SAND2011-1543C

Directed Patterning and Fabrication of Functional Nanoscale Electronic Oxides

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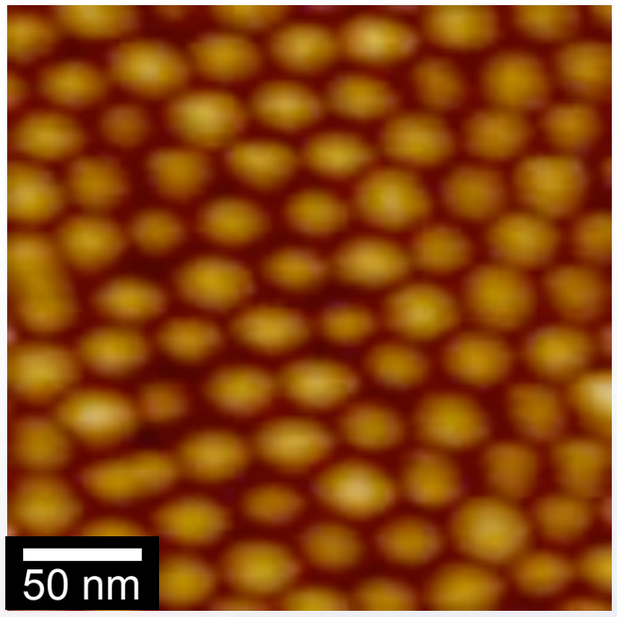

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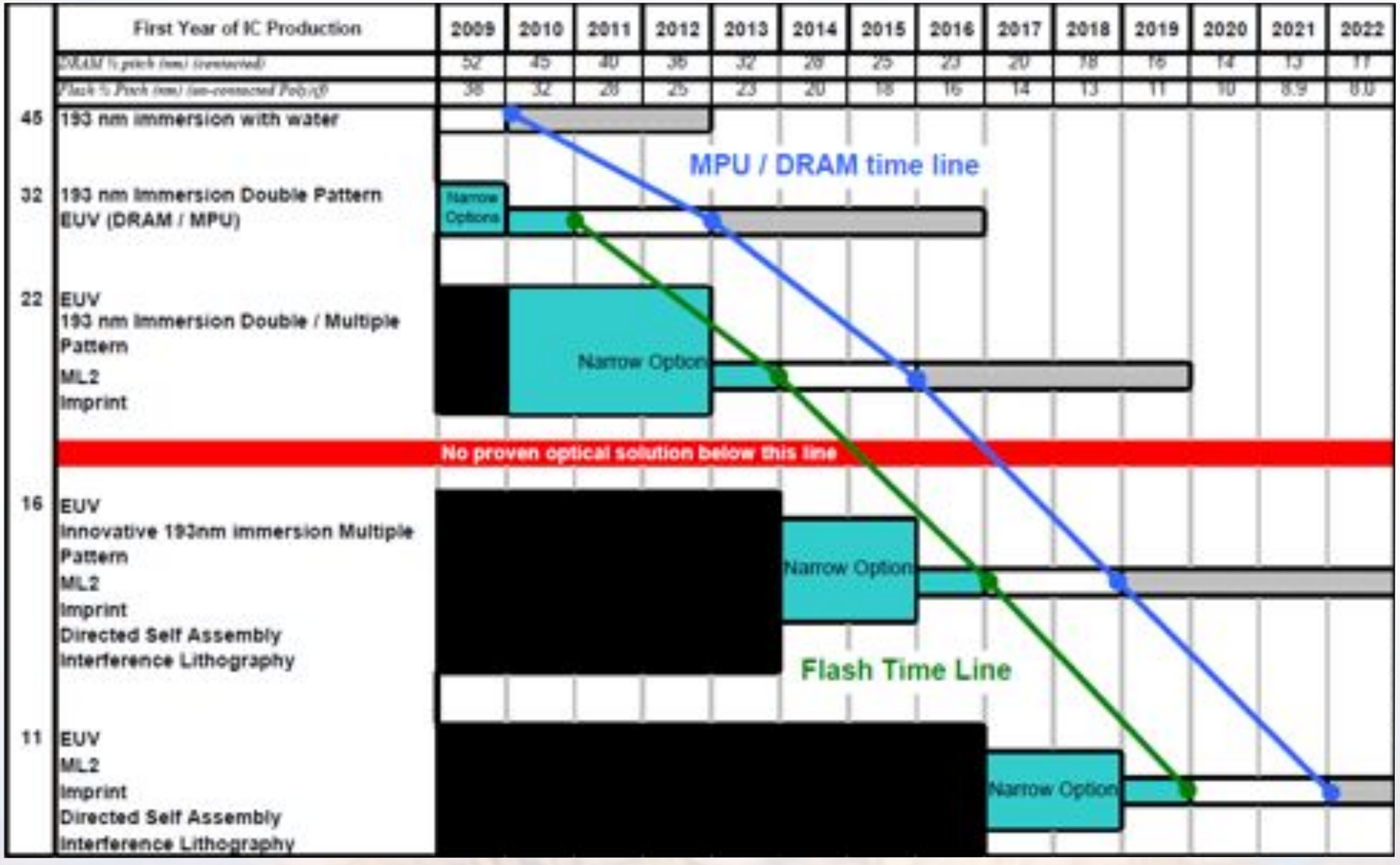
Doing Moore with the Same?



ITRS 2009

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Doing More with the Same?

Integration of materials with new and/or increased functionality

From MRS Bulletin v33 (2008), originally from TI, Ramtron

General Fabrication Technique for Controlled Nanopatterning

- Any material, any substrate
- Arbitrary, addressable features/patterns
- Platform for size/interface effects studies, device development, etc.

Why Ferroelectrics?

- Demonstrate broad applicability
- Study fundamental lateral size and aspect ratio effects
- Ultrahigh density NVRAM

Target Demo Application

Information Storage (NVRAM)

- Reduce physical size
- Reduce power consumption
- Improve operation through interface control

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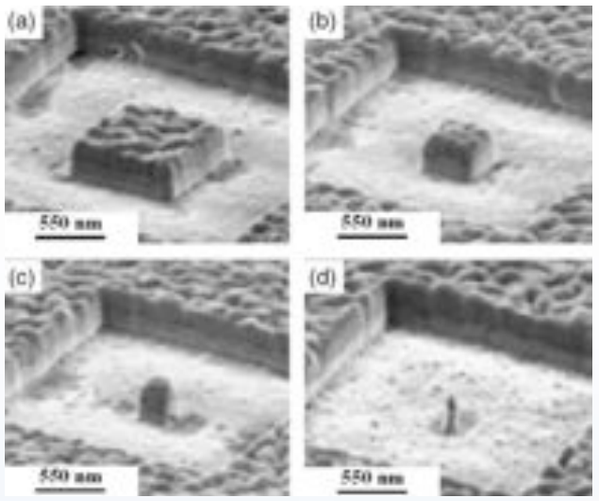
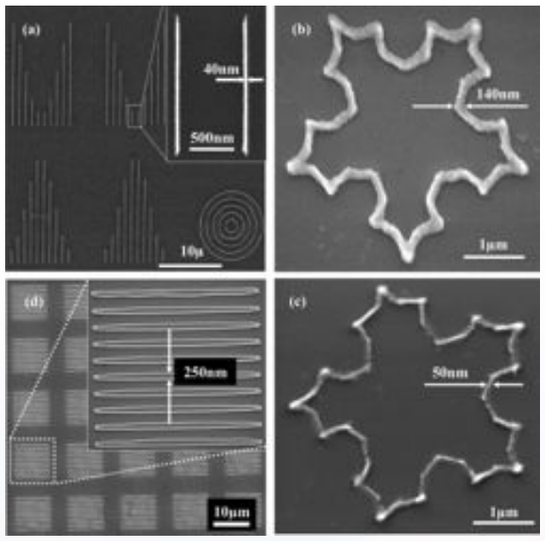
Micro-, Nano-Patterning of Arbitrary Materials

- **Challenges of expanding beyond ‘standard’ materials**

Fabrication | **Patterning** | **Integration** | **Performance**

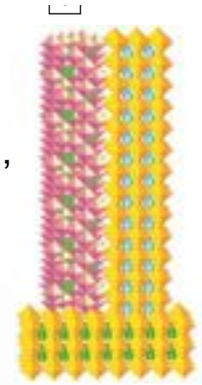


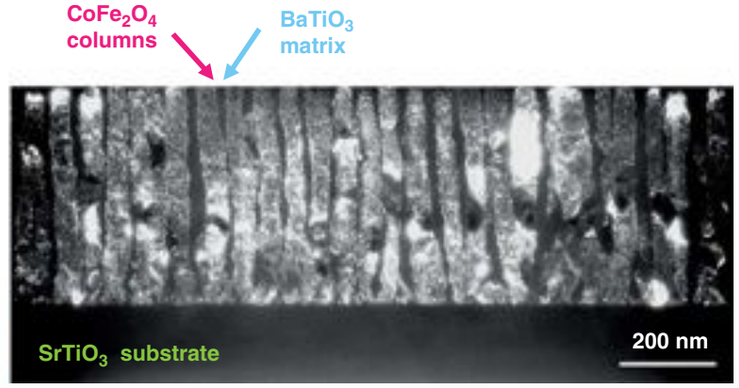
Ganpule et al., MRS Proc. (2001)

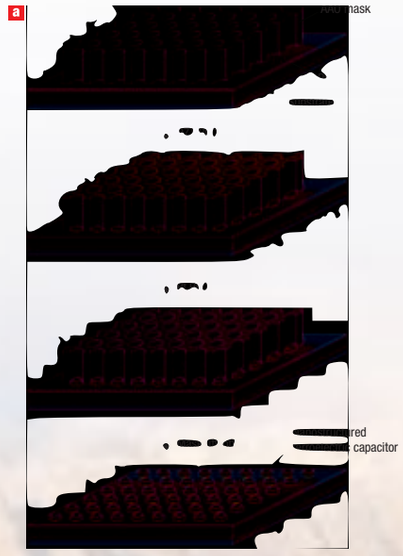


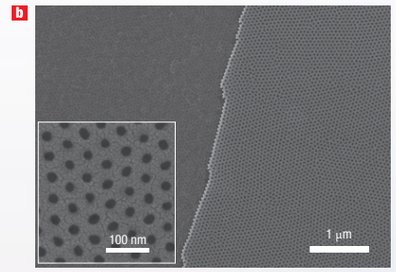
Donthu et al., Nano Lett. (2005)

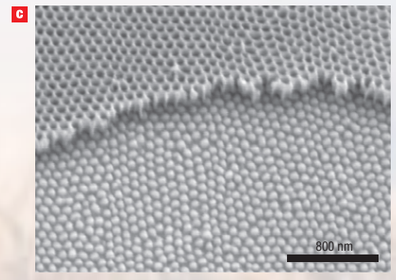
Zheng et al., Science (2004)











Lee et al., Nature Nano (2008)

- Need functional crystalline nanostructures in predetermined locations without needing to develop new etching / integration approaches for each new material(s)

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Overview of Our Approach

- Goal: Combine flexibility and functionality of chemical solution deposition with use of e-beam and BCP patterning capabilities

Solution Deposition

Fabrication

Patterning

Integration

Performance

Feature Definition

Fabrication

Patterning

Integration

Performance

Challenges:

- Avoid etching functional materials
- Avoid any fab-based processes during/ after deposition of functional materials
- Maintain feature integrity after thermal treatment(s)
- Retain function in nanoscale features

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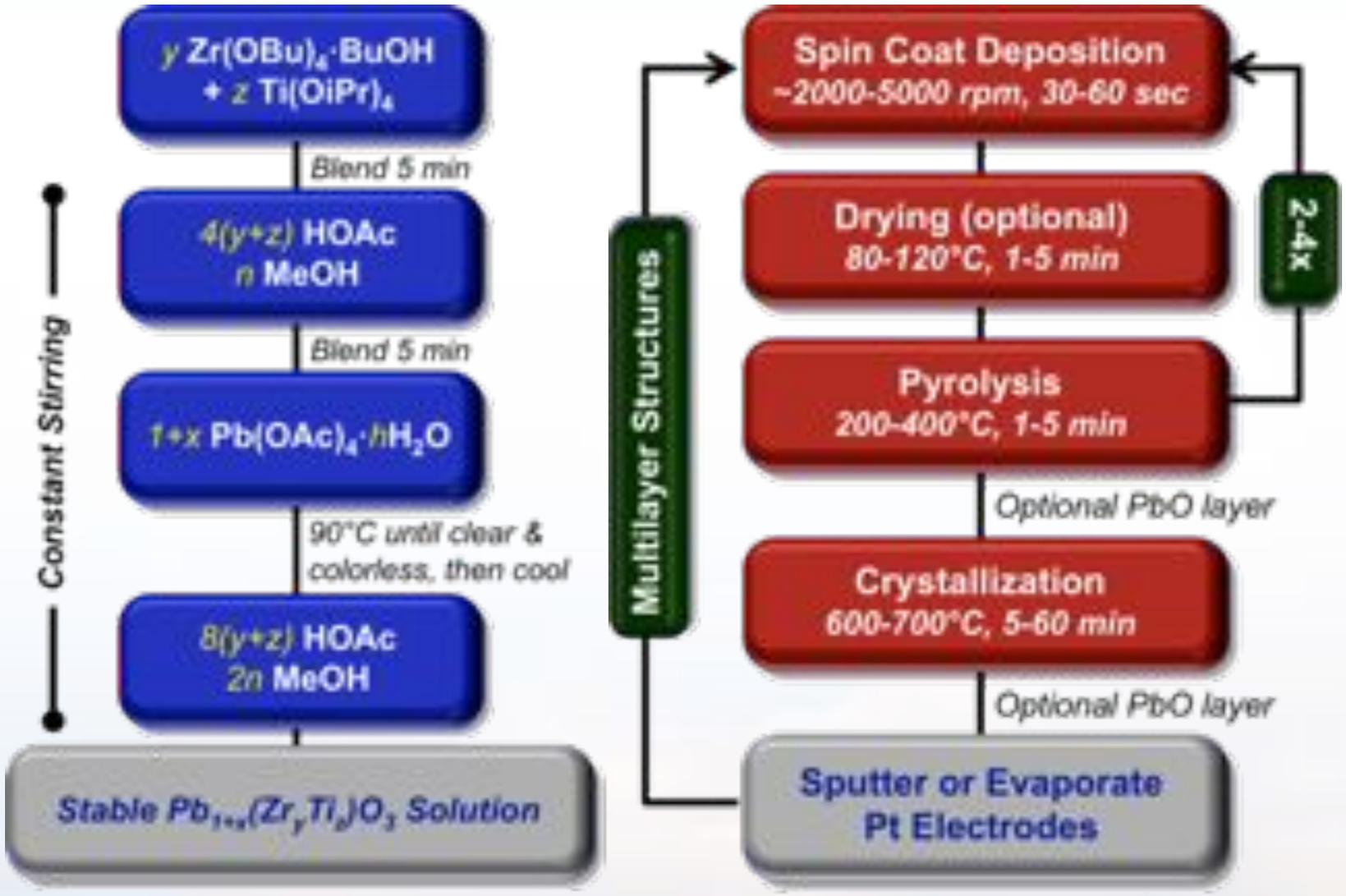
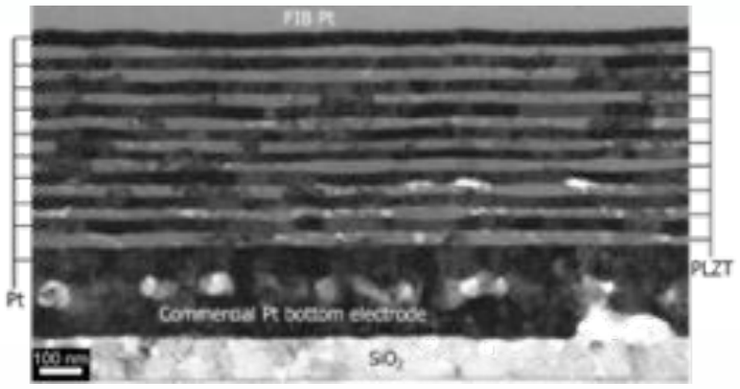
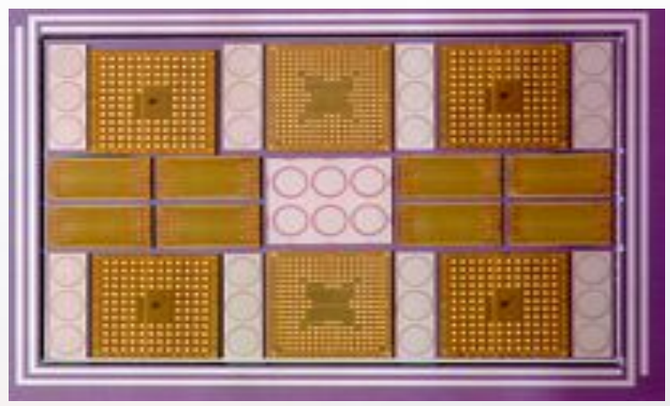
SNL IMO-based Solution Route





Functional thin film multilayer capacitor structure



Multichip module with PZT thin-film capacitor arrays

R.A. Assink and R.W. Schwartz; **Chem. Mater.** (1993)
G. Yi and M. Sayer; **J. Appl. Phys.** (1988)
Brennecka et al., **J. Am. Ceram. Soc**. *feature article* (2010)

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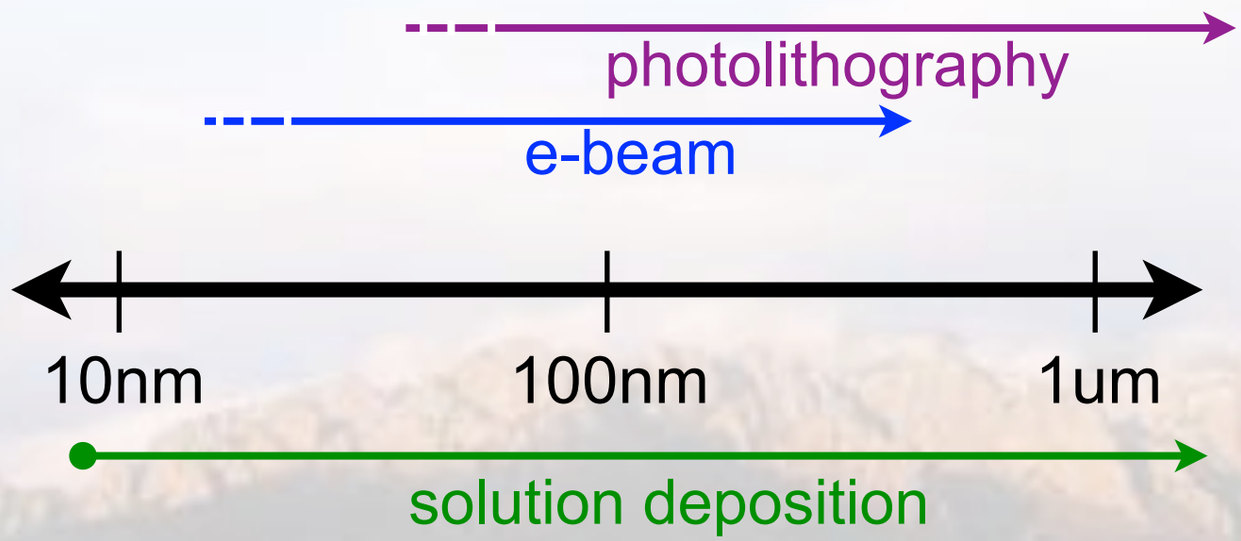
Pattern Definition

- **Continuous films are very limited in function**
- **Difficulties of etching PZT-based films**
  - Access to tools...
  - Property/reliability degradation
- **Alternative approaches to patterning/integration**
  - Direct write
  - Microcontact printing
  - Various transfer techniques
  - PZT-friendly lithography
  - (Directed) self-assembly



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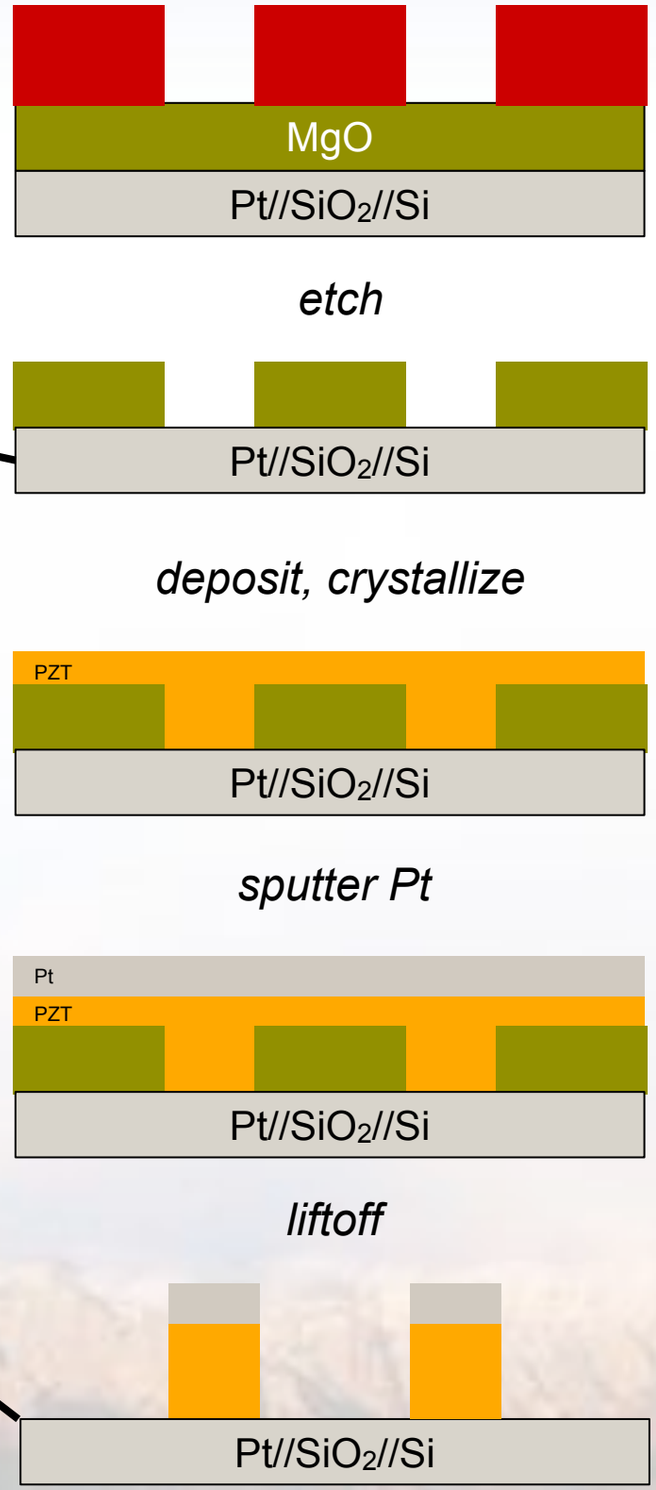
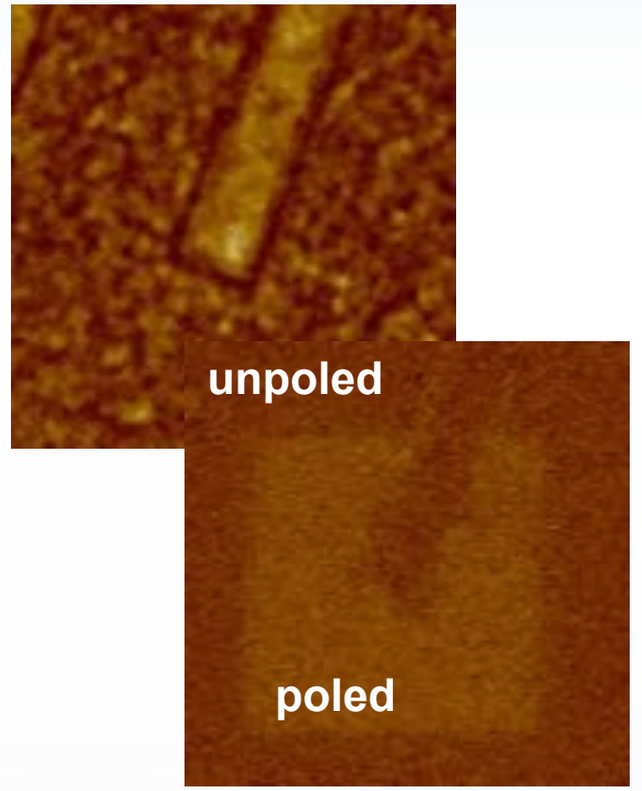
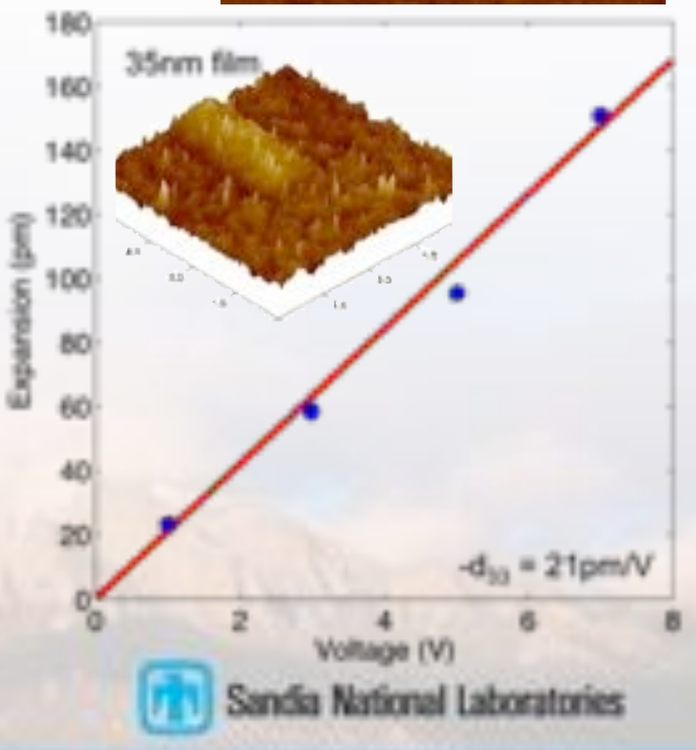
Microscale Patterning







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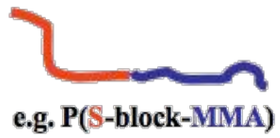

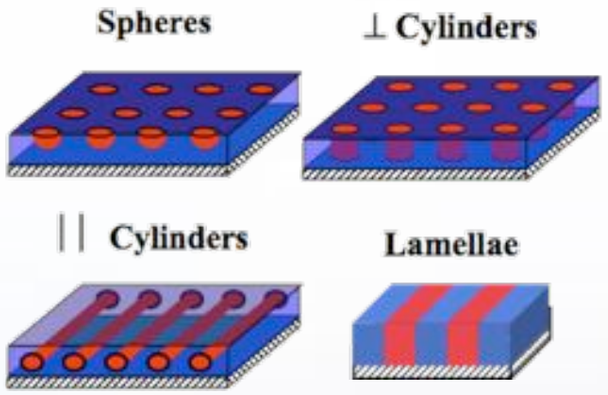

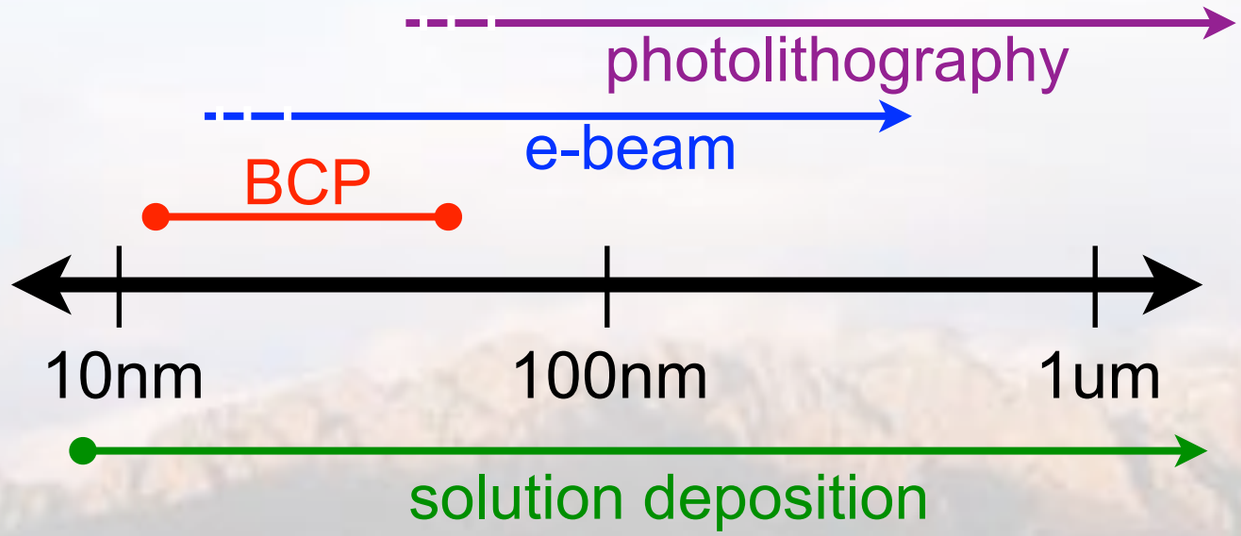

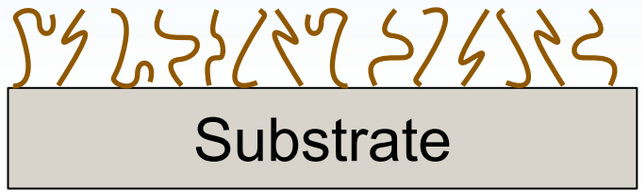

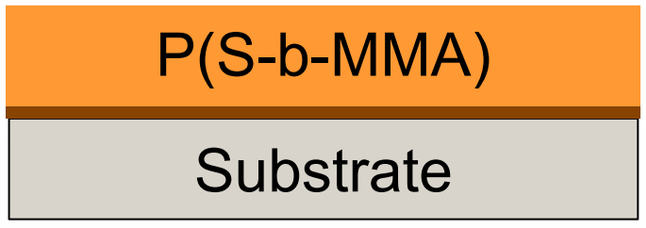

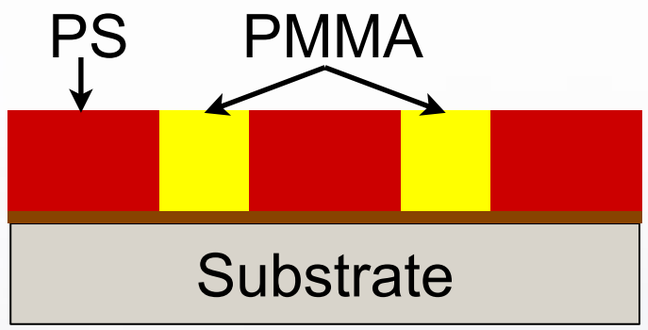

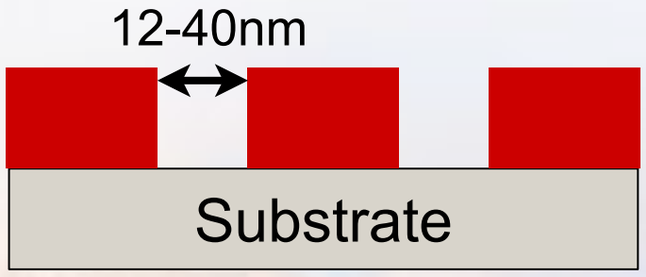

Guarini, K W, et. al., *J. Vac. Sci. & Tech. B*, 2001, **19** (6), 2784-2788

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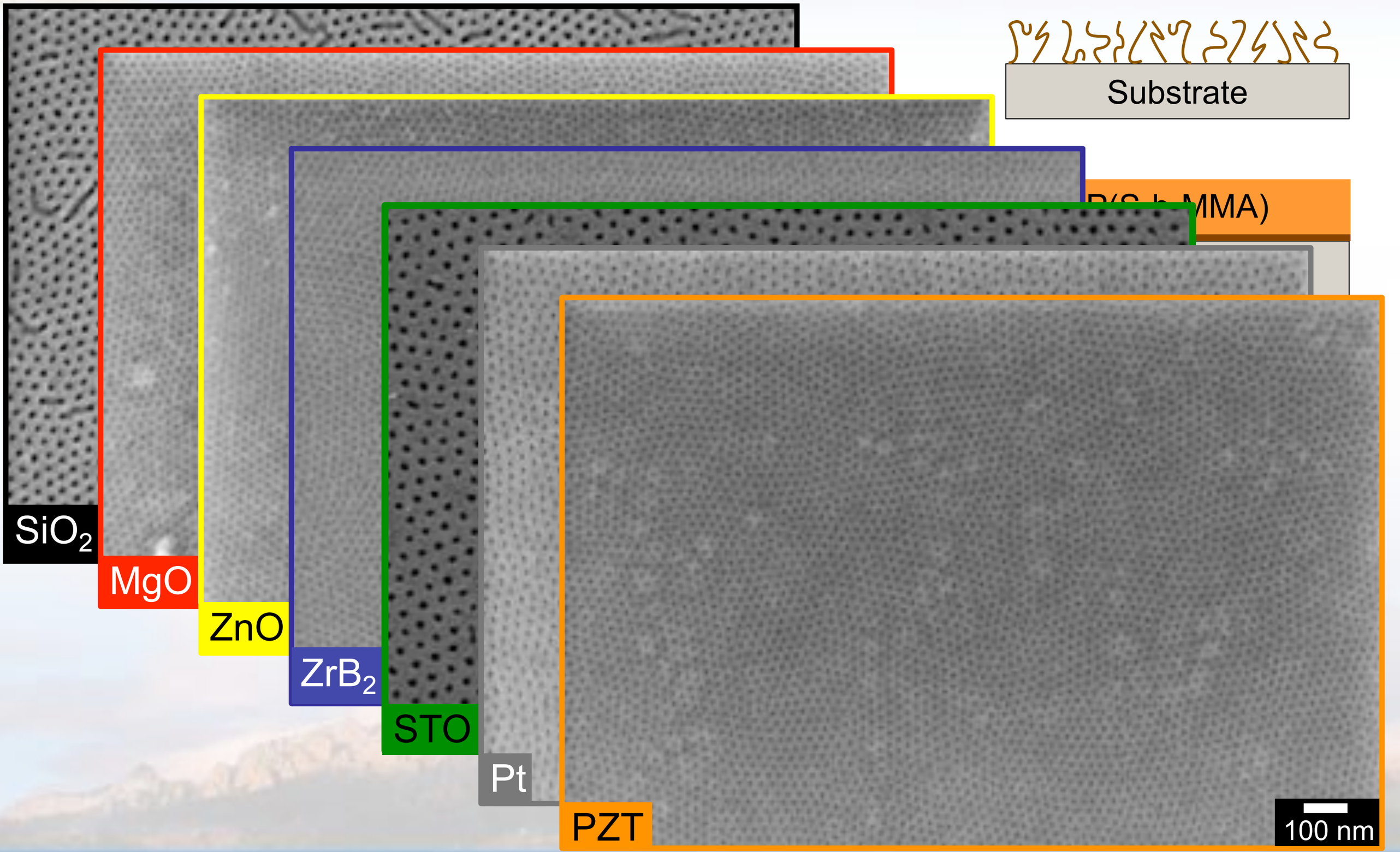
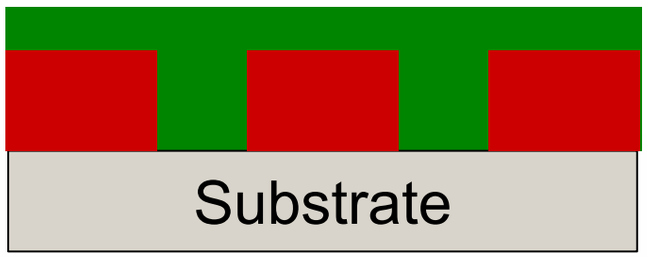
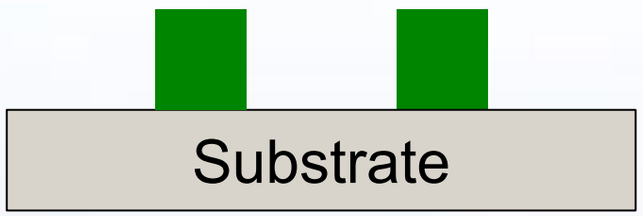
Diblock Assembly on Various Substrates



Additive Fabrication of Patterned Electronic Oxides

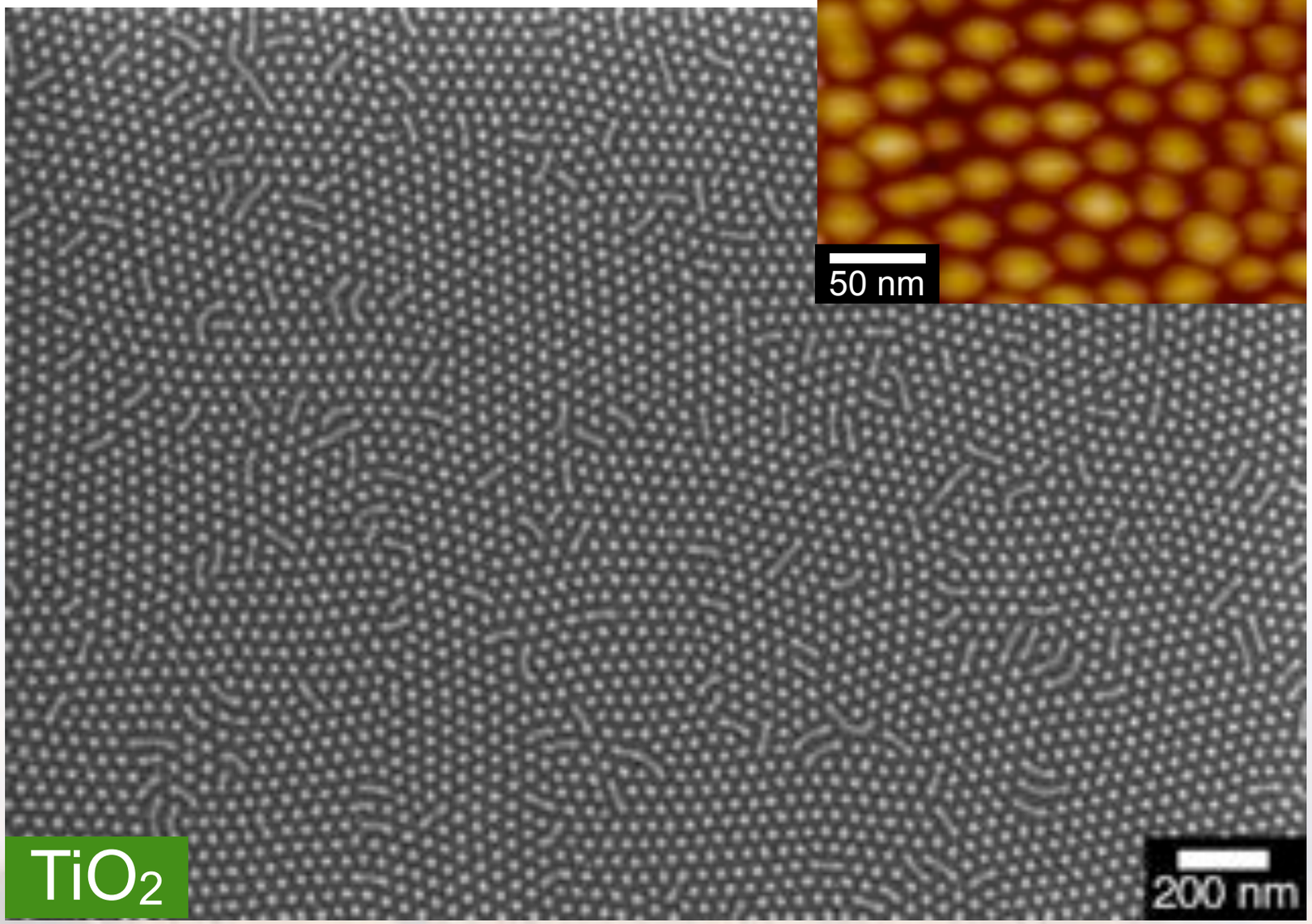


Fill, Gel



Remove Mask

$CHF_3 + O_2$



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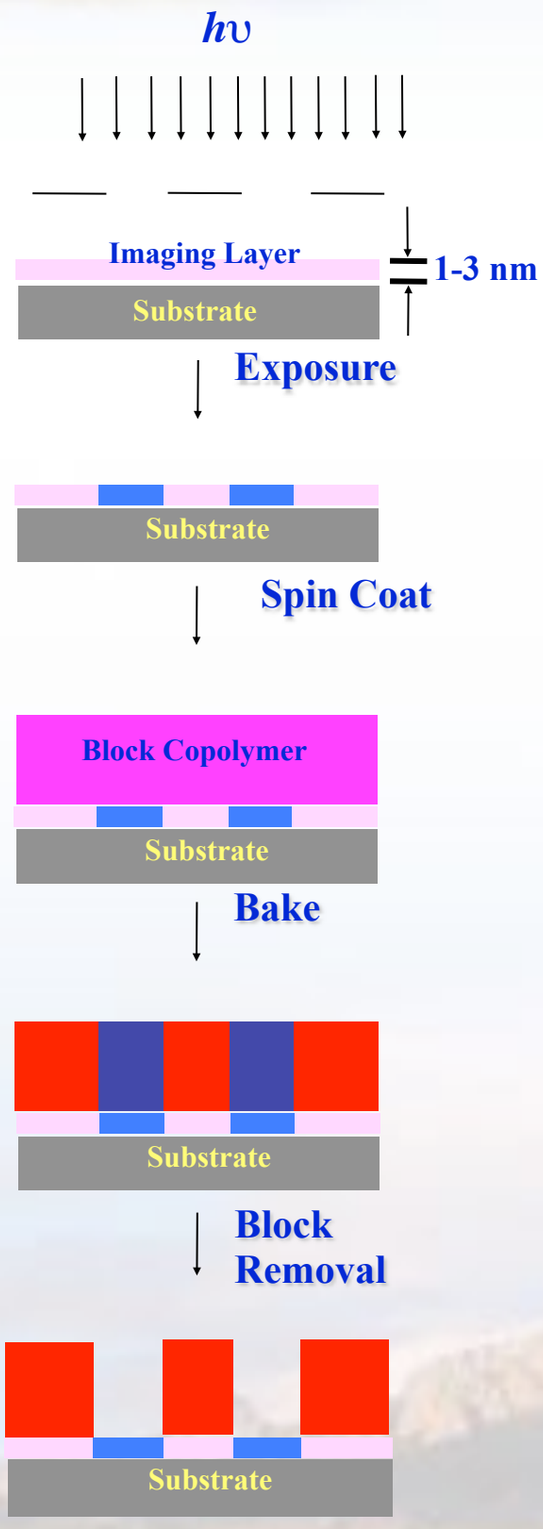
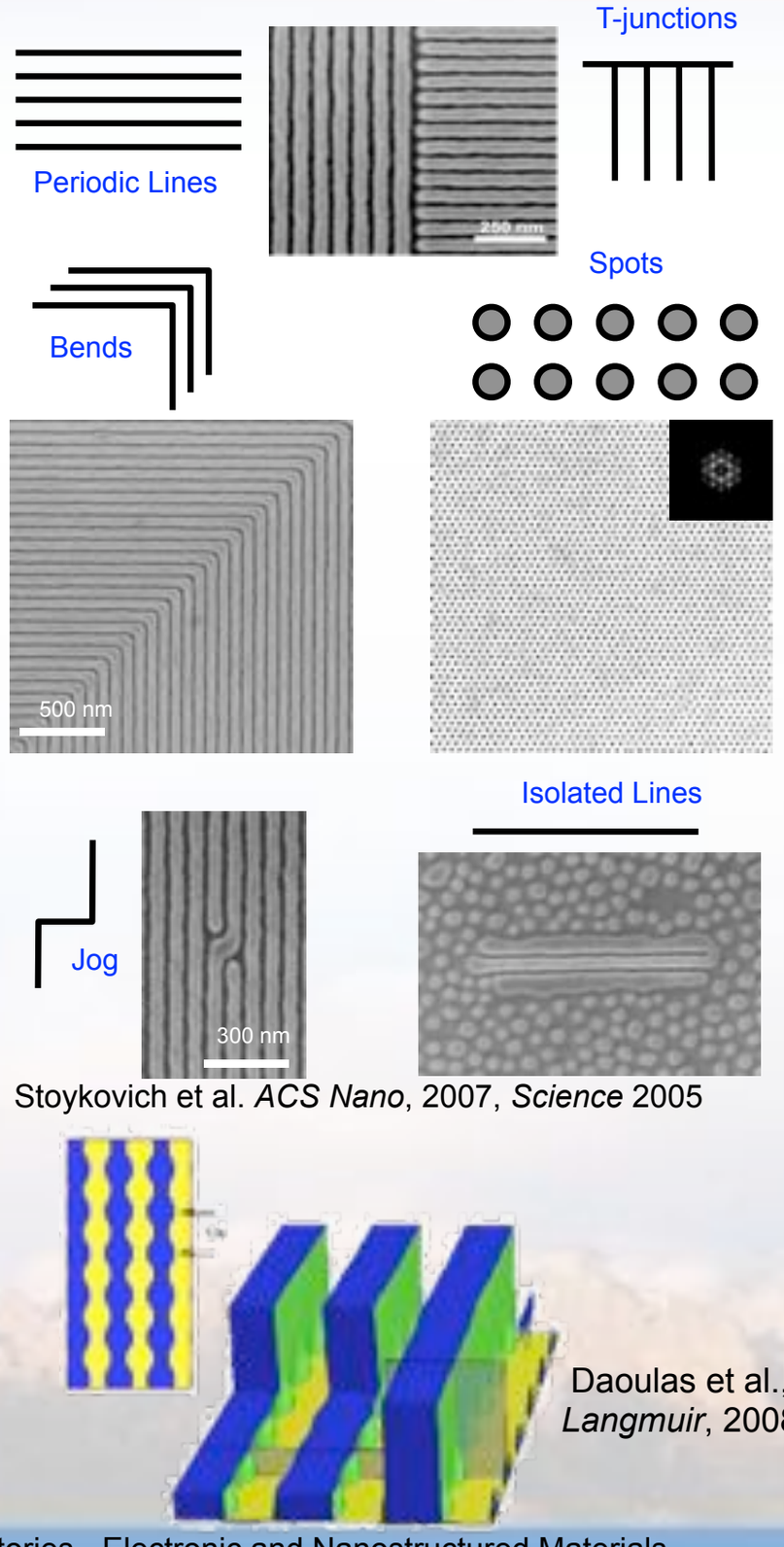
Block-Copolymer Directed Self Assembly

with Prof. Paul Nealey

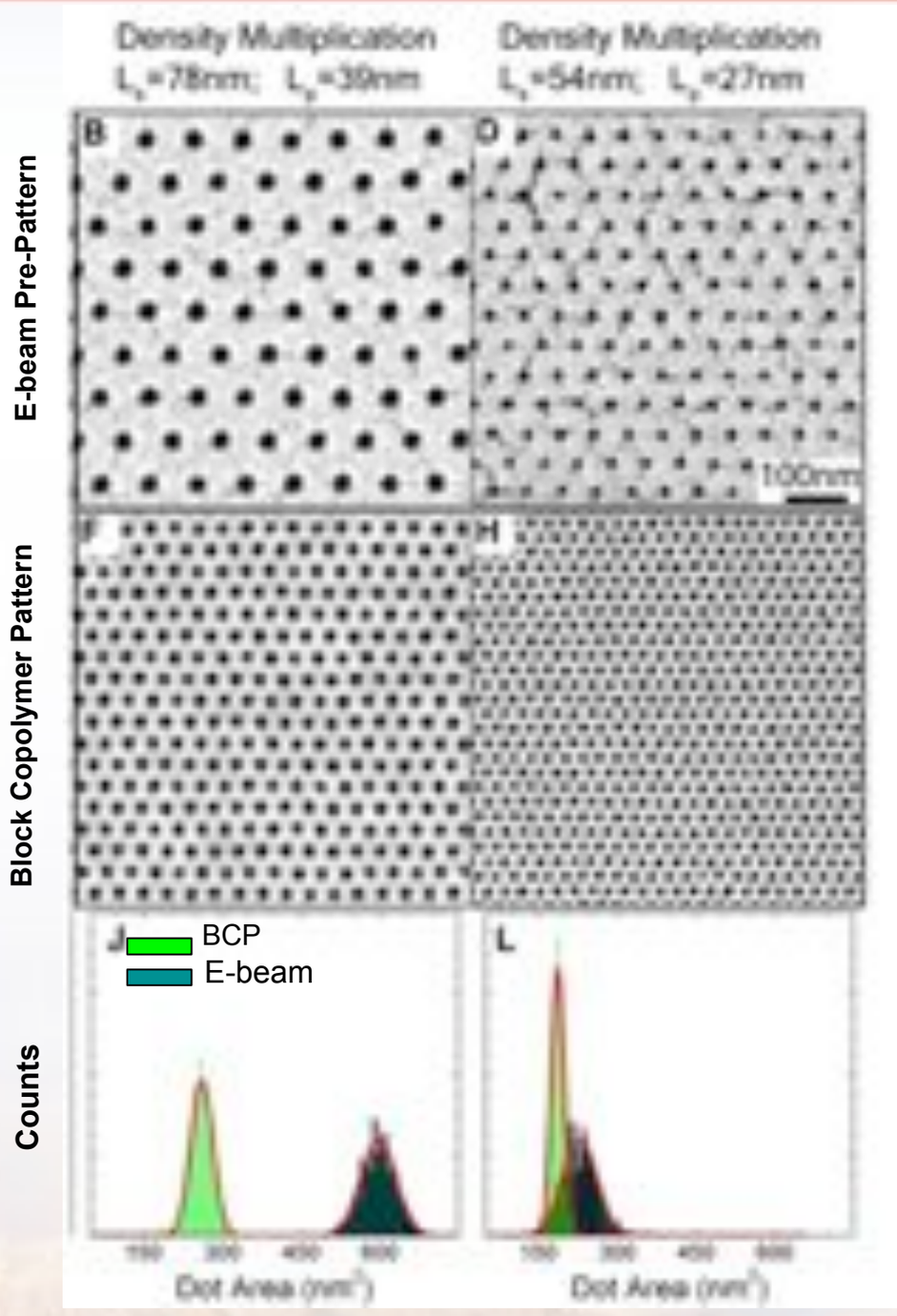
THE UNIVERSITY of WISCONSIN MADISON





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

Daoulas et al., *Langmuir*, 2008



Ruiz, Nealey, de Pablo et al. *Science*, 2008

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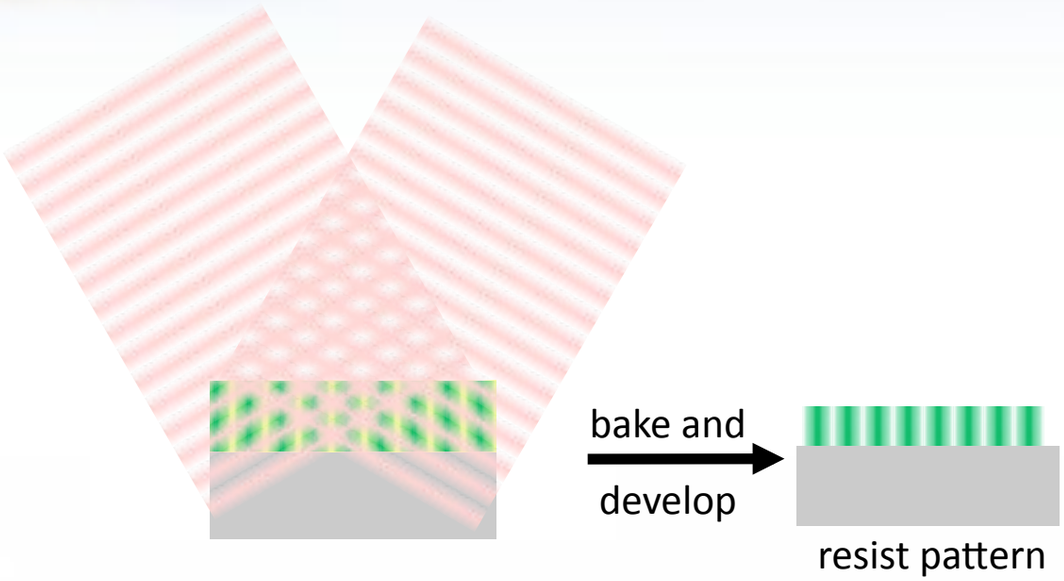
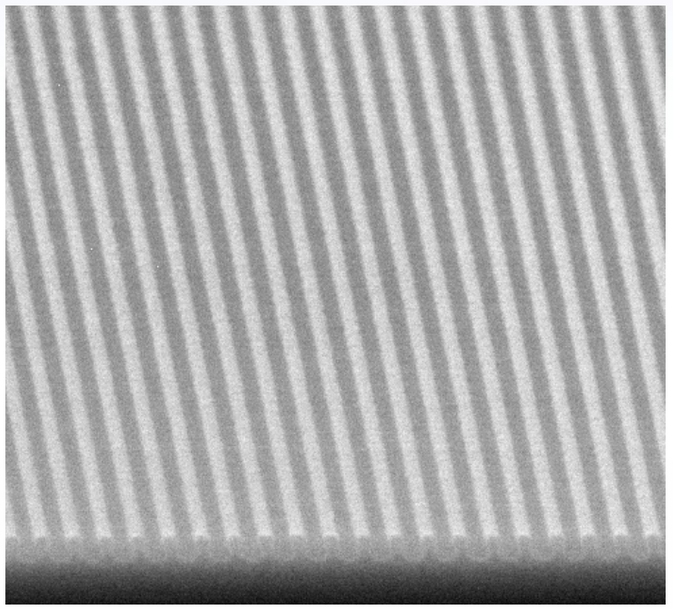
Optical Interference Lithography

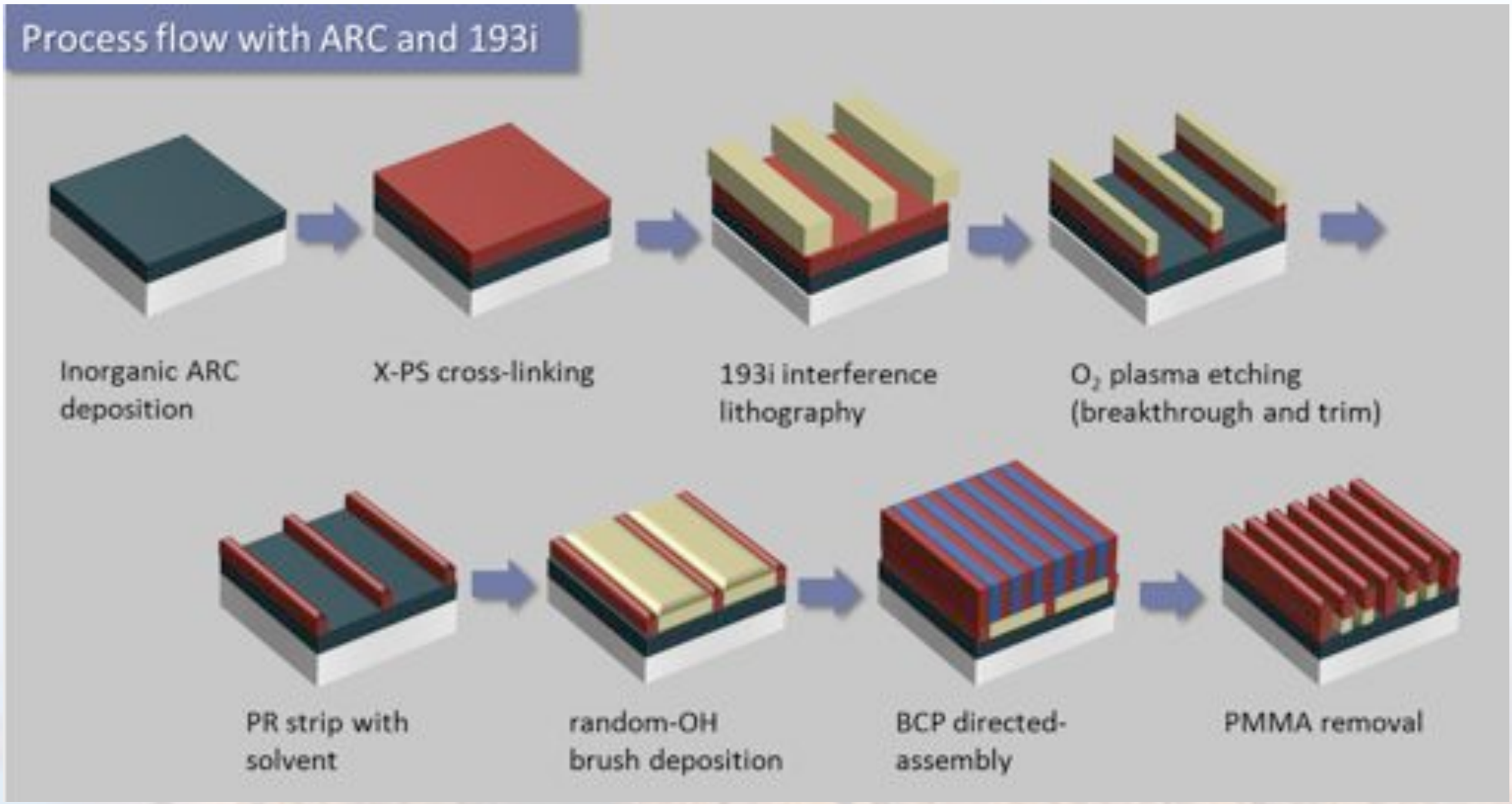
with Prof. Steve Brueck





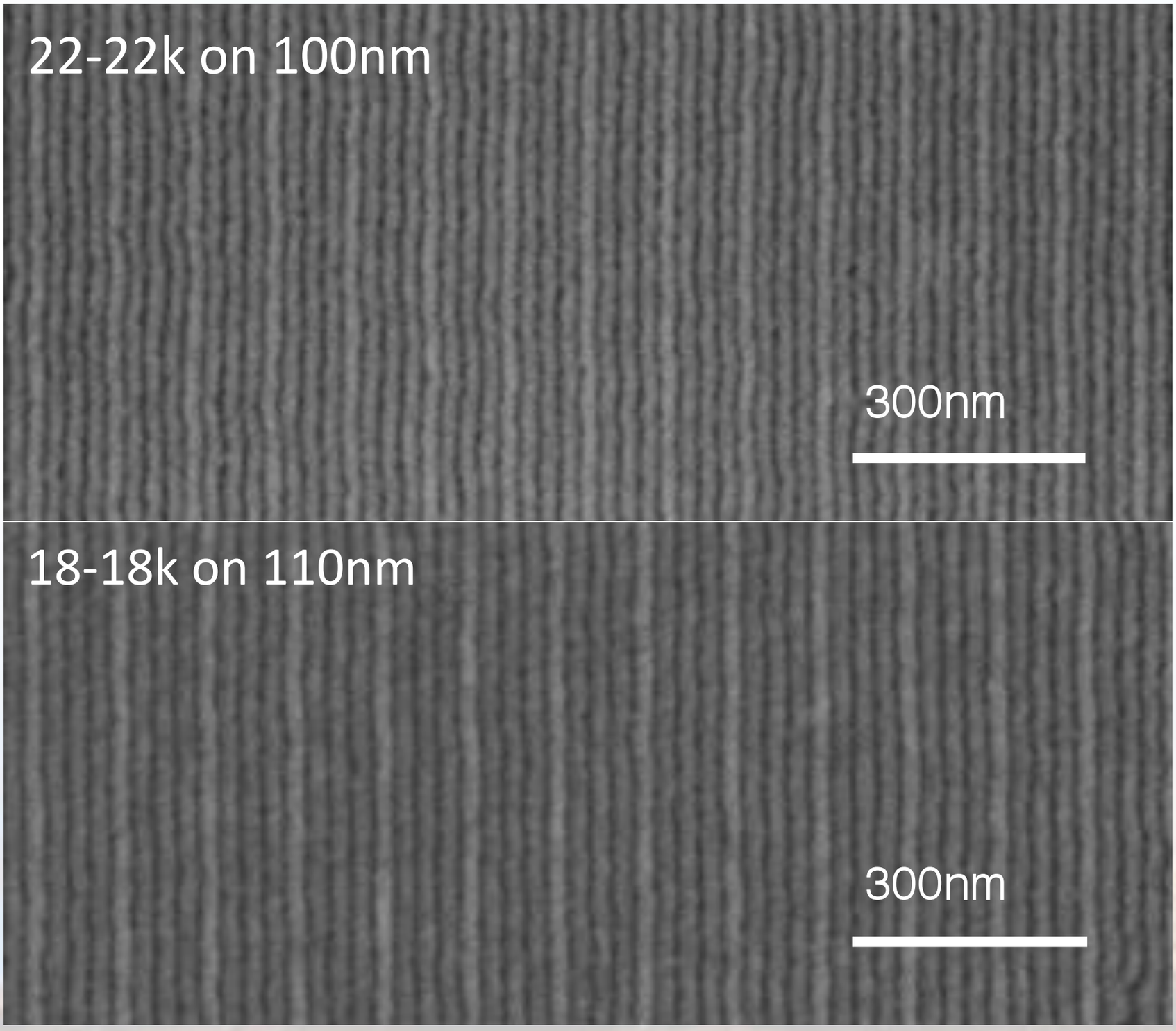
Critical dimensions ~70 nm
Patterned areas ~4cm^2

Density Multiplication



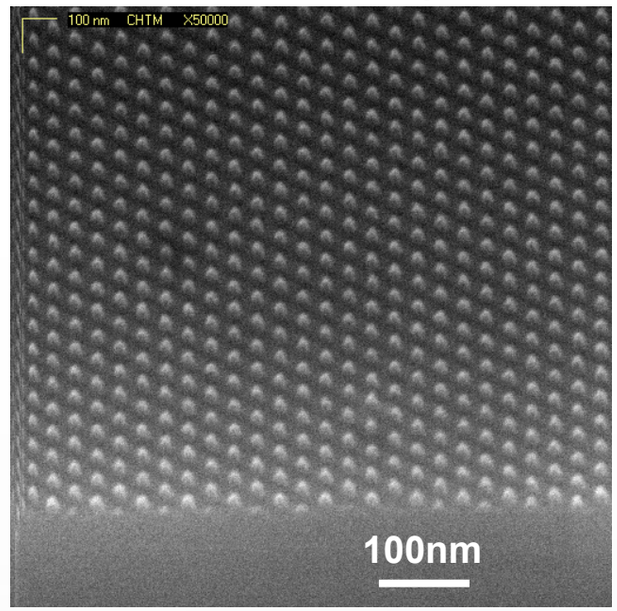
3x density multiplication
30nm features in 90nm IL pattern
over mm^2 areas

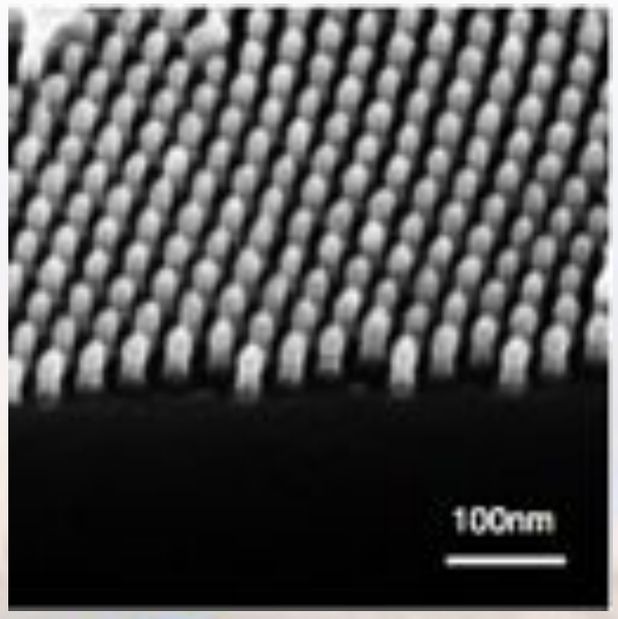
Density Multiplication



4X Multiplication

Cylinders





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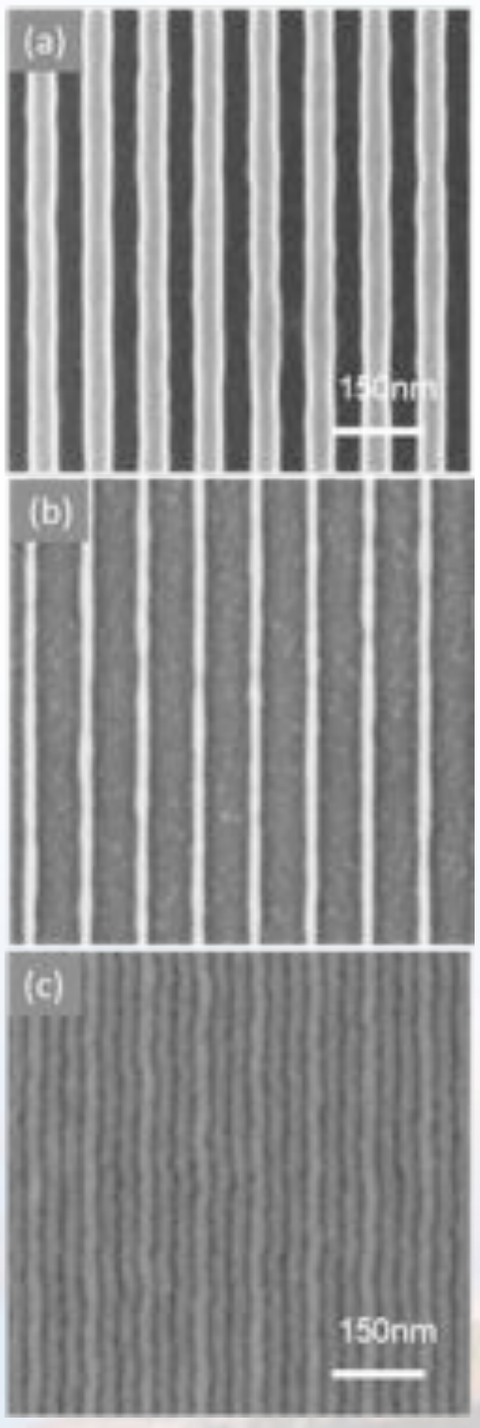
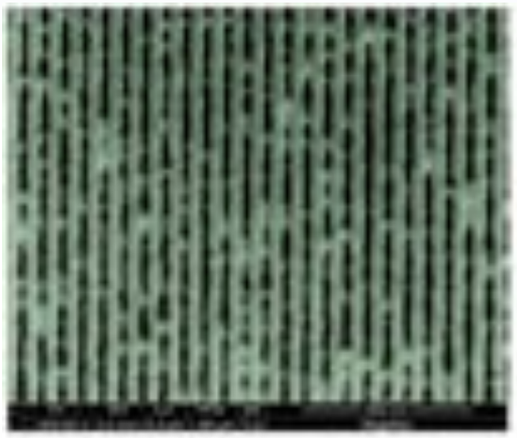
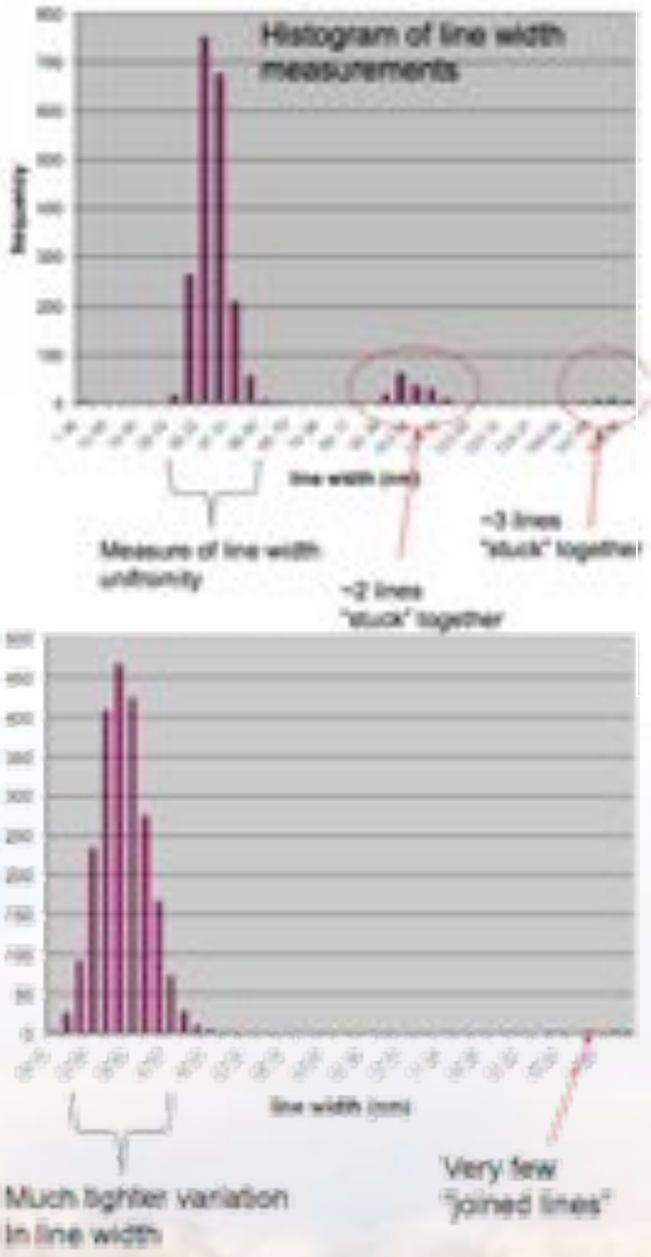
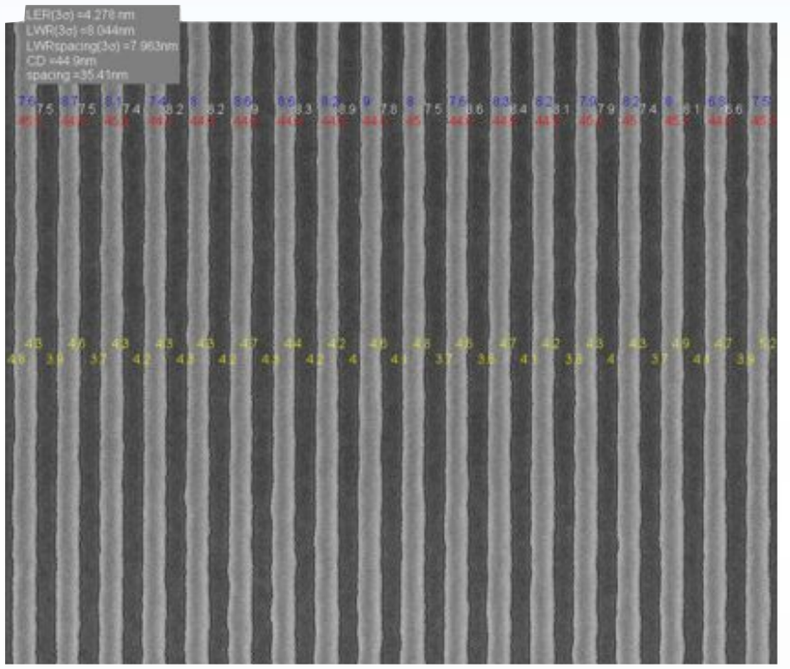
Metrology





After insertion of 100 grid lines and BOOLEAN combination





Line Edge Roughness (LER)
3σ deviation of a line edge from best-fit straight line
target LER < 5 %

Intel-blessed standard, quantitative, non-destructive feature/defect analysis at each stage of process

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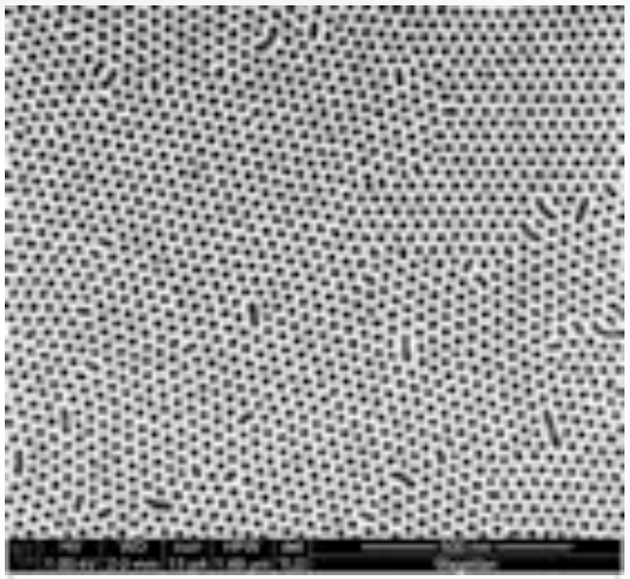
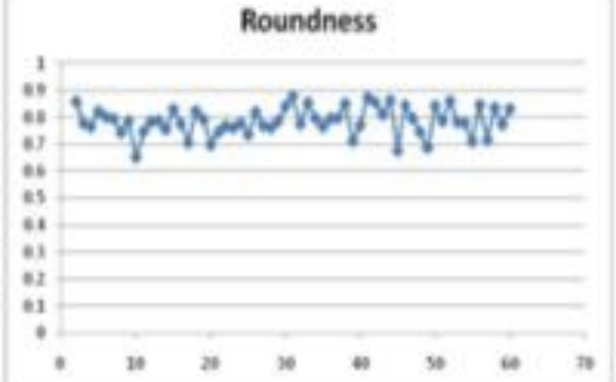
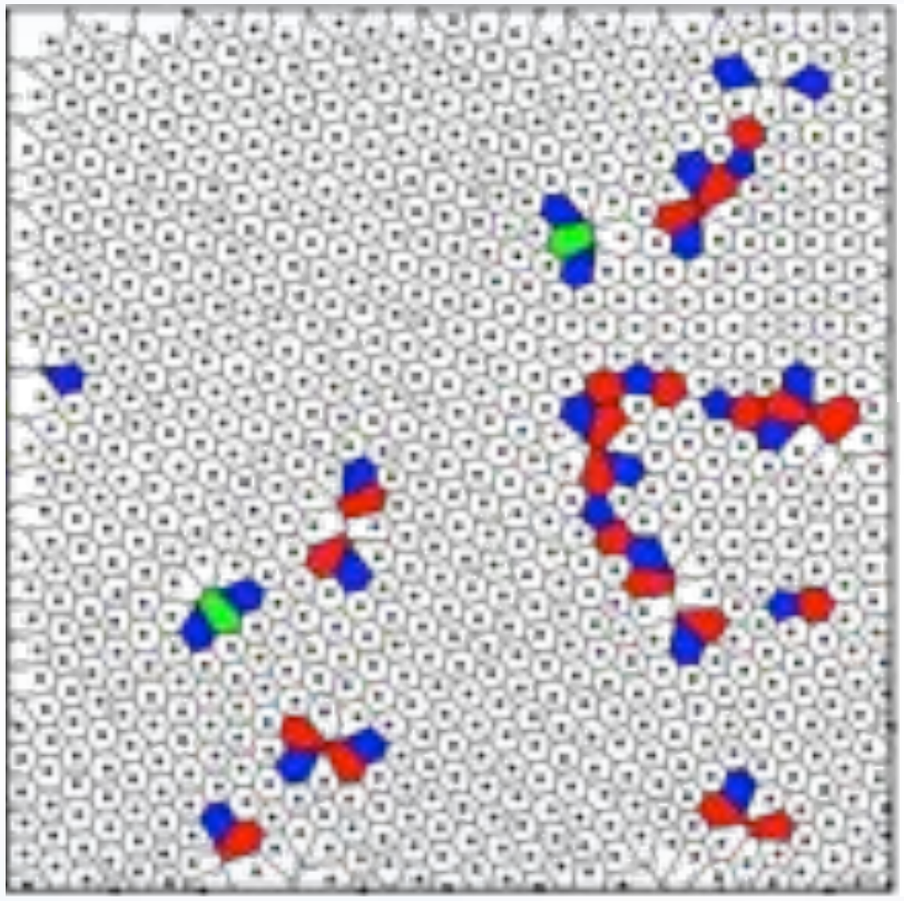
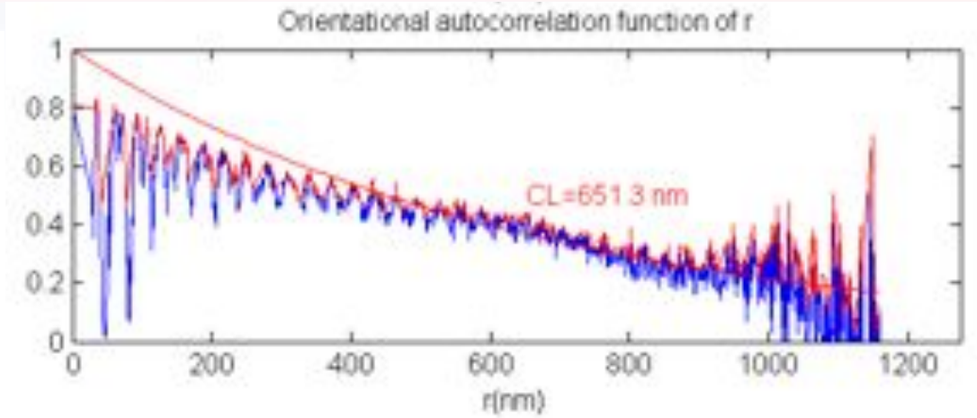
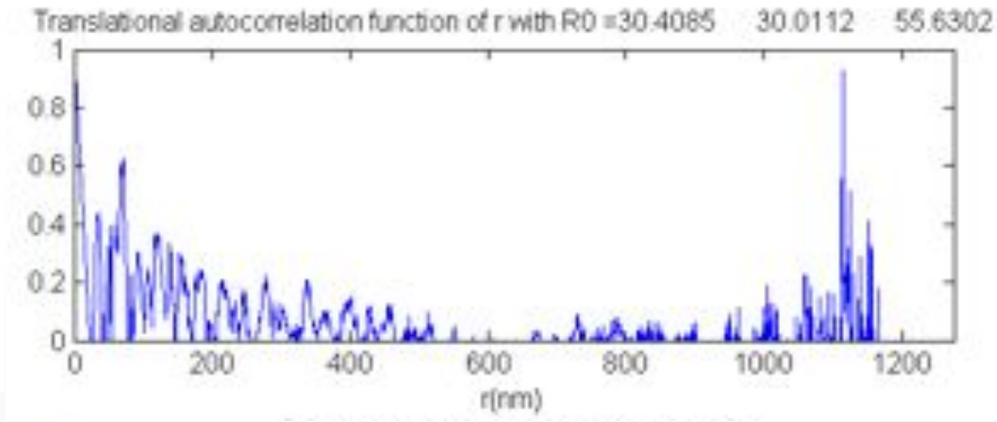
Metrology

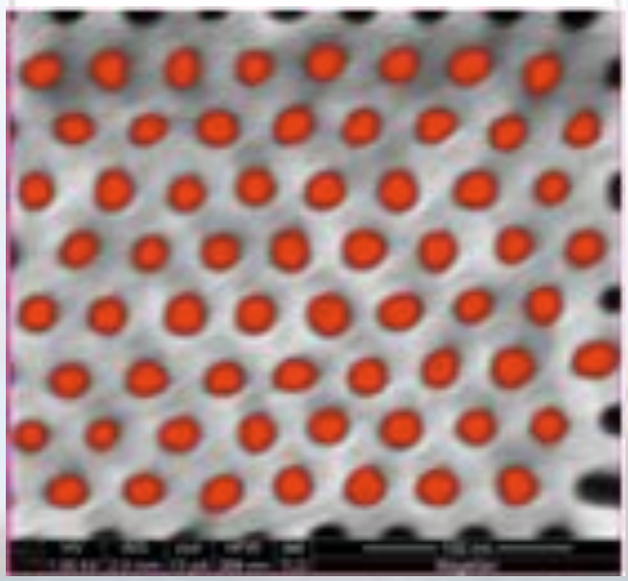












All made possible by FEI Magellan SEM:
quantitative sub-nm measurements from
uncoated samples

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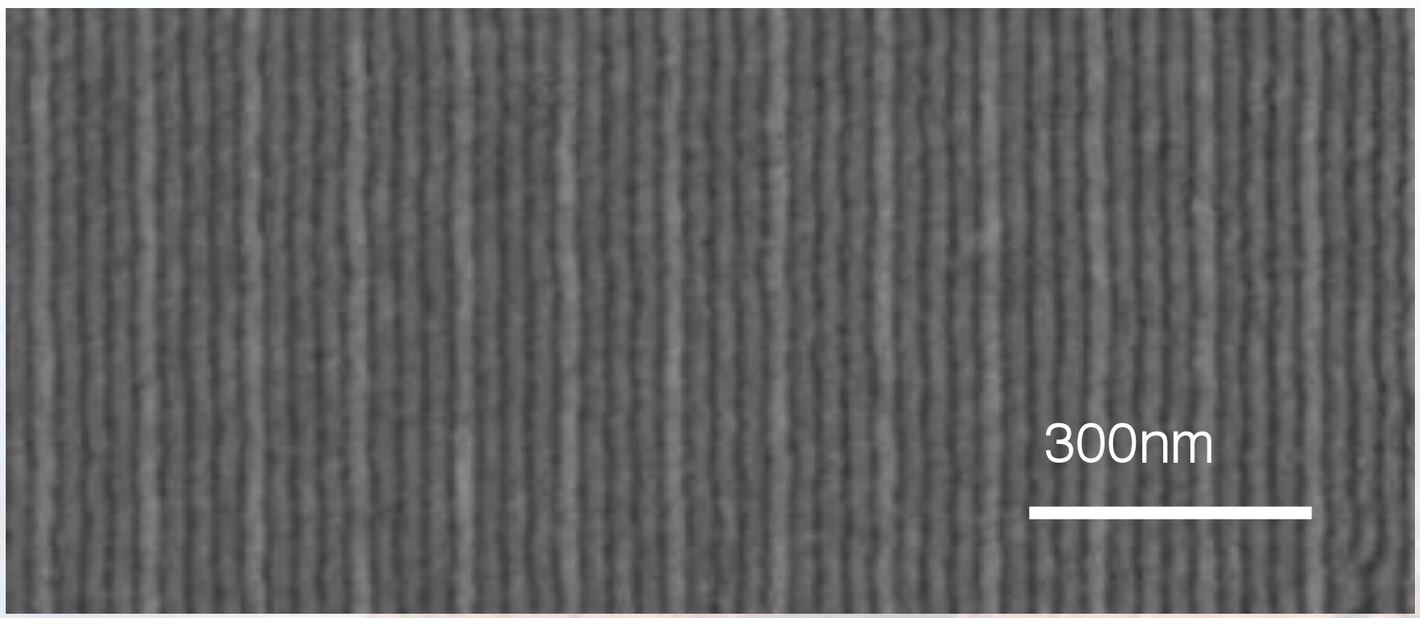
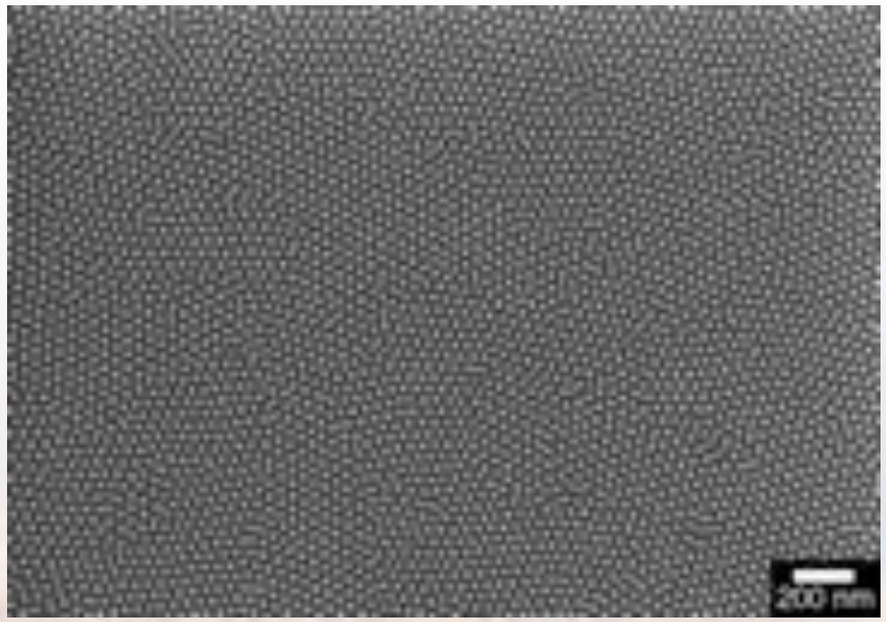
Summary

- Extended BCP-based patterning to wide variety of materials (substrates and solution-derived features)
- Up to 4x density multiplication with DSA-BCP over mm^2 areas
- Near-arbitrary control over position and (to some extent) size of nanoscale features





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Acknowledgments

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- Bonnie McKenzie
- Dick Grant
- Michael Rye
- Jeff Stevens

External Collaborators

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  - Lance Williamson
  - Brandon Peters
- University of Texas-Austin
  - Prof. John Ekerdt
  - Wes Ahearn
  - Wyatt Winkenwerder
  - Ryan Fitzpatrick
- University of Florida
  - Prof. Jacob Jones
  - Krishna Nittala
- Missouri S&T
  - Prof. Bill Fahrenholtz
  - Harlan Brown-Shaklee
- Intel
  - Todd Younkin
  - Mike Garner
  - David Shykind
  - Steve Putna
- ExxonMobil
  - Mark Disko
  - Amy Herhold