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3D electron beam lithography

Motivation

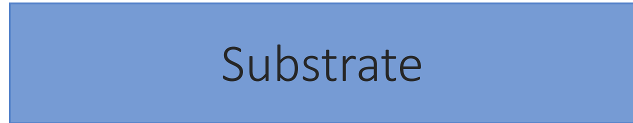
- The need of 3D nanostructures as such as **lenses**, **blazed gratings**, **diffractive optical elements**, and **holograms** is increasing
- **3D lithography** is more **challenging** than binary lithography
  - Low contrast resist processes and accurate adjustment of exposure doses are of uptmost importance
    - Proximity effects modify CD and height of a structure
    - Resist development process affects the lateral development
- **BEAMER** offers a model-based 3D PEC that combines correction for electron scattering proximity and resist development process effects

Outline

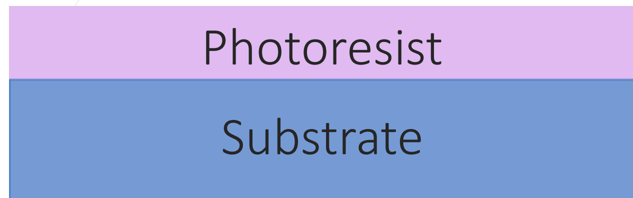
- 2D lithography vs 3D lithography
- 3D e-beam lithography correction
  - Contrast Curve
  - BEAMER Shape Correction
  - Surface roughness
- Summary

General steps in lithography

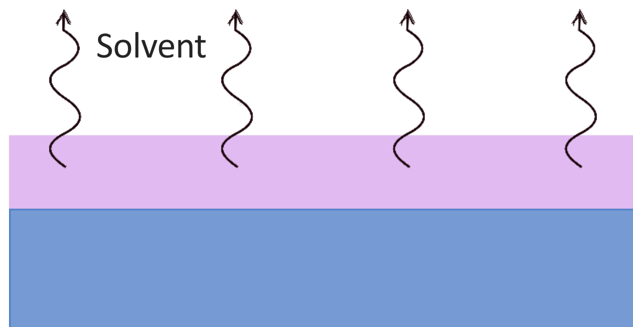
- Preprocessing



Cleaning, Baking, Adhesion Promoter



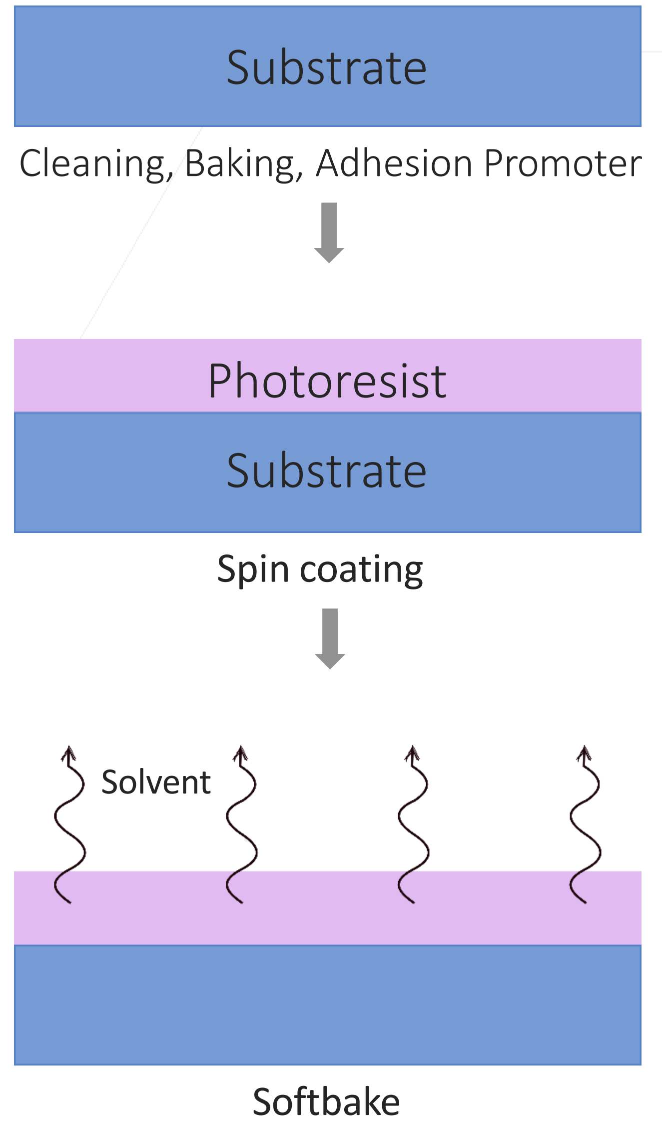
Spin coating



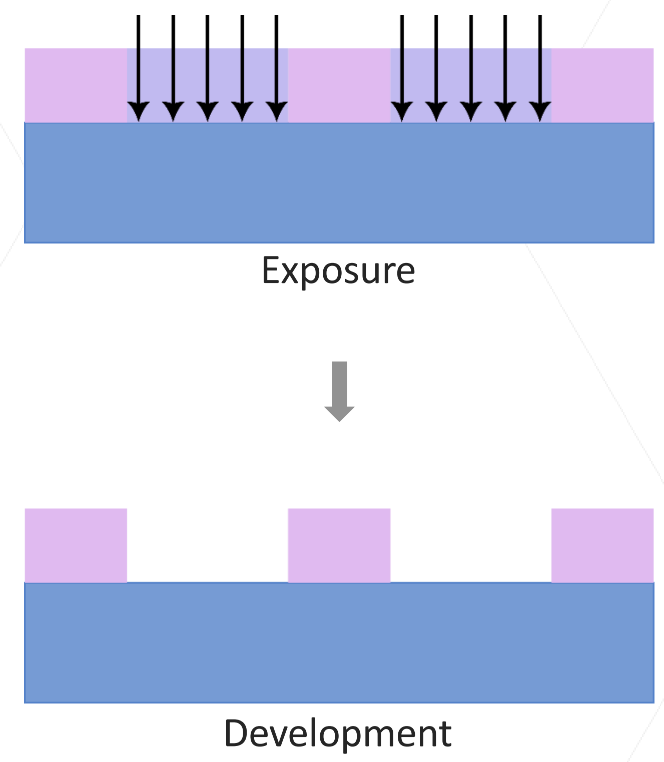
Softbake

2D Exposure

- Preprocessing

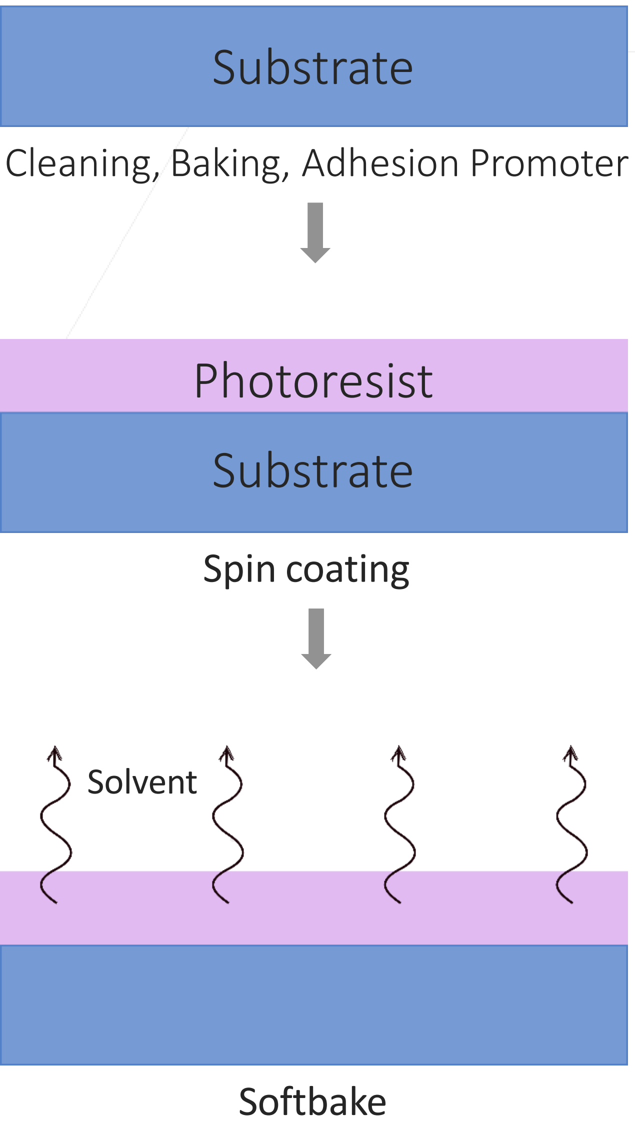


2D Litho

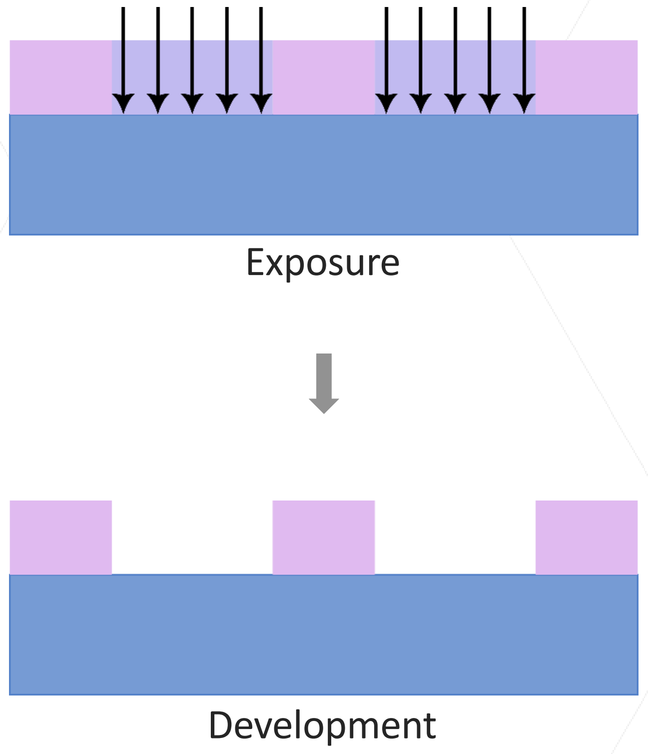


2D vs 3D Exposures

- Preprocessing

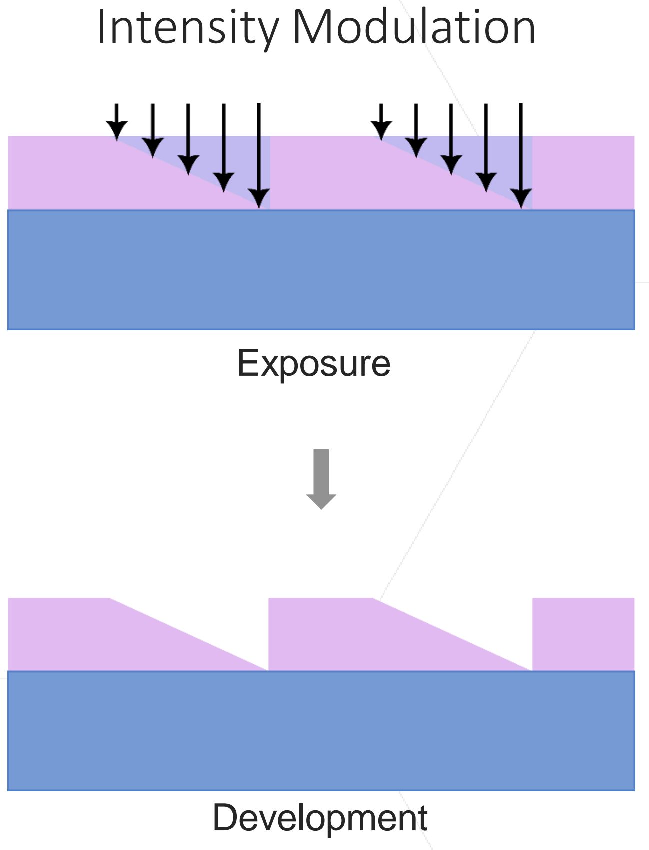


2D Litho



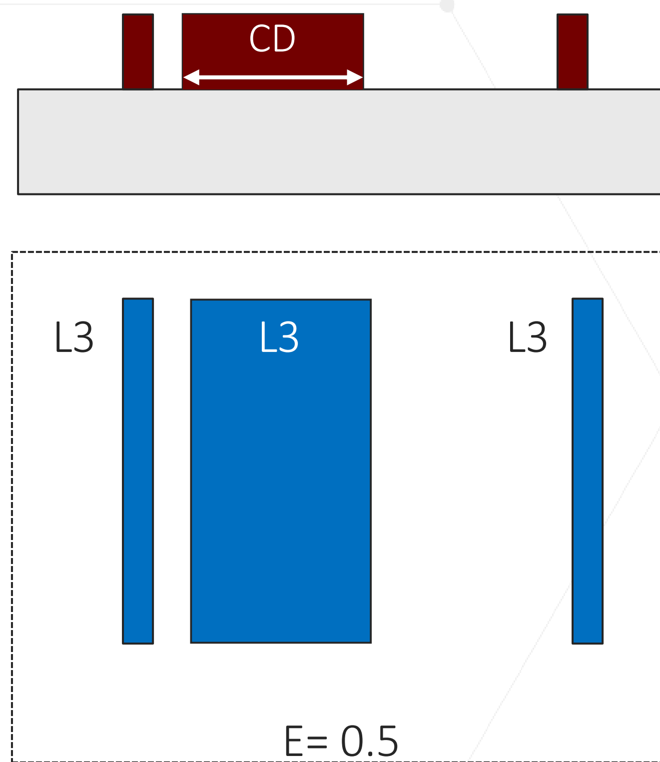
3D Litho

Intensity Modulation



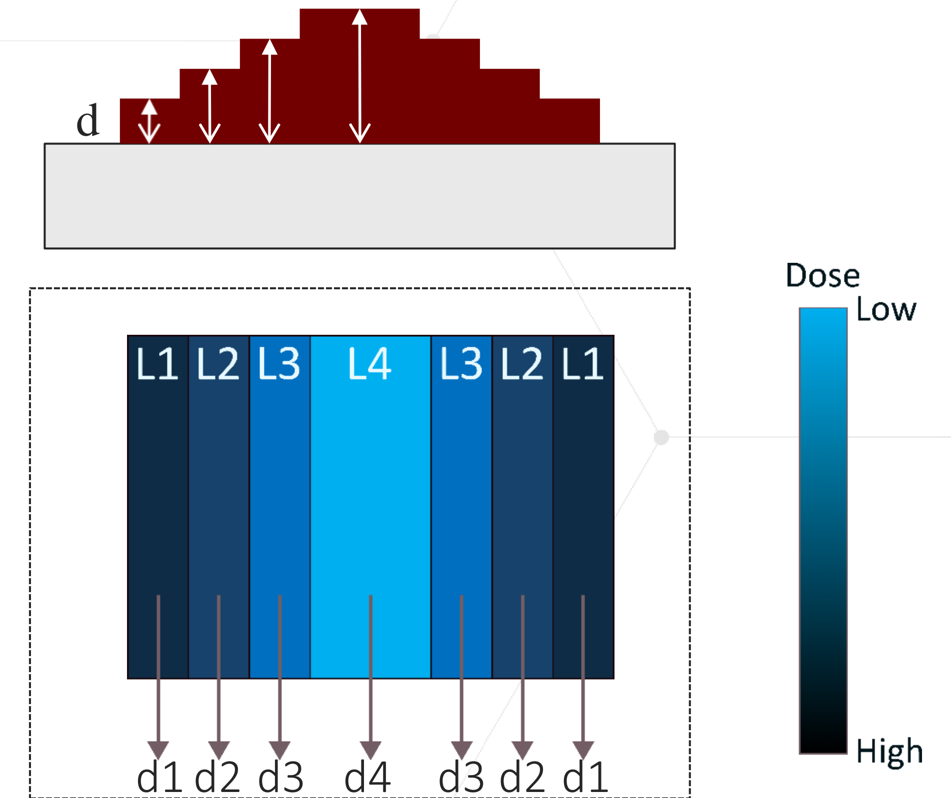
2D vs 3D Correction

2D Correction



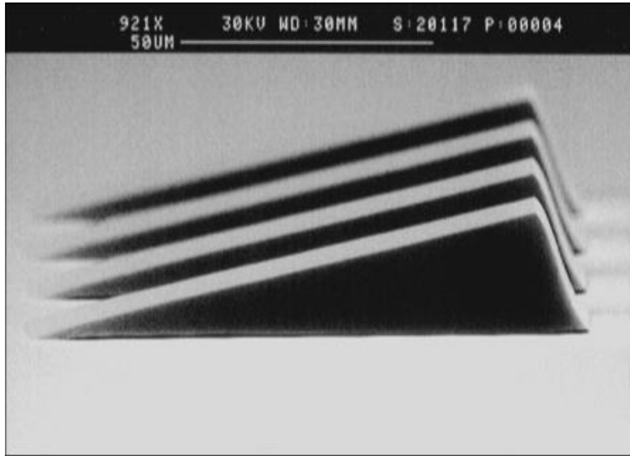
Target: Require absorbed energy at all feature edges to have same value

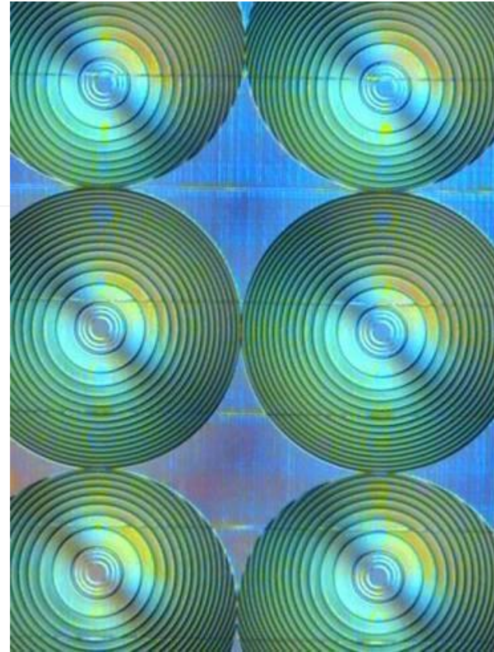
3D Surface PEC



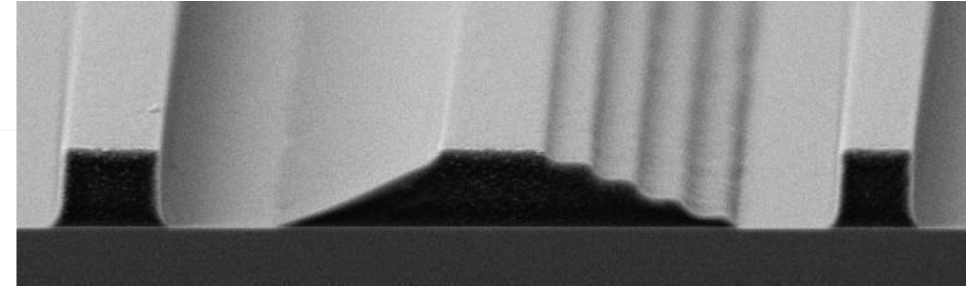
Target: defined resist thickness for all surface level

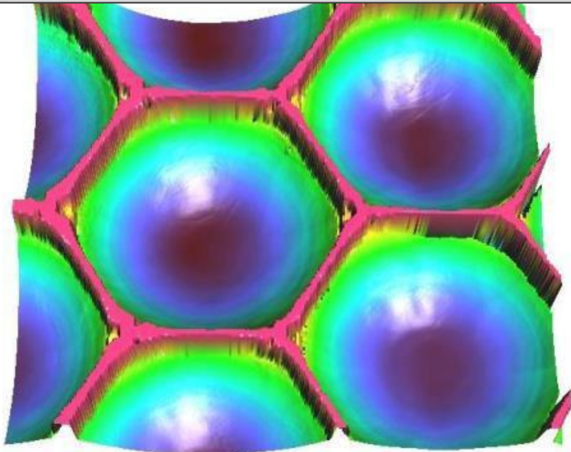
3D Lithography Examples

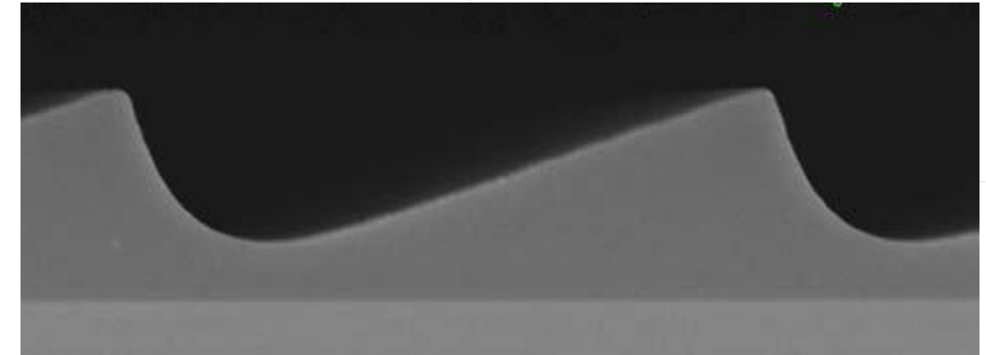


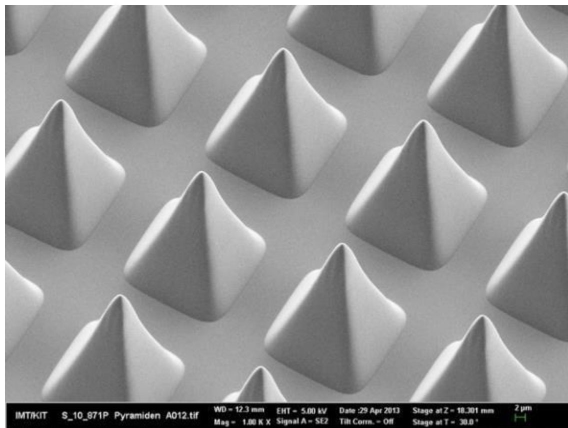


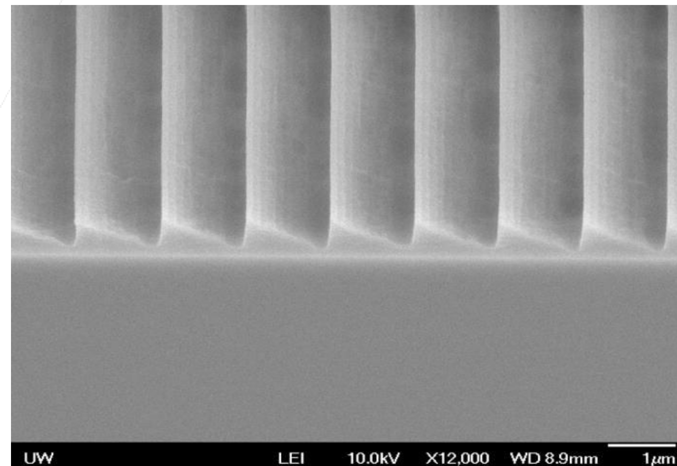
- Micro Lenses
- Lens Arrays
- Blazed Gratings
- Holograms
- Integrated Optics
- Prisms
- MEMS

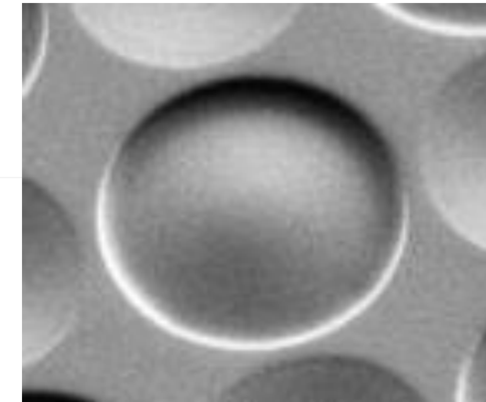


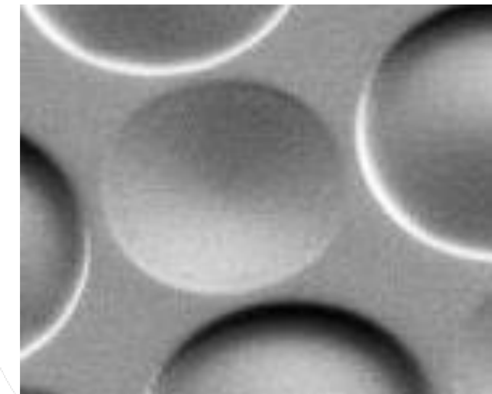




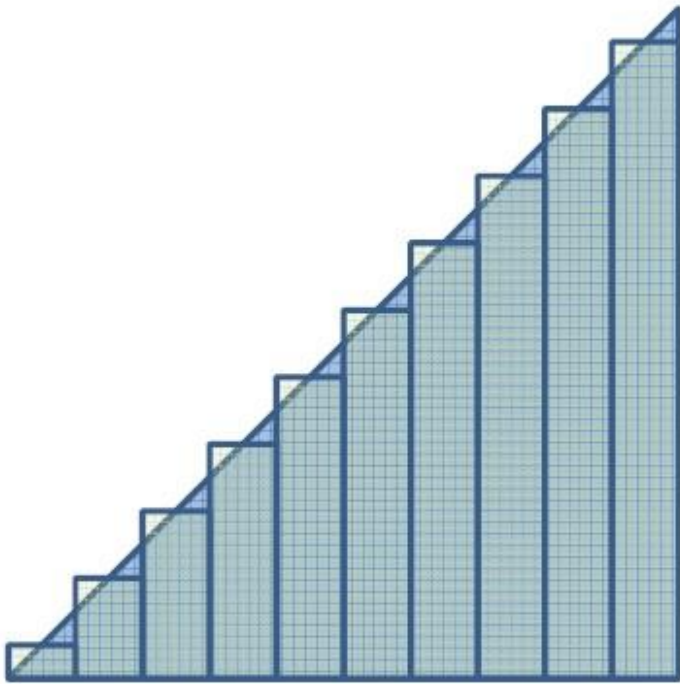


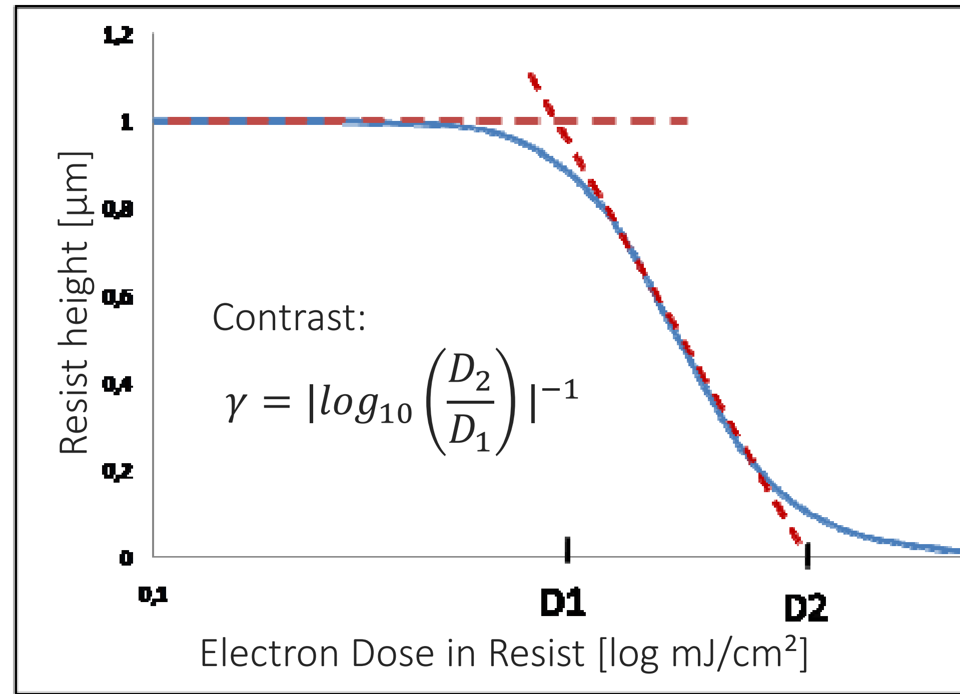


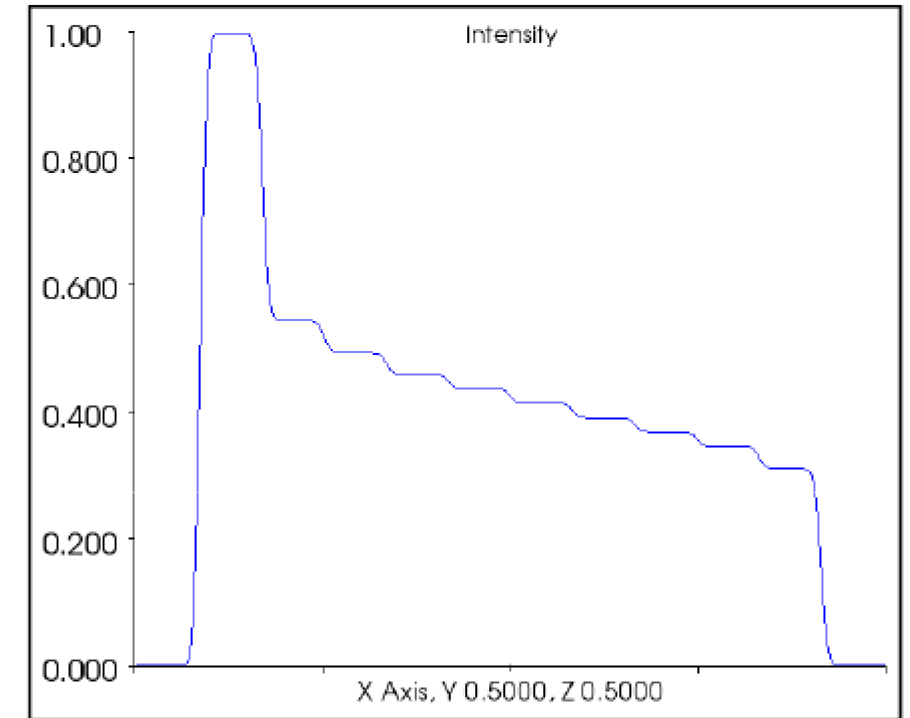




Challenges in 3D Lithography



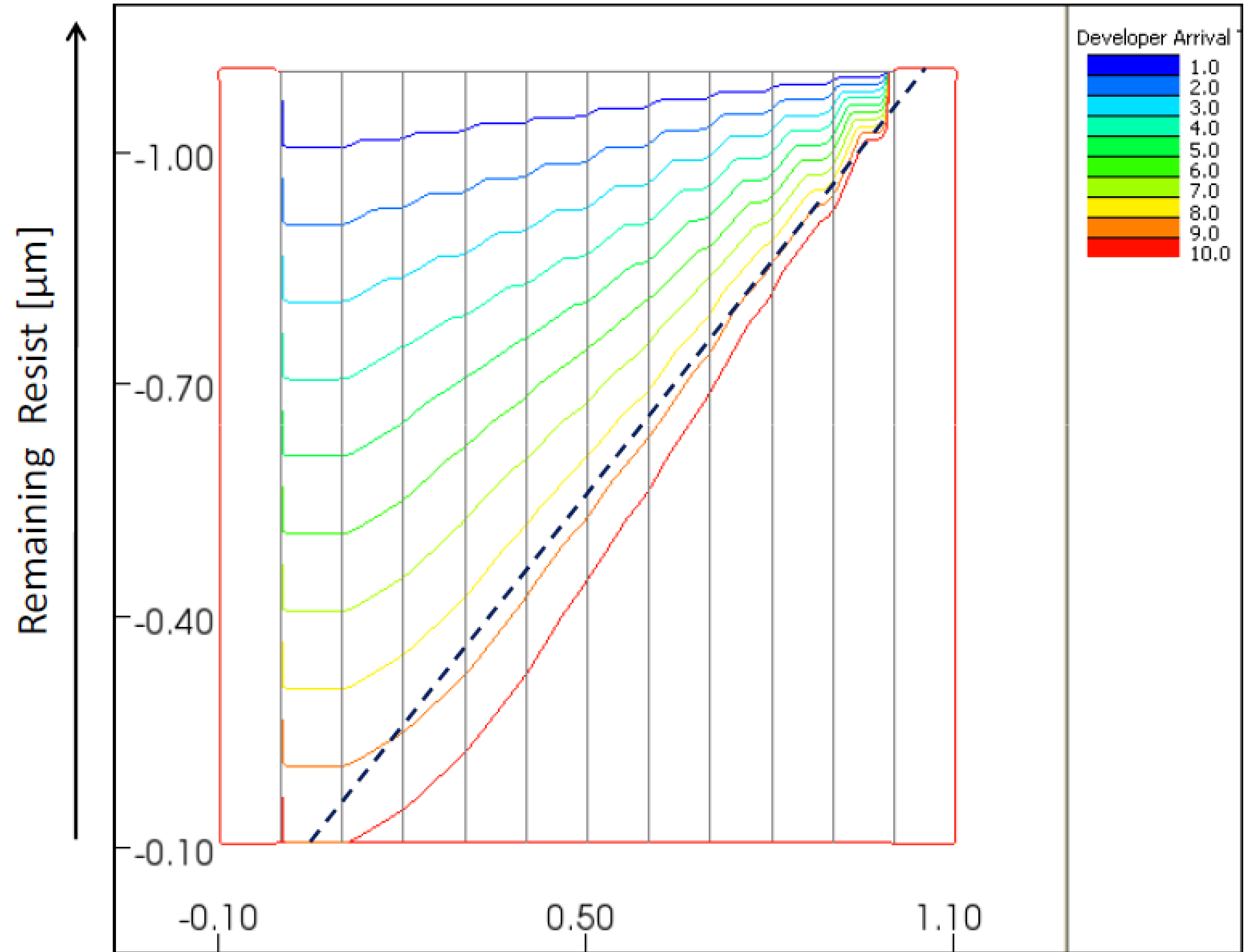




Challenges in 3D Lithography

Complex combination of:

- Exposure proximity effect
- Resist sensitivity curve
- lateral development effect



Outline

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  - Contrast Curve
  - BEAMER Shape Correction
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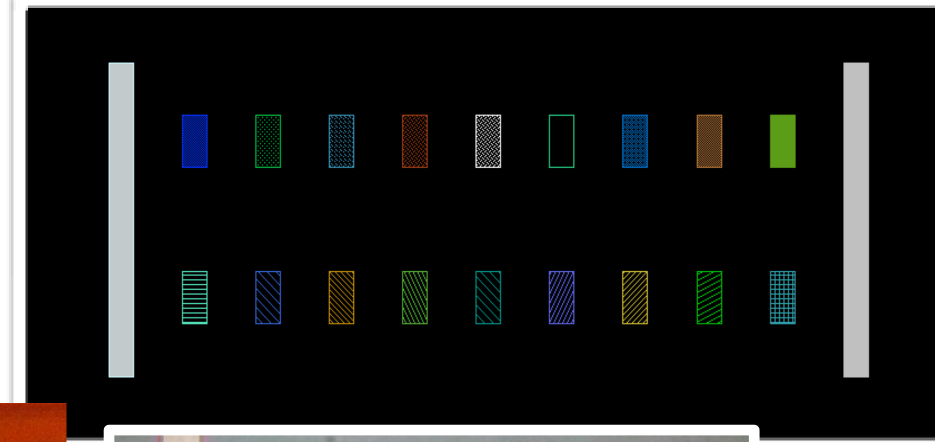
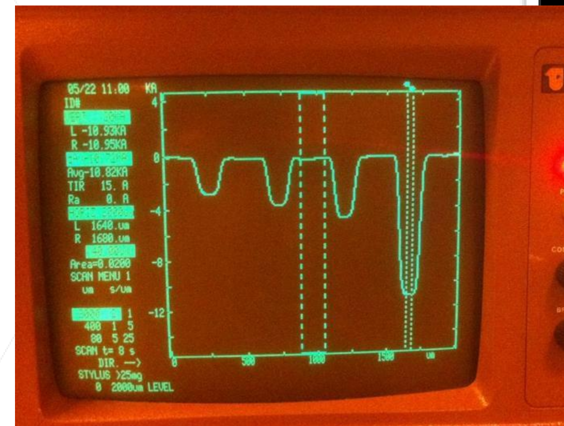
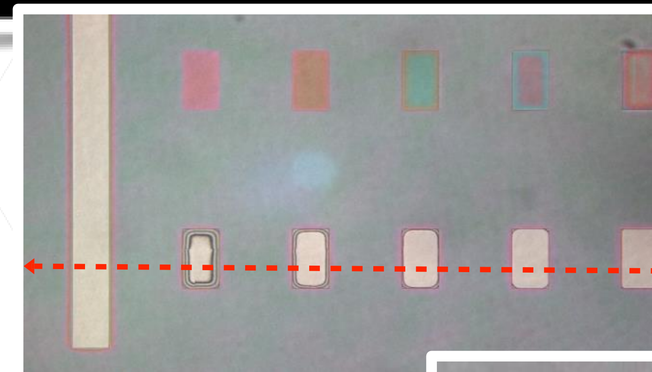
Measuring a Contrast Curve

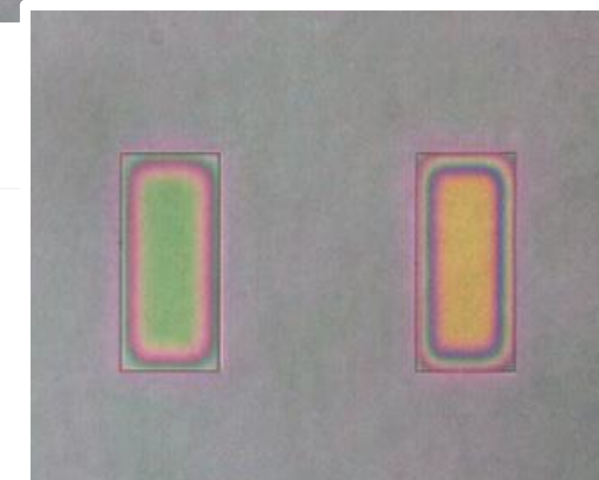
Here is what to do:

- 18 (or more) doses, each block:
  - Width > 3 × Beta (want flat region)
  - Length easy to measure with profilometer
  - Separated to not interact
  - We used 150 µm x 300 µm



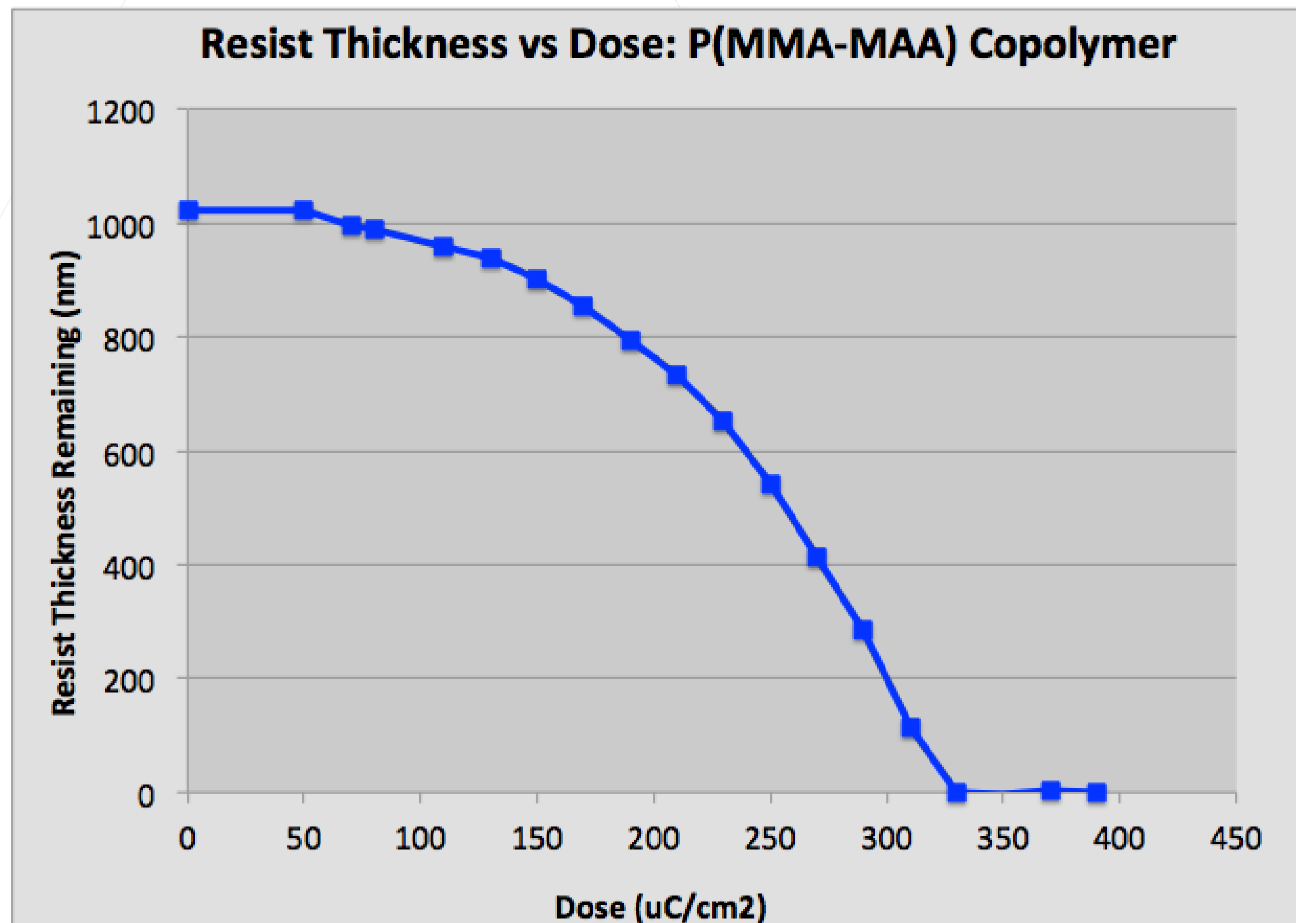






Contrast Curve for Correction

- Resist Thickness vs Dose values are inputs into BEAMER's 3D-PEC Module



Contrast Curve

Original Thickness [um] 9

Grey Value	Resist thickness [um]
0.000000	8.905130
1.000000	8.814754
2.000000	8.728659
3.000000	8.646438
4.000000	8.567715
5.000000	8.492141
6.000000	8.419395
7.000000	8.349183
8.000000	8.281231
9.000000	8.215291
10.000000	8.151136
11.000000	8.088556

Import... Export... Insert Row Delete Row

Development Rate Model

Model

Dev. Rate Mack 4

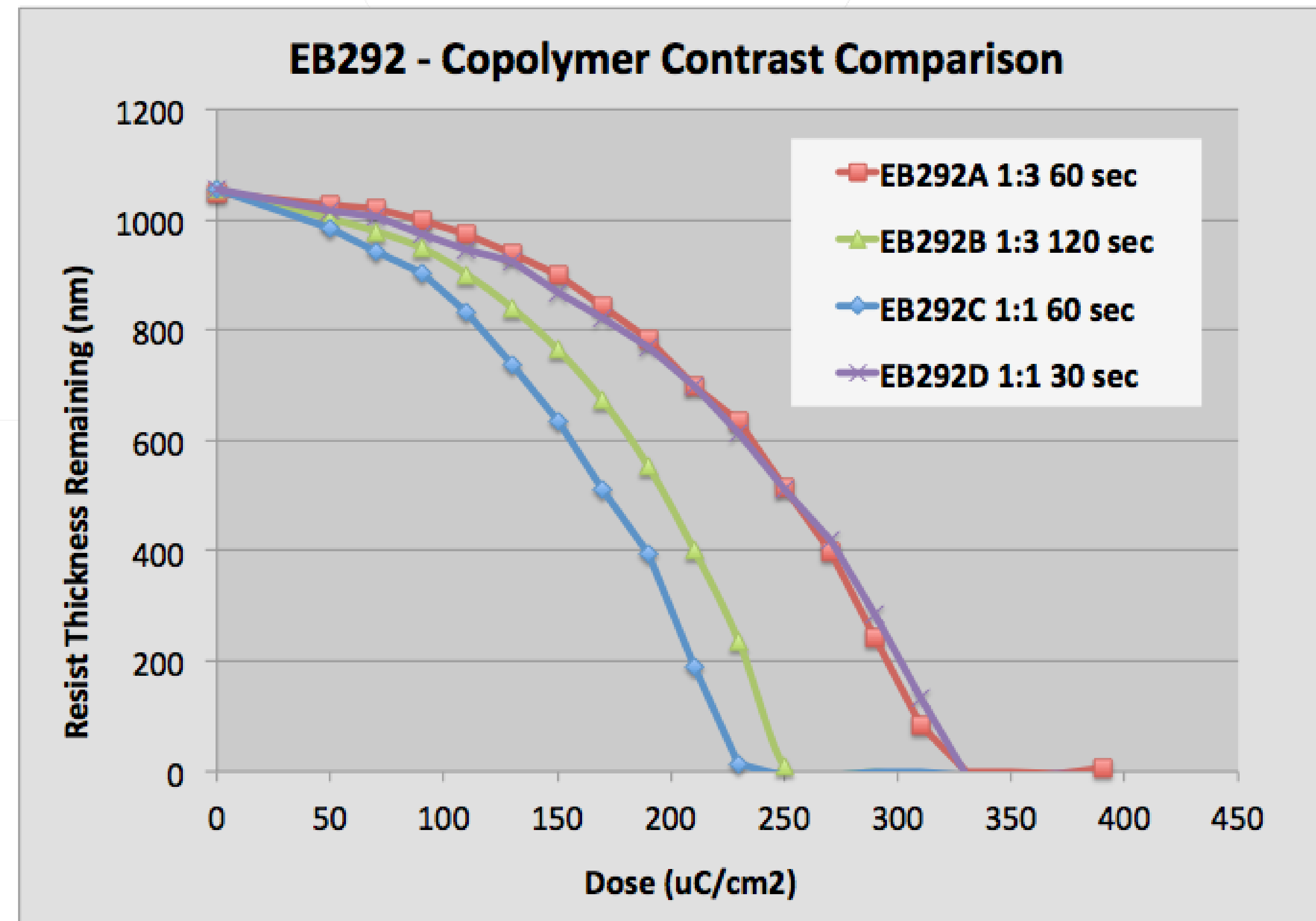
Dill C Absorption

RMS: 5.378 um

Run Fit...

Contrast Curves Examples

- Using common materials
  - P(MMA-MAA 8.5%) Copolymer, EL11
  - Bake 180C, 3 minutes
  - ~ 1000 nm thickness
  - Development 1:3 MIBK:IPA 60 s + IPA rinse for 15 s
- Want <u>lower</u> contrast
- The lowest dose is limited by hardware, so you don't want too much sensitivity or you won't achieve shallow depths!



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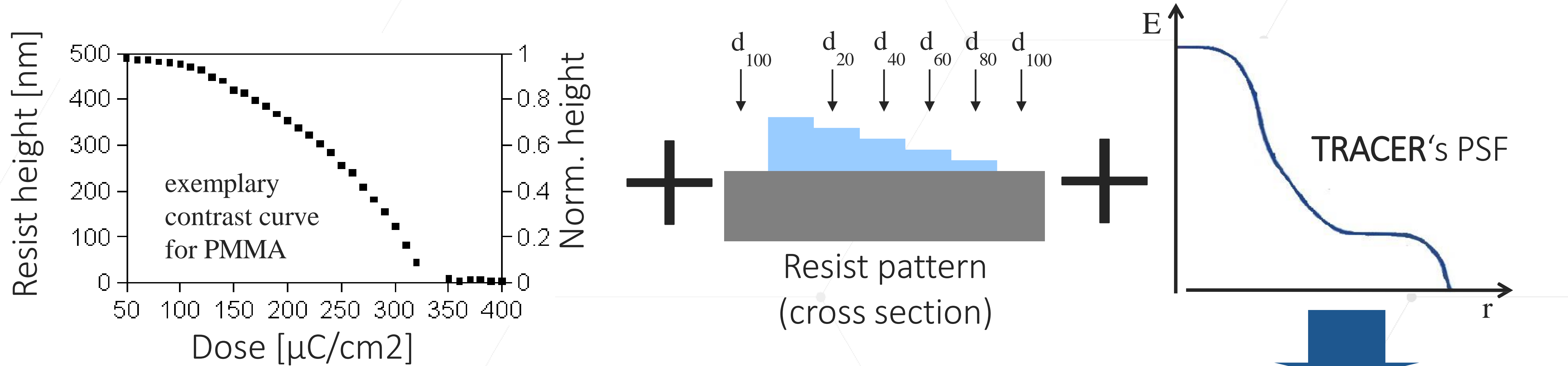
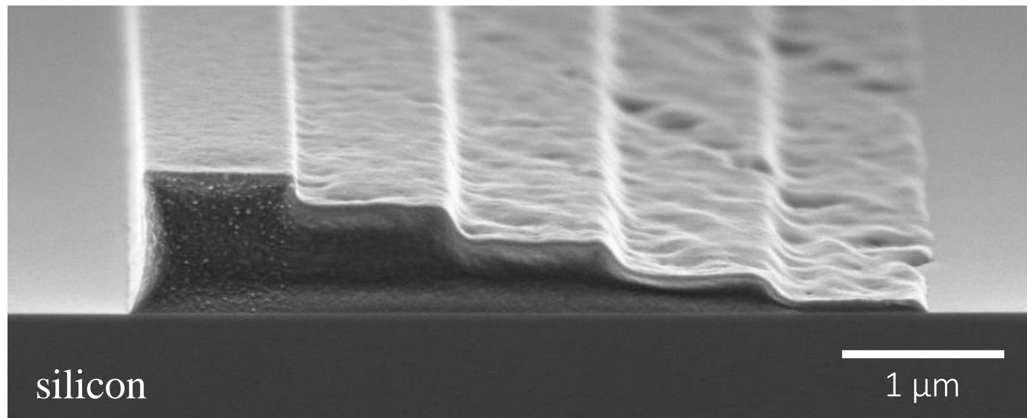
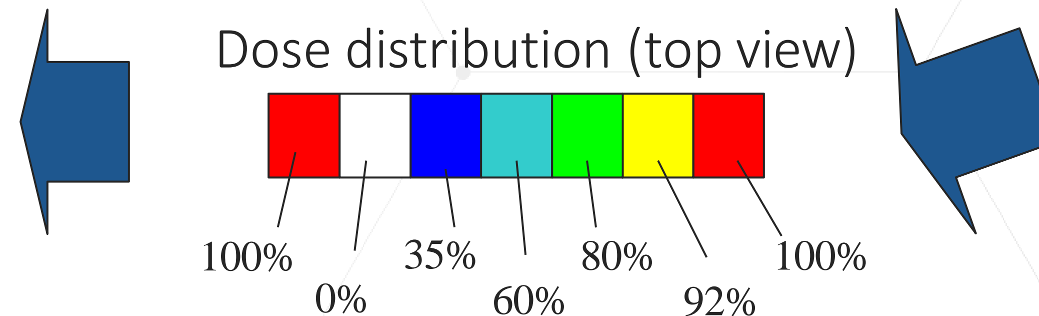
3D Surface PEC

Process chain for multilevel resist pattern (greyscale electron-beam lithography)





1050 nm high PMMA resist after development



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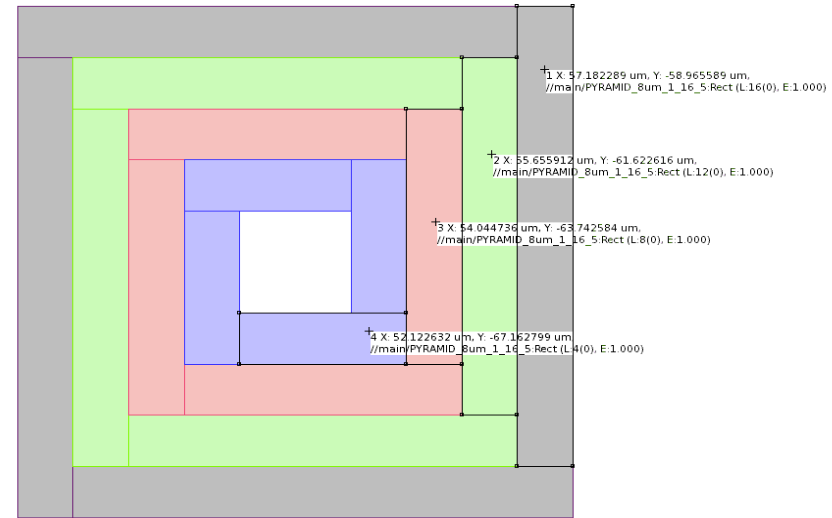
E-Beam Example

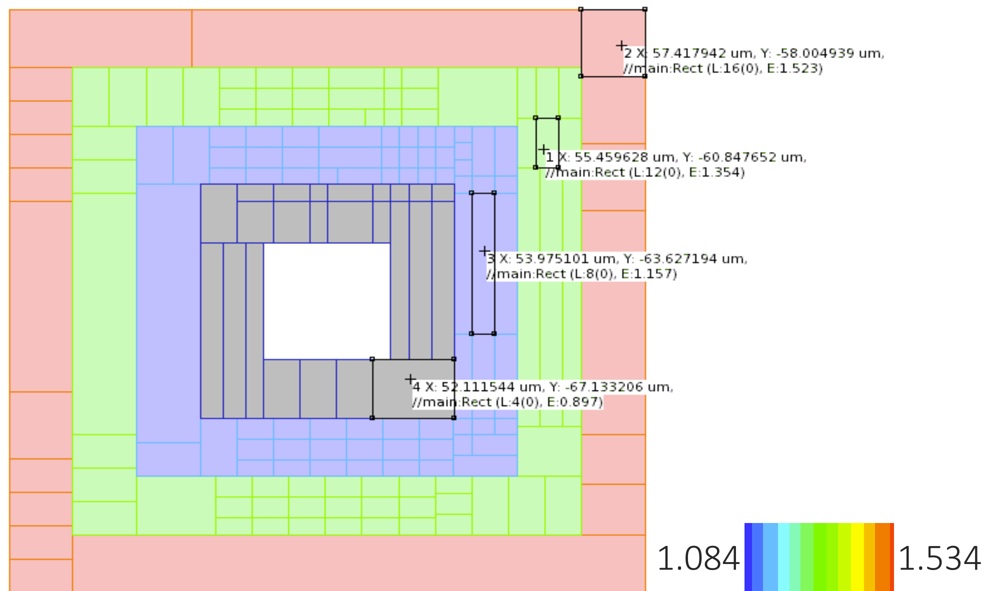
Cross-section Desired

CAD Drawing (Colors are layers)

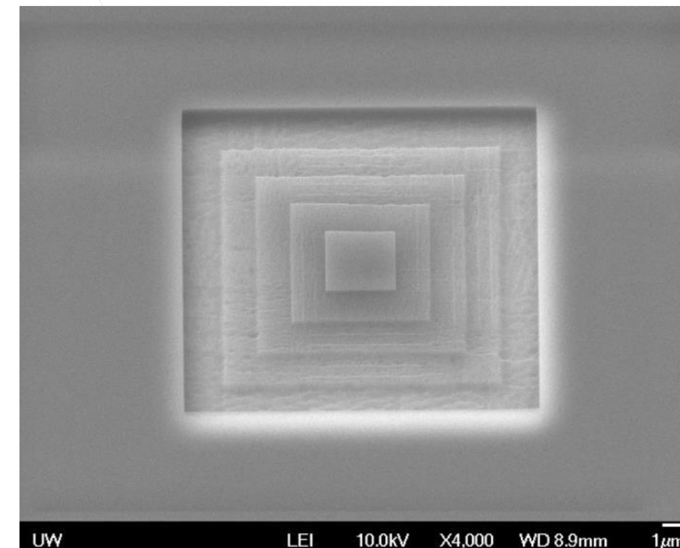


1 um

3D PEC Computes Exposure Doses



Expose and Develop



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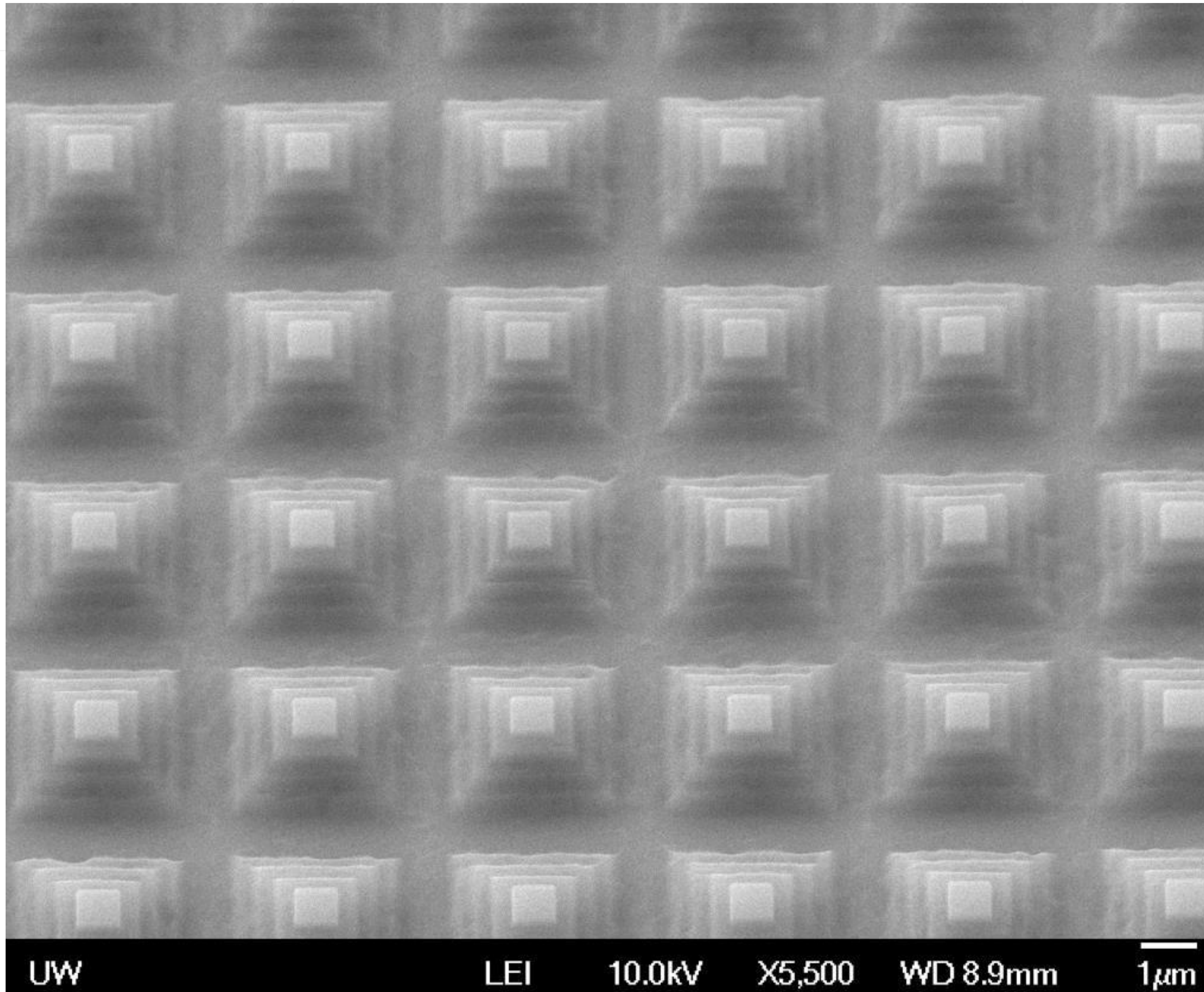
E-Beam Example



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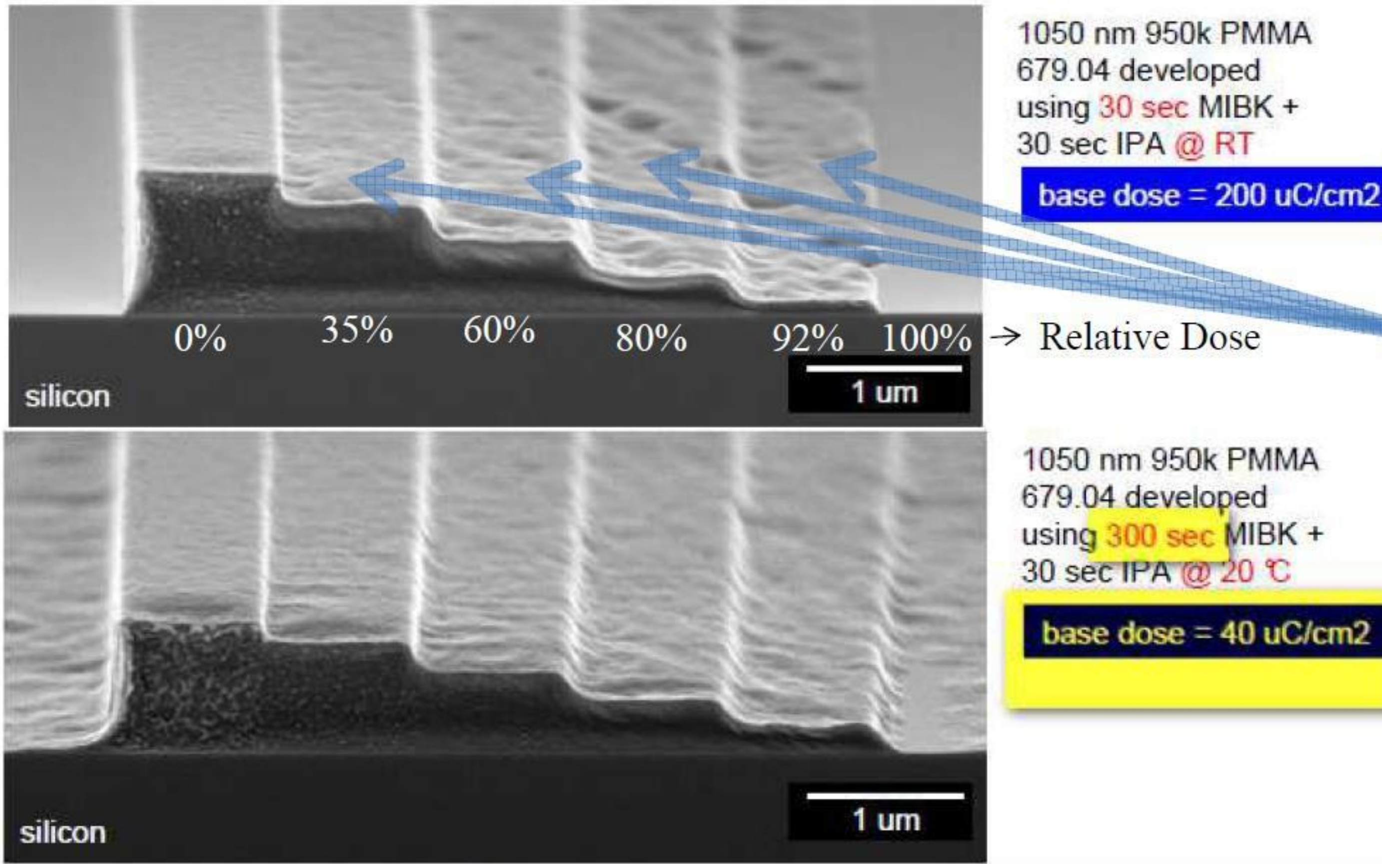
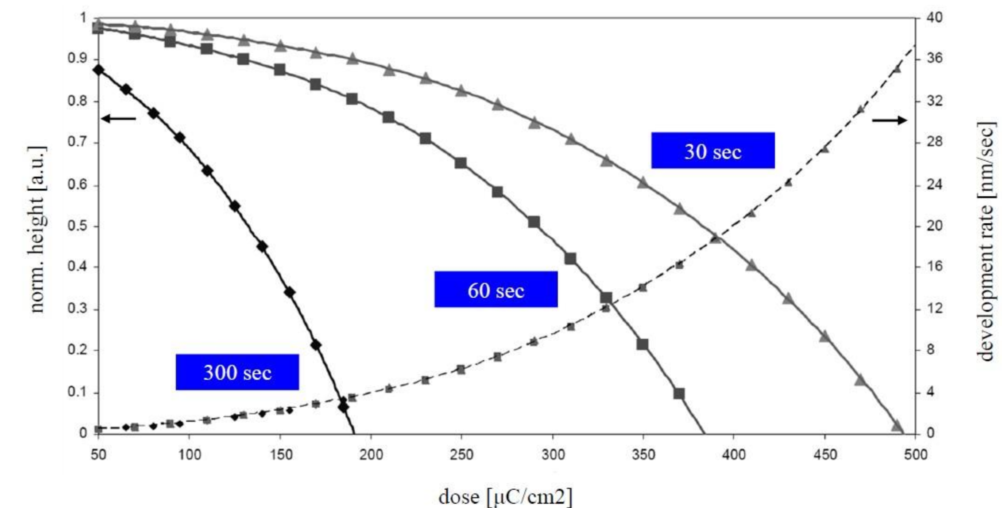
Mitigation of surface roughness

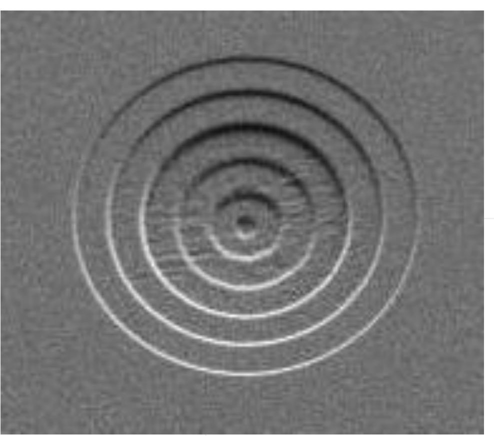
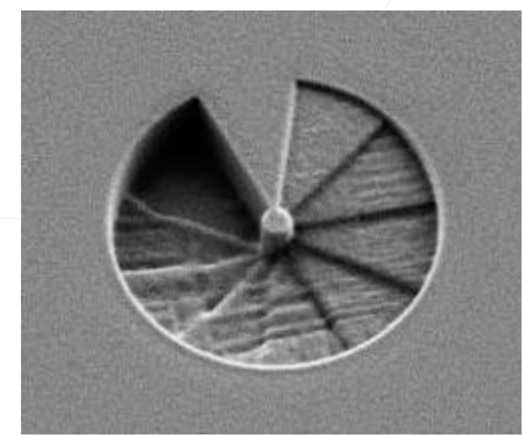
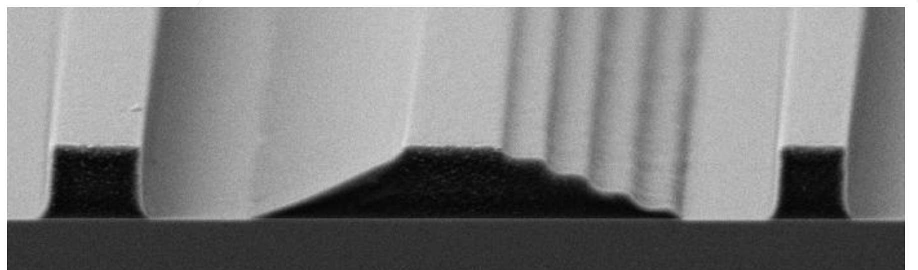
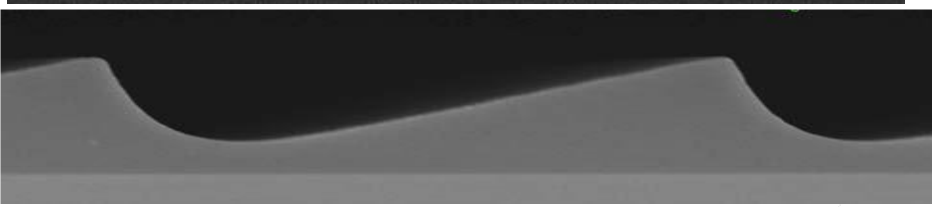
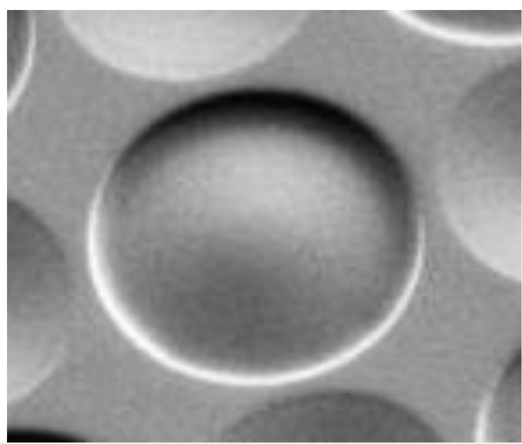
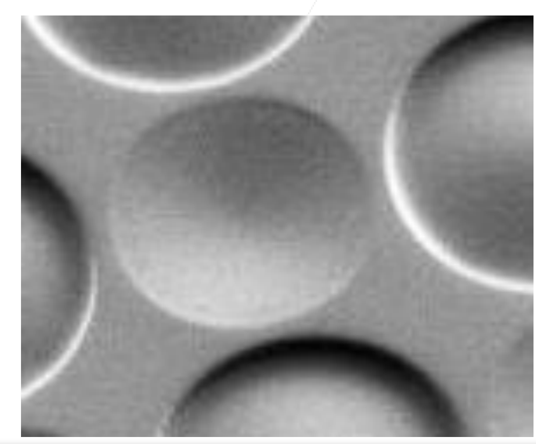


Surface roughness increasing with higher exposure dose



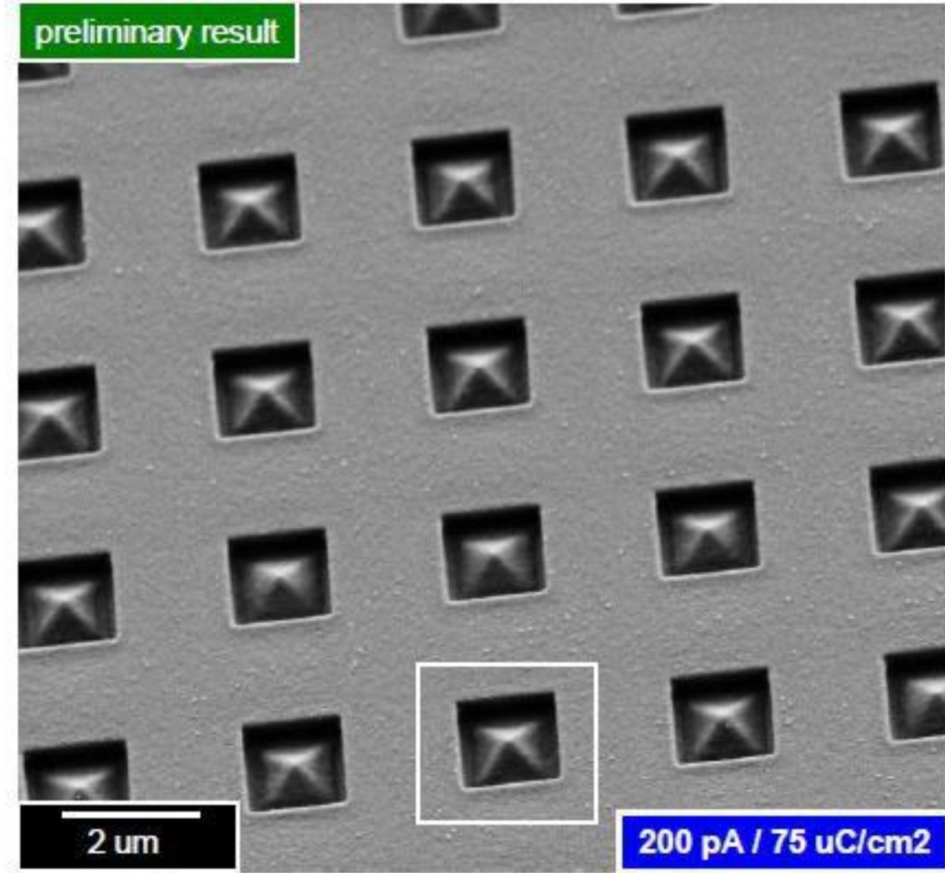
- Longer development times result in lower base doses, leading to reduced roughness
- Multipass (for high doses) helps for reducing roughness

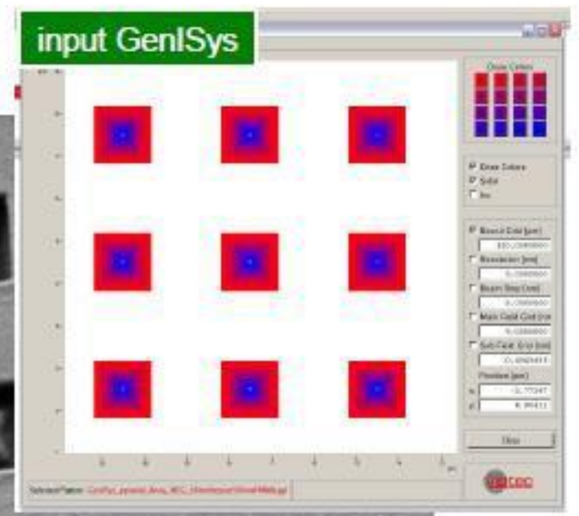
Electron Beam 3D lithography

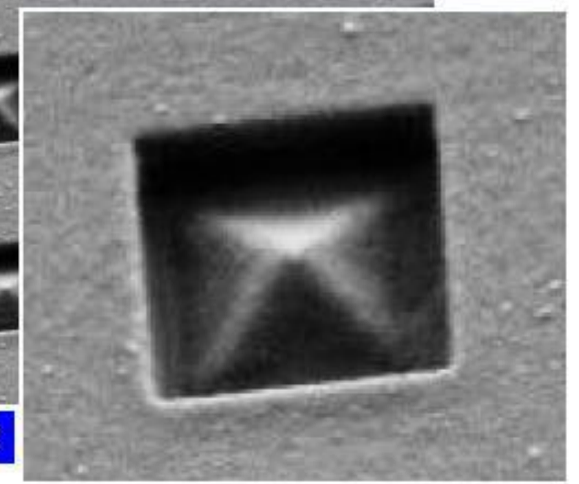







3-D e-beam lithography

520 nm 950k PMMA / Standard development at PSI







Arbitrary 3D Image

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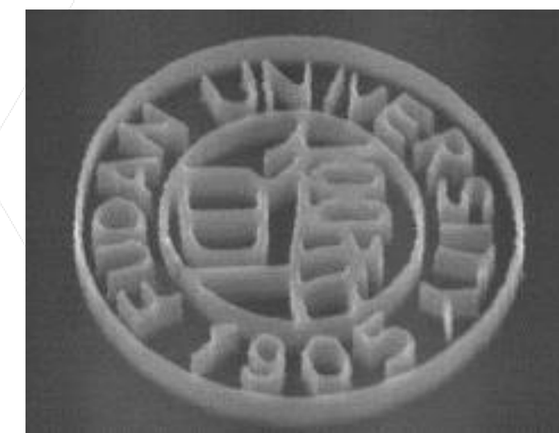

Arbitrary 3D Image

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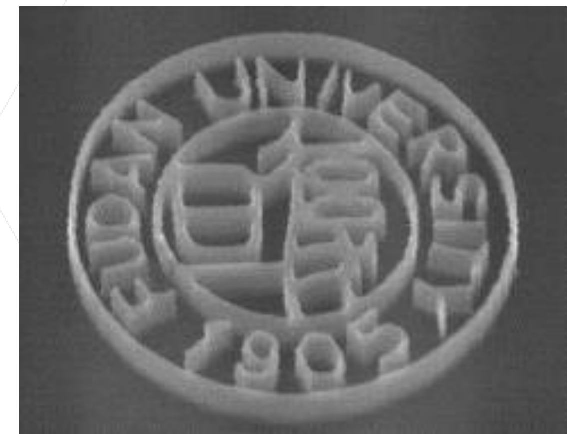

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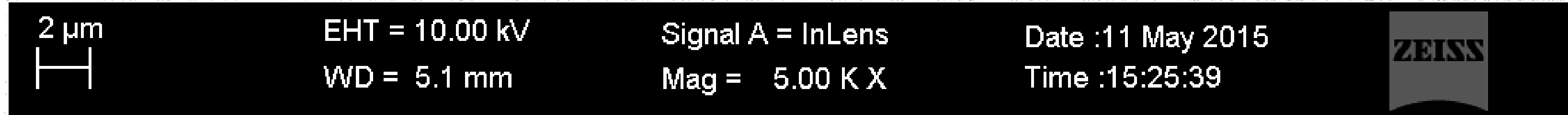
Arbitrary 3D Image



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Summary

- The 3D PEC module in **BEAMER** enables to control the resist thickness
- Contrast curve maps resist thickness to energy, and the PSF corrects the proximity effect
- The resist development process plays a key role for thickness control and smooth surface
- Longer development times, low doses and multippass on high doses reduces suface roughness
- Temperature treatment after development smoothens the surface

Related Literature

2012

- A. Schleunitz, V. Guzenko, C. Spreu, M. Vogler, H. Atasoy, G. Gruetzner, and H. Schift, **Enhancing 3-D structural variety by combination of electron-beam and nanoimprint lithography with thermal reflow**, 56th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication (EIPBN 2012), Waikoloa, USA, May 29 - June 1, 2012 (Invited Poster Presentation)
- A. Schleunitz, V.A. Guzenko, C. Spreu, M. Messerschmidt, H. Atasoy, M. Vogler, and H. Schift, **3-D microfabrication based on a glass transition temperature selective thermal reflow - towards optical applications**, 56th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication (EIPBN 2012), Waikoloa, USA, May 29 - June 1, 2012

2011

- V.A. Guzenko, N. Belic, N. Unal, A. Schleunitz, and C. David, **Modeling and correction of lateral resist development effects in 3-D e-beam lithography**, 24th International Microprocesses and Nanotechnology Conference (MNC 2011), Kyoto, Japan, October 24-27, 2011, 27P-11-66
- V.A. Guzenko, N. Belic, N. Unal, A. Schleunitz, and C. David, **Modeling and correction of lateral resist development effects in 3-D e-beam lithography**, 24th International Microprocesses and Nanotechnology Conference (MNC 2011), Kyoto, Japan, October 24-27, 2011, 27P-11-66
- A. Schleunitz, V.A. Guzenko, A. Schander, M. Vogler, and H. Schift, *Selective profile transformation of electron-beam exposed multilevel resist structures based on a molecular weight dependent thermal reflow*, J. Vac. Sci. Technol. B **29**(6) (2011) 06F302; DOI:10.1016/j.mee.2010.12.046 (*4 pp*).
- A. Schleunitz, V. Guzenko, C. Spreu, M. Vogler, H. Atasoy, G. Gruetzner, and H. Schift, **Enhancing 3-D structural variety by combination of electron-beam and nanoimprint lithography with thermal reflow**, 37th International Conference on Micro- and Nano-Engineering (MNE 2011), Berlin, Germany, September 19-23, 2011, P-LITH-071 (Best Poster Award Winner in category Lithography and Systems)

2010

- A. Schleunitz and H. Schift, *Fabrication of 3-D nanoimprint stamps with continuous reliefs using dose-modulated electron beam lithography and thermal reflow*, J. Micromech. Microeng. **20** (2010) 095002; DOI:10.1088/0960-1317/20/9/095002.
- N. Unal, D. Malahu, O. Raslin, D. Ritter, C. Sambale and U. Hofmann, *Third Dimension of Proximity Effect Correction (PEC), J. Microelectronic Engineering Volume 87, Issue 5-8, May 2010, pages 940-942*

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Thank You!

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