NIL and R2R NIL for Fabricating Active Surfaces and Devices

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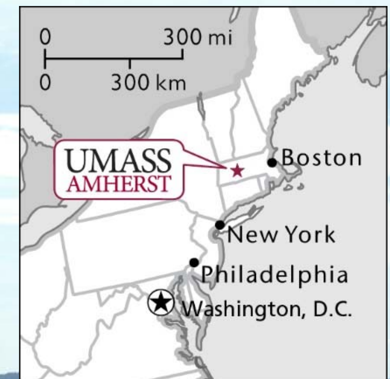
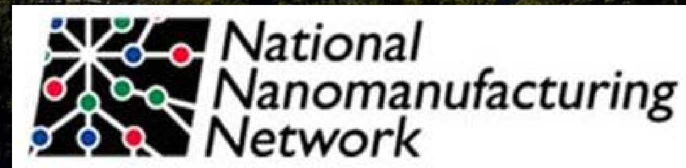




UMass NIL & R2RNIL Process Facility

Goal: **Enable fabrication of nanostructured materials and devices by a simple, rapid, high volume, cost-effective platform.**

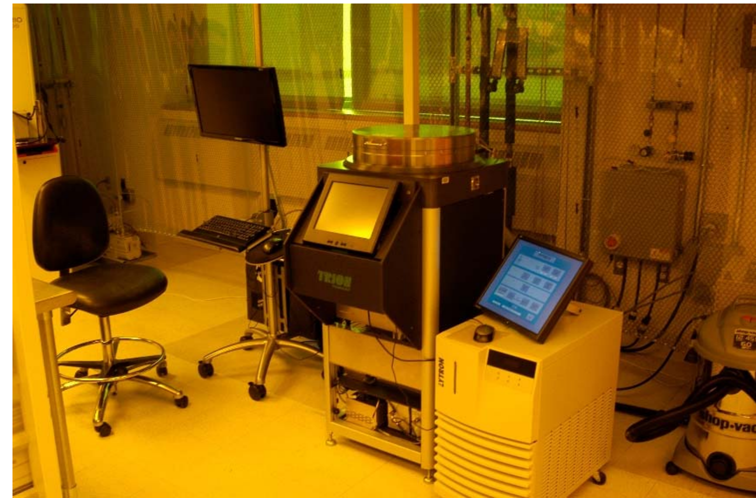
- *Leverage our expertise in NIL and nanoscopically ordered materials to fabricate a number of technologically useful materials and devices.*
- *Fabrication being accomplished with materials & processes that can be moved rapidly towards commercialization (low-cost, high volume manufacturing).*
- *Efforts include the development of functionalized materials to target specific electronic, mechanical and optical properties.*

NIL & R2R NIL can benefit scale up of

- *Flat panel displays*
- *Biomedical devices, microfluidics, membranes*
- *Flexible solar cells, OLEDs, printed electronics, DSA Lithography*
- *Antireflective, Anti-fog, Antibacterial, superhydrophobic / drag reduction etc.*
- *Photonics – Polarizers, holographic patterns, metamaterials, optical filters etc EM sensing*

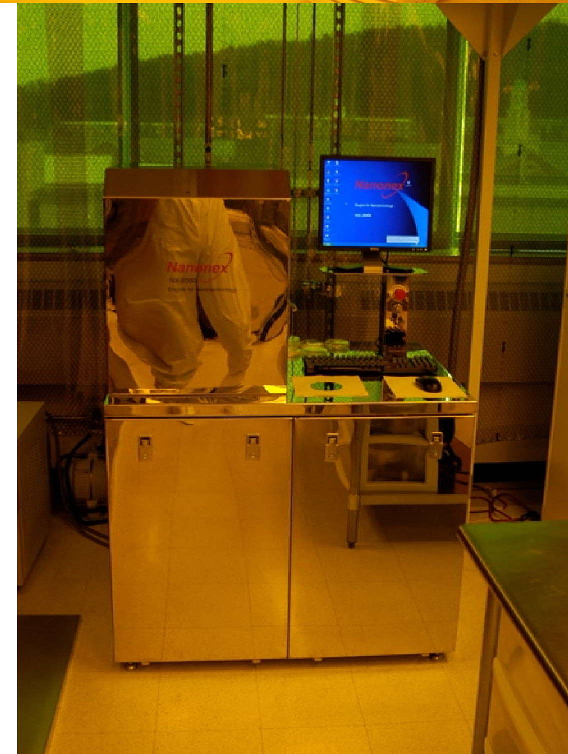
UMass Nanoimprint Lithography Laboratory

Nanonex NX-2600BA
8″ Wafer Nanoimprintor with Alignment and Photolithography



Trion Systems
ICP Etch Tool

Nanonex NX-2000
Nanoimprinter



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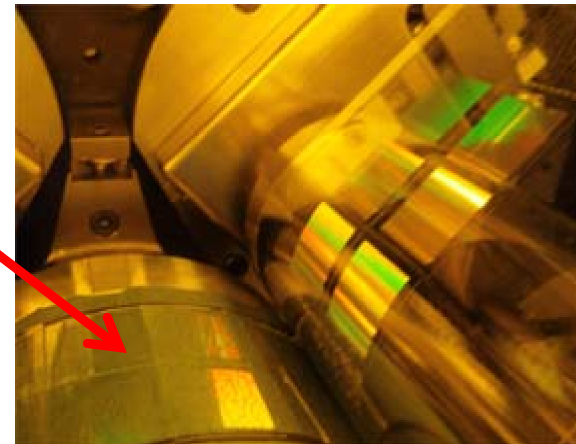
University of Massachusetts Amherst

NX-2600BA: Full-Wafer Imprintor with Alignment and Photolithography

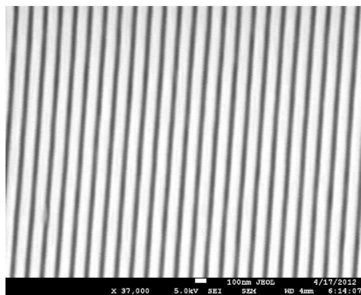
- Full-wafer (up to 8") nanoimprinting tool
- All forms of nanoimprint and high resolution photolithography
- Air Cushion Press (ACP) for ultimate nanoimprint uniformity
- Sub-micron overlay alignment accuracy and optical backside alignment
- Smart Sample Holder for handling different sizes and irregular shapes
- Applications in opto, displays, biotechnologies, data storage, materials, etc

New tool critical for fabrication of molds for R2R NIL!



Roll-to-Roll Test Bed Process Facilities

UV-Assisted Nanoimprint Lithography
May 2011



70 nm grating

R2R Coater for Nanostructured Hybrids
April 2012

Dual Microgravure

Slot Die

Unique R2R Tools Built with Qualified Partners

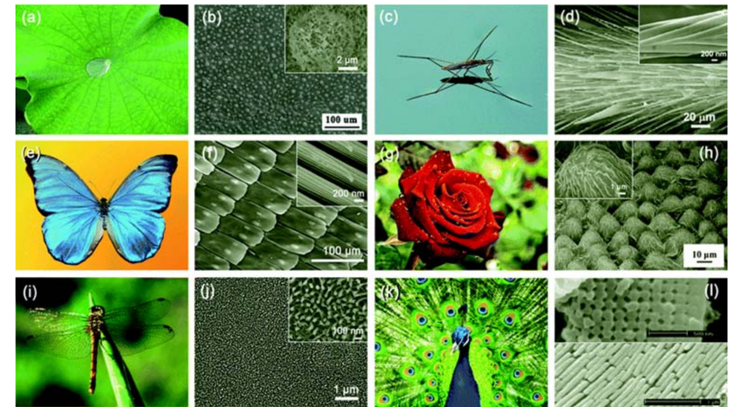
Structural Features Enables Function in Nature

- Nature used hierarchical patterns to accomplish many things. Many are ideal for nano/micro fabrication
- **Superhydrophobicity**

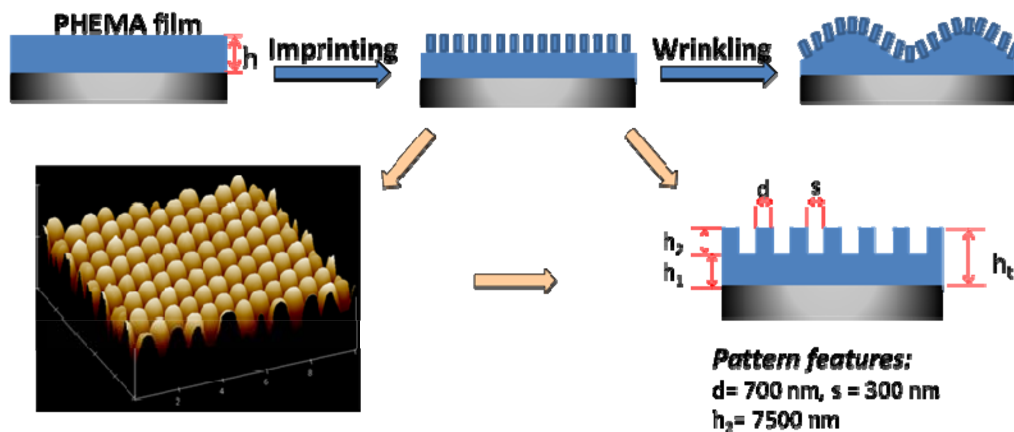
  Water contact angle θ >150°
- **Two factors for superhydrophobicity**

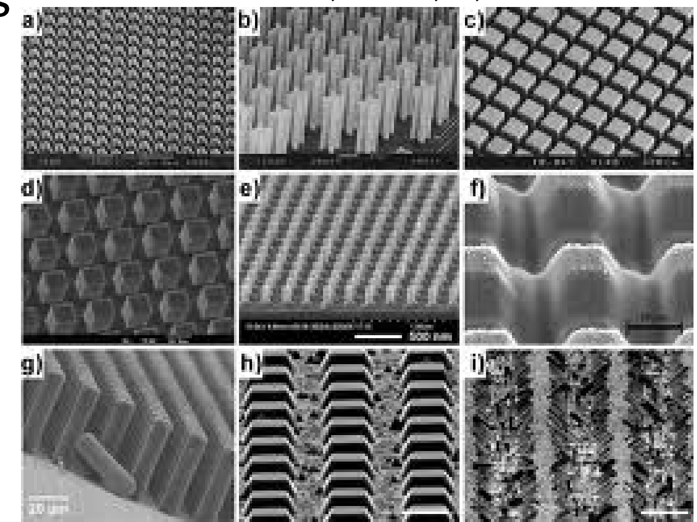
  (1) Surface roughness

  (2) Low surface energy surfaces
- Goal: replicate hierarchically wrinkled patterns
- Develop R2R process for superhydrophobic surfaces



Soft Matter, 2012, 8, 11217

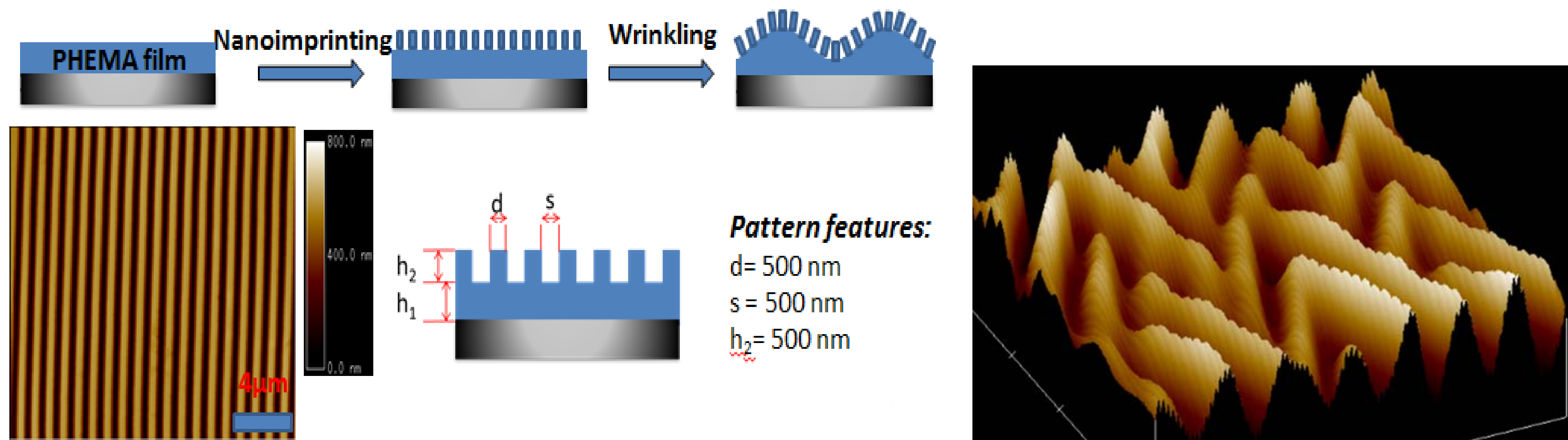




Soft Matter, 2008, 4, 224–240

Roll-to-Roll Fabrication of Biomimetic Self-Cleaning Surfaces

- Fabrication of hierarchical wrinkle patterns
- Develop hydrophobic resin suitable for R2R process: modified Norland Optical Adhesives (NOA)
- R2R nanoimprint of hierarchical wrinkle patterns to achieve superhydrophobic surfaces (SHS) and lubricant imbibed surfaces (LIS)



- Li, Y. Y.; Peterson, J. J.; Jhaveri, S. B.; Carter, K. R.*, *Langmuir* , **2013**, *29(14)*, 4632-4639. DOI: 10.1021/la400155d
- Li, Y. Y.; Dai, S. John, J.; Carter, K. R.*, *ACS Applied Materials and Interfaces*, **2013**, *5(21)*, 11066-11073.DOI: 10.1021/am403209r

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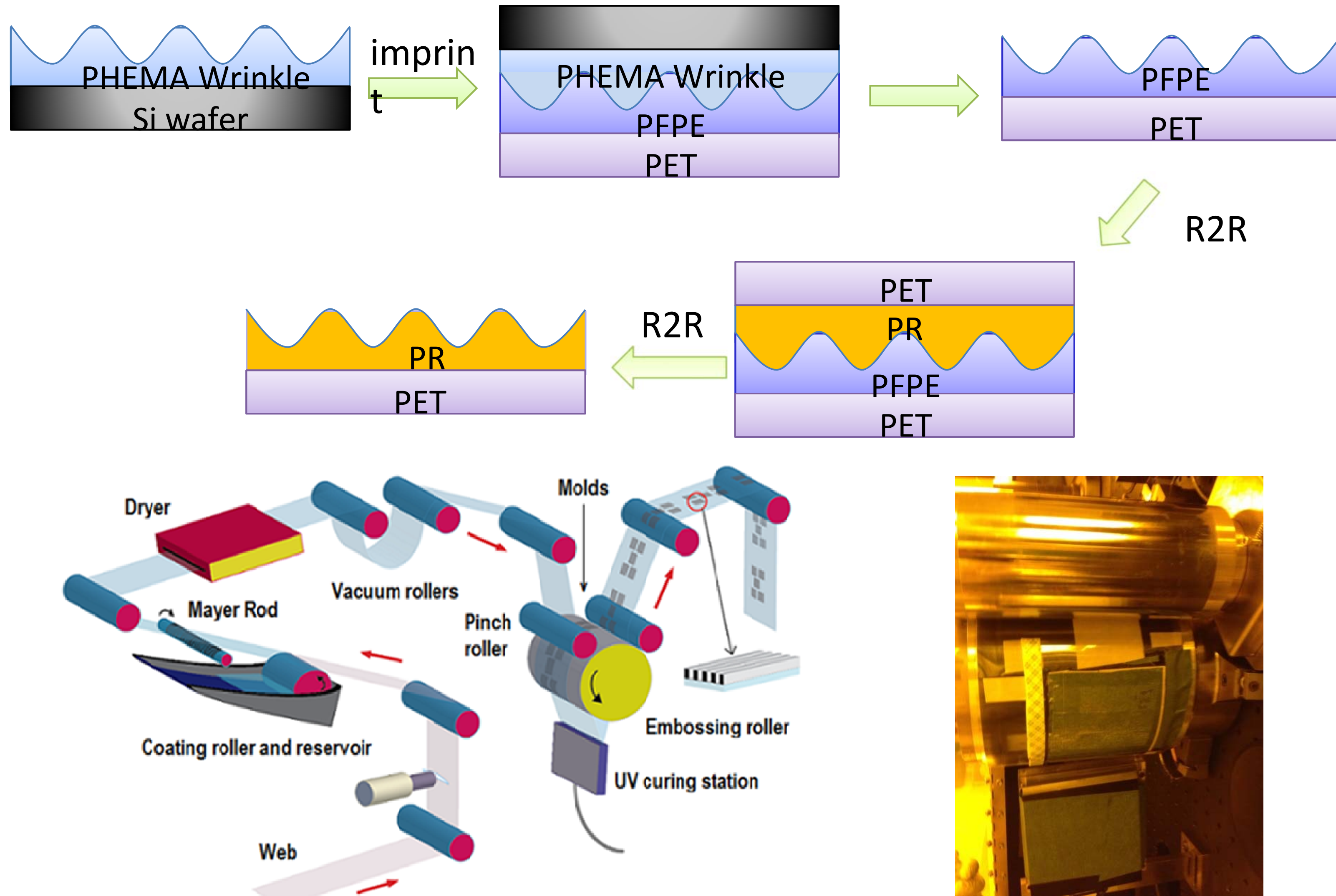
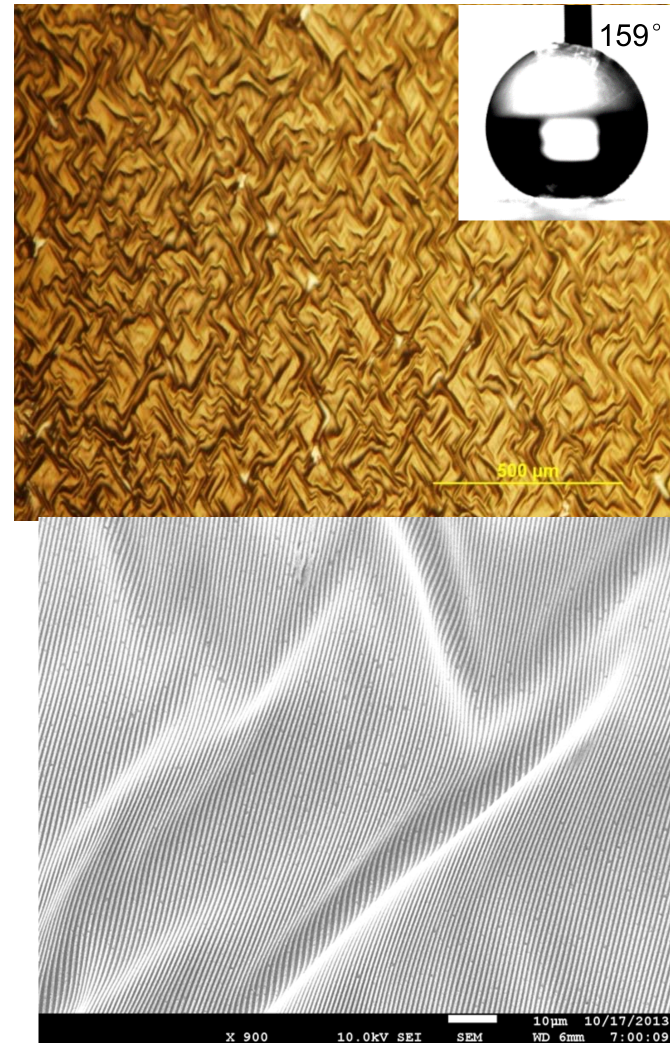
Roll-to-Roll Fabrication of Superhydrophobic Surfaces



- Li, Y.; John, J.; Kolewe, K. W.; Schiffman, J. D.; Carter, K. R.* *ACS Applied Materials and Interfaces*, **2015**, *7*, 23439–23444. DOI: 10.1021/acsami.5b04957

Images of Fabricated Patterns



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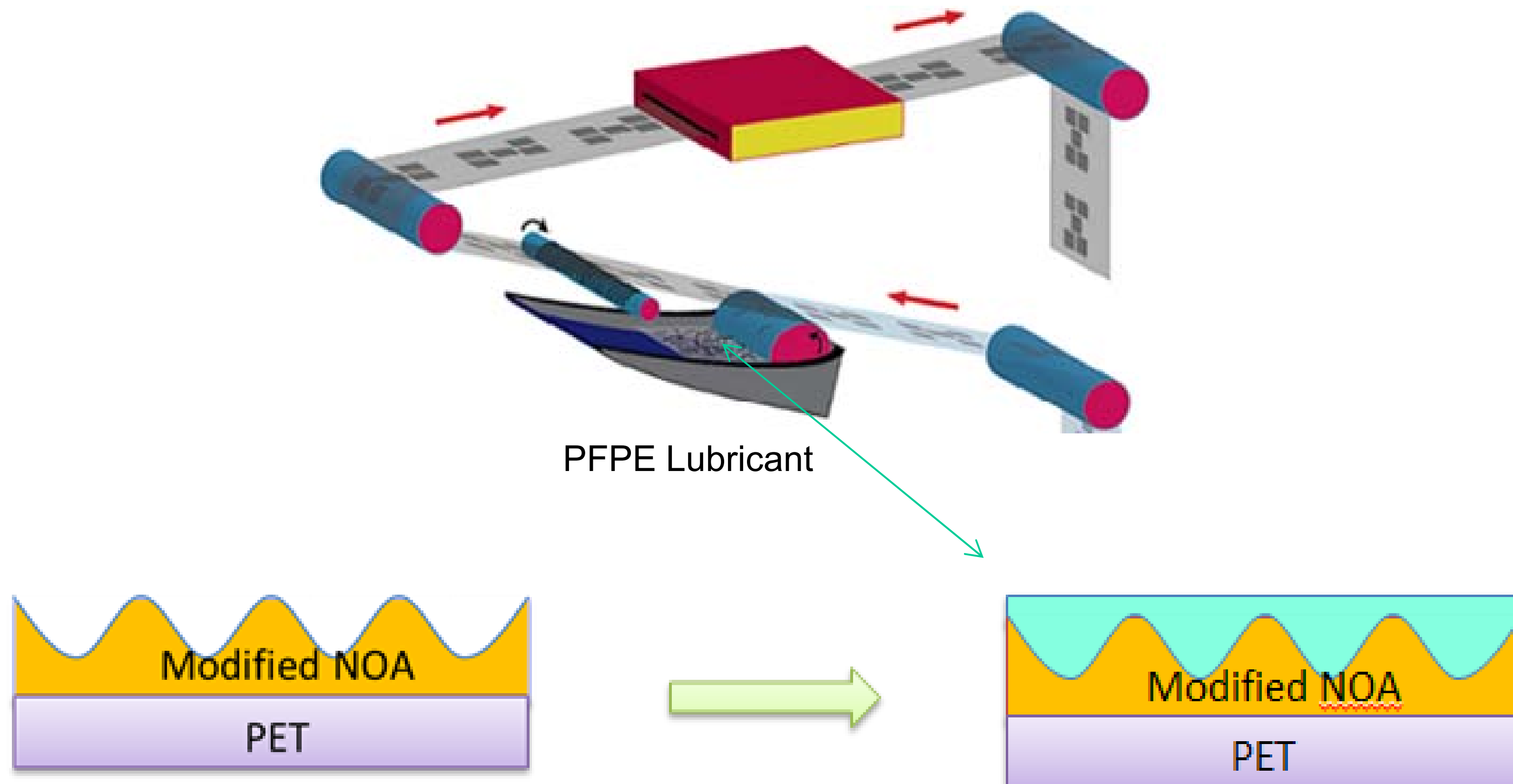
Roll-to-Roll coating of PFPE Lubricant Imbibed Surface (SLIPS)



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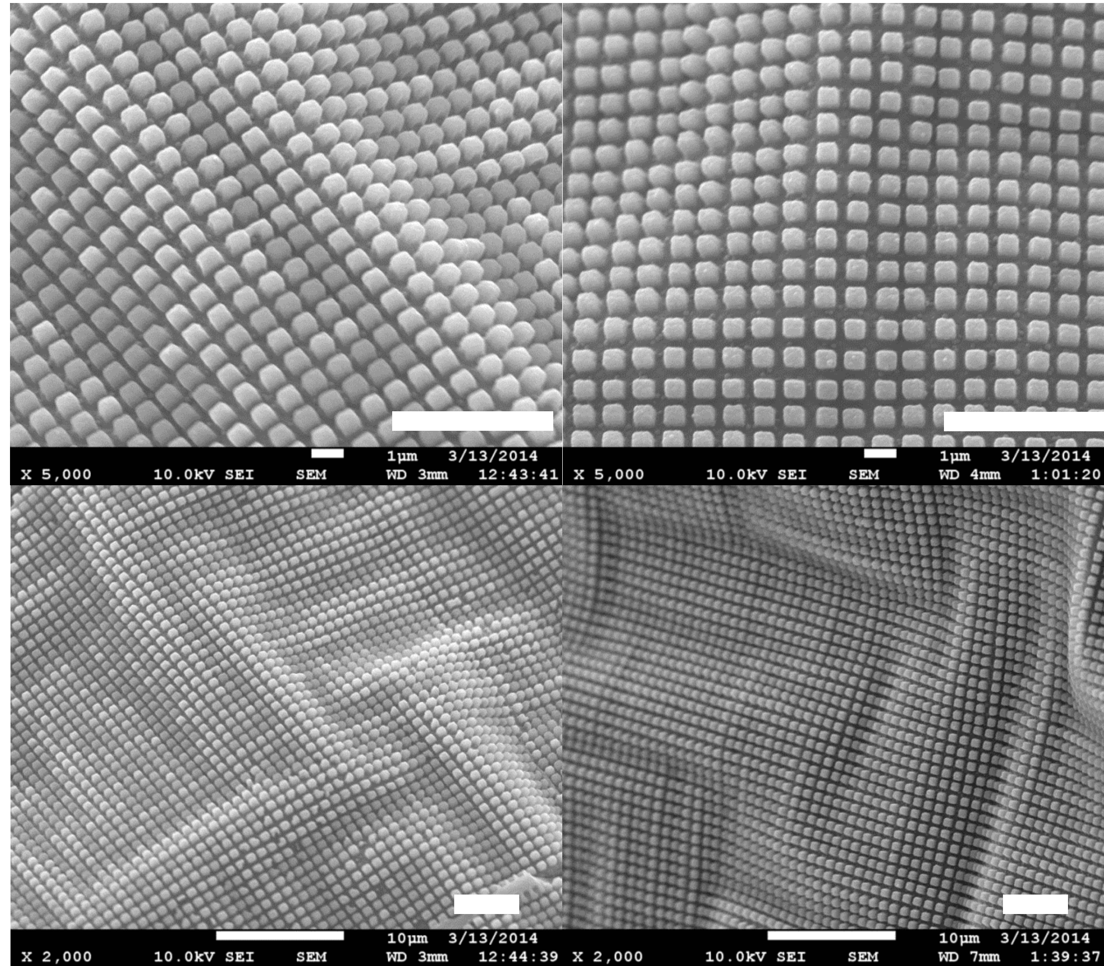
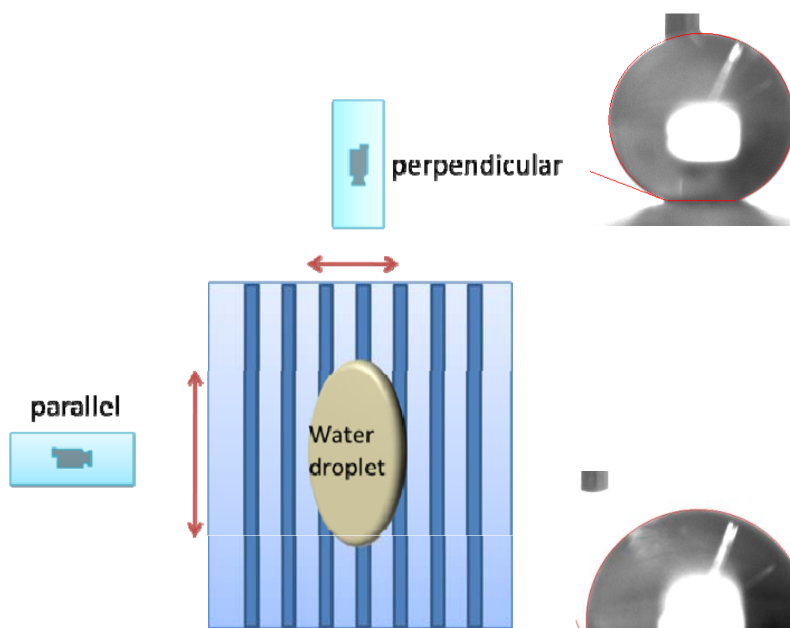
- Li, Y.; John, J.; Kolewe, K. W.; Schiffman, J. D.; Carter, K. R.* *ACS Applied Materials and Interfaces*, **2015**, *7*, 23439–23444. DOI: 10.1021/acsami.5b04957

Comparison of Master Mold with R2R pattern

Master mold   R2R pattern

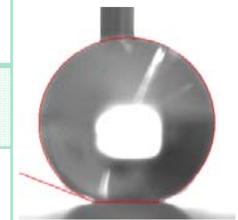


Wetting Behavior of SHS and SLIPS

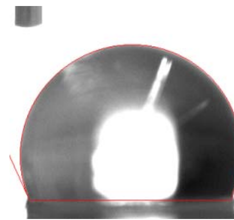


Water on Superhydrophobic surfaces (SHS)

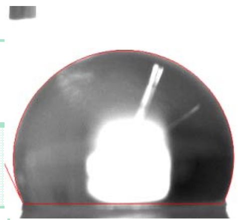
	Parallel	Perpendicular
Advancing	158.9±0.9	158.7±0.4
Hysteresis	19.9±2.7	20.1±3.6
Sliding	25.6±3.2	29.0±2.4



Water on SLIPS



	Parallel	Perpendicular
Advancing	115.3±1.4	116±2.3
Hysteresis	1.2±0.4	1.2±0.8
Sliding	3.4±1.1	3.5±0.6



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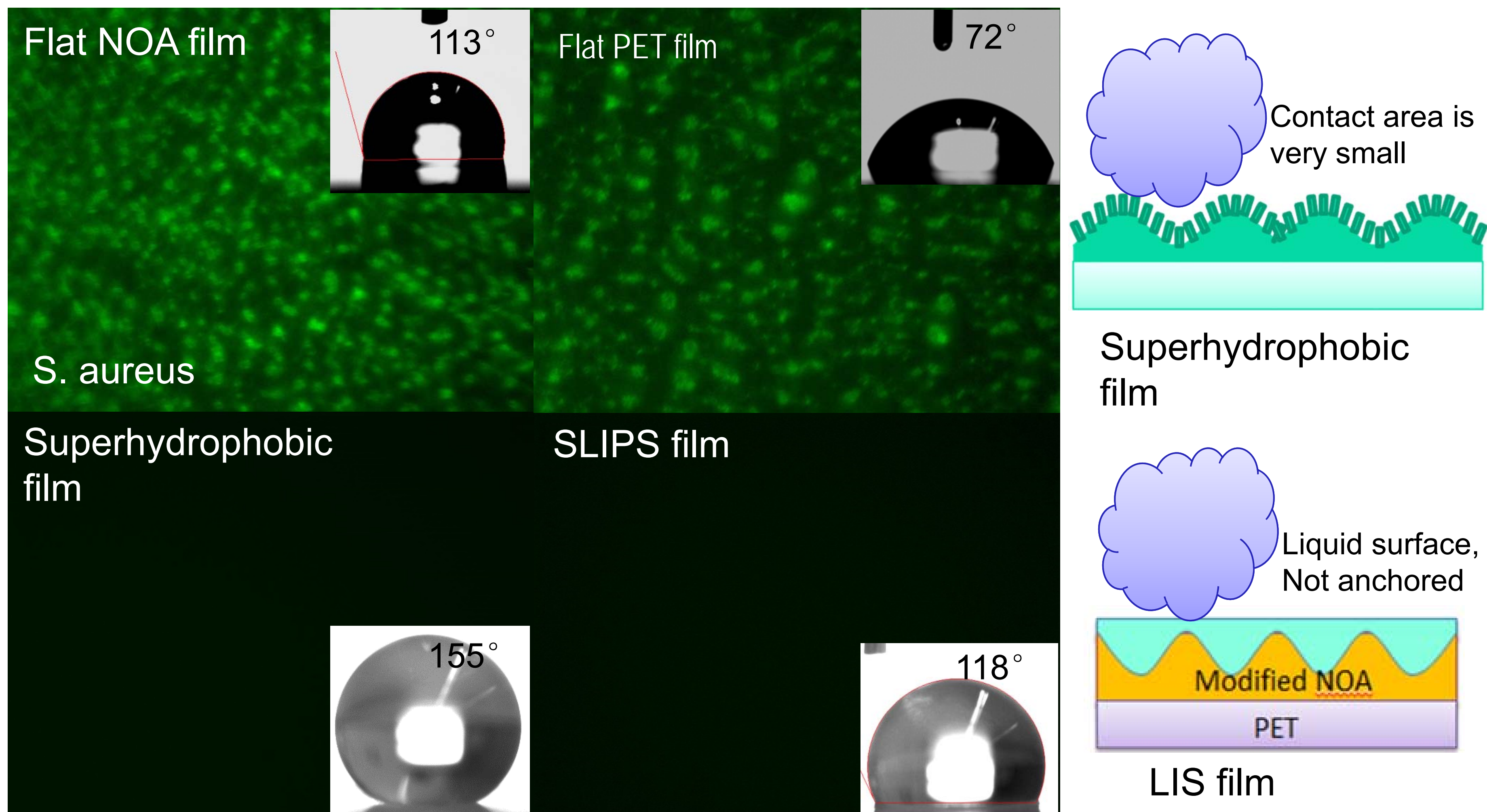
Antibacterial Properties of SHS and SLIPS

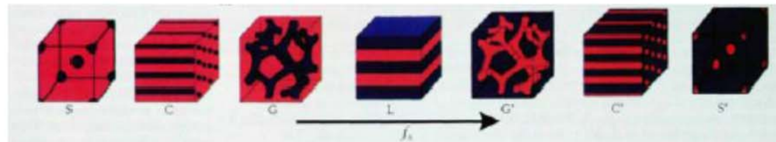


- Li, Y.; John, J.; Kolewe, K. W.; Schiffman, J. D.; Carter, K. R.* *ACS Applied Materials and Interfaces*, **2015**, *7*, 23439–23444. DOI: 10.1021/acsami.5b04957

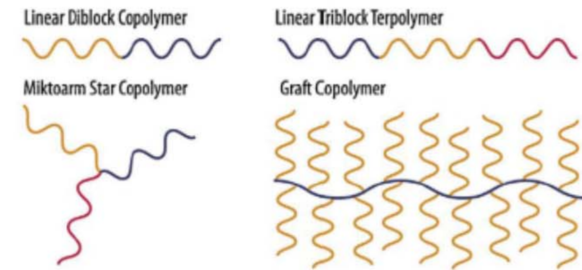
Block Copolymers

❑ Block copolymers (BCPs)

- One class of self-assembling materials
- Attractive route to fabricate 10 - 100 nm scale structures
- Spontaneously assemble a range of well-defined, well-ordered structures including spheres, cylinders, gyroids, and lamellae



Phys. Today, **52**, 38 (1999)

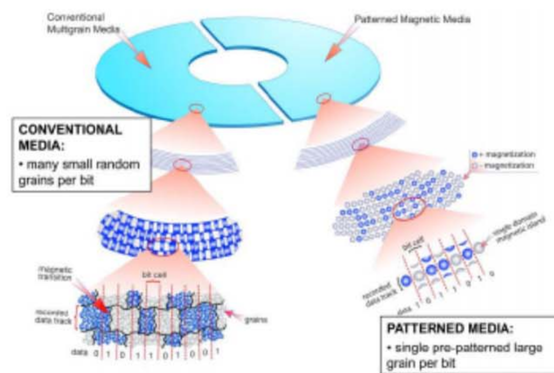


Prog. Polym. Sci., **40**, 3 (2015)

❑ Application in Nanofabrication

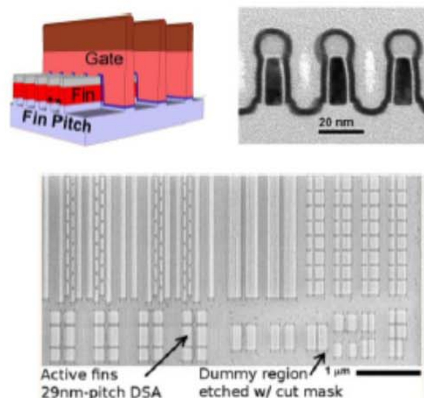
Bit Patterned Media (BPM)

Hitachi Global Storage Technologies



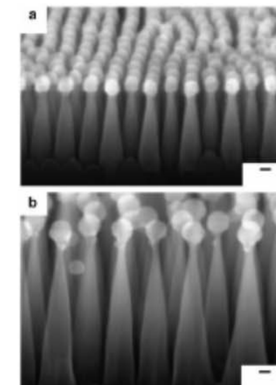
Proc. IEEE, **96**, 1836 (2008)

FinFET Device and Circuit Fabrication



ACS Nano, **8**, 5227 (2014)

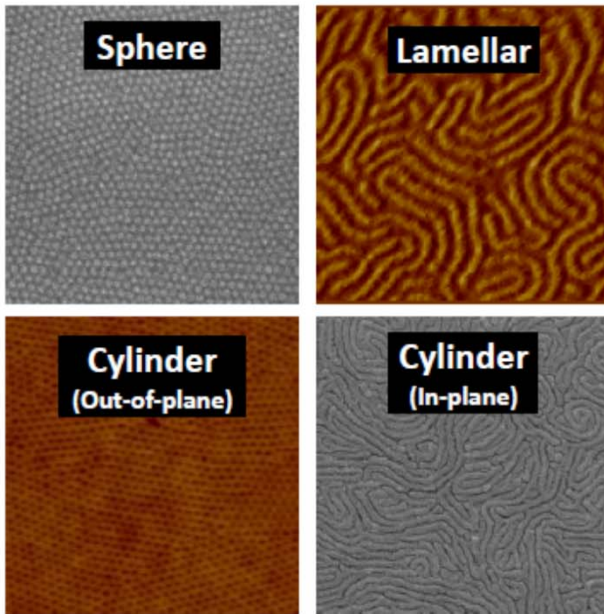
Lithographic Mask



Nat. Commun., **6**:5963 (2015)

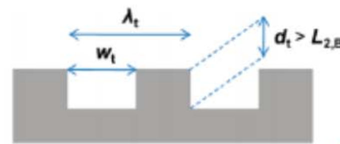
BCP Films with Topographic Patterns

Unpatterned Substrate



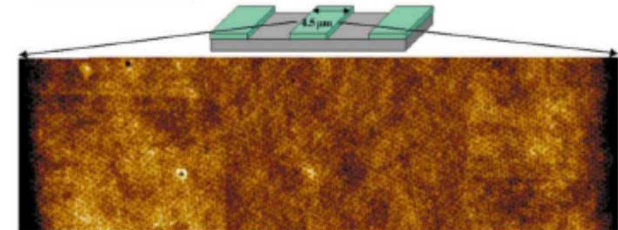
Short-range lateral order

Deep Patterning

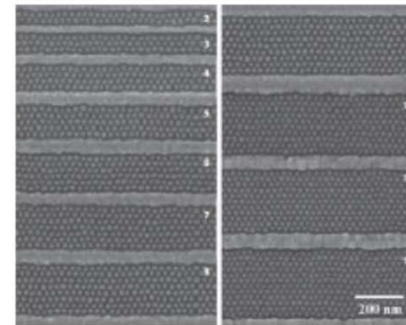


Improving lateral order

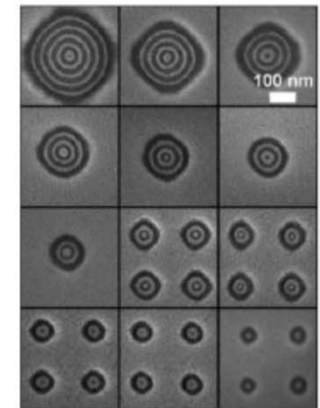
Deep Topographic Patterning



Adv. Mater., **13**, 1152 (2001)



Nat. Mater., **3**, 823 (2004)

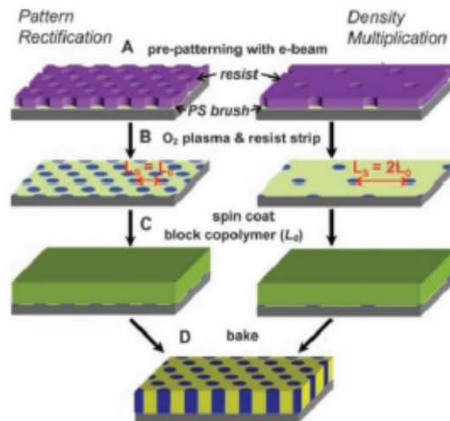


Nano Lett., **8**, 2975 (2008)

Limitation of grain size

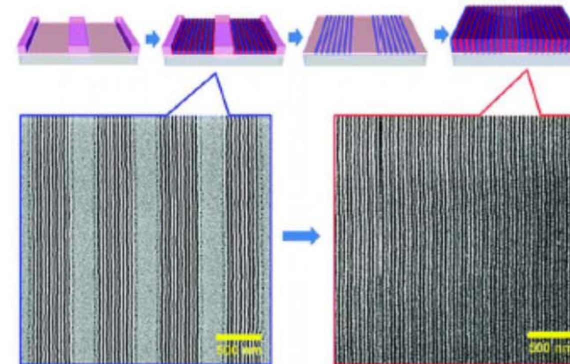
Overcoming BCP Grain Size Limitations

Chemical Patterning



Science, **321**, 936 (2008)

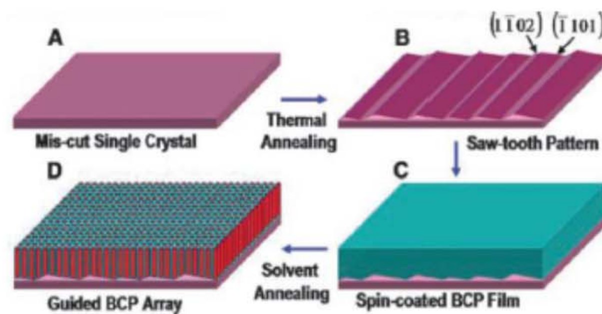
Topographic with Chemical Patterning



ACS Nano, **4**, 5181 (2010)

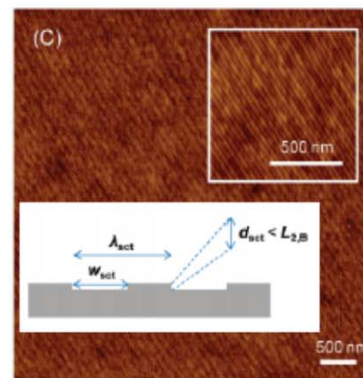
Minimal Topographic Patterning

Faceted Pattern



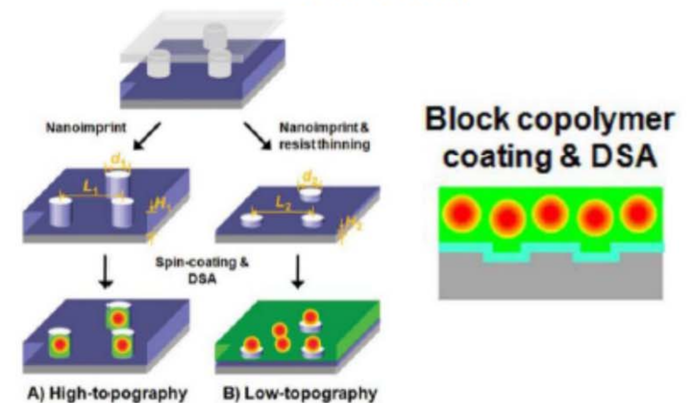
Science, **323**, 1030 (2009)

Shallow Trench



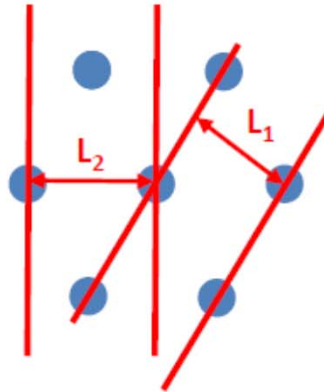
ACS Nano, **5**, 2855 (2011)

Low Pillar



J. Polym. Sci., Part B, **52**, 361 (2014)

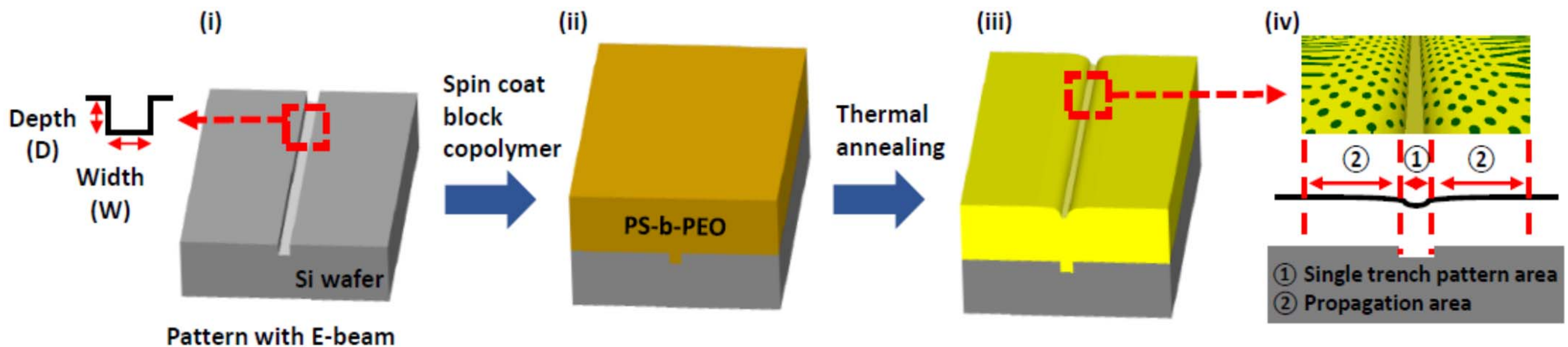
Overcoming BCP Grain Size Limitations



L_1 = **26.8 nm**, the domain spacing of hexagonally packed cylindrical microdomains in bulk

L_2 = **30.9 nm**, center to center distance between cylindrical microdomains in bulk

Directed Self-assembly on Single Trench Pattern



Summary

- Long-range lateral order of hexagonal arrays were produced using minimal topographic patterns with thermal annealing
- Densities of 0.7 terabits/in^2 were achieved
- Highly oriented line patterns on minimal topographic patterns were obtained using solvent vapor annealing

Acknowledgements

Contributors:

- Dr. Jacob John
- Prof T. Russell (PSE)
- Prof. J. Schiffman (ChE)
- J. Nicholson (CHM Cleanroom)
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