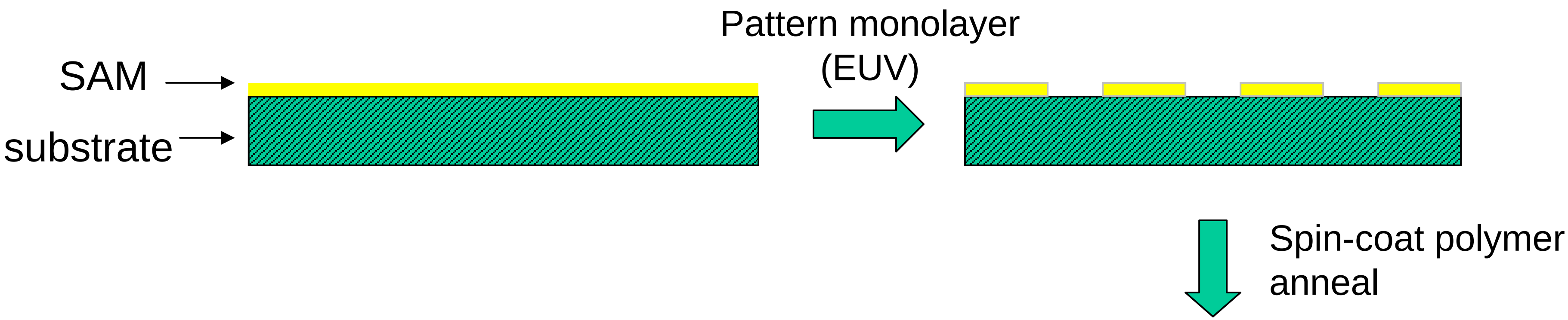
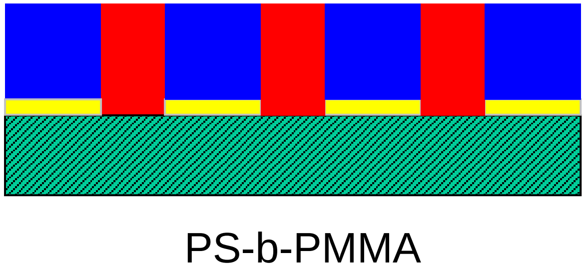
Three Approaches for Nanopatterning

- Lithography
  - allows the design of arbitrary pattern geometry
  - but maybe high cost and low throughput
- Self-Assembly
  - offers high throughput and low cost
  - but limited selections in pattern geometry
  - random locations and multidomain lattice
- Combination of lithography and self-assembly
  - offer the best of both worlds
  - add intelligent guiding

Guiding Self-Assembly by Wetting

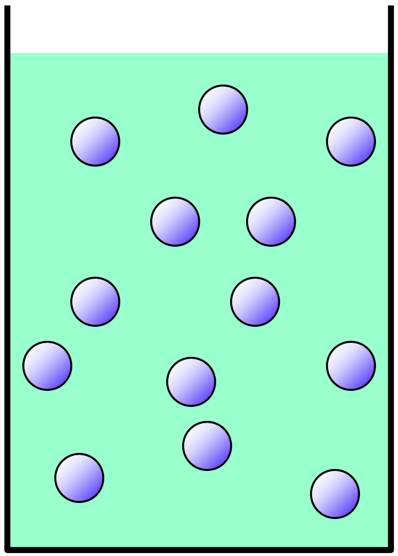


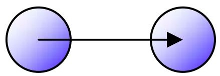
Varying surface energy (by modifying monolayer) causes preferential wetting of phases on domains.

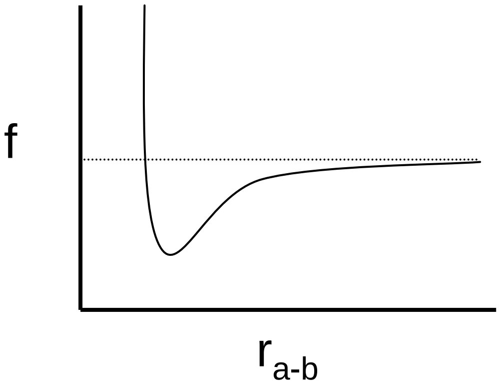


Yang, Peters, Nealey, Solak, Cerrina, Macromol., **33**, 9575-9582 (2000).

Colloidal Particle Self-Assembly



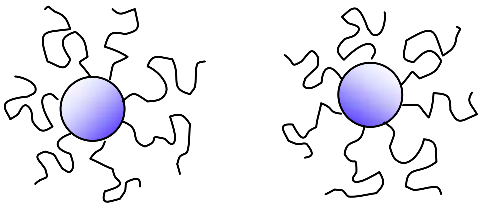




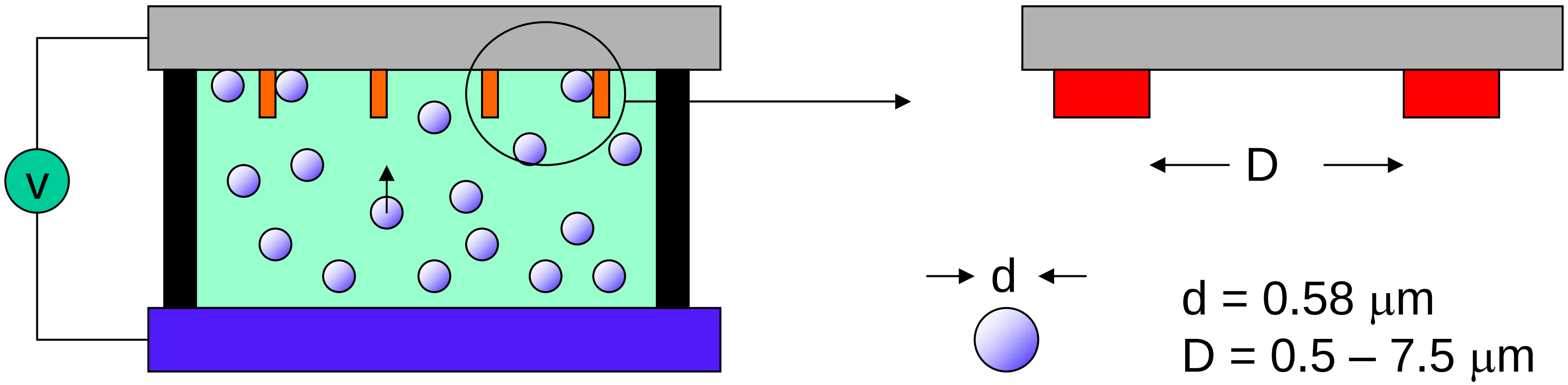
Methods of Colloidal Stabilization:

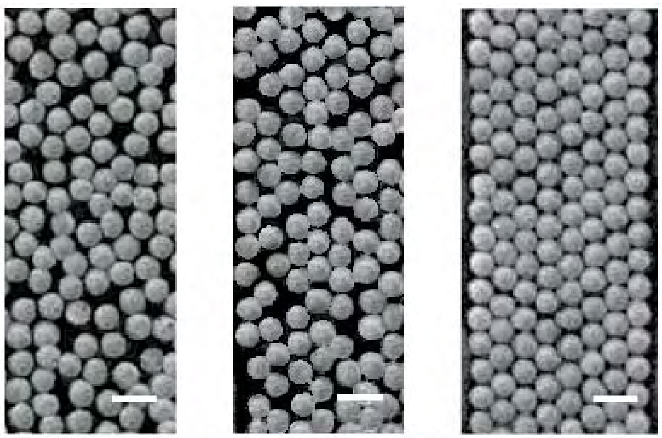
charge stabilization

polymer stabilization

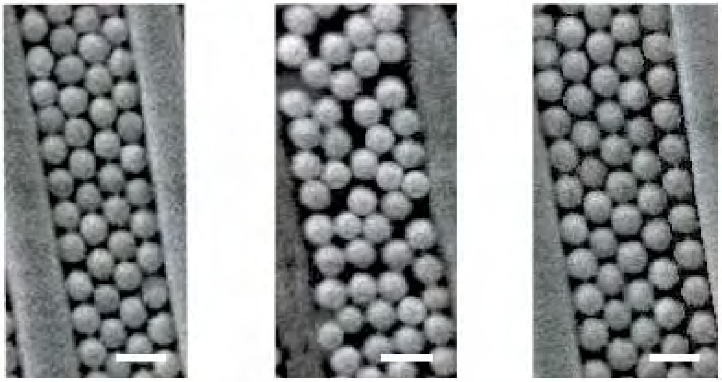


Electrodeposition of Colloidal Crystals





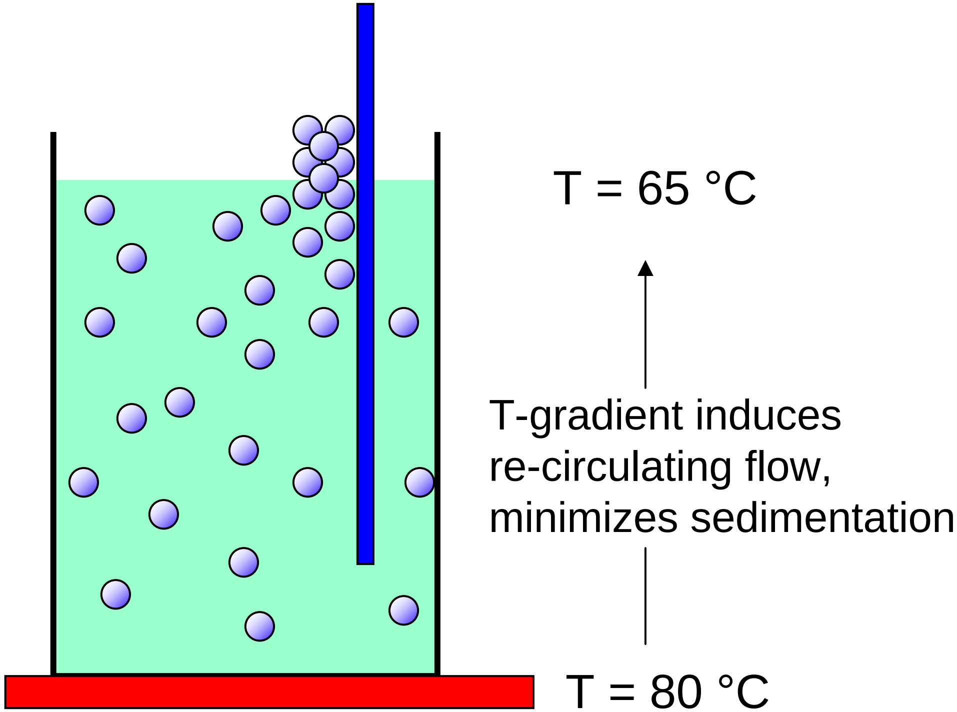
non-patterned D = 5.5 μm D = 4.2 μm



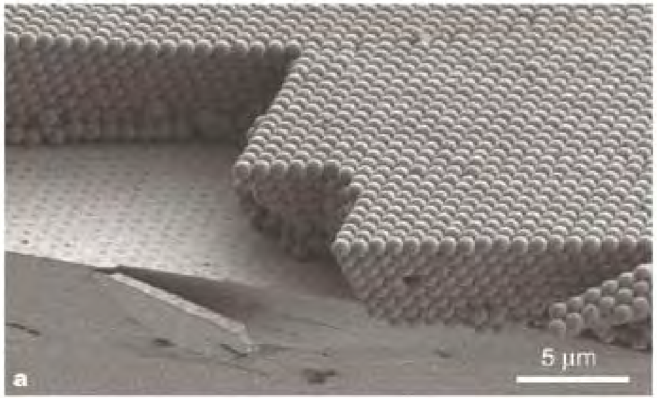
D = 2.22 D = 2.51 D = 2.72 μm

Kumacheva, Golding, Allard, and Sargent, Adv. Mater., **14**, 221-224 (2002)

On-chip Assembly of Colloidal Crystal



d = 855 nm
lattice: FCC

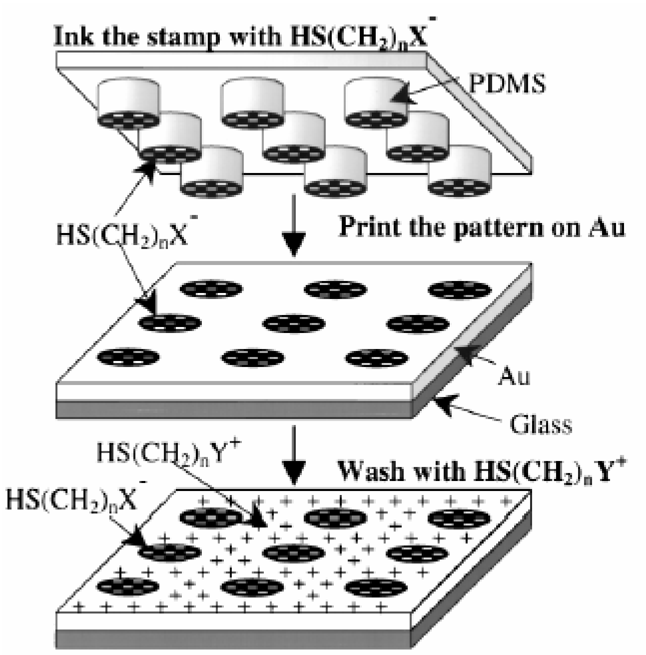


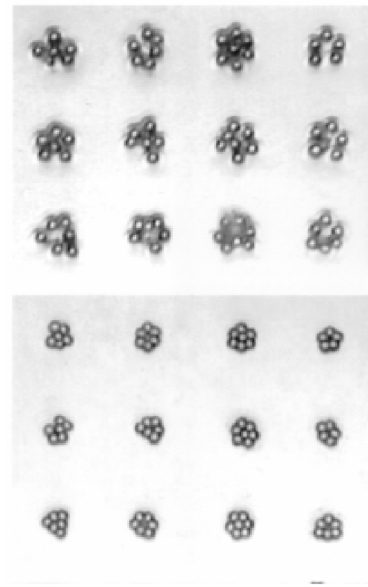
Grain-sizes 1 mm – 1 cm
(10 – 100 x better than sedimented opals)

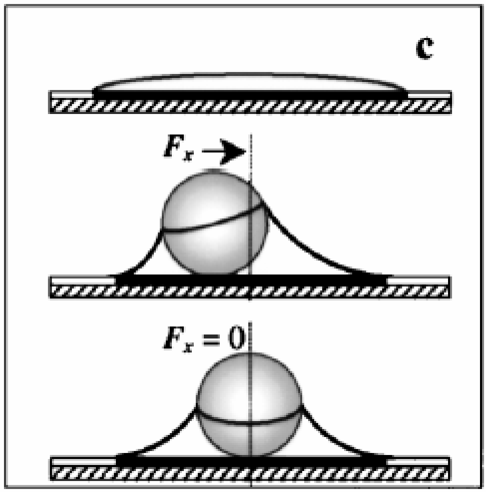
(110) orientation preferred

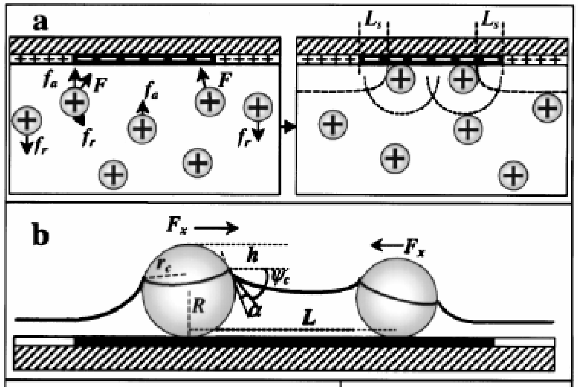
Vlasov, Bo, Sturm, and Norris, Nautre, **414**, 289 – 293 (2001).

Colloidal Deposition onto Charged Surface









Aizenberg, Braun, and Wiltzius, Phys. Rev. Lett., **84**, 2997 – 3000 (2000)

Sumary Colloidal Crystallization

- Colloidal crystallization can be used to grow photonic crystals with good long-range order.

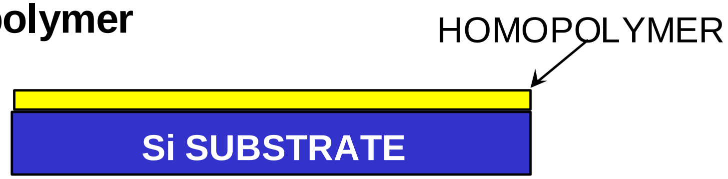
- Physical and chemical templating can lead to improved local order and selective crystallization

Future:

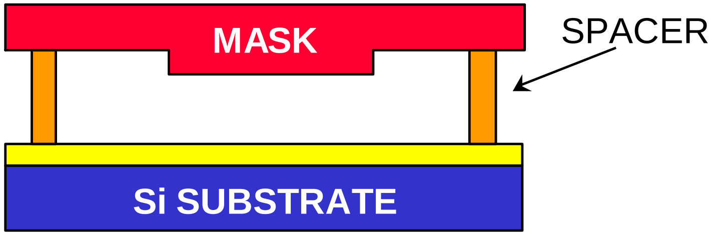
- Use charge templating to seed first layer of deposition and then grow crystal of preferred orientation

Lithography-Induced Self-Assembly (LISA)

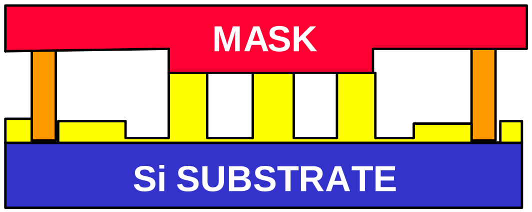
1. **Spin polymer**



2. **Place a mask with spacers**

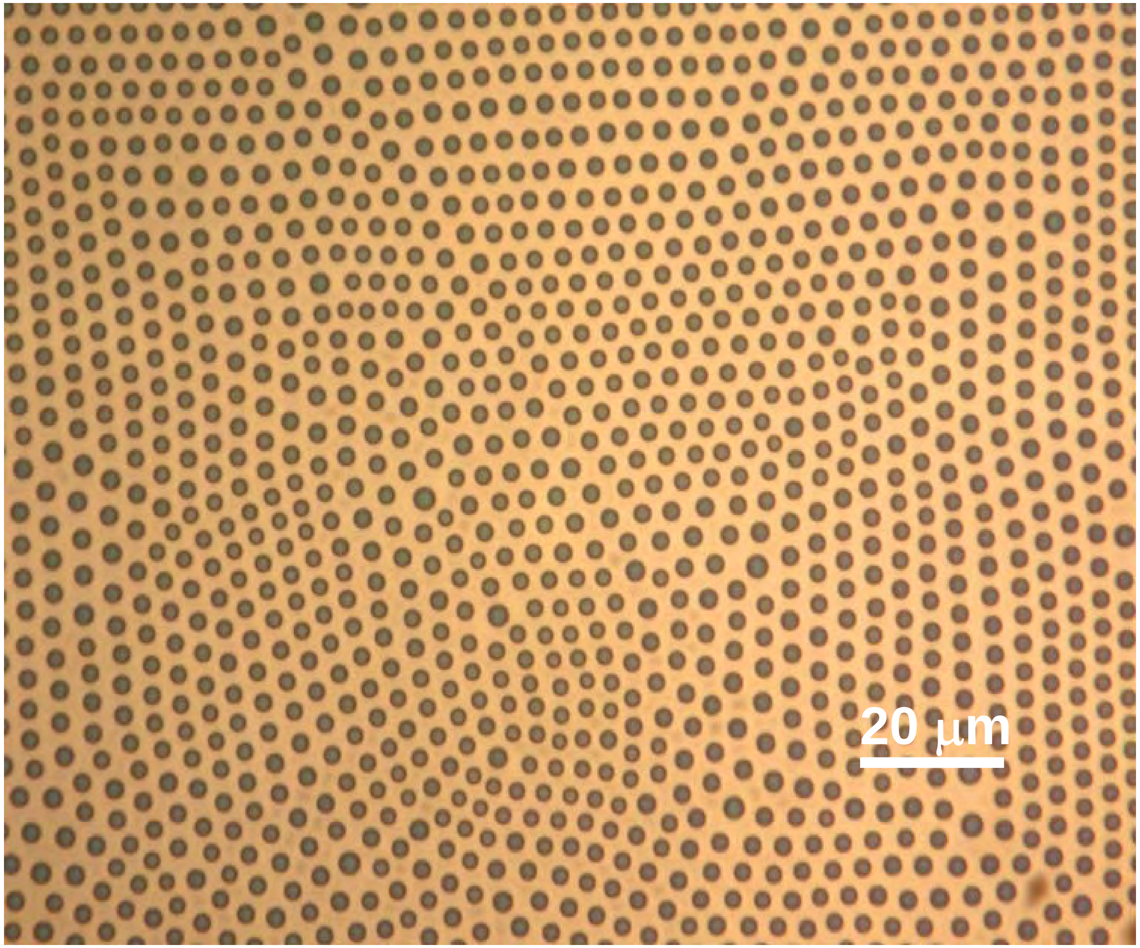


3. **Heat, induce self-assembly**

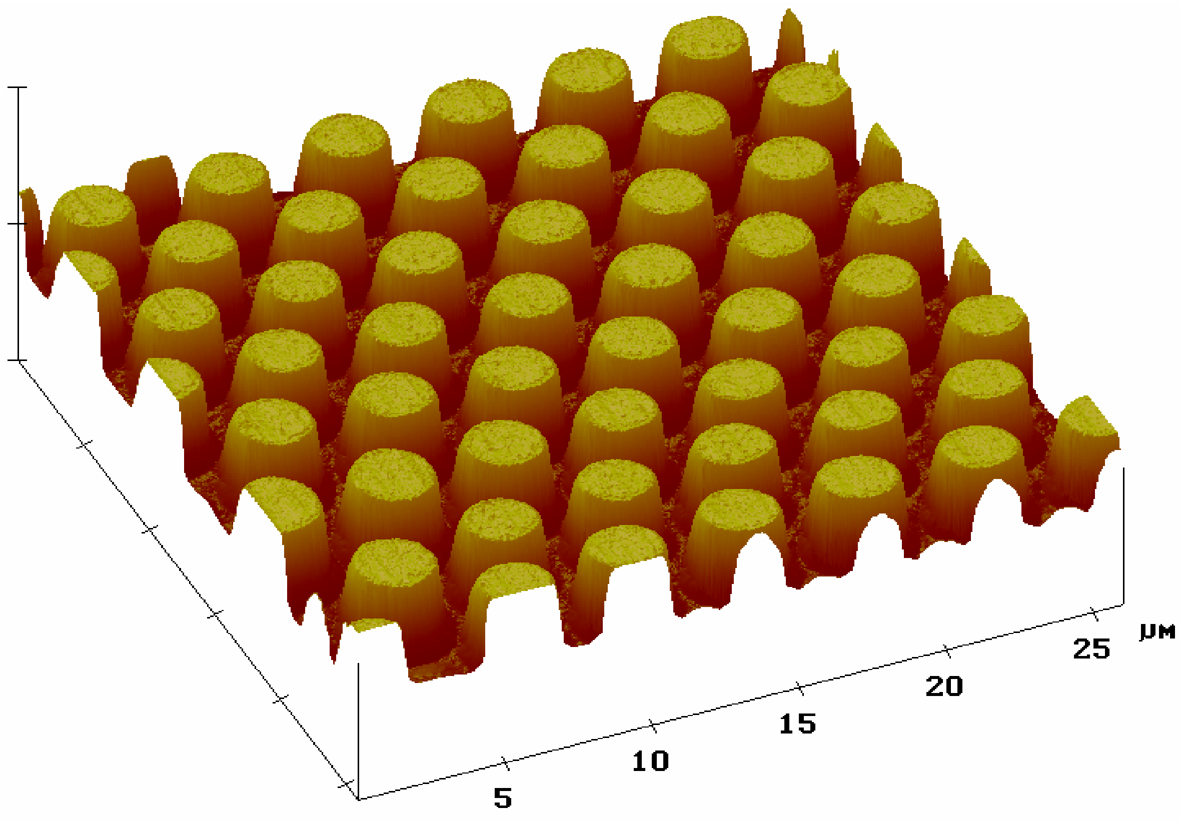


S.Y. Chou and L. Zhuang, J. Vac. Sci. & Technol, **B17**, 3197 (1999)

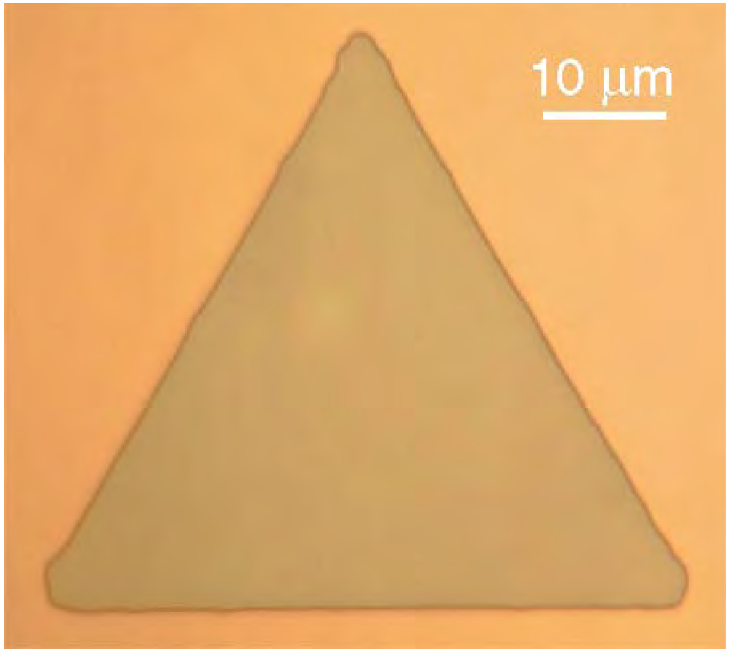
Multidomain LISA Formed under a Flat Mask



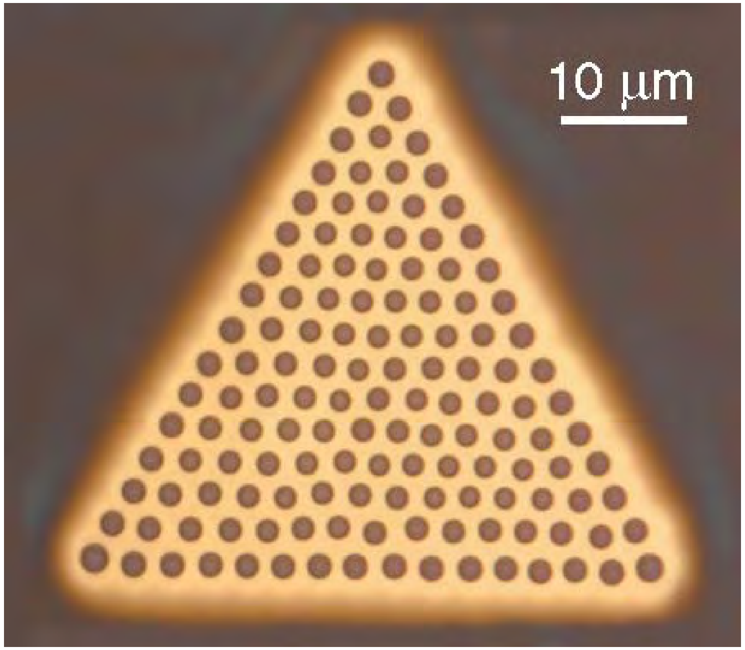
LISA Formed Under a Flat Mask



LISA with a Triangle Mask Pattern

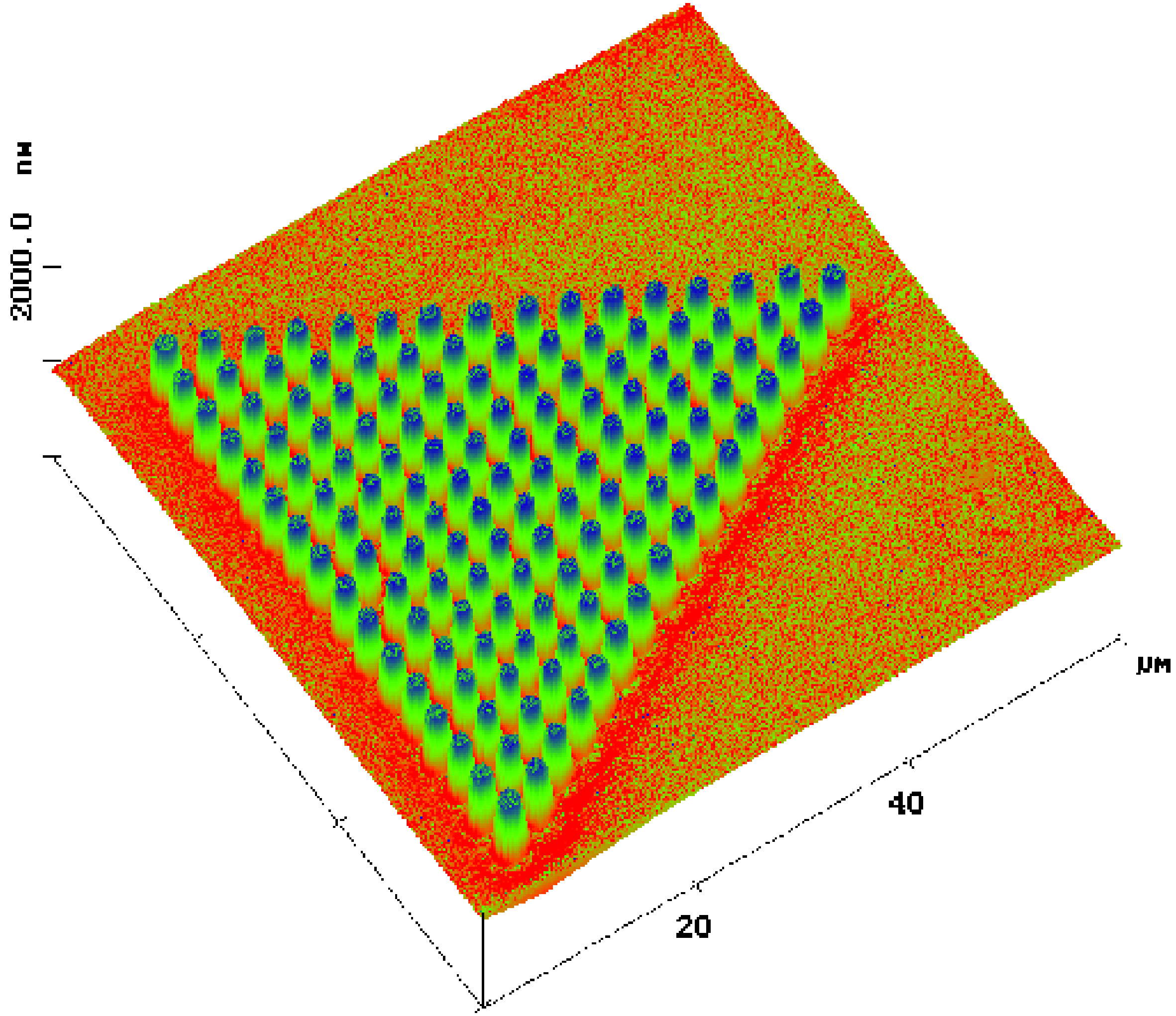


Mask

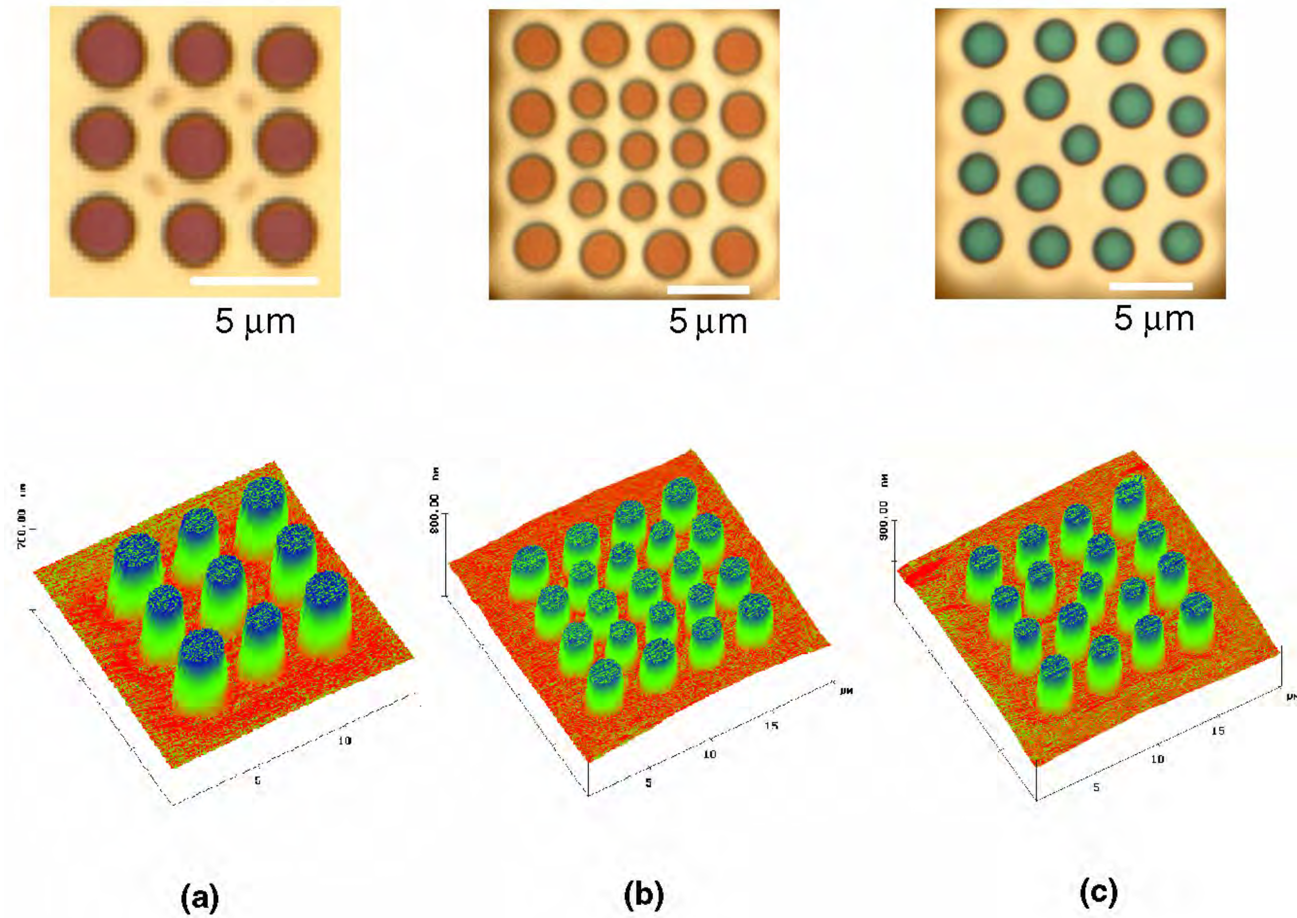


PMMA LISA

LISA with a Triangle Mask Pattern

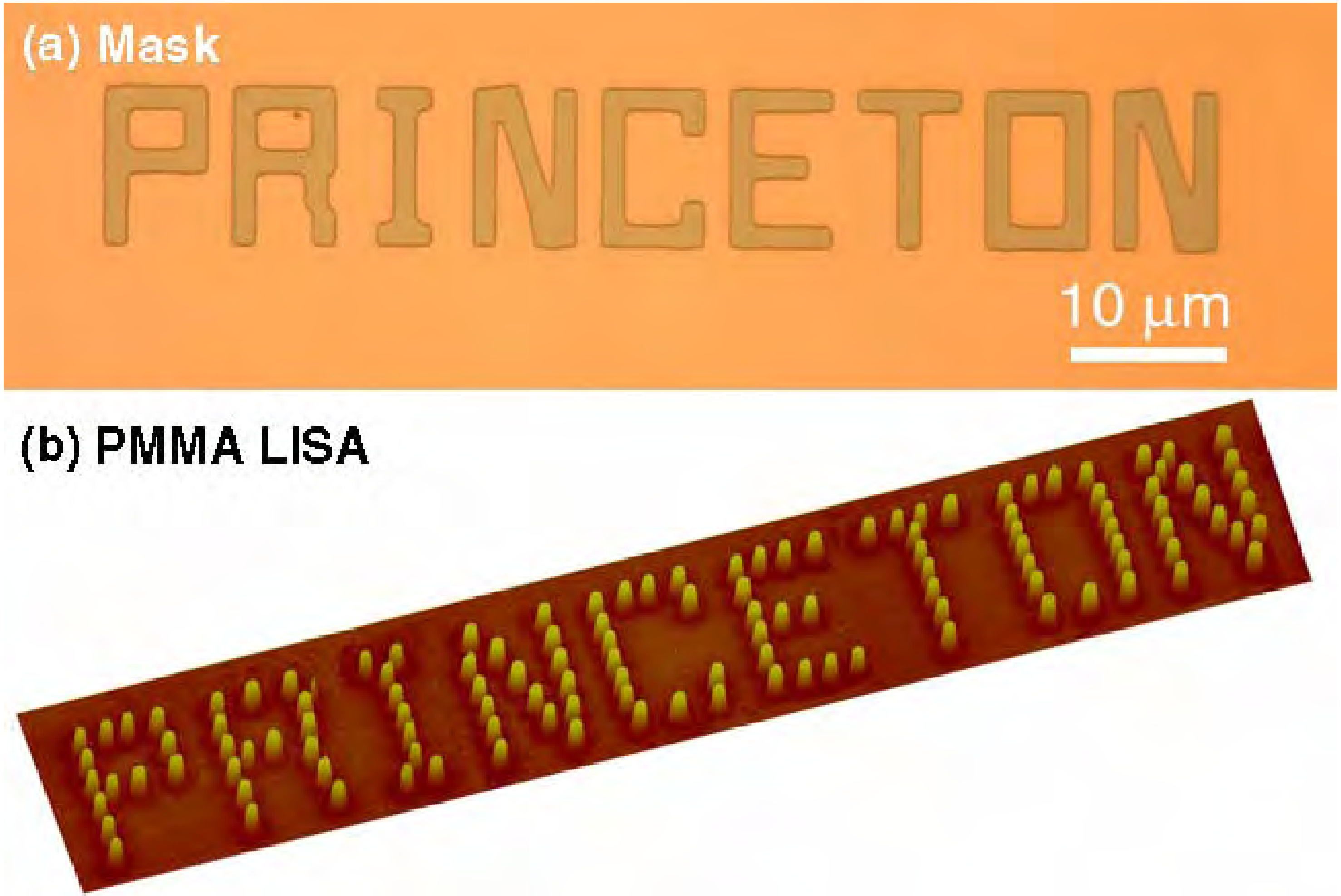


Lithographically-Induced Self-Assembly (LISA) under a Square Mask-Pattern



H=430 nm   H=280 nm   H=360 nm

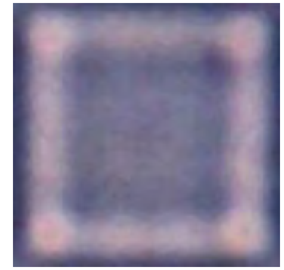
LISA Using a Line Mask Pattern

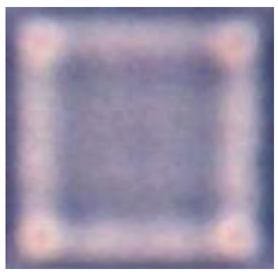


Observed Dynamic Behavior of LISA Formation

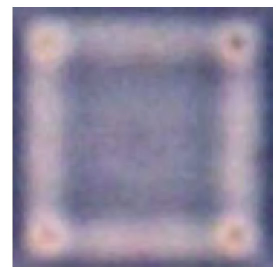

(a)

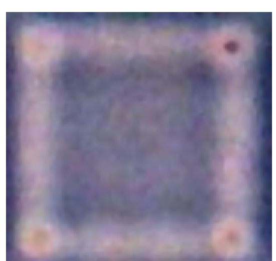

(b) 0 sec

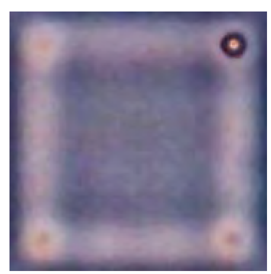

(c) 58:21

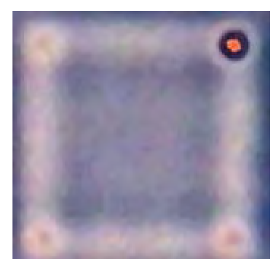

(d) 59:17


(e) 60:44

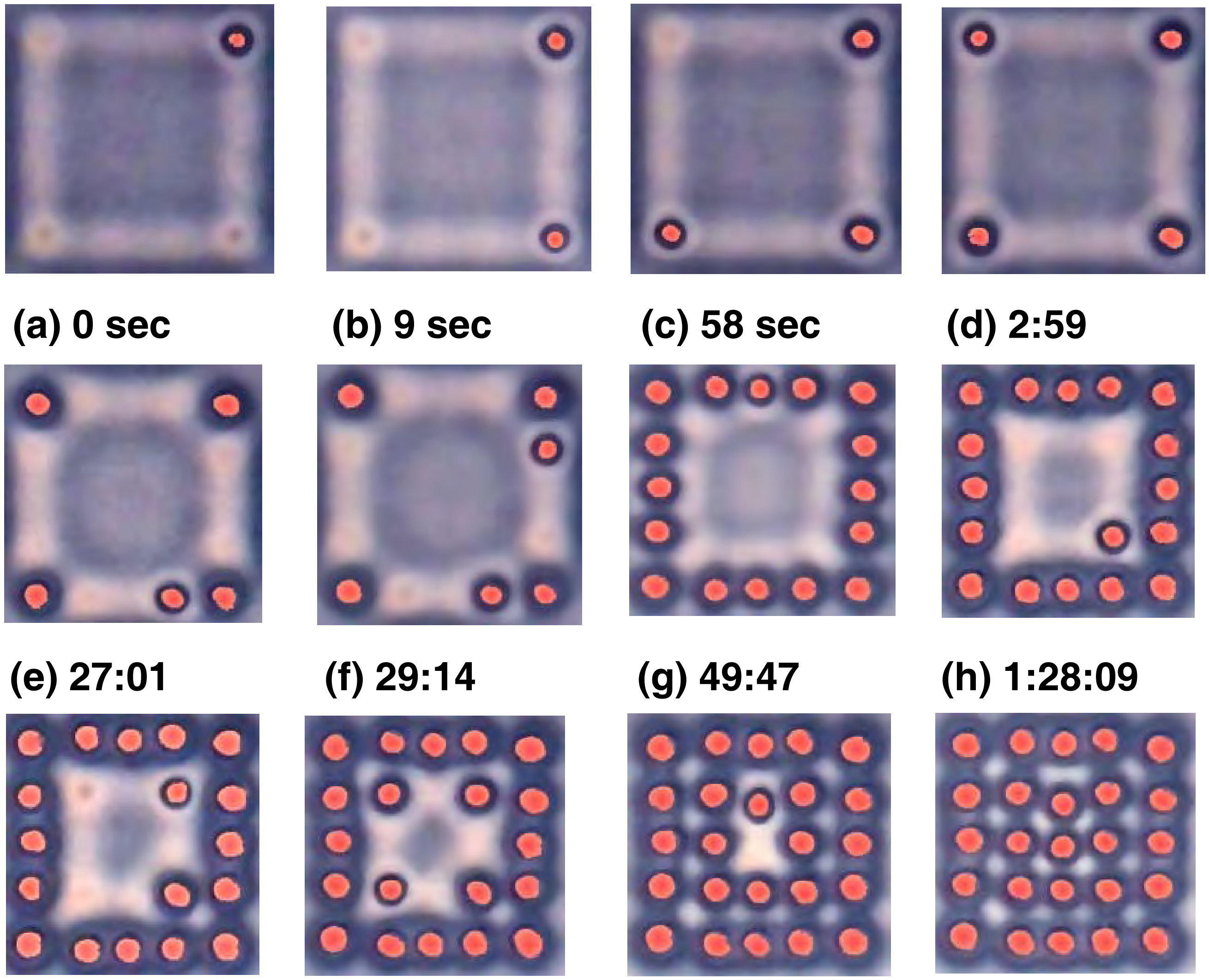

(f) 1:01:41


(g) 1:01:48


(h) 1:01:49


(i) 1:01:54

Observed Dynamic Behavior of LISA Formation

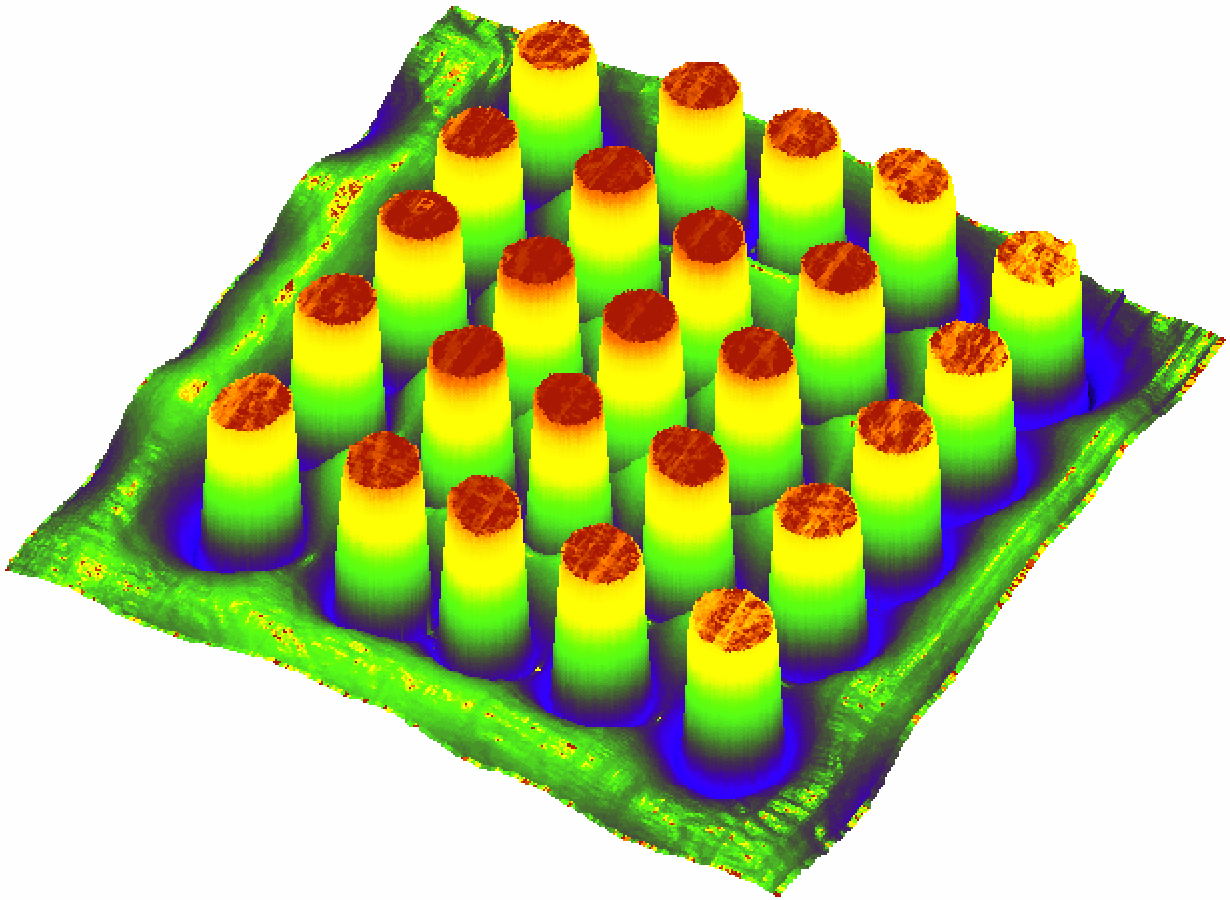


(a) 0 sec (b) 9 sec (c) 58 sec (d) 2:59

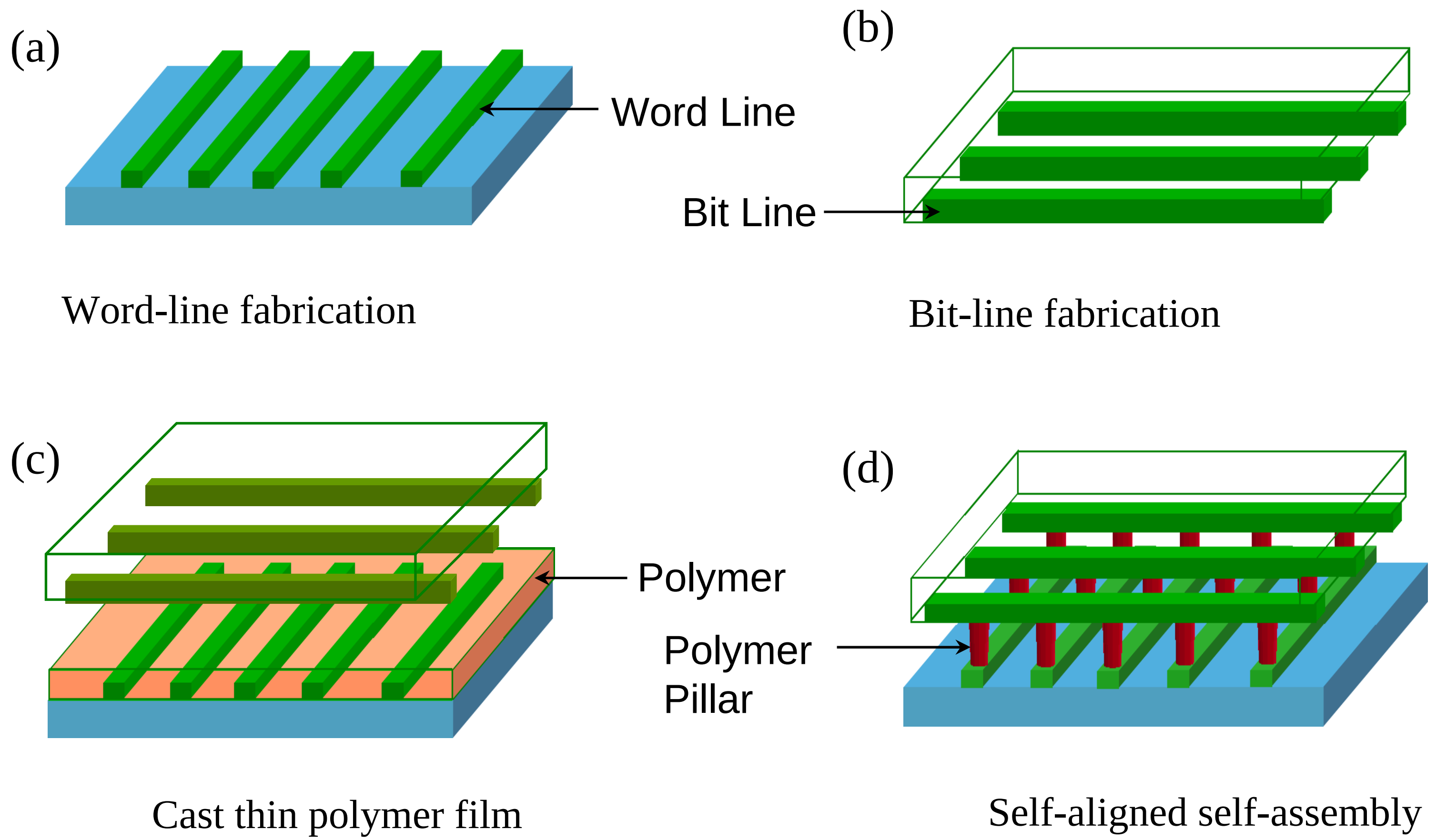
(e) 27:01 (f) 29:14 (g) 49:47 (h) 1:28:09

(i) 1:35:12 (j) 1:38:53 (k) 2:05:29 (l) 2:12:03

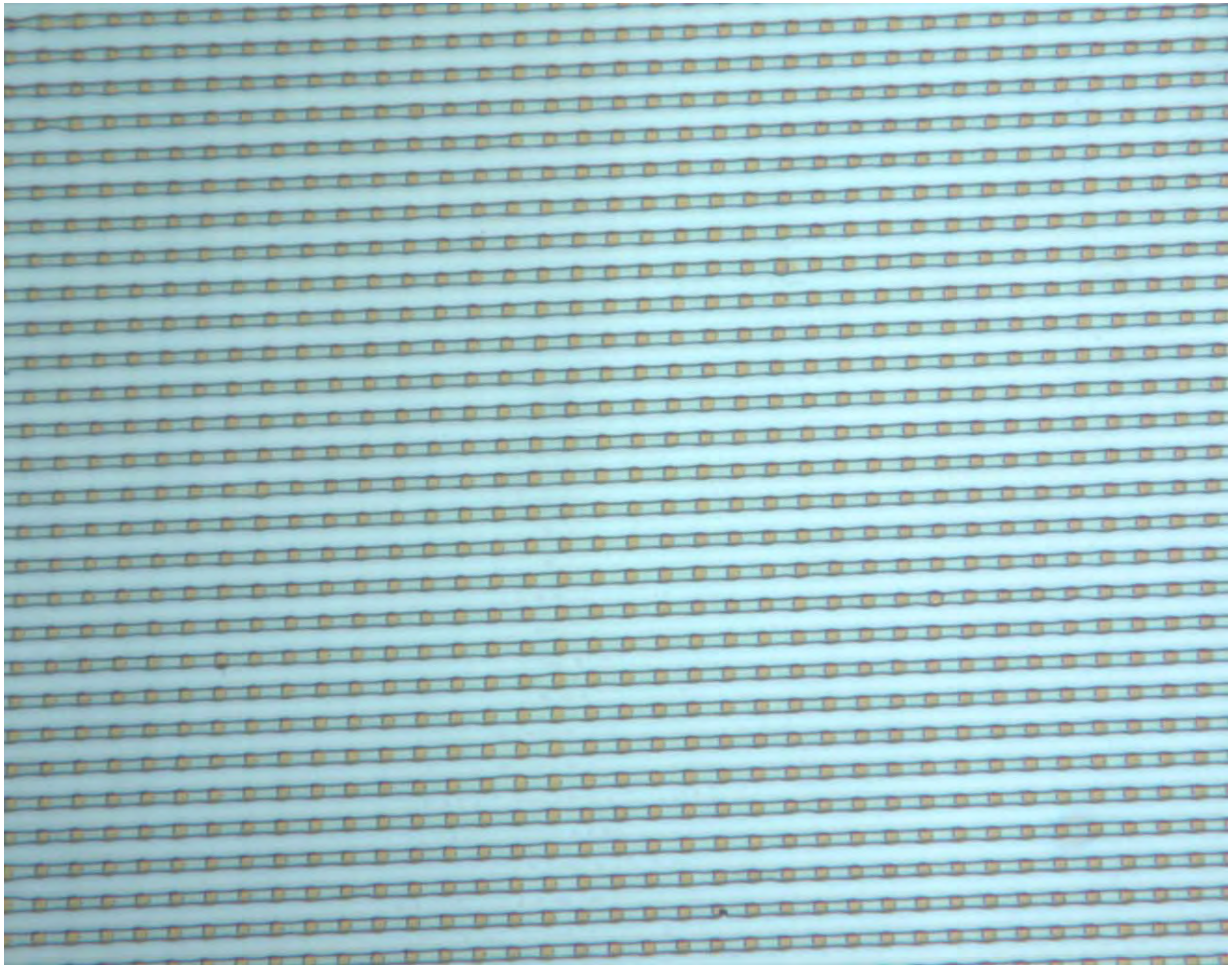
5×5 PMMA LISA Pillar Array Under a Square Mask Pattern



Self-aligned Self-assembly (SALSA) of Random-Access Electronic Devices

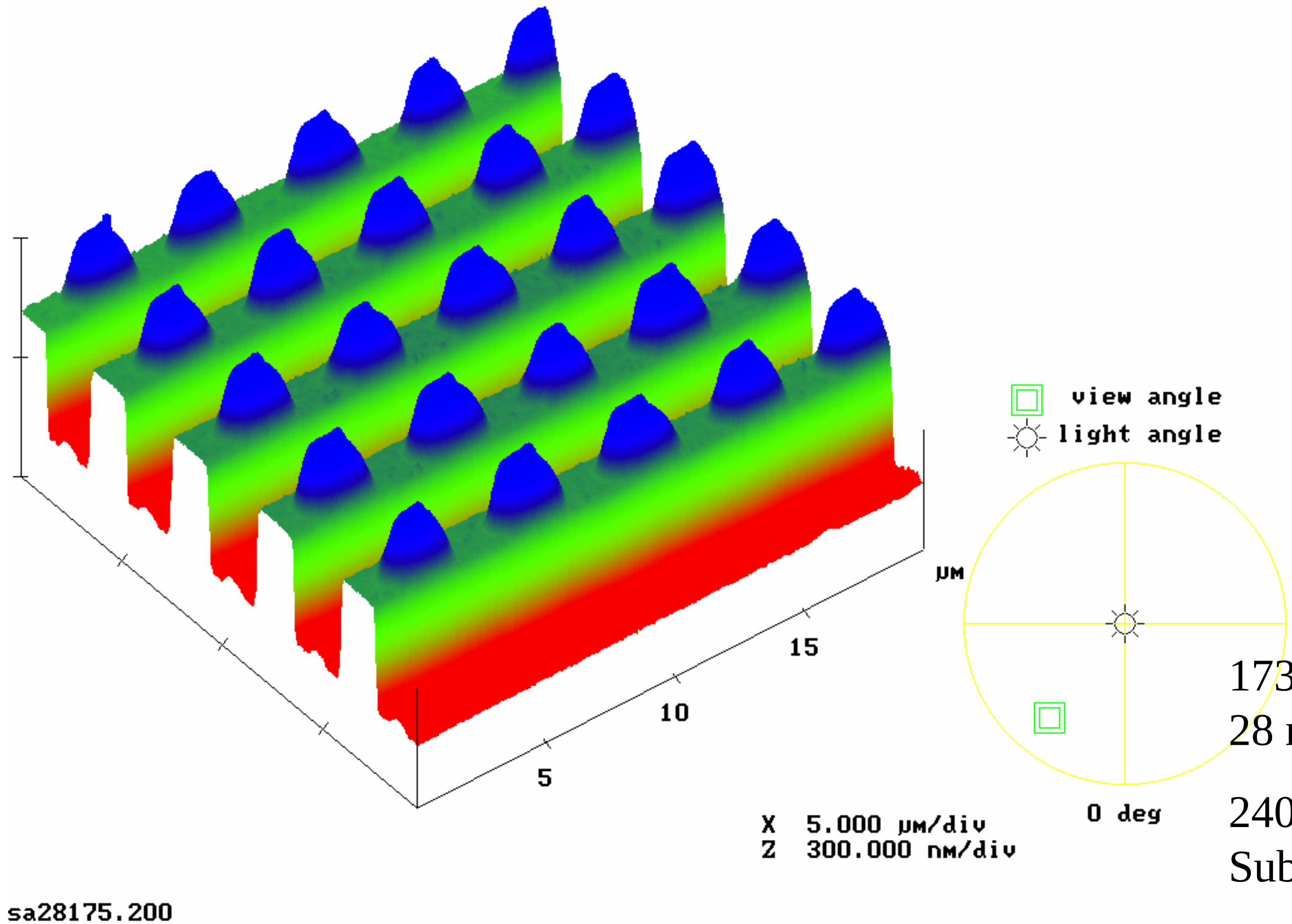


Self-aligned Self-assembly (SALSA) of PMMA Pillars Array between Word-lines and Bit lines



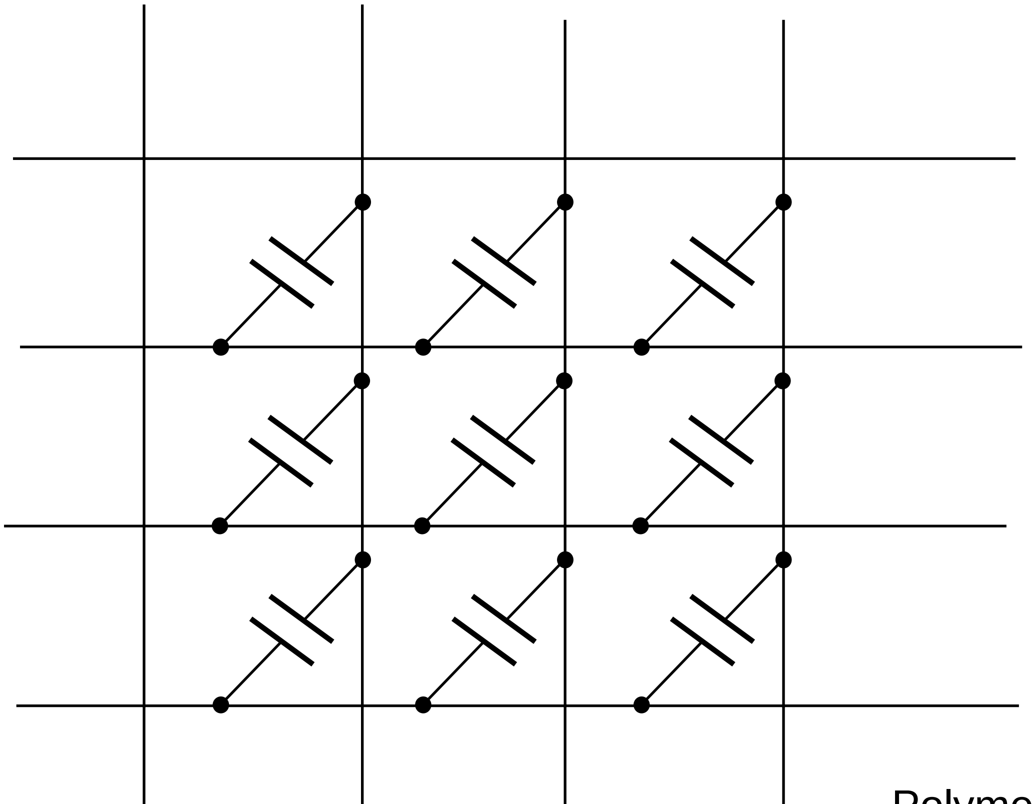
135 nm spacer, 28 nm PMMA

Self-aligned Self-assembly (SALSA) of PMMA pillars On SiO2 Grating Substrate with SiO2 Grating Mask

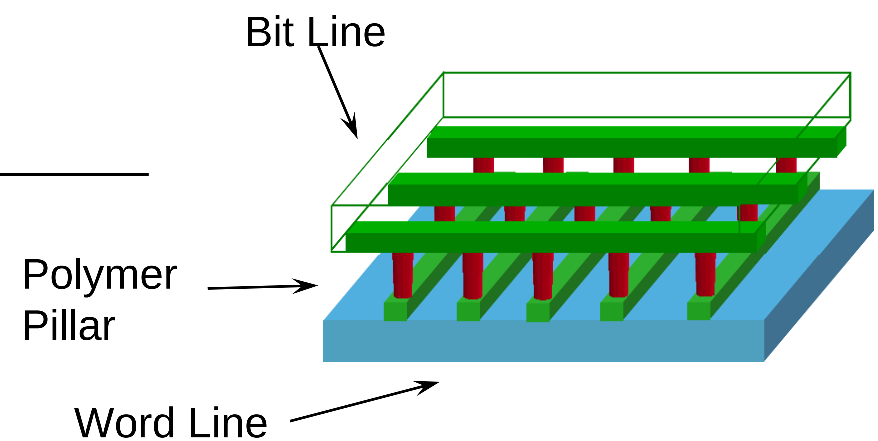


173 nm spacer,
28 nm PMMA,
240 nm high Substrate

Random Accessible Capacitor Array



Bit lines



word lines

Etching

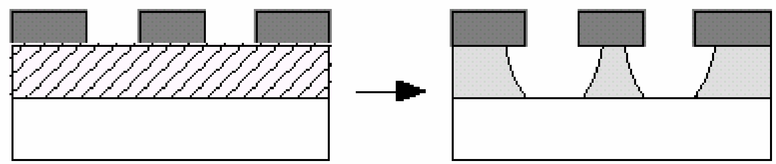
- Wafer cleaning and preparation
- Chemical etching
- Sputter etching
- Chemical assisted ion etching
- *Reactive ion etching (RIE)*

Reactive Ion Etching (RIE)

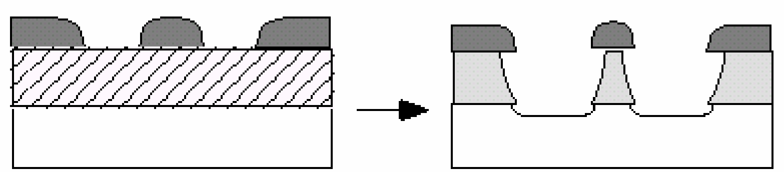
- Anisotropic
- Good selectivity (not as good as plasma etching)
- Advantages over wet chemical etching
  - Better anisotropy
    - steeper sidewalls
  - Less undercutting of structures
  - Easier to control

Anisotropy, Undercutting, and Selectivity

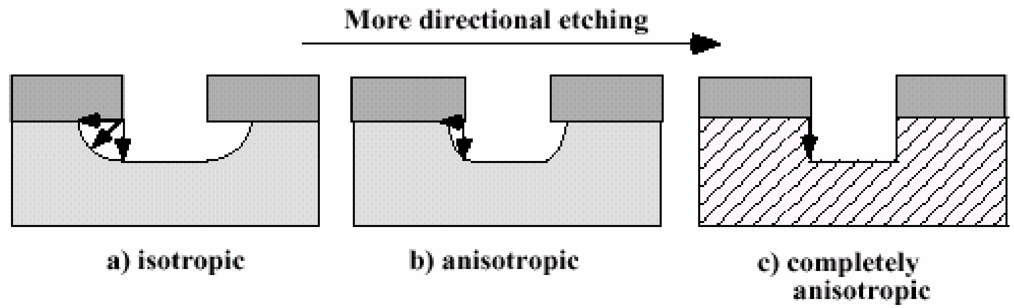
Undercutting



Selectivity



Anisotropy



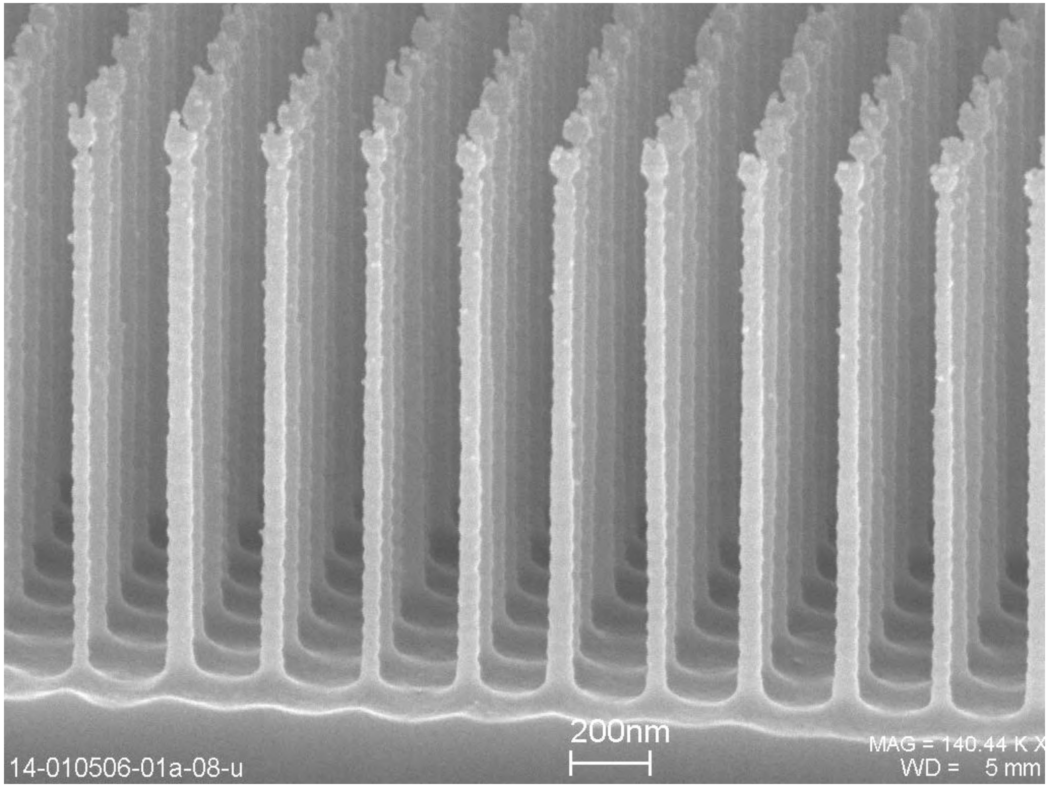
RIE Parameters

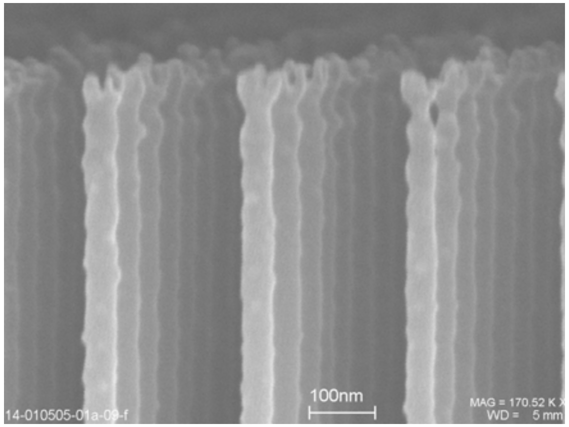
- Etch gas
  - O_2, CHF_3, SF_6, CF_4, Ar
- Gas flow rate (sccm)
- RF power
  - ~50-200 W
- Pressure
  - Need low pressure; ~10-100 mtorr
    - Increases anisotropy
- Etch rate (nm/min)

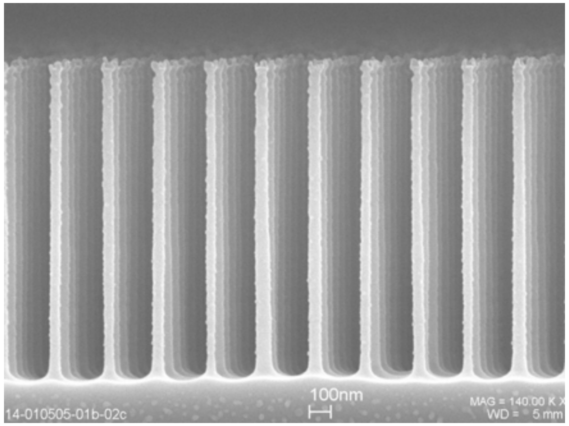
40 nm Pillar Array of Aspect Ratio of 38 by NIL and RIE

Nanonex
Engine for Nanotechnology

D: 40 nm, h: 1475 nm







Morton and Chou to be published

Nanonex:

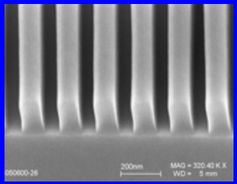
Industrial Turn-Key Nanoimprint Solution

Nanonex

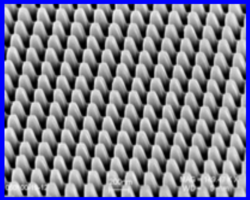
Complete Nanoimprint Solution

Machines

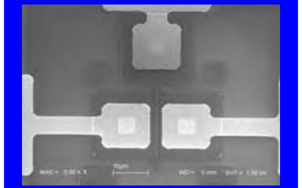
Resists



Masks



Process



Nanonex Current Products (I): NIL Machine Series

Nanonex-1000
- **Thermal plastic resists**
- no alignment
- sub-60 sec/wafer
- 2”, 4”, 6”, and 8” wafers
- opto, displays, bio, data storage, materials, …, appls

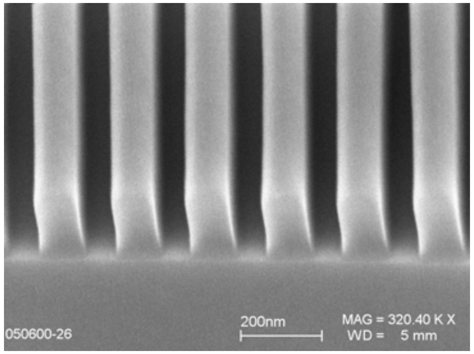
Nanonex-2000
- **Both thermal-plastic & photo-curable resists**
- alignment upgradable
- sub-60 sec/wafer
- 2”, 4”, 6”, and 8” wafers
- opto, displays, bio, data storage, materials, …, appls

Nanonex-3000
- **Photo curable resists**
- precision alignment
- single wafer or step-repeat
- sub-60 sec/wafer*
- 2”, 4”, 6”, and 8” wafers
- micro-wave, opto, displays, bio, data storage, materials, …, appls

Nanonex Current Products (II): Resists Series

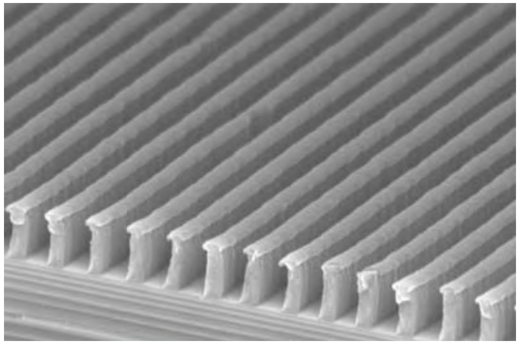
NXR-1000 Series
Thermal Resist

- fast respond time
- excellent flowbility
- spinning
- drop on Demand
- 4 products



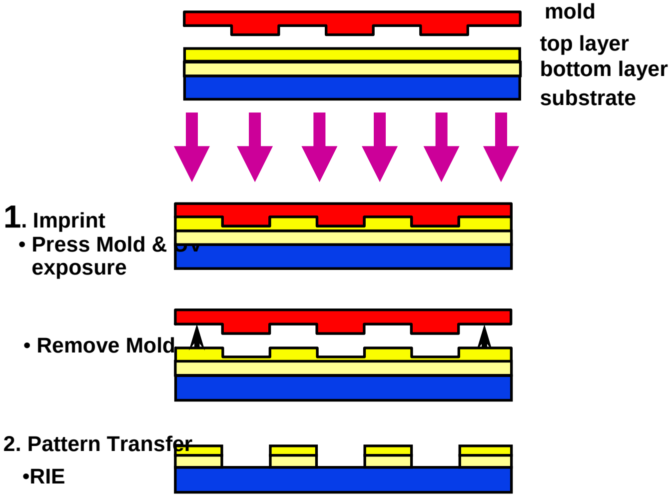
NXR-2000 Series
UV Curable Resist (Top)

- fast response time
- excellent flowbility
- Spinning
- drop on Demand
- 5 products



NXR-3000 Series
Under Layer Resists

- good lift-off properties
- good etching resists
- Spinning
- 4 products



Chou, US Pat 5,772,905, 6,309,580, APL, Vol. 67, 3114 (1995); Science, Vol. 272, 85 (1996)

Additional new materials for direct imprinting

Nanonex Imprint Material Family

Nanoimprint Solutions

Machines *Masks* *Resists* *Processes*

Nanonex

Engine for Nanotechnology™

NXR-1000 Series

Thermal Nanoimprint (T-NIL) Resists
- Fast response
- Excellent uniformity
- Ultra-high resolution
- Low imprint pressure
- Low imprint temperature
- Good flow ability
- Thermoplastic or thermally curable

NXR-2000 Series

Photo-curable Nanoimprint (P-NIL) Resists
- Super fast response
- Unmatched flow ability
- Outstanding uniformity
- Ultra-high resolution
- Low curing dosage
- Very low imprint pressure
- Spin-on or resist-drop dispense

NXR-3000 Series

Underlayer Resists
- Great versatility
- Superior etch resistance
- Enhanced lift-off properties
- Compatible with top-layer

NXR-4000 Series

Mold Materials
- Photocurable
- Excellent chemical resistance
- Excellent thermal stability
- Great durability
- Ultra-high resolution

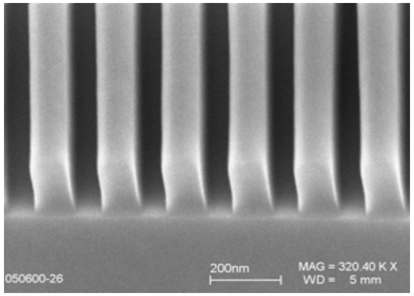
NXT-100 Series

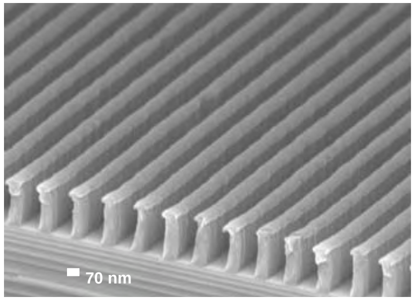
Surface Treatment Agents
- Mold release agents
- Adhesion promoter

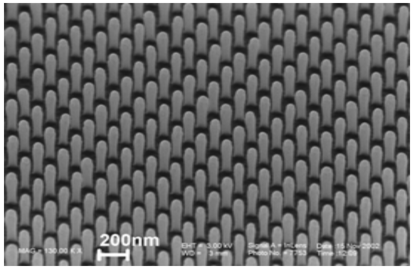
XXXX

Customized Materials

Nanonex offers high performance materials in six series, optimized for nanoimprint processes based on experimental tests of hundreds of material combinations.







LEARN MORE AT

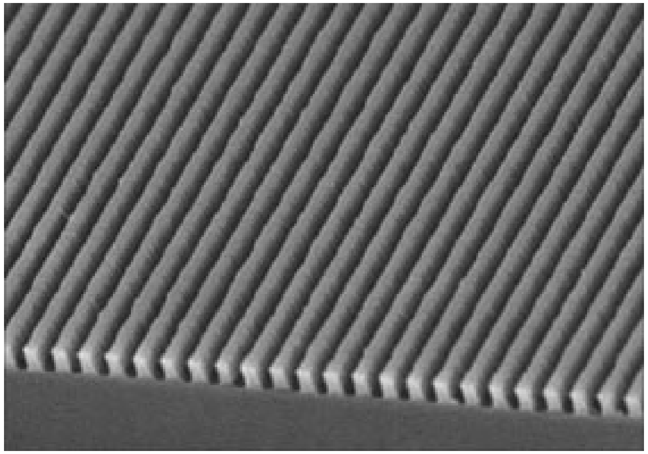
http://www.nanonex.com

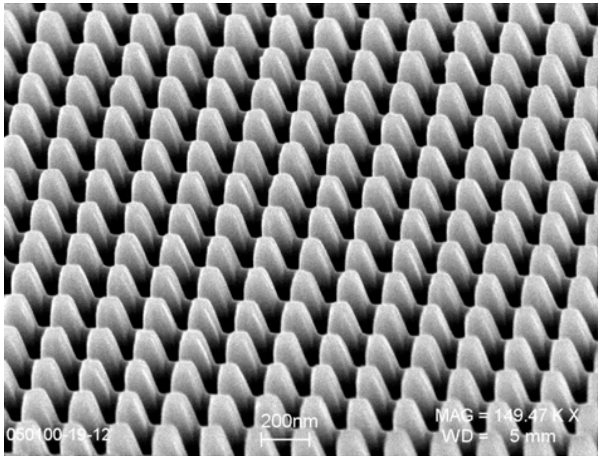
Nanonex Corporation
1 Deer Park Drive, Suite O
Monmouth Junction, NJ 08852
732-355-1600

The specifications may be updated without notice.

Nanonex Current Products (III): Masks

Nanonex offers a variety of NIL masks with periodic patterns of pitch 200 nm and 300 nm, and will assist customers to NIL mask vendors for masks with arbitrary pattern shapes.

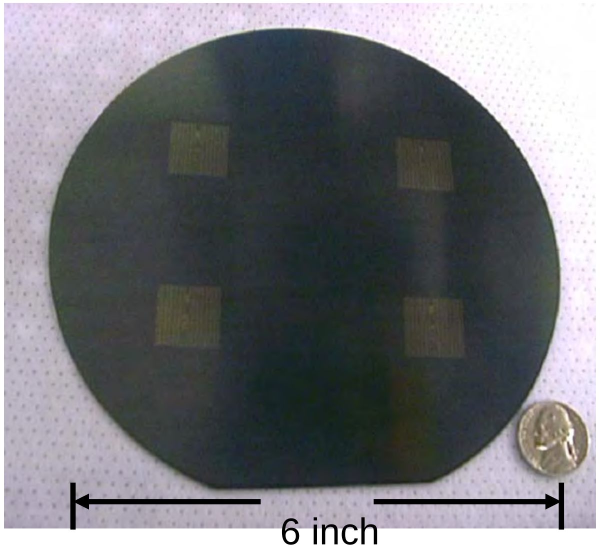


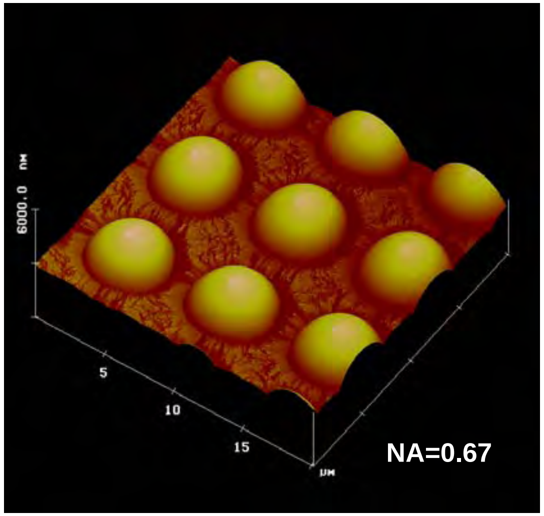


- Masks with periodic 1D or 2D patterns
- Custom mask services available
- Assistance to other mask houses

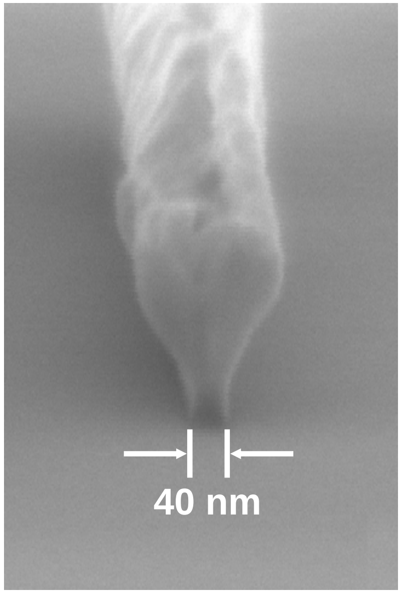
Shipped around globe

Nanonex Current Products (IV): Process & Applications

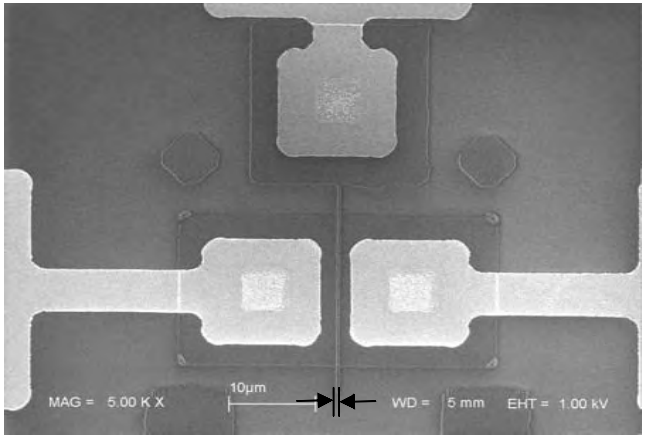




Microlens Array

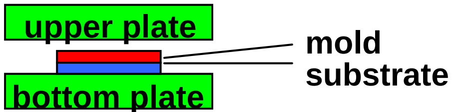


T-Gates for MMICs



60 nm channel MOSFETs on 4” wafer

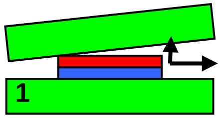
Problems in Solid Parallel-Plate Press (SPP)
-- Poor uniformity, Low-yield, Poor alignment, Damage to mold, and Large thermal mass (Long T-NIL time)



Ideal Case

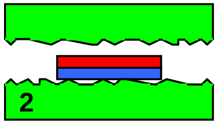
(Two smooth plates are in parallel.)

Reality



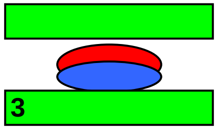
Non-Parallelism Between Two Plates

(Causing relative shift between mold and substrate)



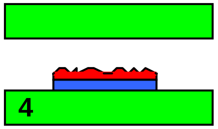
Roughness on Plate Surface

(Causing damage to mold and substrate)



Patterning on Curved Surface

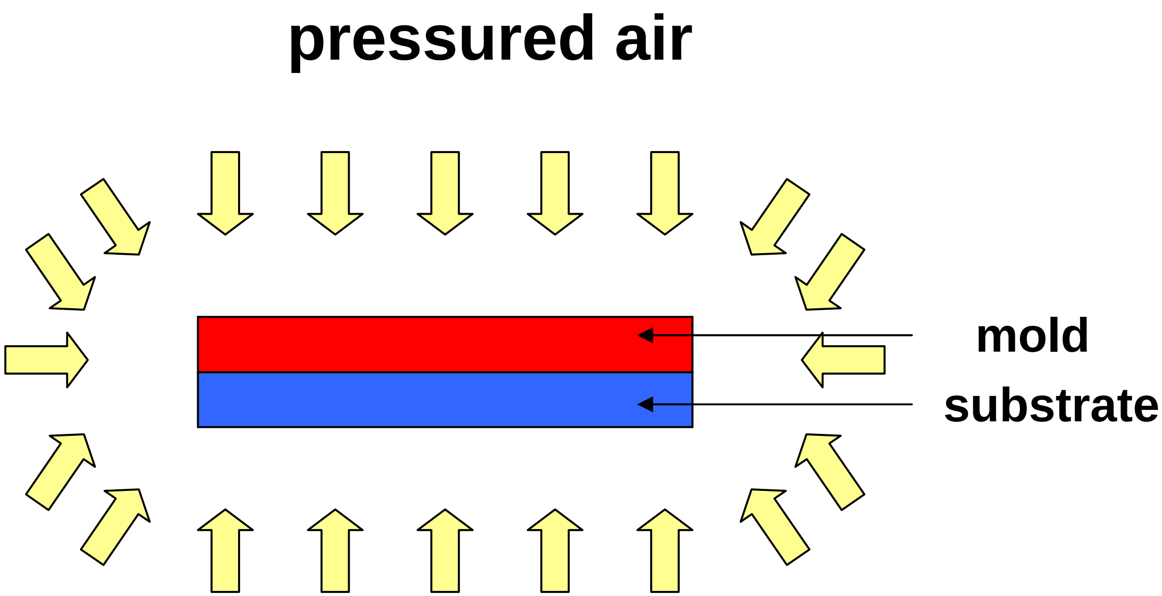
(Can't do it!)



Mold/substrate has uneven backside.

(Can't provide uniform pressure and cause damage to mold And substrate.)

Nanonex's Patented Air Cushion Press (ACP)

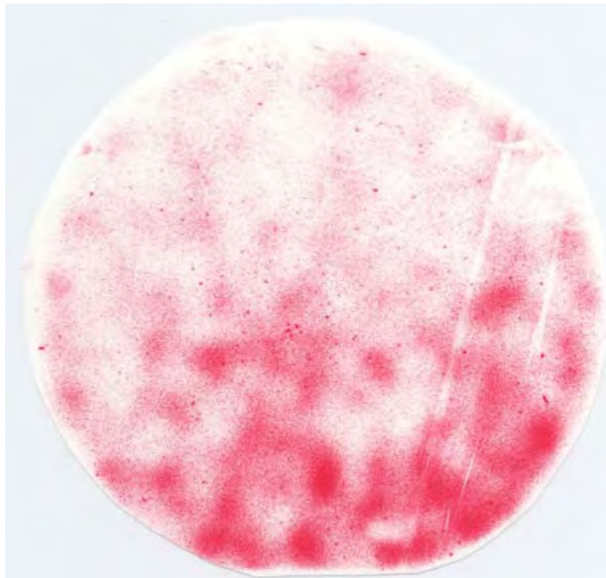


Chou, US Patent 6,482,742

Comparison of Pressure Distributions Over 4-inch Wafers Pressed by Parallel Plates and Nanonex's Air-Cushion Press (ACP)

Pressure-Color Chart

- 450 psi
- 360 psi
- 280 psi
- 210 psi
- 155 psi
- 110 psi
- 75 psi



<u>Conventional Parallel Plates Press</u>

- Applied pressure: 200 psi (1.38MP)
- Actual pressure on the sample varying from <75 psi to >350 psi
- **Over 5 times differences in pressure**

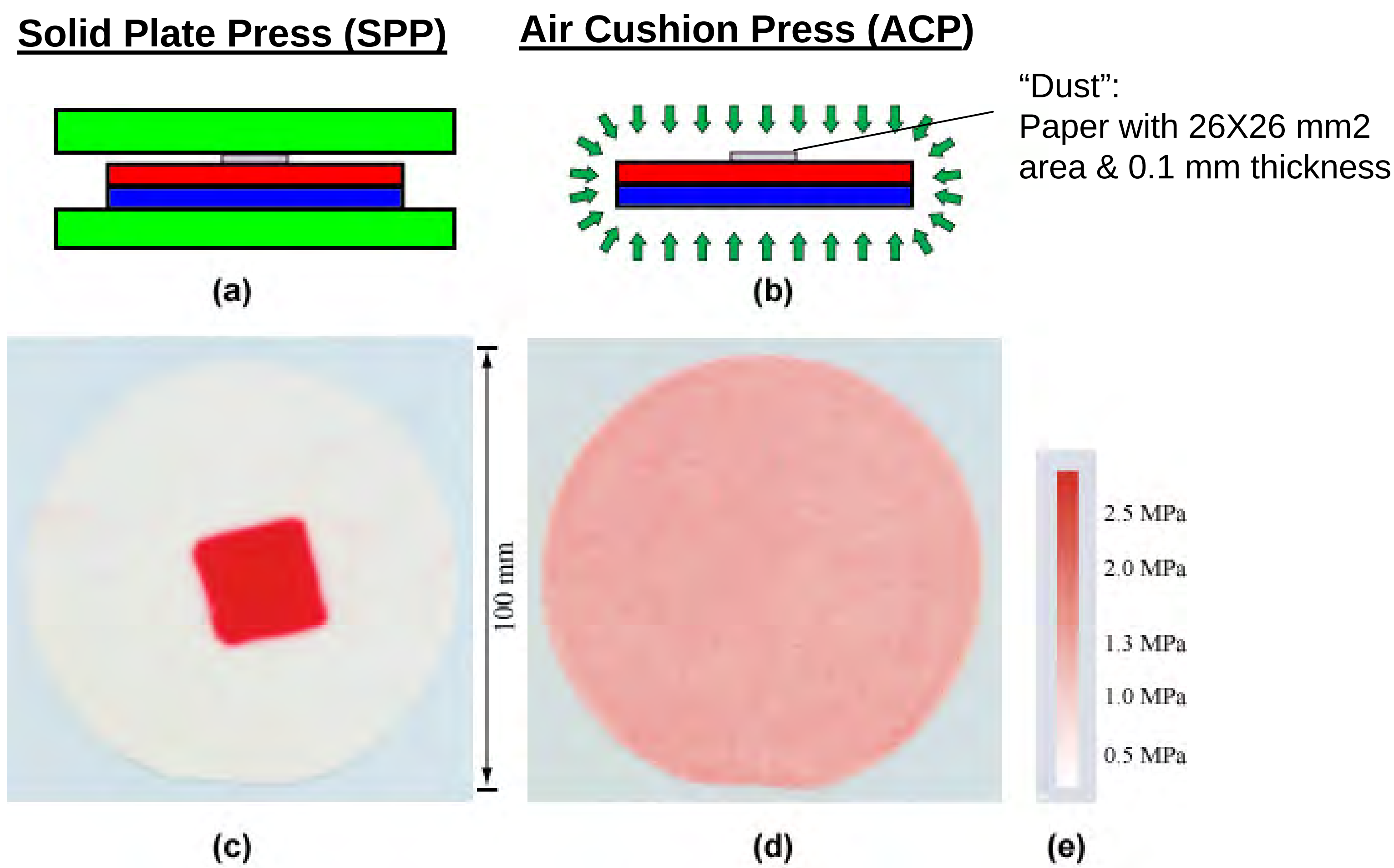
<u>Nanonex ACP</u>

- Applied pressure: 200 psi
- Actual pressure is 200 psi **uniform over the entire wafer**

Courtesy of H.GAO, NSL, Princeton Univ. Nano Lett. 2006

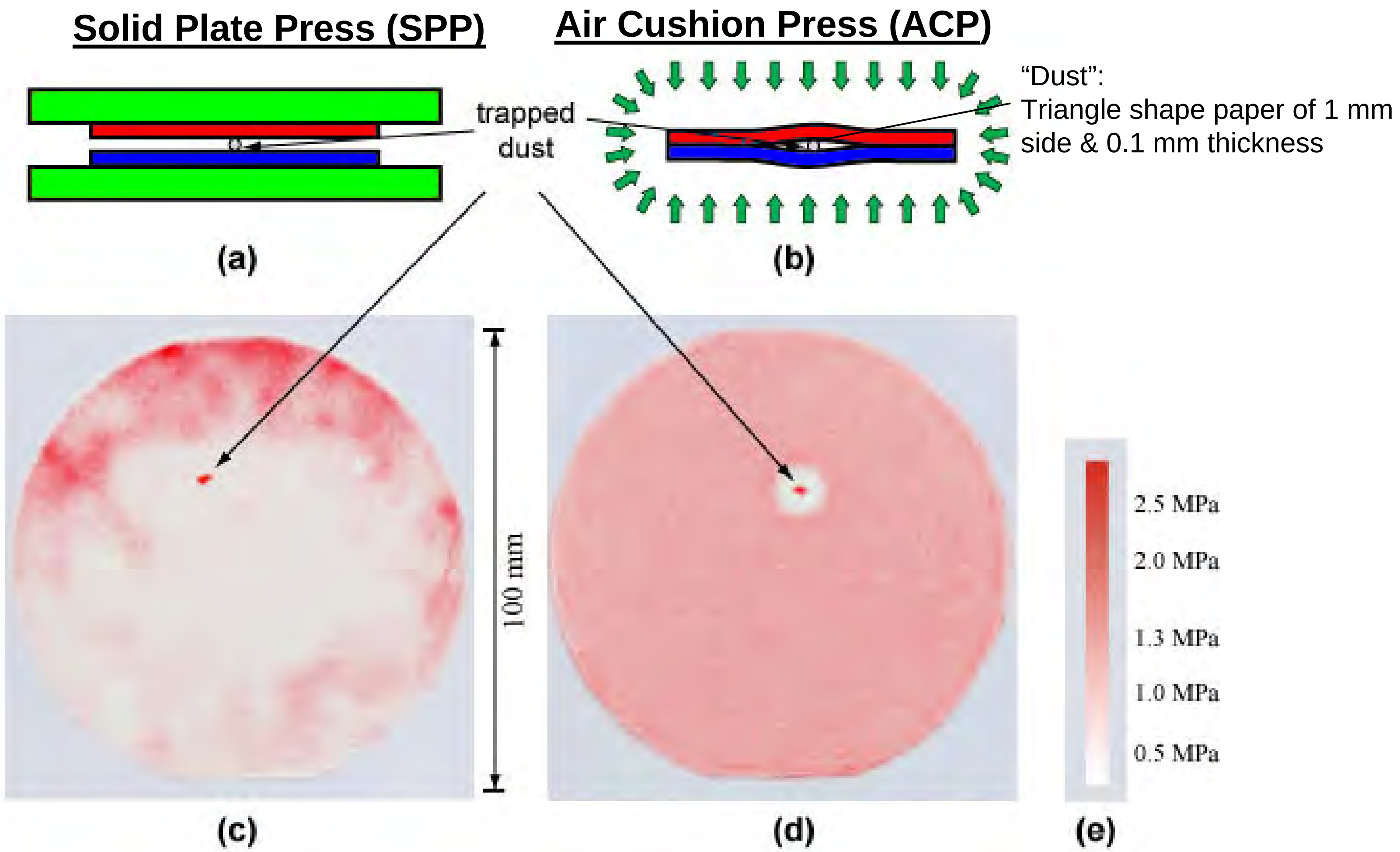
ACP Immune to Wafer/Mold Backside Roughness or Dust

Nanonex



Nominal Pressure: 1.38 MPa (200 psi)

For Dust Between Wafer and Mold, ACP Performs Order of Magnitude Better Than SPP



Nominal Pressure: 1.38 MPa (200 psi)