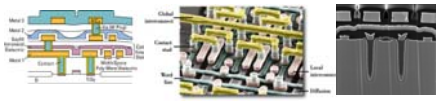
Integration of Self-Assembling Resist Materials into the Lithographic Process

Paul F. Nealey,[1]* Mark P. Stoykovich,[1] Erik W. Edwards,[1] Marcus Müller,[2] Kostas Daoulas,[2] Juan J. de Pablo,[1]
Harun H. Solak,[3] Young-Hye La[1]

[1]Department of Chemical and Biological Engineering and Center for NanoTechnology, [2]Department of Physics, University of Wisconsin – Madison.
[3]Laboratory for Micro- and Nanotechnology, Paul Scherrer Institute, Switzerland.

Semiconductor Device Fabrication

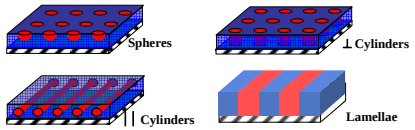


Logic (CMOS) Memory (DRAM)

- Today's microprocessors have 20-30M transistors with smallest features less than 0.15 mm
- Patterning critical dimensions consumes more than 50% of the cost to manufacture and is a limiting technology

Block Copolymer Lithography

:Using the domain structure of a BC thin film to create dense structures at the nanoscale.



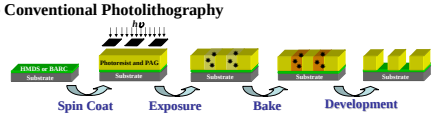
- No Wetting Problems
- Templates

- Pattern Transfer Advantages
- Connectivity
- High Aspect Ratio

Relative lengths determine morphology.

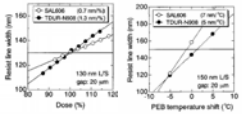
Chain length determines domain spacing.

Conventional Photolithography



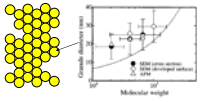
Essential Attributes of Photolithography:
Patterning perfection, Registration and overlay, Non-regular shaped features

CD is difficult to control / many process variables



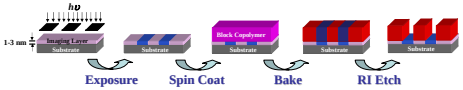
Tanaka Y, Taguchi T, Fujii K, et al., JVST B 16 (6): 3509-3514

LER is limited by the size of aggregates of molecules



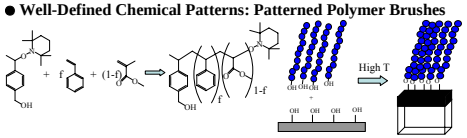
Yamaguchi, T. et al., APL 71 (16): 2338

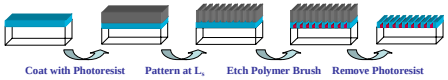
Directed Assembly of Block Copolymers



Key Concepts of Block Copolymer Lithography:
Can be integrated into existing manufacturing processes.
Thermodynamics determines feature dimensions and line edge roughness.
Scalable to feature dimensions of 10 nm and below

Well-Defined Chemical Patterns: Patterned Polymer Brushes

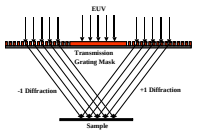




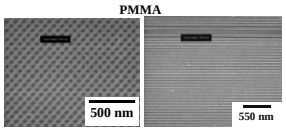
This technique allows us to create patterned polymer brushes of varying chemical composition

EUV-IL Using Transmission Membrane Masks

Two, three, or four diffracted beams interfere to yield dense lines and spaces, or cubic or hexagonal arrays of dots



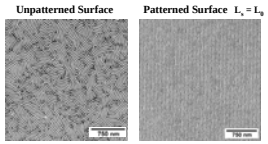
Pattern period is half of grating period



Cubic Array of Holes, 57 nm pitch 1:1 Lines, 55 nm Pitch

H. H. Solak, C. David, J. Gobrecht, V. Golovkina, F. Cerrina, S. O. Kim and P. F. Nealey, Microelectronic Engineering 67-68 56-62 (2003).
Collaboration with Harun Solak-Swiss Light Source

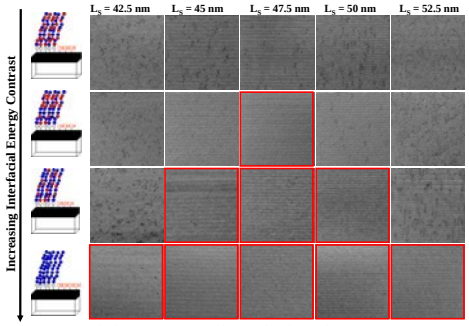
Perfect Registered Assembly of Block Copolymer Domains



Symmetric Poly(styrene-b-methylmethacrylate) L_0~48 nm

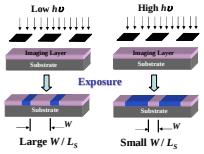
S. O. Kim, H. H. Solak, M. P. Stoykovich, N. J. Ferrier, J. J. de Pablo, P. F. Nealey, *Nature*, 2003, *424*, 411.

Precise control over molecular dimensions of block-copolymer domains using the interfacial energy of chemically nanopatterned substrates

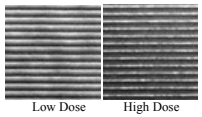


E.W. Edwards, M. F. Montague, H. H. Solak, C. J. Hawker and P. F. Nealey, *Advanced Materials* **2004**, 16, 1315.

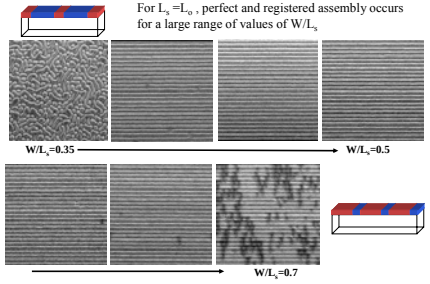
Directed Assembly Process Variations in Chemical Patterning



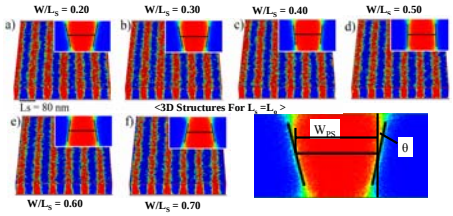
<Photoresist patterned with EUV-IL>



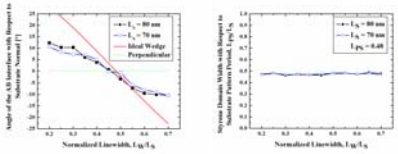
For $L_s = L_o$, perfect and registered assembly occurs for a large range of values of W/L_s



Sub-1nm Dimensional Control

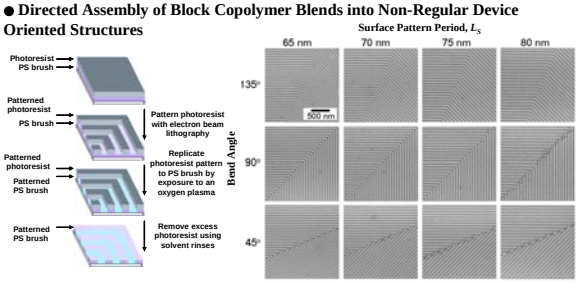


Self-assembling nature of block copolymers allows for sub 1 nm dimensional control in the lithographic process



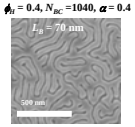
Self-healing structures facilitate pattern transfer processes; sidewall angle does not deviate by more than 10º

Directed Assembly of Block Copolymer Blends into Non-Regular Device Oriented Structures

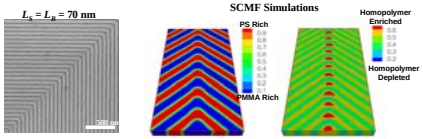


Ternary blend:
PS-*b*-PMMA / PS / PMMA

ϕ_H = 0.4, N_{BC} =1040, α = 0.4



Assembly of non-regular device oriented structures such as 90º bends is facilitated by the localized redistribution of homopolymer.

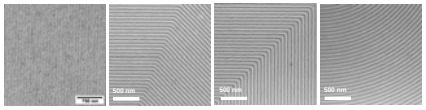


M.P. Stoykovich, M. Mueller, S.O. Kim, H. H. Solak, E.W. Edwards, J. J. de Pablo and P. F. Nealey, *Science* **2005**, *308*, 1442.

Conclusions

Self-assembling materials are being developed as imaging layers for nanoscale lithography to meet strict criteria in manufacturing processes related to the control of feature dimensions and shapes within molecular level tolerances and margins while maintaining essential manufacturing attributes such as pattern perfection and registration.

The extension of block copolymer lithography to pattern features more complex than simple periodic arrays creates opportunities for the use of these non-traditional imaging materials in the production of nanoelectronic devices.



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