Nano-patterning for better and more efficient photonic devices

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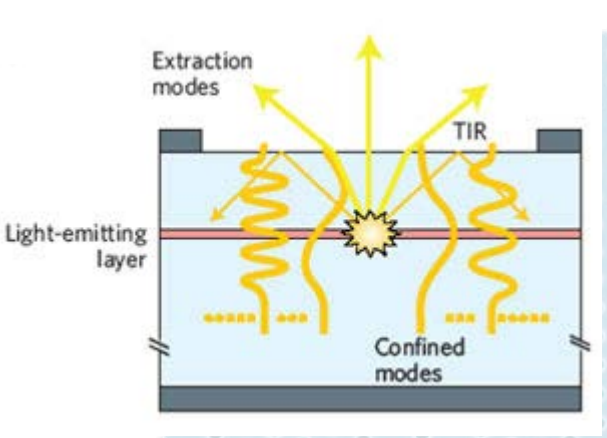
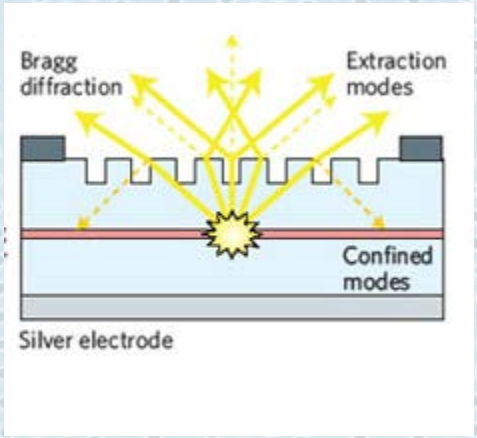
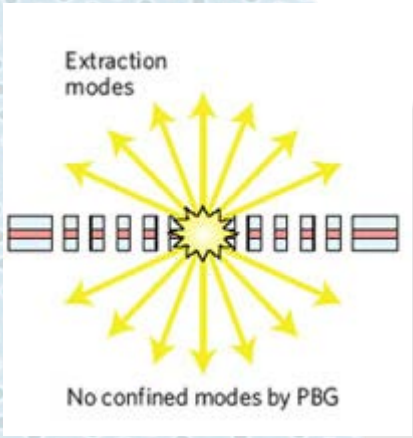
Eulitha AG

Photonic Crystals on LEDs



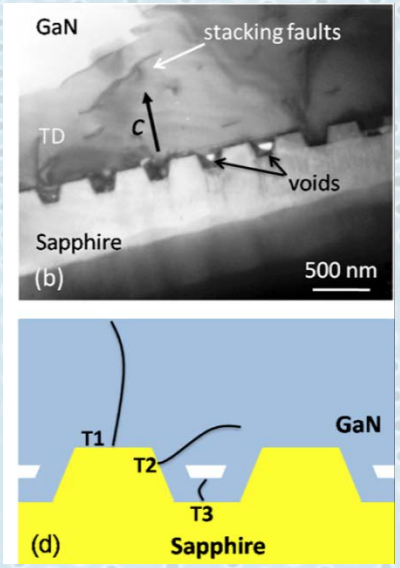




- GaN refractive index >2.5; Total internal reflection angle ~23 degrees
- Light produced in LED chips *trapped inside* due to high refractive index
- Photonic crystal on surface diffracts light out; reduces confined modes
- Complete photonic crystal can totally inhibit confined modes

J. Wierer et al., *Nature Photonics 3, 163 - 169 ,* Noda et al *Nature Photonics 3, 129-130, (2009)*

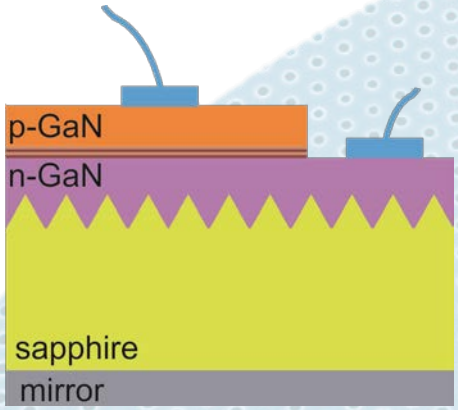
Sapphire Substrate Patterning

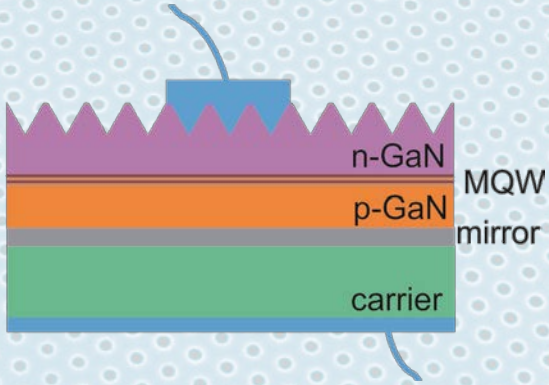


- Micro-patterned sapphire substrates used today to enhance crystal growth and light extraction
- Reducing pattern dimensions to sub-micron scale
  - Enhances crystal quality and internal quantum efficiency by more than 2x*
  - Reduces buffer layer thickness – lower cost

* Li et al., Appl. Phys. Lett. 98, 151102, (2011).

LED Stacks on PSS





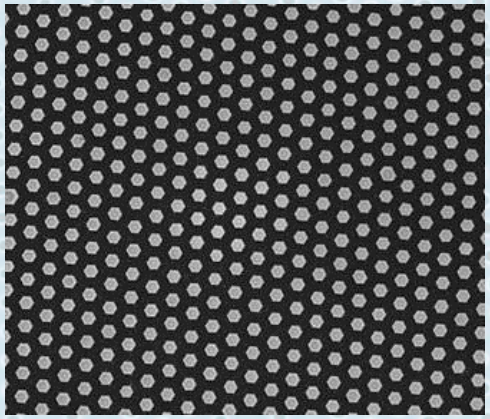
Conventional LED

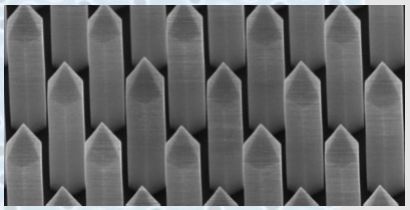
- Simpler process
- Low thermal conductivity
- Light absorption by p-GaN and TCL
- Current crowding

Thin-film LED

- Process complex
- Good thermal conductivity
- Good transmission by thin n-GaN
- Larger active area

Nanowire LEDs



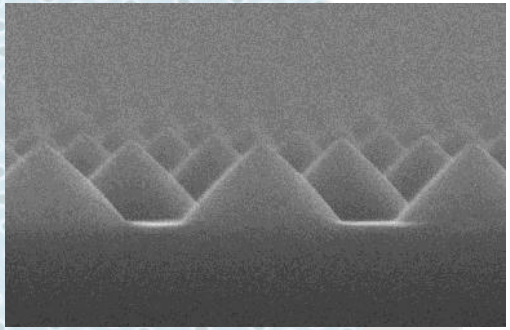


- Semiconductor layers grown as nanowires on pre-patterned template
- Very high quality crystals due to small size – high quantum efficiency

* GLO AB, Sweden

PSS Lithography Problem

Product	Period	Height
PSS	3 um	1.5 um
High-density PSS	2 um	1.0 um
Nano PSS	1 um	0.5 um



- Resolution: 0.5-2 um
- Wafer size: 2”, 4”, 6”
- Wafer bow: 10-50um !
- Sapphire/photoresist etch selectivity: 0.5-0.8

PSS Lithography Solutions

Projection Photolithography (steppers)

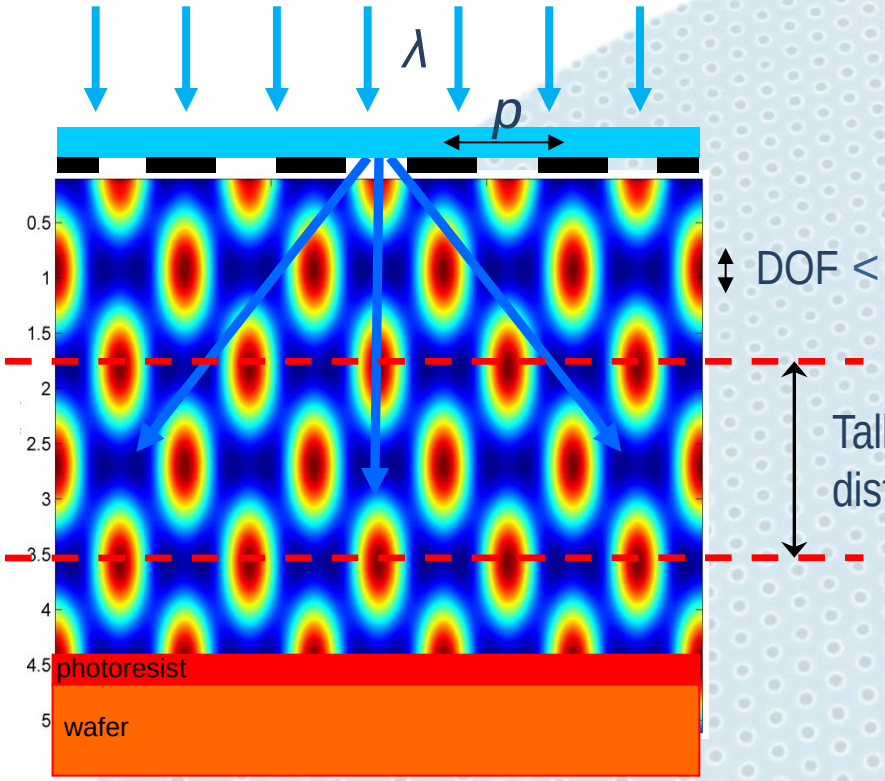
- Widely used in PSS fabrication
- Capital Cost: >1M$ (strong rise with resolution)
- Depth of focus: big issue for nPSS

Nanoimprint Lithography

- Significant process difficulties
- Pattern aspect ratio
- Soft consumable stamp
- Mask lifetime, quality

There is a need for low-cost, high resolution lithography that works on warped/bowed substrates

Displacement Talbot Lithography



Talbot imaging of a
600nm-period linear grating

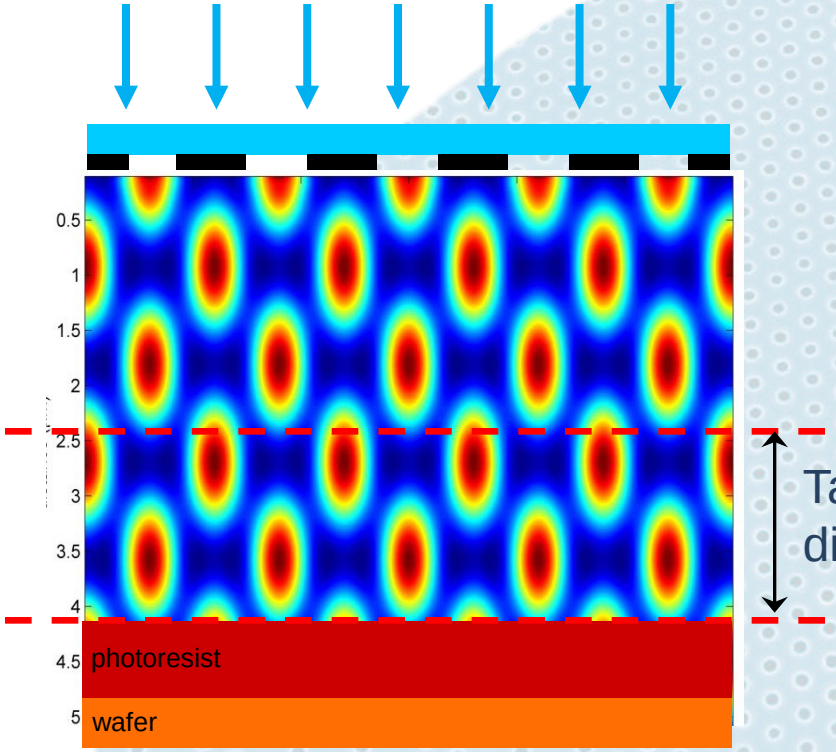
$$\text{DOF} < \frac{p^2}{2\lambda} \xrightarrow{\lambda \approx \text{i-line}} < 0.5\mu\text{m}$$

$$\text{Talbot distance} \approx \frac{2p^2}{\lambda}$$

Requires:

- Precise gap
- Precise parallelism
- No topography
- Thin resist

Displacement Talbot Lithography



Solution: Integrate the intensity distribution over a Talbot distance

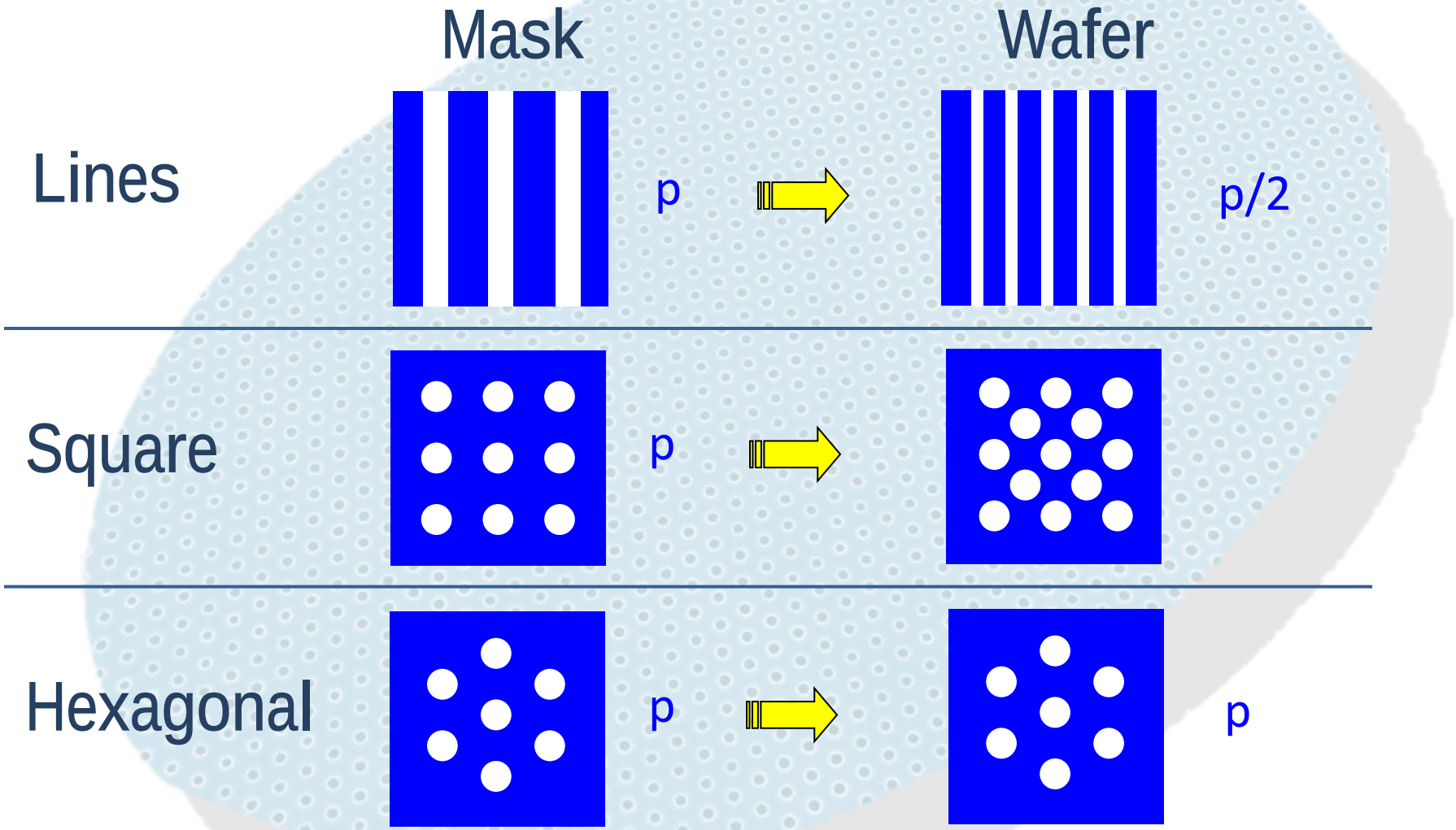
An image with practically unlimited depth of focus obtained

H. Solak, C. Dais, F. Clube, Optics Express, Vol.19, No.11 (2011)

PhableR 100 Exposure System

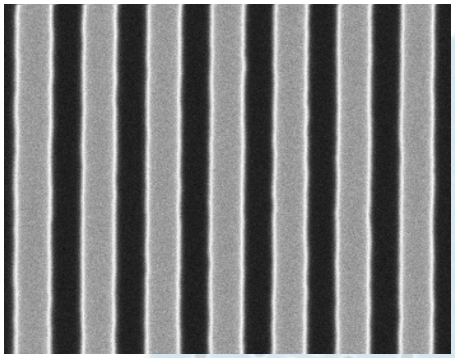
- Resolution: 150nm half-pitch
- Pitch range: 300nm - 3µm
- Exposure wavelength: near-UV
- Wafer size: up to 4"
- Mask size: 5"
- Operation: Manual load, automatic exposure
- Control interface: Touch panel

Pattern transformations with DTL

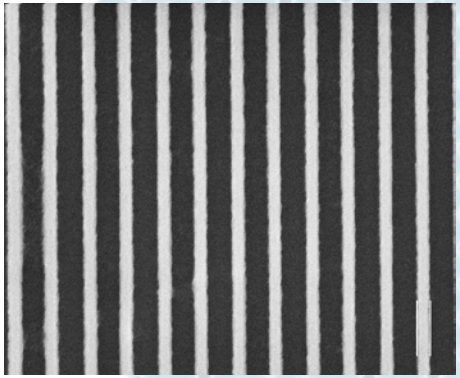


DTL-printed patterns

Linear Grating

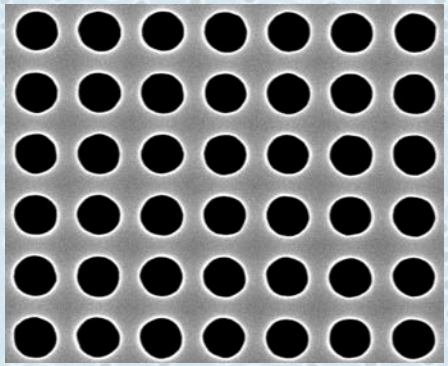


300 nm period

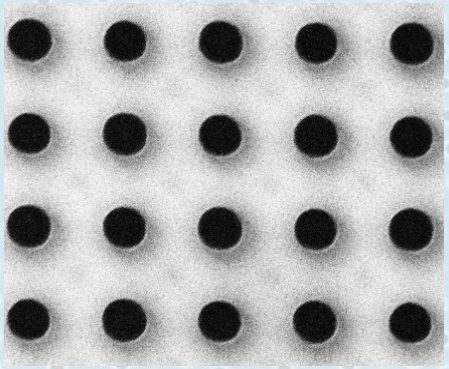


250 nm period

Square Lattice

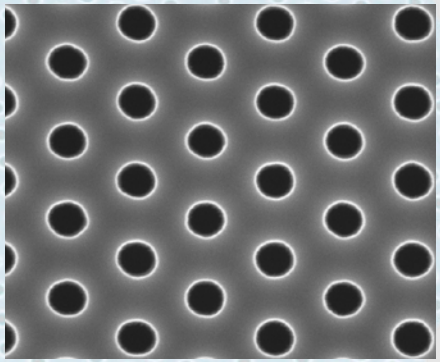


350 nm period

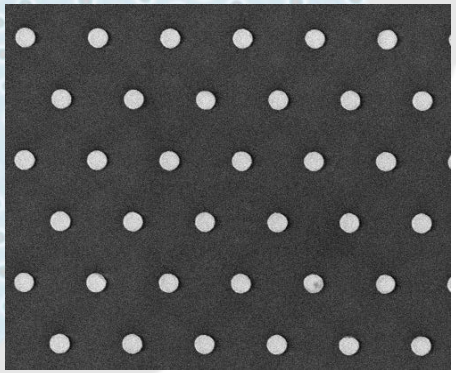


500 nm period

Hexagonal Lattice

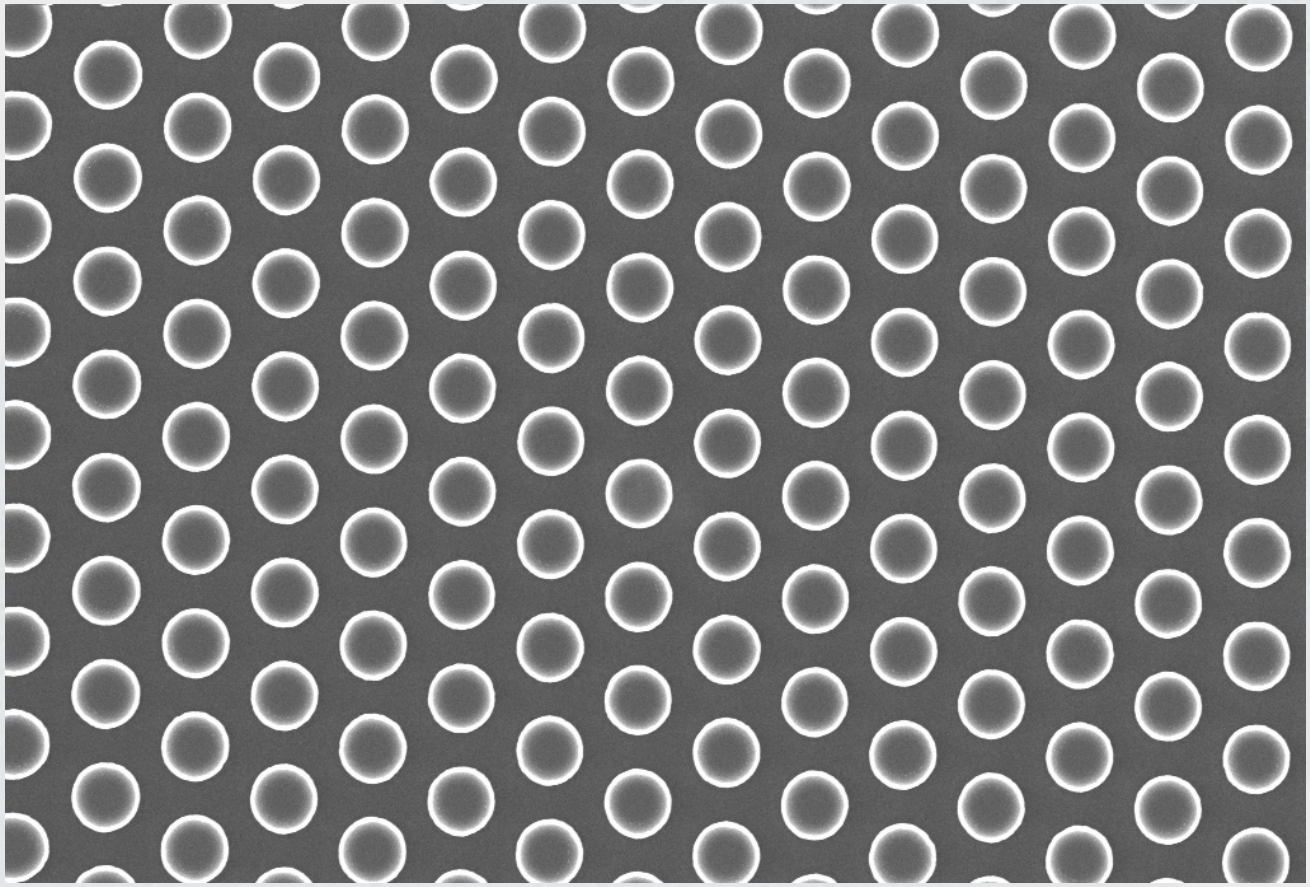


520 nm period



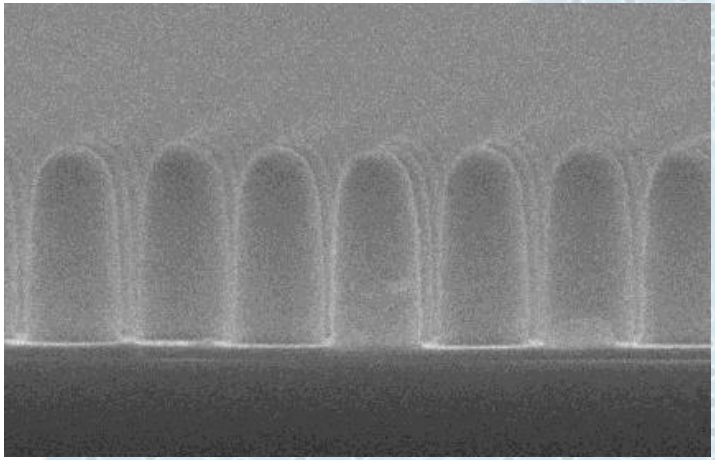
1.5 µm period

High Quality Patterns

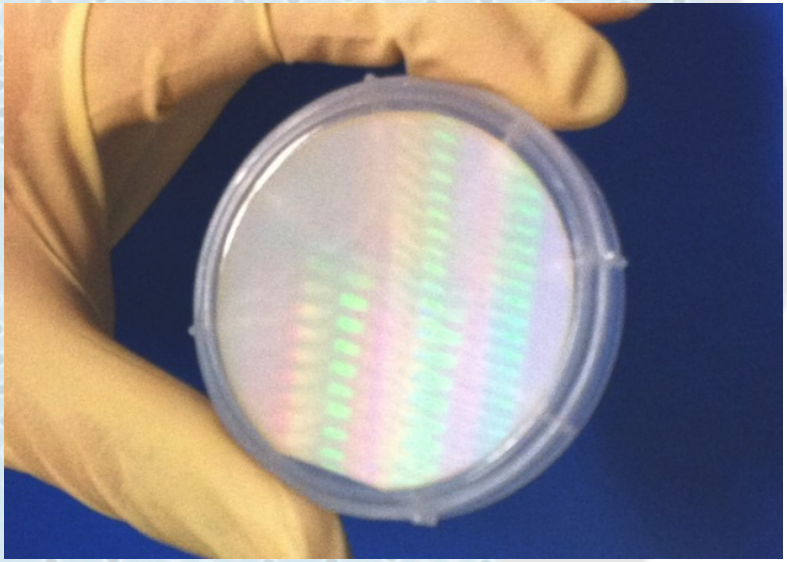


Pillars etched into Si – 3µm-period hexagonal lattice

Sapphire Substrate Patterning



High-aspect ratio photoresist pattern



Patterned 2” sapphire wafer

Conclusions

- New lithography method for high-resolution periodic structures
- Low and high volume tools are in the market
- Suitable for PSS-nPSS fabrication