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

April 2010 update

SNL
Geoff Brennecka (PI)
Bruce Burckel
Matt George
Jack Skinner
Peter Yang
Chip Steinhaus
Sarah Allendorf (PM)

University of New Mexico
Prof. Steve Brueck
Alex Raub
Philip Hakeem

Intel
Todd Younkin
David Shykind
Mike Garner

ExxonMobil
Mark Disko

University of Wisconsin
Prof. Paul Nealey
Prof. Juan de Pablo
Charlie Liu
Darin Pike
Lance Williamson
Brandon Peters

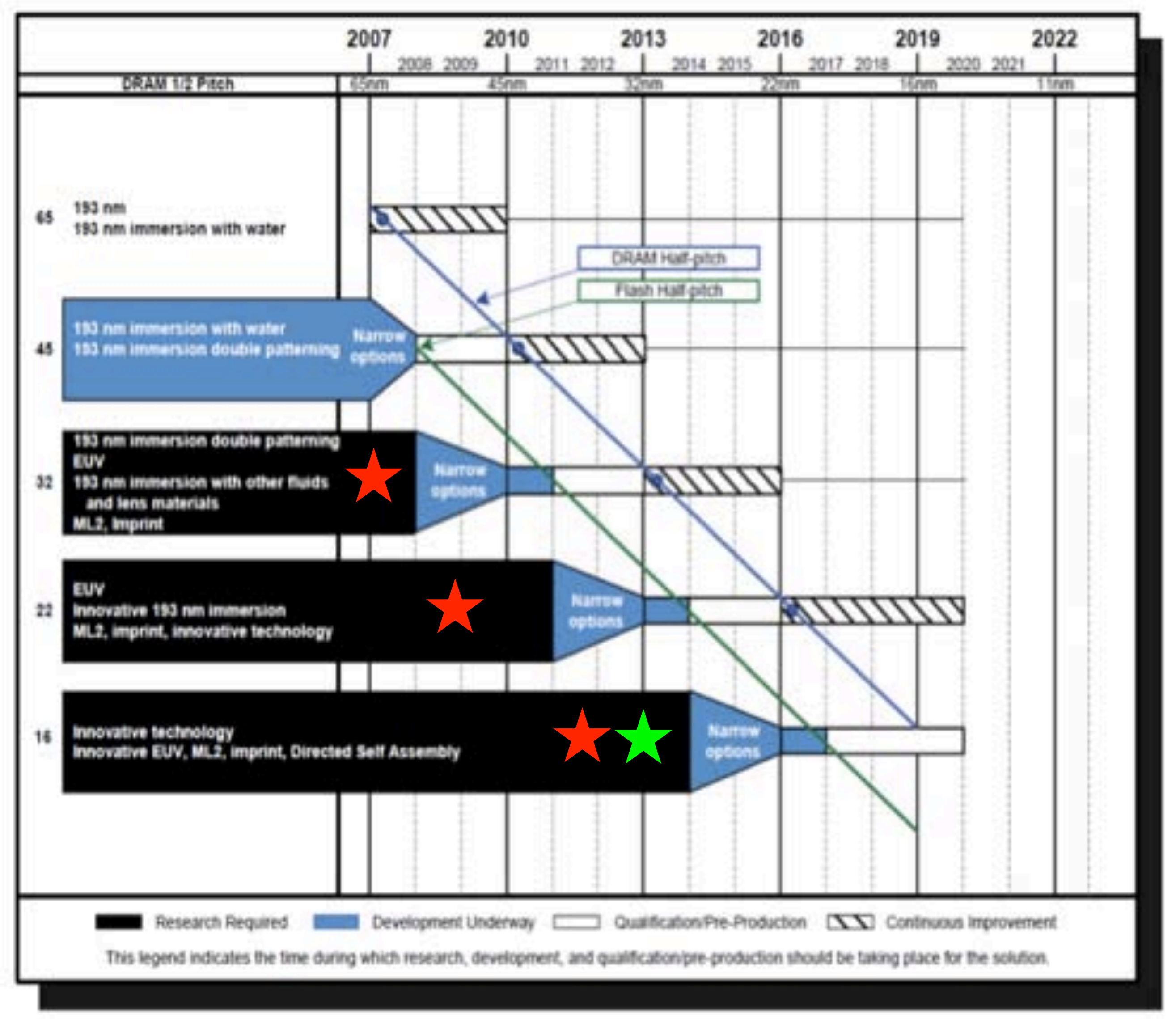
Sandia National Laboratories

Outline

- Brief Review of Concept/Goals (Brennecka)
- Programmatic Update (Brennecka)
- IL Update (Brueck)
- DSA/DBCP update (Nealey and de Pablo)
- NIL update (Skinner)
- Metrology update (Burckel)
- Input from Industry Partners

International Technology Roadmap for Semiconductors (ITRS)

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



Our charge: explore the feasible limits for critical parameters (e.g., CD, defect densities, LRO, LER, etc.) especially as they relate to other relevant parameters (e.g. annealing time for assembly, size and size distribution of directing features, pattern transfer processes, etc.)

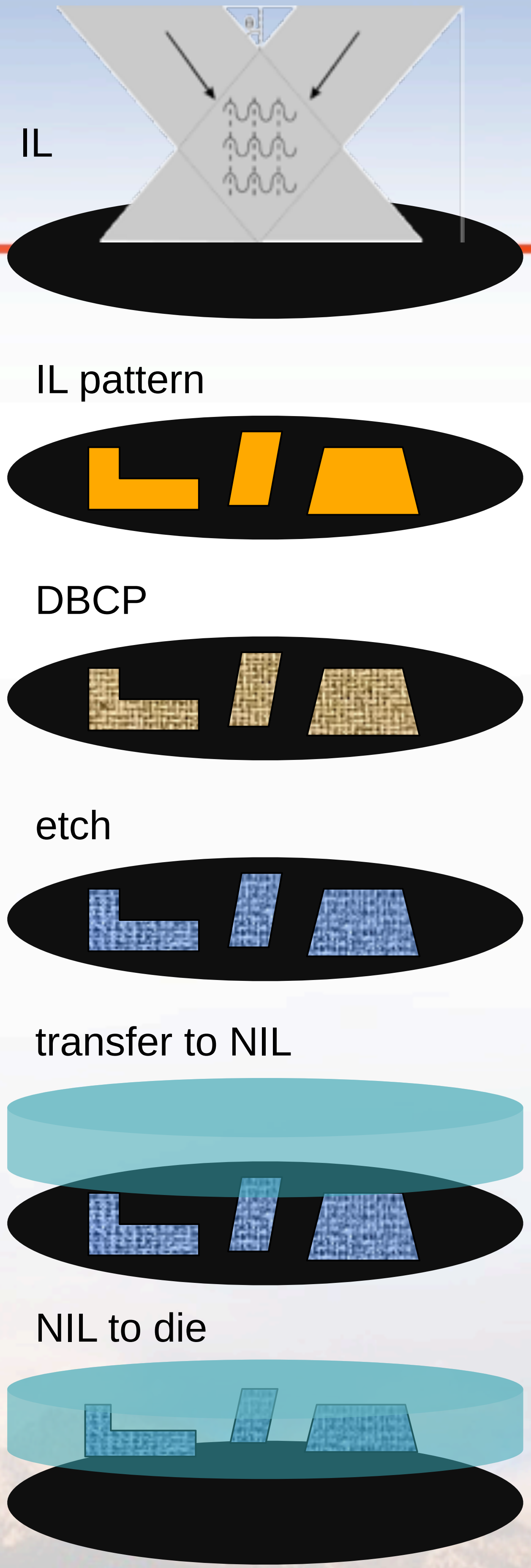
- **Optical Lithography Limit:**
  - **32 nm ½ pitch (193 nm, H_2O, double exposure)**
- **Next Generation Lithography (NGL)**
  - **Extreme Ultraviolet Lithography (EUVL)**
    - **13.2 nm soft x-ray source power**
    - **High-resolution resist development**
    - **Low Line Edge Roughness (LER)**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

Proposed Route

Top-down + Bottom-up

Optical Interference Lithography (IL)
+
Directed self-assembly of di-block-copolymers (DBCP)
+
Nano-Imprint Lithography (NIL)

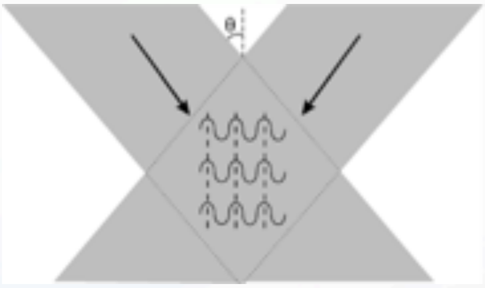
- **Use Interference Lithography (IL) to define chemical pre-patterns**
  - **60-90 nm pitch over ~4 cm^2 areas**
  - **avoid e-beam**
- **Directed self-assembly of di-block copolymers (DBCP)**
  - **20-30 nm pitch device patterns**
  - **10-50 nm CDs**
  - **Half-pitch to ~11 nm over ~4 cm^2 areas**
- **Pattern transfer to create Nano-Imprint lithography (NIL) template masters**
  - **Characterize CD, uniformity, defect density, LER, etc.**
  - **Demonstrate reliable pattern transfer over large areas**
- **Use NIL to demonstrate prototypes of three devices**
  - **Hybrid 1D/2D plasmonic resonator**
  - **Nanowire transistor/sensor array**
  - **Crossbar nanowire array**

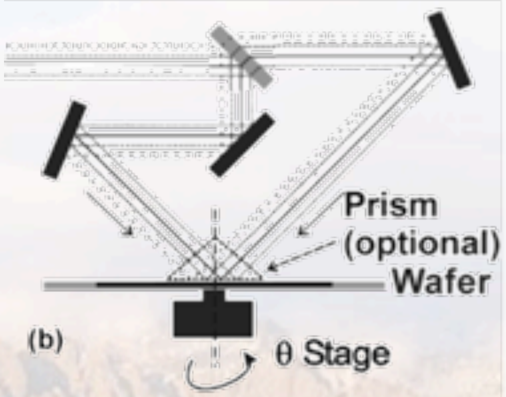


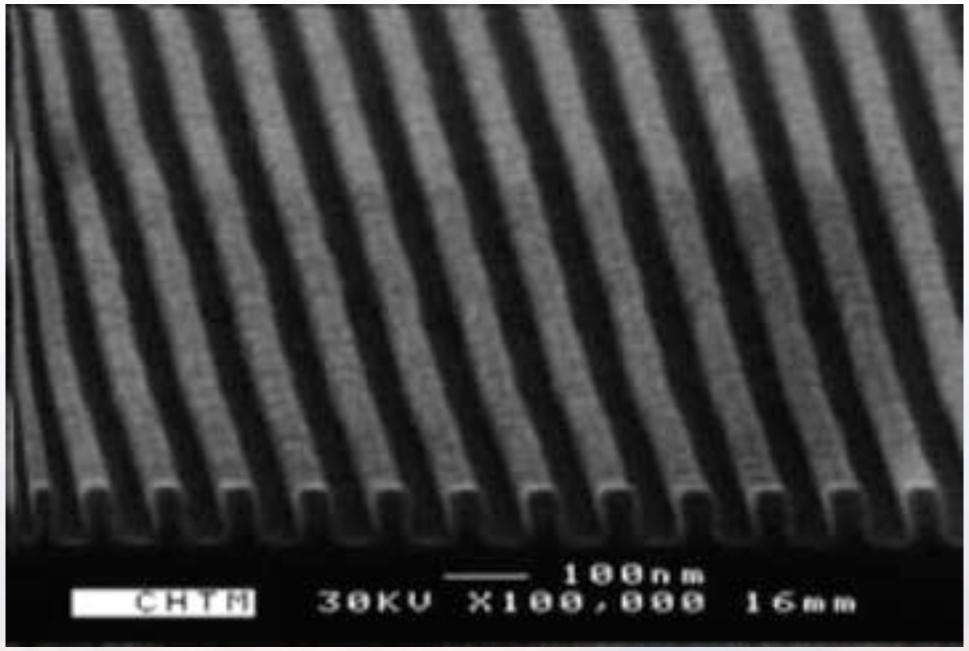
Optical Interference Lithography

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

- An interference pattern is 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 4cm^2







Brueck, Proc. IEEE 93 1704 (2005)

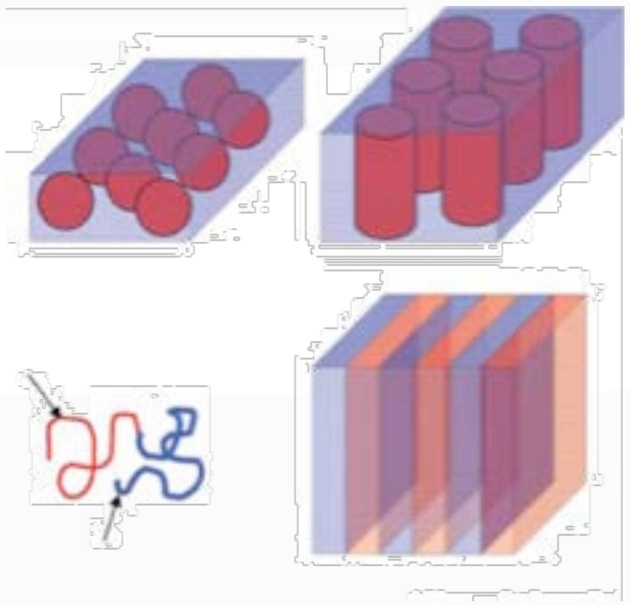
- Receive wafers with chemical brush layer from UW
- Coat with photoresist
- Pattern with IL
- Area ~ 4cm^2
- CD range 60-100 nm

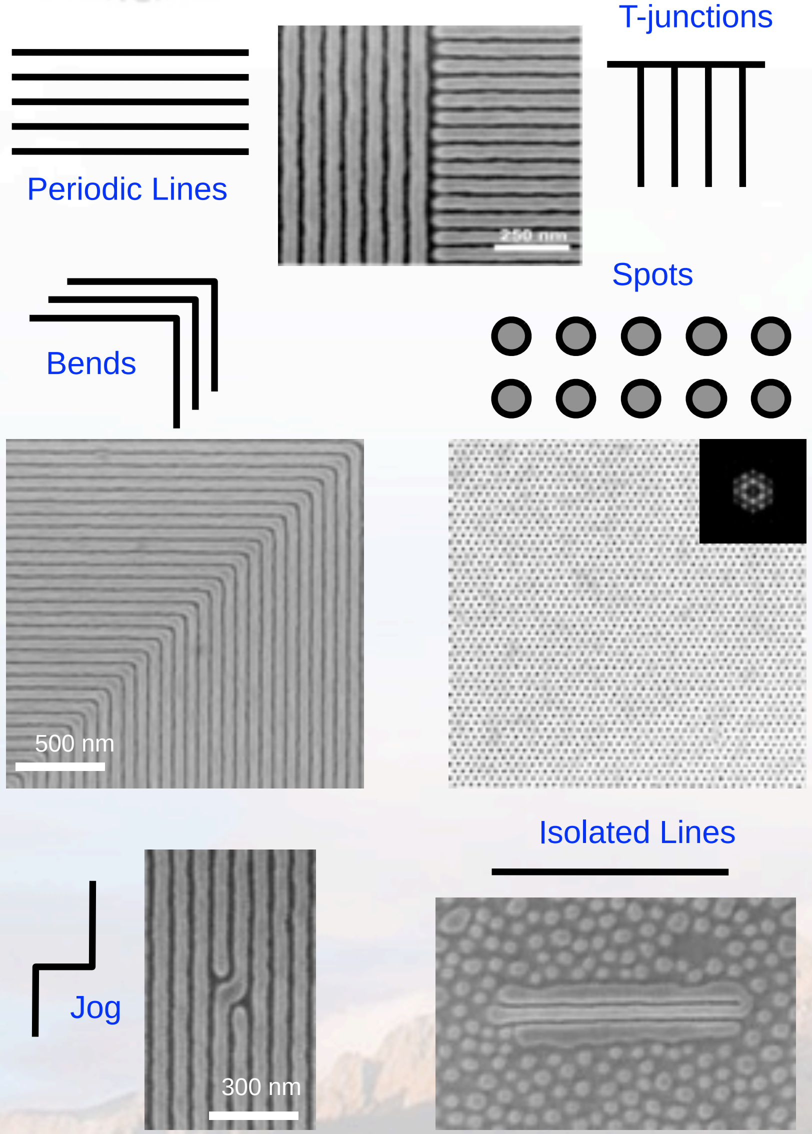
Block-Copolymer Self Assembly

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

- **DBCP: two immiscible polymer covalently bonded together**
- **Periodicity depends on the polymer molecule length and morphology depends on the volume fraction of each block**
- **Structures include lamellae, cylinders, spheres, and gyroids**

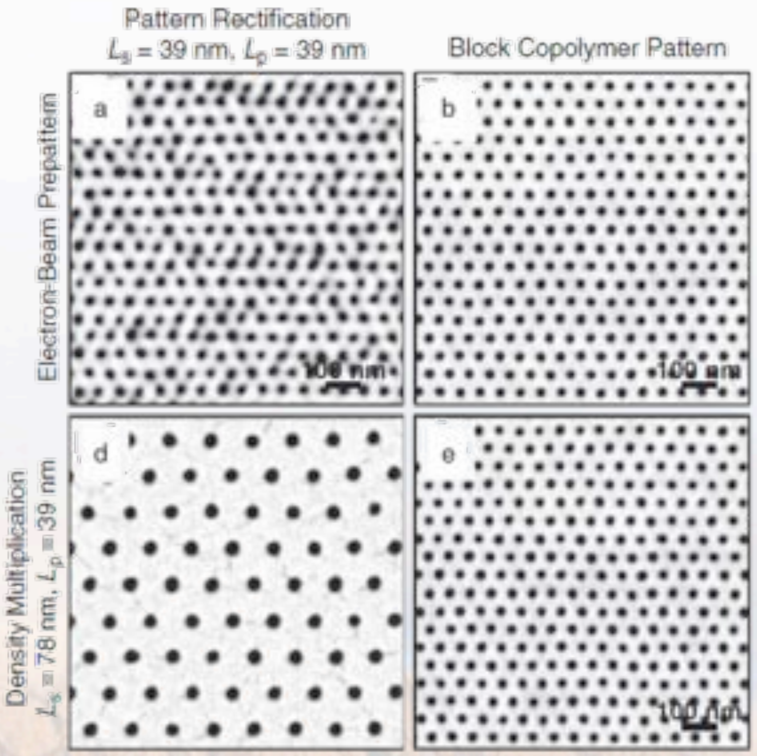
Ross *et al*., MRSB 33 838 (2008)





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

- Receive patterned chemical brush layer from UNM
- Spin-coat block copolymer
- Polymer candidates, polystyrene, PMMA
- Anneal to drive self-assembly (lamellae or cylinders)
- Selectively remove one polymer and brush layer
- Leverage density multiplication to reduce dimensions below 50 nm
- Model mechanisms for polymer and surface interactions, separation, structure formation

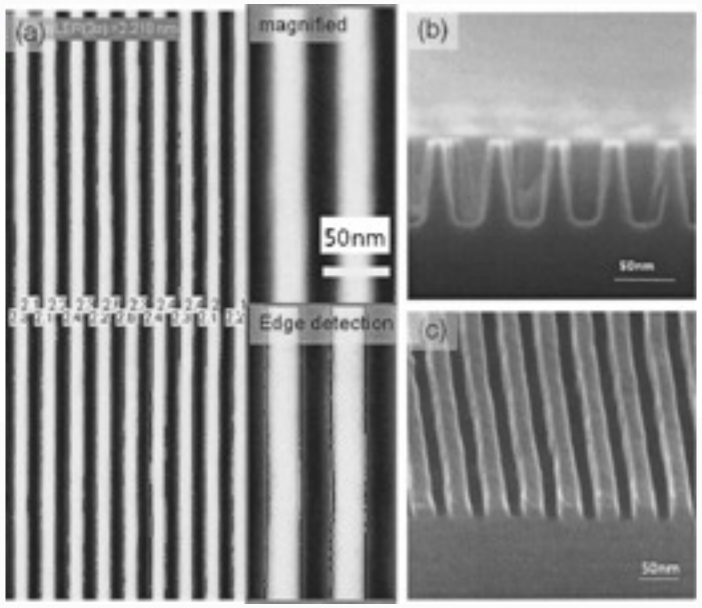


Ruiz *et al*., Science 321 936 (2008)

Pattern Transfer/Metrology

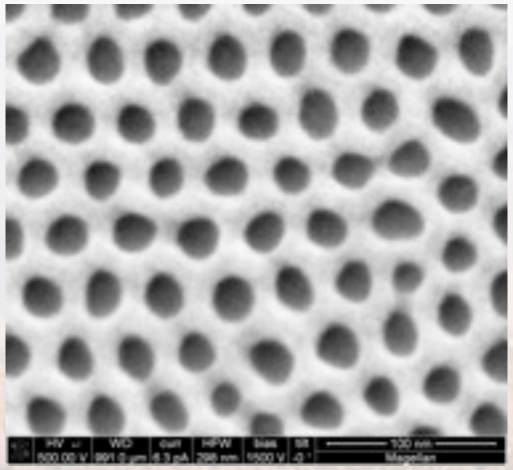
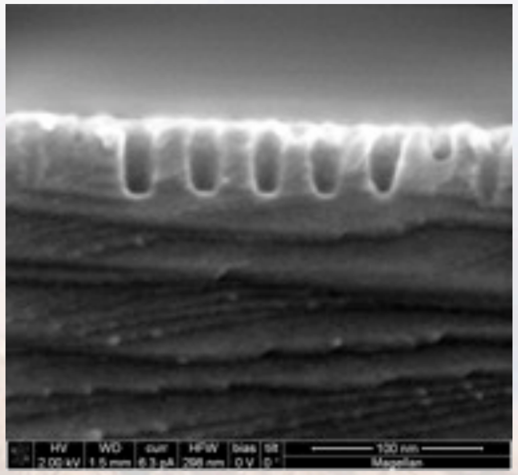
Geoff Brennecka, Bruce Burckel, Matt George

- **The sub-100 nm DBP-based patterns will be used as etch masks, enabling pattern transfer into the substrates by high-density plasma etching**
  - **Dry etching combines chemical reactivity with physical ion bombardment to selective remove desired materials at greater rates than the mask materials**
  - **Material removal is inherently anisotropic**
  - **High-density tools enable independent control of ion energy and density, providing more control over feature profiles, sidewall roughness, etching rates, selectivity**
  - **SOI-type substrates can finely control etch depth by providing an etch stop**
  - **DBCP etch masks and pattern transfer fidelity will be characterized using AFM, SEM, CDSEM, etc.**



Liu *et al.*, JVSTB 25 1963 (2007)

- Receive DBCP-patterned wafers from UW
- Transfer pattern into underlying substrate films using plasma etching
- Characterize defect density, CDs, LER, defect densities before and after etching with high-resolution SEM, AFM
- Demonstrate reliable pattern transfer over large areas
- Fabricate DBCP-NIL prototype devices

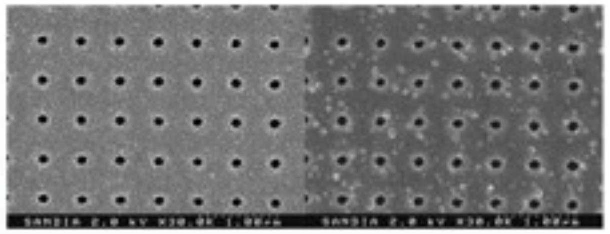
Nano-Imprint Lithography

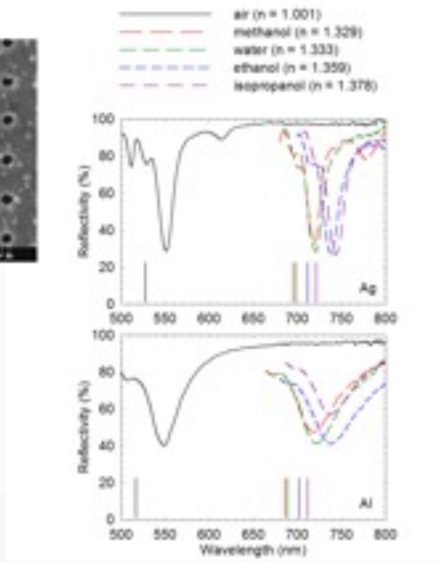
Jack L. Skinner, Peter Yang, Elaine Yang, Chip Steinhaus

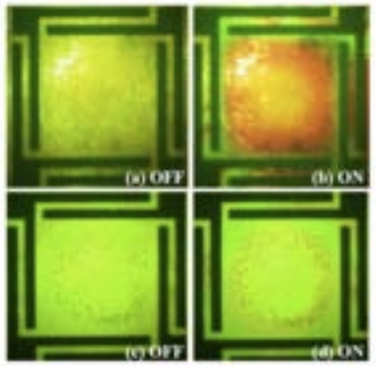
Nanoimprint lithography (NIL) uses a mold to transfer patterns into a thermally or UV cured resist

- **NIL can be used to fabricate large areas of features with sizes <10 nm.**
- **Compared with e-beam and FIB, NIL can pattern entire wafer surfaces in the matter of minutes, which is important for high throughput**
- **NIL is cost effective and shows great promise as an economical nanoscale manufacturing technology.**
- **We have used NIL to create:**
  - **Plasmonic optical sensors for visible light**
  - **Nanowire chemical sensors**
  - **Narrow band optical modulators**

Skinner *et al*., TNANO. 7 527 (2008)

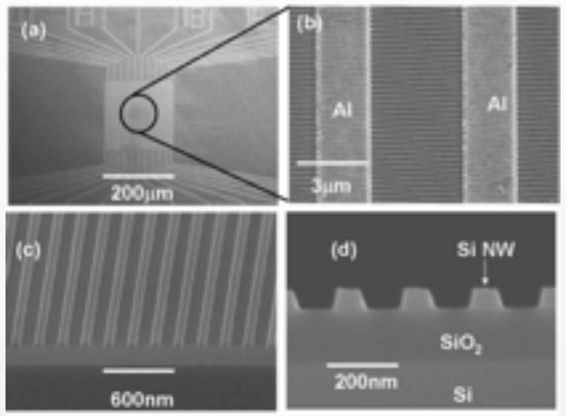


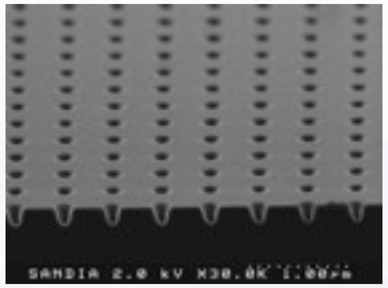




Skinner *et al*., Opt. Express 16 3701 (2008)

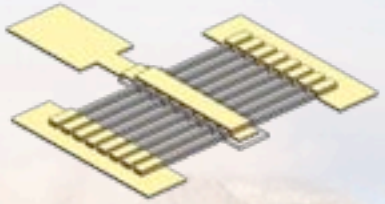
Talin *et al*., APL. 89 153102 (2006)



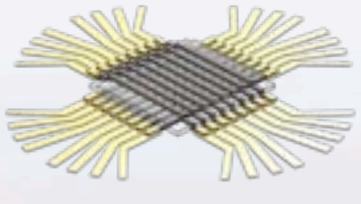


- Receive NIL Templates from SNL-NM
- Pattern wafers using NIL templates
- Characterization of defect density, CDs, LER, defect densities (SNL-NM)
- Design device patterns/masks
- Pattern prototype devices
- Fabricate devices (w/SNL-NM)
- Characterize device performance

Hybrid 1D/2D plasmonic resonator

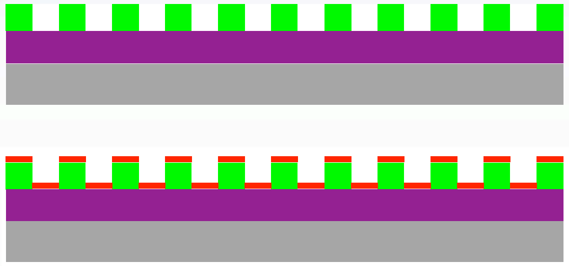


Nanowire transistor sensor array



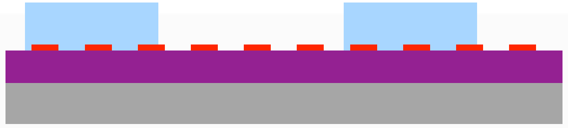
Crossbar nanowire array

Demonstration Structures

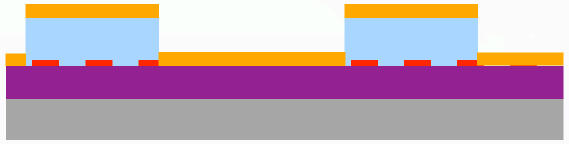


BCP shown after deposition, annealing, and removal of minority block

1D plasmonic structures after lift-off of majority block

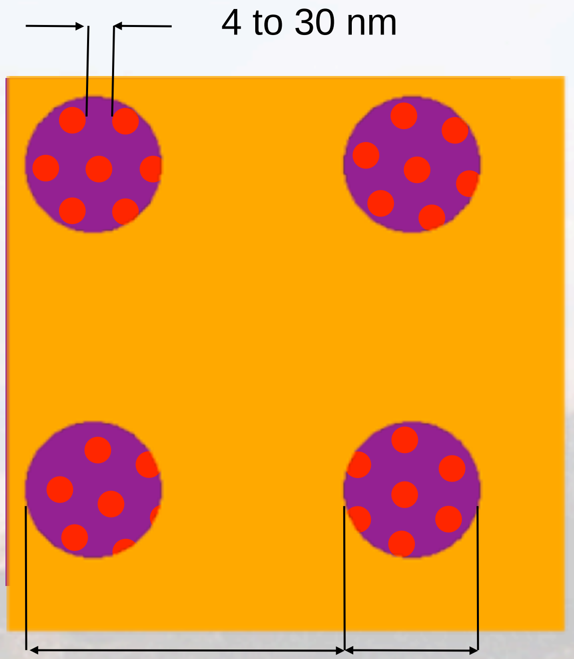


PMMA cylinders shown after NIL



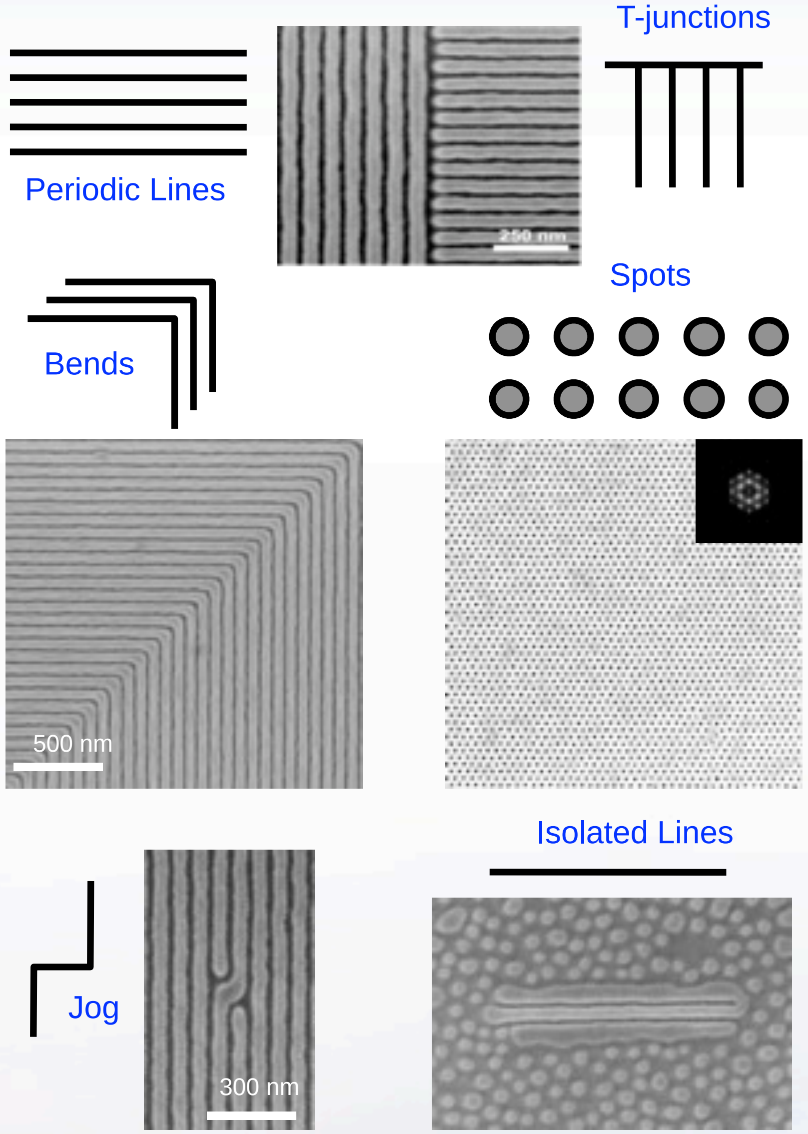
Second metal deposition with evaporation

Integrated 1D/2D plasmonic device shown after final lift-off



Top view of 1D/2D plasmonic device.

Start with straightforward plasmonic structure to establish proof of concept and initiate characterization; structure can also be fabricated with IL-directed self assembly (not shown).



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

Eventually demonstrate ability to fabricate wide variety of feature types, sizes, and pitches all on single die. Quantify defects at every stage, independent and compounding

Technical Goals and Milestones

The overall goals are to demonstrate IL+DBCP+NIL as a viable method for patterning large areas with low defect densities, fabricate prototype electronic and photonic devices with this technology, push CD to 11 nm half pitch, and increase understanding of directed DBCP self assembly mechanisms through modeling and simulation

Goal	Milestone	Completion Date
NIL template using IL directed BCP assembly (20nm half pitch)	IL directed BCP assembly (lines and dots, 20nm half-pitch	06/30/2010
	Si template fabrication	09/30/2010
	Quantitative characterization of pattern quality	12/31/2010
Photonic/electronic device prototypes	Hybrid 1D/2D plasmonic resonator	04/30/2011
	Nanowire transistor array	08/31/2011
	Crossbar nanowire array	12/31/2011
NIL template using IL directed BCP assembly (11nm half pitch)	IL directed BCP assembly (lines and dots, 20nm half-pitch)	06/30/2012
	Si template fabrication	09/30/2012
	Quantitative characterization of pattern quality	12/31/2012
	Submit SAND report	12/31/2012

Programmatic Update

- **Funding**
  - – NINECo corporate funding still awaiting IP agreements (?)
  - – Budgeted for $70k, appears that only $55k will be coming through; SNL will take the hit this year

- **Next meeting:**
  - – EIPBN is 7 weeks out (June 1-4); propose either:
    - project meeting 1-2 weeks before EIPBN to (p)review content for talks
    - project meeting 1 or 3 weeks after EIPBN, including new ideas
  - – NINE ‘nano-expo’ is June 6-12; more details should be coming from Regan...

- **Students**
  - – UNM still searching for a replacement for Philip Hakeem
  - – Lance Williamson will be at SNL-NM this summer with access to both SNL and UNM facilities; Brandon’s status is pending, but should be in ABQ with access to supercomputer facilities
  - – Students budgeted for university pay rates; supplemental contracts to bring their pay in line with ‘normal’ SNL student interns?

- **Internal SNL project review at end of April**
  - – Considering excellent progress so far, do not anticipate problems
  - – Welcome any figures, prose for inclusion