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Integration of Block-Copolymer with Nano-Imprint Lithography: Pushing the Boundaries of Emerging Nano-Patterning Technology

Sandia National Laboratories New Mexico

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LDRD Laboratory Directed Research & Development

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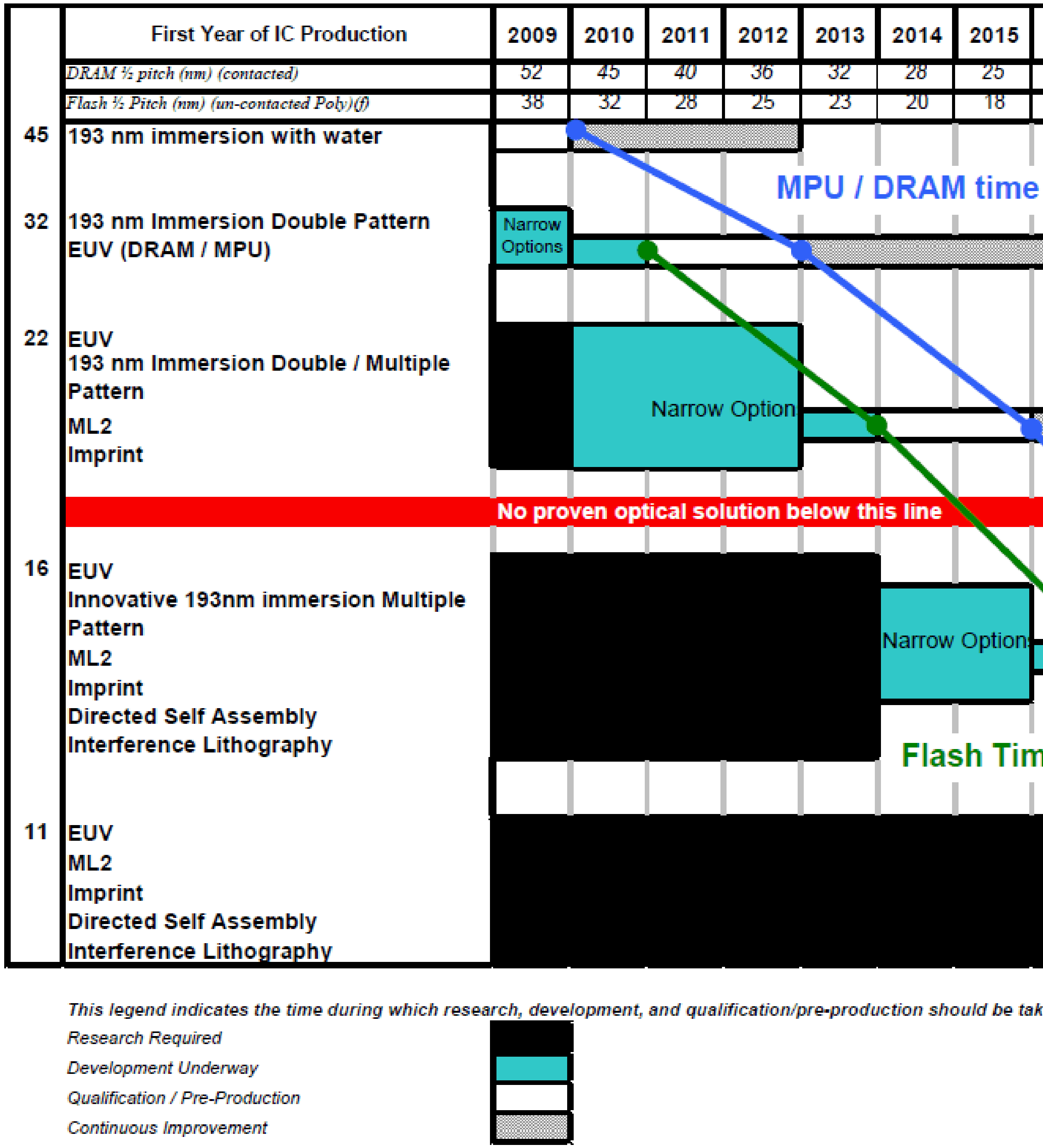
International Technology Roadmap for Semiconductors (ITRS)

11 nm half-pitch for dense pattern, 4.5 nm CDs by 2022

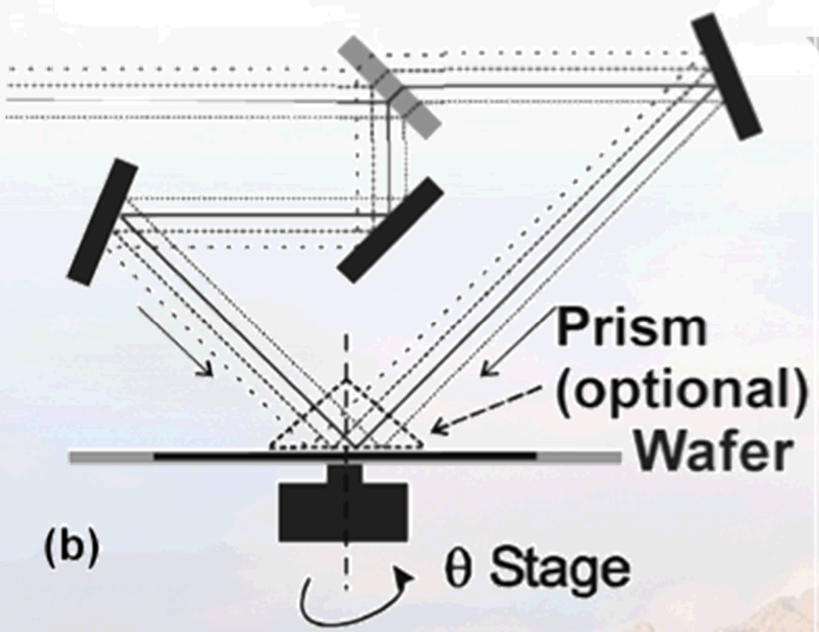


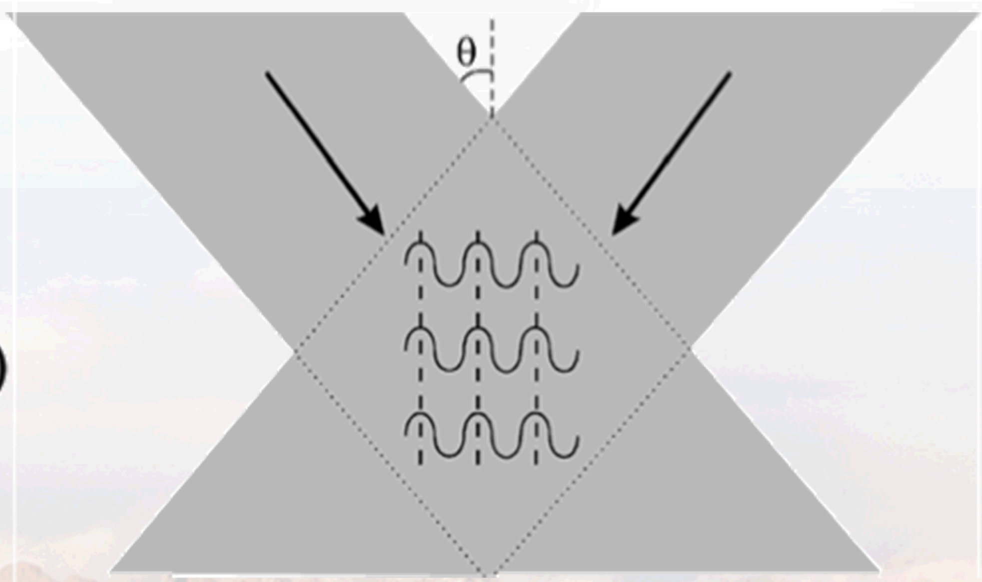
- Optical Lithography Limit:
  32 nm ½ pitch (193 nm, H_2O, double exposure)
- Extreme Ultraviolet Lithography (EUV)
  - 13.2 nm soft x-ray source power
  - High-resolution resist development
  - Low Line Edge Roughness (LER)
  - Complexity and cost
- Maskless (ML2)
  - Electron-beam = costly, slow, charging
- Imprint Lithography
  - Overlay
  - Defect density
  - Low cost
- Directed Self-assembly
  - Defect density
  - Alignment
  - Assemble various pattern densities/pitches
  - Long-range order

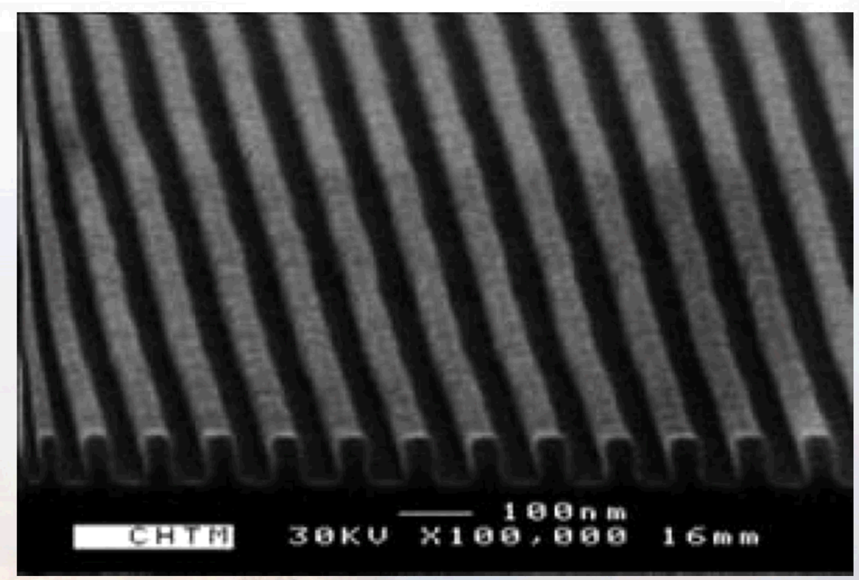
Optical Interference Lithography

Prof. Steven J. Brueck, Alex Raub, Ruichao Zhu *Matt George*, *Lance Williamson*

- Interference pattern formed by splitting two or more spatially and temporally coherent light waves, producing a periodic series of fringes with intensity minima and maxima.
  - 2-beam interference produces fringes with a period of $(\lambda/2)/\sin(\theta/2)$
  - 3-beam interference produces arrays with hexagonal symmetry
  - 4-beam interference produces arrays with rectangular symmetry
- This interference pattern is recorded in a photopolymer which is subsequently baked/developed
- Critical dimensions approach 50 nm, patterned areas approach $4 cm^2$





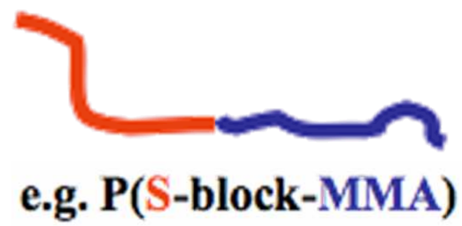


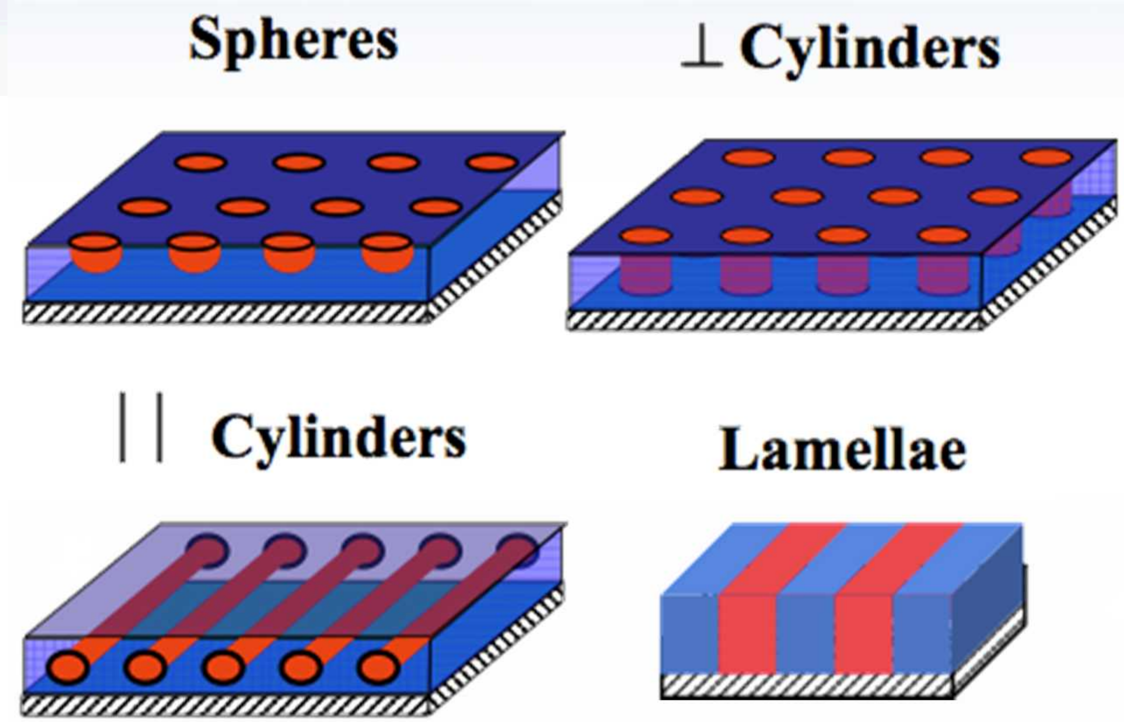
Brueck, Proc. IEEE 93 1704 (2005)

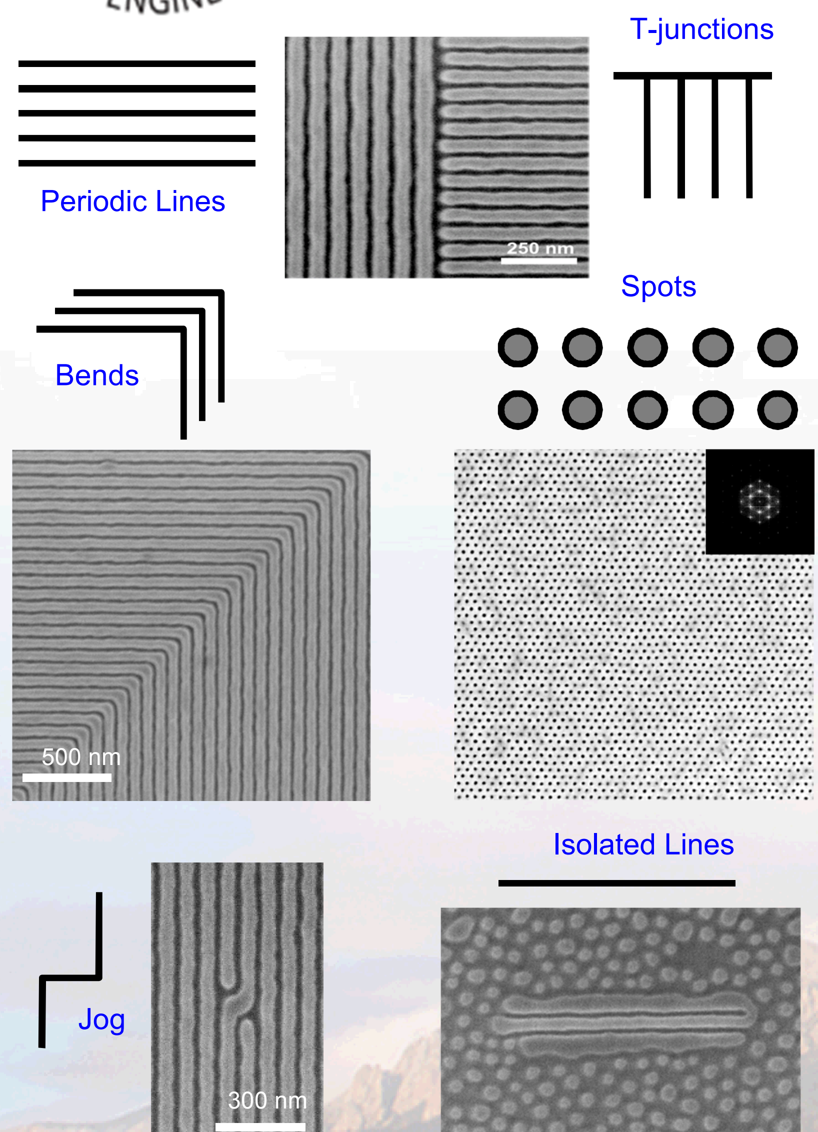
Block-Copolymer Self Assembly

Prof. Paul F. Nealey, Charlie Liu, Lance Williamson
Prof. Juan de Pablo, Darin Pike, Brandon Peters

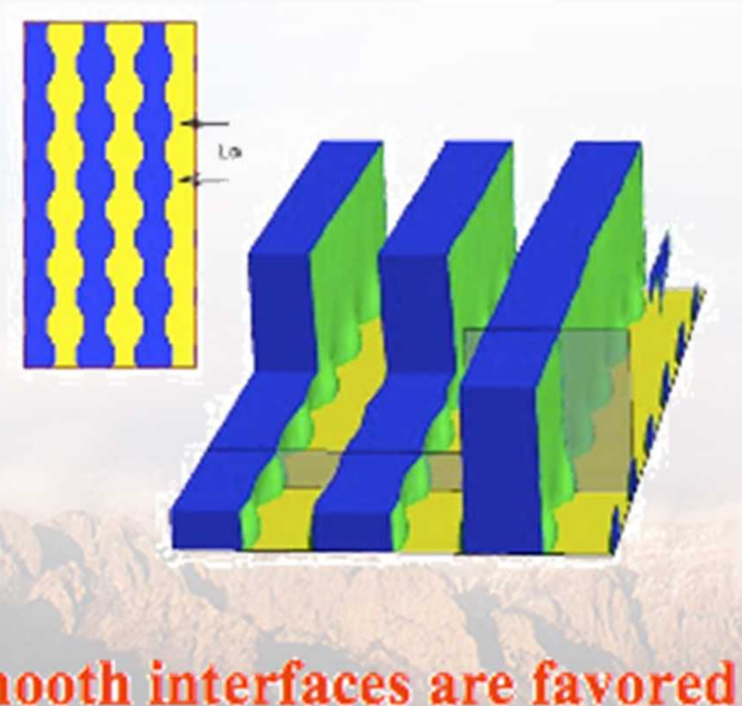
- Immiscible polymer blocks covalently bonded
- Periodicity depends on the molecule length, morphology depends on the volume fraction of each block
- Dense patterns of 5 - 50nm features



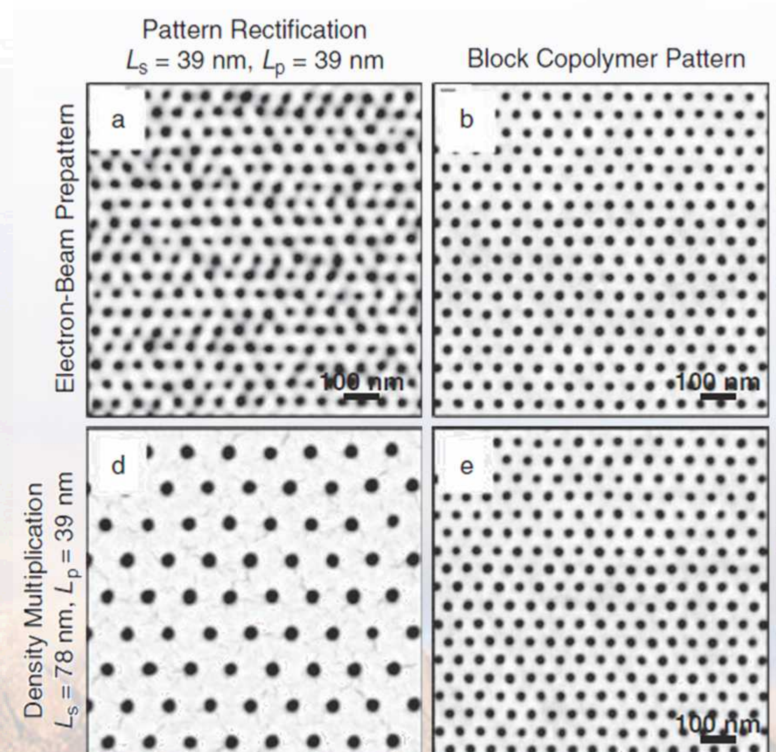




Stoykovich et al. *ACS Nano*, 2007, *Science* 2005



Daoulas et al., Langmuir, 2008



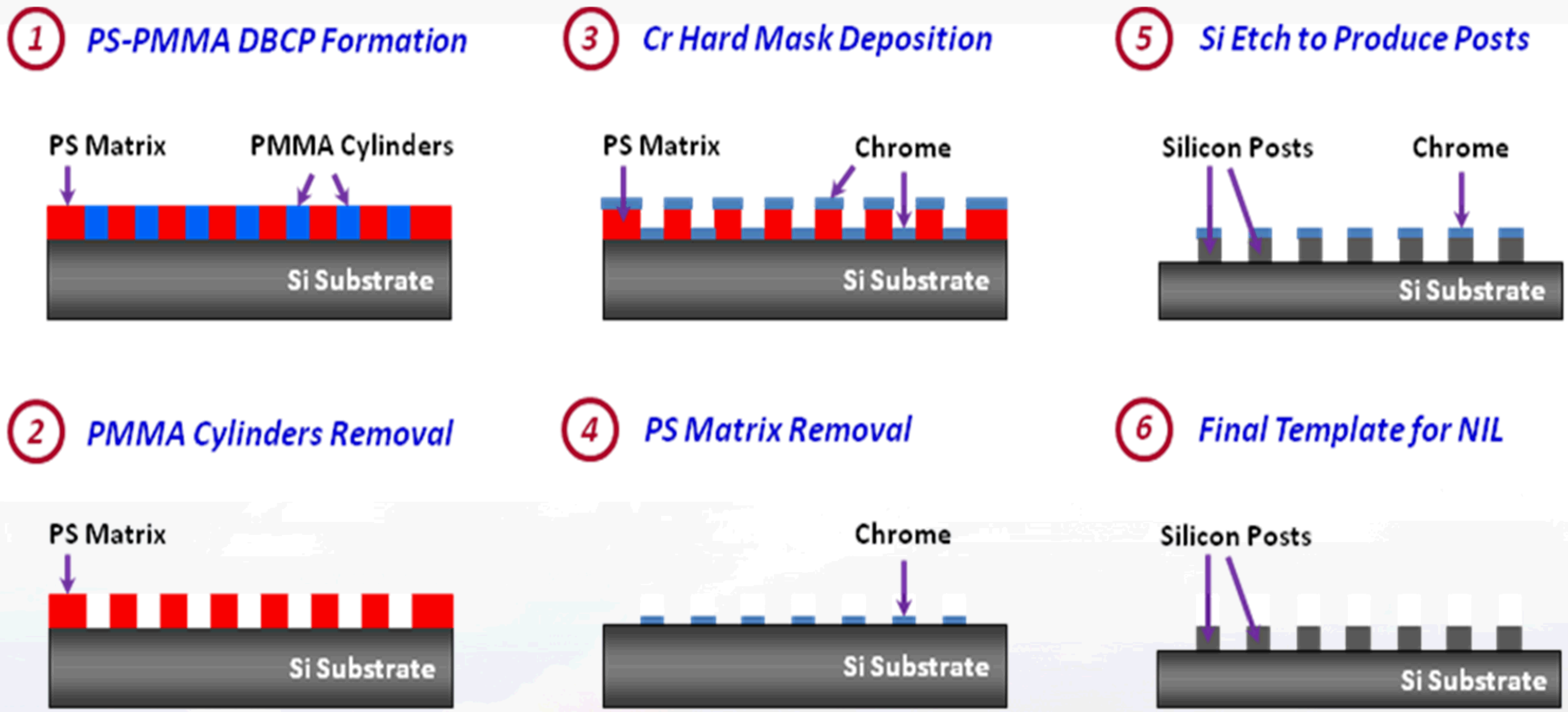
Ruiz *et al.*, Science 321 936 (2008)

Nano-Imprint Lithography

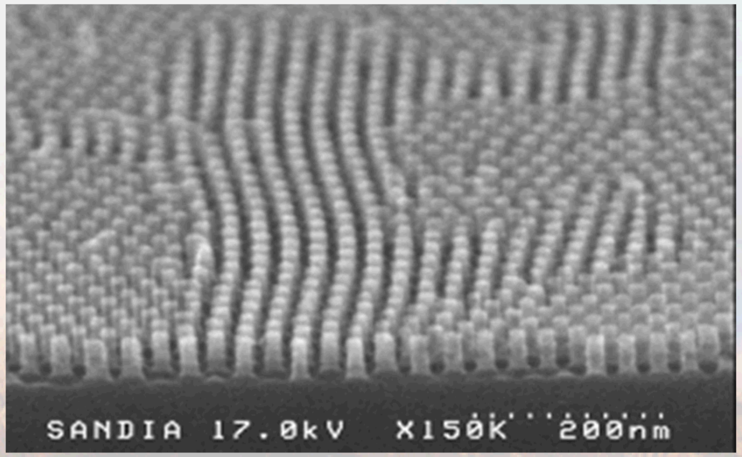
Jack L. Skinner, Peter Yang, Chip Steinhaus

Sandia National Laboratories
California

NATIONAL INSTITUTE FOR NANO ENGINEERING
NINE



- Uses a mold to transfer patterns into a thermally or UV cured resist
- Can fabricate large areas of features with sizes <10 nm
- Pattern entire wafer surfaces in the matter of minutes



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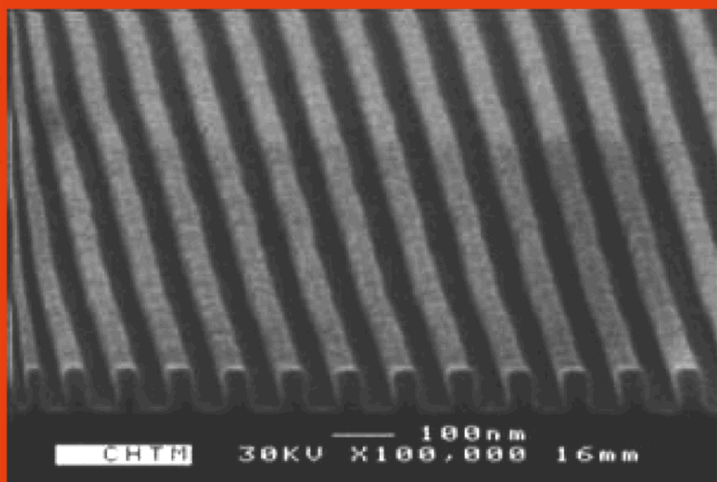
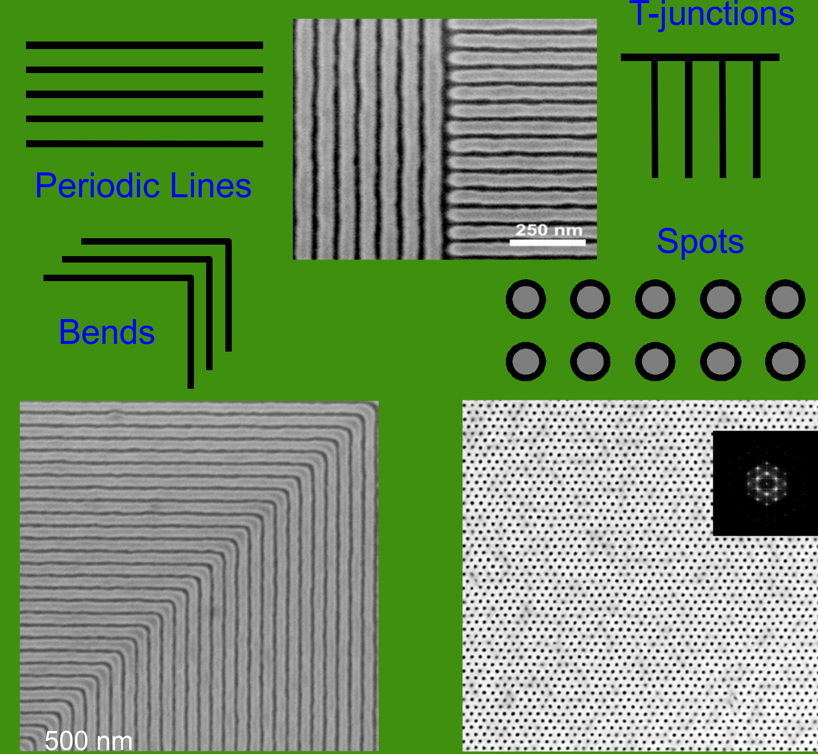
Technical Approach

1) <100nm feature definition by IL

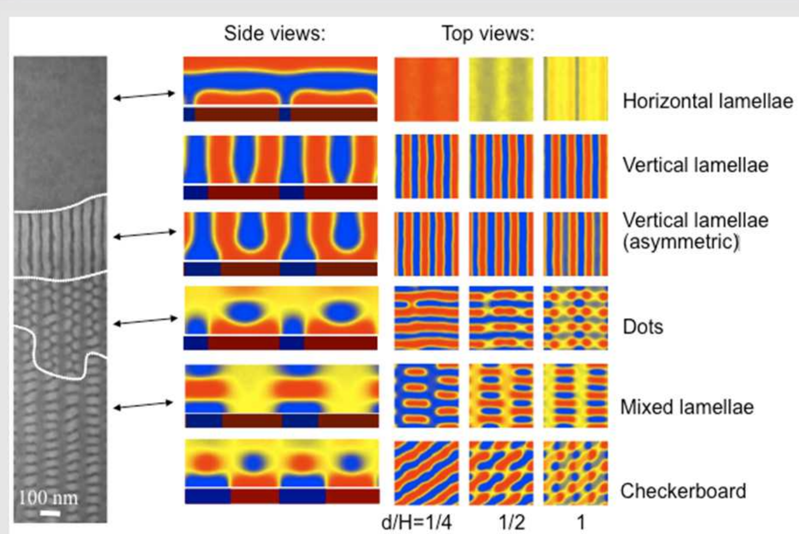


Brueck, Proc. IEEE **93** 1704 (2005)

2) BCP self assembly directed by IL to form final 10-50nm features



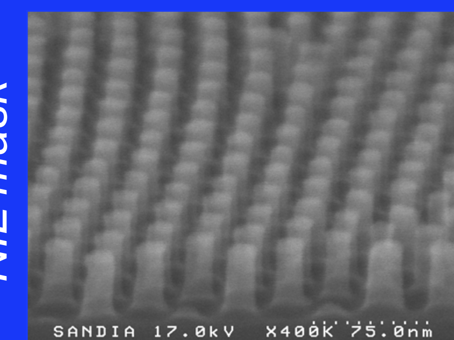
Stoykovich et al. *ACS Nano*, 2007, *Science* 2005

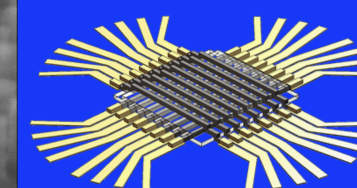


3) Transfer of BCP structures to NIL mask for device-capable patterning

Hybrid 1D/2D plasmonic resonator

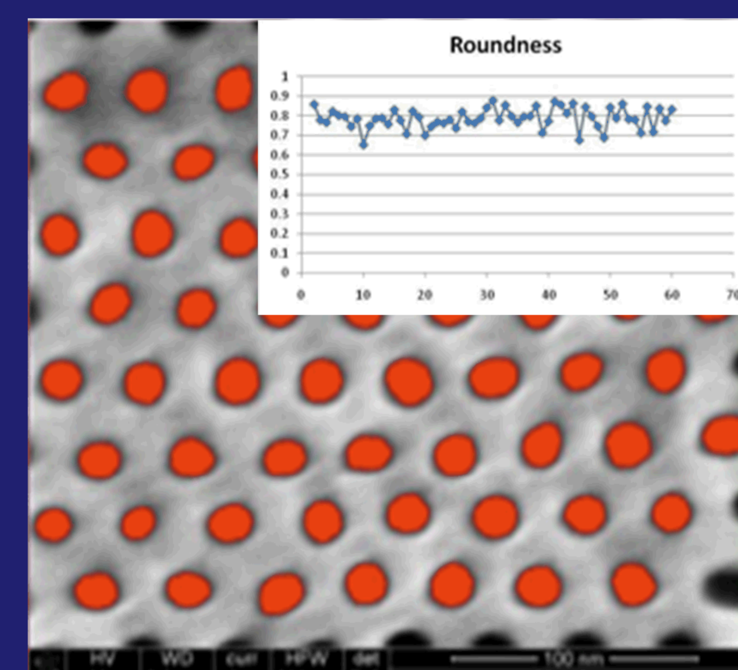
NIL mask





Crossbar array

4) Extensive metrology throughout; identify, quantify coupled parameters



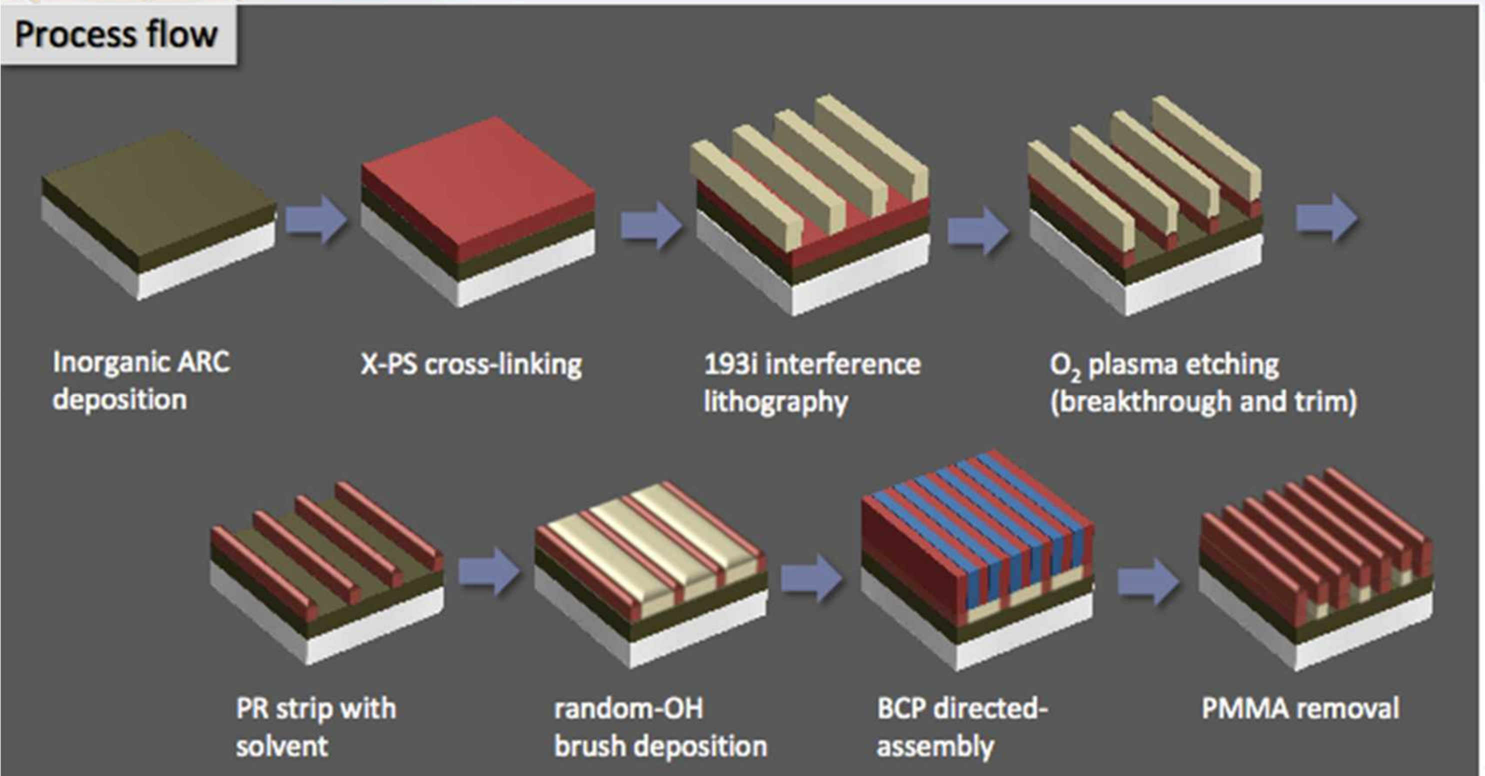
Focus on the science of DSA and multi-technique integration

Probe ultimate limitations and feasibility of BCP techniques

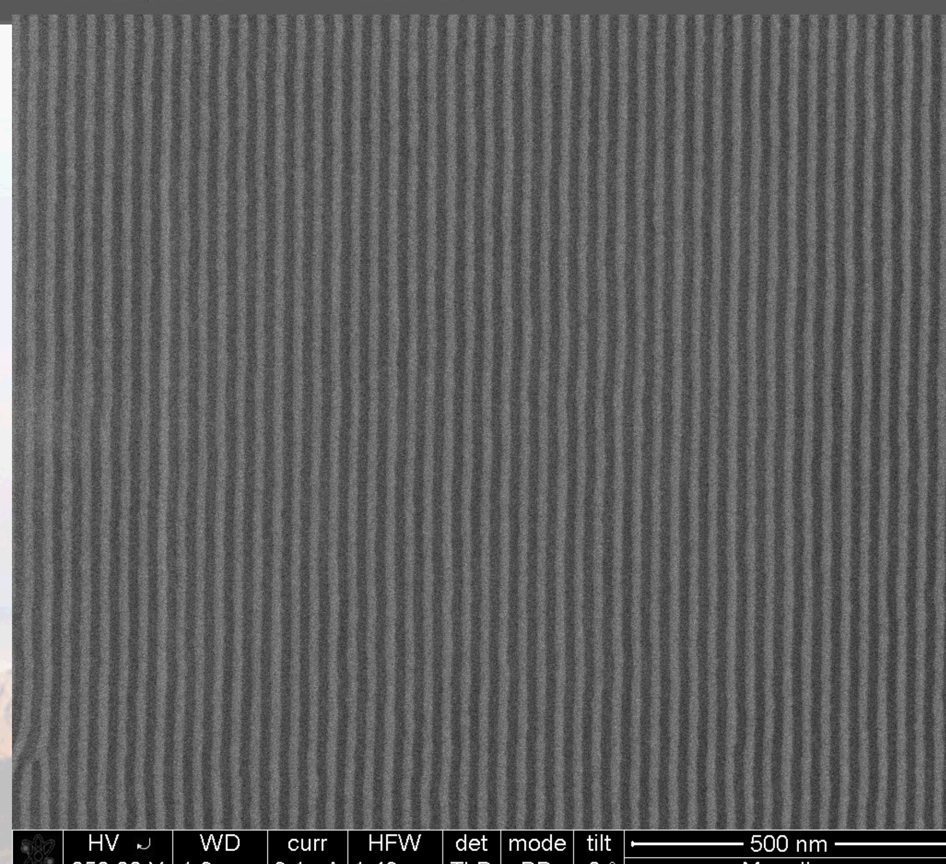
Develop tools for probing, understanding, and directing nanoscale interfaces, structures, behaviors, interactions

Deliver knowledge and understanding, not devices.

Directed Self Assembly

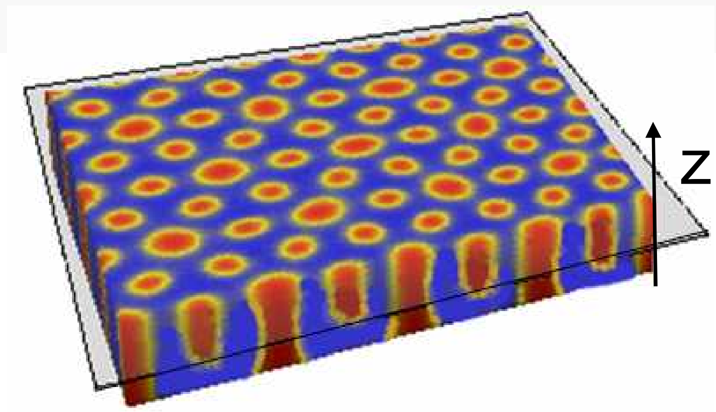


IL + BCP

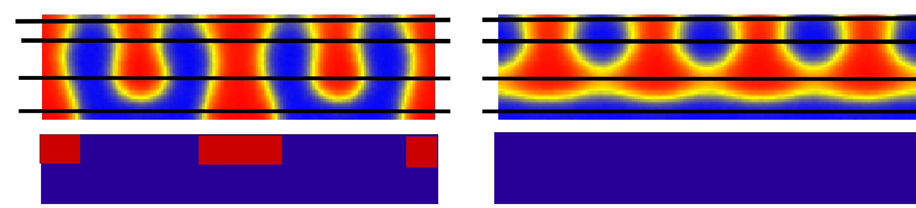


Chemically-patternable mat
+ end grafted brush

Simulations of Surface-Dominated Structures



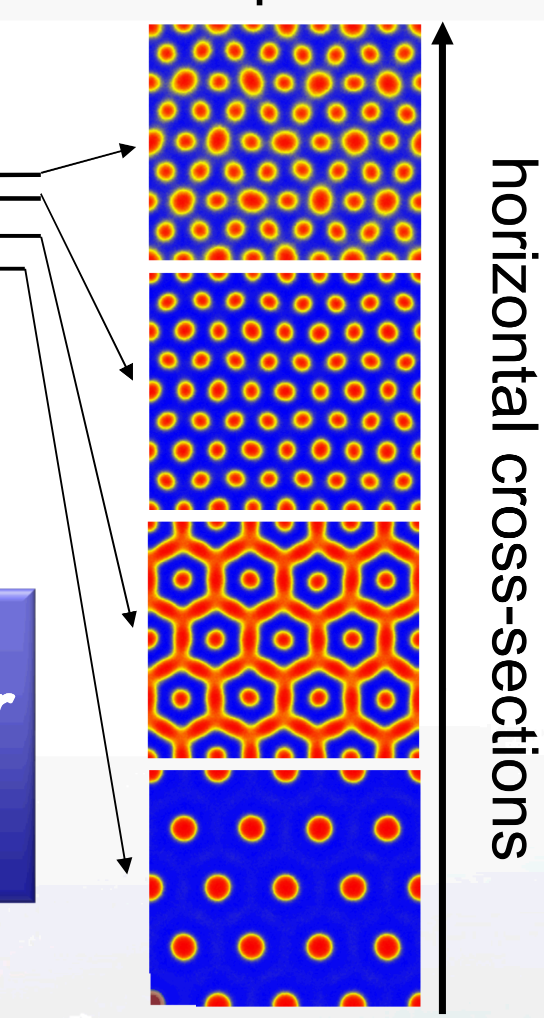
vertical cross-sections



patterned line

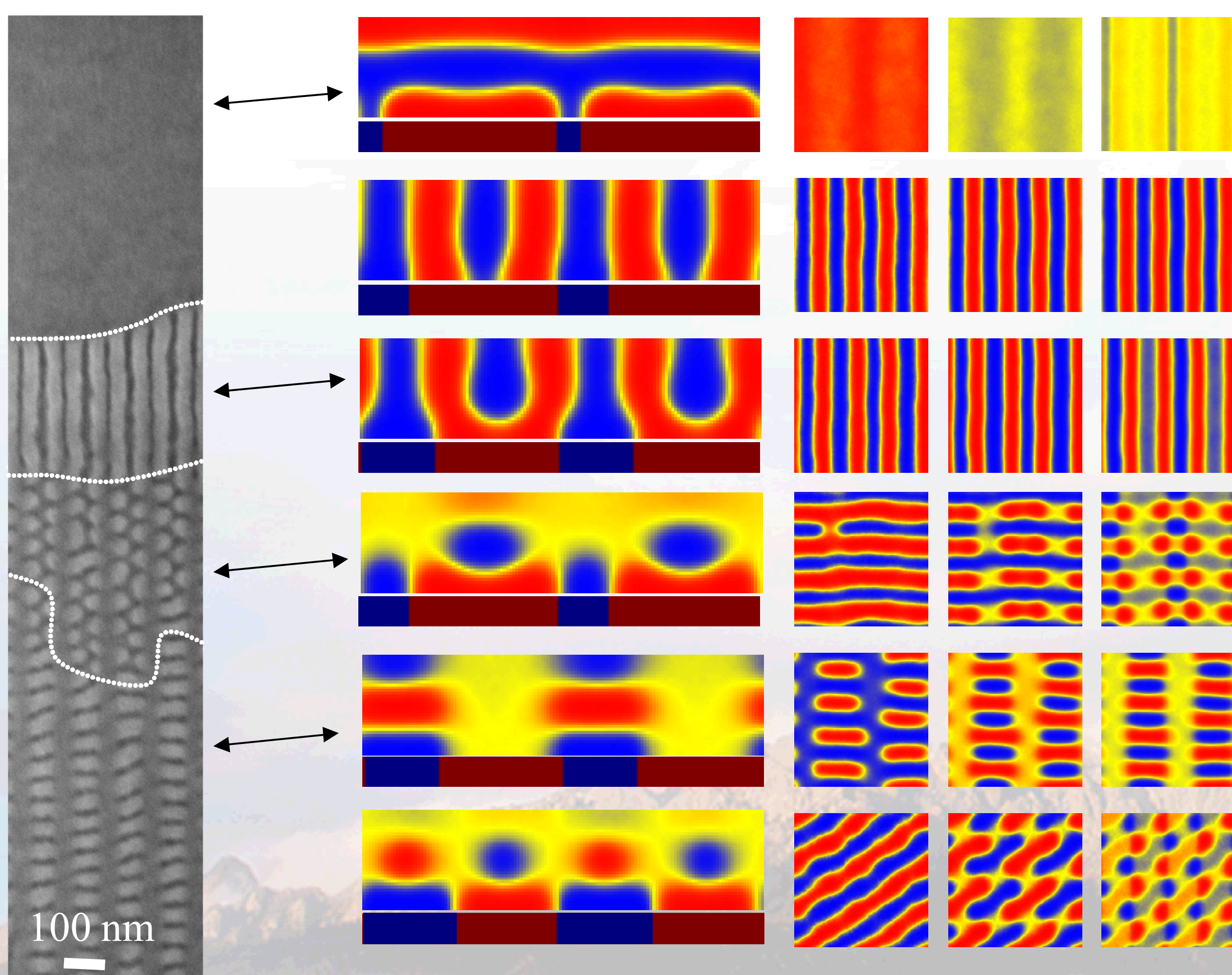
non-patterned line

top surface

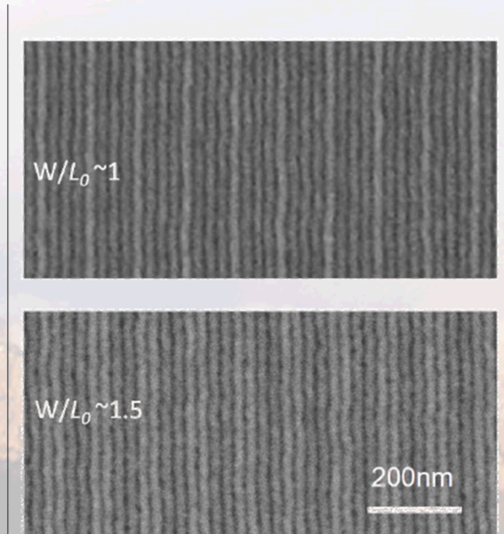


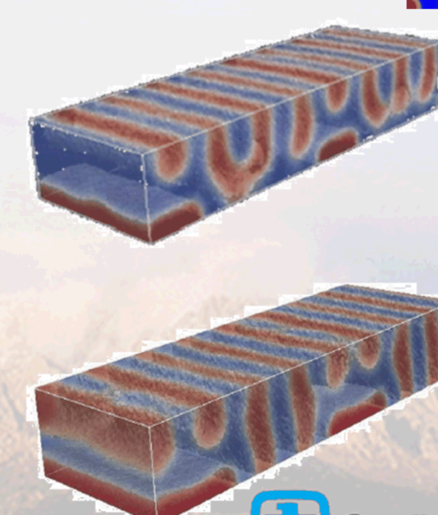
substrate

Side views: Top views:



Substrate and surface interactions are critical for density multiplication via interpolation





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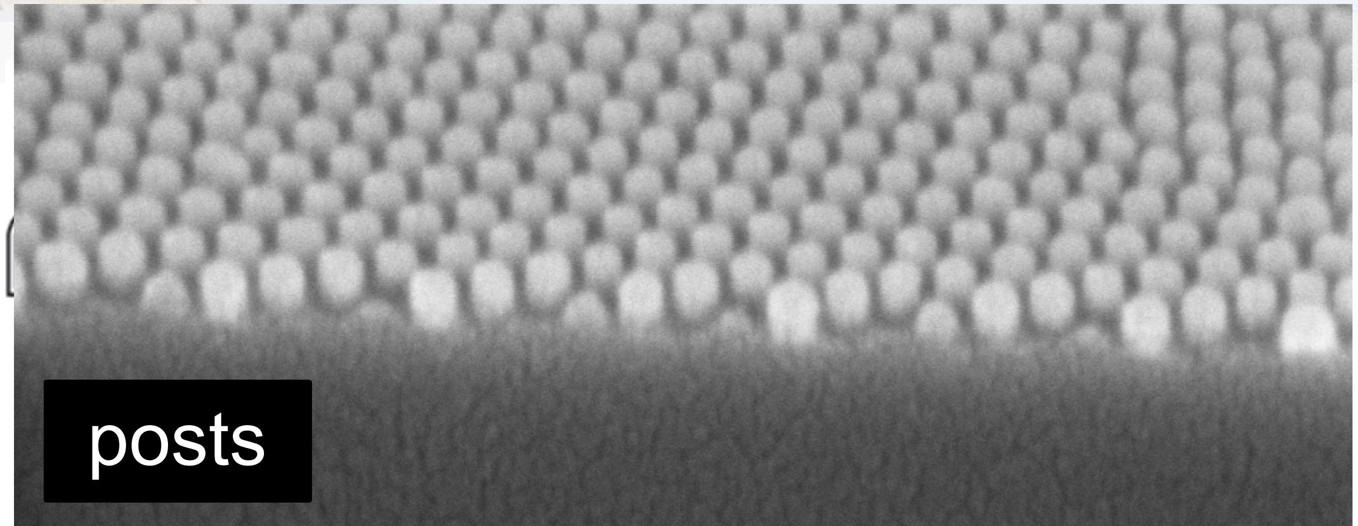
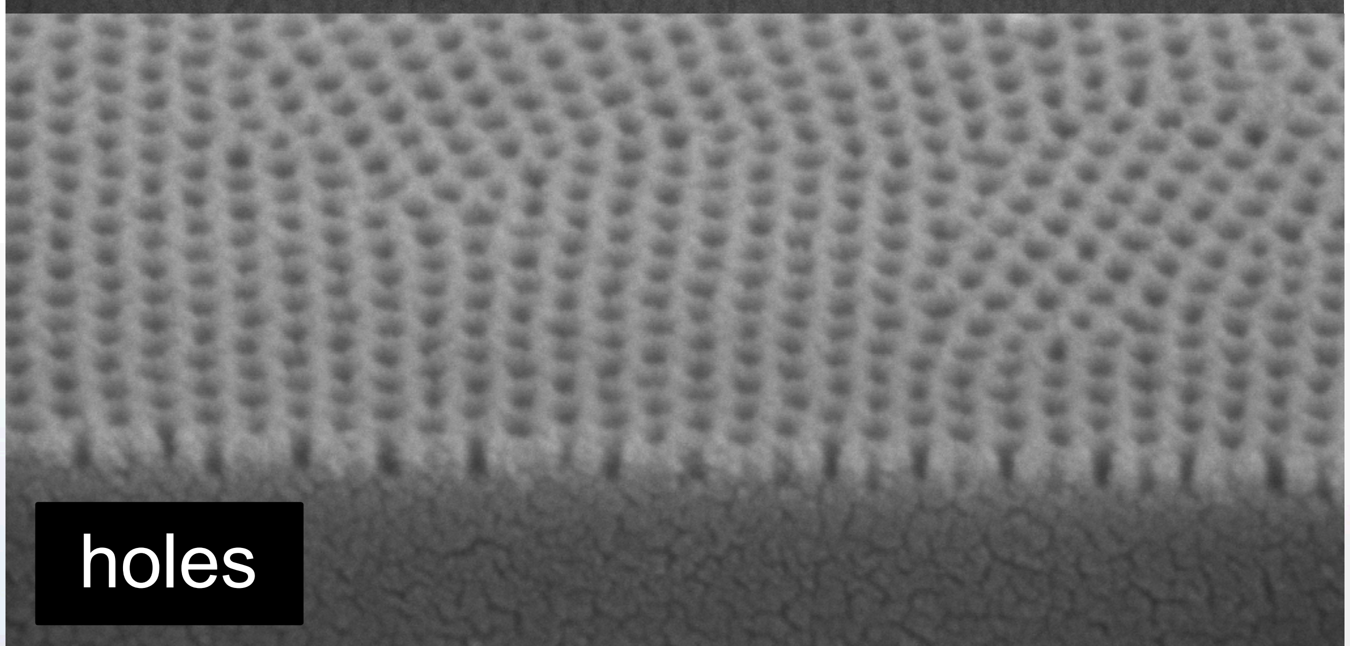
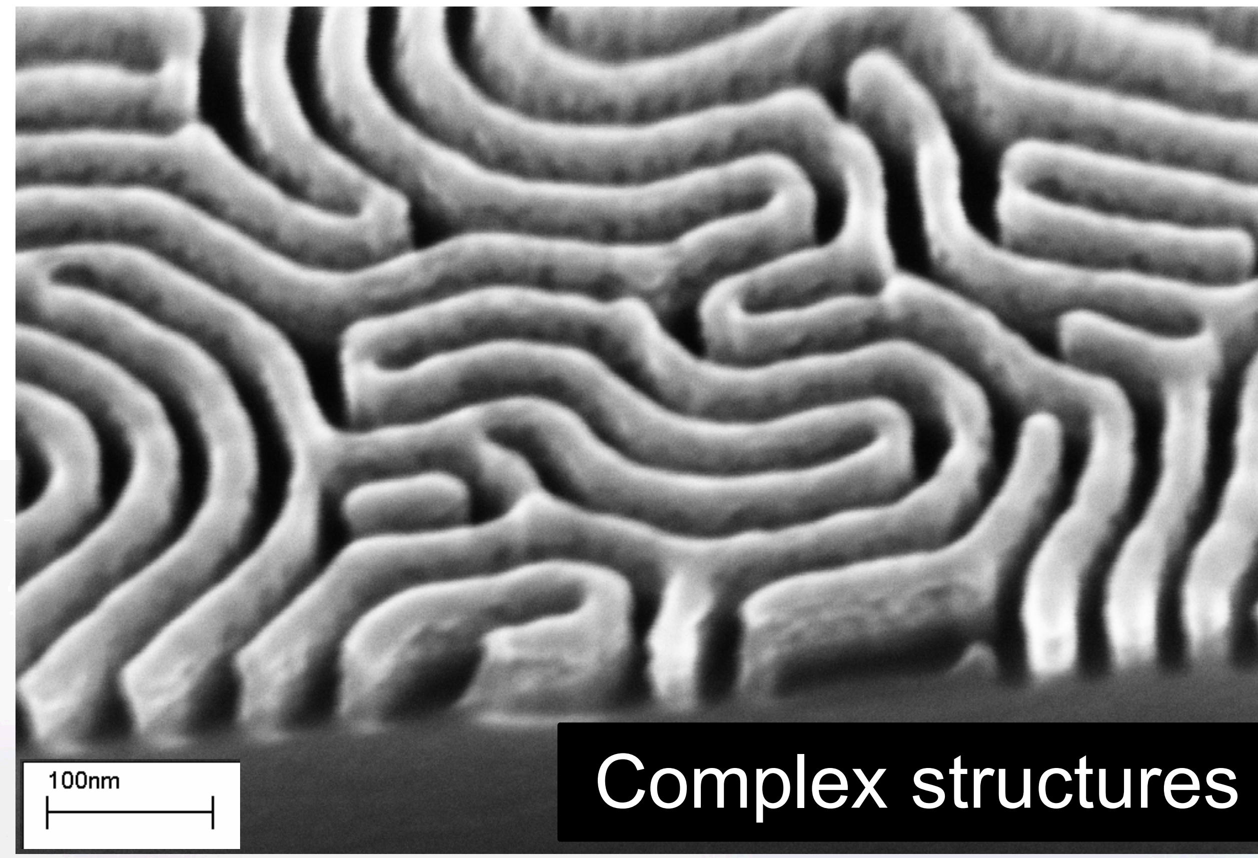
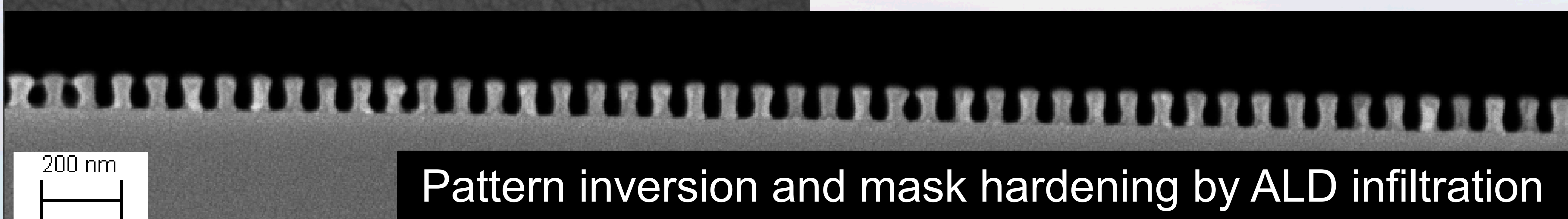
Pattern Transfer





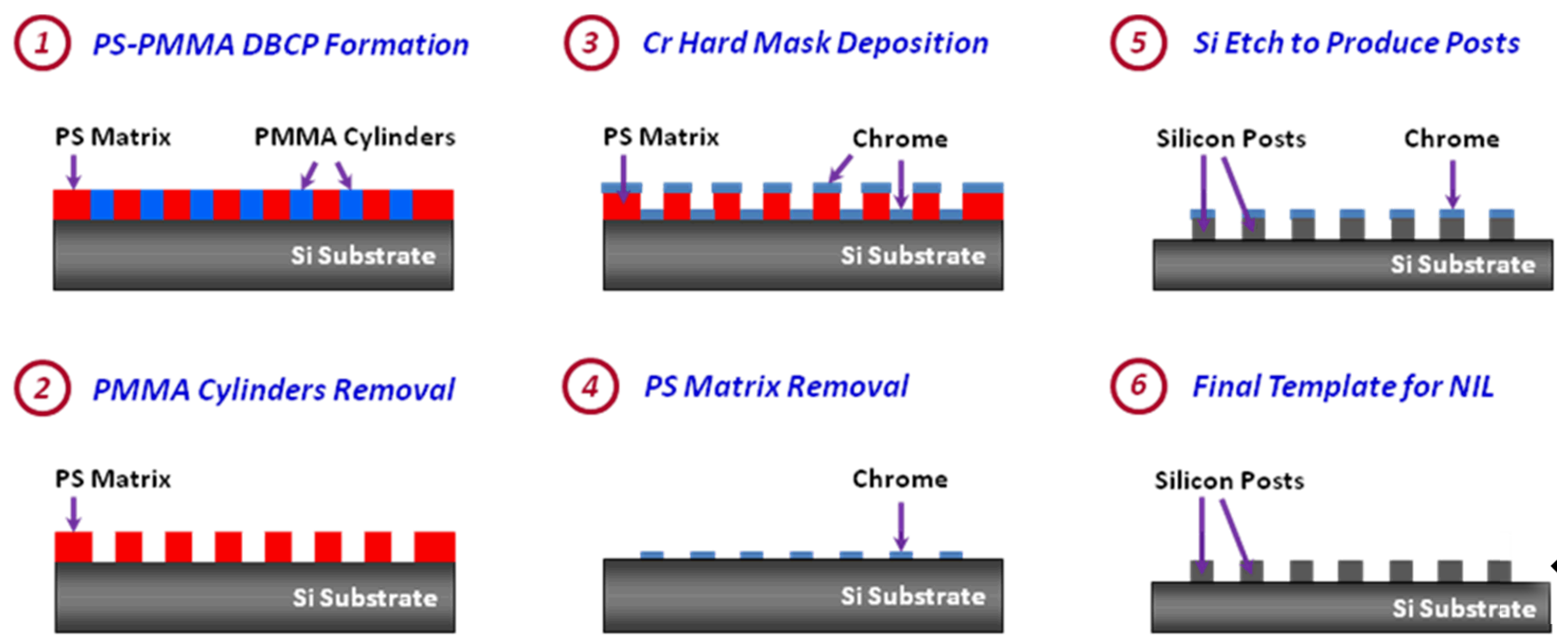
Dense patterns of 13-50nm features can now be fabricated in Si, SiO_2, Si_3N_4, Al_2O_3, TiO_2, Al, Cr, and more…

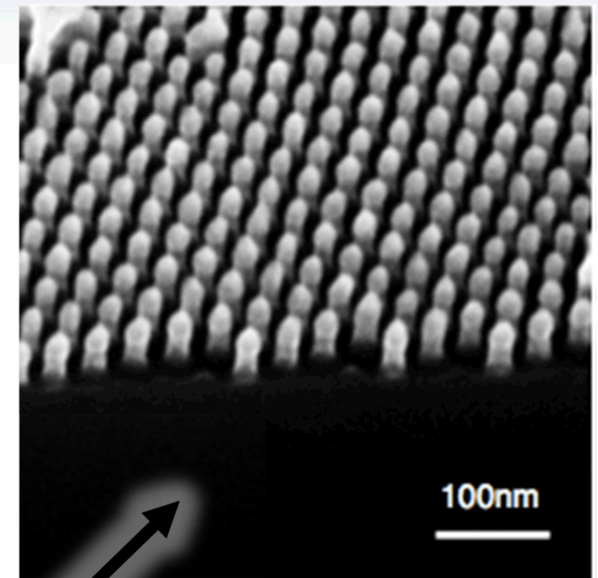




Enhanced Optical Response from NIL Features

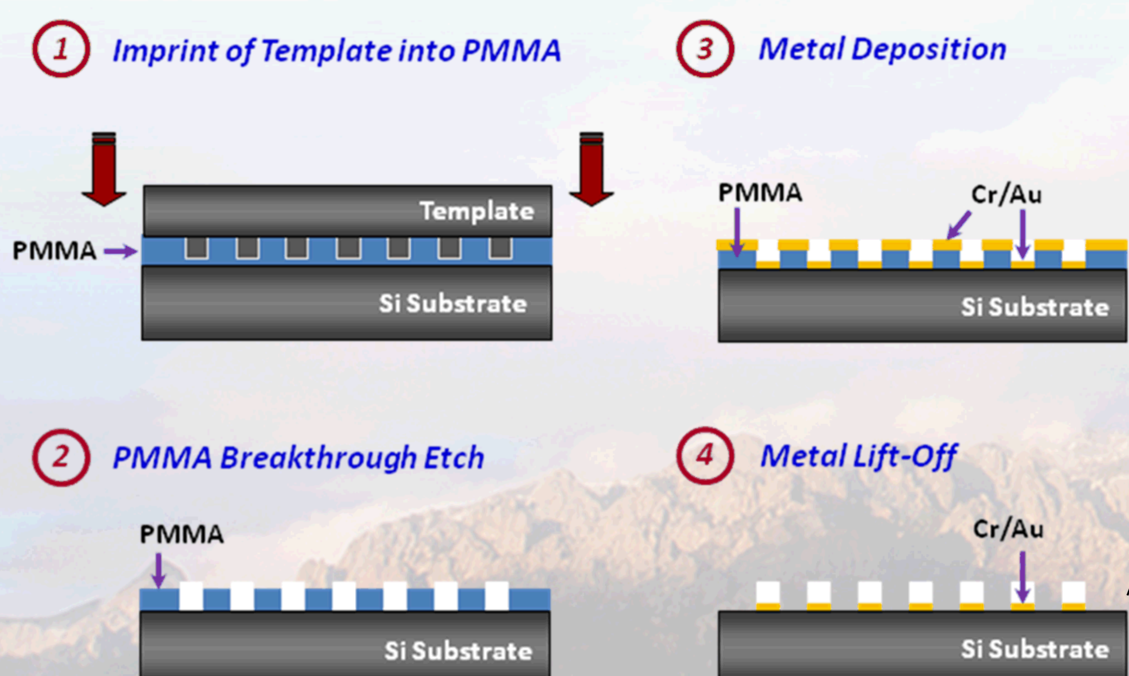
NIL mold via BCP

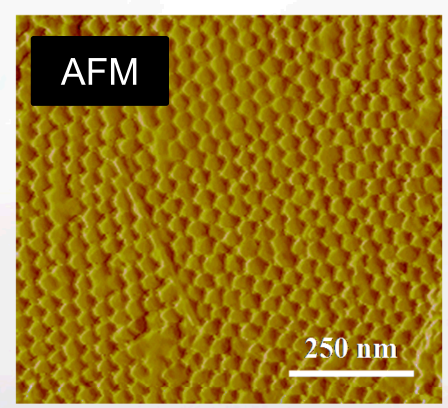


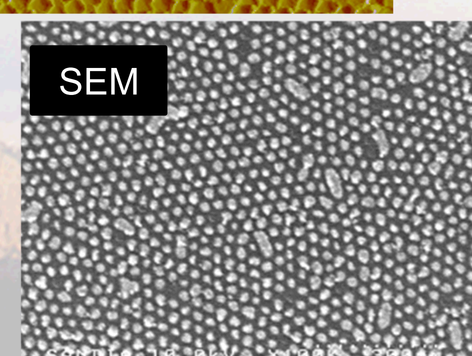


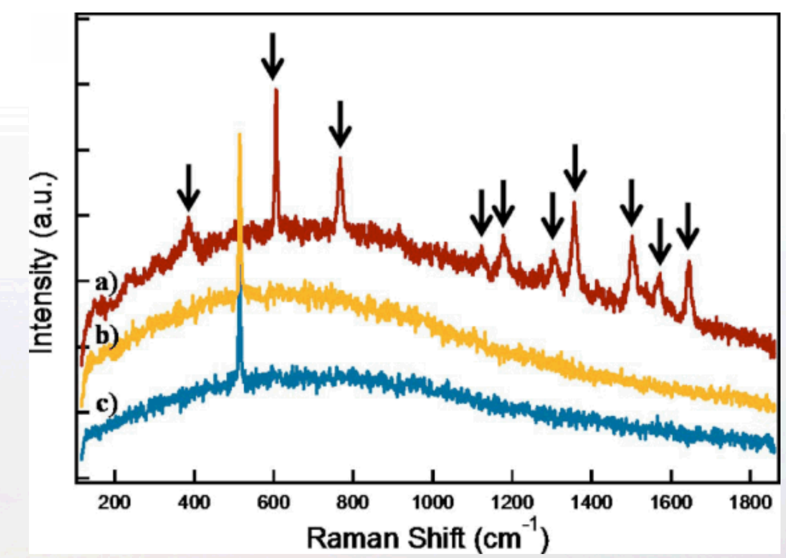
Integration of block copolymer self assembly and nanoimprint lithography presents a more rapid and cost-effective approach to nanofabrication compared to e-beam template writing.

Simple SERS demonstration via NIL









Raman scattering plots of R6G on a) device chip - patterned section, b) control chip - bare silicon, and c) device chip – bare silicon section. Black arrows denote R6G scattering peaks.

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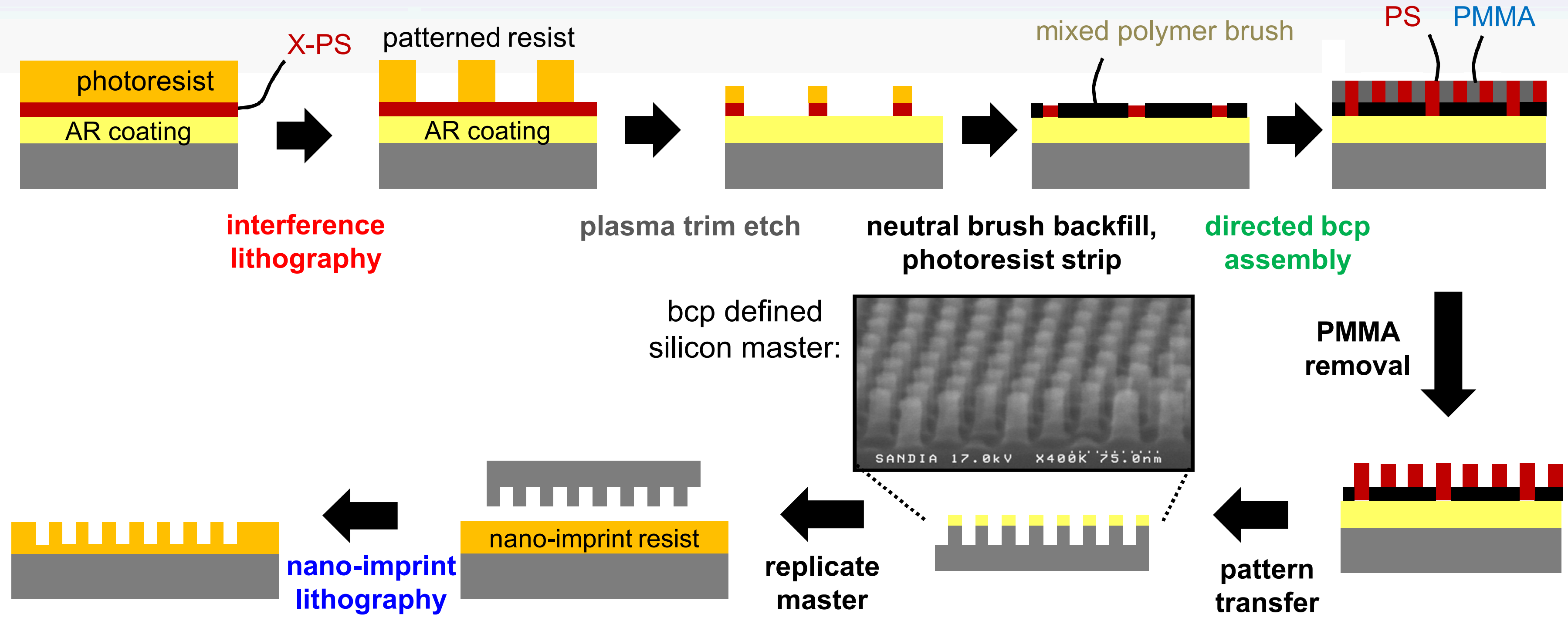
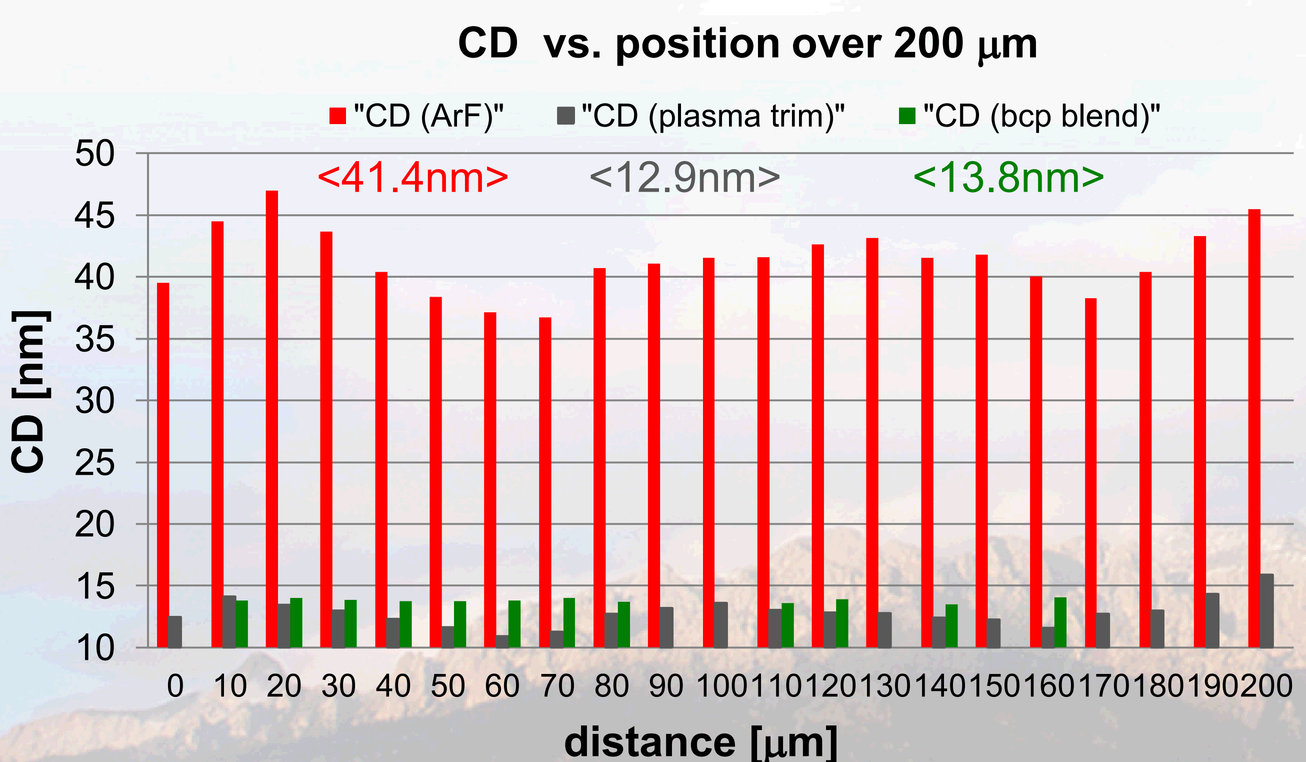
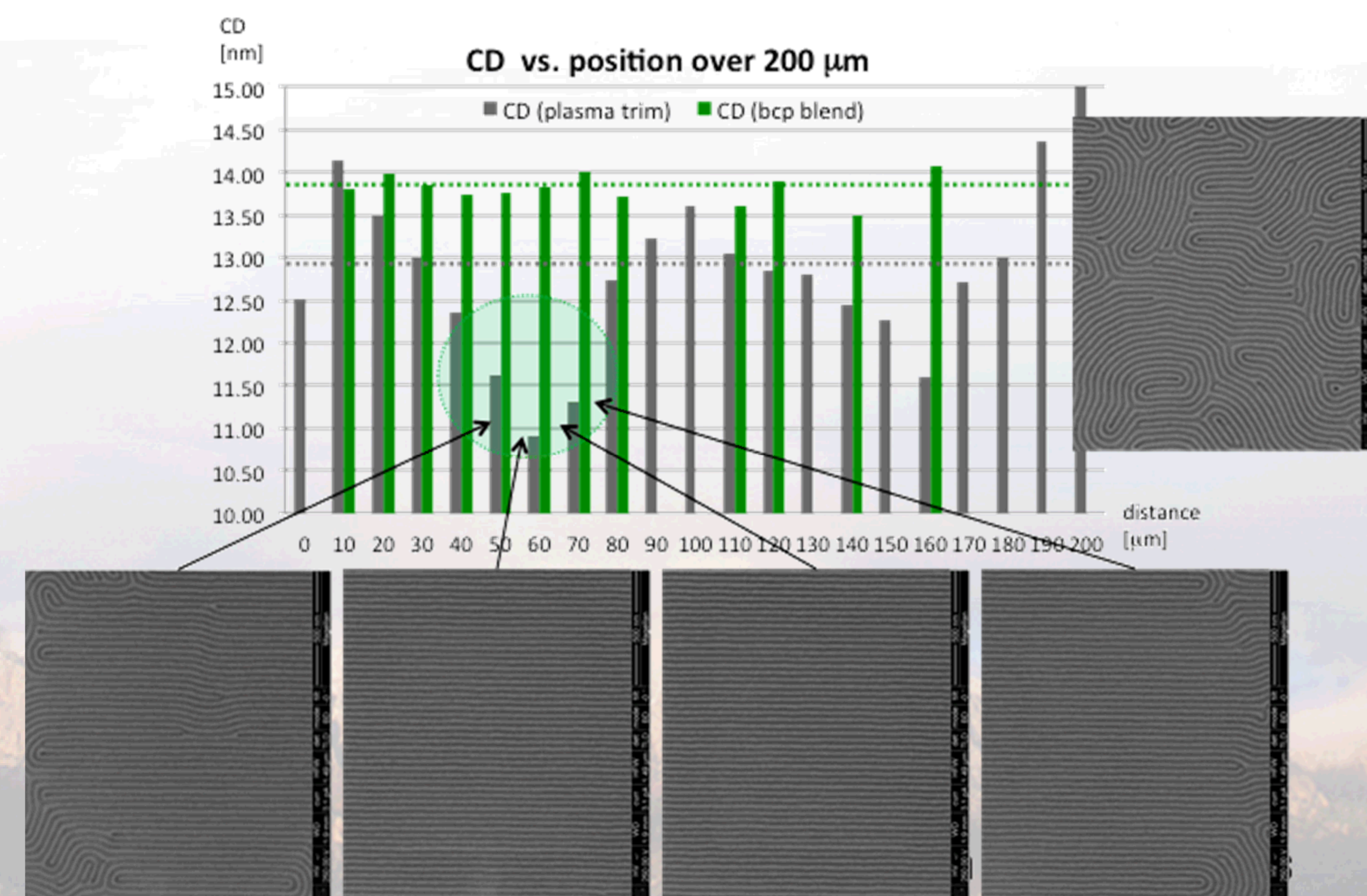
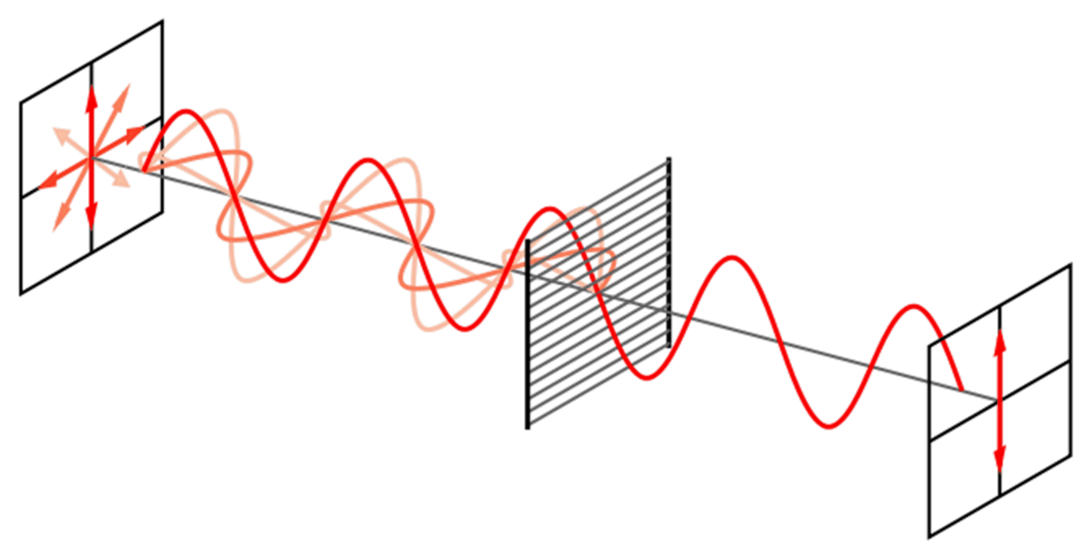
Metrology Throughout

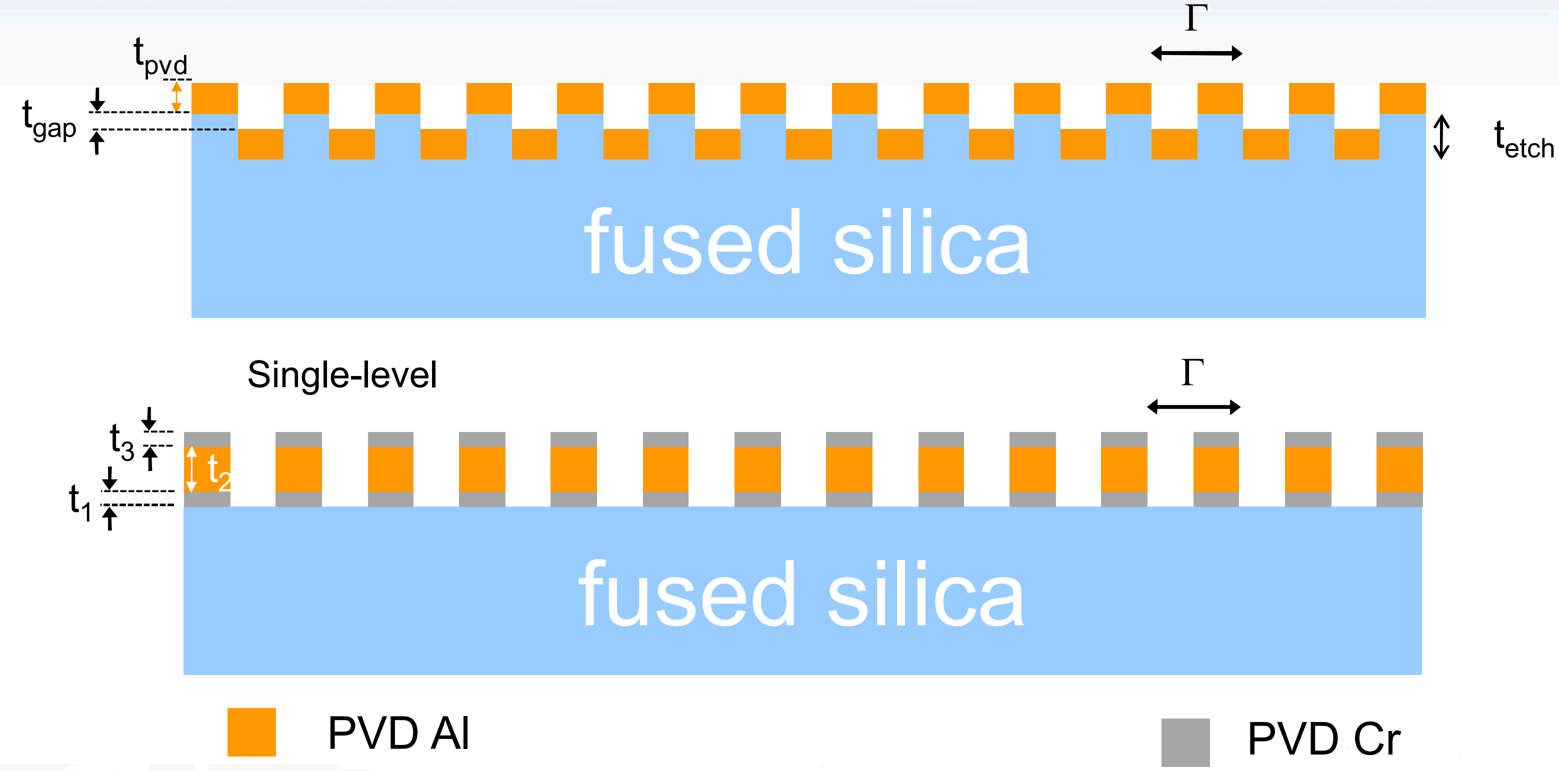




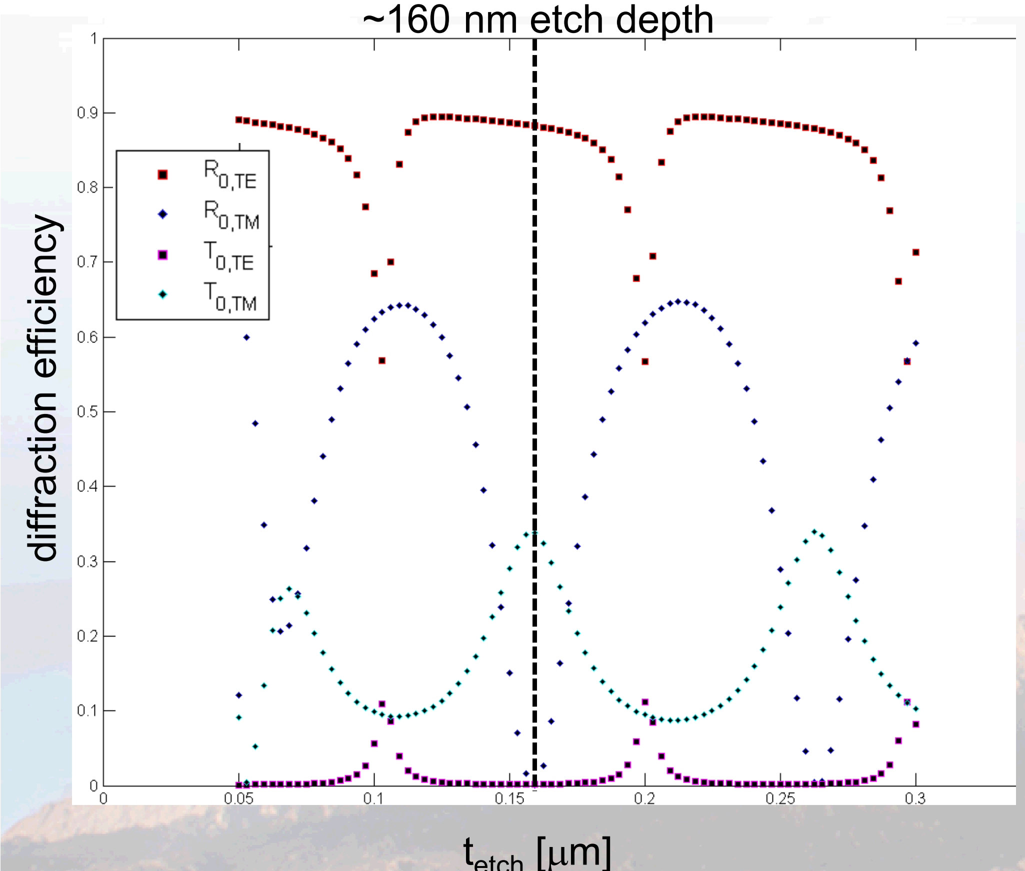


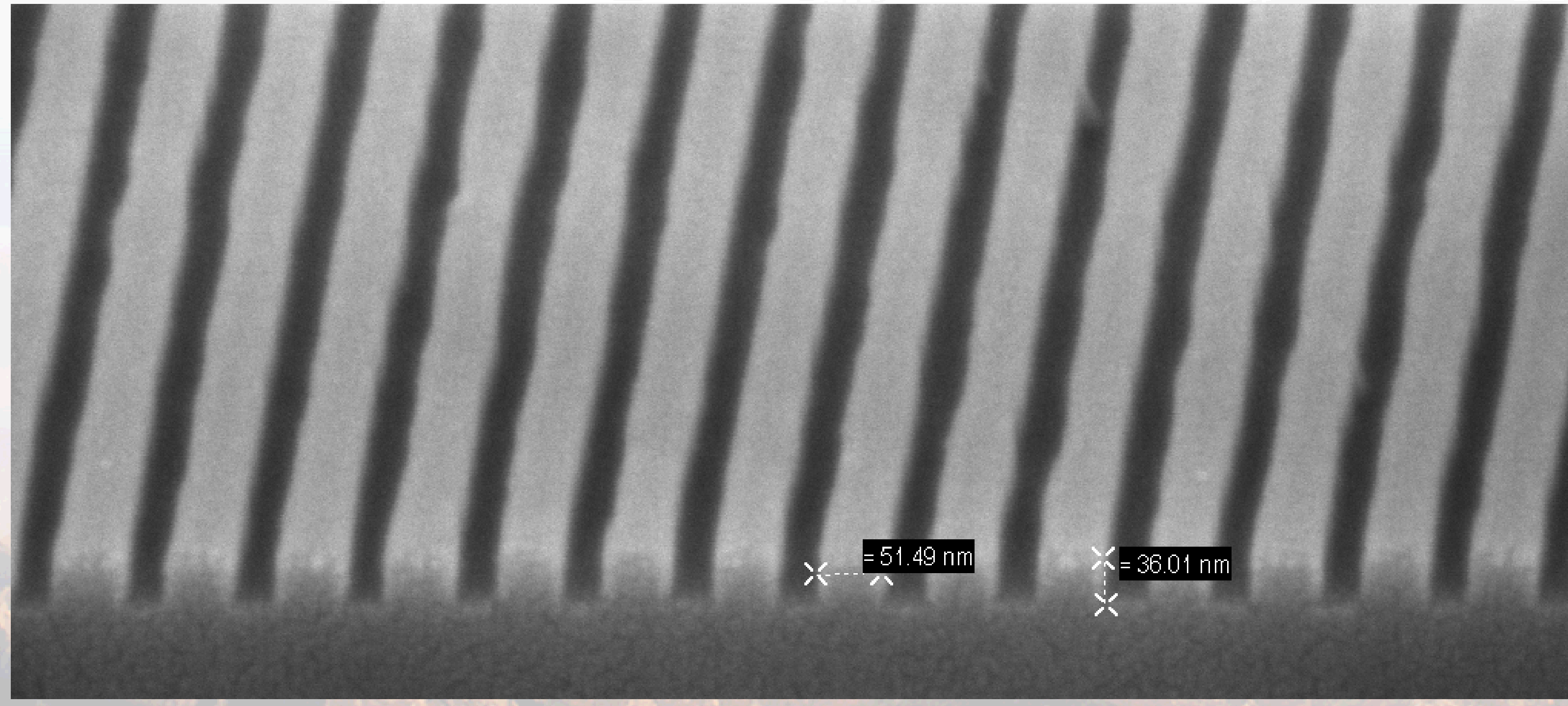
Wire Grid Polarizer





Transmission and Reflectance vs. etch (gap) depth
~160 nm etch depth





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Personnel Advancement

Matt George – employed at Moxtek
Jack Skinner – Professor at MT Tech

Charlie Liu – employed at IBM
Darin Pike – employed at SNL
Lance Williamson – close to graduating
Brandon Peters – close to graduating

Alex Raub – employed by Periodic Structures, Inc.
Ruichao Zhu – finishing 2nd year of grad school

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Publications

15 articles published, 4 articles currently in press, several more in preparation.

1. Yang C.Y.P.; Yang E.L.; Steinhaus C.A.; et al., “Planar-localized surface plasmon resonance device by block-copolymer and nanoimprint lithography fabrication methods,” *Journal of Vacuum Science & Technology B*, 30[2] 026801 (2012).
2. Yoshimoto K.; Peters B.L.; Khaira G.S.; et al., “Scalable simulations for directed self-assembly patterning with the use of GPU parallel computing,” *Proceedings of the SPIE, Alternative Lithographic Technologies IV*, San Jose, CA, USA, 8323, 83232P (2012).
3. Lo J.C.; Horsley D.A.; Skinner J.L., “Fabrication of large arrays of plasmonic nanostructures via double casting,” *Proceedings of the SPIE, Advanced Fabrication Technologies for Micro/Nano Optics and Photonics V*, San Francisco, CA, 8249, 824915 (2012).
4. Chi-Chun Liu; Thode C.J.; Rincon Delgadillo P.A.; et al., “Towards an all-track 300 mm process for directed self-assembly,” *Journal of Vacuum Science & Technology B*, 29[6] 06F203 (2011).
5. Guoliang Liu; Nealey P.F.; Ruiz R.; et al., “Fabrication of chevron patterns for patterned media with block copolymer directed assembly,” *Journal of Vacuum Science & Technology B*, 29[6] 06F204 (2011).
6. Pike D.Q.; Muumlller M.; de Pablo J.J., “Monte-Carlo simulation of ternary blends of block copolymers and homopolymers,” *Journal of Chemical Physics*, 135[11] 114904 (2011).
7. Liu Chi-Chun; Han Eungnak; Onses M. Serdar; et al., “Fabrication of Lithographically Defined Chemically Patterned Polymer Brushes and Mats,” *Macromolecules*, 44[7] 1876-1885 (2011).
8. de Pablo J.J., “Coarse-Grained Simulations of Macromolecules: From DNA to Nanocomposites,” *Annual Review of Physical Chemistry*, 62 555-74 (2011).
9. Ji Shengxiang; Liao Wen; Nealey Paul F., “Block Cooligomers: A Generalized Approach to Controlling the Wetting Behavior of Block Copolymer Thin Films,” *Macromolecules*, 43[16] 6919-6922 (2010).
10. Detcheverry Francois A.; Nealey Paul F.; de Pablo Juan J., “Directed Assembly of a Cylinder-Forming Diblock Copolymer: Topographic and Chemical Patterns,” *Macromolecules* 43[15] 6495-6504 (2010).
11. Chi-Chun Liu; Craig G.S.W.; Kang H.; et al., “Practical implementation of order parameter calculation for directed assembly of block copolymer thin films,” *Journal of Polymer Science, Part B: Polymer Physics*, 48[24] 2589-603 (2010).
12. Yuk-Hong Ting; Chi-Chun Liu; Sang-Min Park; et al., “Surface Roughening of Polystyrene and Poly(methyl methacrylate) in Ar/O_2 Plasma Etching,” *Polymers* 2[4] 649-63 (2010).
13. Chi-Chun Liu; Nealey P.F.; Raub A.K.; et al., “Integration of block copolymer directed assembly with 193 immersion lithography,” *Journal of Vacuum Science & Technology B*, 28[6] C6B30 (2010).
14. Yang E.L.; Liu C.C.; Yang C.Y.P.; et al., “Nanofabrication of surface-enhanced Raman scattering device by an integrated block-copolymer and nanoimprint lithography method,” *Journal of Vacuum Science & Technology* 28[6] C6M93 (2010).
15. Detcheverry F.A.; Pike D.Q.; Nealey P.F.; et al., “Simulations of theoretically informed coarse grain models of polymeric systems,” *Faraday Discussions*, 144 111-25 (2010).

Summary

- 1x, 2x, 3x, 4x density multiplication via DSA
- Simulation and experiment actually correspond!
- Pattern transfer by etching, ALD infiltration, NIL
- NIL from BCP → plasmonic device
- Metrology processes developed, demonstrated