GenISys
Advancing the Standard

3D E-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

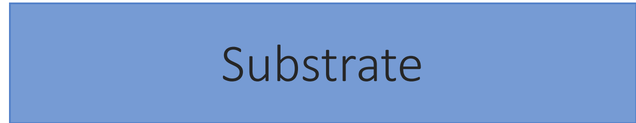
- **BEAMER** offers a model-based 3D PEC that combines correction for electron scattering proximity and resist development process effects

Outline

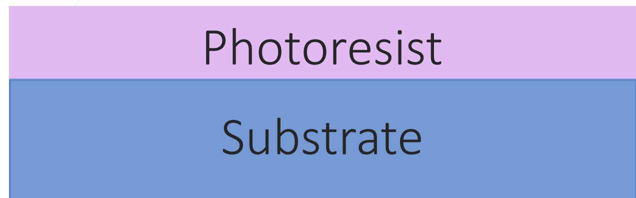
- 2D lithography vs 3D lithography
- 3D e-beam lithography correction
  - Contrast Curve
  - BEAMER Shape Correction
  - Surface roughness
- Summary

General steps in lithography

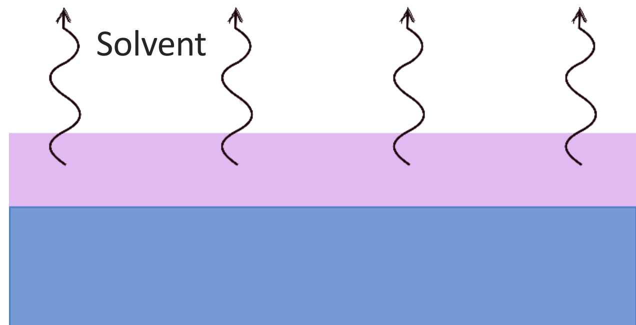
- Preprocessing



Cleaning, Baking, Adhesion Promoter



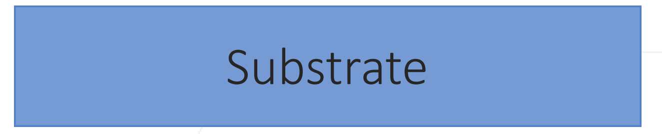
Spin coating



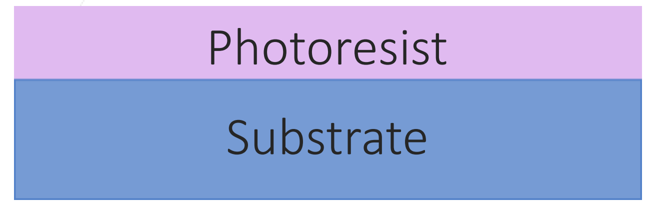
Softbake

2D Exposure

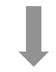
- Preprocessing

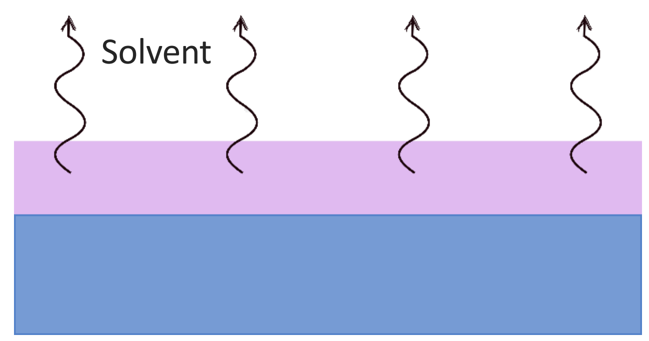


Cleaning, Baking, Adhesion Promoter



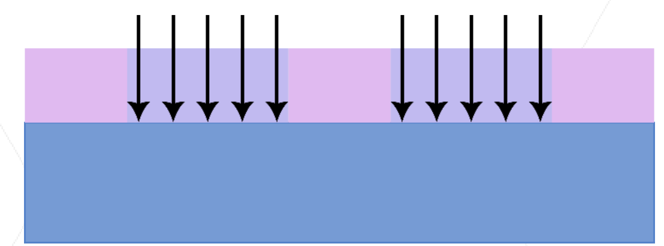
Spin coating



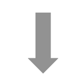


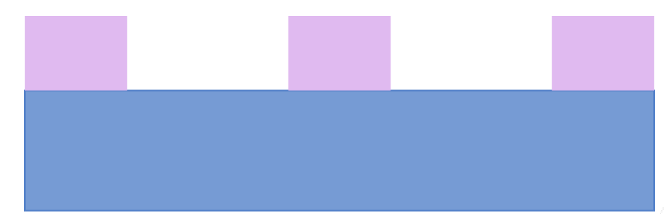
Softbake

2D Litho



Exposure

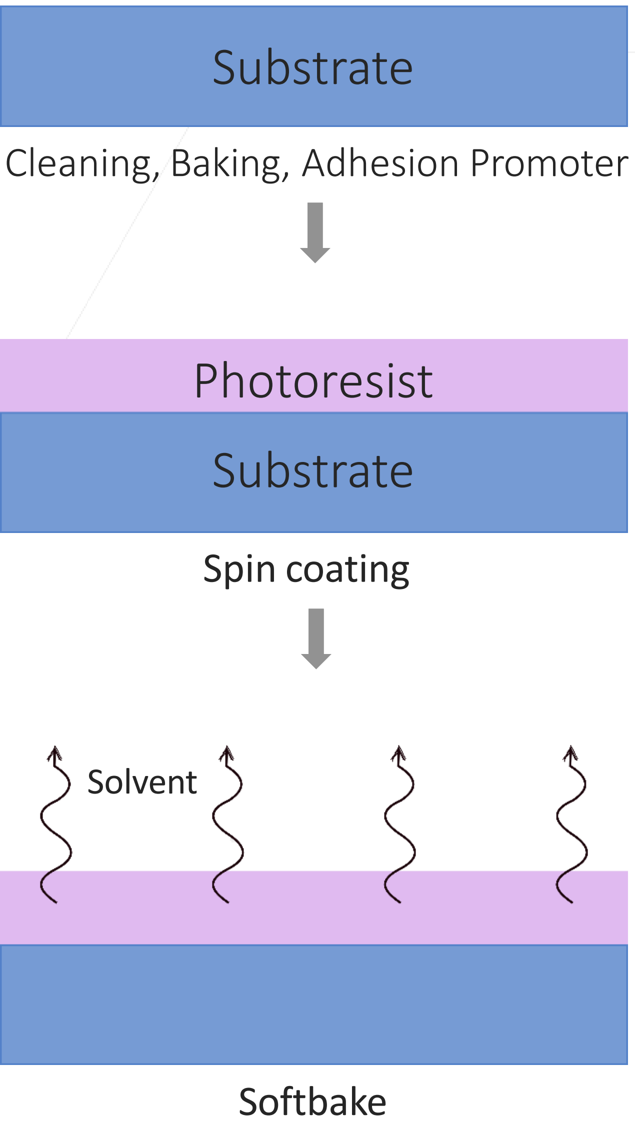




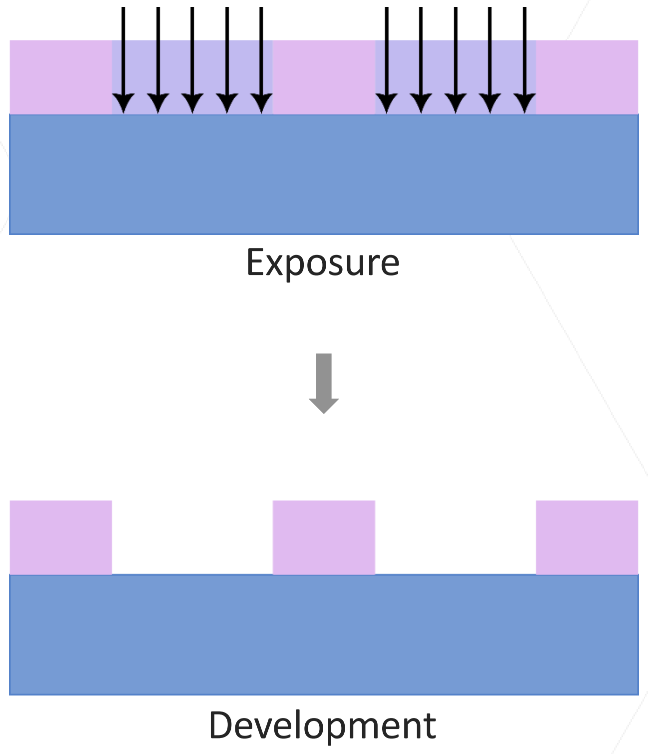
Development

2D vs 3D Exposures

- Preprocessing

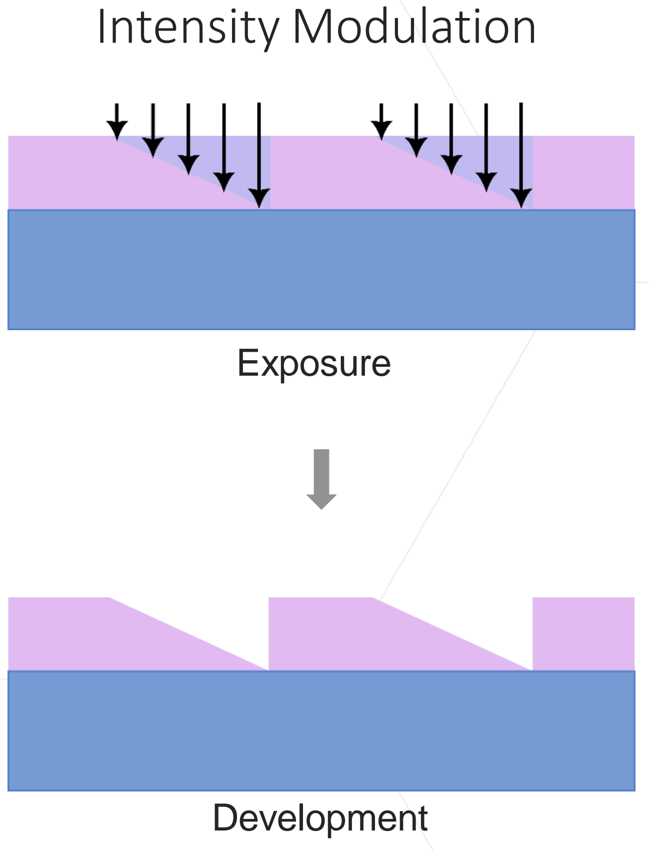


2D Litho



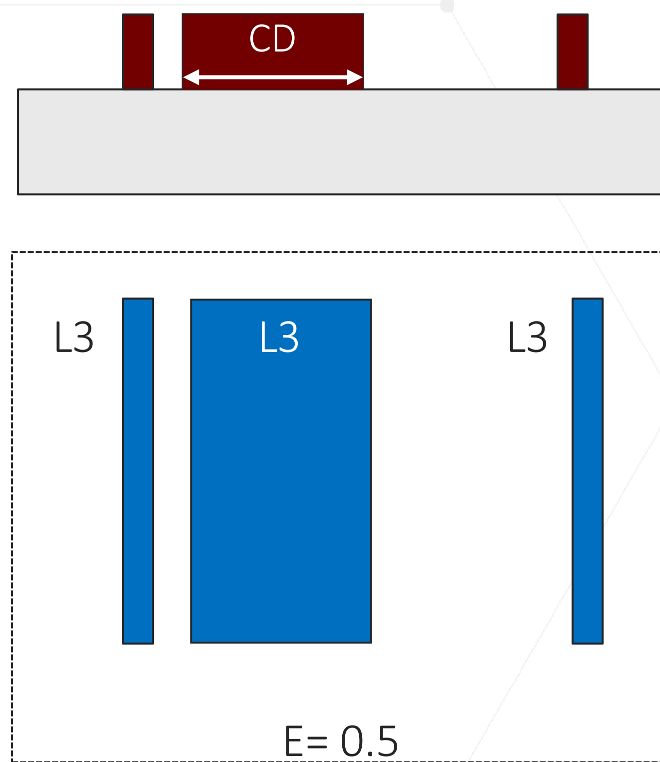
3D Litho

Intensity Modulation



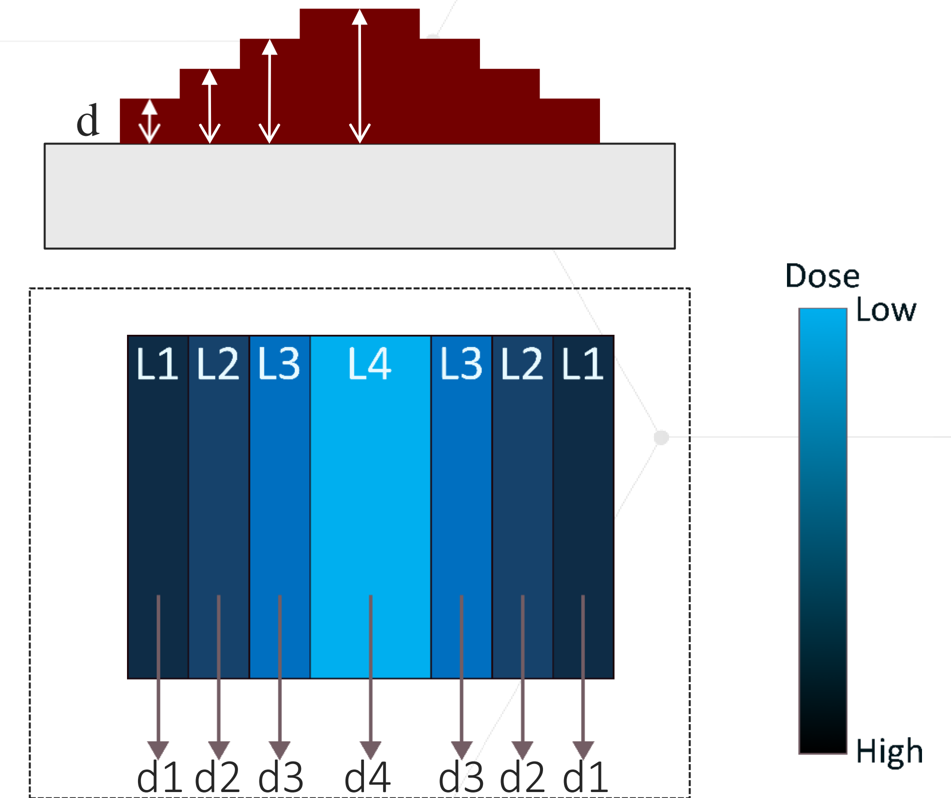
2D vs 3D Correction

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

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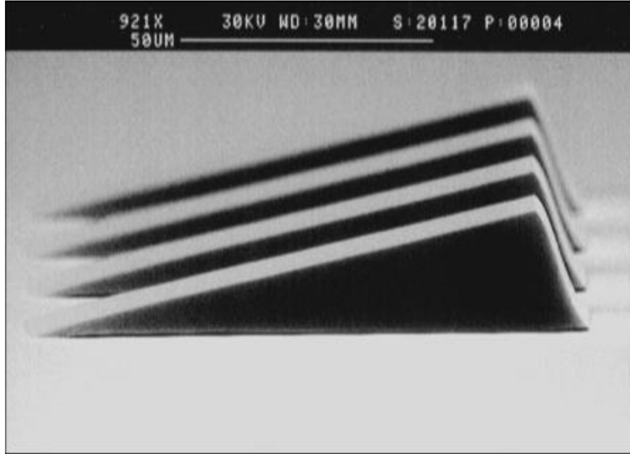
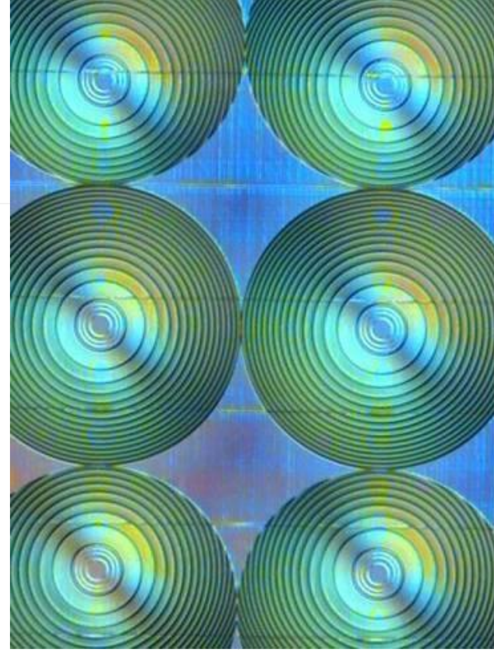
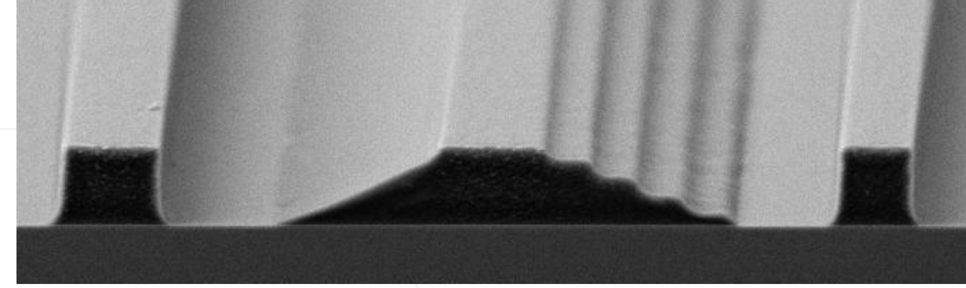
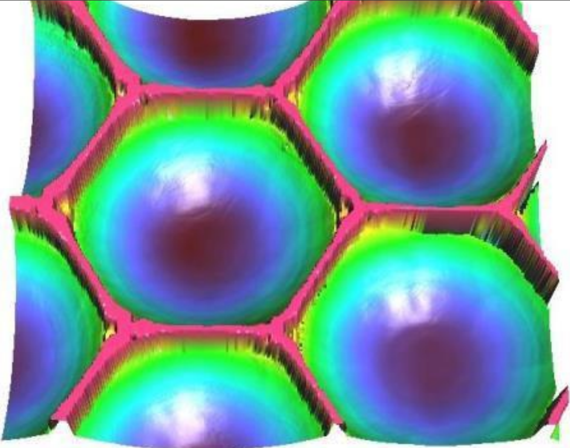
3D Lithography Examples

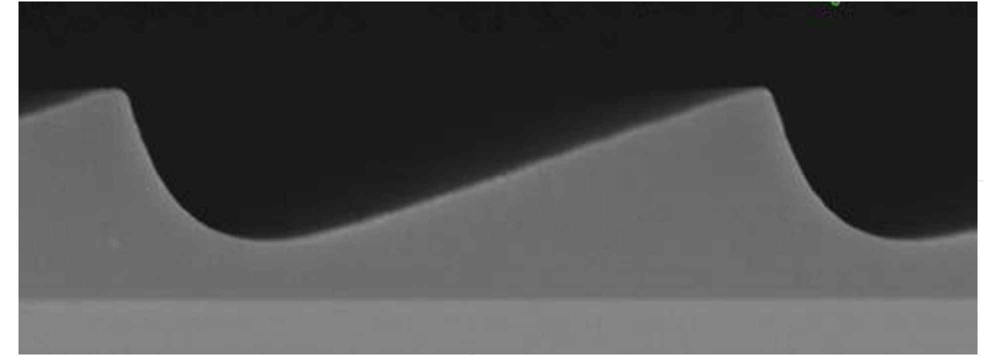


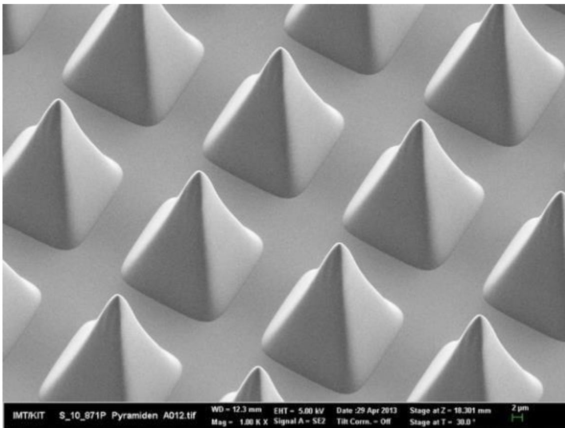


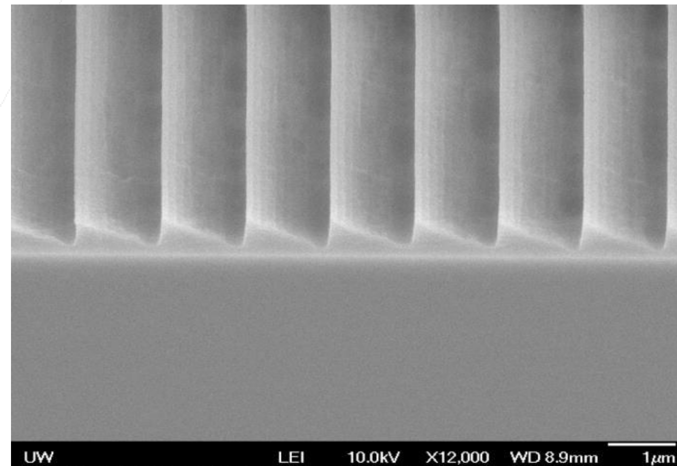
- Micro Lenses
- Lens Arrays
- Blazed Gratings
- Holograms
- Integrated Optics
- Prisms
- MEMS

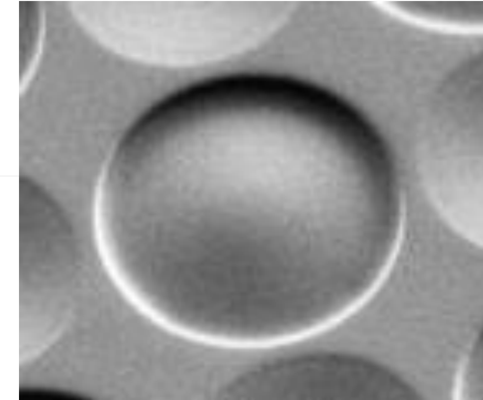


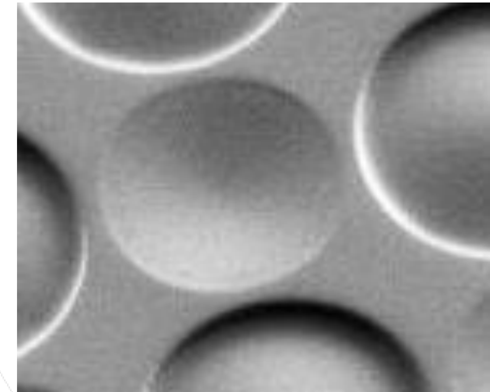




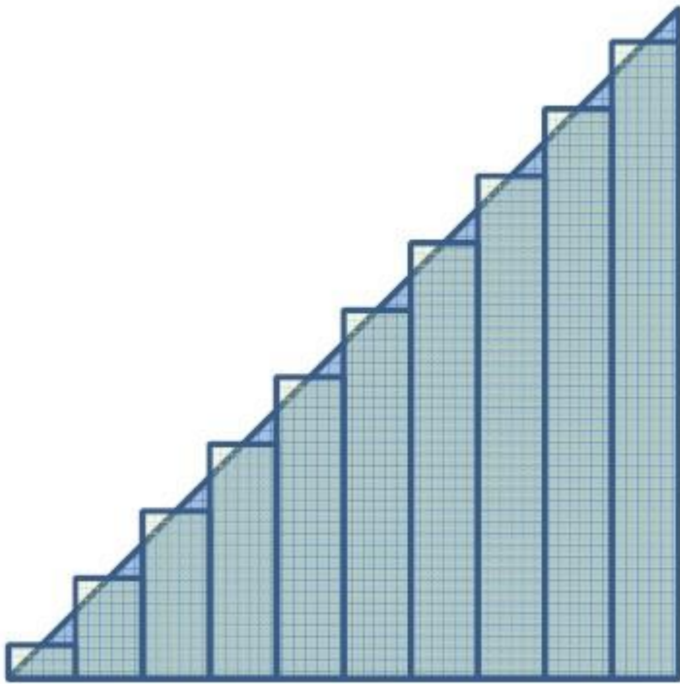


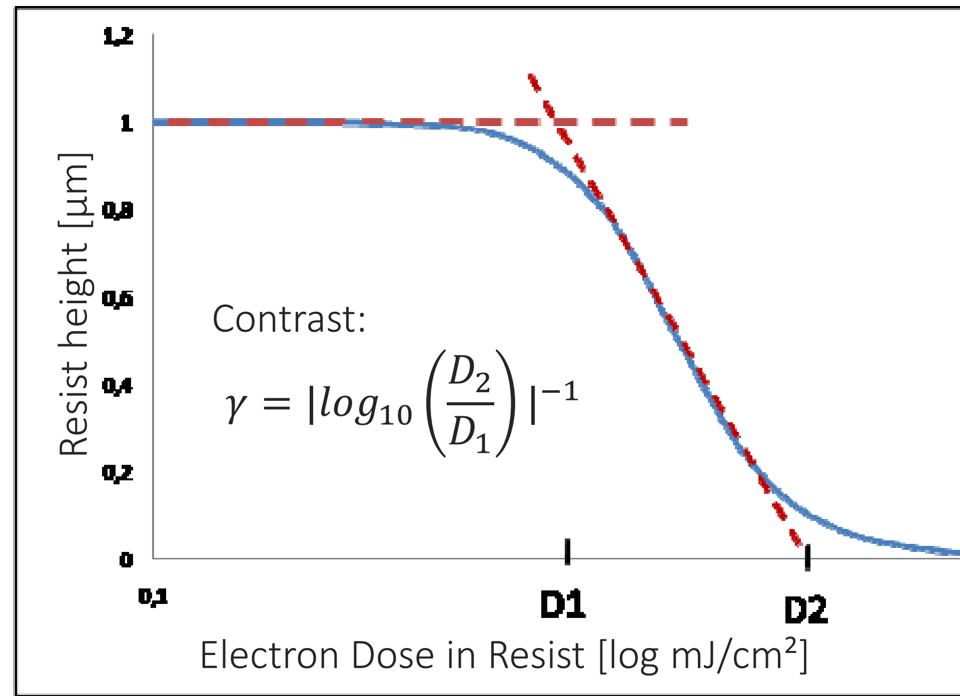


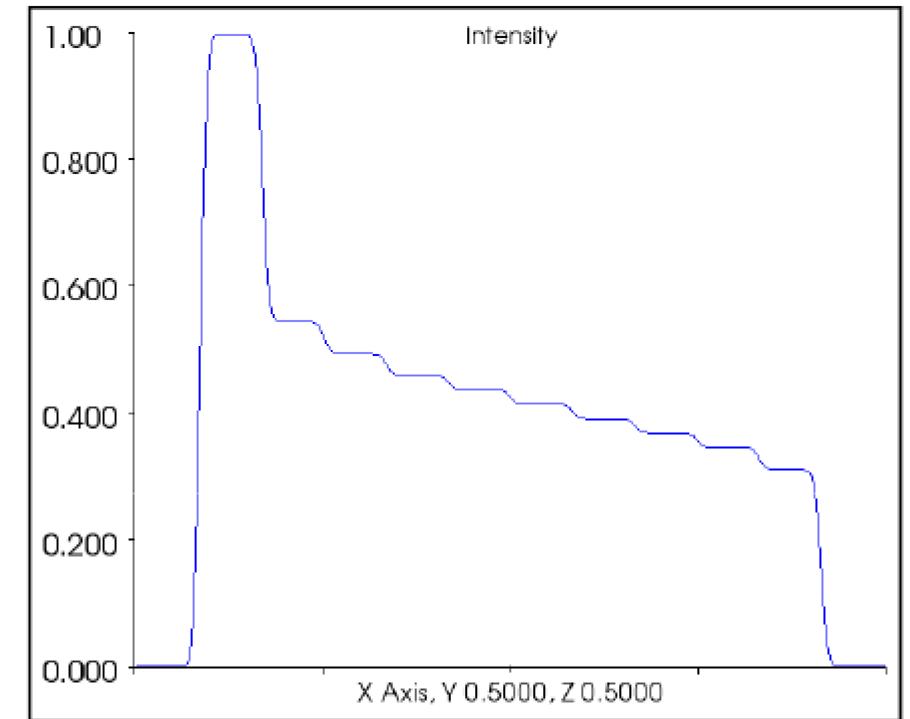




Challenges in 3D Lithography



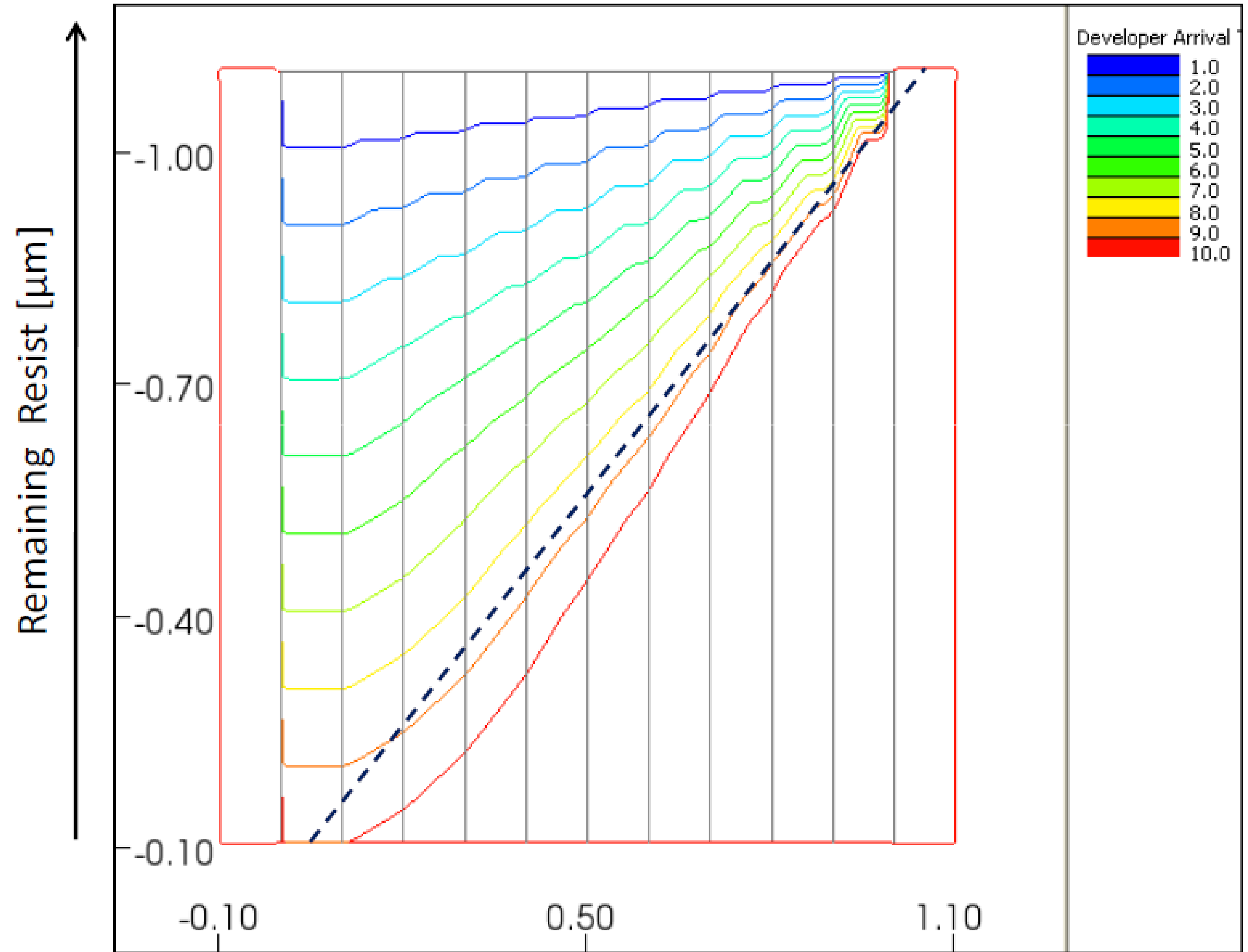




Challenges in 3D Lithography

Complex combination of:

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



Outline

- 2D lithography vs 3D lithography
- 3D e-beam lithography correction
  - Contrast Curve
  - BEAMER Shape Correction
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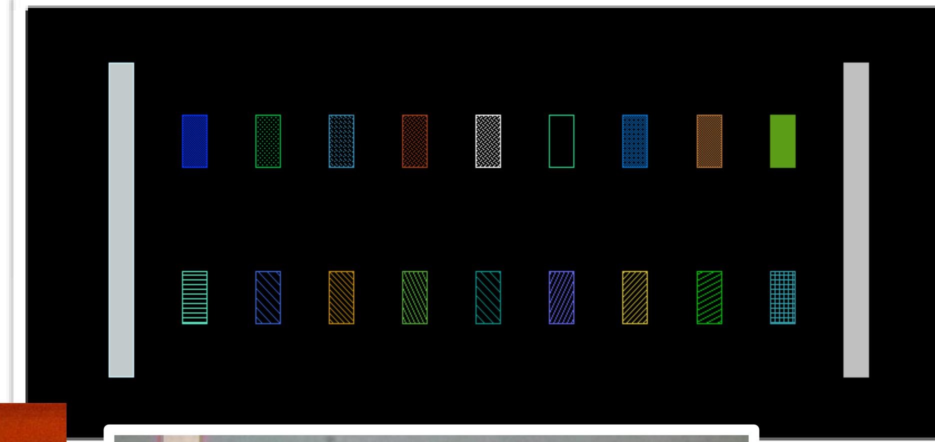
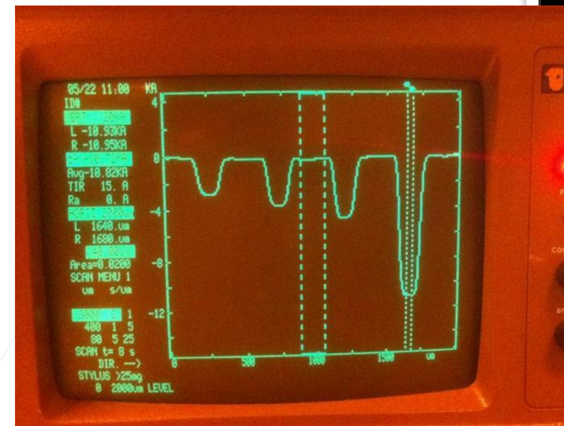
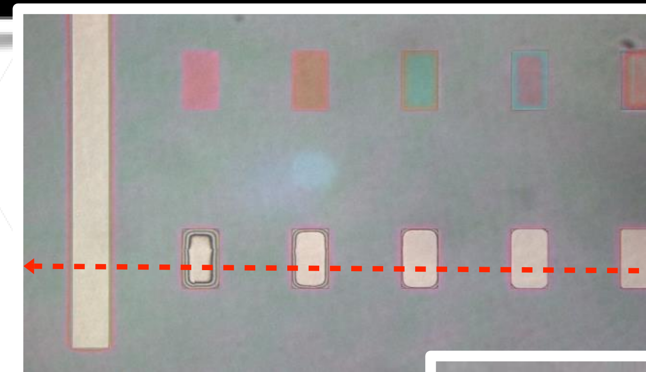
Measuring a Contrast Curve

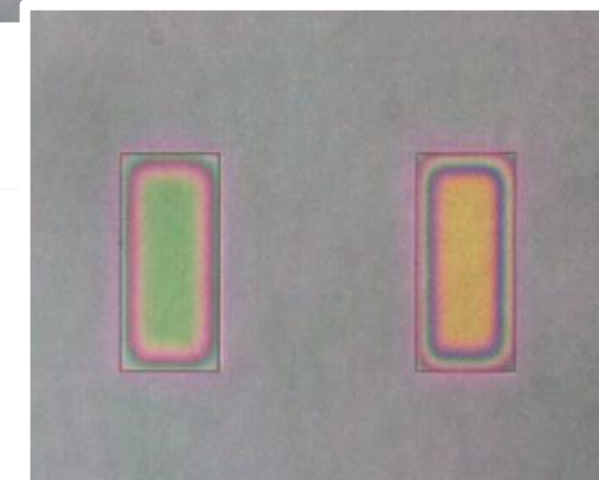
Here is what to do:

- 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



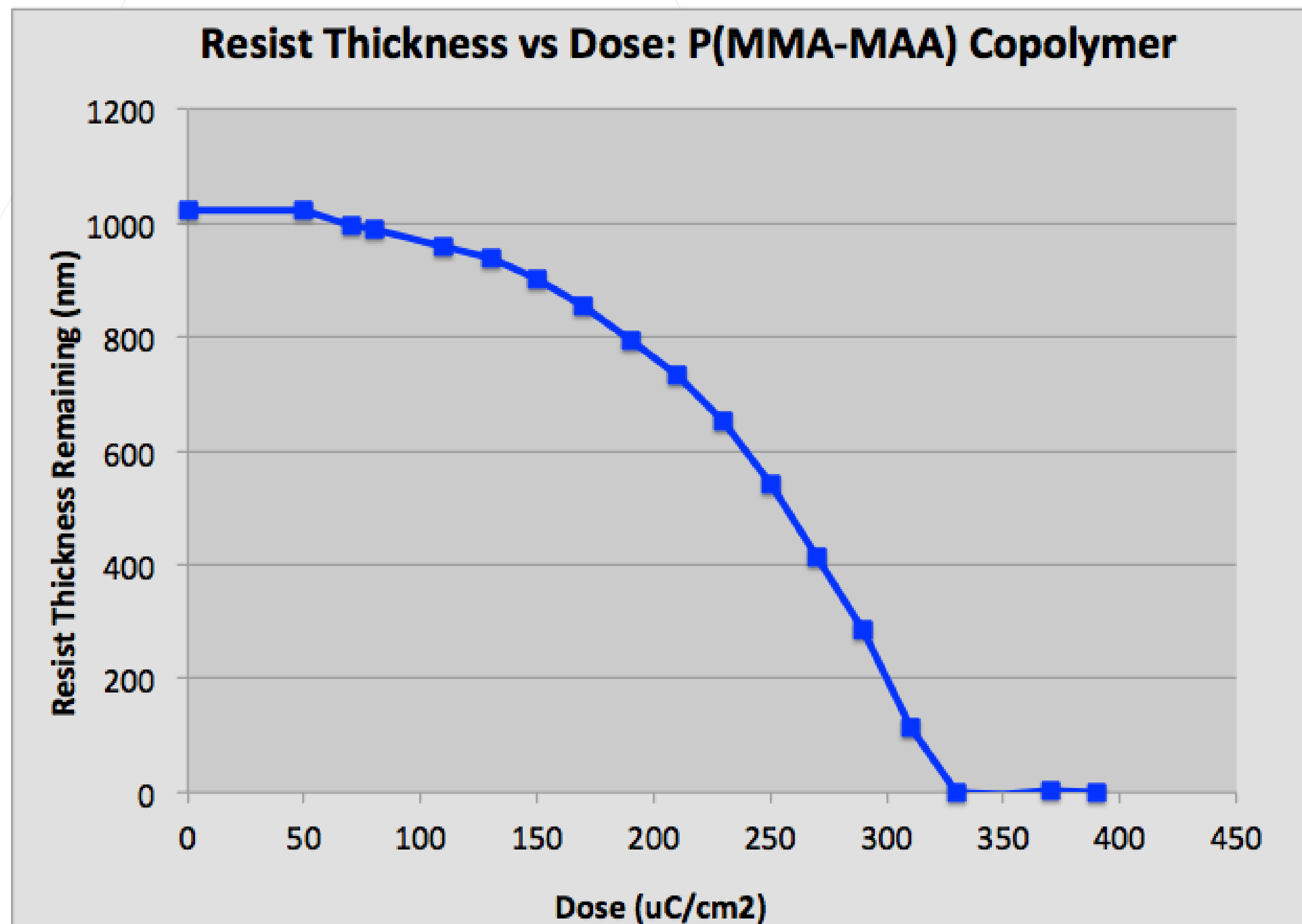


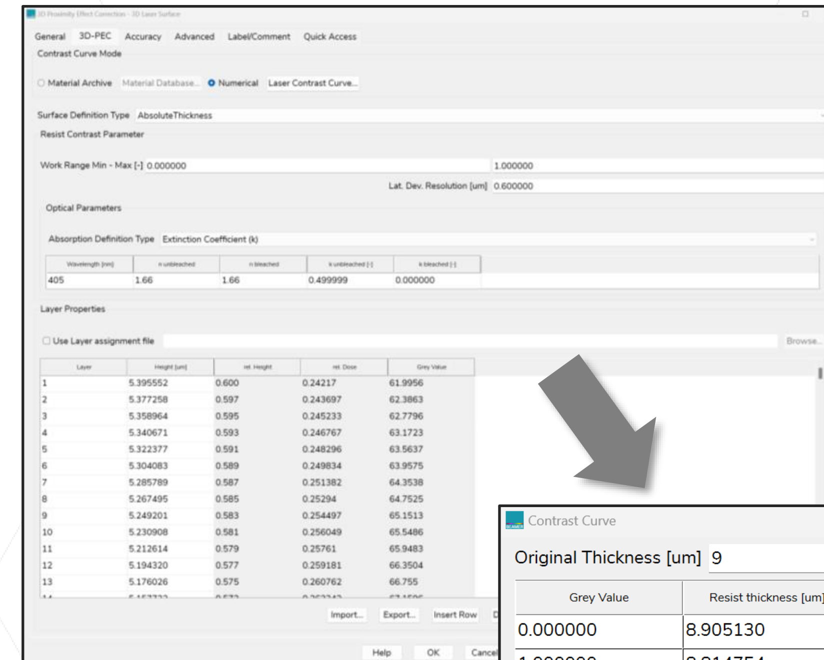


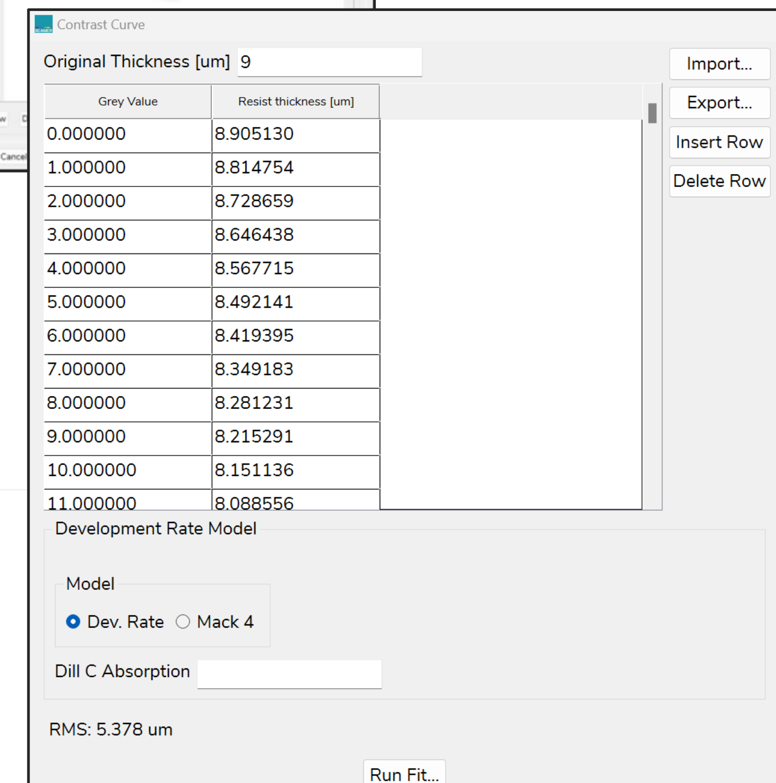


Contrast Curve for Correction

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

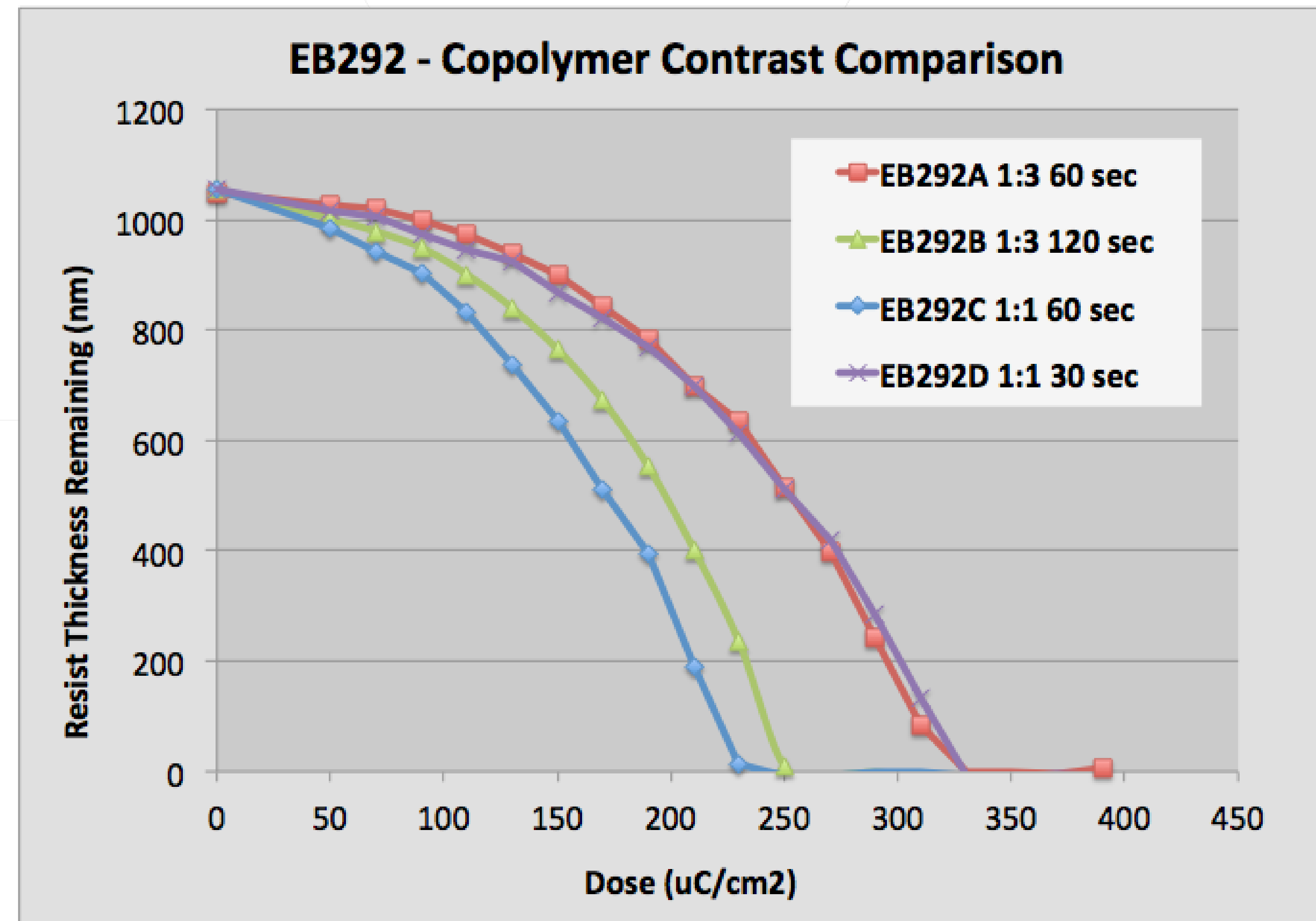






Contrast Curves Examples

- 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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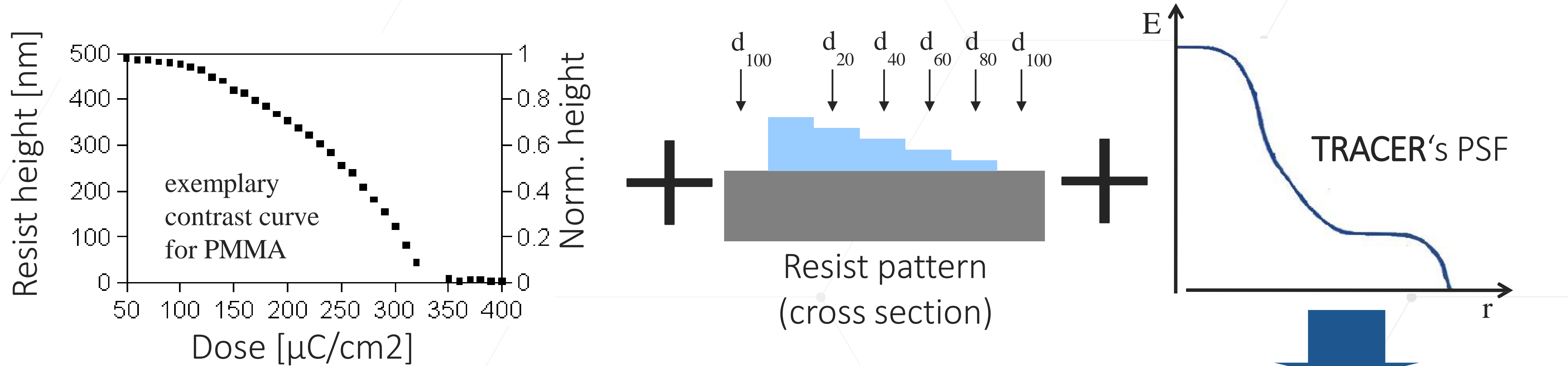
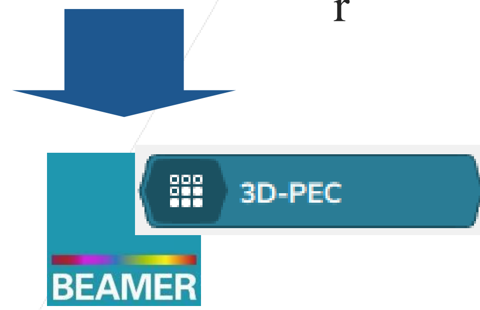
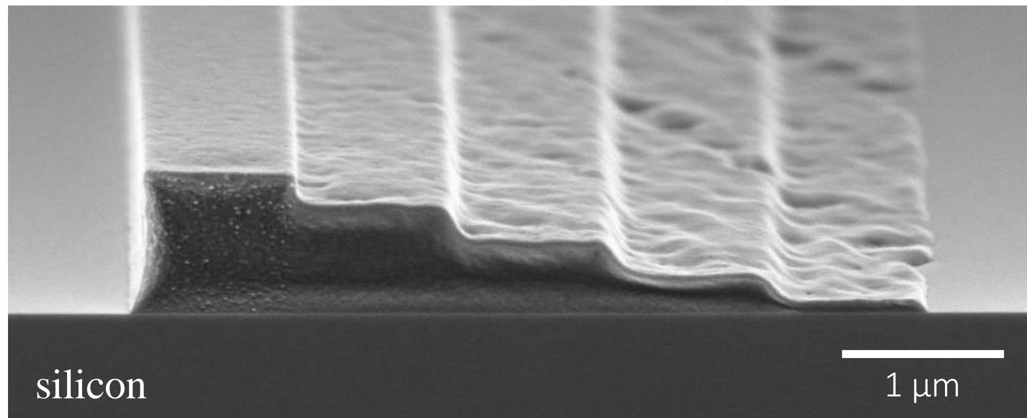
3D Surface PEC

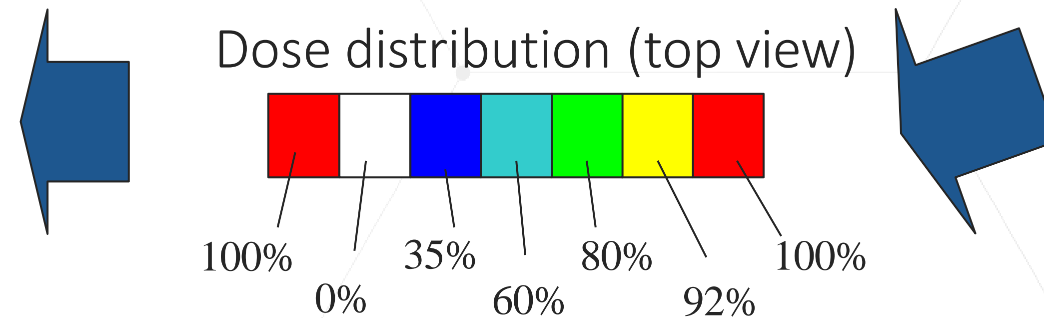
Process chain for multilevel resist pattern (greyscale electron-beam lithography)







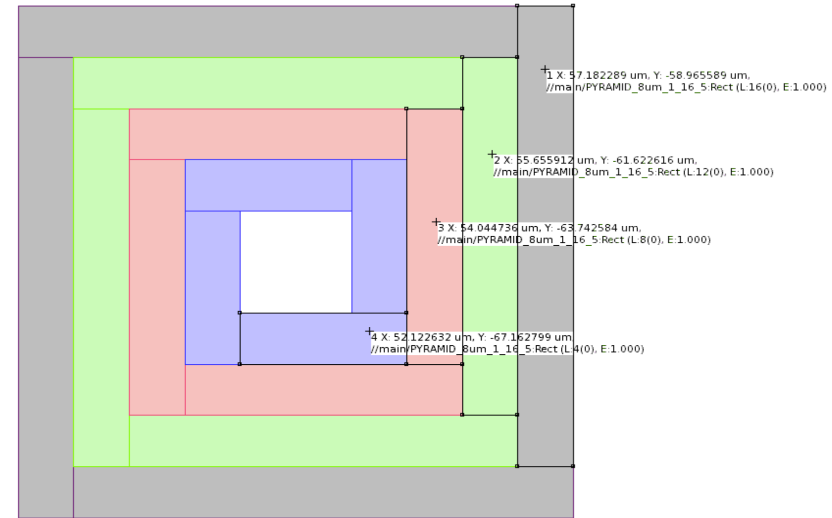
1050 nm high PMMA resist after development



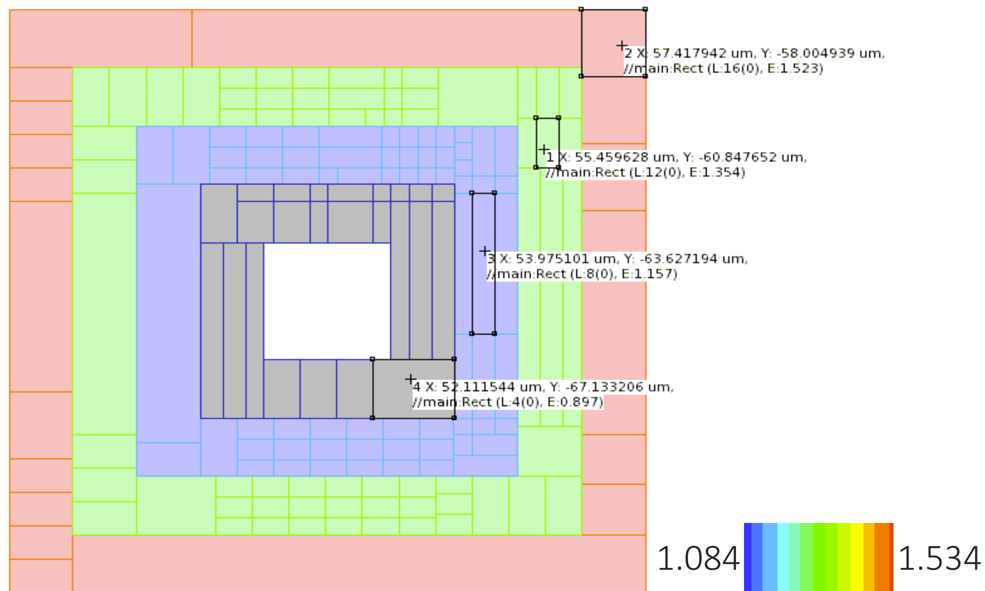
E-Beam Example

Cross-section Desired

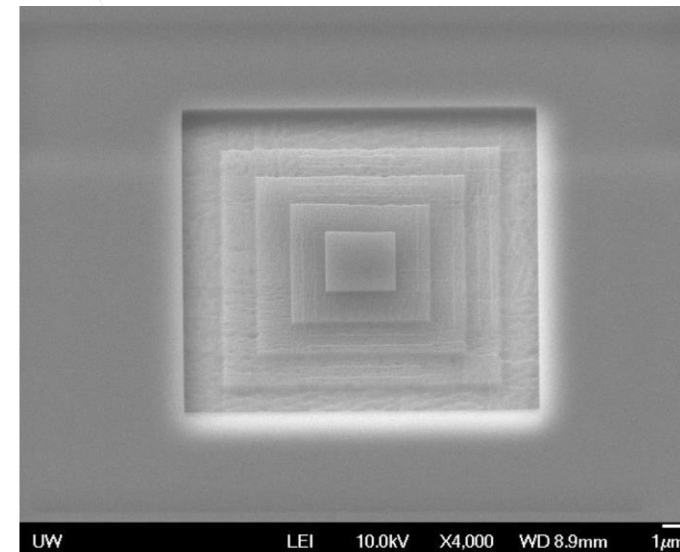
CAD Drawing (Colors are layers)



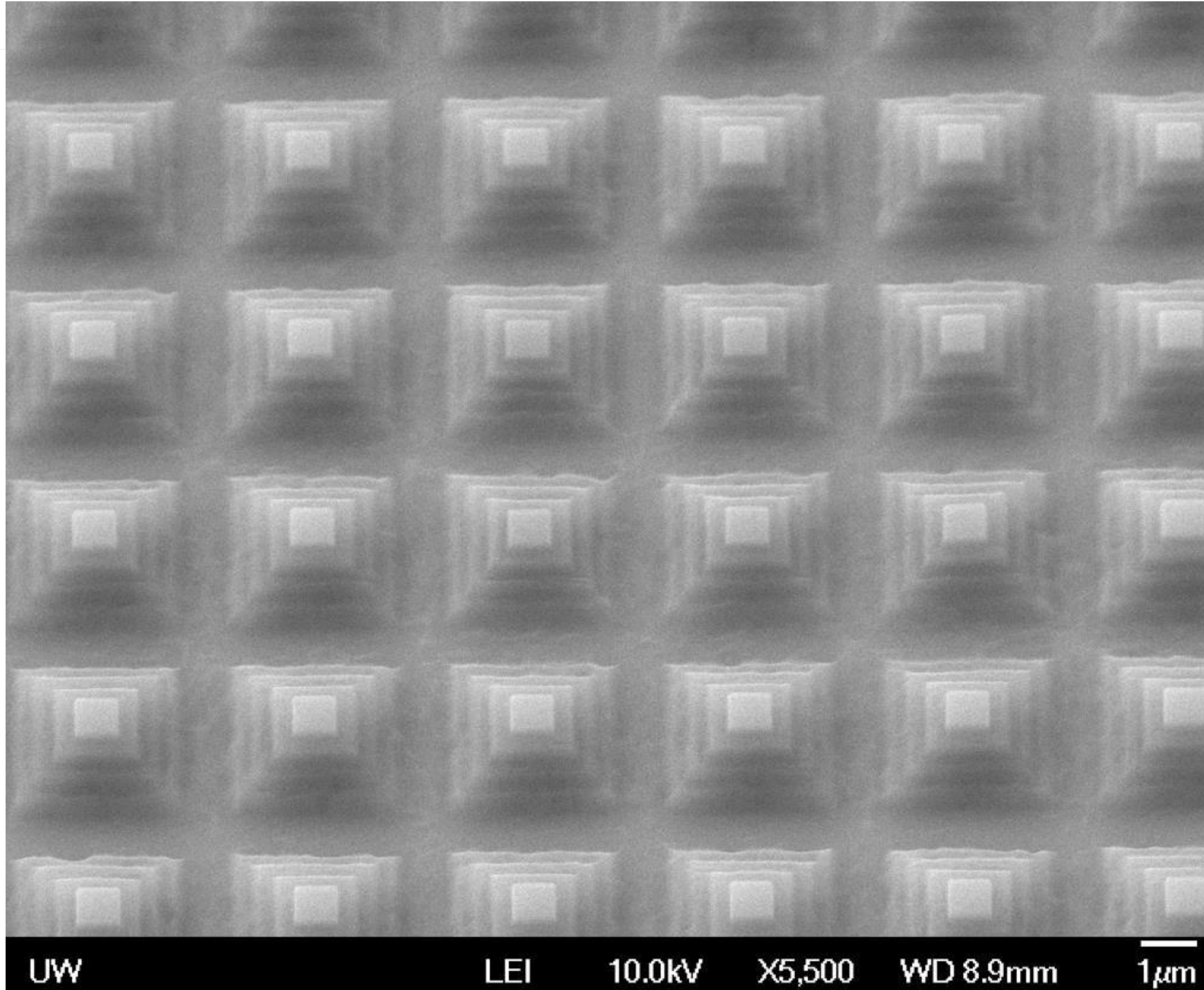
3D PEC Computes Exposure Doses



Expose and Develop



E-Beam Example



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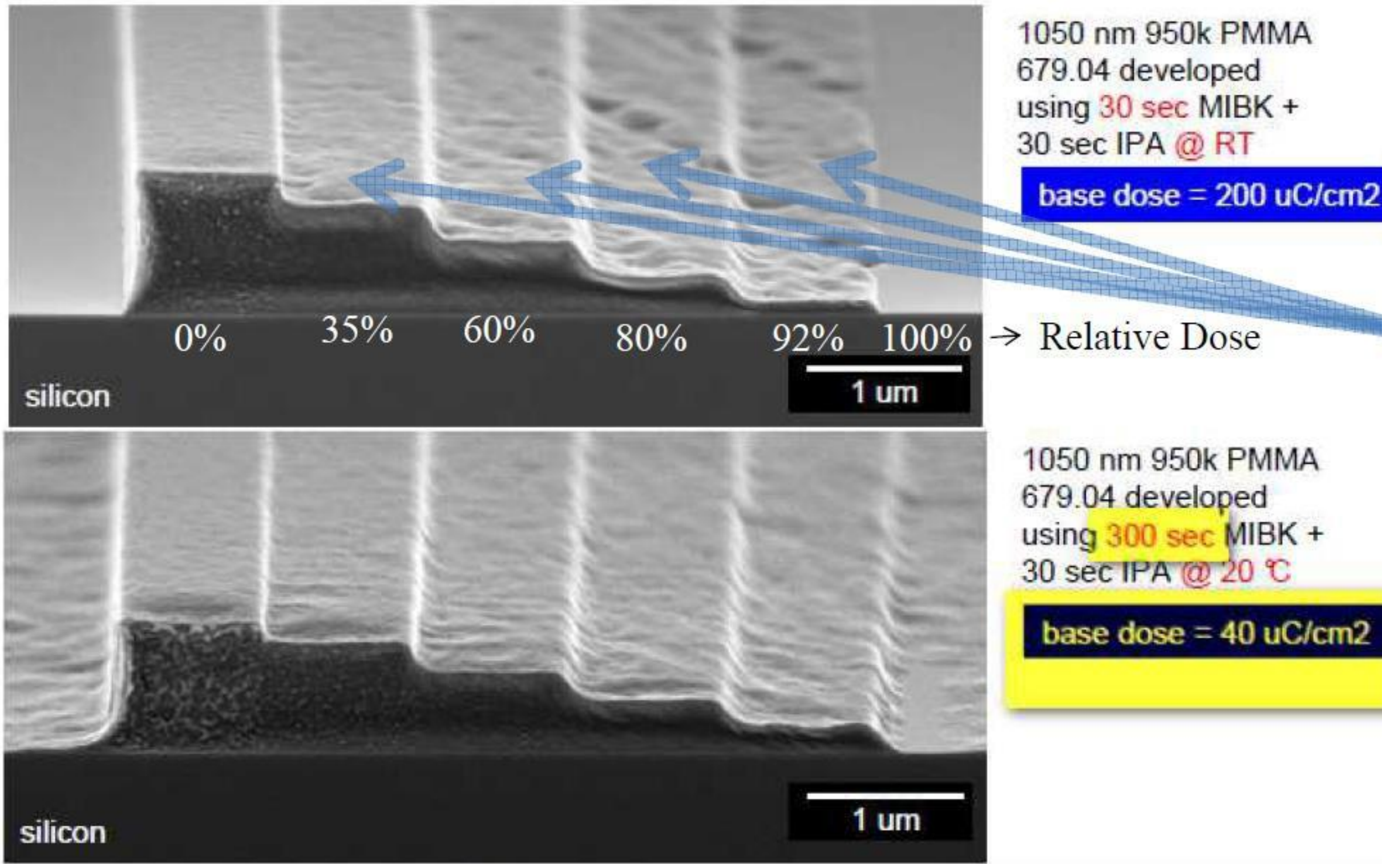
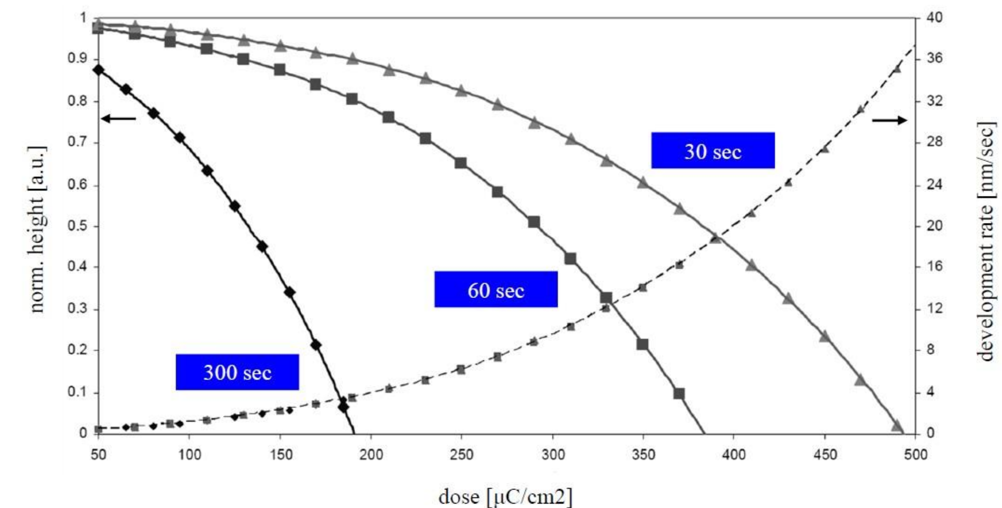
Mitigation of surface roughness

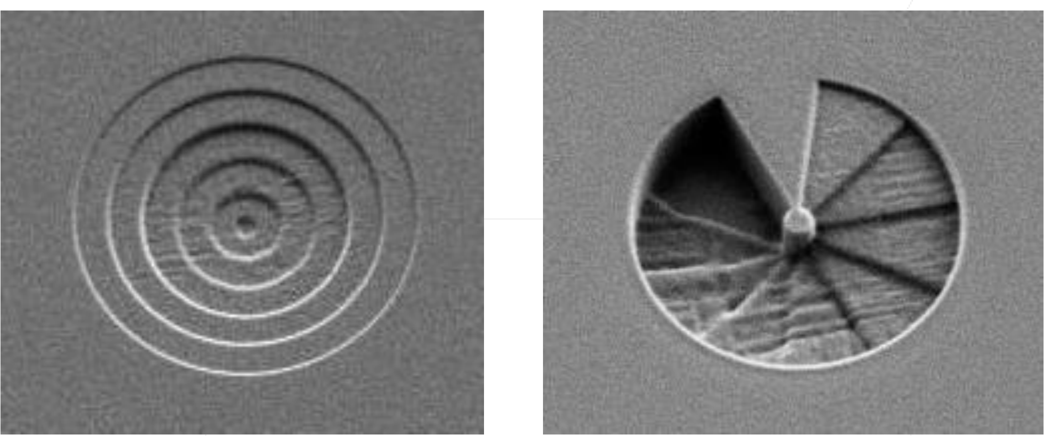


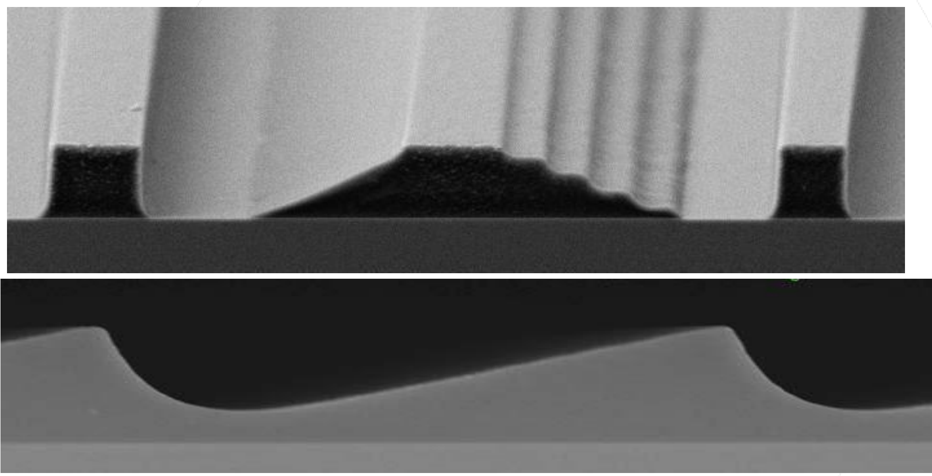
Surface roughness increasing with higher exposure dose

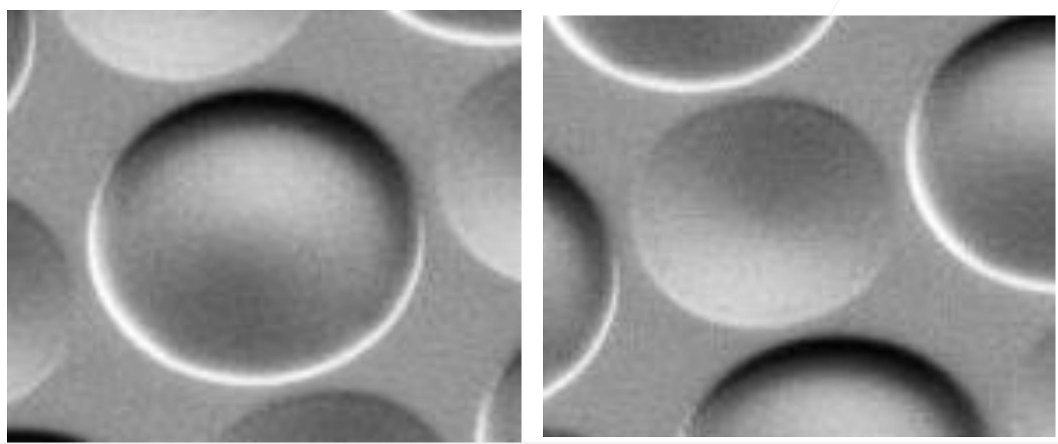


- Longer development times result in lower base doses, leading to reduced roughness
- Multipass (for high doses) helps for reducing roughness

Electron Beam 3D lithography

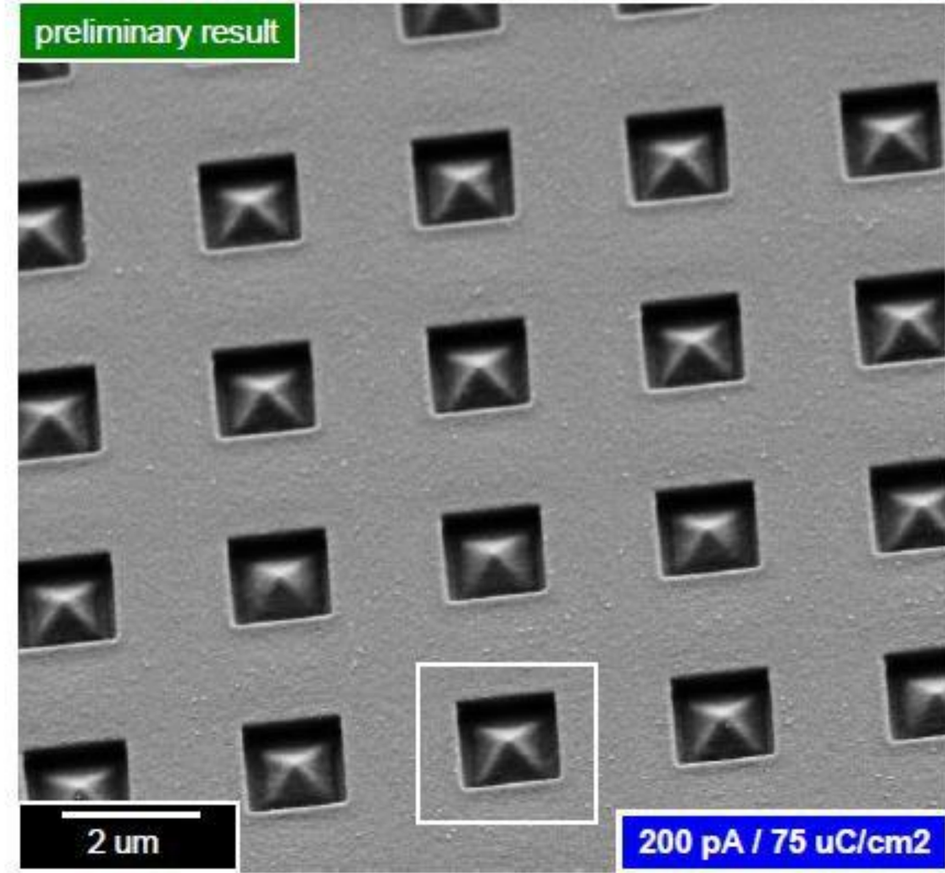


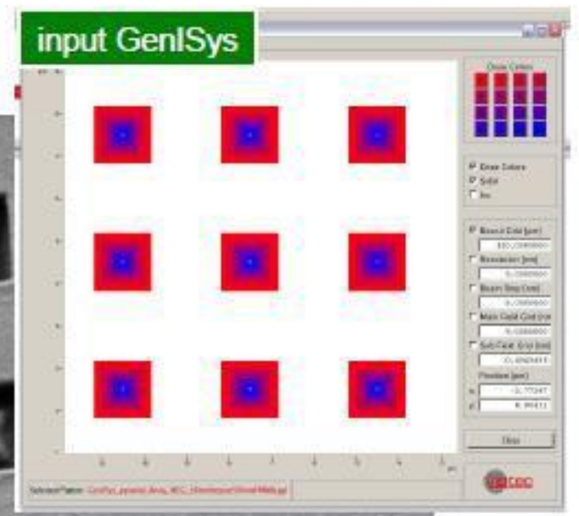


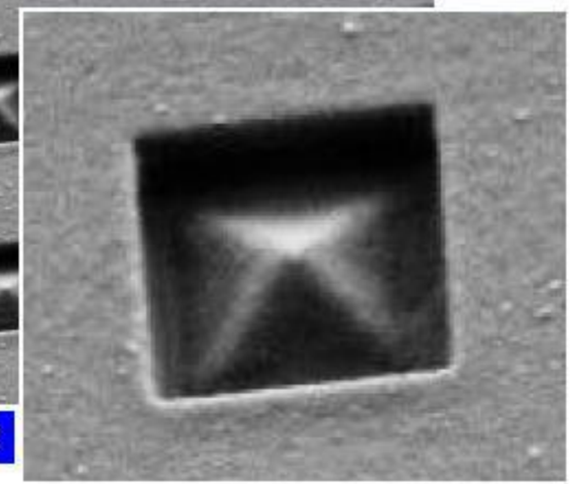


3-D e-beam lithography

520 nm 950k PMMA / Standard development at PSI







Arbitrary 3D Image

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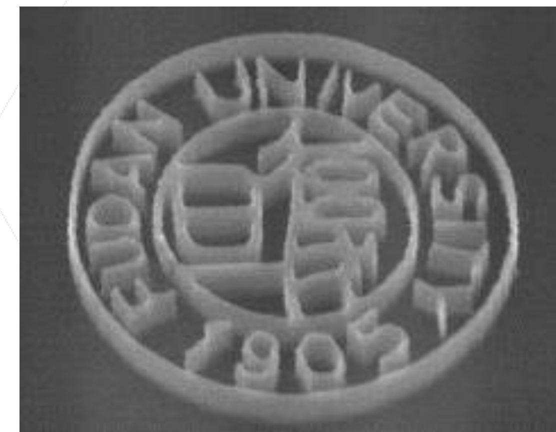
Arbitrary 3D Image

复旦大学邯郸校区



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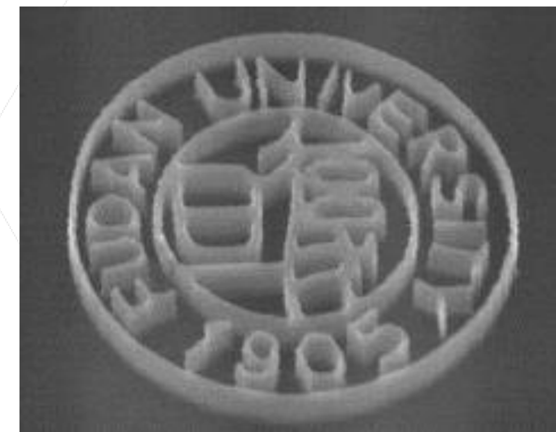

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Summary

- 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*

Thank You!

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