Deep Lithography for Microfabrication

Part 2: UV Deep Lithography (UVDL)

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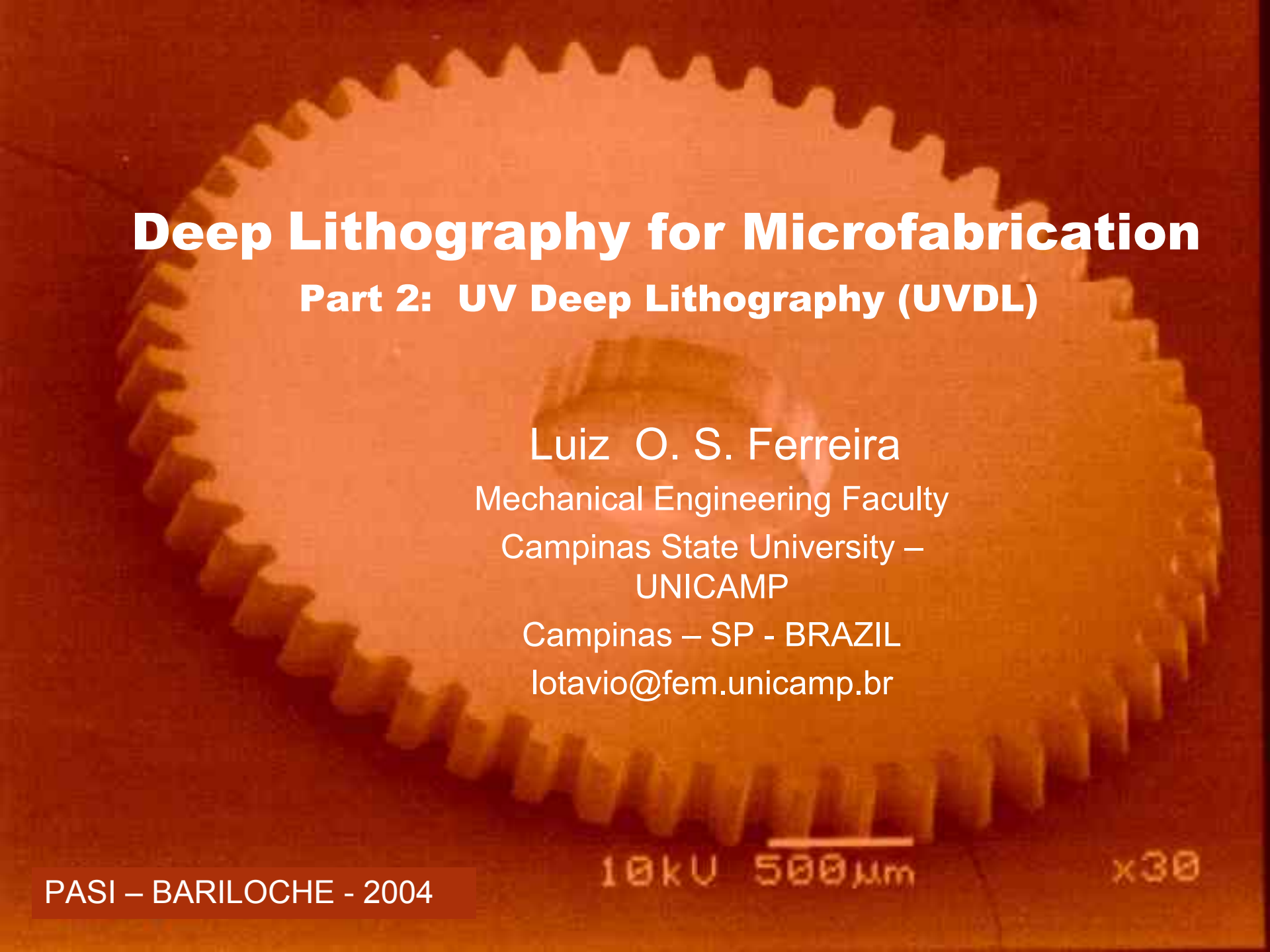


Acknowledgments

- Government
  - LNLS
- People
    - LNLS staff: Graziele Natal, Angelo Gobbi

Presentation Outline

- Introduction
- Positive-tone Resists for UDVL
- Dry films on UDVL
- Gray tone lithography
- The SU8 photoresist
- Inclined lithography
- Final remarks

Introduction

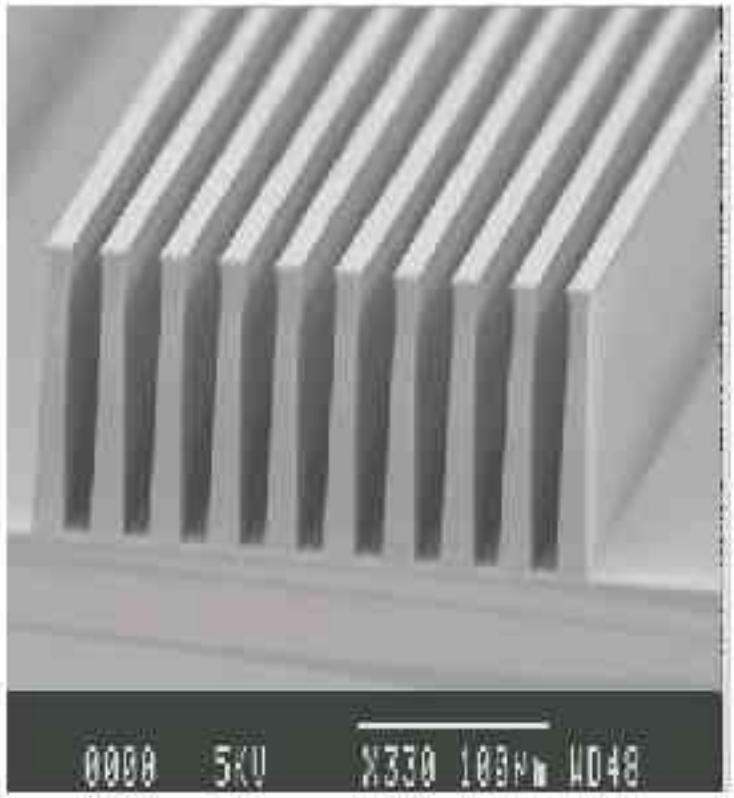
- Before 1996
  - Thick resists were used primarily as electroplating mold material.
    - UV lithography on PMMA: < 5μm thick
    - Positive tone resists: < 50 μm thick
    - Negative tone resists: (polyimide) < 150 μm thick
- 1996 SU-8 is released
- After 1996
  - New applications to UV deep lithography
  - UV-LIGA; HARMST

Positive-tone Resists for DUVL

- Thickness limited by transparency
  - Thickness < 150 μm
  - Aspect-ratio (7 – 15)
  - Easy removal
  - Good as mold for electroplating
  - Bad as structural material

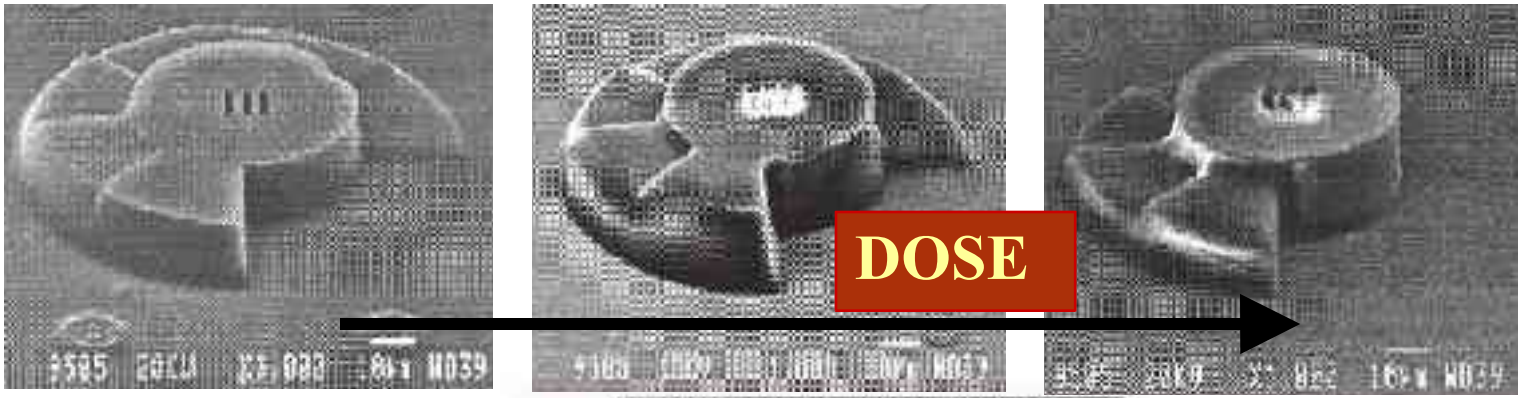
Positive-tone Resists for DUVL

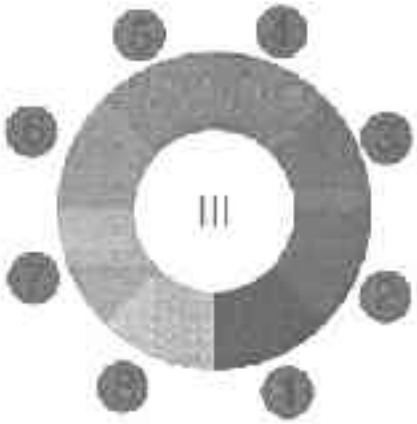
- 100 μm thick film.
- Spinning tips:
  - Use ramped speed profile
- Confined spinner chamber helps on thicker films

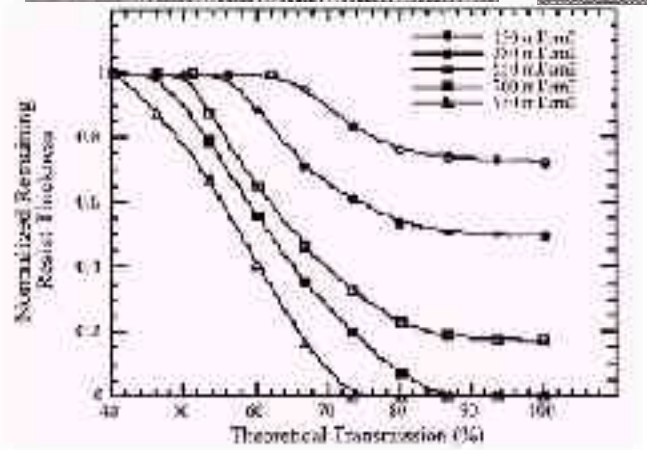


Picture from: V Conedera, B Le Goff and N Frabre, **"Potentialities of a new positive photoresist for the realization of thick moulds"**, *J. Micromech. Microeng.*, **9** (1999) 173-175.

Gray-tone Lithography - 1

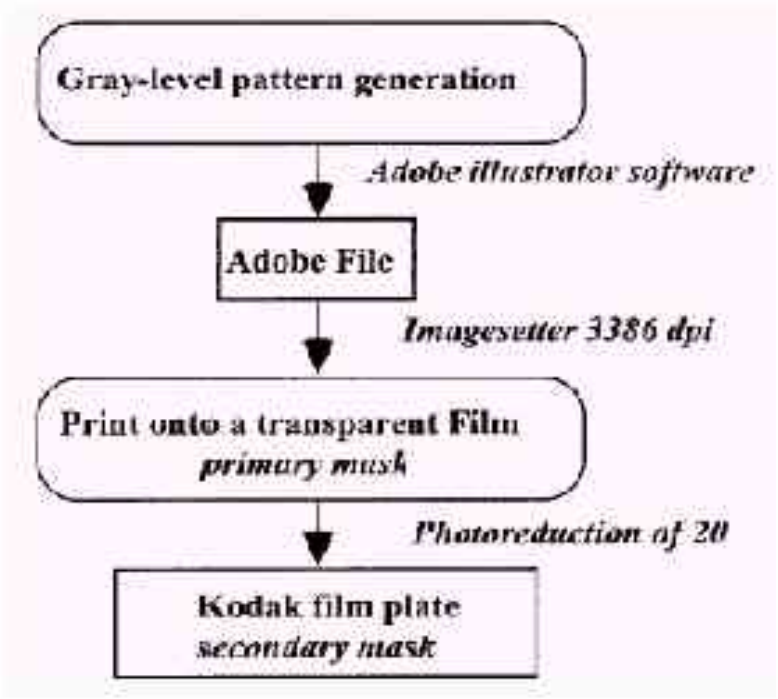


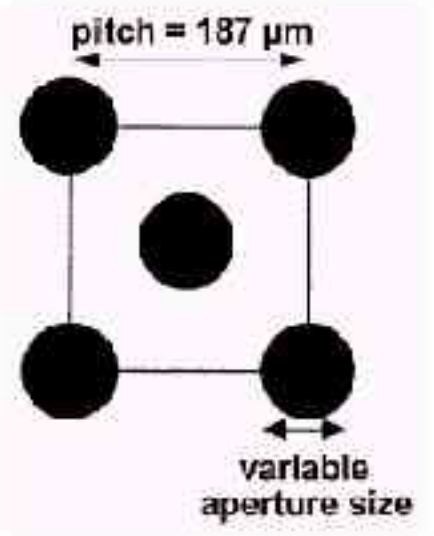




From: S. Nicolas, E Dufour-Gergam, A Bosseboeuf, T Bourouina, J-P Gilles and J-P Grandchamp, **"Fabrication of a gray-tone mask and pattern transfer in thick protoresists"**,*J. Micromech. Microeng.*, **8** (1998) 95-98.

Gray-tone Lithography - 2





Gray-tone binary mask.

PWM of the light intensity

Scale = 200.

Constant pitch.

256 levels of gray.

An additional reduction of 10X was used to tranfer the 3D pattern from the secondary mask into photoresist.

From: S. Nicolas, E Dufour-Gergam, A Bosseboeuf, T Bourouina, J-P Gilles and J-P Grandchamp, **"Fabrication of a gray-tone mask and pattern transfer in thick protoresists"**,*J. Micromech. Microeng.*, **8** (1998) 95-98.

Negative-tone Resists for DUVL

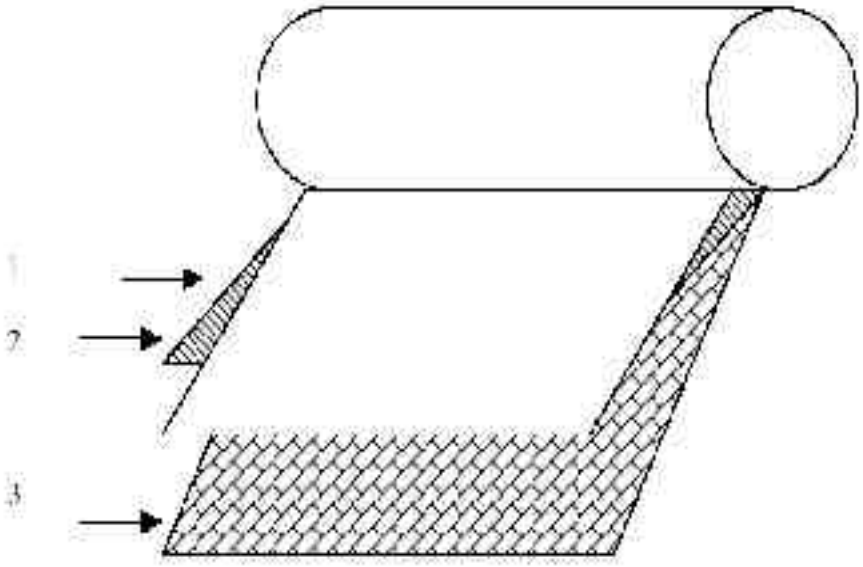
- Exceptional transparency
  - Thickness 1000 µm
  - Aspect-ratio: 5-25
  - Good as mold for electroplating
  - Some resists are good as structural material
  - Dry film and liquid resists.

Dry Films on DUVL

- From PCB industry.
  - 20 μm, 50 μm and other thickness.
  - > 200 μm on multilayer.
  - Laminated on the substrate.
  - Good for electroplating.
  - Easy stripping.

From: E. Kukharenka, M M Farooqui, L Grigore, M Kraft and Hollingshead, **"Electroplating moulds using dry film thick negative photoresist"**, *J. Micromech. Microeng.*, **13** (2003) S67-S74.

Dry Films on DUVL - Structure



Three-layer structure of dry film photoresist.
1: polyethylene separation sheet; 2: photoresist and 3: polyester support.

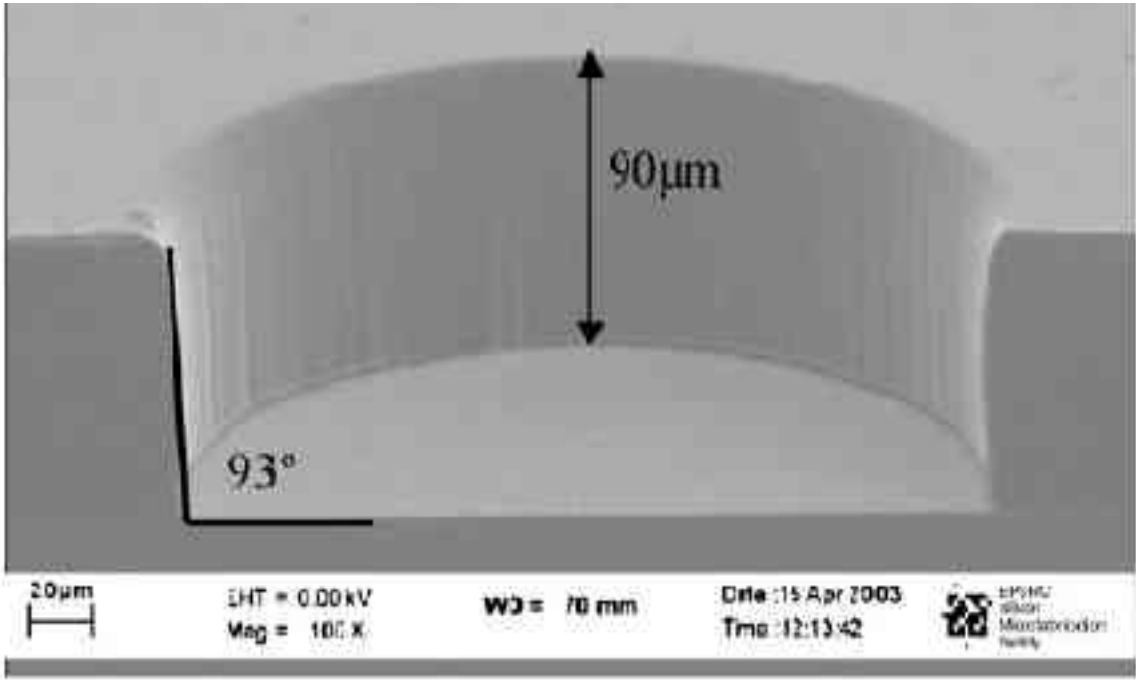
From: E. Kukharenka, M M Farooqui, L Grigore, M Kraft and Hollingshead, **"Electroplating moulds using dry film thick negative photoresist"**, *J. Micromech. Microeng.*, **13** (2003) S67-S74.

Dry Films on DUVL - Processing

- Peeling of the polyethilene film.
- Lamination to the substrate.
- Conformation by heating under pressure.
- UV exposure.
- Peeling of the polyester film.
- Development.

From: E. Kukharenka, M M Farooqui, L Grigore, M Kraft and Hollingshead, **"Electroplating moulds using dry film thick negative photoresist"**, *J. Micromech. Microeng.*, **13** (2003) S67-S74.

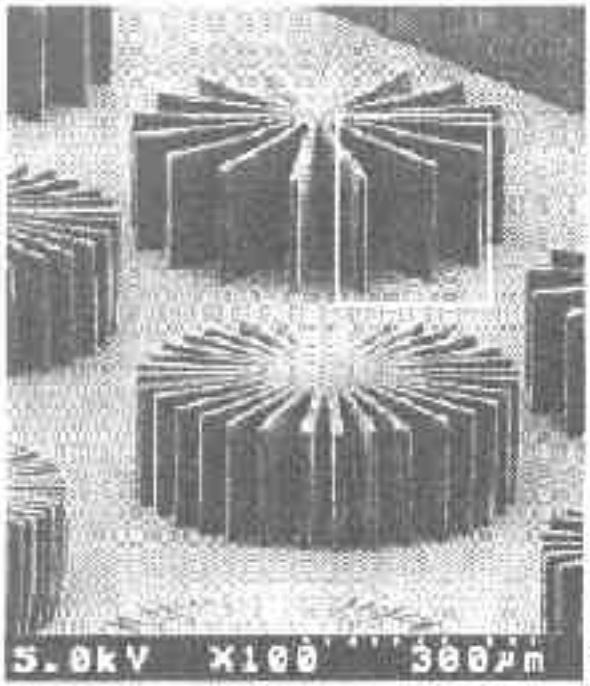
Dry Films on DUVL - Sample

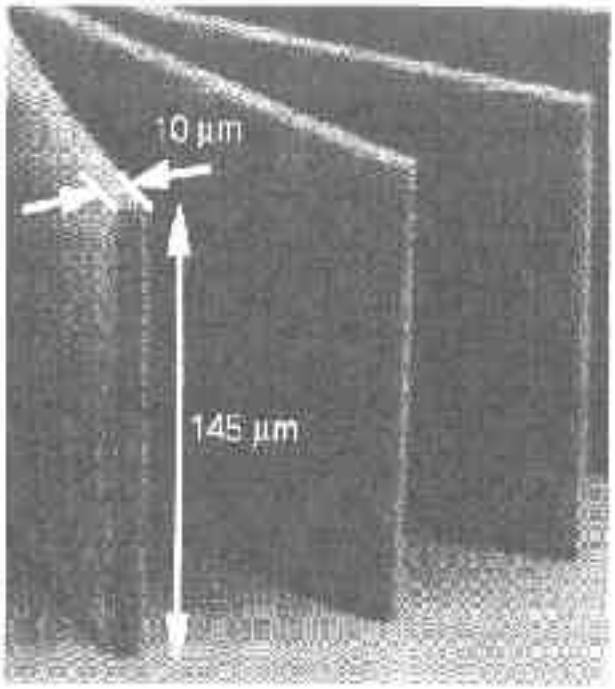


SEM image of 90 μm thick mould in Ordyl P-50100.

From: E. Kukharenka, M M Farooqui, L Grigore, M Kraft and Hollingshead, **"Electroplating moulds using dry film thick negative photoresist"**, *J. Micromech. Microeng.*, **13** (2003) S67-S74.

The SU8 Photoresist





- Negative-tone, high aspect ratio, near UV epoxy based photoresist.
- Good mechanical, electrical, optical and chemical properties.
- UV-LIGA

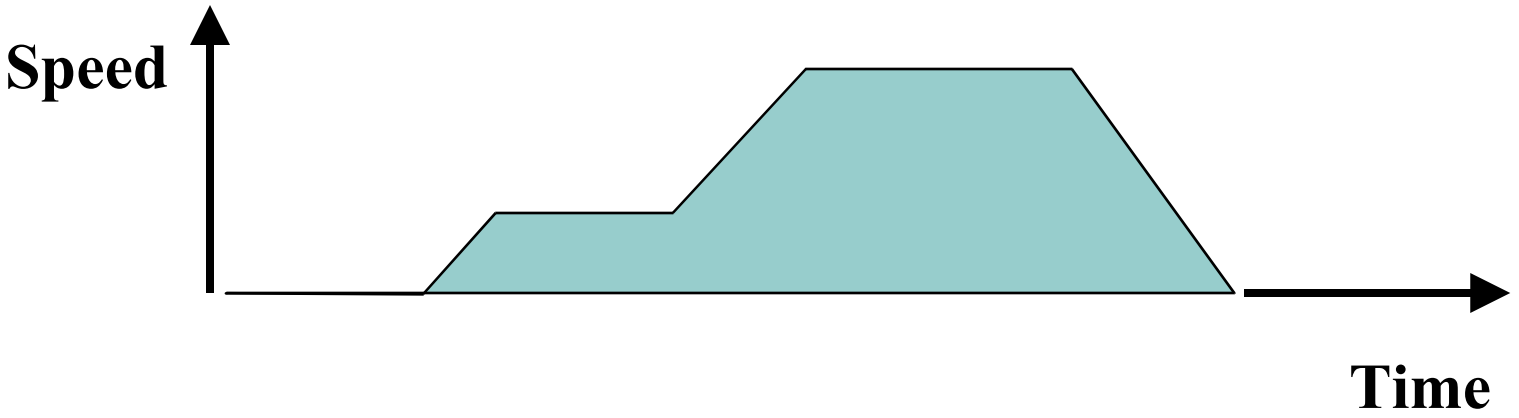
From: H Lorenz, M Despont, N Fhrni, N LaBianca, P Renaud and P Vettiger, **"SU-8: a low-cost negative resist for MEMS"**, *J Micromech. Microeng.* 7 (1997) 121-124

SU8 - General

- It was developed by IBM for e-beam lithography.
- Highly transparent to near UV
- EPON® Resin SU-8, from Shell Chemical, dissolved in an organic solvent (GBL or cyclopentanone) plus a photoinitiator.
- Chemical amplification by a post-bake.
- Stripping with hot NMP (1-methyl-2-pyrrolidon), plasma or laser ablation.
- Hard baked (30 min @ 200 ^{o}C): withstands nitric acid, pH 13 NaOH @ 90 ^{o}C, etc.

From: H Lorenz, M Despont, N Fhrni, N LaBianca, P Renaud and P Vettiger, **"SU-8: a low-cost negative resist for MEMS"**, *J Micromech. Microeng.* 7 (1997) 121-124

SU-8 Processing - Spinning



- Low speed for spreading the resist on the substrate.
- High speed for thinning the resist film.
- Use ramped speed changes (100-200 rpm/s).

SU-8 Processing - Soft-bake

- Temperature = 95^{o}C.
- Tg = 55^{o}C for unexposed film.
- Hotplate is preferable to owen.
- Hotplate **must be** levelled.

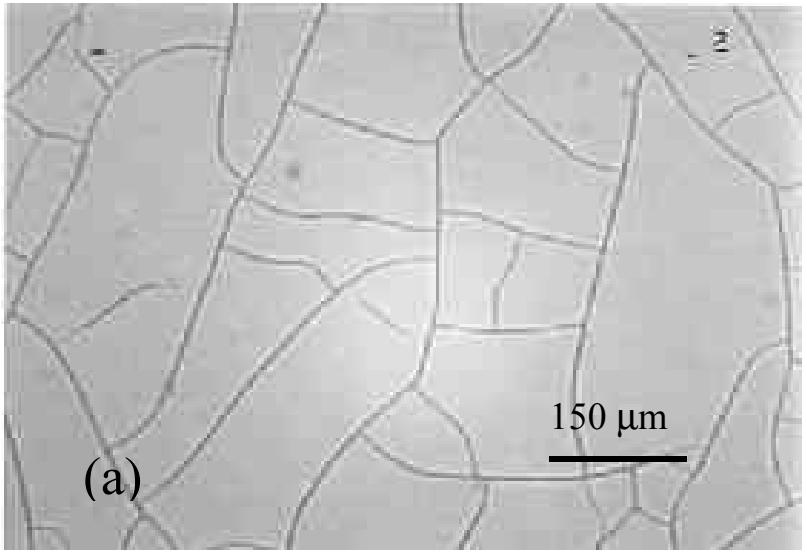
SU-8 Processing - Exposure

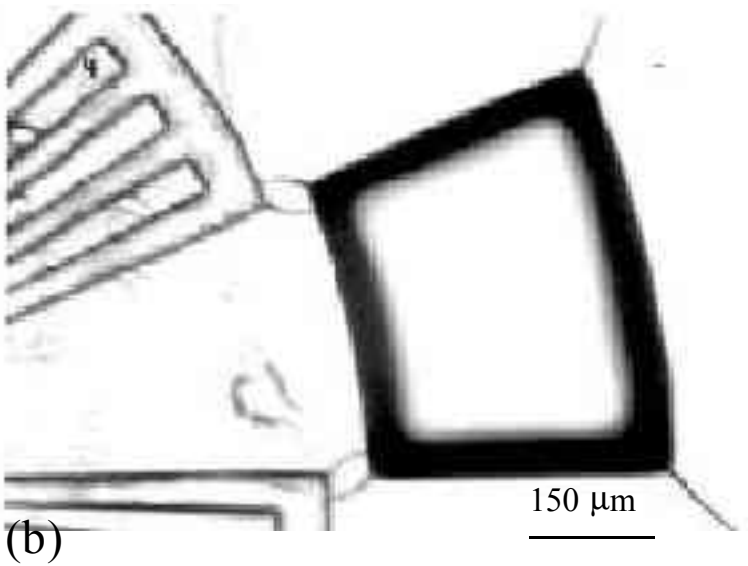
- For thick films:
  - Fraction your dose on short exposures and one minute intervals to avoid crust formation.
- 130 μm thick film: 165 mJ/cm^2.

SU-8 Processing - Post-bake

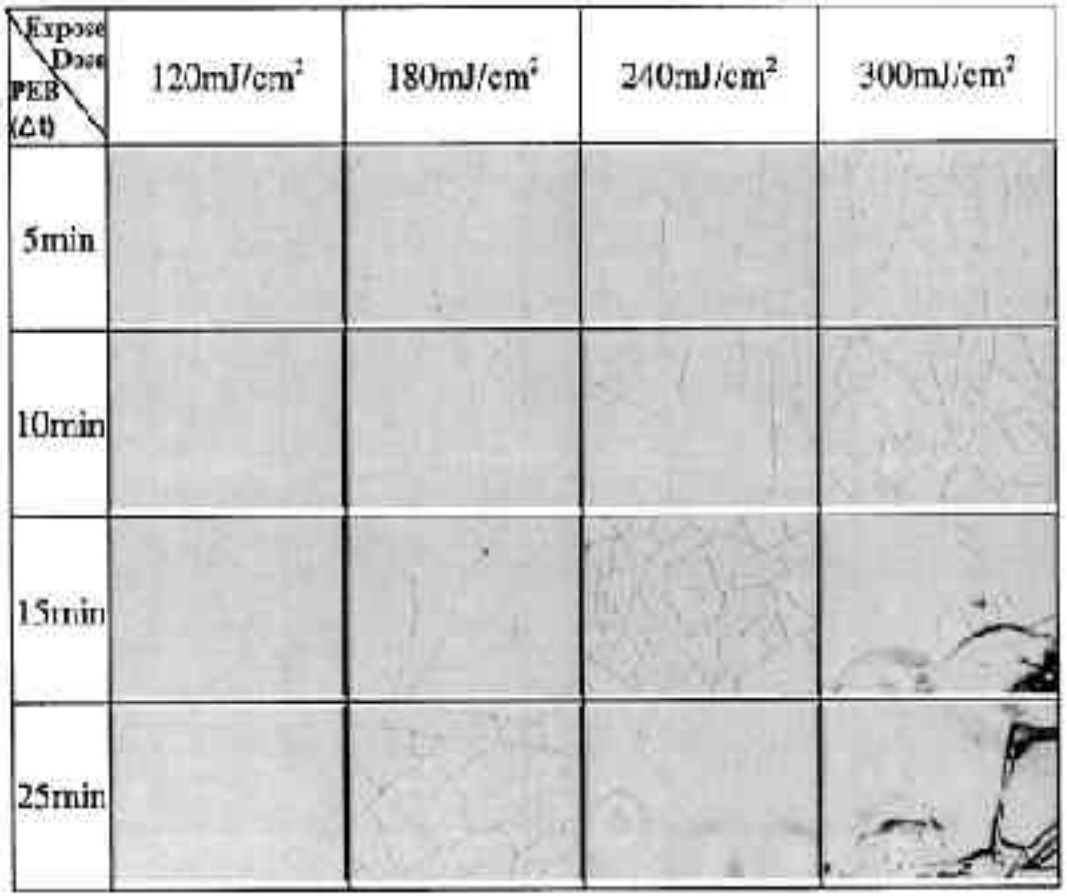
- More crosslinked when heated.
- Crosslinked film: Tg > 200°C
- Cooling cicle:
  thermal expansion mismatch produces stress.
- Thermal expansion:
  - **SU-8:** **21-52 ppm/K**
  - **Si:** **2.36 ppm/K**

SU-8 Processing – Stress - 1



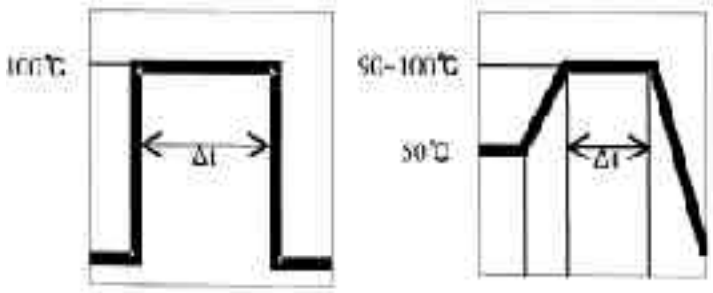


SU-8 Processing – Stress - 2



From: Hyun-Kee Chang and Yong-Kweon Kim, **"UV-LIGA process for high aspect ratio sructure using stress barrier and C-shaped etch hole"**, *Sensors and Actuators.* **84** (2000) 342-350

SU-8 Processing – Stress - 2



Exposure Dose / PEB (Δt)	120mJ/cm²	180mJ/cm²	240mJ/cm²	300mJ/cm²
1min				
3min				
5min				
10min				

From: Hyun-Kee Chang and Yong-Kweon Kim, **"UV-LIGA process for high aspect ratio sructure using stress barrier and C-shaped etch hole"**, *Sensors and Actuators.* **84** (2000) 342-350

SU-8 Processing - Development

- (for a 130 μm thick film)
  - A) 5 min in pure developer PGMEA (propylene glycol methyl ether acetate)
  - B) Rinse with IPA
  - C) Repeat steps A and B until no white stains remain.
- WARNING: do not rinse with water.

SU-8 Processing - Stripping

- Lift off : easy.
- Piranha: (H_2SO_4:H_2O_2)
- Plasma etch
- Laser ablation

SU-8 Processing - Hardbake

- 30 min @ 200^{o}C
- After hardbake it withstands chemicals like nitric acid, KOH, NaOH, acetone, etc.

SU8 Properties - Mechanical

Modulus of elasticity : E	4.02 GPa
-	4.95 +/- 0.42 GPa
-	4.4 GPa
Bi-axial modulus of elasticity : E/(1 - n)	5.18 +/- 0.89 GPa
Poisson ratio	0.22 postbaked at 95C, SM blend
Film stress	19 - 16 Mpa
Max stress	34 Mpa
Max sheer	0.009
Plastic domain limit	'no' plastic domain observed
Friction coefficient :μ	0.19

From: http://aveclafaux.freeservers.com/SU-8.html

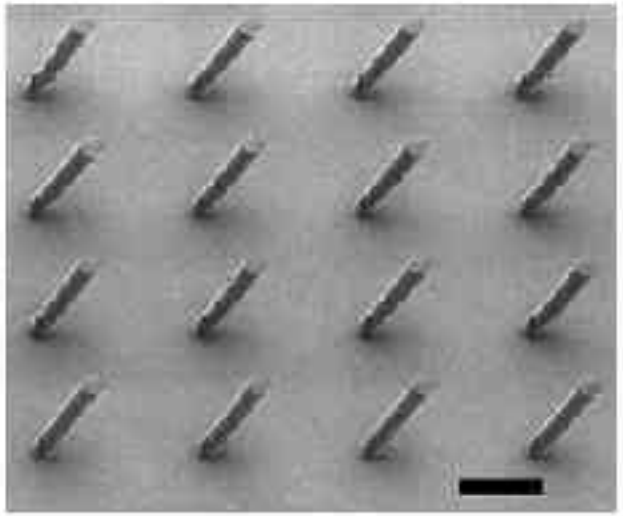
SU8 as structural material

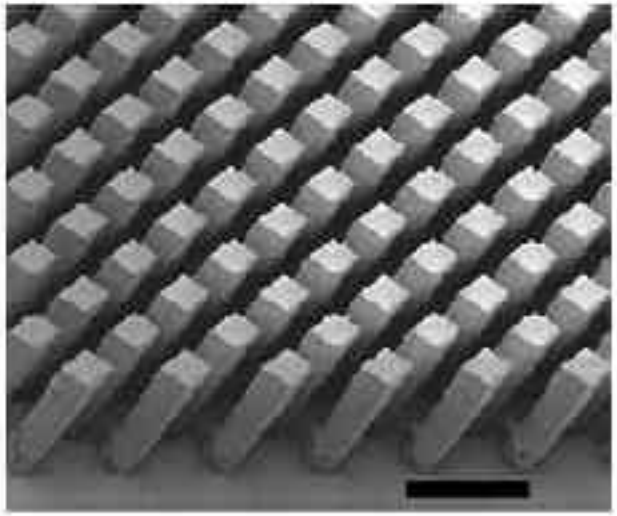
SU8 Properties - Other

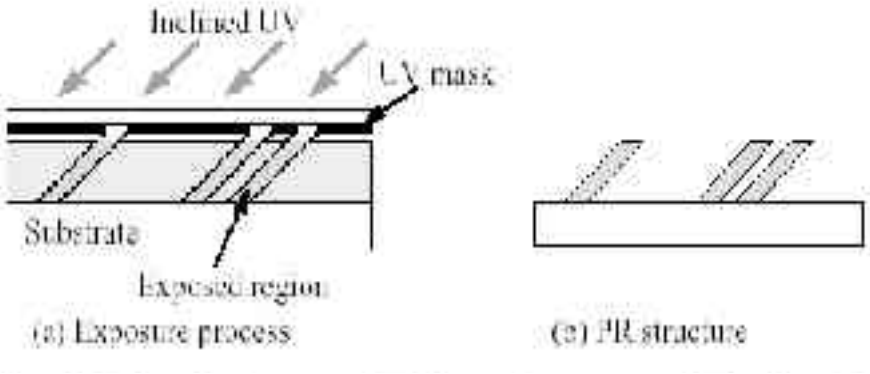
- Aspect ratio: 1:20 and 1:25 typical
- May be gray-tone lithographed.
- May be MeV proton lithographed.
- Adhesion is good but depend on the material.
- Have good biocompatibility.

From: http://aveclafaux.freeservers.com/SU-8.html

SU-8 Inclined Lithography - 1



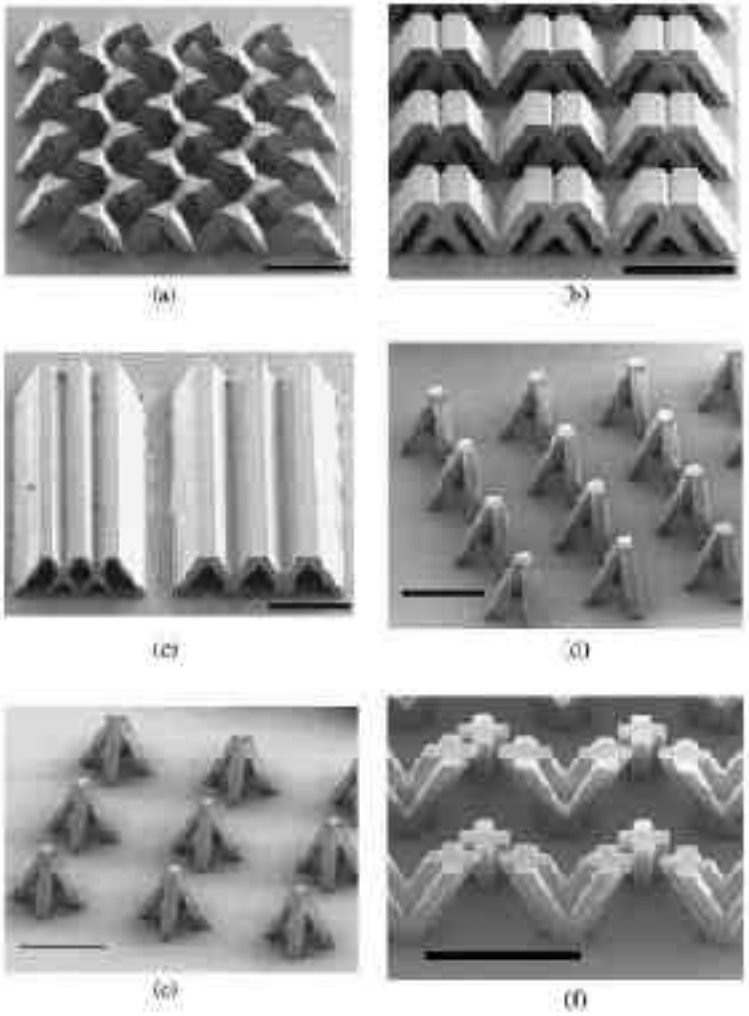




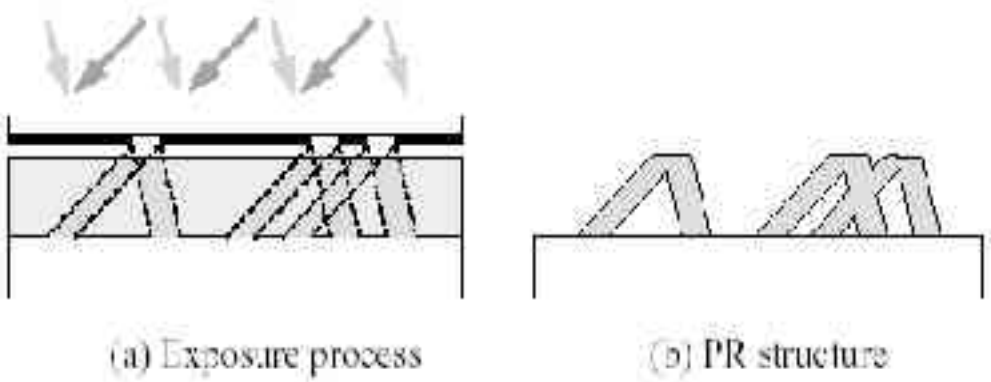
TRACE = 100 μm

From: Manhee Han, Woonseob Lee, Sung-Keun Lee, Seung S Lee, **"3D microfabrication with inclined/rotated UV lihtography"**, *Sensors and Actuators.A* **111** (2004) 14-20

SU-8 Inclined Lithography - 2



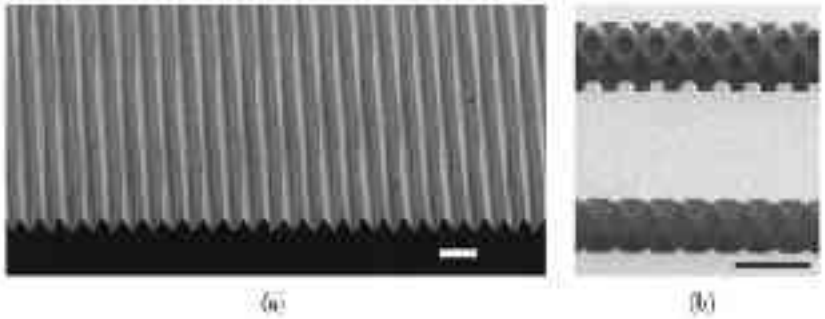
- **Several inclined exposures**

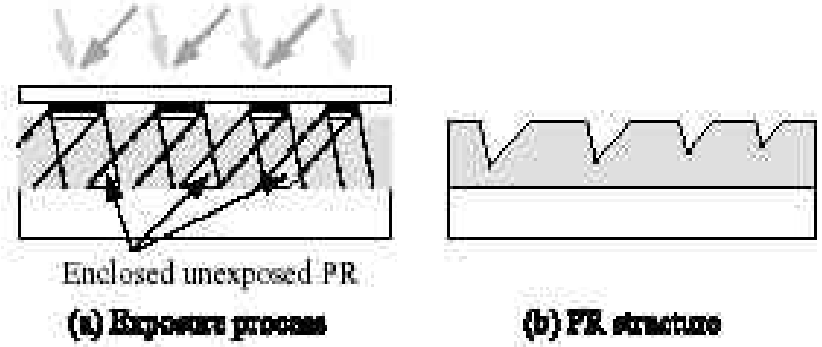


TRACE = 200 µm

From: Manhee Han, Woonseob Lee, Sung-Keun Lee, Seung S Lee, **"3D microfabrication with inclined/rotated UV lihtography"**, *Sensors and Actuators.A* **111** (2004) 14-20

SU-8 Inclined Lithography - 3



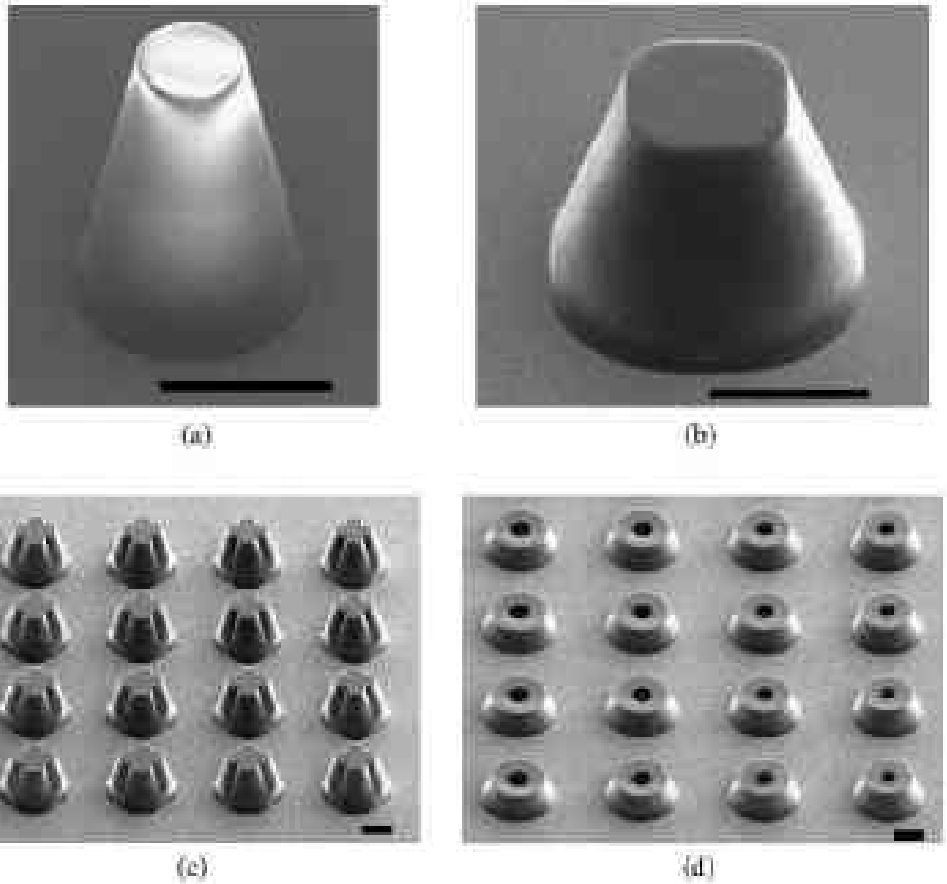


Double inclined exposure.

TRACE = 100 µm

From: Manhee Han, Woonseob Lee, Sung-Keun Lee, Seung S Lee, **"3D microfabrication with inclined/rotated UV lihtography"**, *Sensors and Actuators.A* **111** (2004) 14-20

SU-8 Inclined Lithography - 4

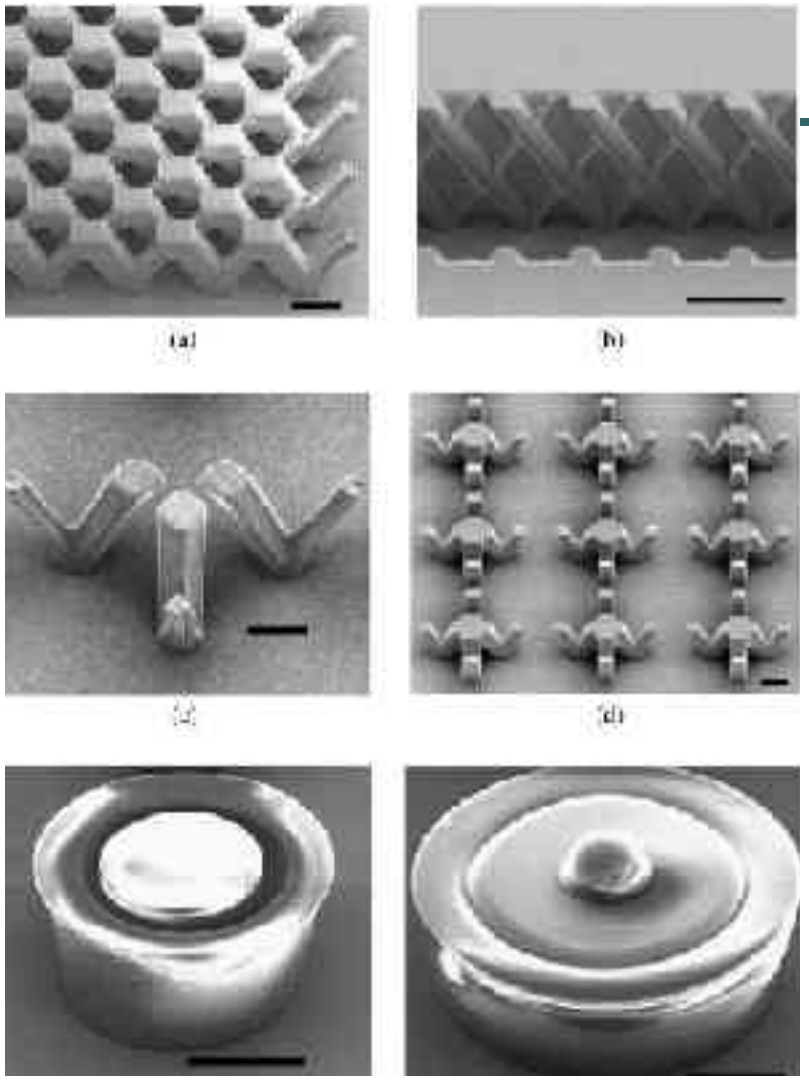


Inclined and rotated exposure.

TRACE = 50 μm

From: Manhee Han, Woonseob Lee, Sung-Keun Lee, Seung S Lee, **"3D microfabrication with inclined/rotated UV lihtography"**, *Sensors and Actuators.A* **111** (2004) 14-20

SU-8 Inclined Lithography - 5



Reflected UV exposure.

TRACE = 50 μm

From: Manhee Han, Woonseob Lee, Sung-Keun Lee, Seung S Lee, **"3D microfabrication with inclined/rotated UV lihtography"**, *Sensors and Actuators.A* **111** (2004) 14-20

Final Remarks

- Deep lithography is on its beginning.
- Many resists from industry branchs other than microelectronics have potential for use on deep lithography.
- Gray tone have good evolution potential. It is interesting mainly to fluidics and photonics.
- MeV proton looks to be a strong competitor to DXRL.
- Inclined/rotated lithography may be a real enhancement to actual techniques.

The End

- THANKS FOR ATTENTION.
- QUESTIONS?