Preparation of Nanostructures I: Next Generation Lithography

MB-JASS 2006

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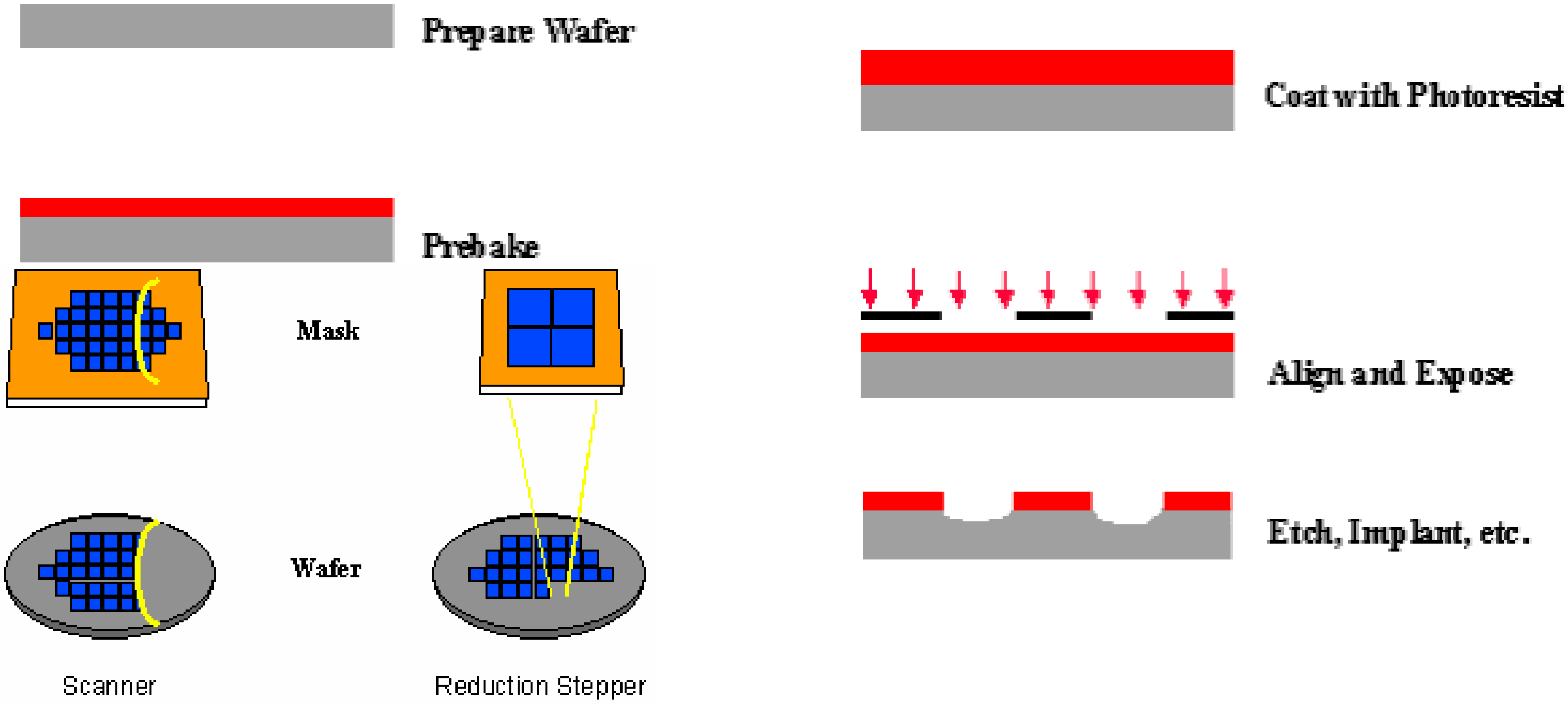
Agenda

- **State-of-the-art lithography**
- Advanced optical lithography
  - Liquid immersion lithography
  - Hybrid lithography
  - EUV lithography
- Nanoimprint lithography
- Two-photon lithography

GD1

State-of-the-art lithography



Source: Chris Mack

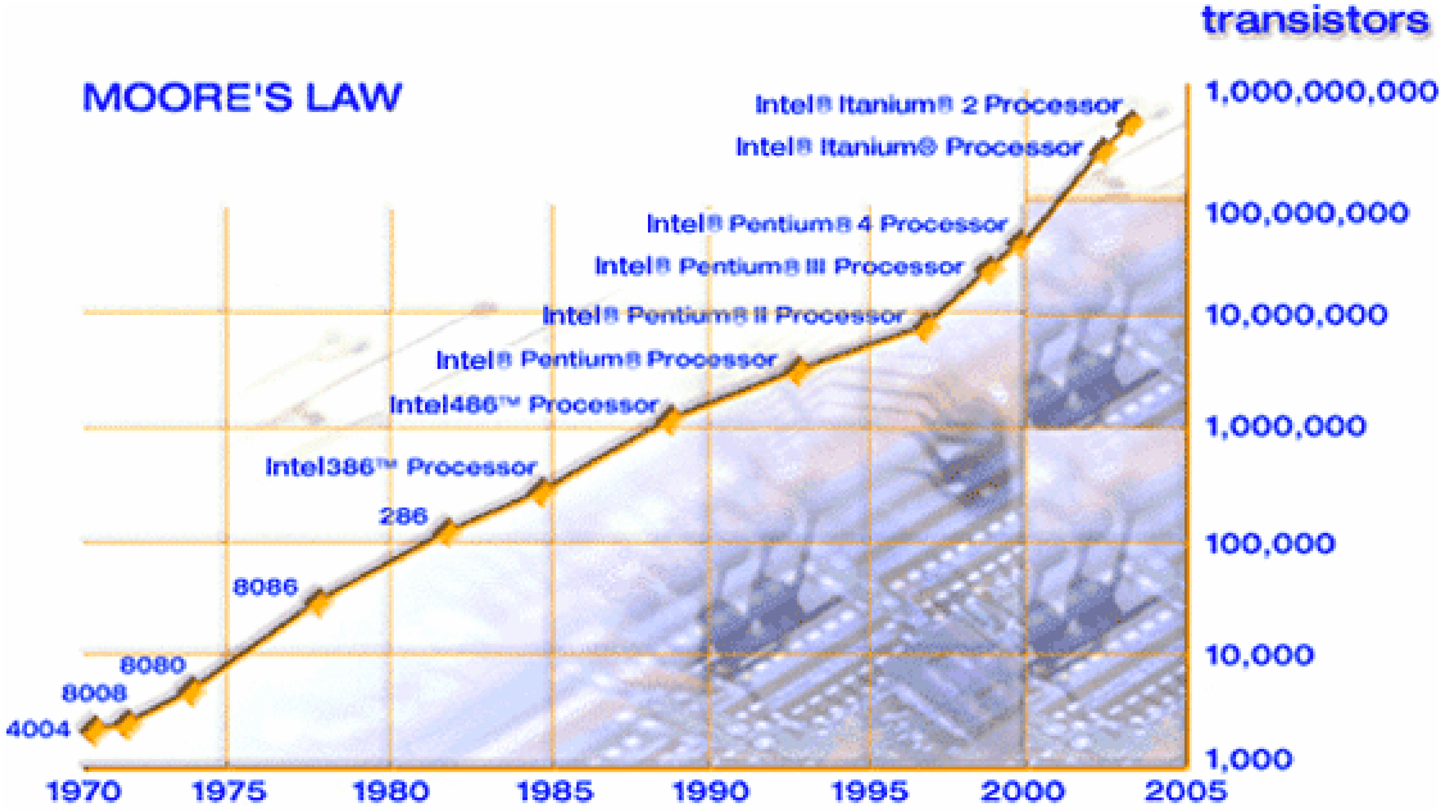
Slide 3

GD1 nano:= <100nm @2003

Georg Dürr, 05/03/2006

State-of-the-art lithography

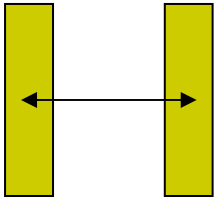
- Historical overview: Moore’s Law



Source: Intel

State-of-the-art lithography

- 193-nm light source: ArF excimer lasers
- Feature size: 65 nm half pitch



- Critical tools: phase-shifting masks, proximity corrections
- Materials: Optics, resists

State-of-the-art lithography

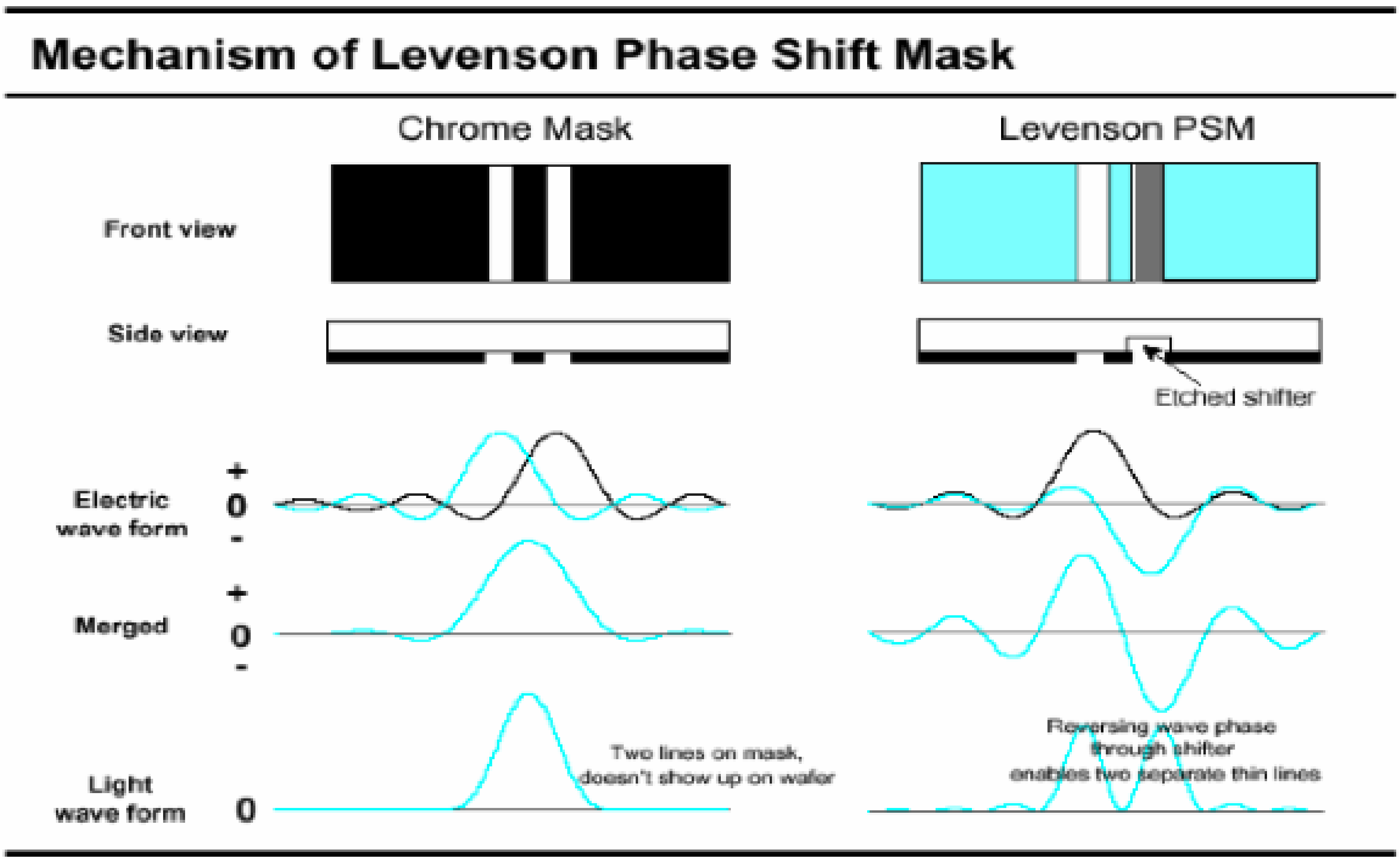
- Rayleigh-criterion:

$$W = \frac{k\lambda}{NA}$$

- *k*: empirical constant
- $NA = n \sin \theta$

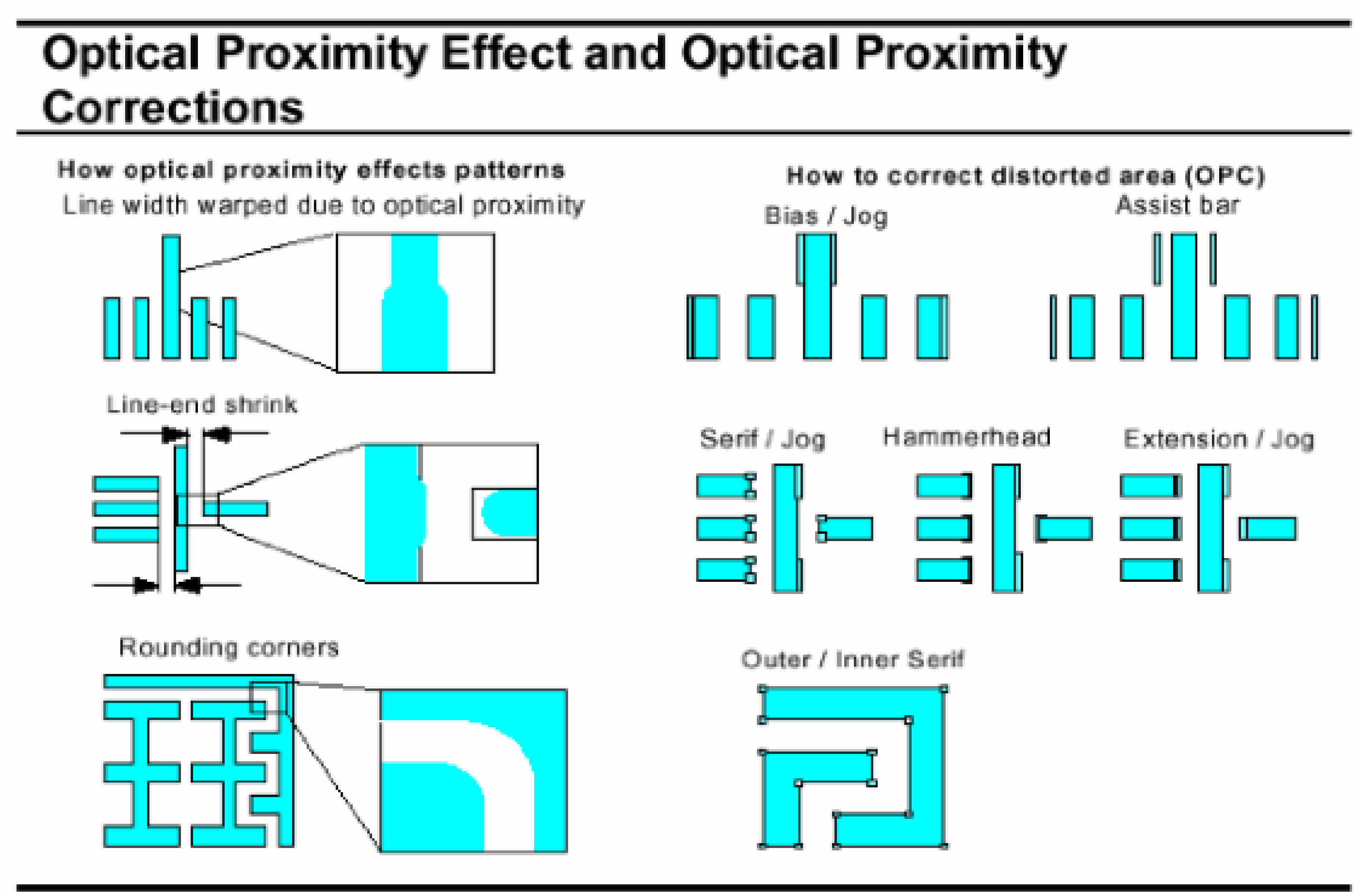
- → Enhance quality of optical instruments (*k*)
- → reduce wave length λ
- → increase *NA*

State-of-the-art lithography



Source: Dai Nippon Printing

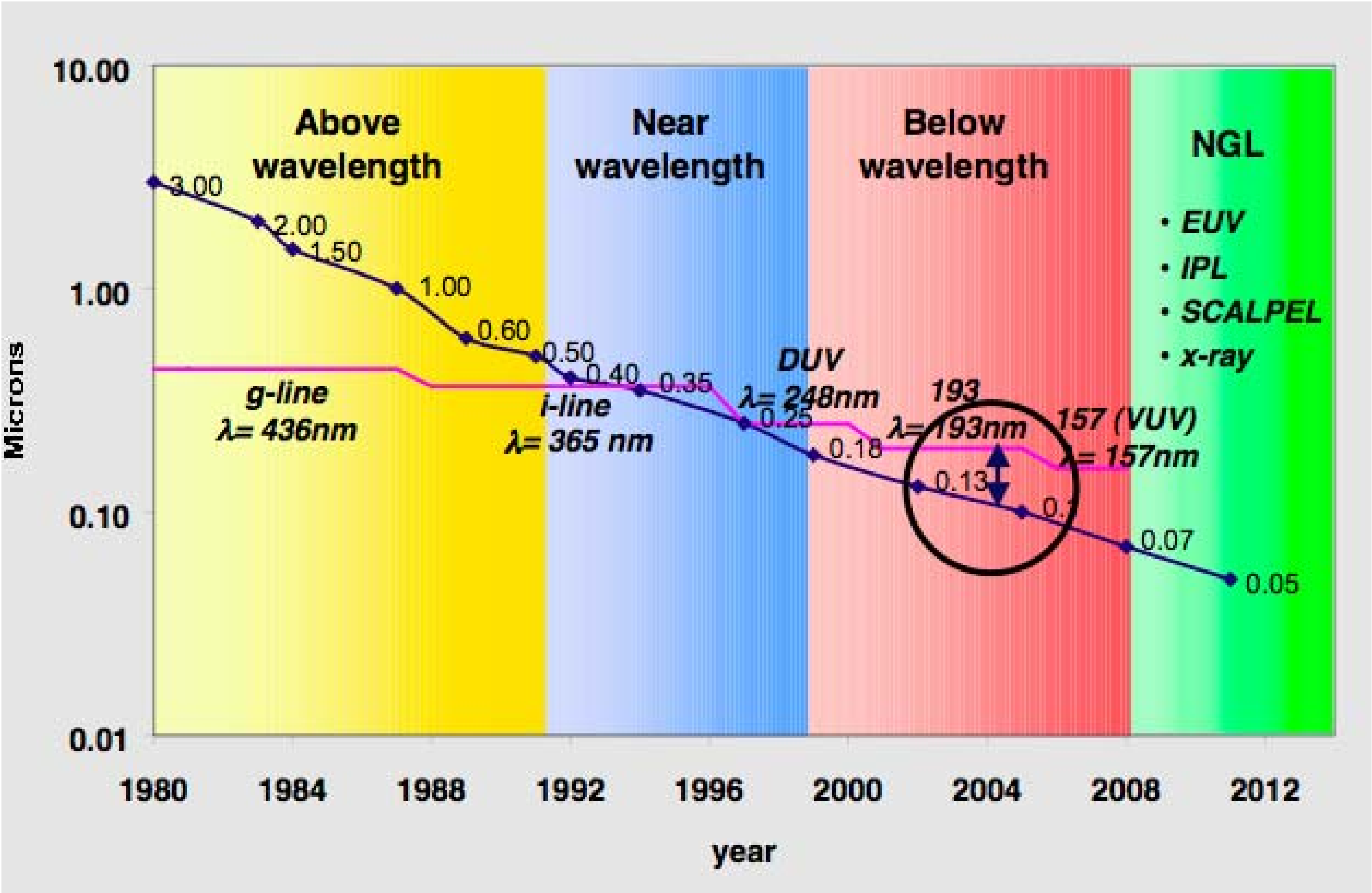
State-of-the-art lithography



Optical Proximity Effect and Optical Proximity Corrections

Source: Dai Nippon Printing

State-of-the-art lithography



Source: Infineon

Agenda

- State-of-the-art lithography
- **Advanced optical lithography**
    - Liquid immersion
    - Hybrid lithography
    - EUV
- Nanoimprint lithography
- Two-photon lithography

Advanced optical lithography

- Reduce wavelength

- Reduce wavelength of light source
- Reduce effective wavelength (immersion)

Advanced optical lithography

- Proposed new light source: 157-nm F2 lasers

- Development of many new materials

- Lack of photo mask protection
- Lack of high-yield growth of crystals
- Improved 193-nm developed instead

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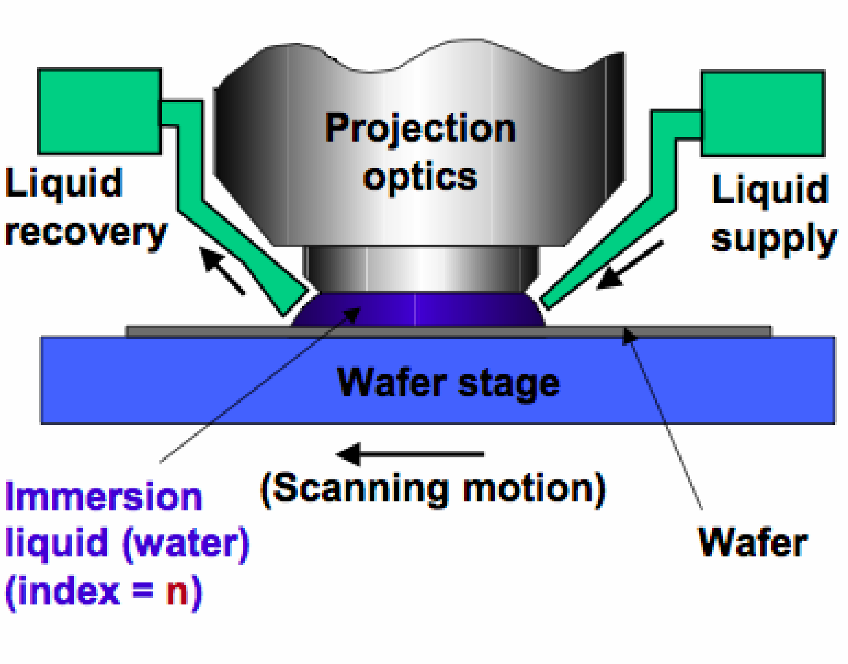
Liquid immersion lithography

- Improved 193-nm technology

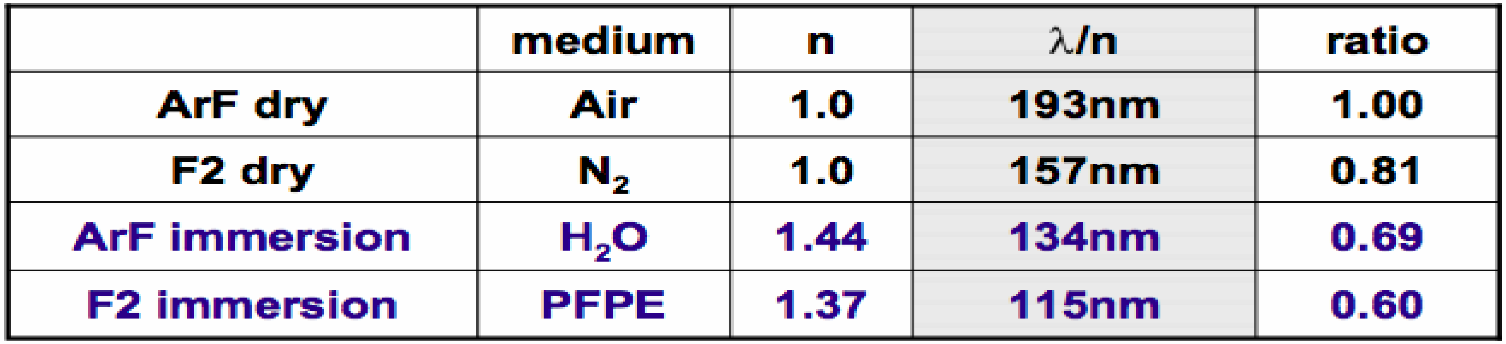


Source: Tokyo Electron

Liquid immersion lithography

- Advantages of liquid immersion:

- keep investments in steppers, masks etc.
- Reduction of effective wavelenght:



	medium	n	λ/n	ratio
ArF dry	Air	1.0	193nm	1.00
F2 dry	N_2	1.0	157nm	0.81
ArF immersion	H_2O	1.44	134nm	0.69
F2 immersion	PFPE	1.37	115nm	0.60

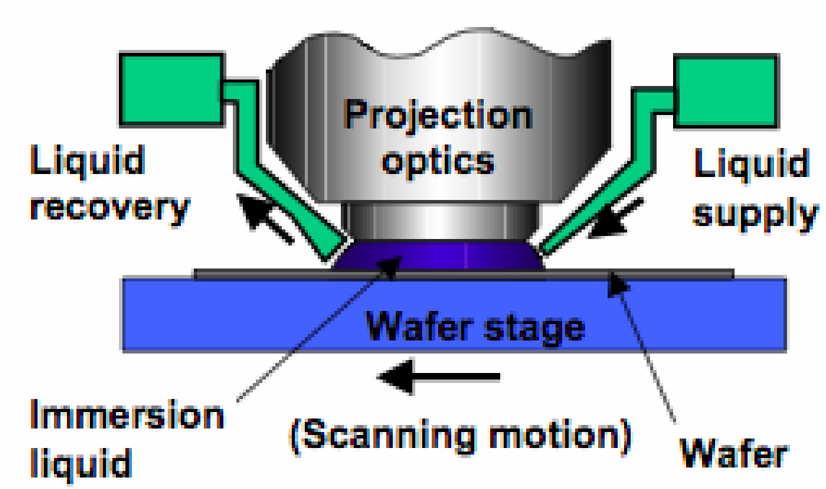
Source: Tokyo Electron

Liquid immersion lithography

- Liquid immersion lithography: challenges

- Water fill:

  Local fill:

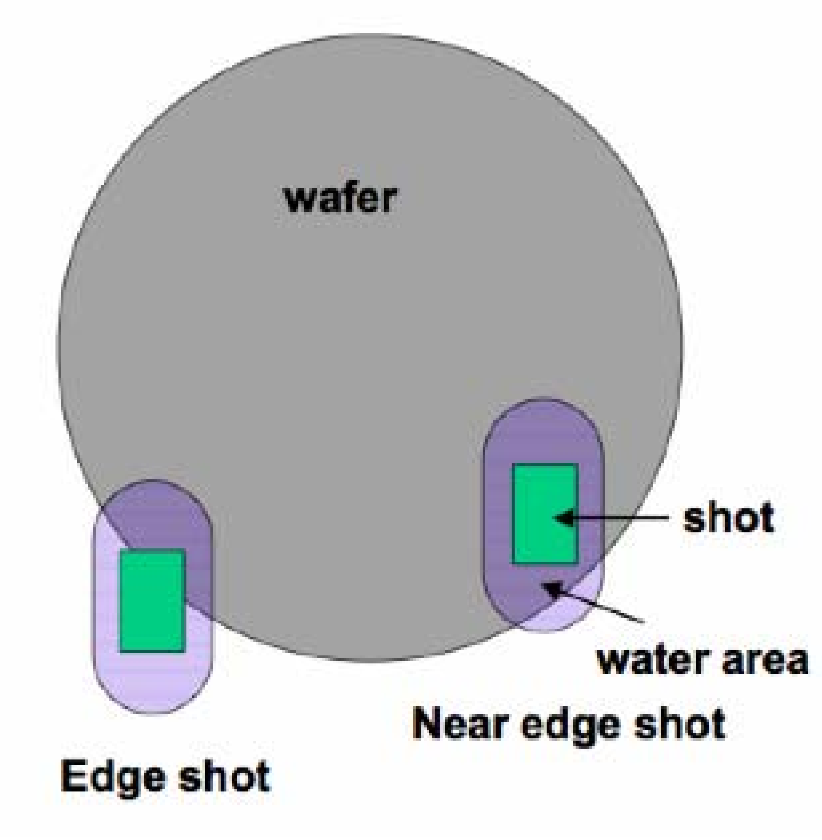


Source: Tokyo Electron

Liquid immersion lithography

- Liquid immersion lithography: challenges

- Water fill
- Edge shot:

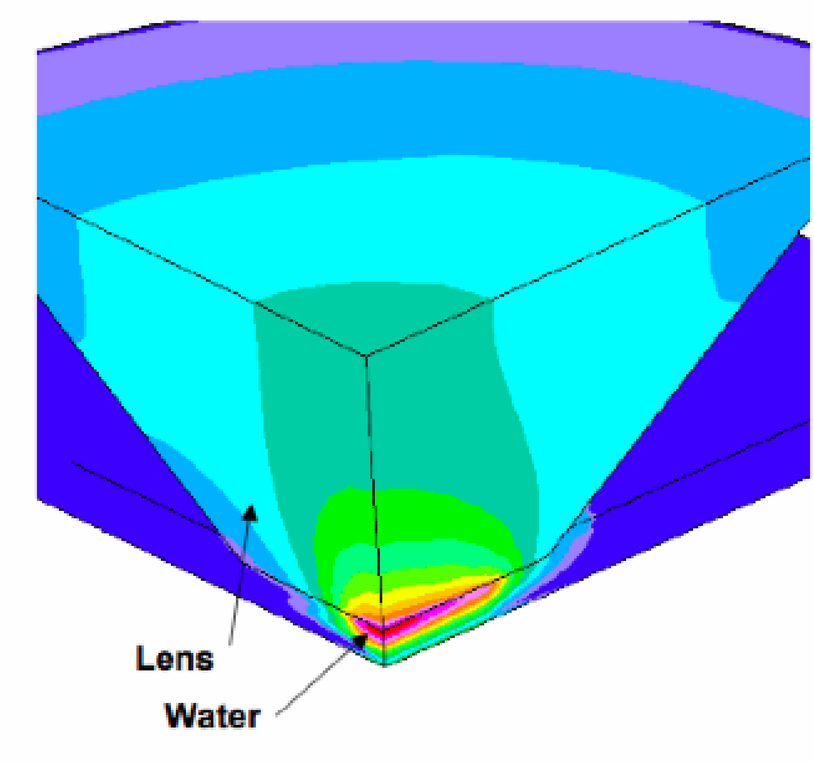


Source: Tokyo Electron

Liquid immersion lithography

- Liquid immersion lithography: challenges

- Water fill
- Edge shot
- Thermal aberration:

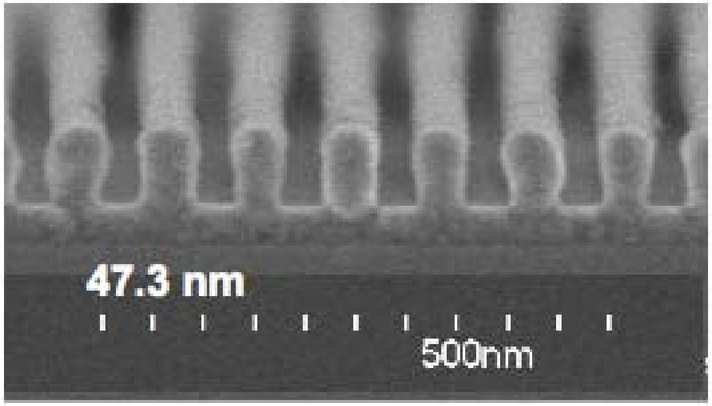


Source: Tokyo Electron

Liquid immersion lithography

- Liquid immersion lithography: challenges

- Water fill
- Edge shot
- Thermal aberration
- Resist avilability:

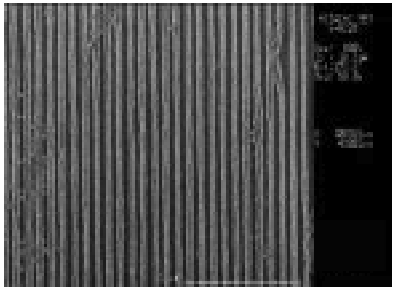


45nm half pitch

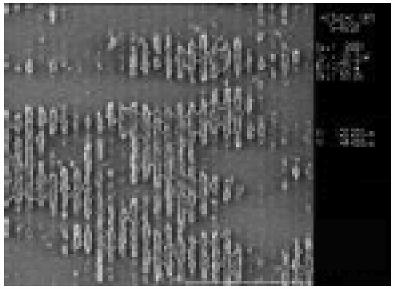
Source: Tokyo Electron / Clariant

Liquid immersion lithography

- Liquid immersion lithography: challenges



- Water fill
- Edge shot
- Thermal aberration
- Resist avilability:



Source: Tokyo Electron / TOK

Liquid immersion lithography

- Liquid immersion lithography: challenges

- Water fill
- Edge shot
- Thermal aberration
- Resist avilability
- Leaching ?
- Small bubbles ?
- Water contamination ?

Liquid immersion lithography

- Liquid immersion lithography:

- AMD, IBM: ***wet*** 193 nm for 65 nm
- Intel: ***dry*** 193 nm down to 45 nm, switching directly to EUV sources

- IBM demonstrated 22 nm with ***dry*** 193 nm

Liquid immersion lithography

- Next step: 32 nm with 193-nm light

- High-index fluids, n=1.9
- E.g. hydrocarbon fluids, n=1.6

- Or take wet 157-nm
- And take up additional challenges!

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Hybrid lithography

- A different approach: using interference

- Optical grid
- High throughput
- Creating only periodic grid structures
- Up to 32 nm structures

- Hybrid lithography

Advanced optical lithography

- Sooner or later: reduce the wavelength

- Extreme UV (EUV)
- Electron beam
- Projection electron beam (SCALPEL)
- Ion Beam (IPL)
- X-ray

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EUV lithography

- Overview

Pitch/2 (nm)	k_1	λ (nm)	NA
32	0.30	193	**1.81**
32	0.30	157	**1.47**
32	**0.59**	13.5	0.25

Source: ASML

EUV lithography

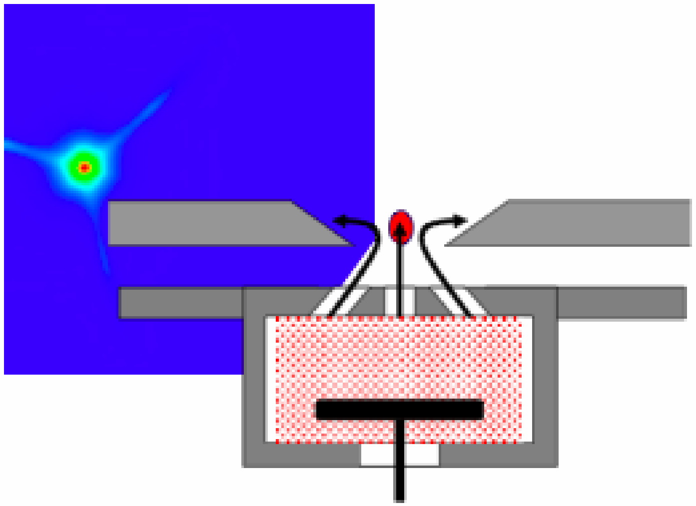
- Requirements

- Wavelength: 13.5 nm
- Power in focus: 115 W
- Condenser lifetime: min. 30,000 hrs.
- Energy stability, ±0,3%

Source: ASML

EUV lithography

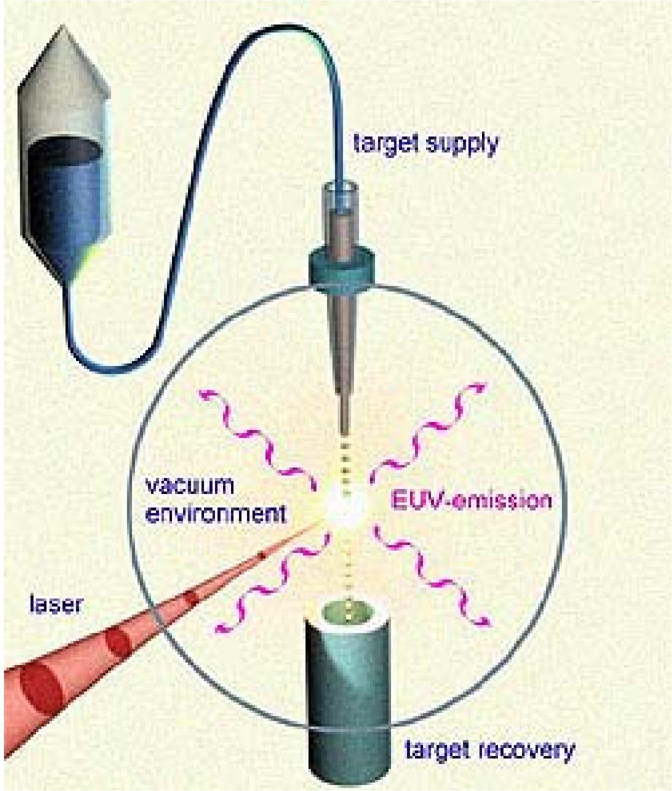
- Sources:
- Gas discharge Plasma:



Source: Philips Extreme UV GmbH

EUV lithography

- Sources:
- Laser produced plasma:



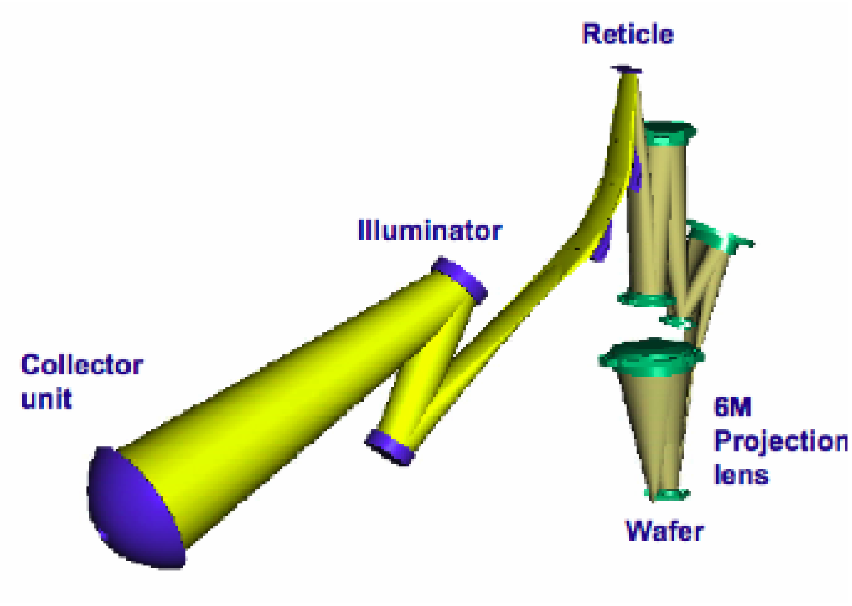
Source: Xtreme Technnologies

EUV lithography

- Sources:
- GDPP: preferred - contamination, power, lifetime still unsufficient
- LPP: costly

EUV lithography

- Optics:
- Mirror optics required
- Enhance reflectivity (70%)
- Contamination
- Perfect surfaces
- Lifetime



Source: ASML

EUV lithography

- More issues:

- Mask handling
- Resist resolution

- ... Yet to be resolved

EUV lithography

- Announced in 1997 by Intel, Motorola, AMD: in use for production by 2004

- Today: Intel, ASML plan introduction in 2009

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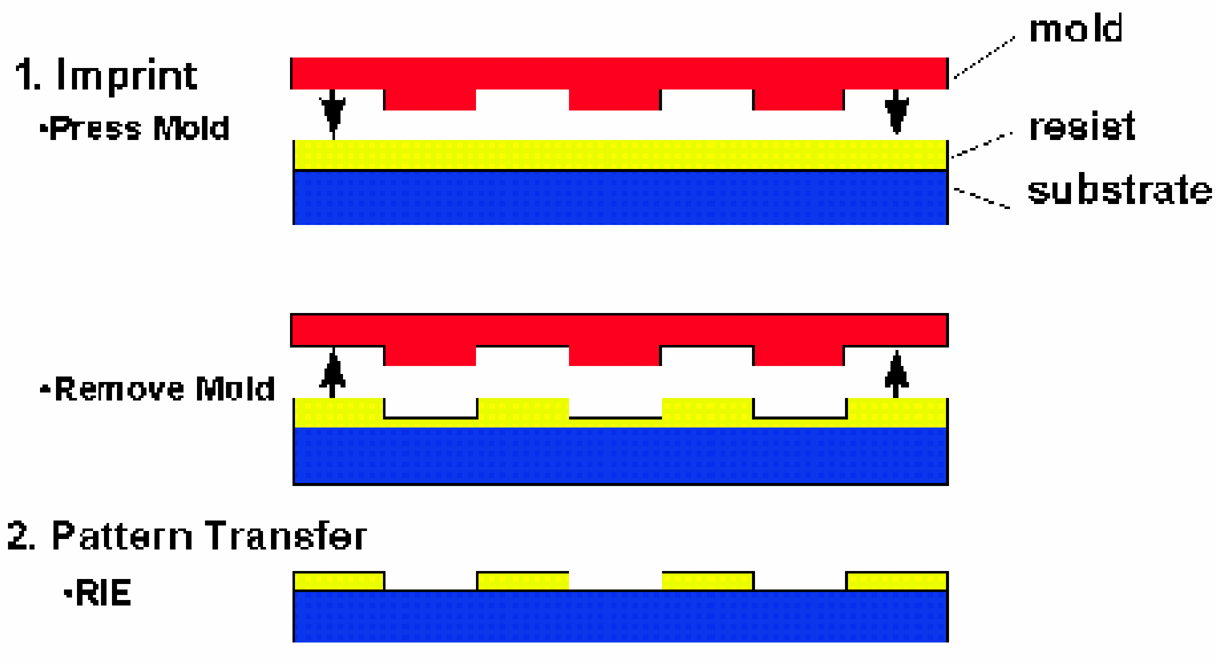
Nanoimprint lithography

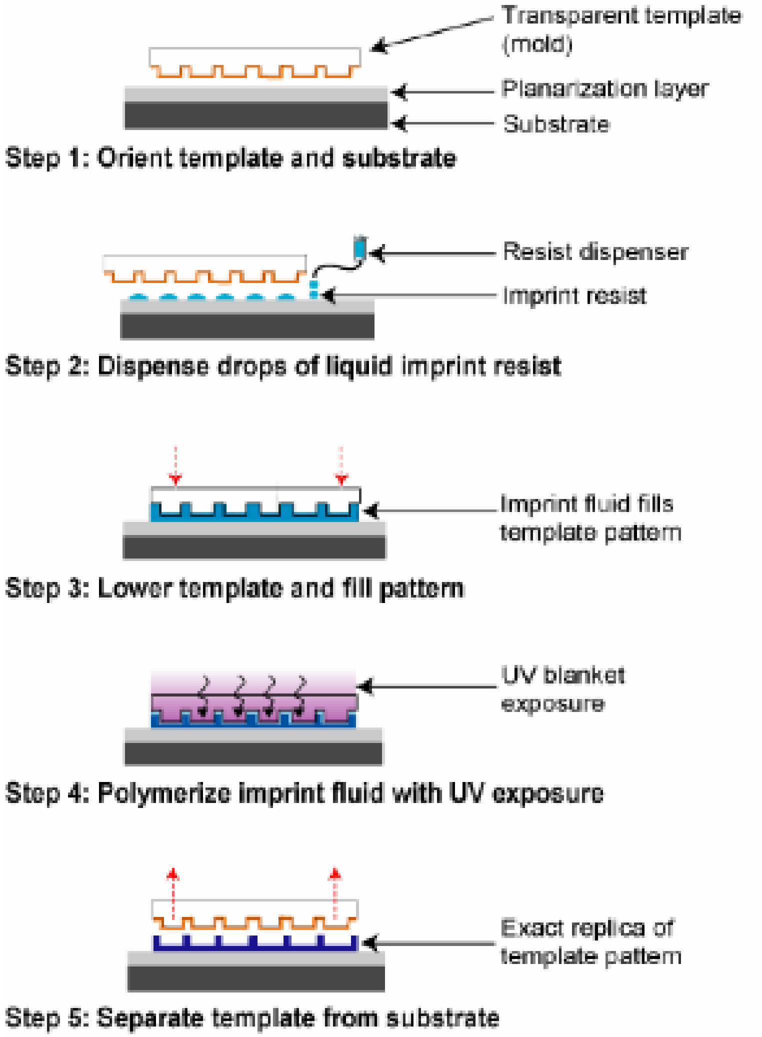
- Thermal NIL



Source: Public Domain

Nanoimprint lithography

- UV-NIL



Source: Public Domain

Nanoimprint lithography

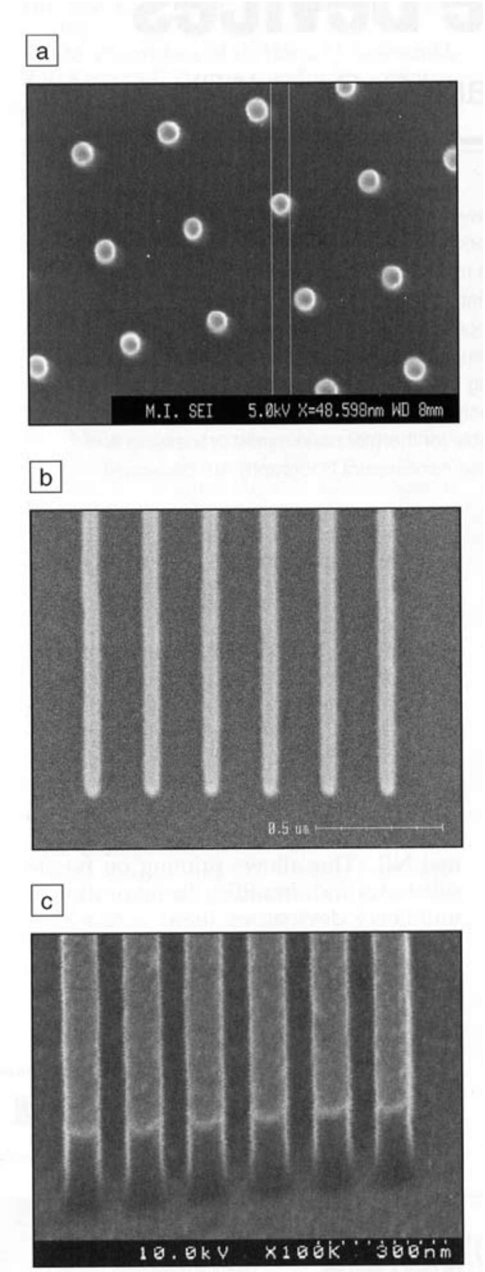
- Why UV-NIL?

- Lower forces: 100 kPa instead of 500-5000 kPa
- No heating, no cooling
- Longer lifetime, faster imprint
- Sub 5-nm demonstrated

Nanoimprint

- What can you do with NIL?

- MOSFET
- TFT
- Microfluidics



Source: MRS Bulletin

Nanoimprint lithography

- Issues

- Production of templates
- Defect control
- Small throughput
- Materials

- Possibly 10 nm with self assembled nanostructures
  ... Far beyond 2010

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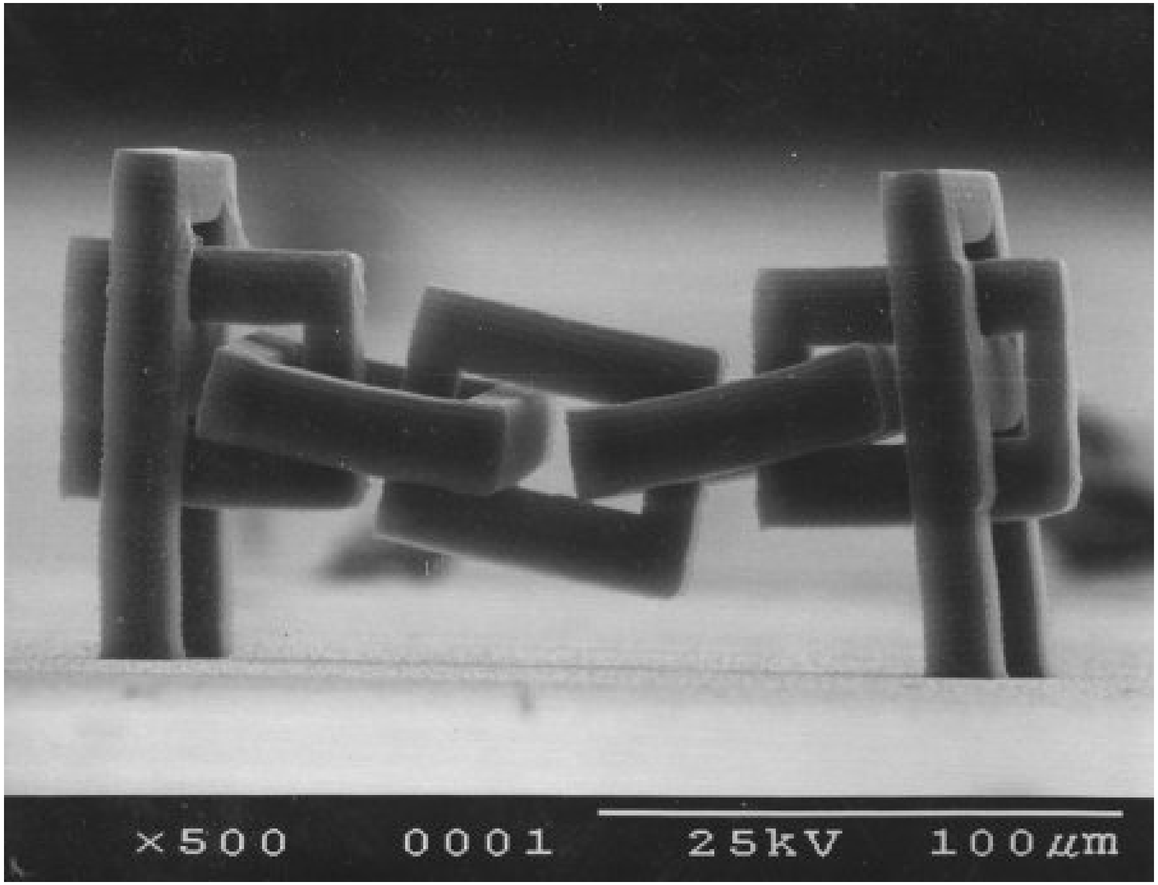
Two-photon lithography



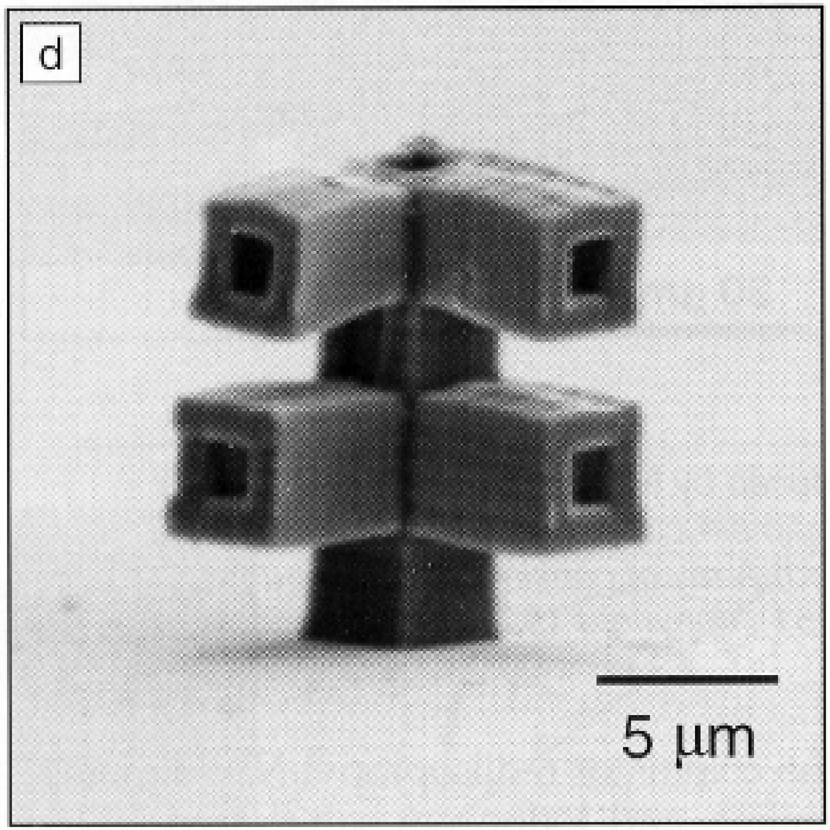
Source: Georgia Institute of Technology

Two-photon lithography

- Chromophores with nonlinear absorbance

- Absorbance only inside the focal point
- Femtosecond laser beam
- E.g. polymerization in close proximity
- Order of 250 nm in practice

- Positive working systems realized

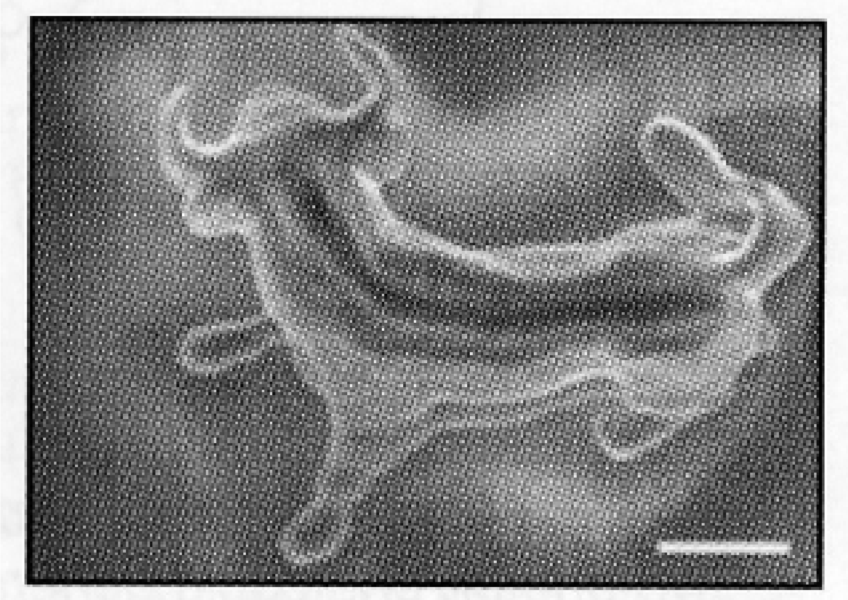


Source: MRS Bulletin

Two-photon lithography

- Applications

- Controlled photonic crystals
- Using even doped materials, metals
- MEMS / NEMS
- Protein matrices as drug delivery devices



Source: MRS Bulletin

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