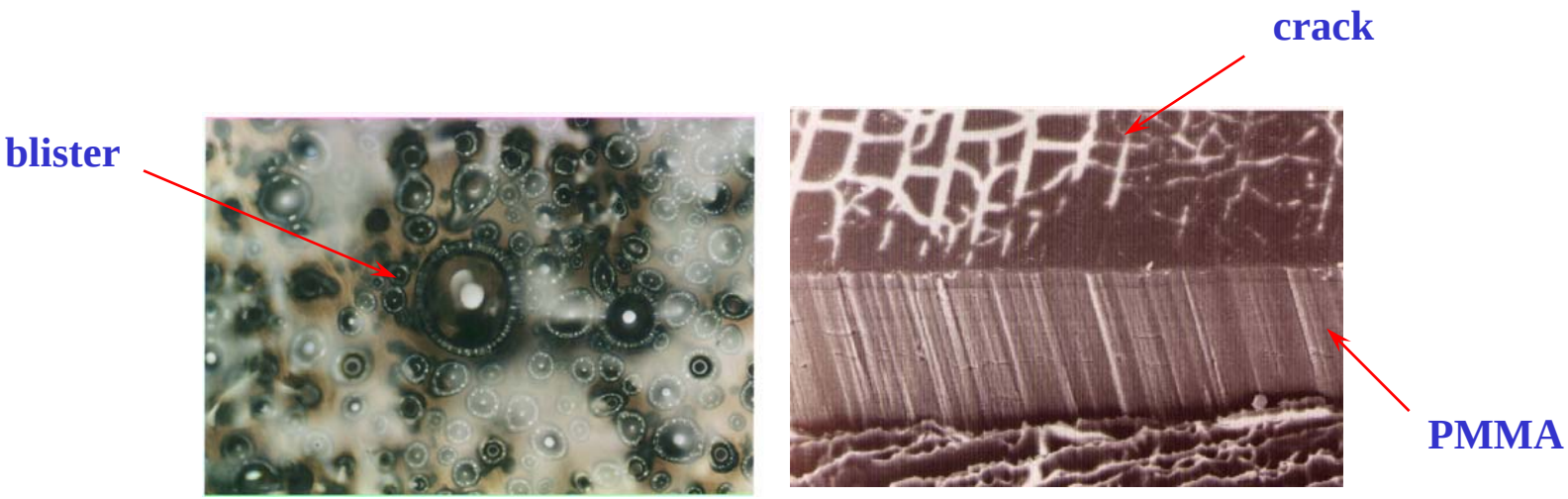
- The polymer structure is destroyed after PMMA exposed to the X-ray, therefore molecular weight of the polymer is reduced
- A proper developer is selected to dissolve the low molecular weight polymer, but will not attack the high molecular weight polymer

- **Casting of the resist layer has the following advantages**

  + Residual stress can be removed by annealing

  + Molecular weight of the polymer can be controlled

- **The resist might have (1) blister, and (2) crack after exposing and developing processes if the operating conditions is not proper**



M. Jiang, personal contact

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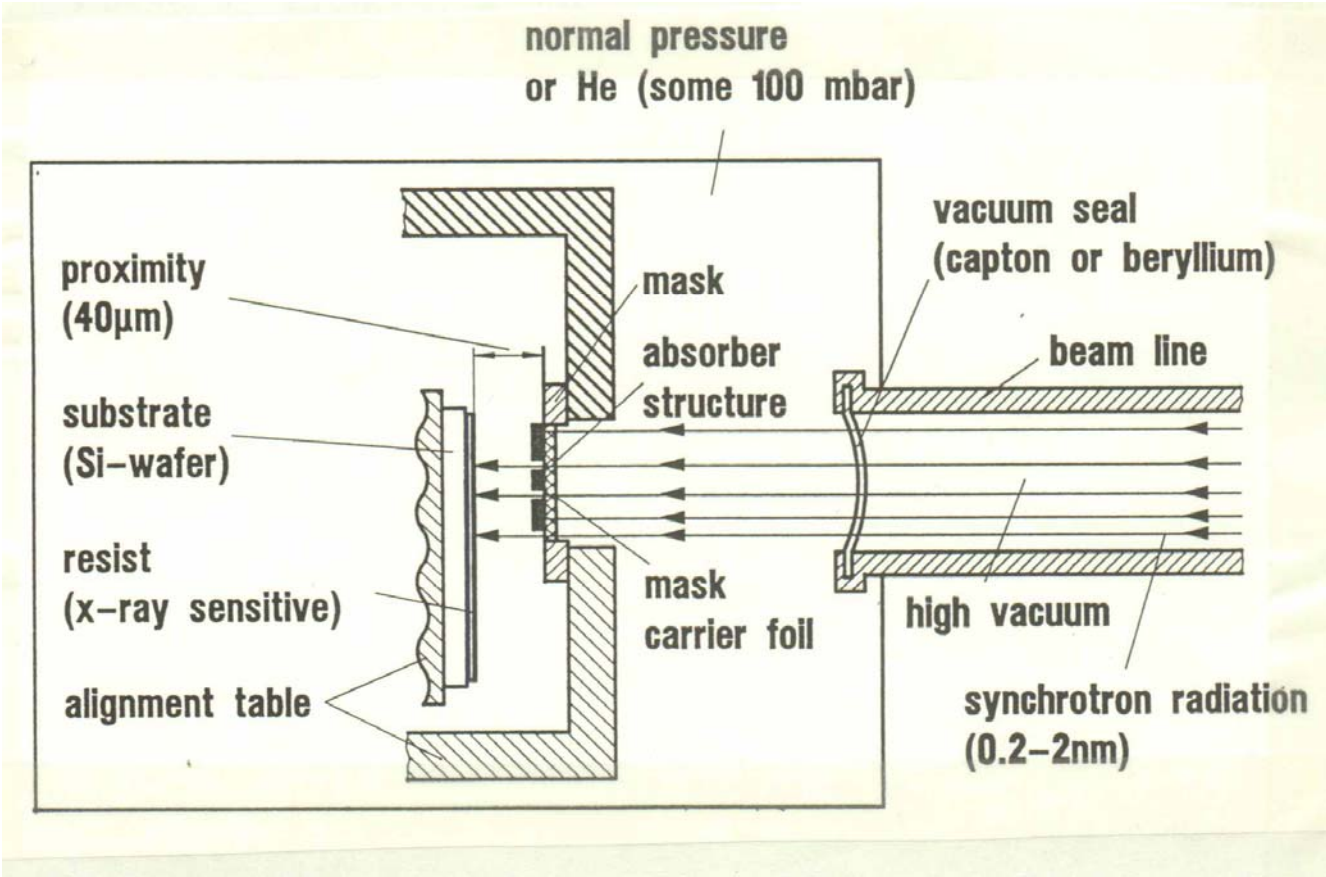
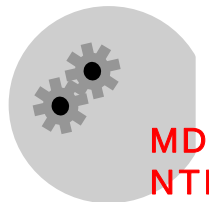
X-ray (Synchrotron Radiation)



Microsystem Technology for Engineers Intensive Course, W. Menz, 1994

Electroplating

- The structures fabricated by X-ray lithography are plastic material, the following electroplating process is used to make metal structures in LIGA
- Nickel (Ni) is the most common material for electroplating the mould in LIGA process
- Both metal and alloy can be deposited by electroplating, however it is difficult to predetermine the composition of alloy
- There are several important issues for electroplating
  - + Adhesion
  - + High aspect ratio
  - + Residual stress
  - + Hydrogen bubble



Adhesion

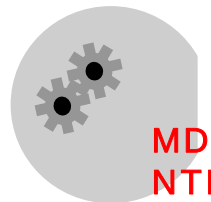
- In order to obtain a microstructure with the desired pattern, good adhesion is necessary for (1) PMMA and the initially deposited metallic layer, and (2) electroplated metallic layer and the initially deposited metallic layer

- The oxidization of a deposited titanium layer (TiO_x) can satisfy the requirements

  + Mechanical interlocking

  + Conductor (although TiO_2 is an isolator)

- The oxidation process can be fulfilled chemically by hydrogen peroxide



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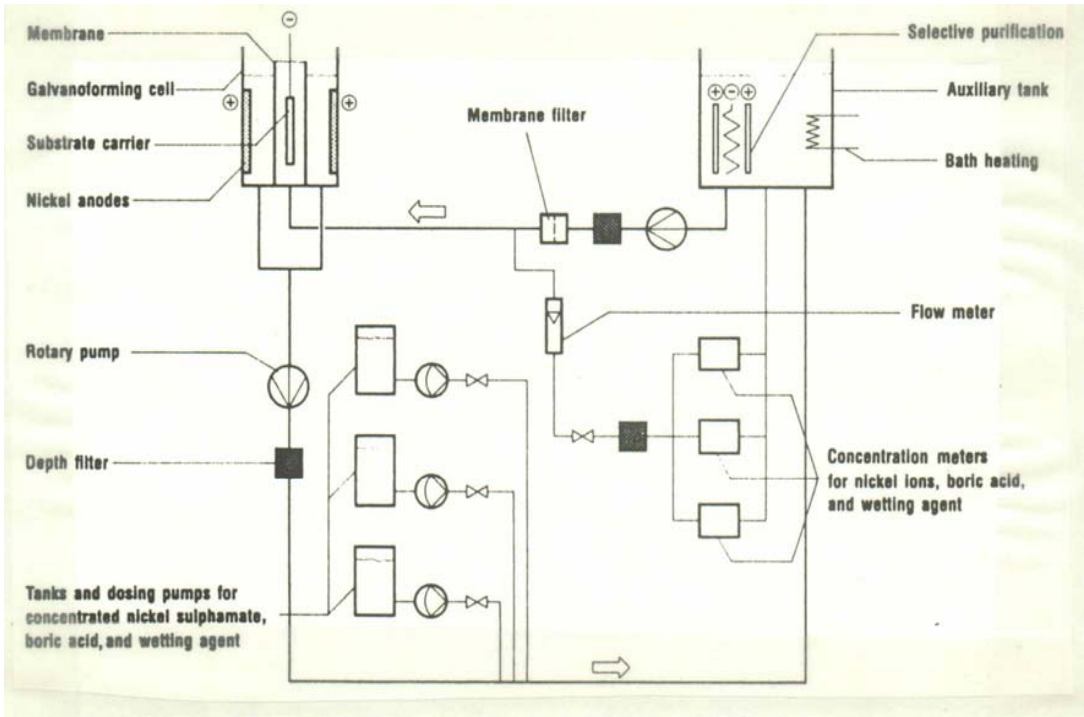
Hydrogen bubble

- **Hydrogen bubble induced by the particles in the electrolyte**
- **These particles which come from the electrolyte or surrounding atmosphere can be removed by filter**



E.W. Becker, Microelectronic Engineering, 1986

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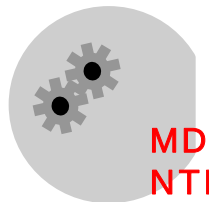
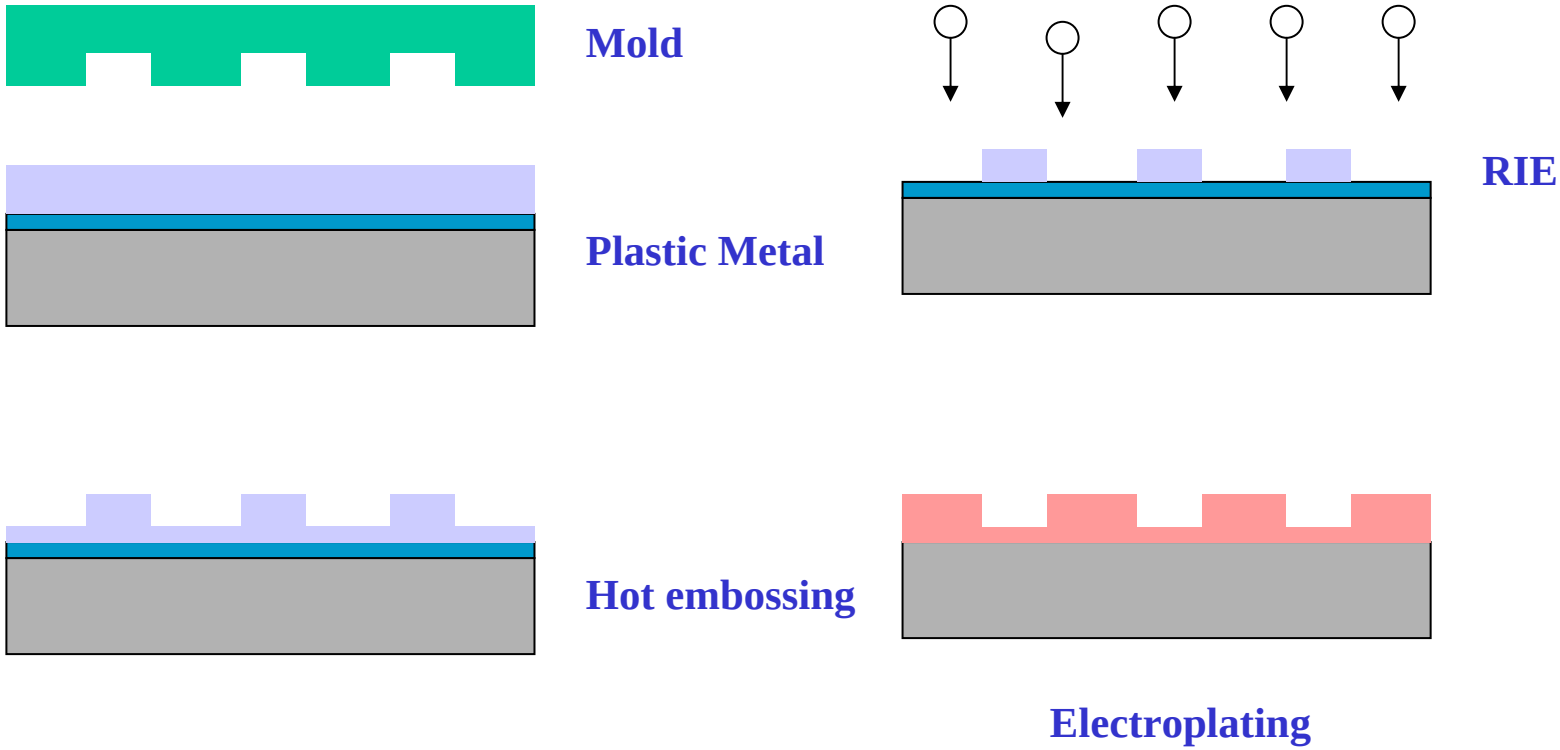
Molding

- Conventional technique is injection mold
  - + melting the material
  - + injecting the material to the mold by pressure
  - + solidifying the material after cool down
- Hot embossing is a new technique for fabricating microstructure
- Hot embossing can apply to do molding process on a substrate with electronics components
- After hot embossing, an additional RIE process is required to remove the residual layer



- **Hot embossing**

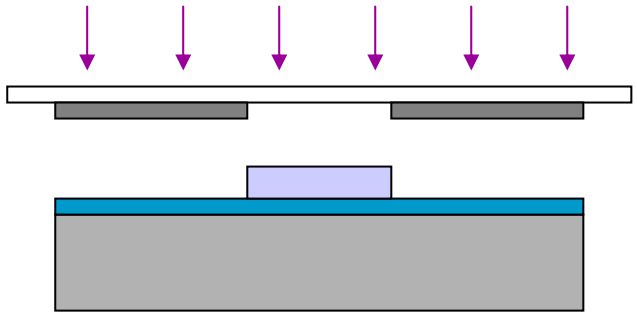


3.3.2 SLIGA

- SLIGA – combining the LIGA process with sacrificial layer technique, therefore movable microstructure is available

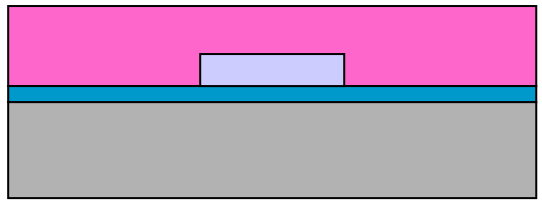
- Fabrication processes

Deposit a metallic layer on substrate



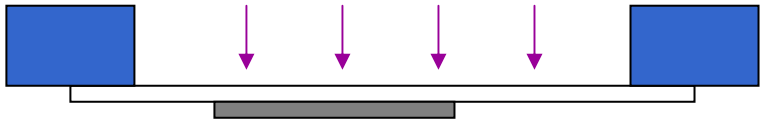
Pattern resist layer by UV light to define the sacrificial layer

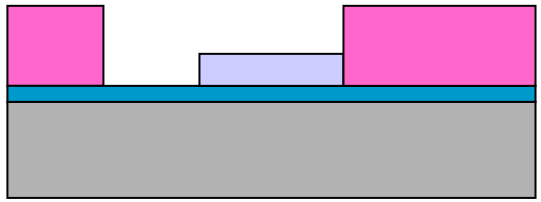
Coat a sacrificial layer



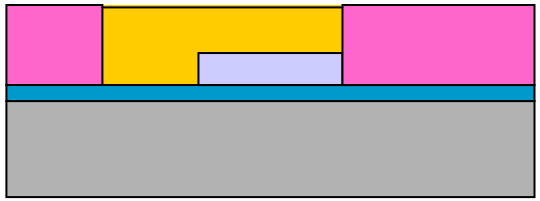
Cast a thick PMMA

X-ray

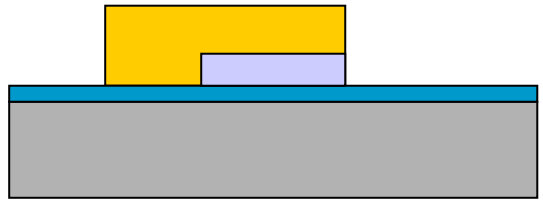




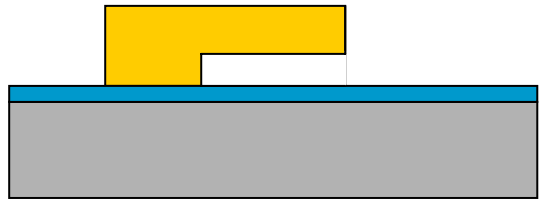
Pattern the PMMA by X-ray



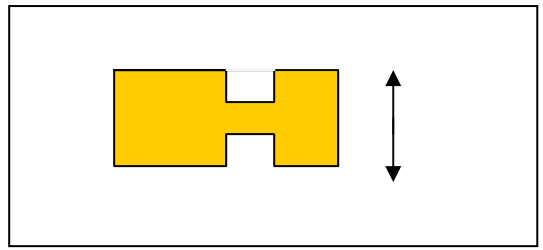
Electroplating



Remove the PMMA



Etch the sacrificial layer



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- **The most critical process in SLIGA is the mask alignment**

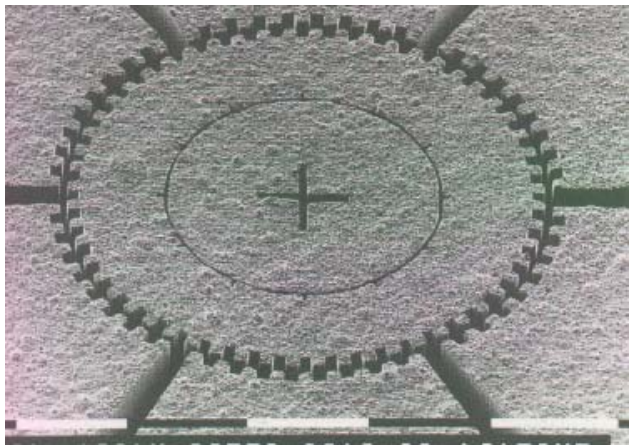
  + Special jig for X-ray mask and the substrate is required

  + The substrate with patterned sacrificial layer and the X-ray mask is aligned by a double side mask aligner

  + After the X-ray mask and the substrate is aligned, they will be clamped by jig

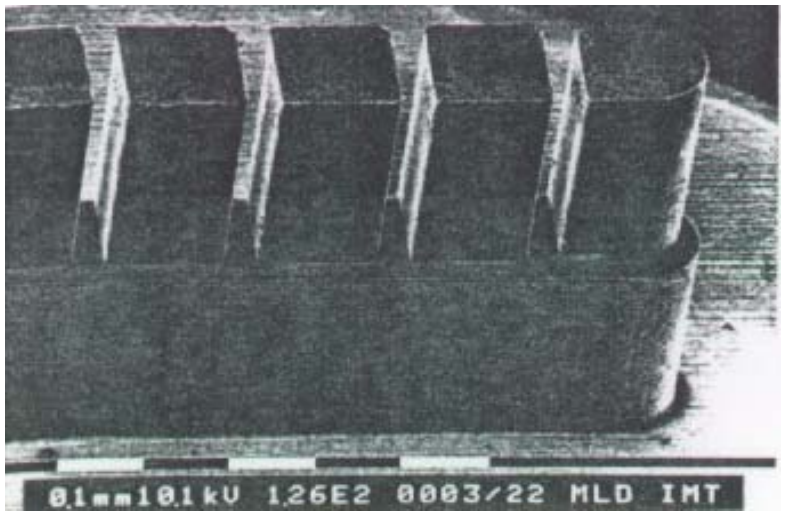
- **Polyimide is considered to be a good material for the sacrificial layer. Its thickness can reach up to 10 μm by spin coating**

- **A microrotor made by SLIGA process**



U. Wallrabe et al., J. of Micromechanics and Microengineering, 1994.

- **Stepped LIGA - are the LIGA structures with different level of height. The stepped LIGA structures can be produced by a two mask process**
- **The most critical process in making stepped LIGA structures is also mask alignment**
- **A stepped LIGA structure**



A. Rogner et al., J. of Micromechanics and Microengineering, 1992.

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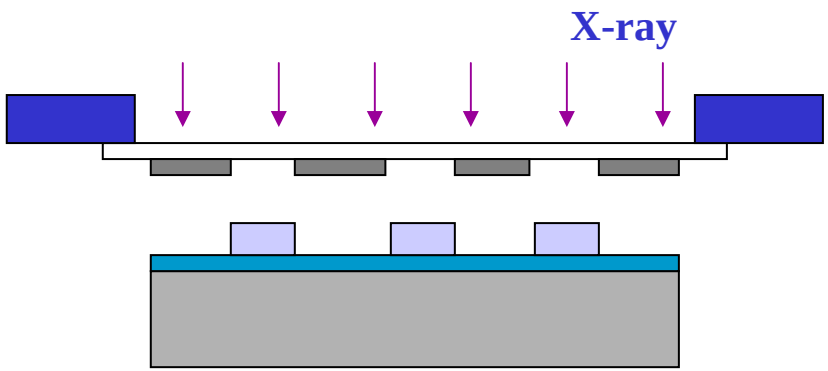
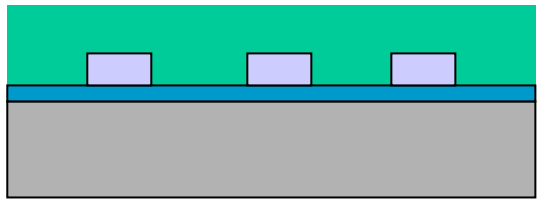
- **Fabrication process**

Deposit a metallic layer

Cast a thick resist layer (PMMA)



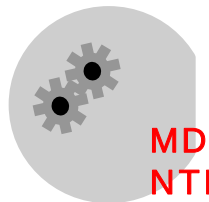
Pattern resist layer by X-ray

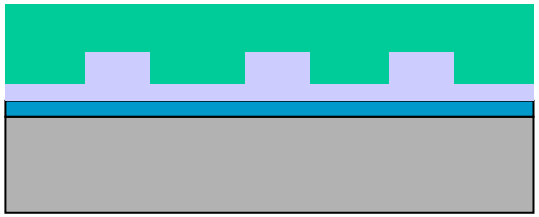


Electroplating the mold insert

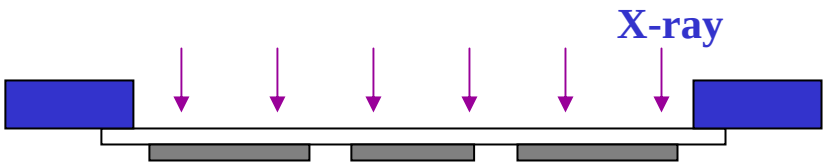
Mold insert

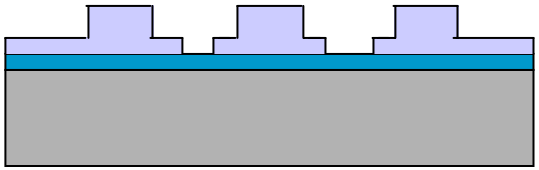
Deposit a metallic layer



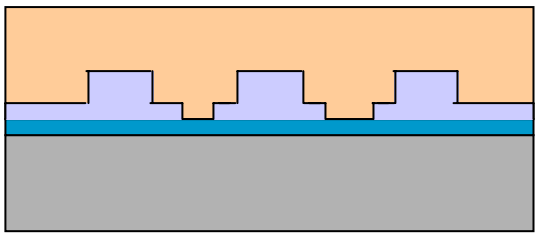


Use the mold insert to form the resist



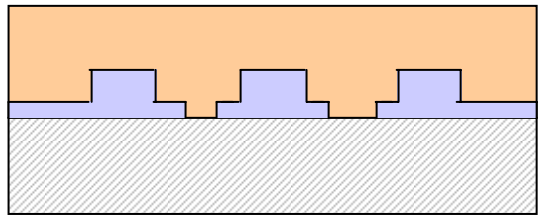


Pattern resist layer by X-ray
with 2nd mask

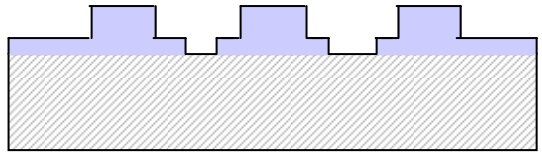


Electroplating

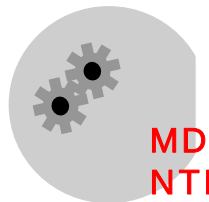
Final mold insert



Use the mold insert to
form multiple plating base



Remove the mold insert



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3.3.3 Other deep lithography process

- **LIGA by UV light - LIGA process can be conducted by UV light when using polyimide as the photoresist**
- **The thickness this technique can reach is 1 ~ 150 μm**
- **Advantages (vs X-ray LIGA)**

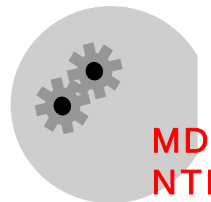
  + Standard exposure equipment

  + Conventional mask

  + IC process compatible

  + The excellent chemical and thermal stability of polyimide materials allow electroplating process operated in a variety of environment

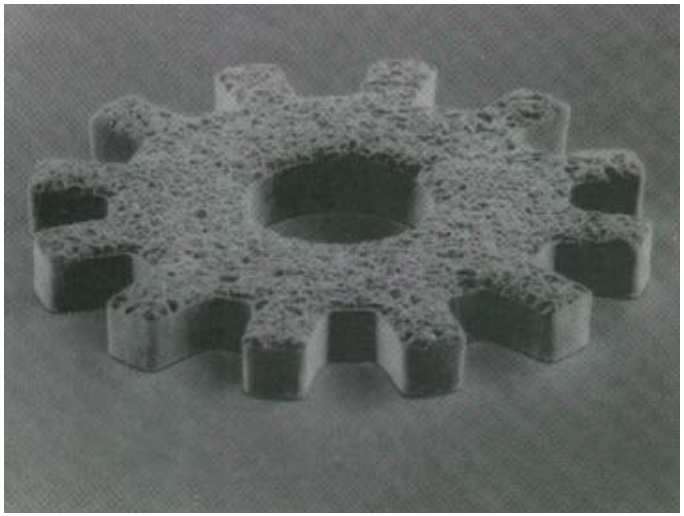
  + The possibility of fabricating a vertically integrated structures by multiple coats



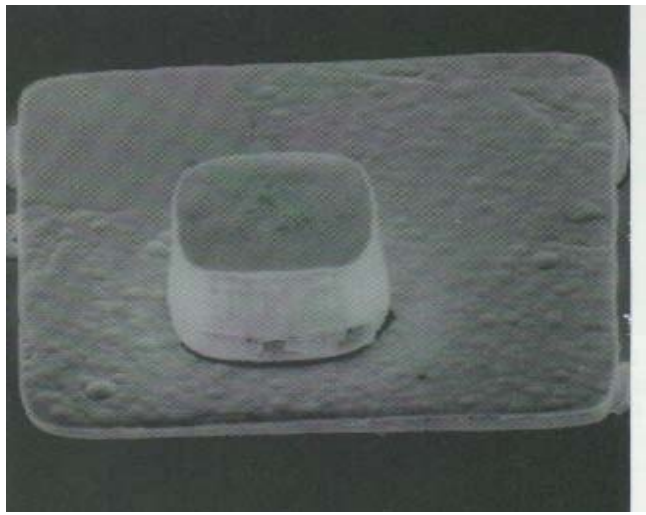
- **Disadvantages (vs X-ray LIGA)**

  + Thickness of X-ray lithography is relatively large

  + X-ray lithography has more sharp sidewalls



Gear fabricated by UV LIGA



Vertically integrated structure

A.B. Frazier and M.G. Allen, J. of MEMS, 1993

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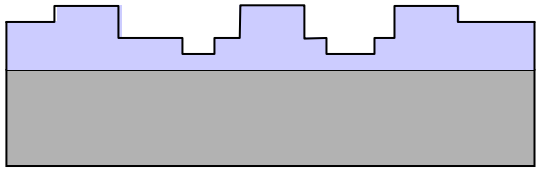
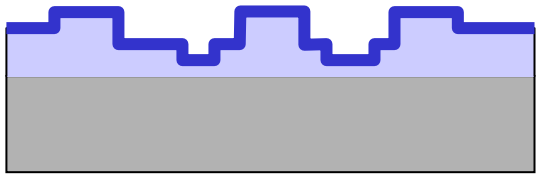
- **Laser LIGA – the polymer layer is patterned by excimer laser (not X-ray)**

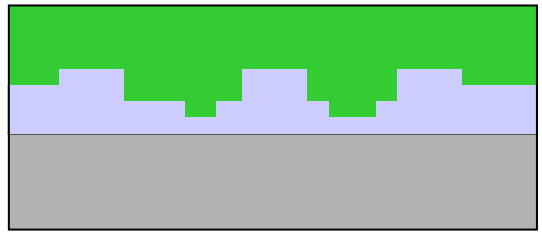
Cast a polymer layer



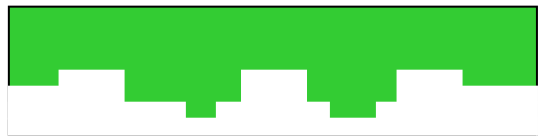
Pattern the polymer layer by excimer laser



Deposit a metal layer



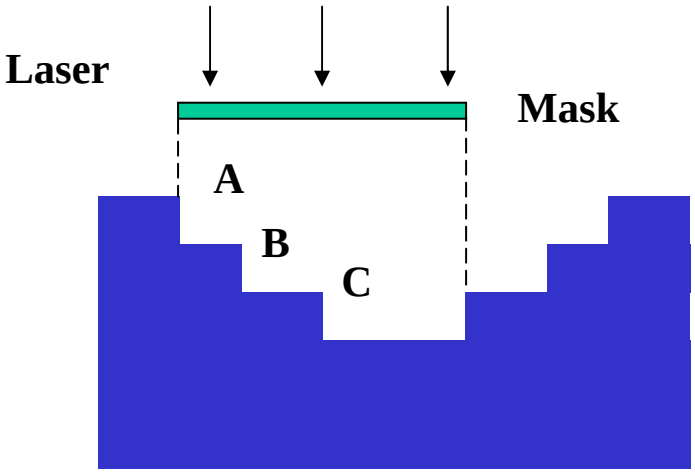
Electroplating

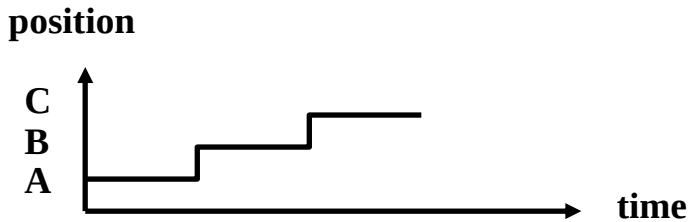


Mold insert

- The polymer is removed by laser ablation
- The etching depth can reach approximately 200 μm
- 3D structures are available since the thickness removed by the excimer laser can be controlled by,

  + modulating the light intensity
  + the motion of the sample as well as the timing of laser pulse during laser ablation





Motion of the sample

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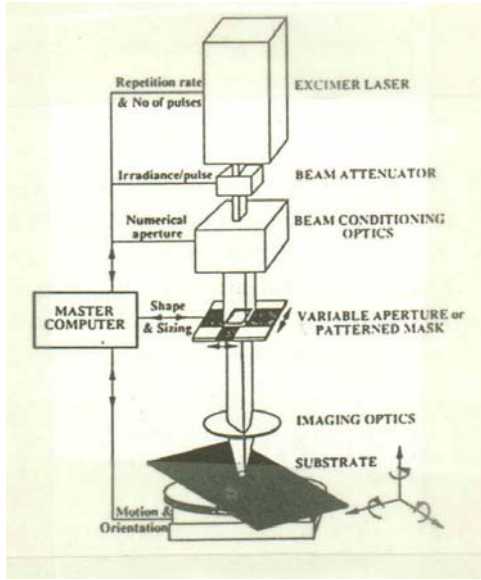
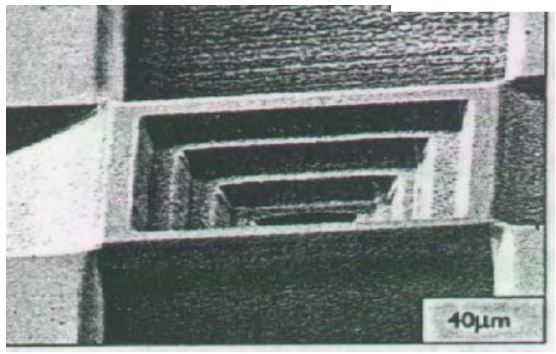
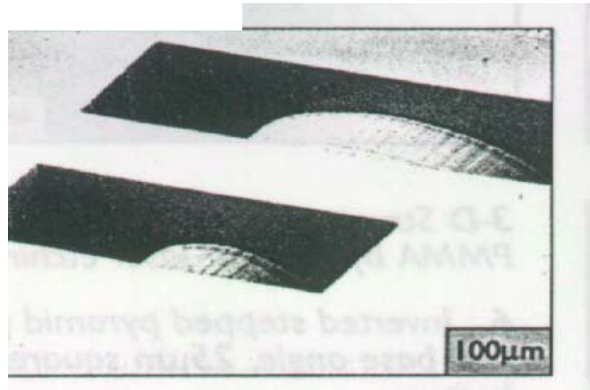
- **A conceptual setup of the laser ablation tool**



Exitech commertial advertisement, 1994

- **Some typical products by laser ablation**





Exitech commertial advertisement, 1994

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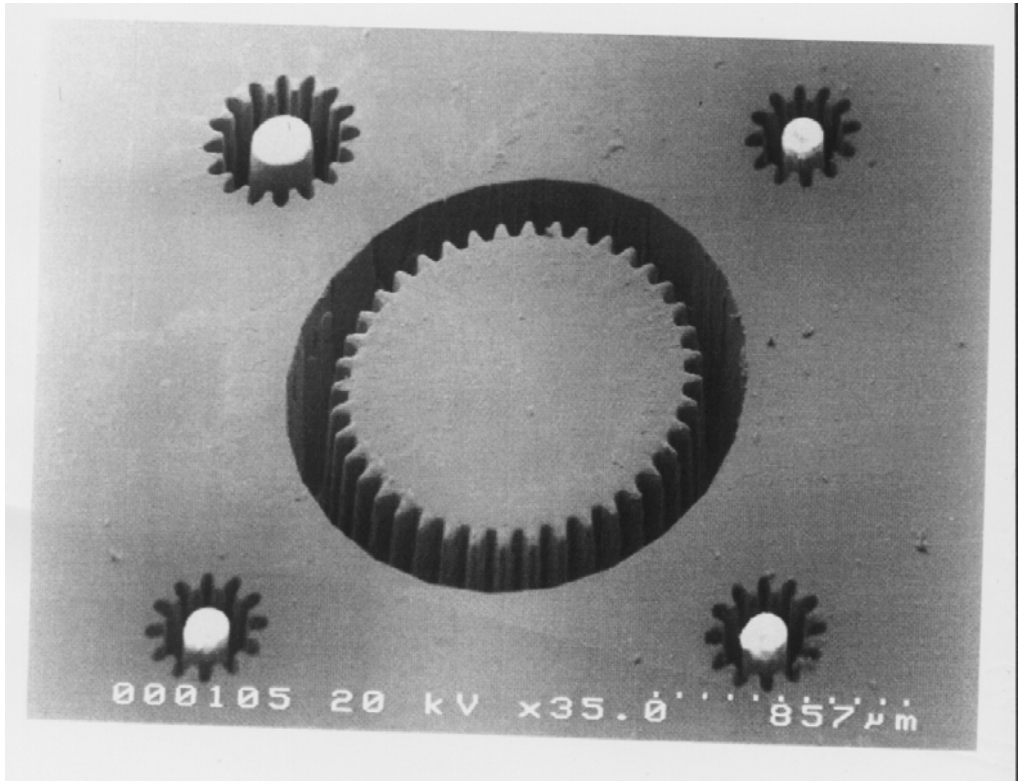

C.-R. Yang at PIDC and C.-H. Lee at NTHU, 1998

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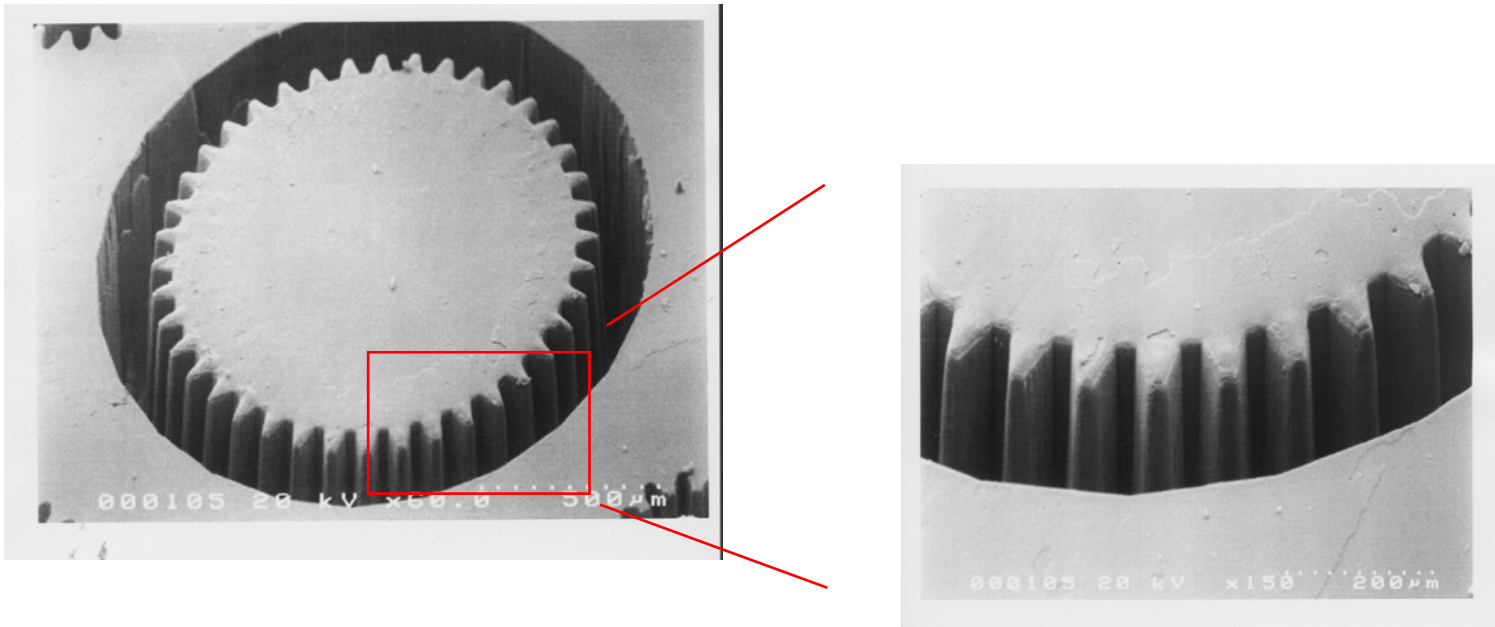

C.-R. Yang at PIDC and C.-H. Lee at NTHU, 1998

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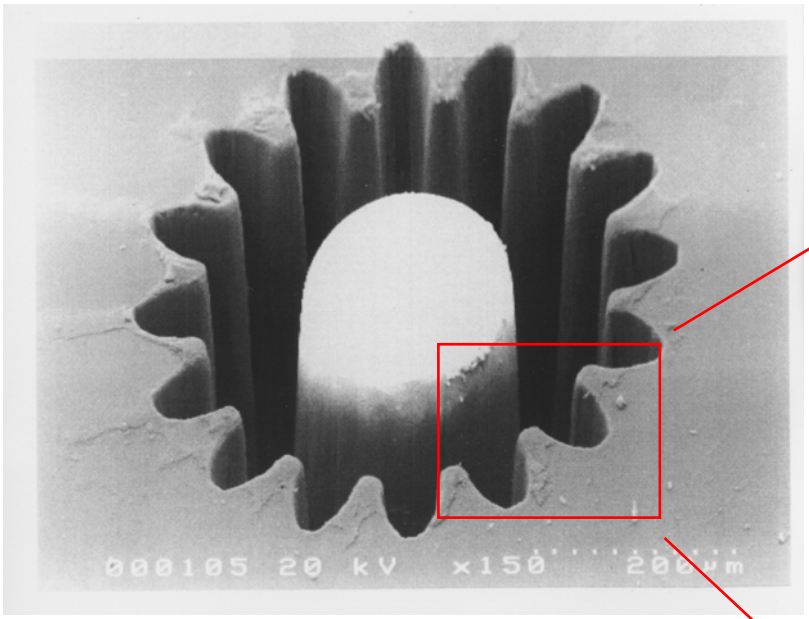

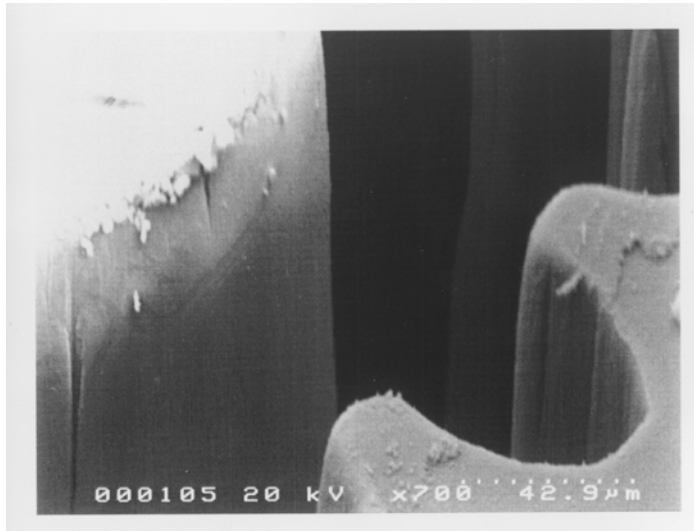

C.-R. Yang at PIDC and C.-H. Lee at NTHU, 1998

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