Improving the Lithographic Process

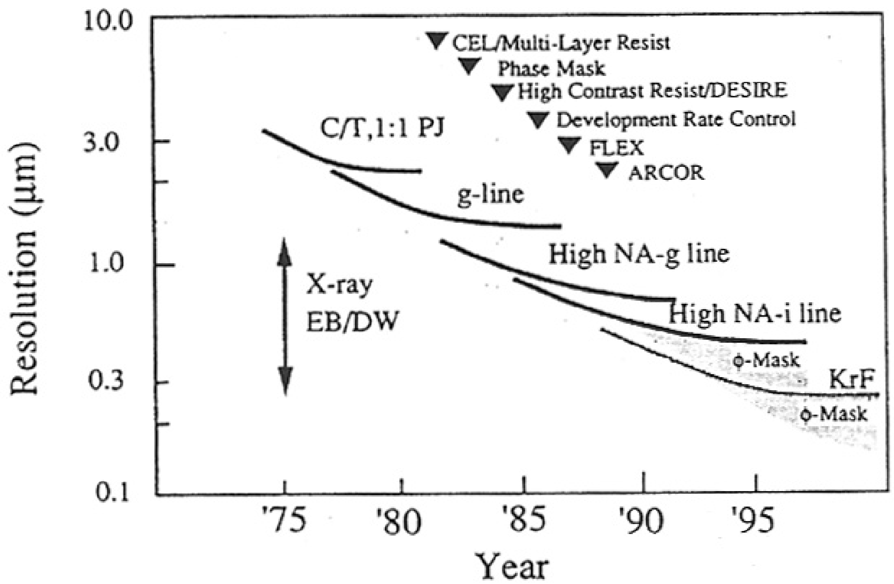


FIG. 1. Evolution of developments in optical lithography.

Okazaki, 'Resolution Limits of Optical Lithography', J. Vac. Sci. Technol. **B9**(6) 1991

- Decreasing the minimum feature size that can be patterned
- Improving *alignment* accuracy
- Maintaining *low cost, high throughput*

Writing with electrons

Imprint lithography

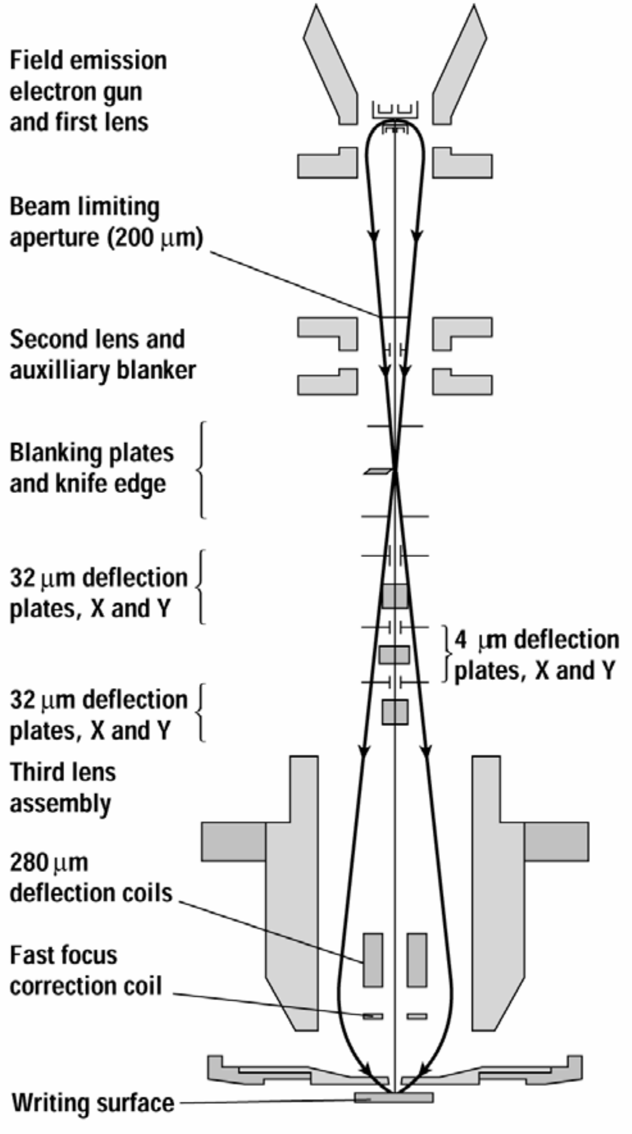


Figure 9.5 System schematic of an early EBES system. The basic column is similar in current generation EBL systems *(after Herriot et al., reprinted by premission, © 1975 IEEE).*

Electron Beam Writer

- Photons <-> electrons
- Dielectric lenses <-> magnetic lenses
- 'shutters' to blank beams, deflectors to move beams

What determines the spatial resolution (minimum feature size) of e-beam lithography?

- focus of the beam?
- energy of the beam?
- other?

JEOL JBX-6300FS

- "Hi-brightness" Thermal Field Emitter Source (ZnO/W)
- 25, 50, and 100 kV operation
- Minimum Spotsize ~ 2nm @ 100kV

The wavelength of the electrons in a 10 kV SEM is then 12.3 x 10-12 m (12.3 pm)
while in a 200 kV TEM the wavelength is 2.5 pm.

Electron Scattering and the Proximity Effect

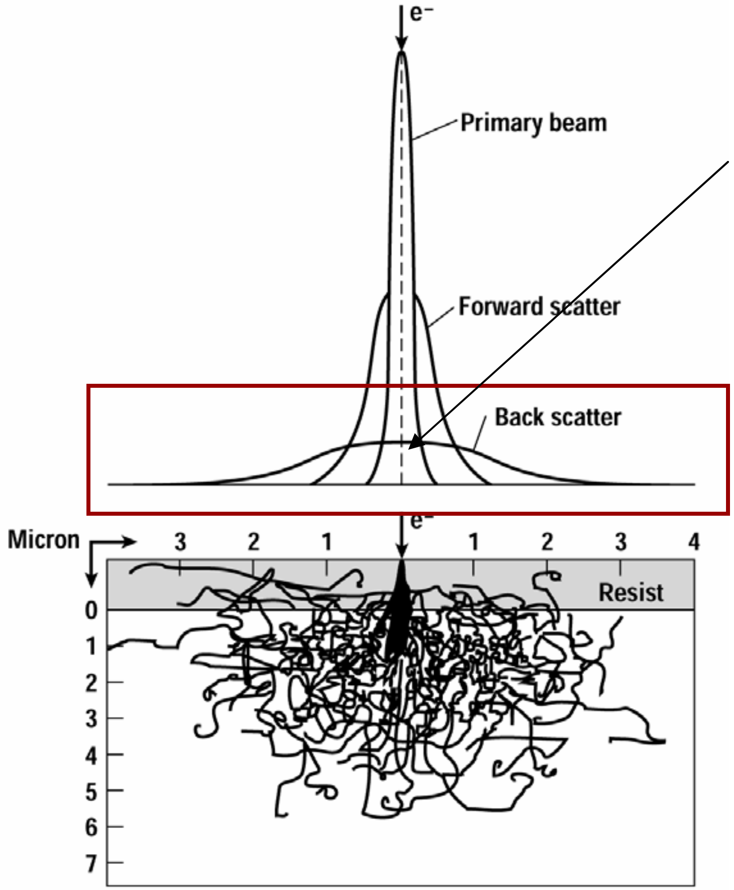


Figure 9.10 Monte Carlo simulation of electron trajectories during an EBL exposure. The upper curve indicates the forward and backscattered components of the beam *(after Hohn, reprinted by permission, SPIE).*

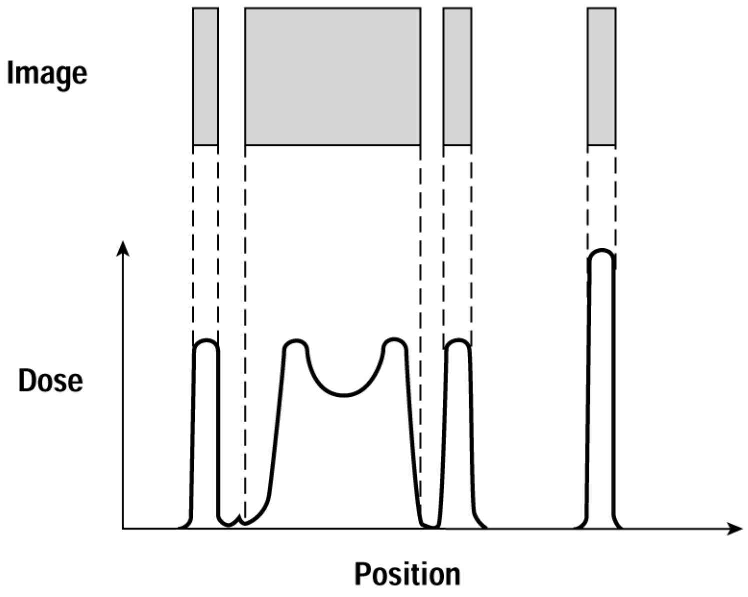
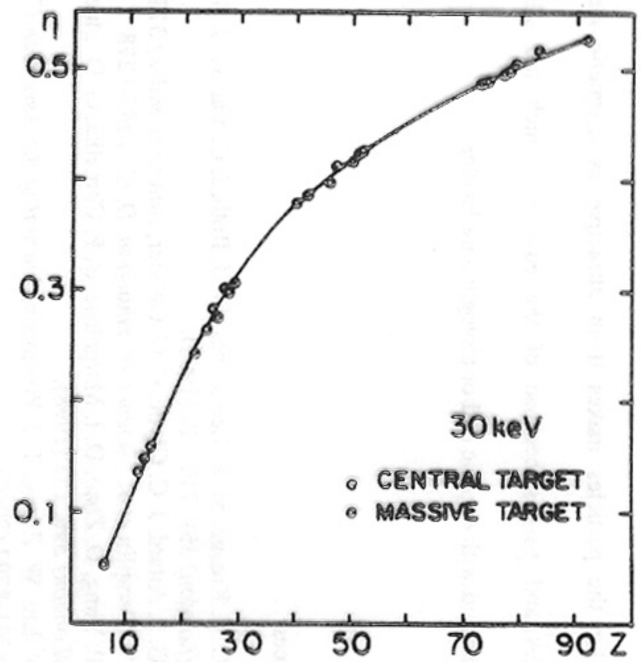


Figure 9.11 Small and large figures to be patterned with EBL requires position-dependent dosage to compensate for proximity effects.

Back-scattered Electrons: strong dependence on substrate material

Backscattered electrons:

dependence on Z: sensitive to composition



Electron backscatter coefficient η, $E_0 = 30$ keV as a function of the atomic number Z of the target (Heinrich[12]).

The 'volume' of electrons in the substrate

Low Z High Z

Low accelerating voltage (electron energy)

High voltage

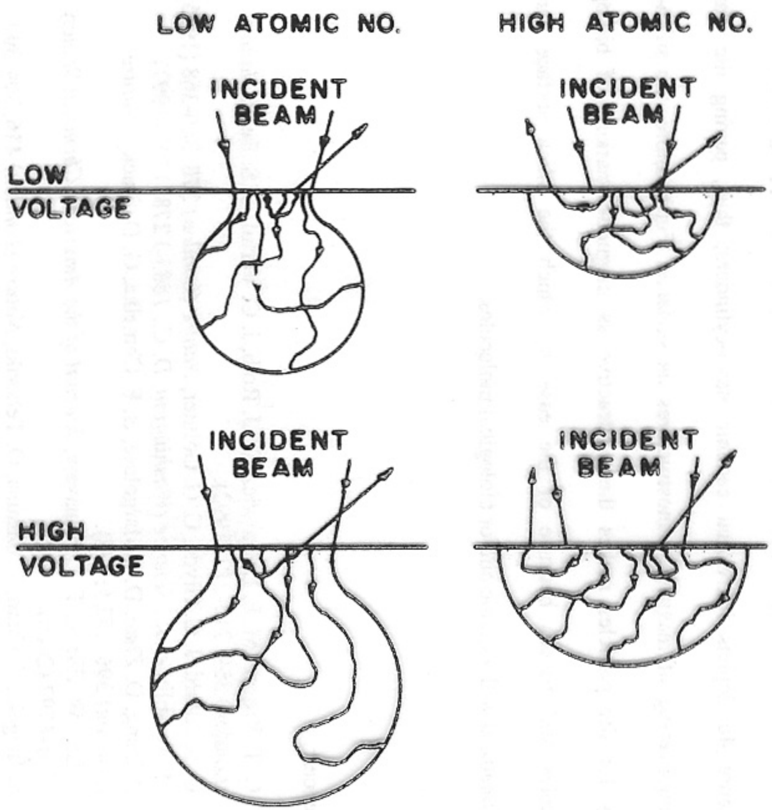
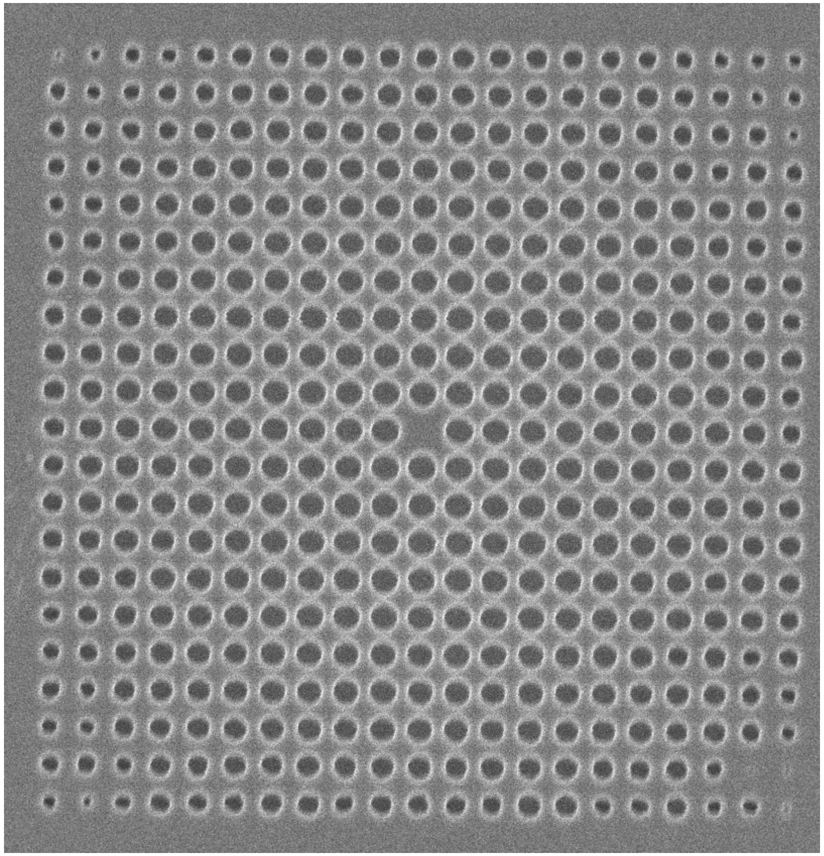


FIGURE 1. Section through specimen surface illustrating the variation of electron scattering with voltage and atomic number (from Duncumb and Shields[9]).

Goldstein,
Practical Scanning Electron Microscopy

How 'bad' is the proximity effect?



Lattice constant = 280 nm

Photonic Crystal Pattern
E-beam written into GaAs
50 kV accelerating voltage

What can be done?

Remove most of the substrate

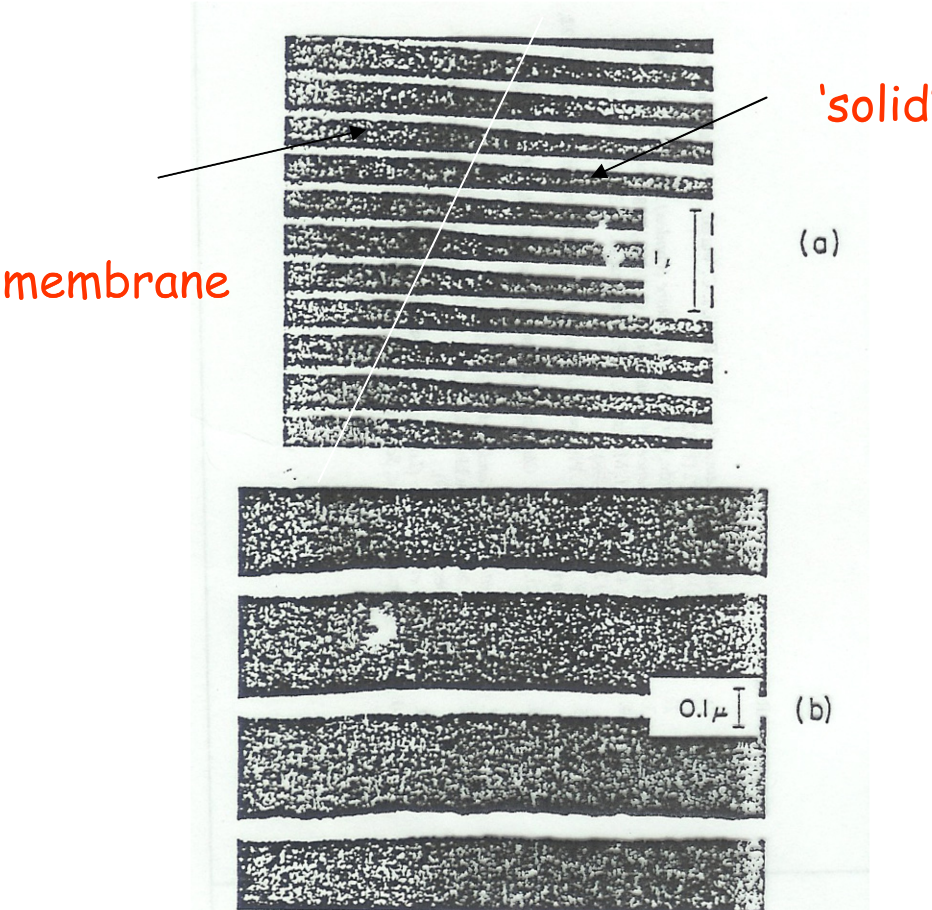
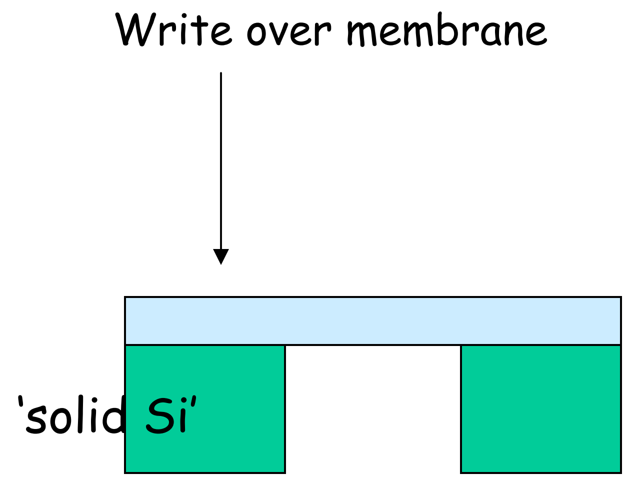


Fig. 5. (a) Metal line pattern fabricated over Si wafer (light, right portion) and over 4 mils Si_3N_4 window (dark, left portion); (b) higher magnification view of metal lines over window.



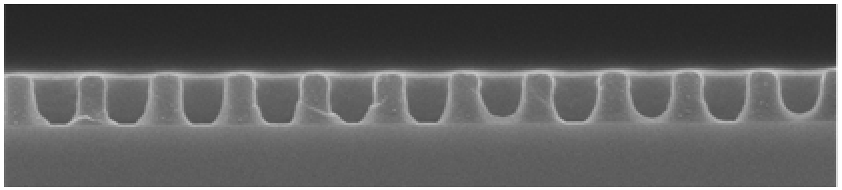
Removing the substrate removes the source of backscattering

Would changing the accelerating voltage help?

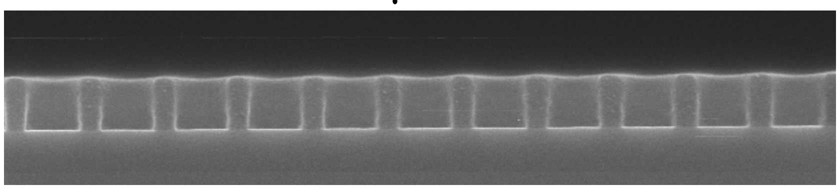
Sedgwick. Broers, Agule
J. Electrochem. Soc. 1973

Changing Dose in e-beam exposure (ZEP resist)

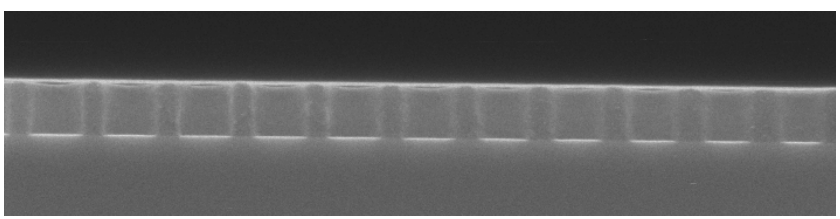
133 μC cm^{-2}



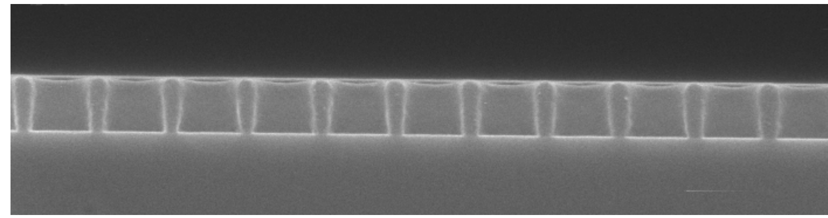
+ 43 μC



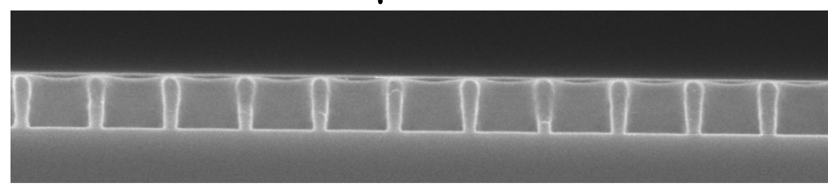
+ 72 μC



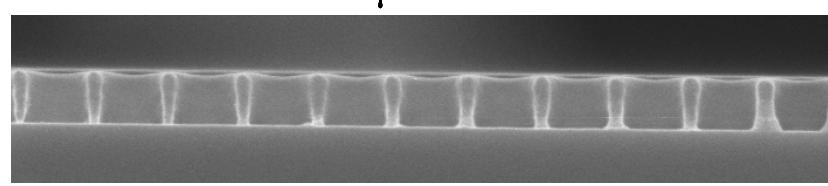
+ 87 μC



+ 101 μC



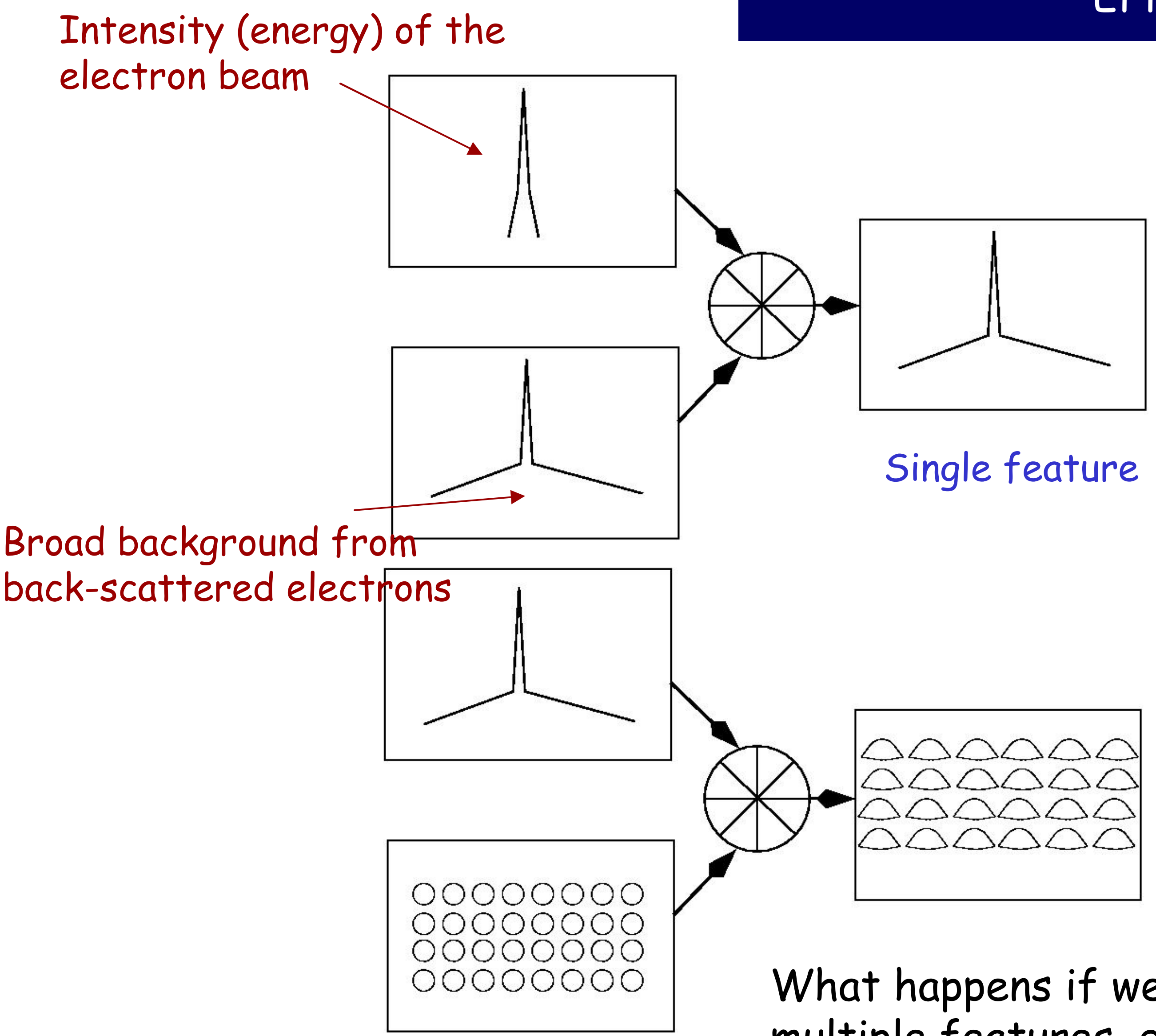
+ 115 μC



a = lattice constant, variable, ~ 250 nm
r = radius of the hole

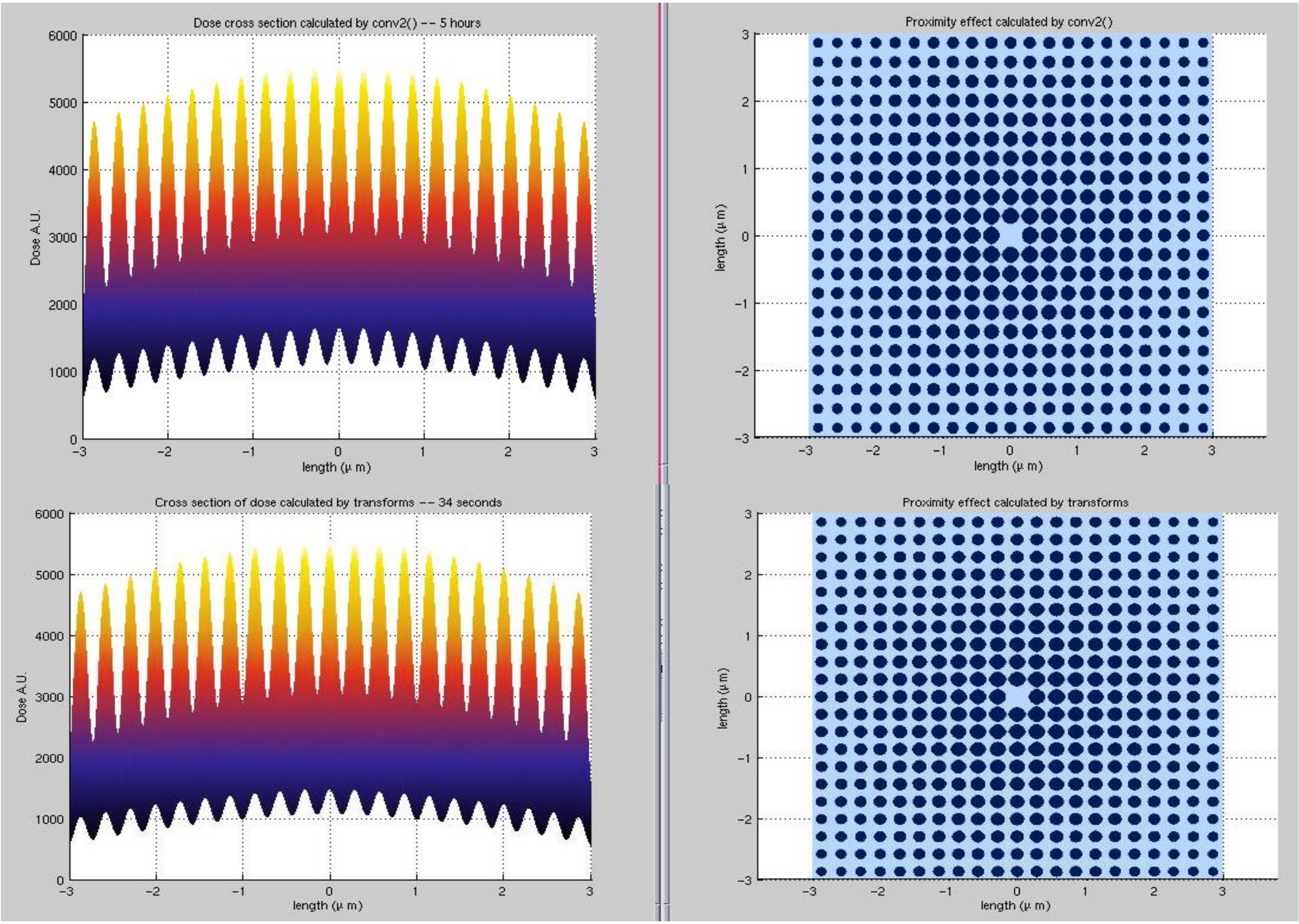
CORRECT FOR THE PROXIMITY EFFECT

Kevin Hennessey



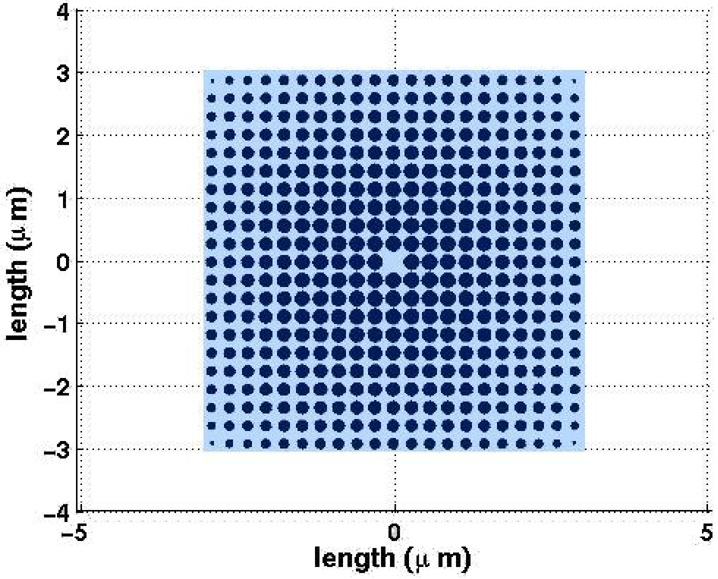
What happens if we were to write multiple features, densely packed?

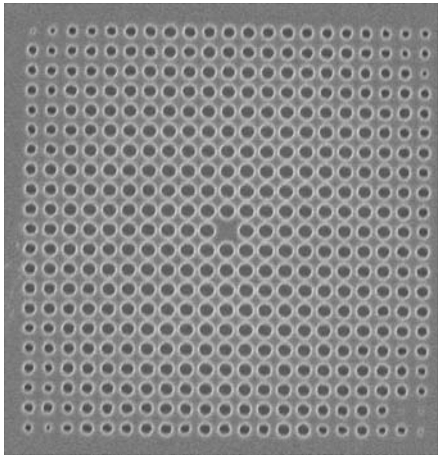
Kevin's Simulations of Full Electron Dose for a Photonic Crystal Pattern



Simple Proximity Effect Correction

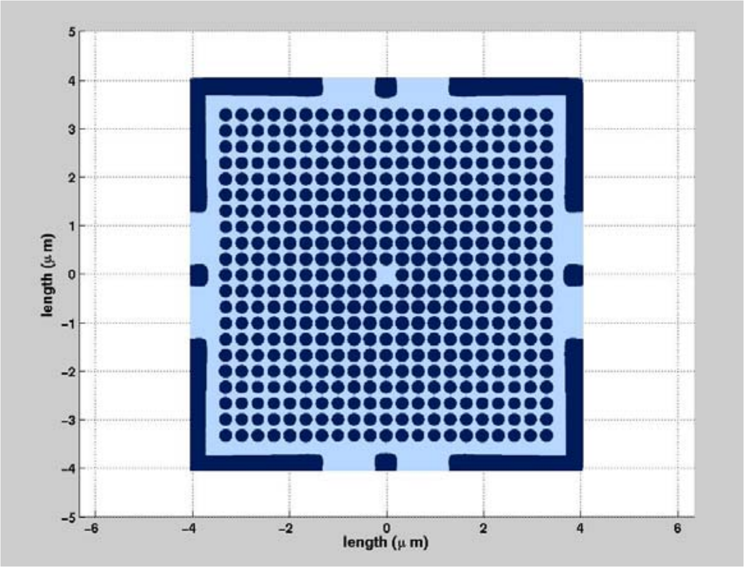
simulation

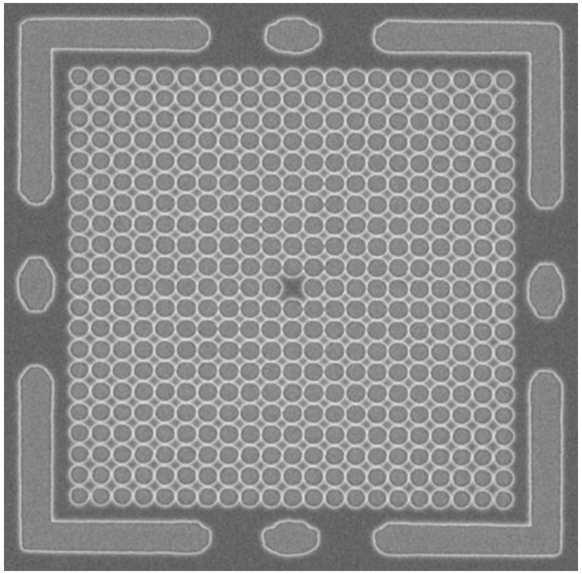




E-beam written pattern in GaAs

Lattice constant = 280 nm





The uses of E-beam Lithography

Desired Features

- Decreasing the minimum feature size that can be patterned
- Improving *alignment* accuracy
- Maintaining *low cost, high throughput*

Are there disadvantages?

Shaping Beams

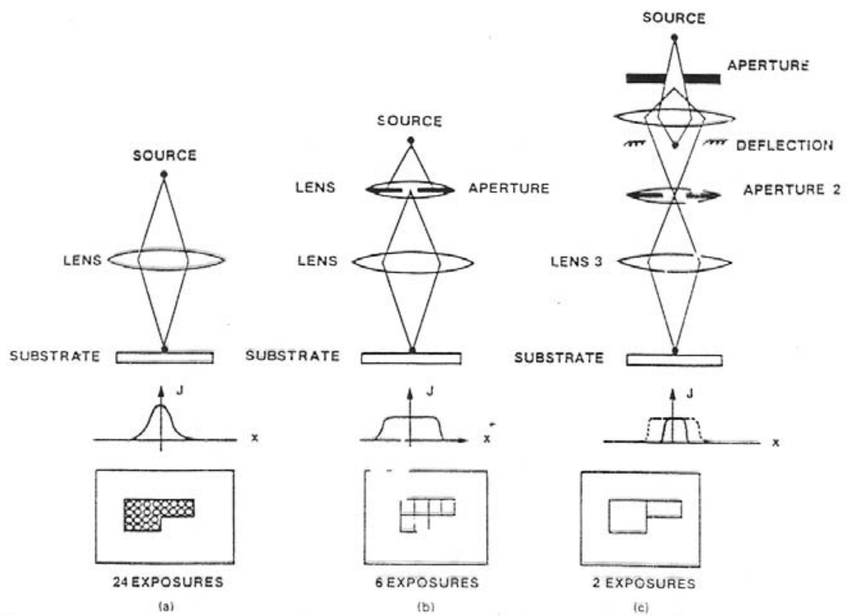


Fig. 1.43. Spot forming strategies used in scanning electron-beam lithography.

Fine Line Lithography,
Ed. Newman, North-Holland 1980

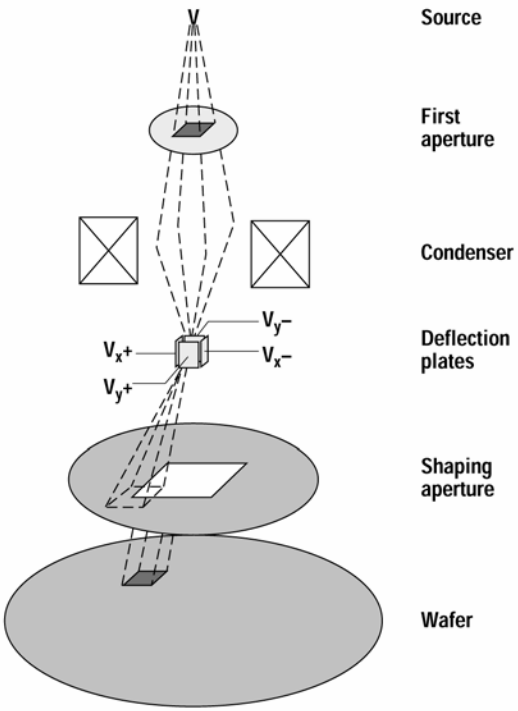


Figure 9.7 A variable shaped beam exposure system using mechanical beam stops for beam shaping. The broad beam exposes many pixels simultaneously, but dimensional control is not as reliable as standard EBL.

Campbell

Scanning Electron Beam Writing: SCALPEL

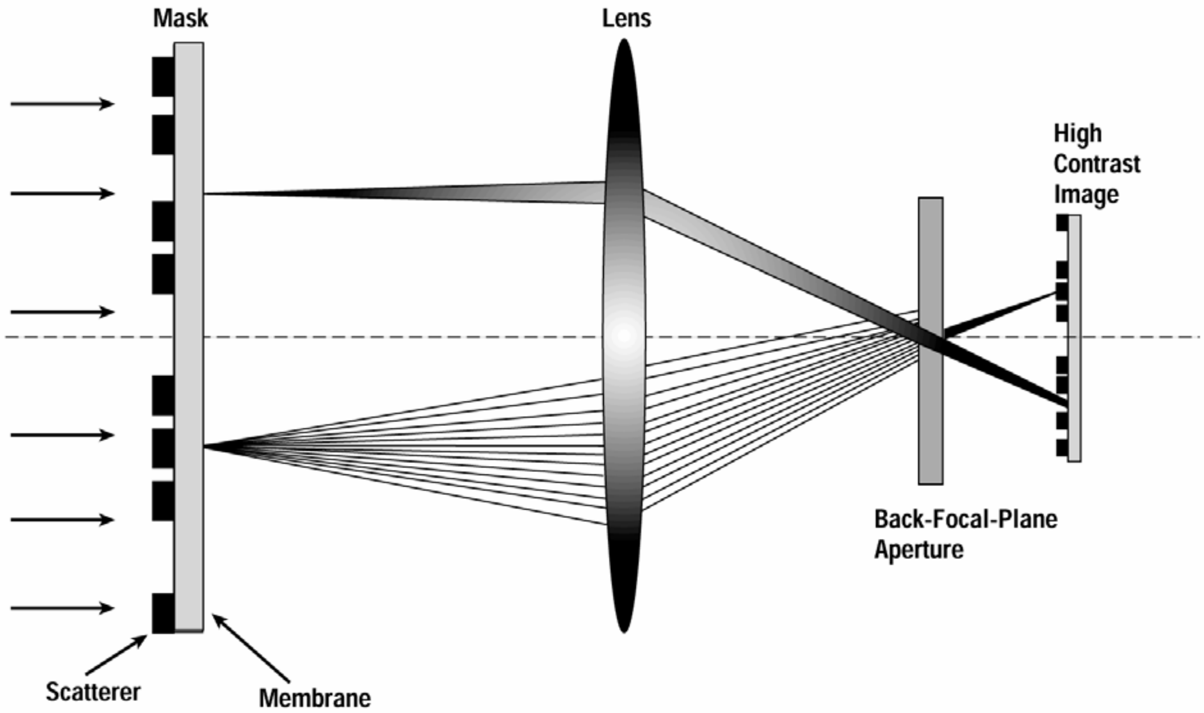
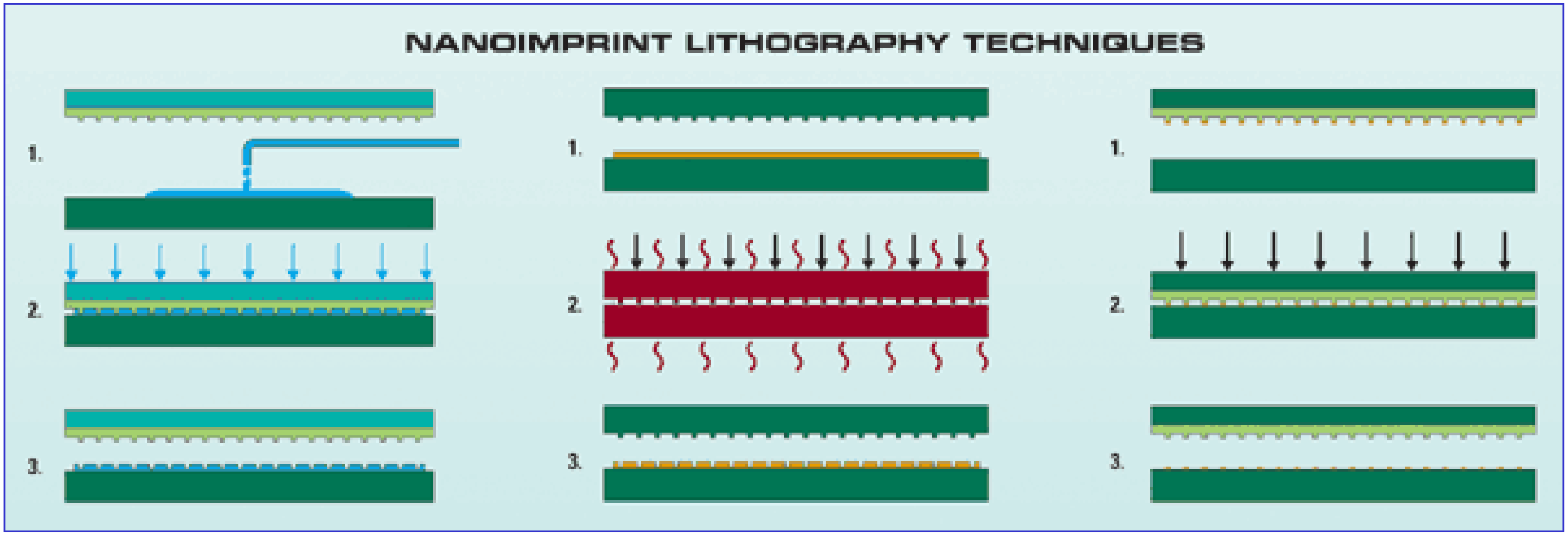


Figure 9.25 SCALPEL principle of operation.

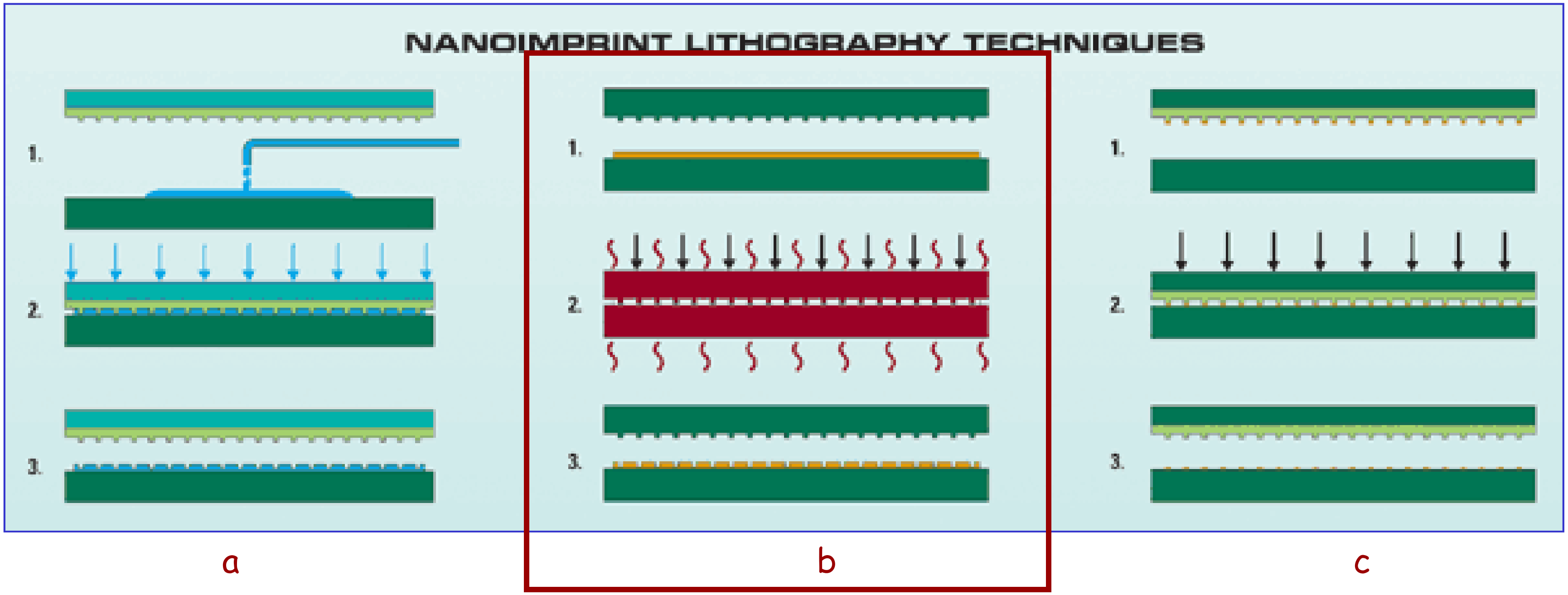


a b c

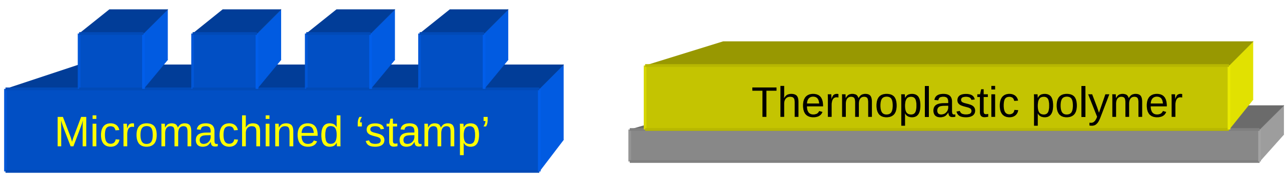
a. UV-Nanoimprint Lithography :uses low viscosity materials, which are cross-linked during a UV exposure process forming the hard polymer features.
b. Hot Embossing :uses polymer substrates to imprint structures created on a master stamp.
c. Micro Contact Printing :An inked stamp transfers a material to a novel metal surface just by a soft contact, which forms a self-assembled monolayer (SAM). In this method soft stamps like PDMS are used. The process occurs at RT and under low contact forces of below 100 N.

http://www.evgroup.com/productgroup.asp?prgrp_id=6

Hot Embossing (Thermoplastic)

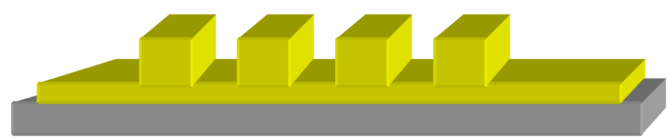


(1)



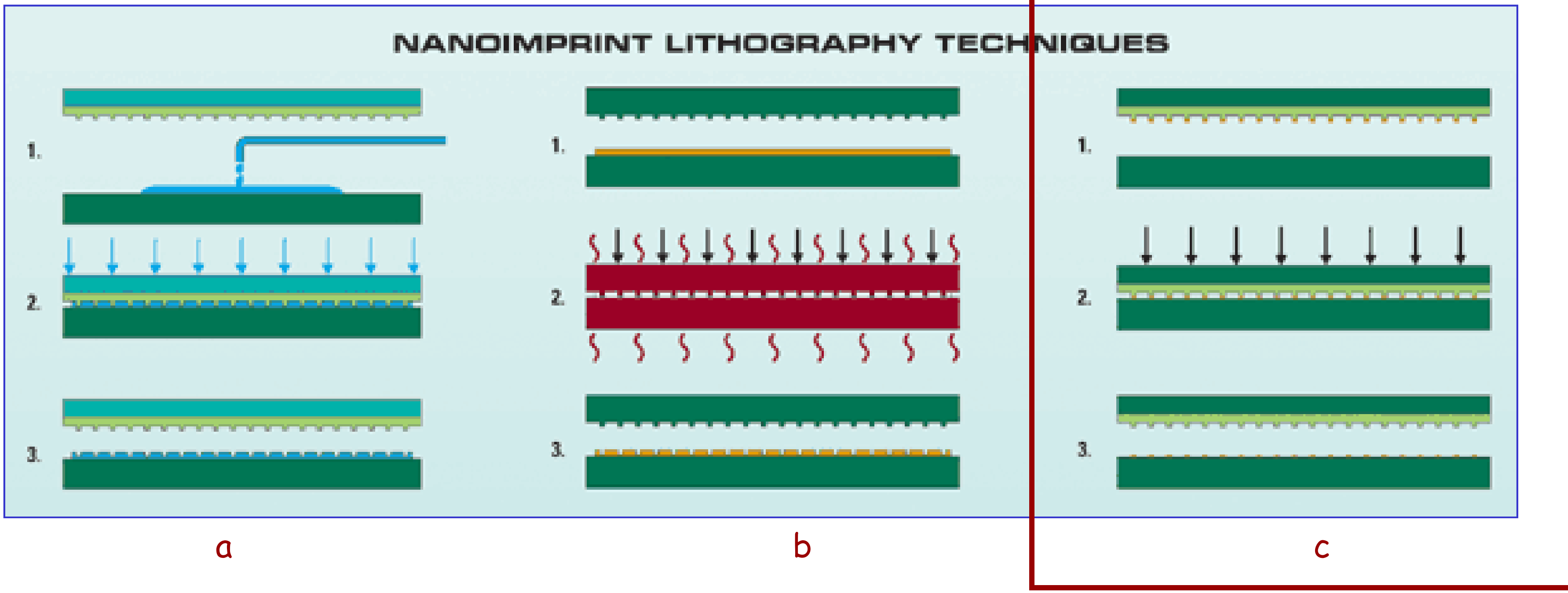
Master stamp onto thermoplastic polymer

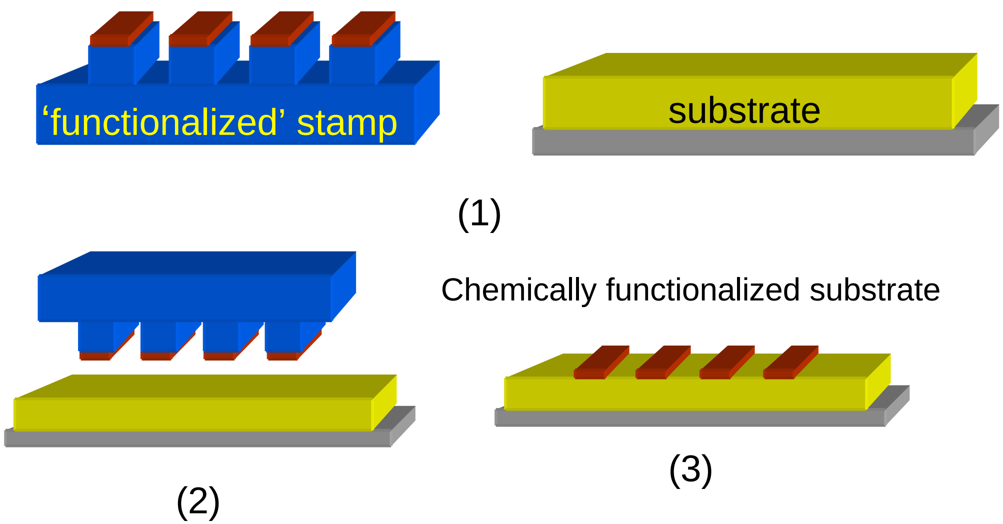
(2)



(3)

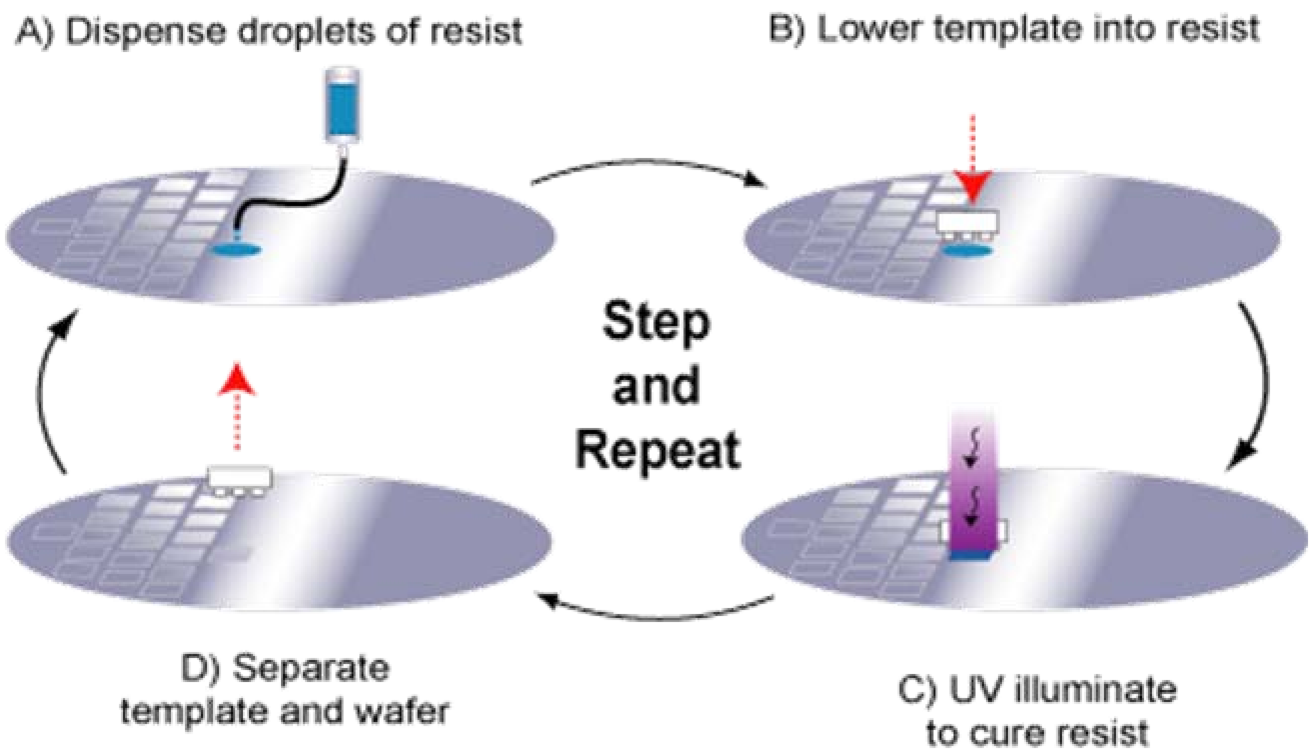
Micro-Contact Printing (Chemical Stamping)





An inked stamp transfers a material to a novel metal surface just by a soft contact, which forms a self-assembled monolayer (SAM).

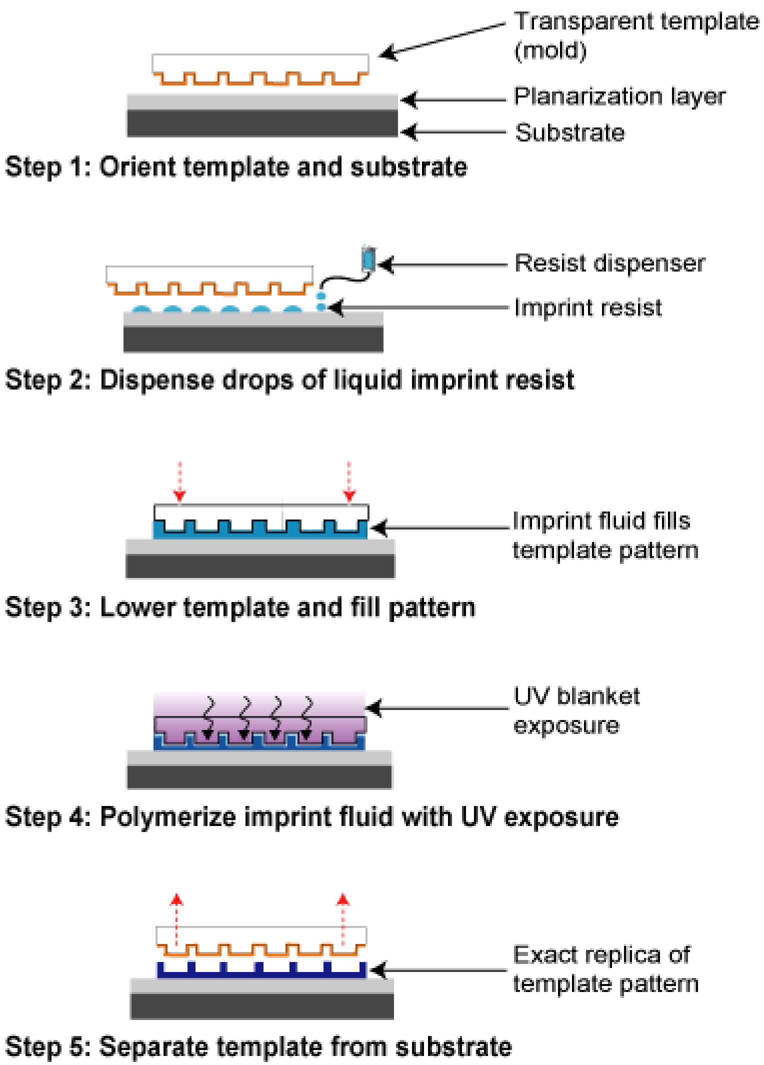
UV Nano-imprint



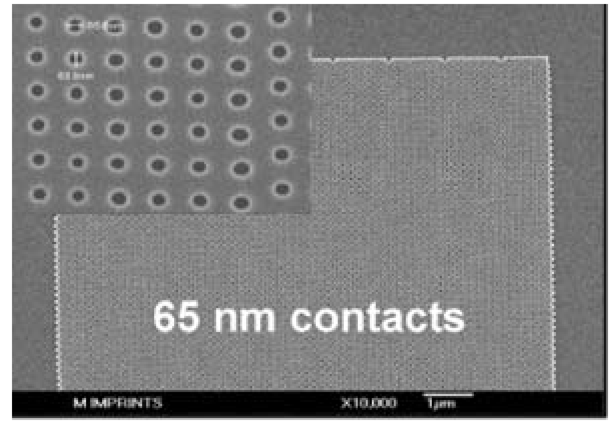
uses low viscosity materials, which are cross-linked during a UV exposure process forming the hard polymer features.

Molecular Imprints, Inc.

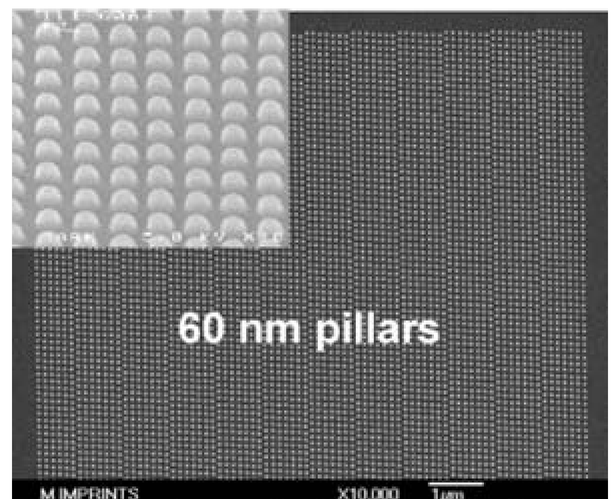
UV Nano-imprint



What kinds of patterns can be formed?



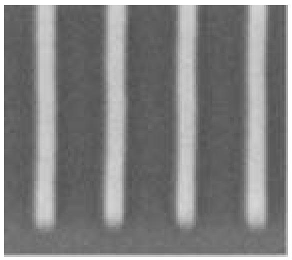
Example of imprinted 65 nm contacts



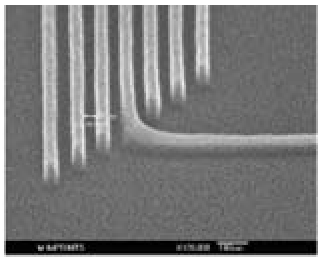
Example of imprinted 60 nm dense pillars

Molecular Imprints, Inc.

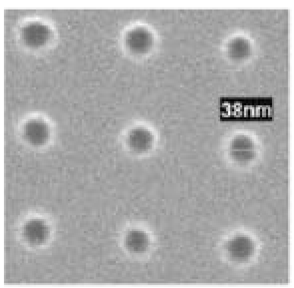
Patterns from Nano-Imprinting



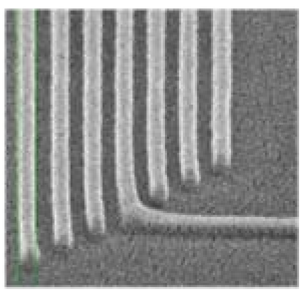
Imprinted 20 nm isolated lines



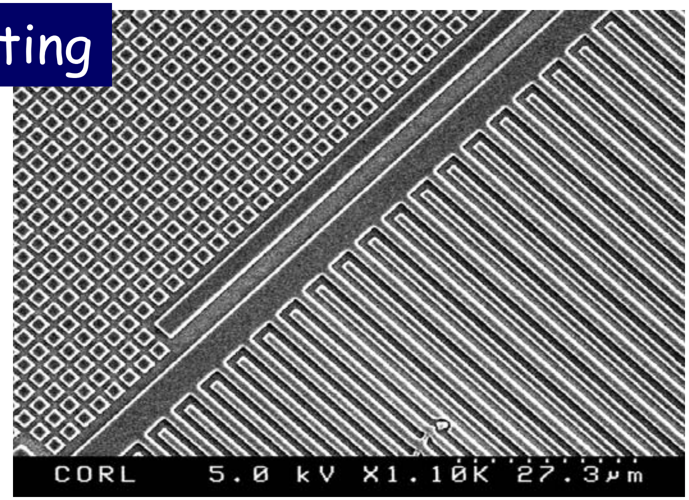
Imprinted 30 nm dense lines



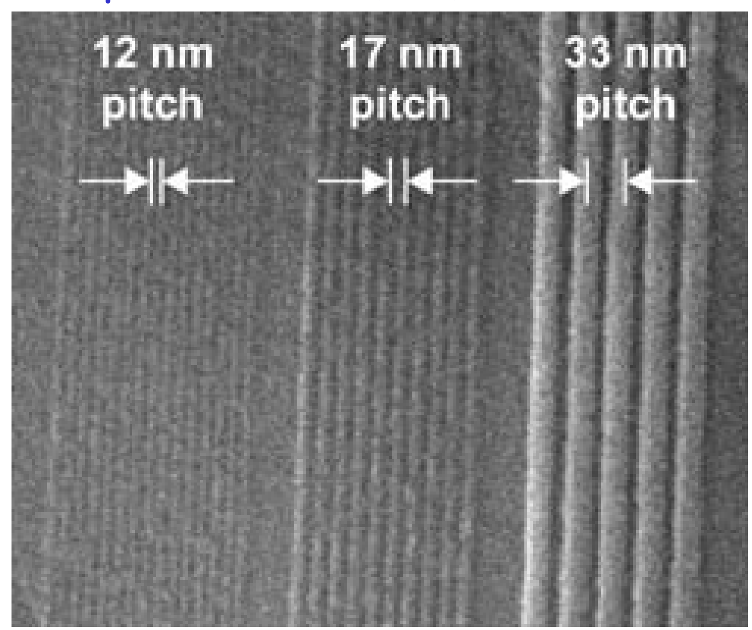
Imprinted sub-40 nm contacts



Imprinted 50 nm dense lines



Molecular Imprints, Inc. (UV)



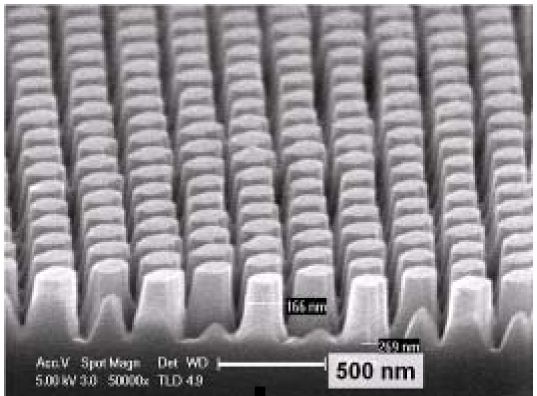
Nanonex (thermoplastic)

Imprint Lithography for Photonic Crystal Fabrication

Needed: PhC lattice ~ 200 nm, PhC depth ~ 300 nm, Chip size ~ 1x1 cm^2

Kelly McGroddy, Elison Matioli

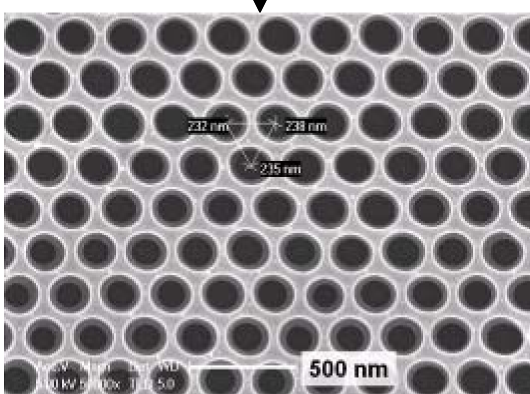
Si stamp



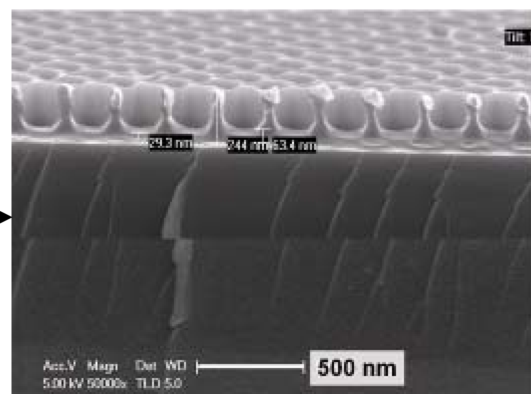
Holographic lithography: PhC lattice ~ 240nm
- simplest method for regular PhC pattern
- direct patterning of GaN or making Si-imprint stamp

Imprint lithography: PhC lattice ~ 240 nm
- Home-made Si master stamp
- Process development for transferring PhC pattern from mask layers to GaN with high fidelity

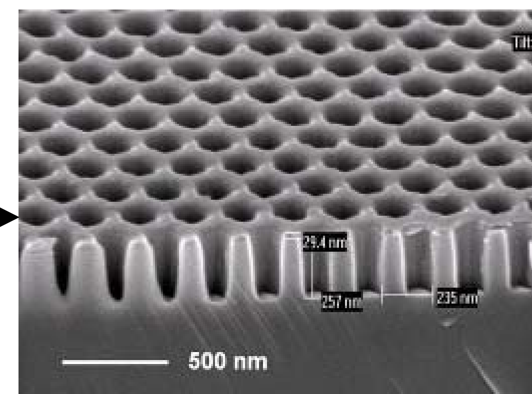
Etch mask



Etch mask



GaN PhC



Nanonex Imprinter