

Introduction to nanofabrication

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Lesson plan

- Lesson 1: introduction to nanofabrication
- Lesson 2: diffractive optics and X-ray microscopy
- Lesson 3: 3D fabrication and optical manipulation and spectroscopy

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ELETTRA



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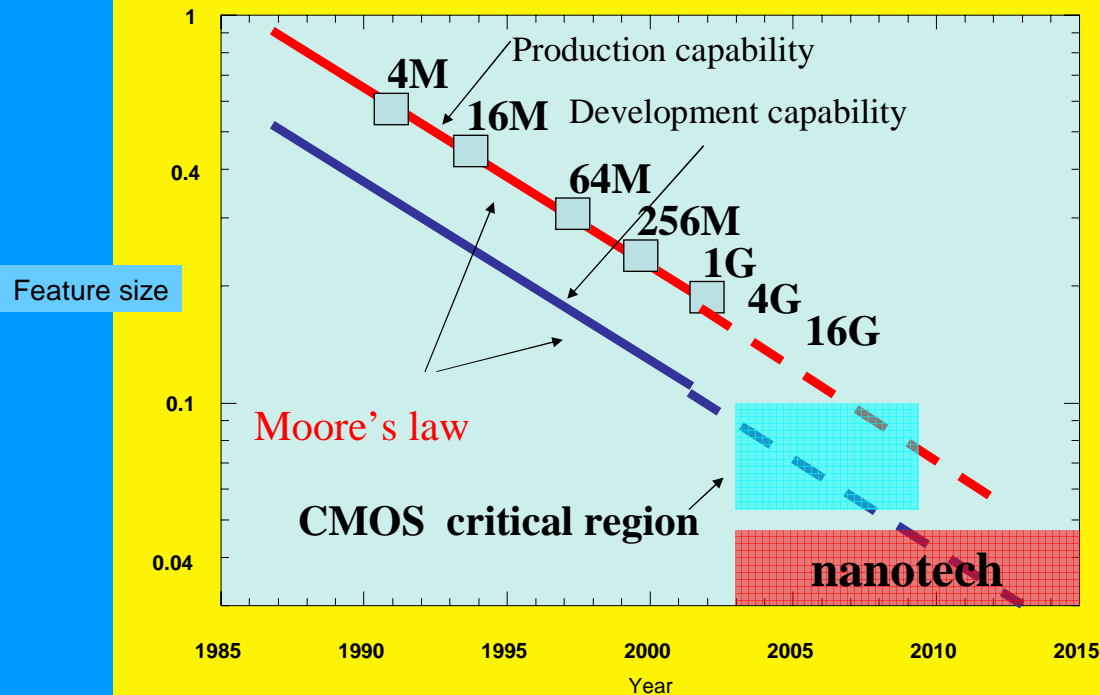
TASC National Laboratory of INFM



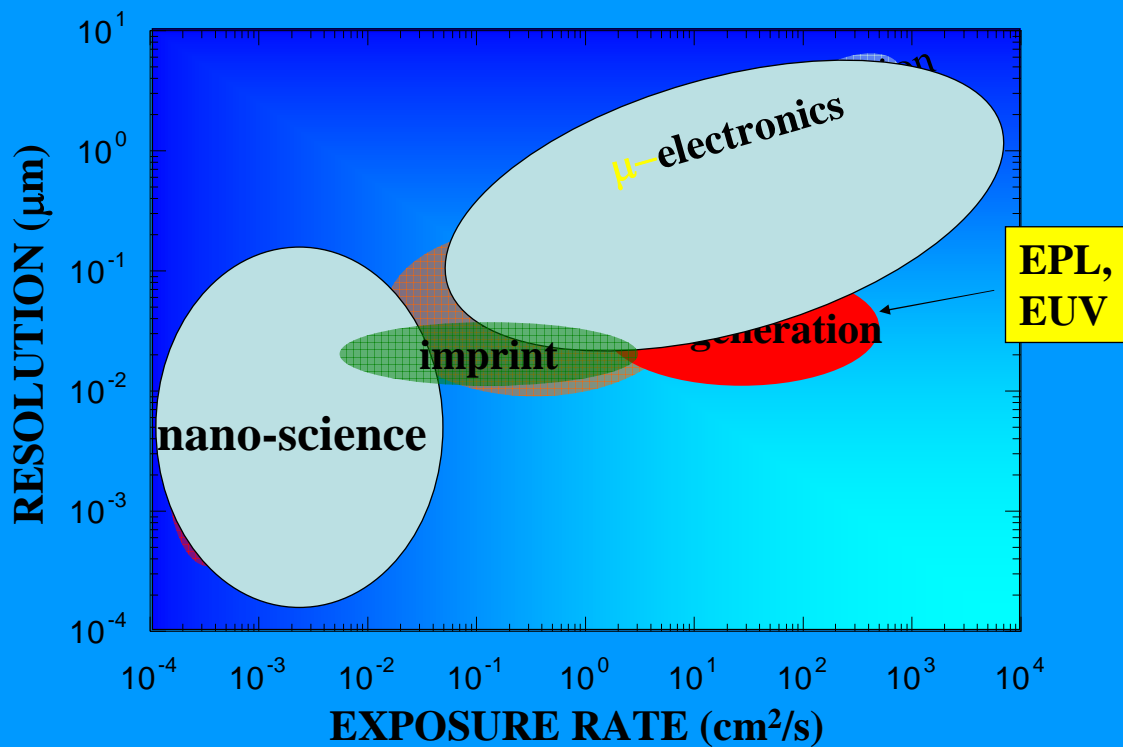
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Why reduce the sizes?

DRAM litho requirements

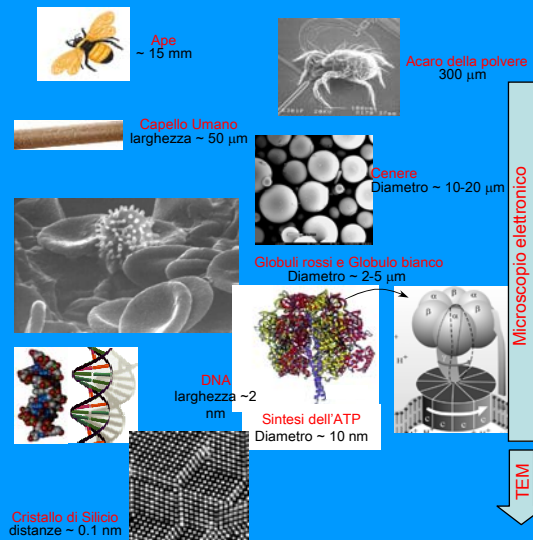


Lithographic techniques

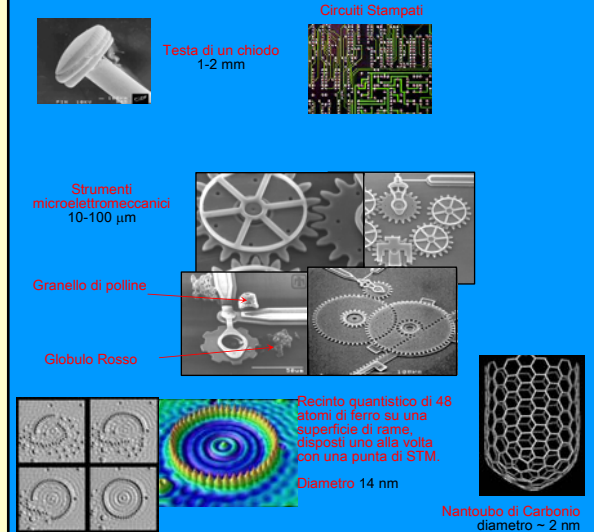


The scale length of things

"Objects" from nature



Artificial objects



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Tools to observe the nano world

- (SPM, scanning probe microscope):
 - STM (scanning tunneling microscope) Resolution ~0.1 nm
 - AFM (atomic force microscope) Resolution ~1.0 nm
- SEM (scanning electron microscope) Resolution ~1 nm
- TEM (transmission electron microscope) Resolution ~0.1 nm

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STM microscope

Muovendo la punta sopra la superficie, si misura la corrente di elettroni che che passano dalla superficie alla punta (o viceversa) per effetto tunnel. Spostando la punta con dei piezoelettrici (precisione 0.01 nm) si ottiene una mappa della densita' elettronica.

Densita' elettronica di una superficie di Nickel (110).

Realizzazione ed elaborazione IBM

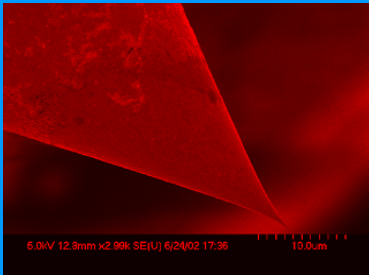
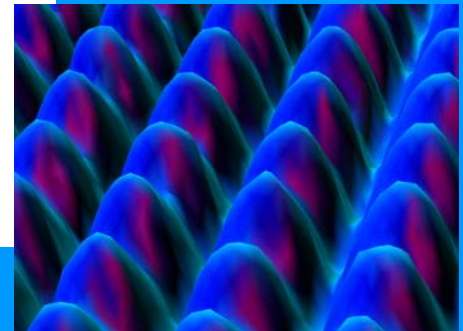
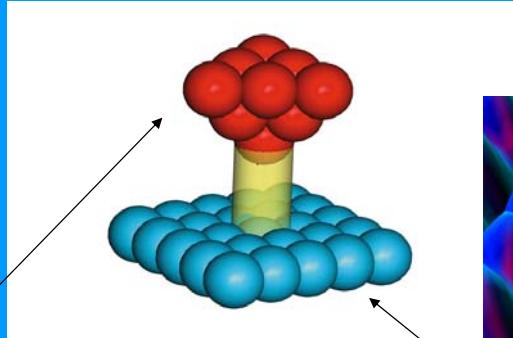


Immagine di una punta per STM



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AFM microscope

Muovendo la punta sopra il campione, si misura il piegamento della piccola leva (canti-lever) dovuto alle forze di interazione atomiche e molecolari.

Si ottiene una immagine topografica della superficie che consente di misurare anche materiali isolanti (organici, biologici)

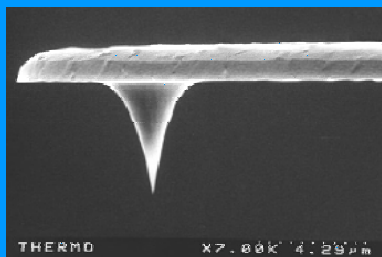
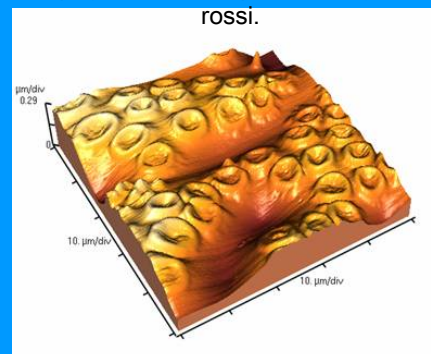
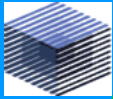


Immagine di una punta montata su una piccola leva per AFM

Topografia della superficie di globuli rossi.



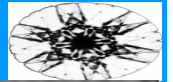
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INFM - TASC

Elvio Carlino - Electron Microscopy Centre

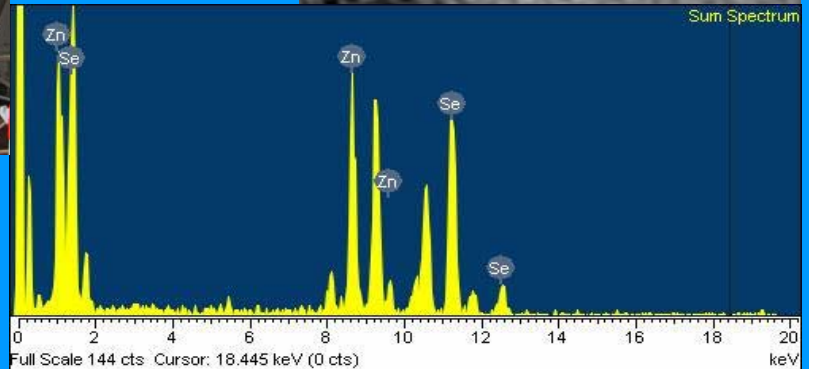
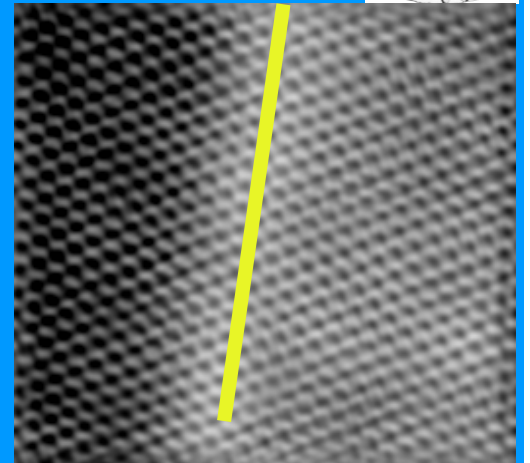
ZnSe/GaAs heterostructure



TEM at the Centre for Electron Microscopy

Elvio Carlino

Centro di Microscopia Elettronica - INFM - TASC



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Lithography Techniques for Nanofabrication

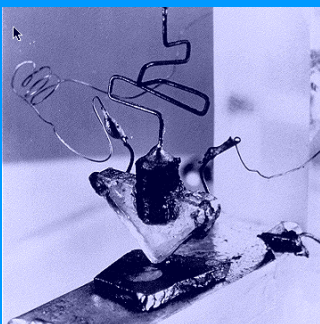
- Fundamentals of Lithography
- Beam Lithography
- Alternate Nanolithography Techniques

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Fundamentals of Lithography

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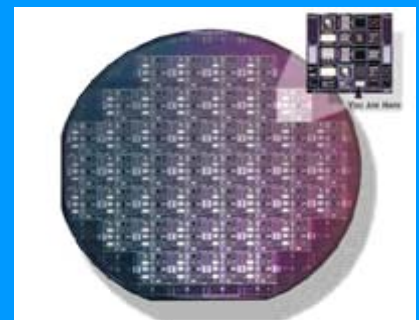
The Si revolution...



**First Transistor
Bell Labs (1947)**



**Si integrated circuits
Texas Instruments (~1960)**



Modern ICs

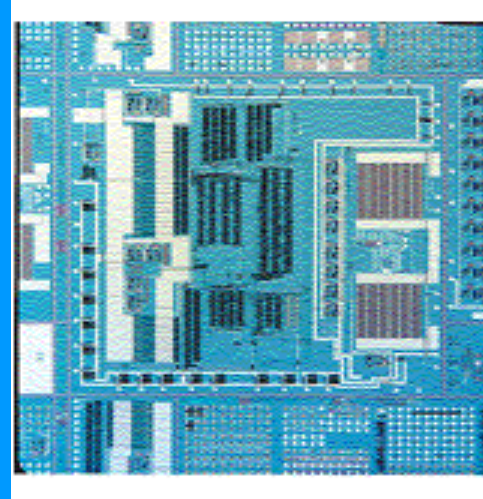
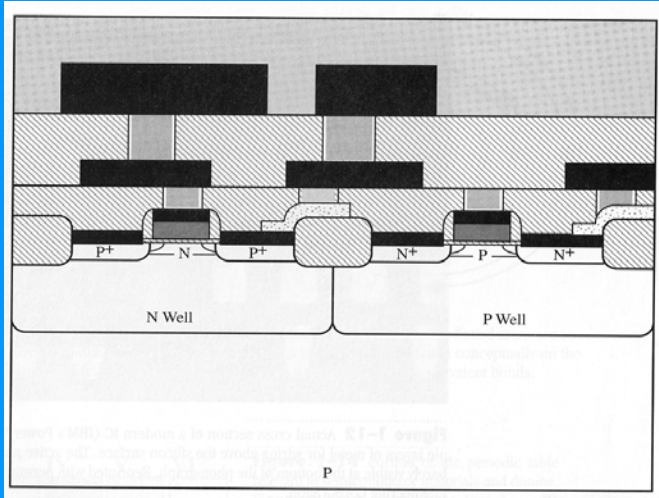
More ? Check out:

<http://www.pbs.org/transistor/background1/events/miraclemo.html>

<http://www.ti.com/corp/docs/company/history/firstic.shtml>

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The need of micropatterning



The batch fabrication of microstructures requires a low-cost, high throughput surface patterning technology

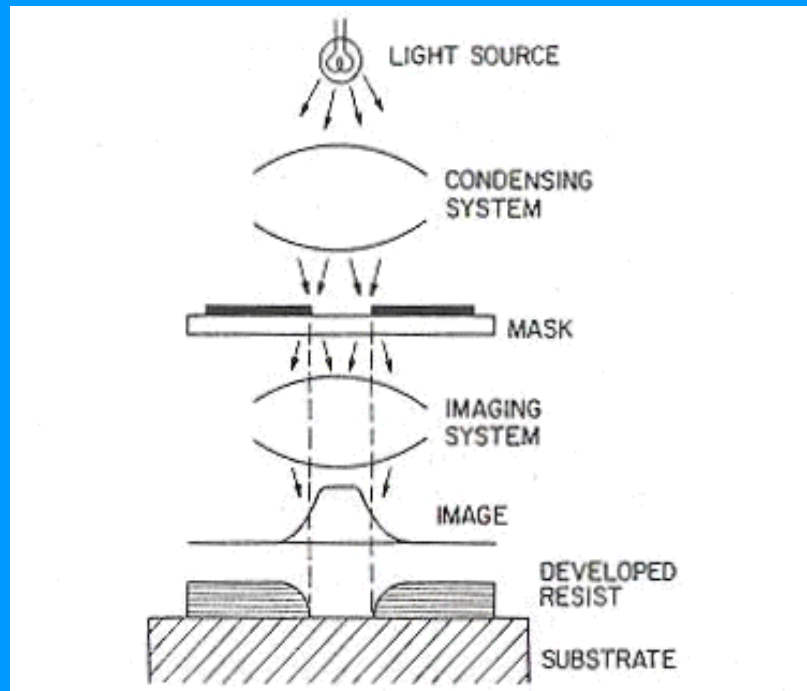
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Elements of photolithography

- **Lithography** consists of patterning a substrate by employing the interaction of beams of photons or particles with materials.
- **Photolithography** is widely used in the integrated circuits (ICs) manufacturing.
- The process of IC manufacturing consists of a series of 10-30 steps or more, called **mask layers** where layers of materials coated with resists are patterned then transferred onto the material layer.

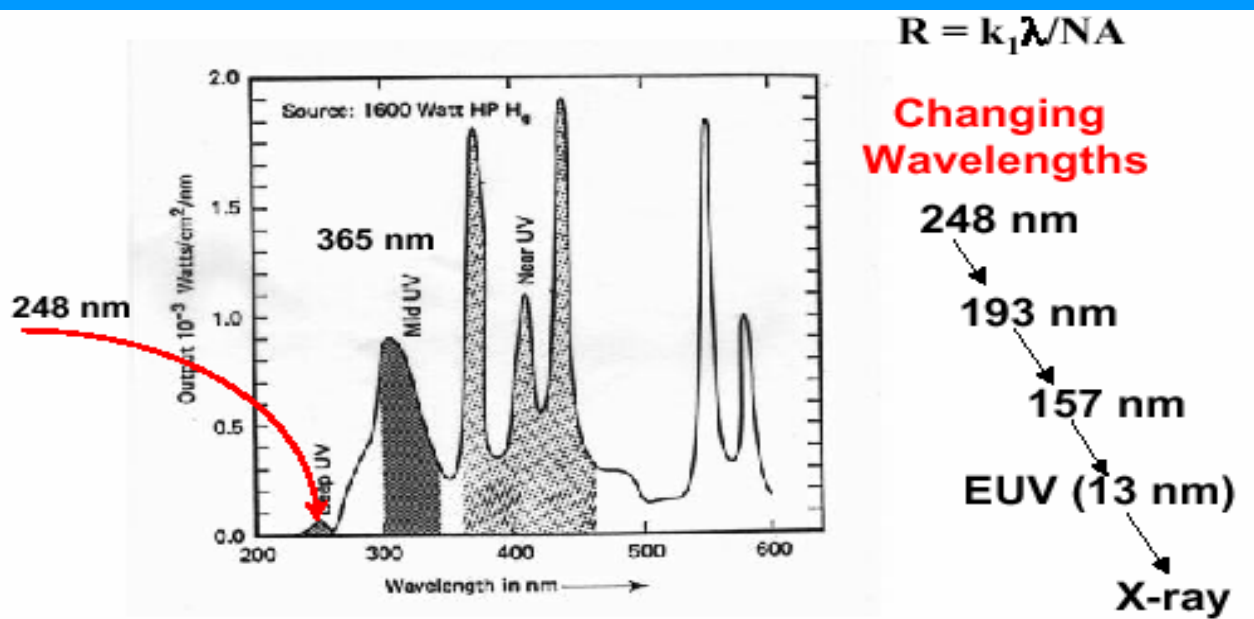
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Elements of photolithography (ctnd.)



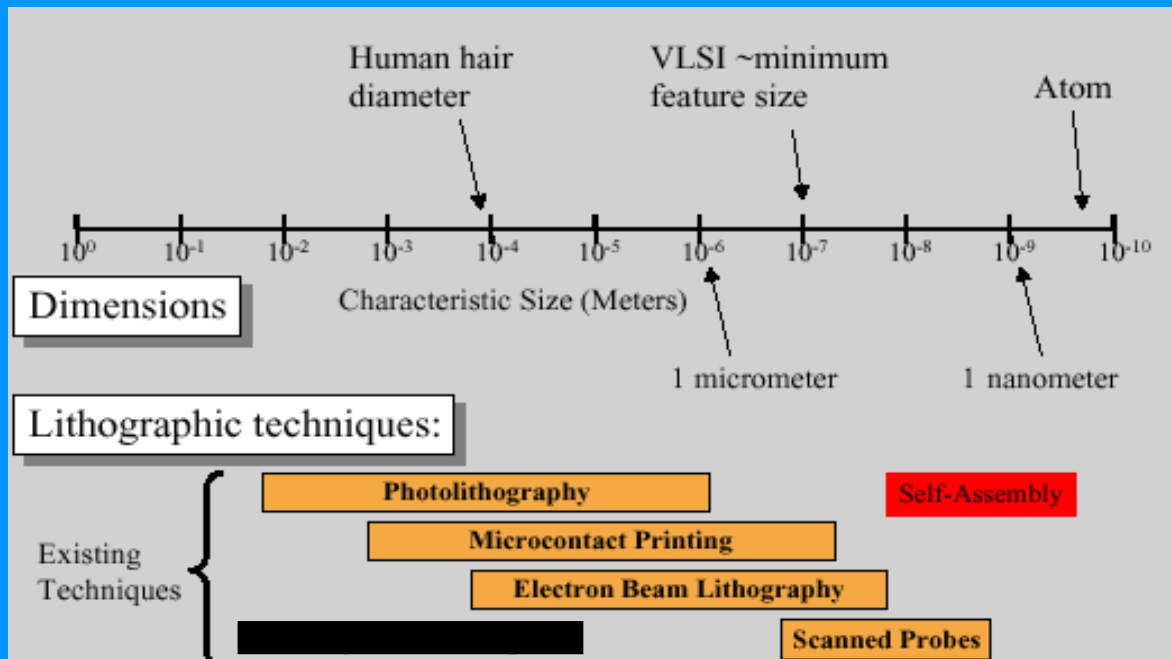
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Output Spectrum of Hg Arc Lamp



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Size Scales Accessible to Nanofabrication Approach



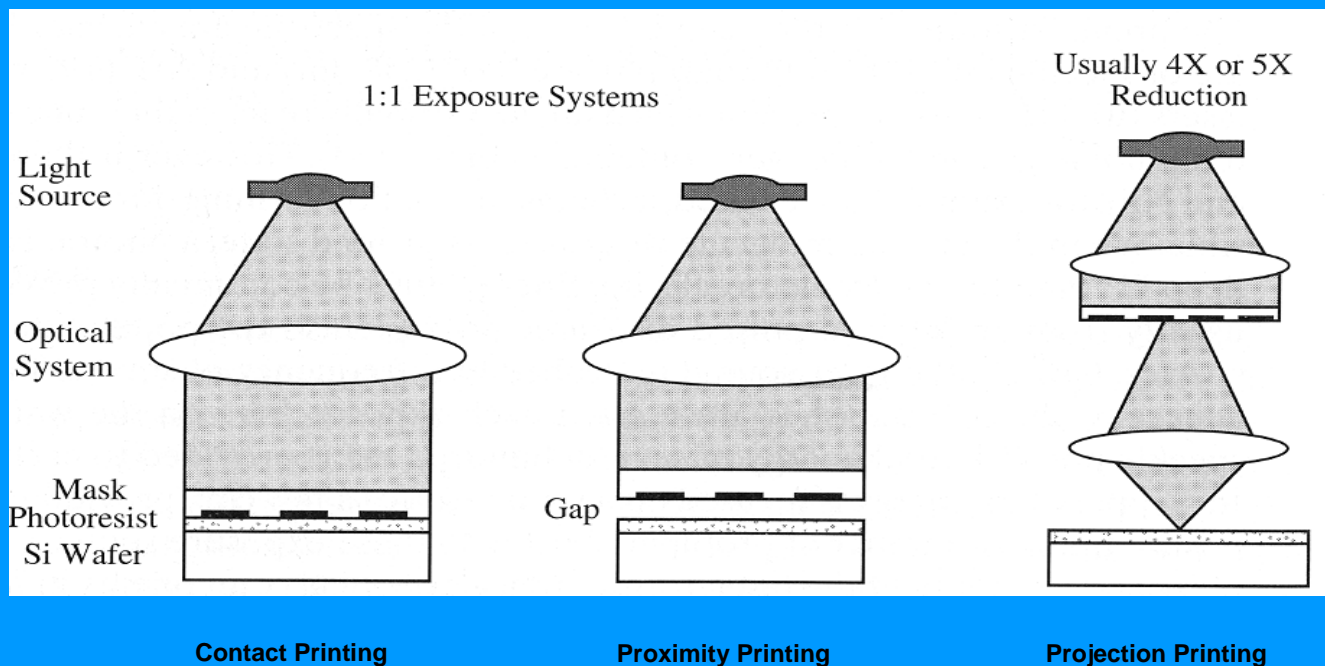
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Elements of photolithography (ctnd.)

- A photolithography system consists of a light source, a mask, and an optical projection system.
- **Photoresists** are radiation sensitive materials that usually consist of a photo-sensitive compound, a polymeric backbone, and a solvent.
- **Resists** can be classified upon their solubility after exposure into: **positive resists** (solubility of exposed area increases) and **negative resists** (solubility of exposed area decreases).

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Types of photolithography



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Micro- and nanolithography

- Present techniques in IC manufacturing involve dimensions in order of 100-150 nm.
- Diffraction and other optical effects limit the resolution of "standard" UV photolithography to the ~100 nm range.
- Photolithography continues to support IC manufacturing in the sub-100 nm region through continuous advances in optics (UV to DUV to EUV) and resist engineering.
- Exploratory research in the sub-100 nm region may also be accomplished through alternate patterning techniques such as x-ray-, ion- and electron beam-lithography.

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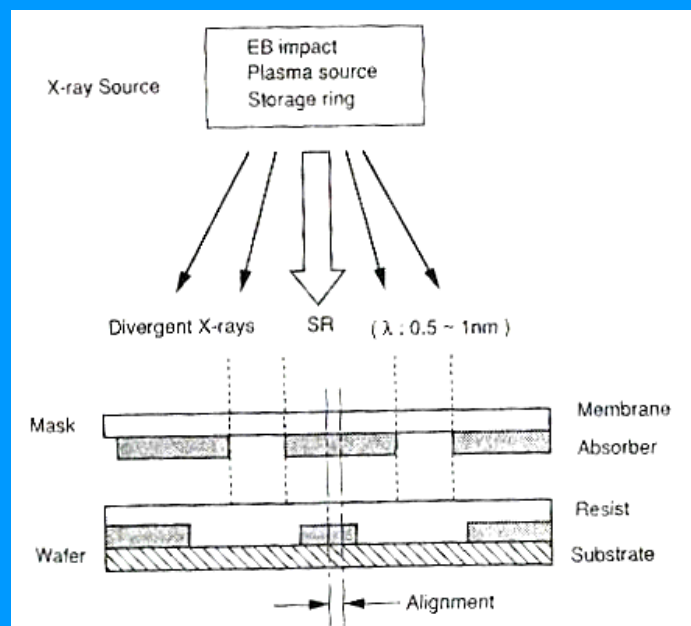
BEAM ASSISTED LITHOGRAPHY

- X-ray
- Electron Beam
- Ion Beam

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X-Ray lithography

- Diffraction limits lithography resolution to $\lambda/2$
- Obvious solution: use lower wavelengths sources
- DUV and EUV approaching standardization
- X-Ray lithography still posing no threat to optical



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X Rays



Features:

- Discovered by Wilhelm Conrad Röntgen in 1895
- Experiments in a vacuum tube made a nearby fluorescent screen glow.

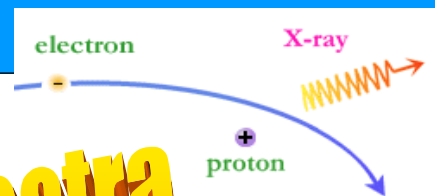
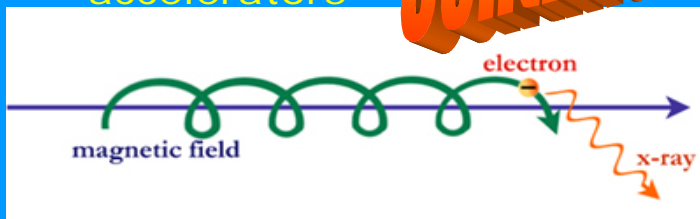
- 1901 **W. C. Roentgen** in Physics for the discovery of x-rays.
 1914 **M. von Laue** in Physics for x-ray diffraction from crystals.
 1915 **W. H. Bragg and W. L. Bragg** in Physics for crystal structure derived from x-ray diffraction.
 1917 **C. G. Barkla** in Physics for characteristic radiation of elements.
 1924 **K. M. G. Siegbahn** in Physics for x-ray spectroscopy.
 1927 **A. H. Compton** in Physics for scattering of x-rays by electrons.
 1936 **P. Debye** in Chemistry for diffraction of x-rays and electrons in gases.
 1962 **M. Perutz and J. Kendrew** in Chemistry for the structure of hemoglobin.
 1962 **J. Watson, M. Wilkins, and F. Crick** in Medicine for the structure of DNA.
 1979 **A. McLeod Cormack and G. Newbold Hounsfield** in Medicine for computed axial tomography.
 1981 **K. M. Siegbahn** in Physics for high resolution electron spectroscopy.
 1985 **H. Hauptman and J. Karle** in Chemistry for direct methods to determine x-ray structures.
 1988 **J. Deisenhofer, R. Huber, and H. Michel** in Chemistry for the structures of proteins that are crucial to photosynthesis.

X Rays

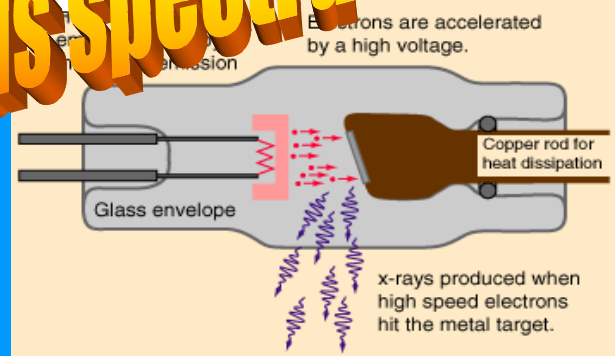
Methods of production:

- acceleration of free electrons

- X ray tubes
- accelerators



Continuous spectra



- Excitation of atomic electrons

Discrete spectra

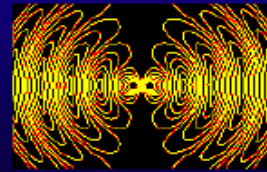
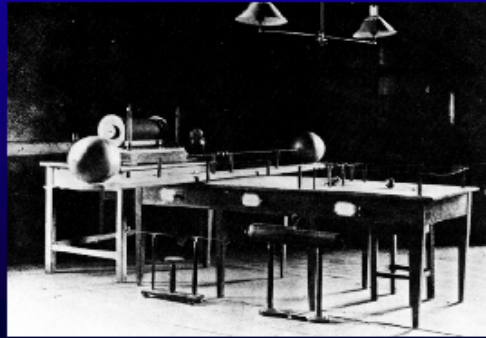


THEORETICAL UNDERSTANDING →

1873 Maxwell's equations

→ made evident that changing charge densities would result in electric fields that would radiate outward

1887 Heinrich Hertz demonstrated such waves:

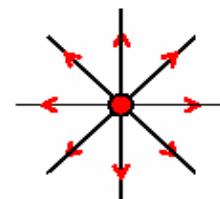


..... this is of no use whatsoever !

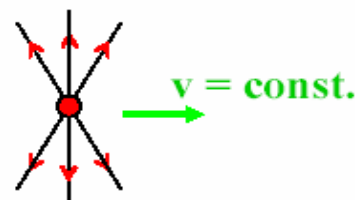
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Why do they radiate?

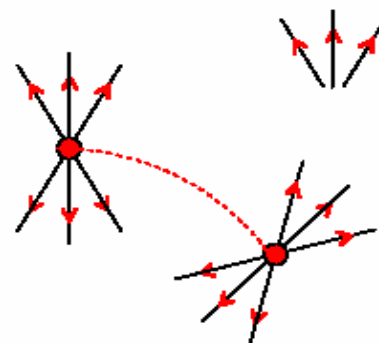
Charge at rest: Coulomb field



Uniformly moving charge



Accelerated charge



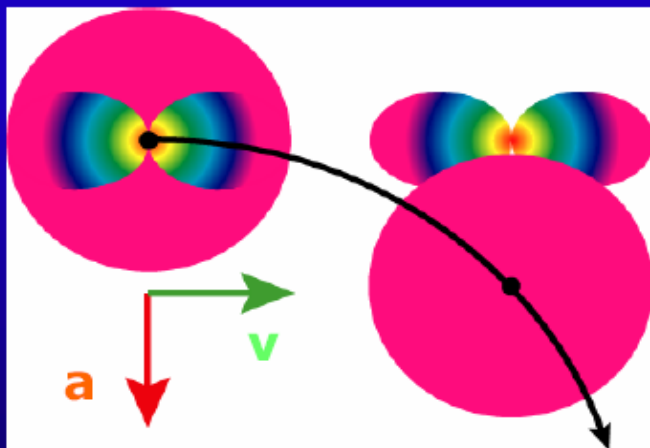
Fields of a moving charge

$$\vec{E}(t) = \frac{q}{4\pi\epsilon_0} \left[\frac{\vec{n} - \vec{\beta}}{(1 - \vec{n} \cdot \vec{\beta})^3 \gamma^2} \cdot \frac{1}{r^2} \right]_{ret} +$$

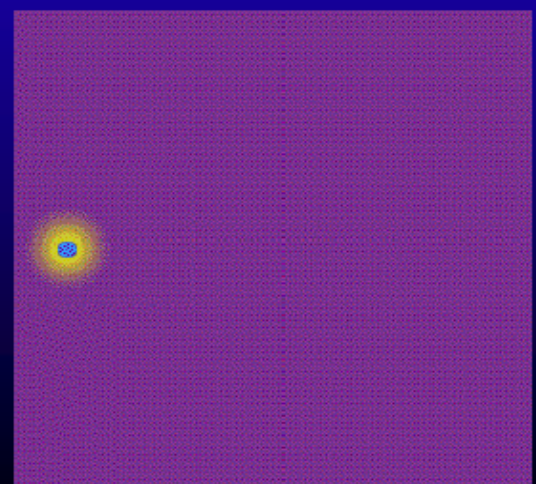
$$\frac{q}{4\pi\epsilon_0 c} \left[\frac{\vec{n} \times [(\vec{n} - \vec{\beta}) \times \dot{\vec{\beta}}]}{(1 - \vec{n} \cdot \vec{\beta})^3 \gamma^2} \cdot \frac{1}{r} \right]_{ret}$$

$$\vec{B}(t) = \frac{1}{c} [\vec{n} \times \vec{E}]$$

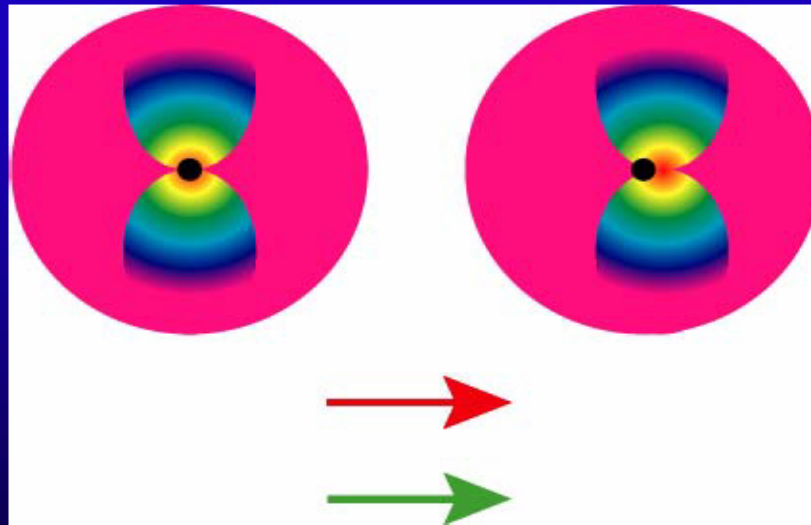
Transverse acceleration



Radiation field quickly separates itself from the Coulomb field

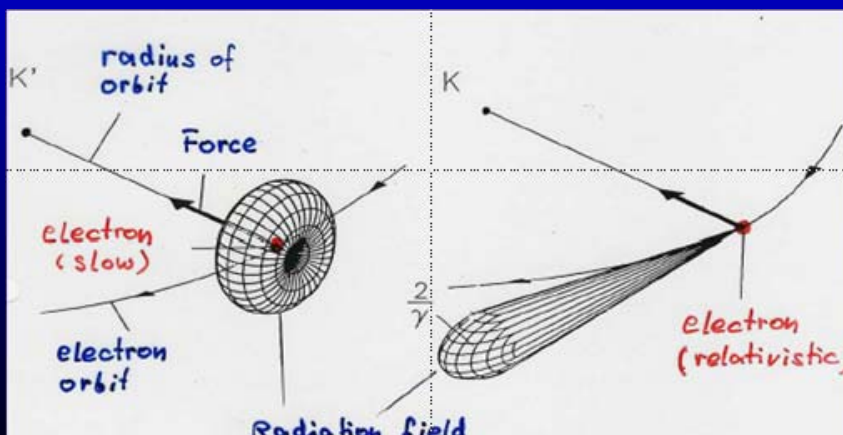
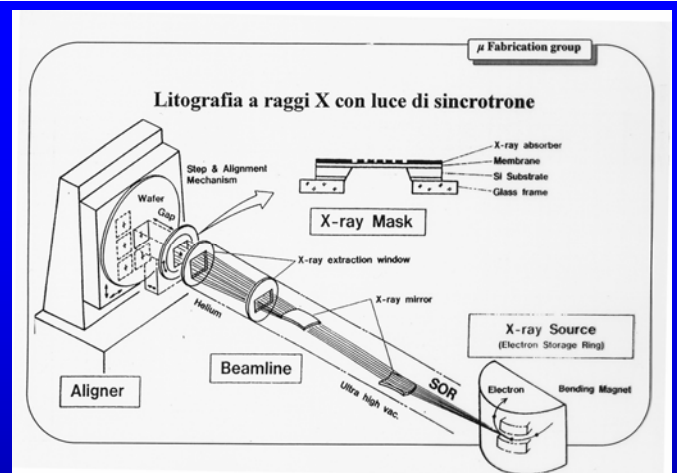


Longitudinal acceleration

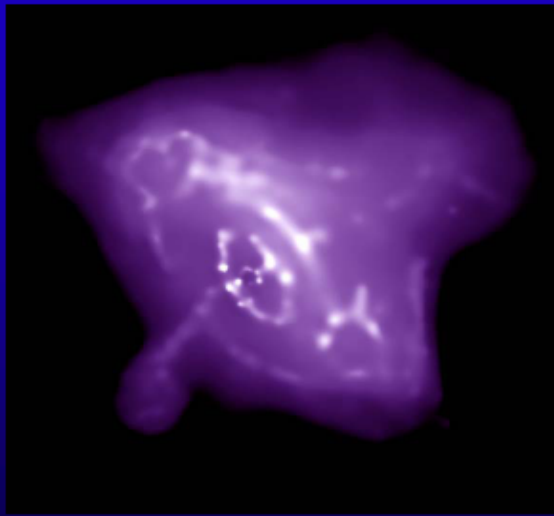


Radiation field cannot separate itself from the Coulomb field

Radiation is emitted into a narrow cone
Into a narrow cone

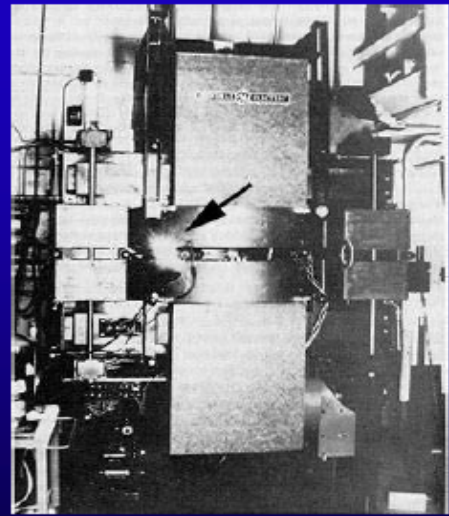


**Crab Nebula
6000 light years away**



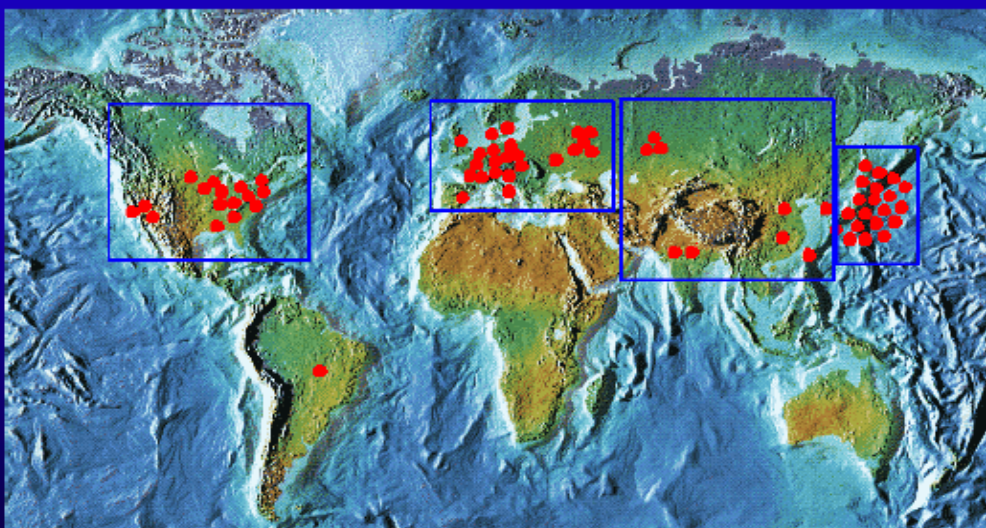
**First light observed
1054 AD**

**GE Synchrotron
New York State**



**First light observed
1947**

20 000 users world-wide



Scheme of a typical synchrotron X-ray lithography system

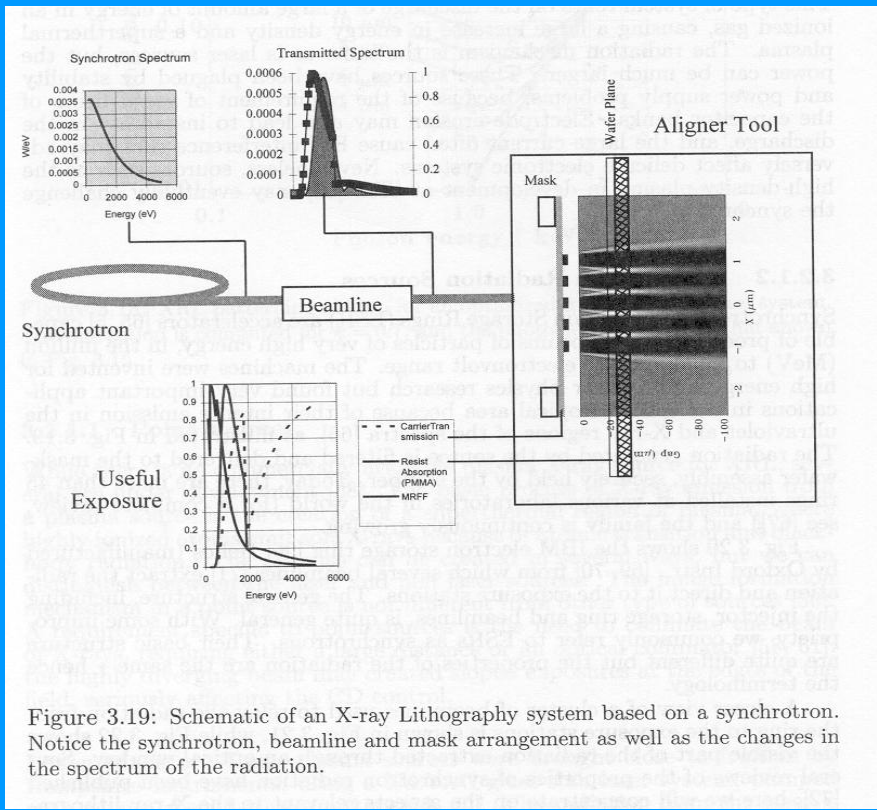
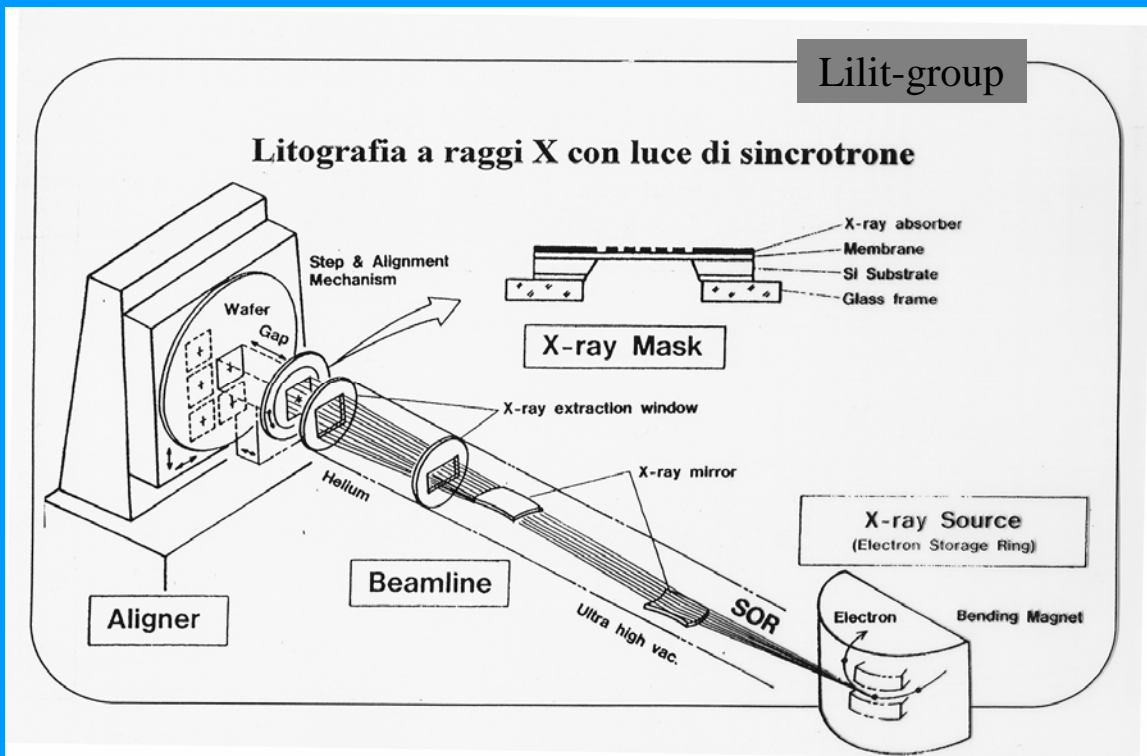


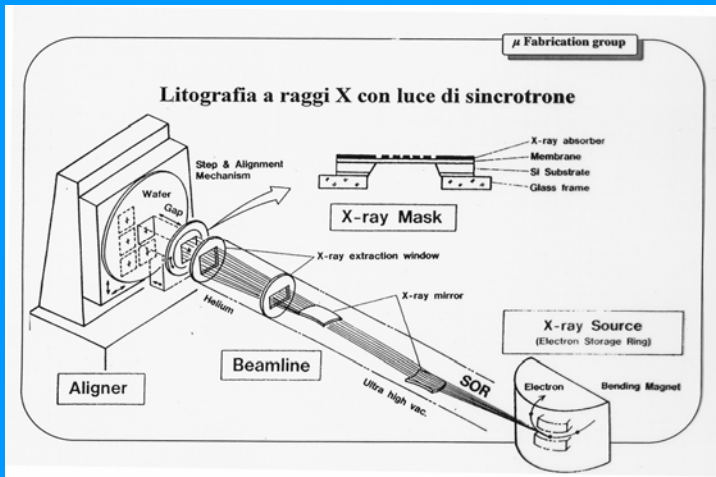
Figure 3.19: Schematic of an X-ray Lithography system based on a synchrotron. Notice the synchrotron, beamline and mask arrangement as well as the changes in the spectrum of the radiation.

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The Stepper



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LILIT energy spectrum

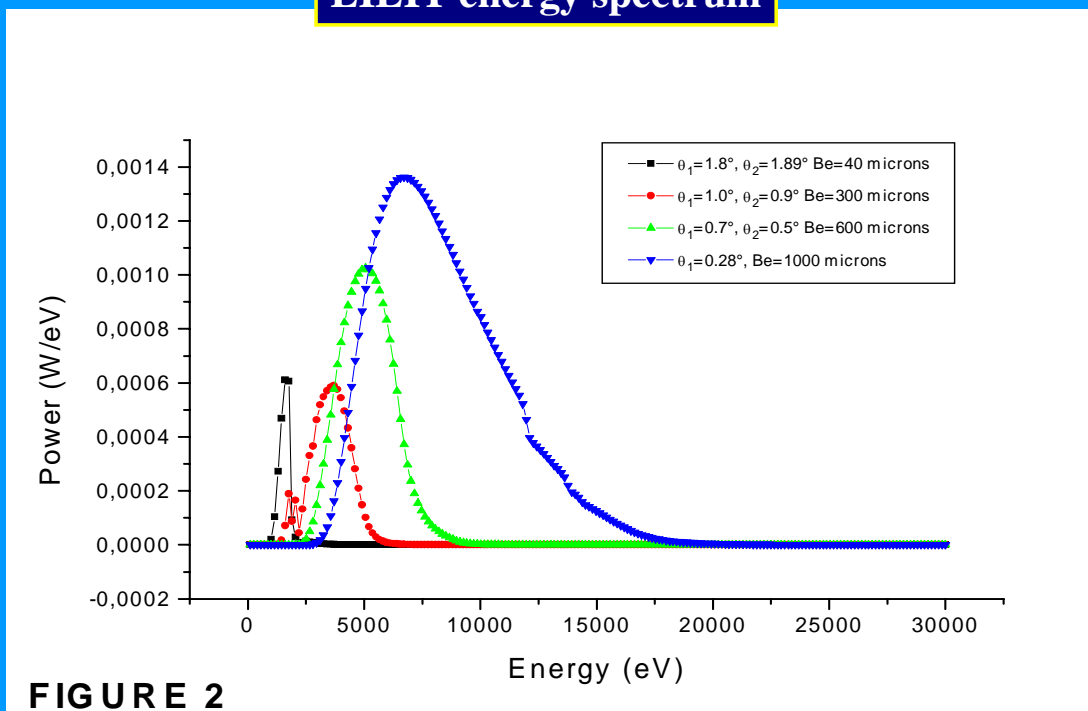
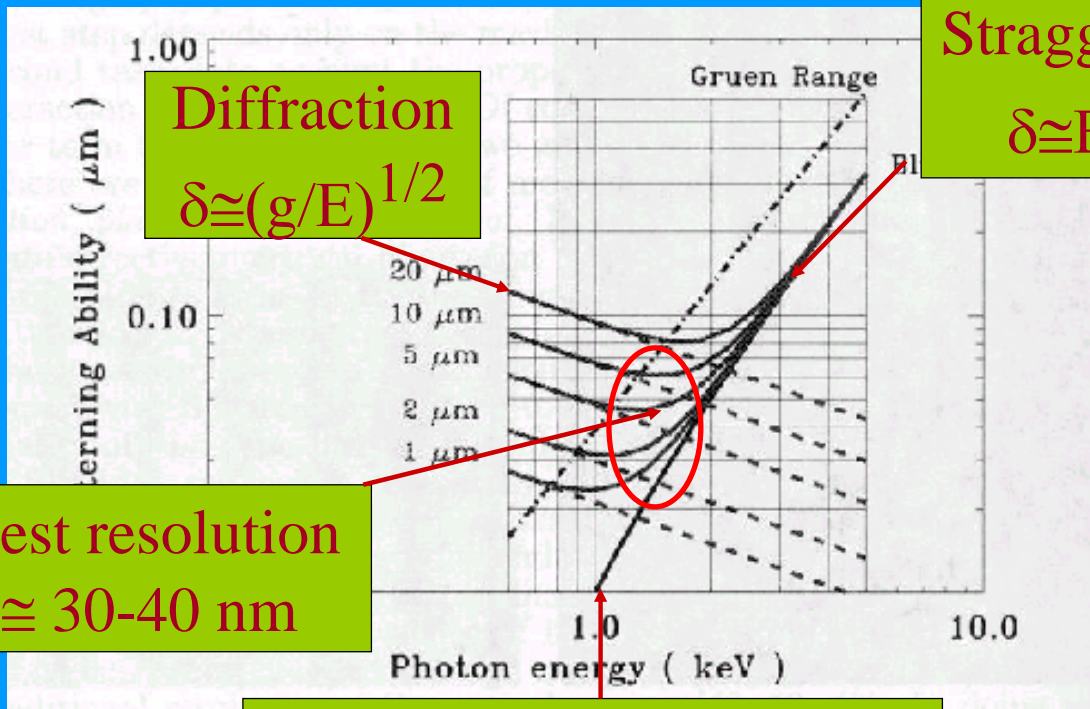


FIGURE 2

Calculated transmission spectra of the beamline for different values of the incidence angles. The absorption from two Berillium windows of various thicknesses is included in the calculation.

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Patterning ability of an X-ray lithography system



Diffraction
 $\delta \approx (g/E)^{1/2}$

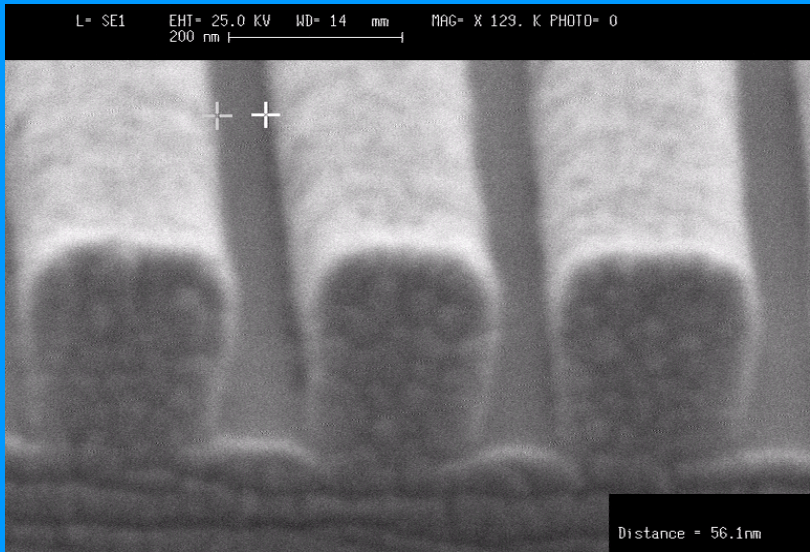
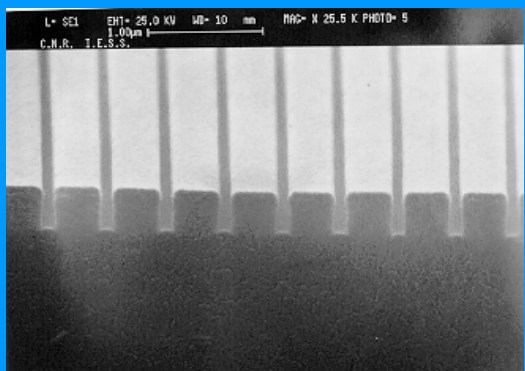
Straggling
 $\delta \approx E^2$

Best resolution
 $\approx 30\text{-}40\text{ nm}$

Optimized Energy $\approx 1\text{ keV}$

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50 nm Test pattern



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Layered approach for the E.M. field

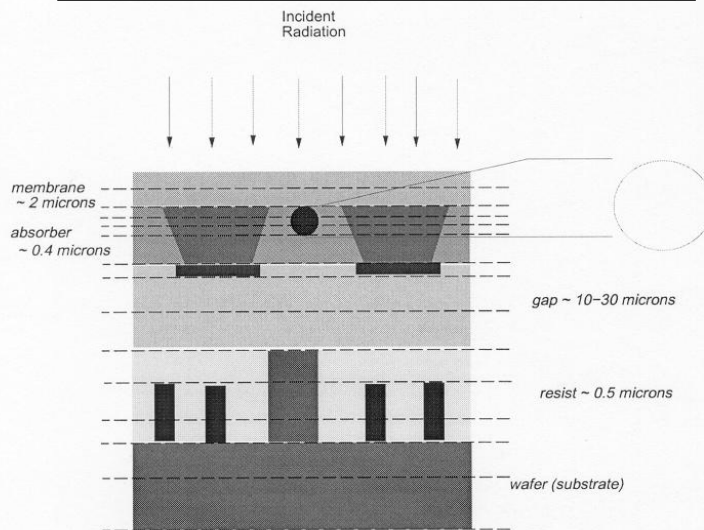
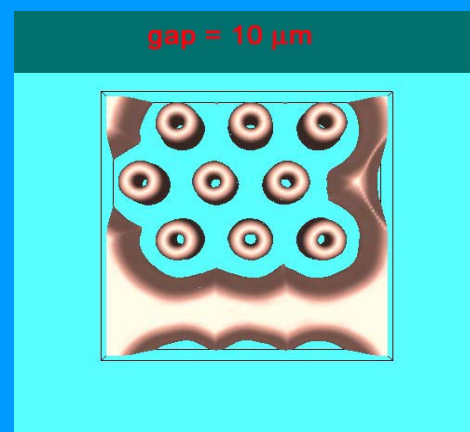
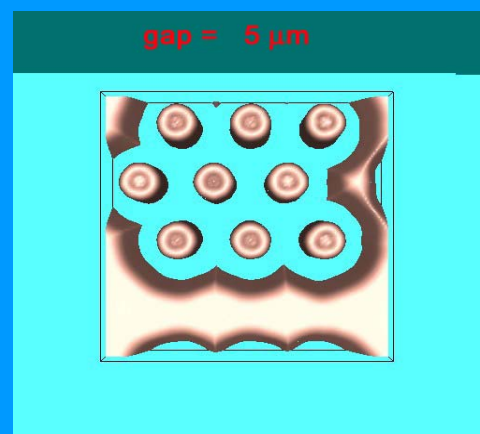
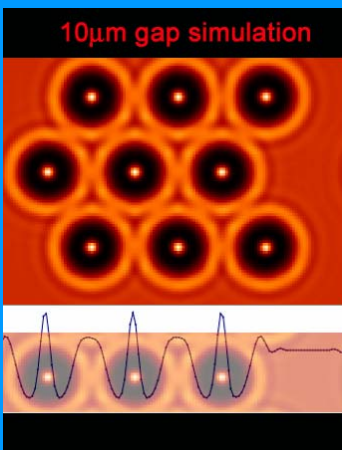
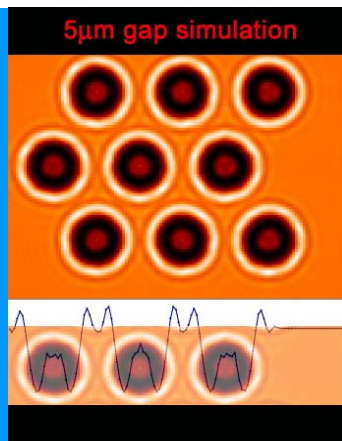


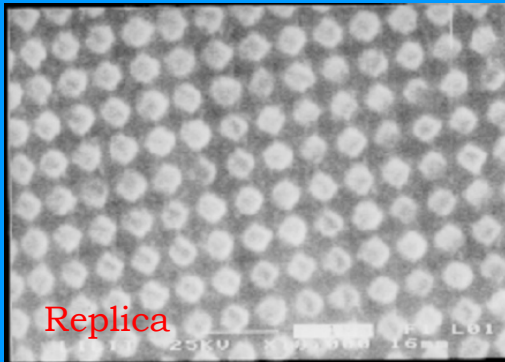
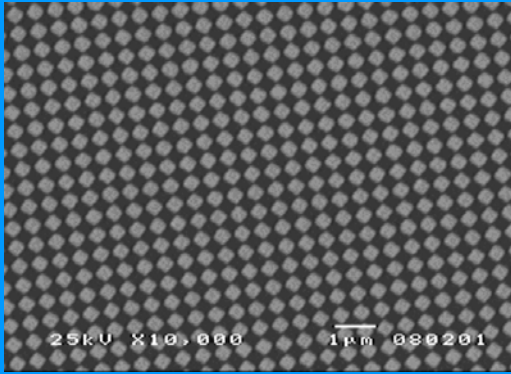
Figure 8: *Illustration of the layered approach. Materials of arbitrary shape can be treated as a stack of layers with varying transmission. The figure is not drawn to scale, in order to show the structure clearly. A spherical particle in the mask can be approximated by circular discs*

- Step 1:** Compute the transmission of the l-th layer
- Step 2:** Compute the transmitted E.M. field
- Step 3:** Obtain the Fourier Tranf. of the E.M. field
- Step 4:** Propagate the field through the thickness d in the Fourier domain
- Step 5:** obtain the diffracted E.M. field by inverse FFT
- Step 6:** go to next layer



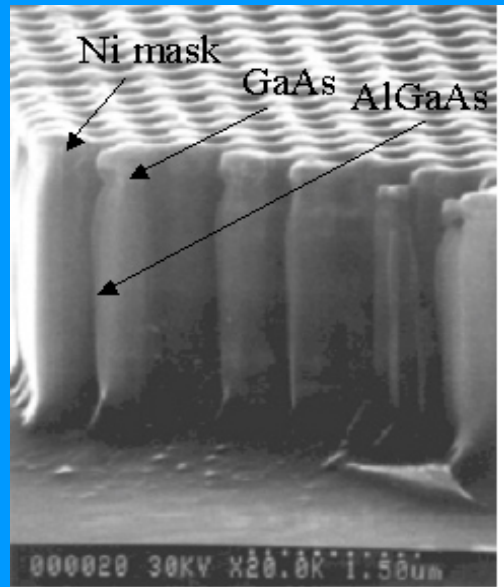
1:1 XRL for 2D GaAs/AlGaAs PC

XRL Mask



Replica

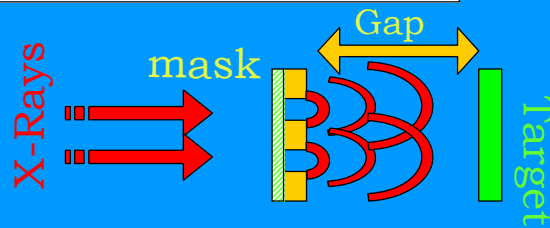
Etched sample



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Diffraction, partial-coherence and lithography

Calculated coherence length for Lilit beam line (Van Cittert Zernicke theorem) ~ **10µm**

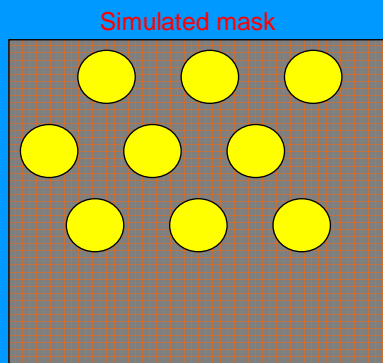


Dot distance=**400nm**

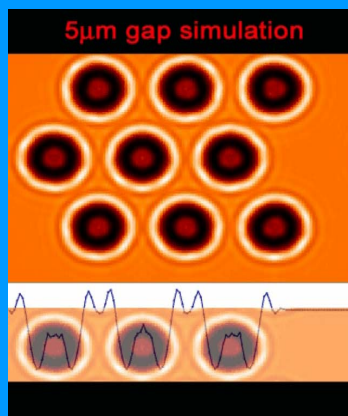
At LILIT:

$$l_c = \frac{\lambda^2}{2\Delta\lambda} \approx 5nm$$

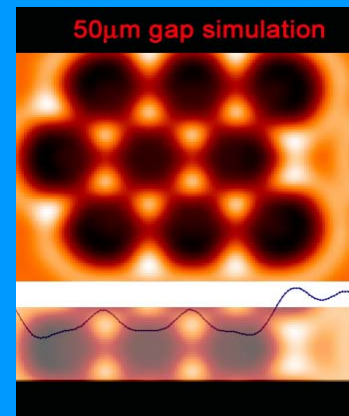
$$l_c^{spatial} = \frac{\lambda}{2\pi} \frac{L}{S} \approx 10\mu m$$



Simulated mask



5µm gap simulation

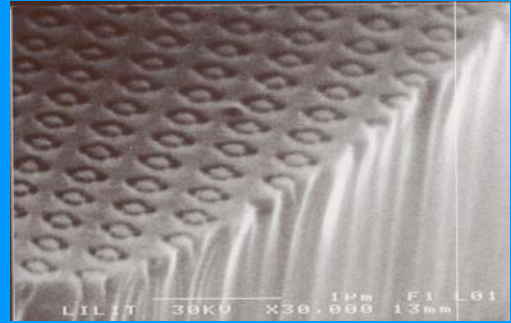
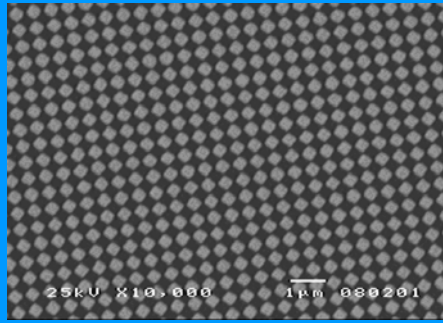


50µm gap simulation

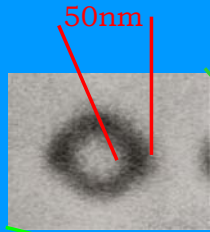
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Experimental results: unconventional base

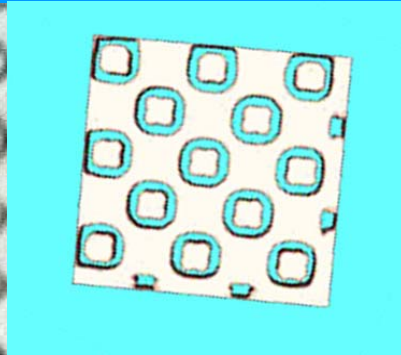
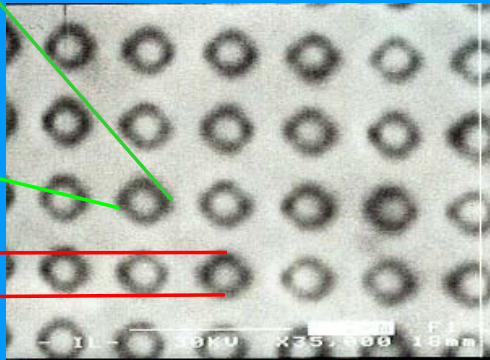
XRL Mask



Gap=0µm



250nm



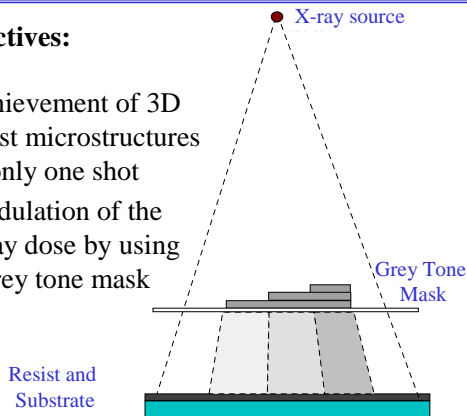
Gap=7µm

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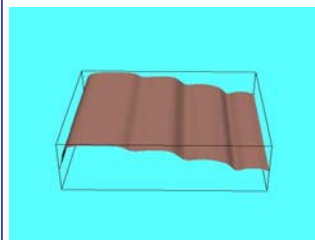
INTRODUCTION

Objectives:

- Achievement of 3D resist microstructures in only one shot
- Modulation of the x-ray dose by using a grey tone mask



Simulation of illumination effect

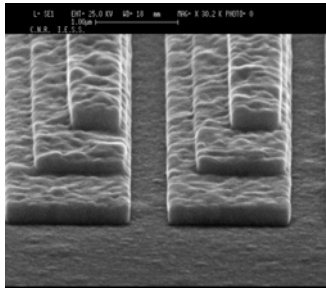


By computer simulation, we obtain this shape for the developed resist exposed by the x-rays passing through the described mask

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MASK FABRICATION

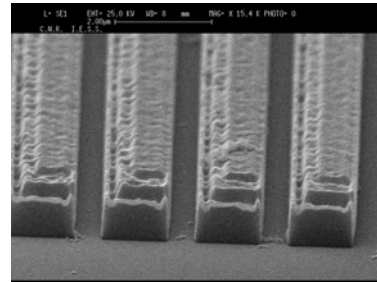
Picture of the mask



3	240 nm
2	170 nm
1	220 nm

X-RAY EXPOSURES

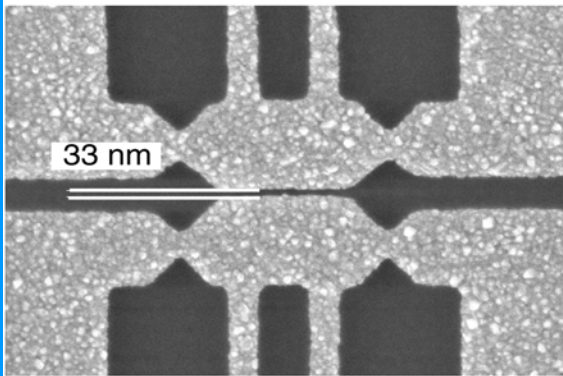
SEM image of 3D shaped resist
dose of 7000 mJ/cm², and gap of 13 μm.



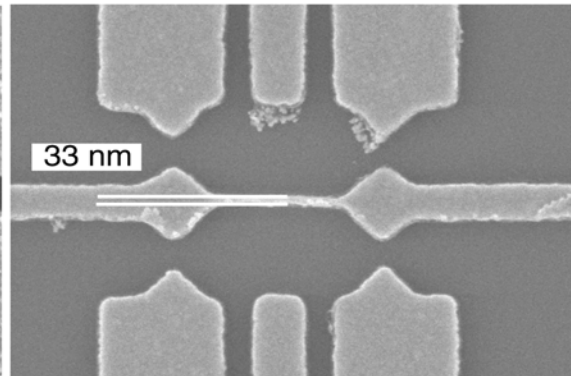
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Structures produced with X-ray litho.

X-ray Mask



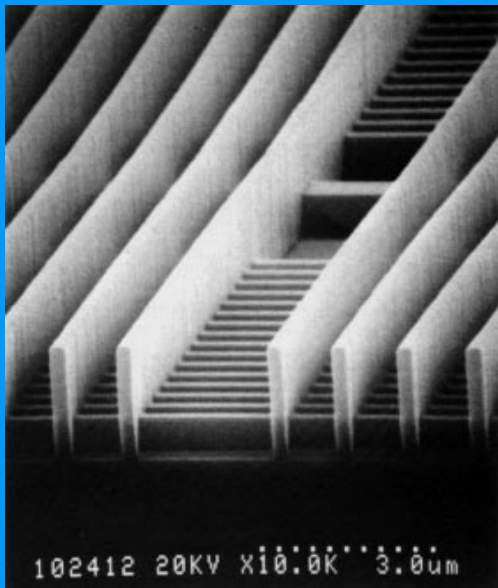
X-ray Replication
& Liftoff (Ti/Au)



Device patterns with feature sizes less than 40 nm achieved by x-ray lithography and by liftoff.

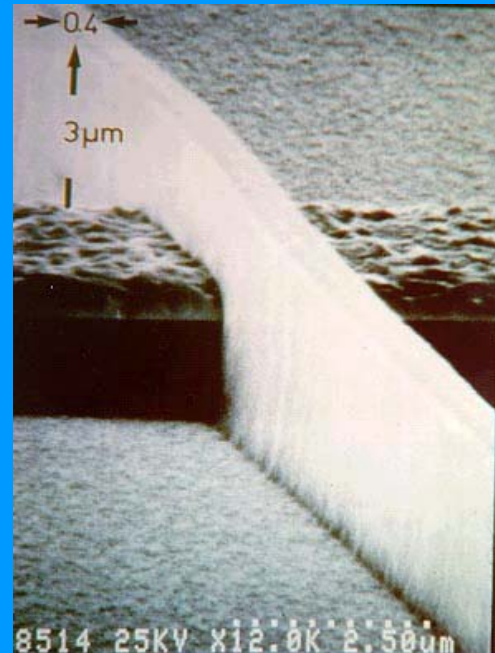
More ? Check out Prof. H. I. Smith, MIT
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Structures produced with X-ray litho. (ctnd.)



200 nm lines of 2 um thick resist over thick steps (NTT-AT)

Source: SAL, Inc.



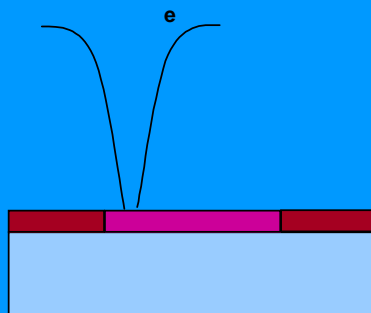
400 nm by 3 um resist over poly line (ISiT)

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Electron beam lithography



1) Casting of thin PMMA film



2) E-beam patterning of PMMA



3) Development of PMMA



4) Metallization



5) Lift-off

Employs a beam of electron instead of photons

Advantage: resolution and direct writing method

Disadvantage: Slow throughput

More ? [Google it !](#)

Also, check out R.F.W. Pease, Stanford

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Electron-Beam nanolithography systems Installed in Pirelli Labs-Milan

Developed further to the needs of micro-electronics industry, electron-beams are systems able to impress a thin layer of photosensitive material (photoresist) with a resolution orders of magnitude higher than that achieved by optical methods



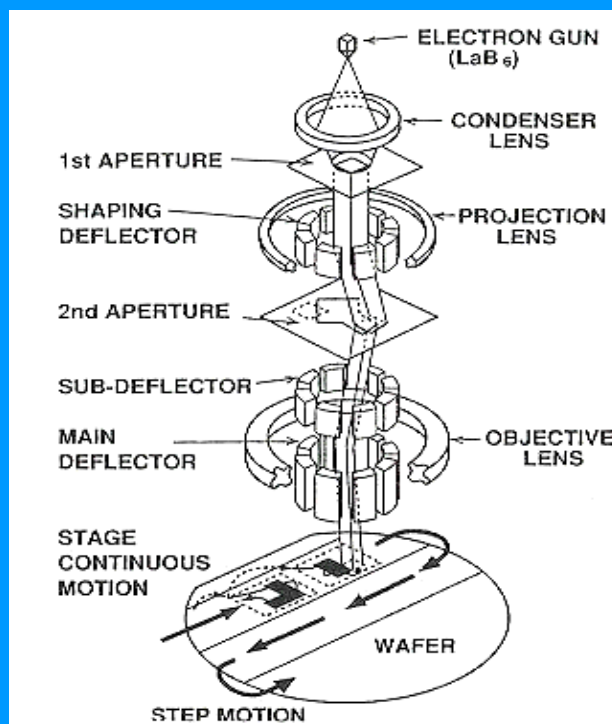
Typical parameters of operation:

- spot size of the beam: 5nm
- resolution: 15nm (conservative)
- size of the wafer: 8", 12" standard, larger sizes developed for semiconductor industry

Typical e-beam system used in the production (Leica VB6 HR type)

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Electron beam lithography system



Throughput enhanced by variable beam shaping

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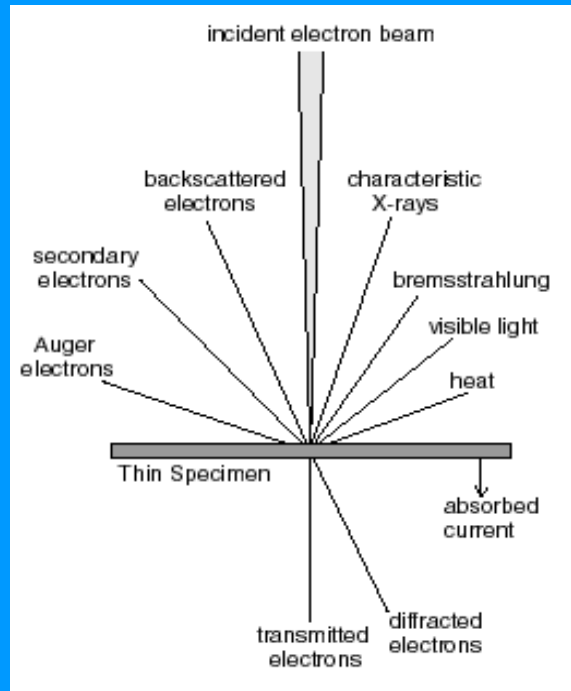
Effects produced by electron bombardment of a material.

Two major factors control which effects can be detected from the interaction

volume. **First**, some effects **are not produced from certain parts** of the interaction volume (Figure 2.1b).

Beam electrons lose energy as they traverse the sample due to interactions with it and if too much energy is required to produce an effect, it will not be possible to produce it from deeper portions of the volume. **Second**, the degree to which an effect, once produced, can be observed is controlled by how strongly it is diminished by absorption and scattering in the sample.

For example, although **secondary and Auger electrons** are produced throughout the interaction volume, **they have very low energies** and can only escape from a thin layer near the sample's surface. Similarly, **soft X-rays, which are absorbed more easily than hard X-rays**, will escape more readily from the upper portions of the interaction volume. Absorption is an important phenomenon and is discussed in more detail below.



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Interaction volumes

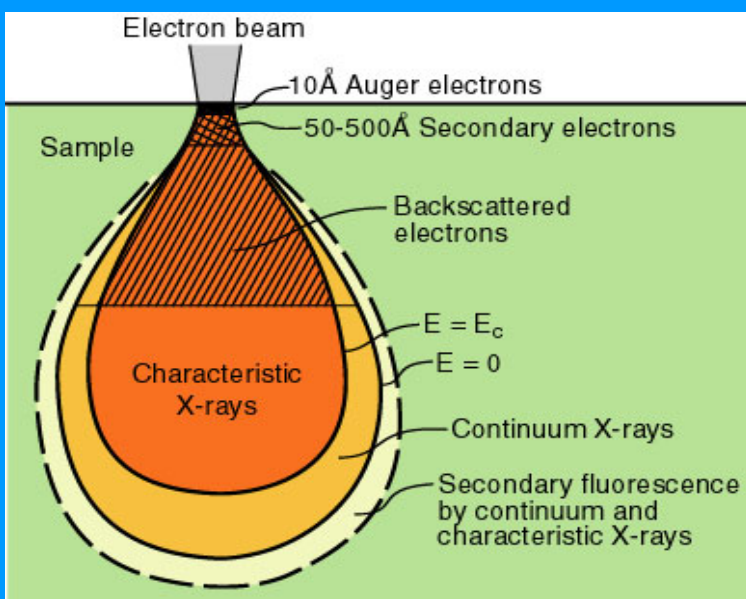


Figure 2.1b. Generalized illustration of interaction volumes for various electron-specimen interactions. Auger electrons (not shown) emerge from a very thin region of the sample surface (maximum depth about 50 Å) than do secondary electrons (50-500 Å).

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Volume of Excitation

Two factors limit the size and shape of the interaction volume: (1) energy loss through inelastic interactions and (2) electron loss or backscattering through elastic interactions. The resulting excitation volume is a hemispherical to jug-shaped region with the neck of jug at the specimen surface. The analyst must remember that the interaction volume penetrates a significant depth into the sample and avoid edges where it may penetrate overlapping materials. The depth of electron penetration of an electron beam and the volume of sample with which it interacts are a function of its angle of incidence, the magnitude of its current, the accelerating voltage, and the average atomic number (Z) of the sample. Of these, accelerating voltage and density play the largest roles in determining the depth of electron interaction (Figure 2.2a).

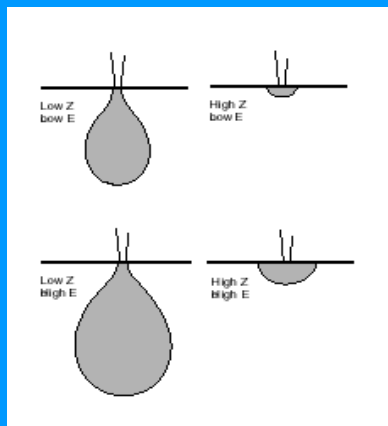


Figure 2.2a. Schematic depiction of the variation of **interaction volume shape** with average sample atomic number (Z) and electron beam accelerating voltage (E_0). The actual shape of the interaction volume is not as long-necked since the electron beam in microprobe analysis has a diameter of about 1 μm (see Figure 2.1b).

$$x (\mu\text{m}) = \frac{0.1 E_0^{1.5}}{\rho}$$

where E_0 = accelerating voltage (keV),
and ρ = density (g/cm^3)

Electron penetration generally ranges from 1-5 μm with the beam incident perpendicular to the sample. **The depth of electron penetration is approximately** (Potts, 1987, p. 336):

For example, bombarding a material with a density of 2.5 g/cm^3 , about the minimum density for silicate minerals, with $E_0 = 15$ keV, gives $x = 2.3$ μm . The width of the excited volume can be approximated by (Potts, 1987, p. 337):

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Both of these are empirical expressions. A theoretical expression for the "**range**" of an electron, the straight line distance between where an electron enters and its final resting place, for a given E_0 is (Kanaya & Okayama, 1972):

The volume of interaction can be modeled by Monte Carlo simulation. In such models, the likelihood of incident electrons interacting with the sample and scattering and the angle of deflection are determined probabilistically. X-ray generation depths depend strongly on density and accelerating voltage (Figure 2.2b.). The results derived from Monte Carlo modeling yield a volume of interaction that is very similar to that determined by etching experiments. The excited volume is roughly spherical and truncated by the specimen surface. The depth of the center of the sphere decreases with increasing atomic number of the target.

$$y (\mu\text{m}) = \frac{0.077 E_0^{1.5}}{\rho}$$

where E_0 = accelerating voltage (keV),
and ρ = density (g/cm^3)

$$r (\mu\text{m}) = \frac{2.76 \times 10^{-2} A E_0^{1.67}}{\rho Z^{0.89}}$$

where ρ = density of the material (g/cm^3),
 Z = atomic number,
 A = atomic mass,
and E_0 = accelerating voltage.

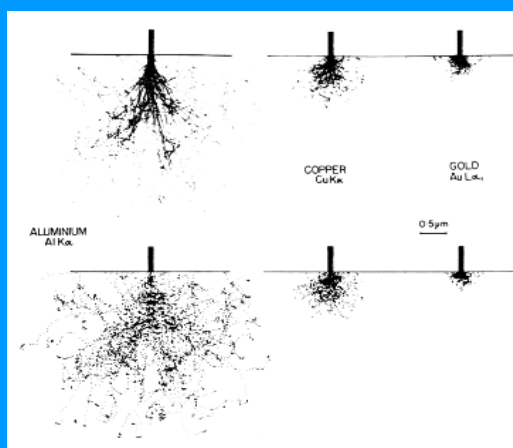


Figure 2.2b. Comparison of electron paths (top) and sites of X-ray excitation (bottom) in targets of aluminum, copper, and gold at 20 keV, simulated in a Monte Carlo procedure (after Heinrich, 1981).

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PEC (Proximity Effect Correction)

a. Dose Distribution due to PE

G (x) EID (Exposure Intensity Distribution) function

(Dose distribution of EB resist at one point (x=0) irradiation)

$$g(\mathbf{x}) = C \{g_f(\mathbf{x}) + \eta_E g_b(\mathbf{x})\}, \quad (1)$$

$$g_f(\mathbf{x}) = (1/\pi \sigma_f^2) \exp \{-(\mathbf{x} - \mathbf{x}')^2 / \sigma_f^2\} \quad (2)$$

$$g_b(\mathbf{x}) = (1/\pi \sigma_b^2) \exp \{-(\mathbf{x} - \mathbf{x}')^2 / \sigma_b^2\} \quad (3)$$

(Parameter)

gf (x): Term for forward scattering electron (FSE)

gb (x): Term for backward scattering electron (BSE)

ηE: gf (x)/gb (x)

σ f f: Forward scattering coefficient

: Backward scattering coefficient

C: Constant

(Factor for parameter)

1. Material of substrate

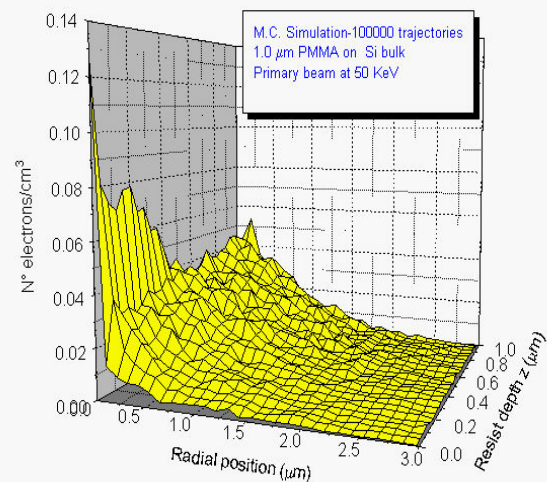
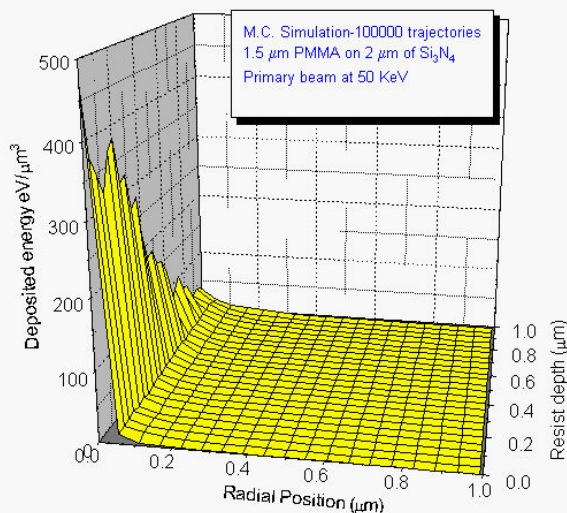
2. Acceleration voltage

3. Resist material

4. Resist thickness

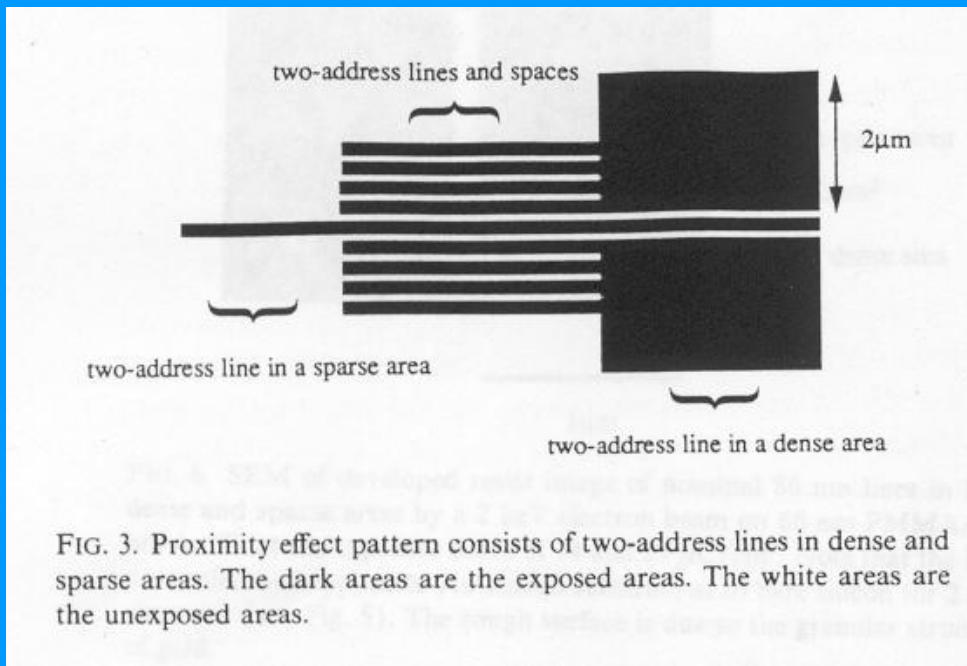
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EBL - Electron-Solid interaction



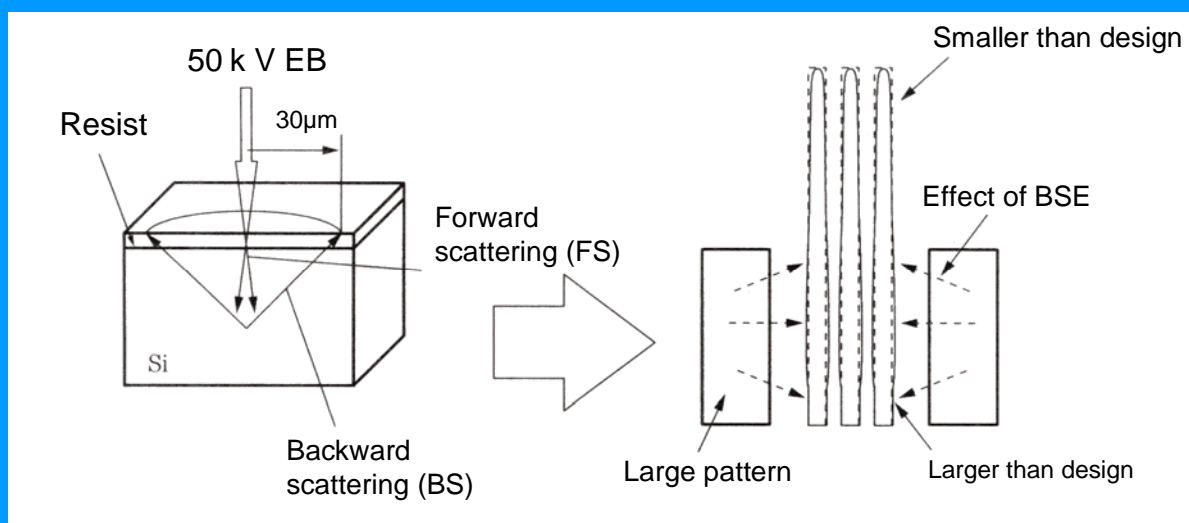
$$I = AD \quad a_{ij} \propto \int_{A_i} \int_{A_j} f(r_{ij}) dA_i dA_j$$

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Cause of Proximity Effect



(a) Electron scattering (b) Pattern size change caused by BSE from peripheral patterns

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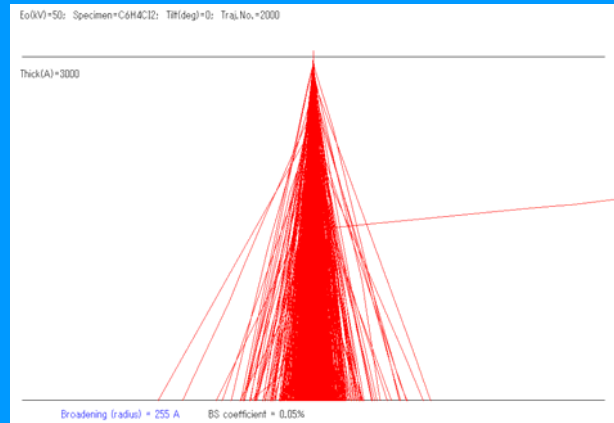
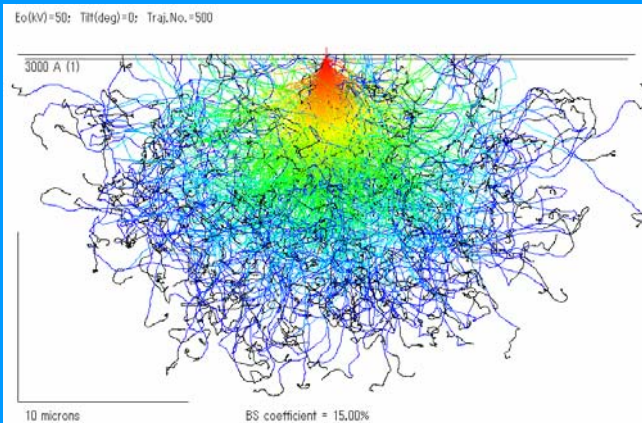
Simulation for Incident Electron trajectories

**Vacc:50kV , Substrate: Si Wafer ,
300nm**

Resist Thickness :

Resist + Substrate

Resist Part Enlargement



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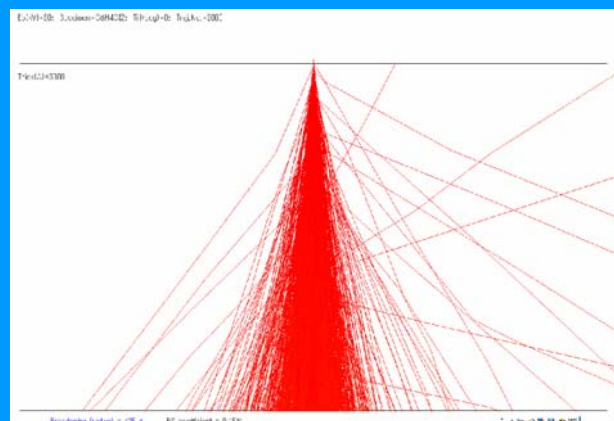
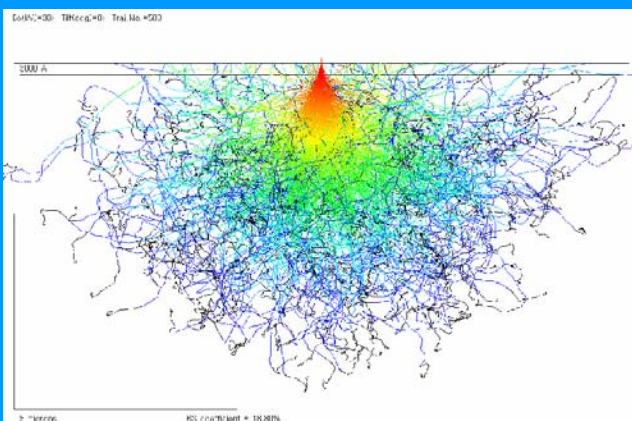
Simulation for Incident Electron trajectory

**Vacc:30kV , Substrate:Si Wafer ,
300nm**

Resist Thickness :

Resist + Substrate

Resist Part Enlargement



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Dose Distribution (DD) Simulation

* Resist dose amount at X in case of irradiating pattern A

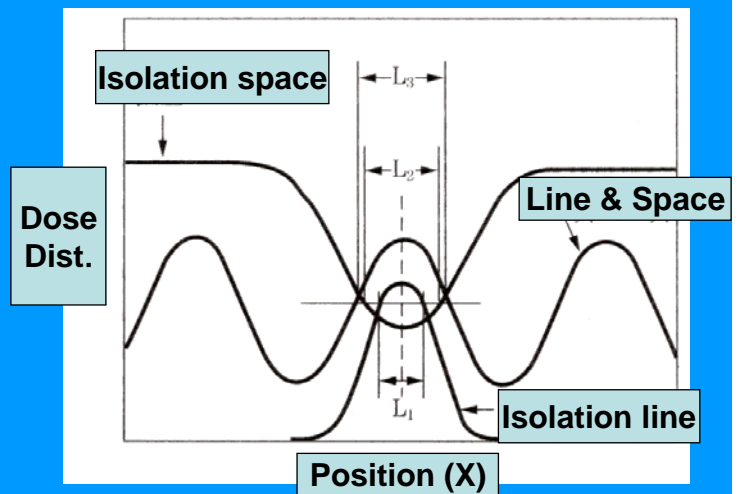
$$E(x) = \int_{X \in A} D(x') g(x-x') dx'$$

When,

Integration: area A irradiated by EB

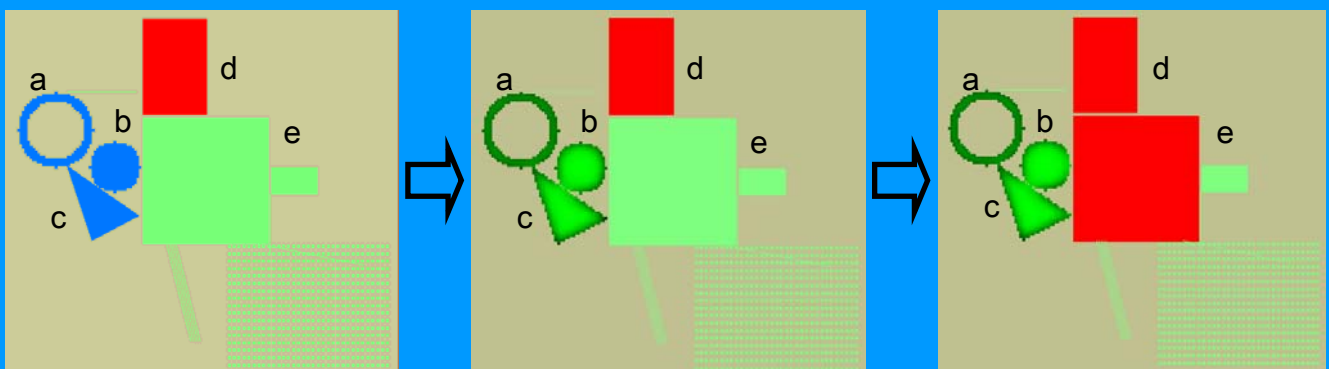
D(x'): Irradiation amount at x'

* Pattern dependence of resist dose amount



Dose distribution changes due to pattern density.

Dose Distribution (DD) Simulation (2)

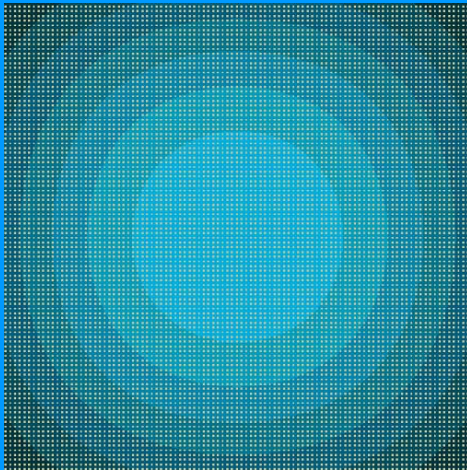


■ : E B uniform irradiation
■ : E B uniform irradiation

DD of a,b,c change due to EB irradiation at d.

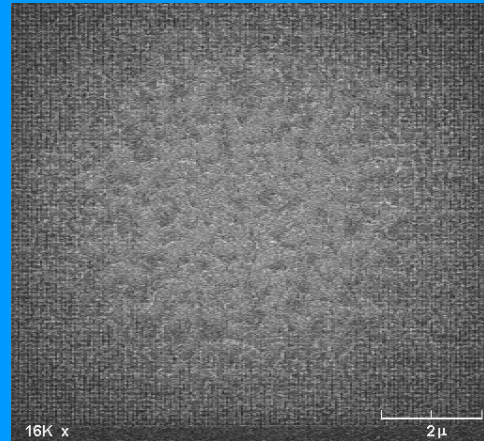
DD of a,b,c change again due to EB irradiation at e.

Dose Distribution Simulation vs Writing Result



(Simulation parameter)

Backward scattering coeffi. : $3\mu\text{m}$



(Writing cond)

Vacc : 30kv,

Field size : $500\mu\text{m}^2$

Dose Time :

$6.25\mu\text{sec/dot} \times 0.6$

Pattern : 50 nm L&S lattice

(Double exposures at cross points)

Writing area :

$10\mu\text{m}^2$, Resist : ZEP520

Resist thickness :

300nm

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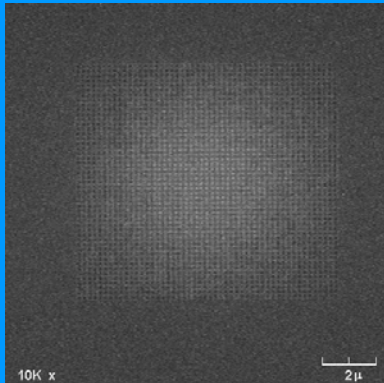
Main PEC Methods

- 1. Irradiation Correction:** To adjust irradiation amount every position
- 2. Ghost :** To suppress dose amount change by carrying out additional irradiation
- 3. Pattern Shape Correction:** To change in advance pattern size in view of affect of peripheral patterns

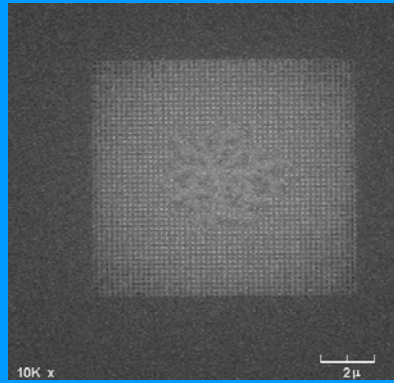
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Proximity Effect for 100nm L&S Lattice

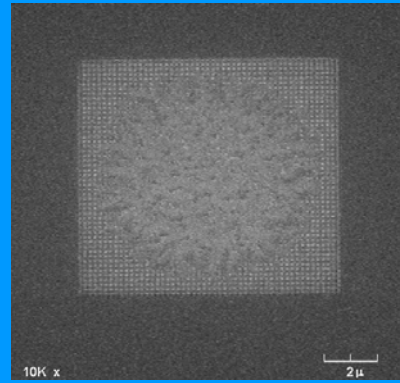
45% Nominal dose



50% Nominal dose



55% Nominal

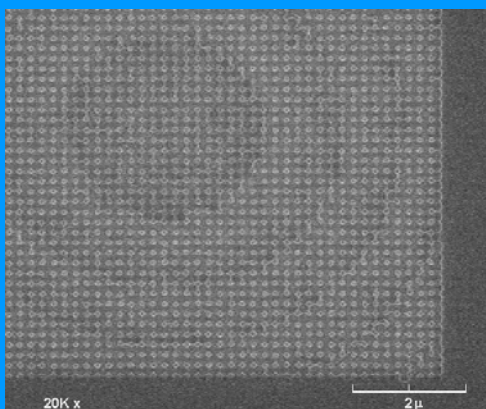


(Writing conditions)

Vacc:	30kV	Nominal Dose:	50 μ C/cm ² (6.25 μ sec/dot)
Field Size:	500 μ m	Resist:	ZEP520
Writing Area:	10 μ m	Resist Thickness:	300nm
Cross Point:	Double exposure		

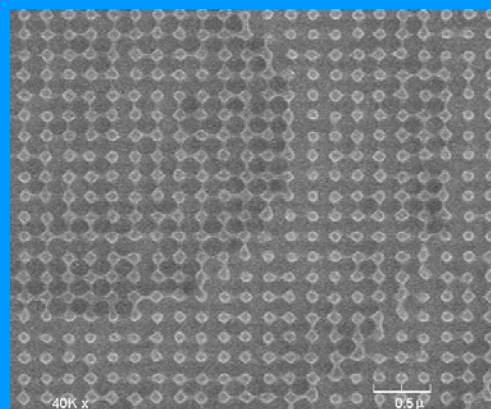
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PEC(Proximity Effect Correction) for 100nm L&S Lattice



(Writing Conditions)

Vacc:	30kV
Field Size:	500 μ m
Writing Area:	10 μ m
Resist / Thickness:	ZEP520/300nm
Pixel:	20,000 x 20,000 dot
I B:	50pA

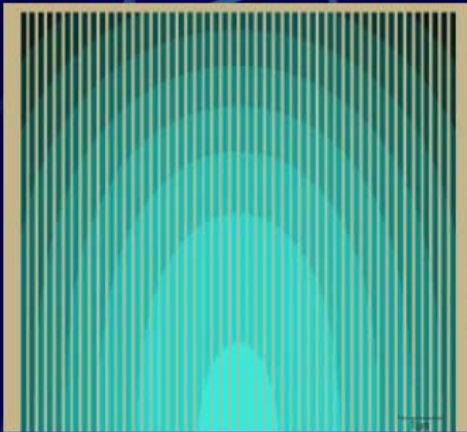


(PEC Conditions)

PEC:	Irradiation amount correction
Correction Amount:	5 stage corr. as base of nominal dose on basis of simulation result
Nominal Dose:	50 μ C/cm ² (6.25 μ sec/dot)

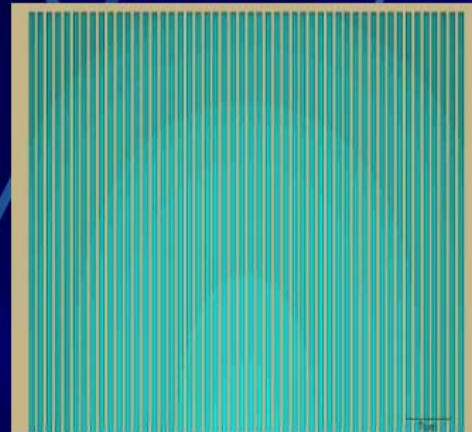
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DDS for L/S



Backward scattering only:

$$\sigma_b = 5\mu\text{m}, \eta = 0.75.$$

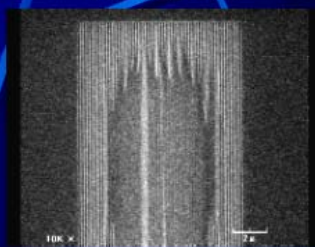


Forward and backward scattering:

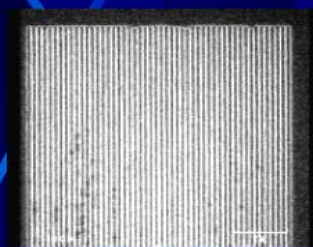
$$\sigma_f = 30\text{nm}, \sigma_b = 5\mu\text{m}, \eta = 0.75.$$

PEC result for L/S

Before PEC



After PEC



(condition) 30kV, 50pA, 500 μm sq, L/S=125/75 nm on Si

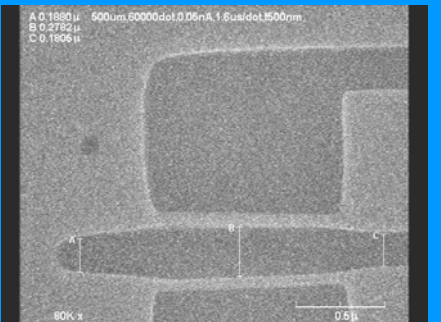
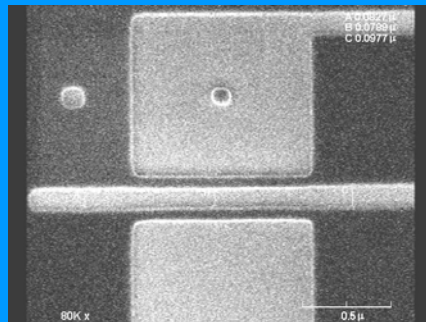
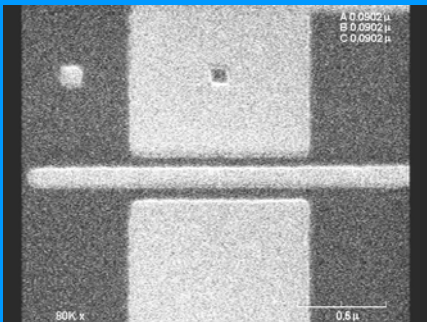
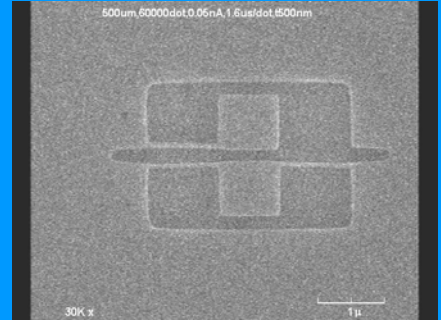
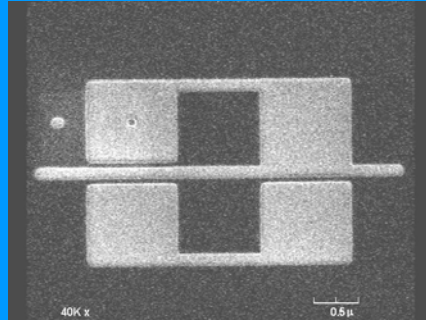
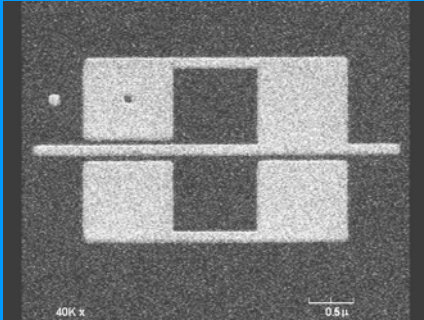
L 50 μm \times W 10 μm , 20,000 dot, ZEP520-300nm

Resist Thickness Dependence of Proximity Effect

Resist Thickness: 50nm

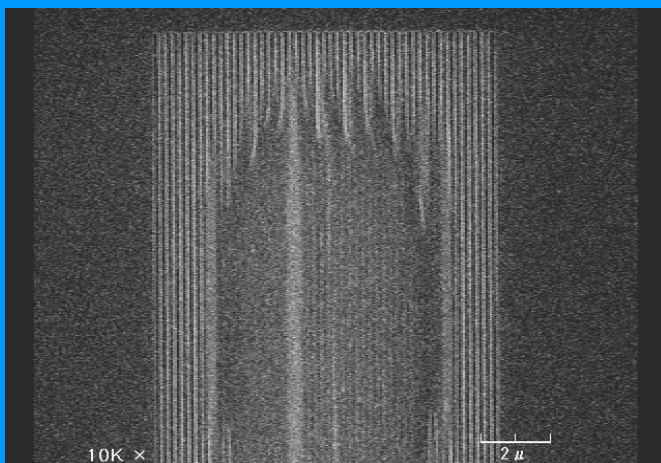
:100nm

:500nm



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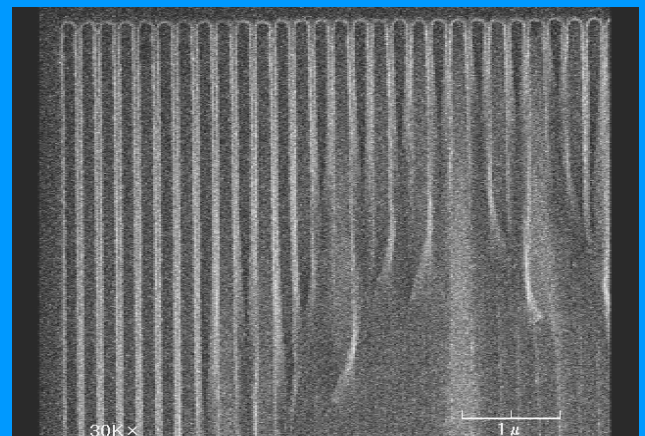
Without PE Correction



Pattern design:
500mm field, 20000dot
=Line 125nm/Space 75nm
Size: 50mm x10mm

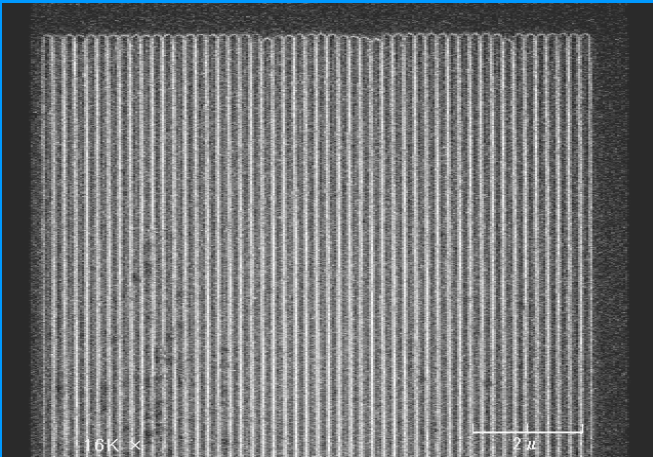
ZEP520 300nm thickness on Si sub.

e⁻ Beam = 30kV / 50pA

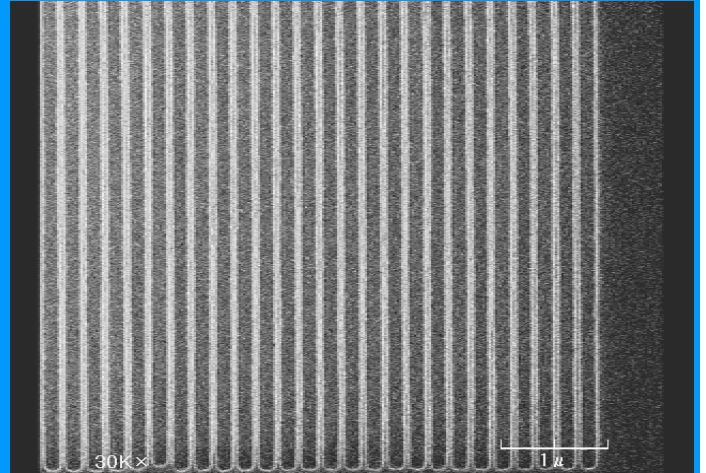


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With PEC Correction



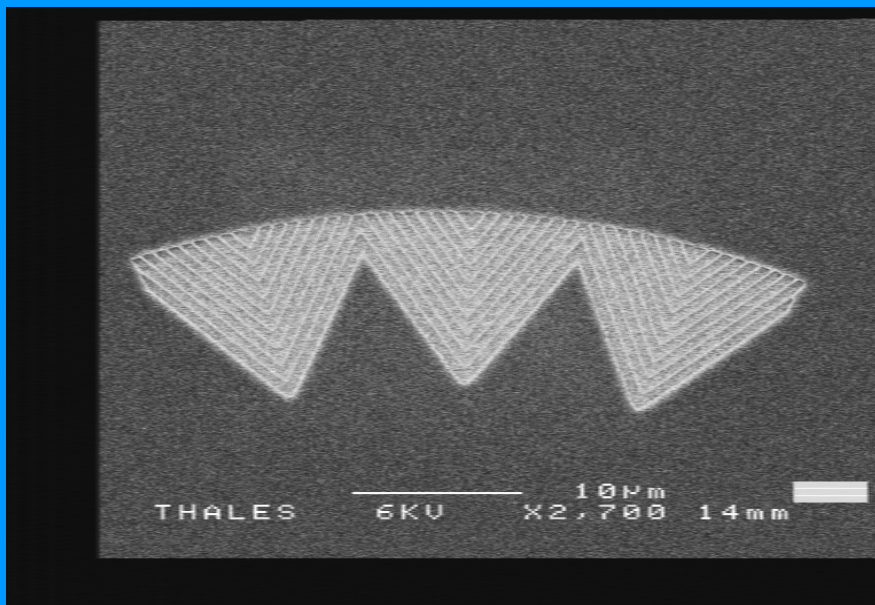
Collection point 2, connection 2/3,
quantization level 6



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Proximity Effect Correction

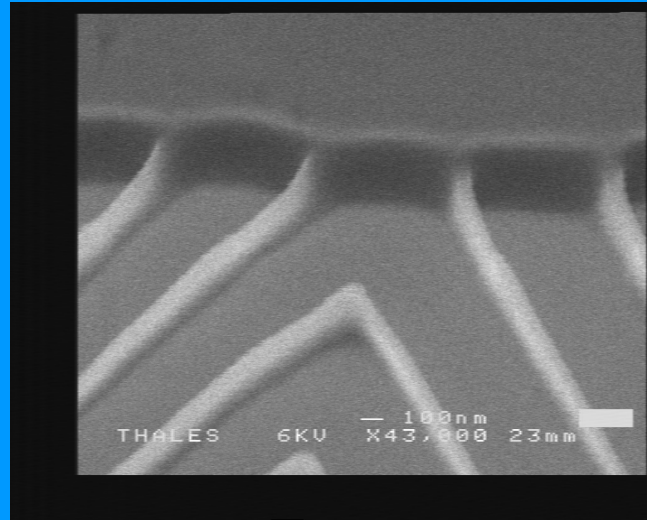
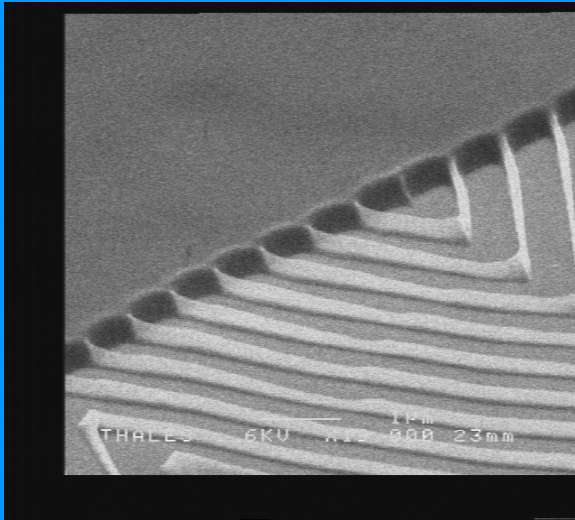
(Data supplied by Thales Research & Technology)



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Proximity Effect Correction

(Data supplied by Thales Research & Technology)

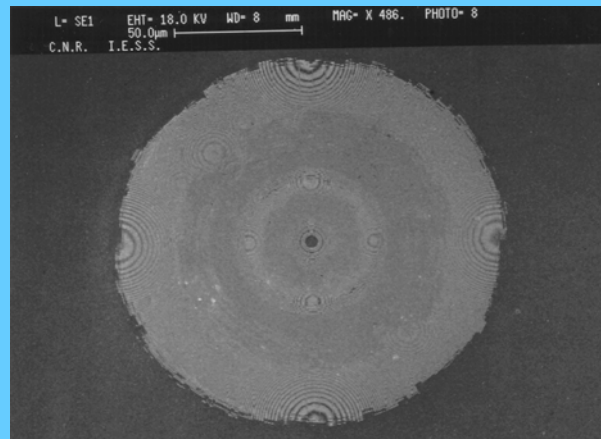


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With proximity correction



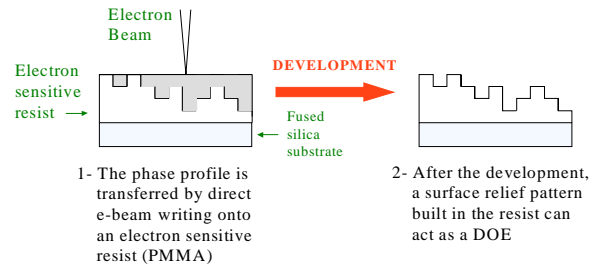
Without proximity correction



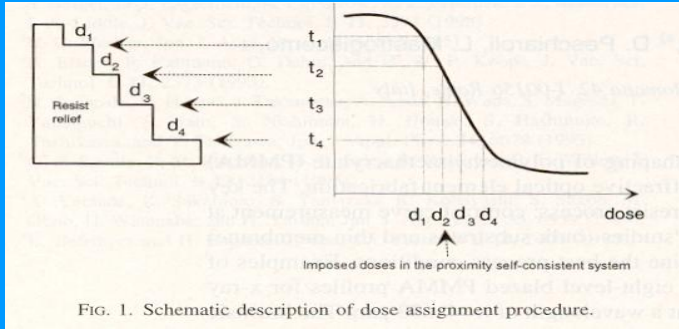
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Diffraction Optical Elements

The E-Beam Lithography fabrication process of 3D profiles for phase DOEs

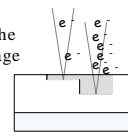


CNR-IIESS - μFab Group

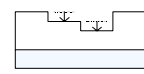


The key for a good DOE efficiency

The left resist thickness depends on the electron dosage absorbed per unit area



The DOE overall efficiency is high when every couple of consecutive levels has the same height difference

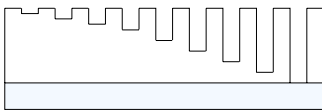


For a highly efficient resulting DOE, the electron dosages are to be assigned accurately, in order to achieve **equally spaced resist levels**

CNR-IIESS - μFab Group

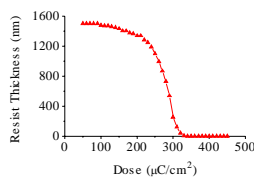
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The dose calibration



Resist pads are exposed at increasing electron dosages (the pad lateral size is larger than the electron backscattering range) → the exposure dosage is equal to the absorbed dosage

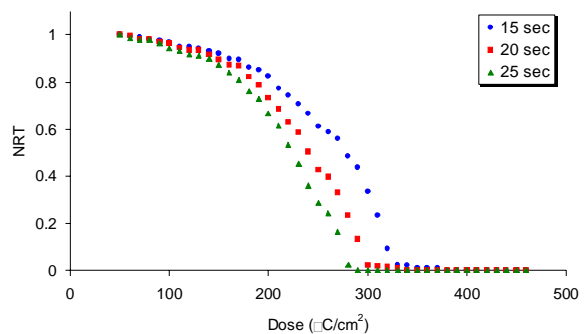
From the remaining resist thickness vs. absorbed dosage curve it is possible to interpolate the electron dosage values necessary to achieve determined resist thicknesses



CNR-IIESS - μFab Group

Continuous profiling

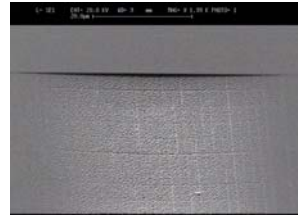
Normalized Resist Thickness vs. absorbed dosage curve obtained with MiBK-IPA 3:1



CNR-IIESS - μFab Group

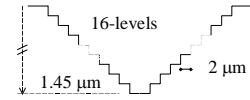
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Scanning Electron Microscope analysis

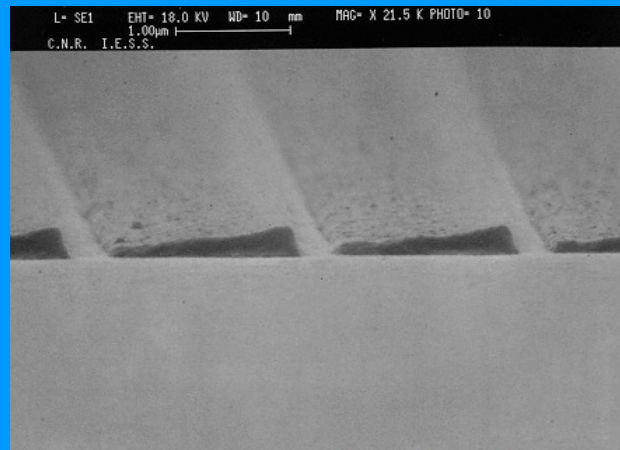


SEM image of a 16-level, 32 steps double ramp-shaped pattern.
Development: MiBK-IPA 3:1 for 20 sec.

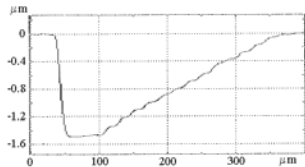
Expected profile



CNR-IESS - μFab Group



Testing the dose calibration on a practically realized multi-level profile



Profilometer measurements of the resist thickness performed on a 16-level ramp-shaped pattern.

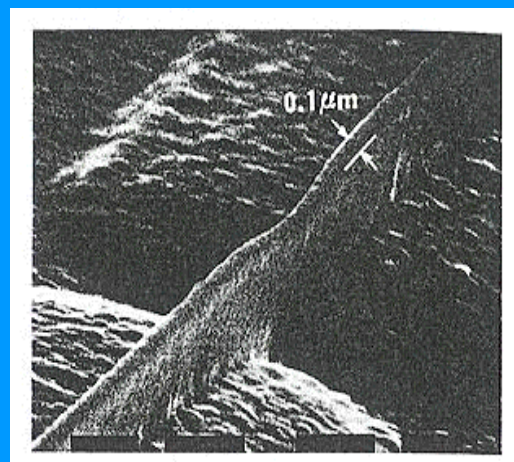
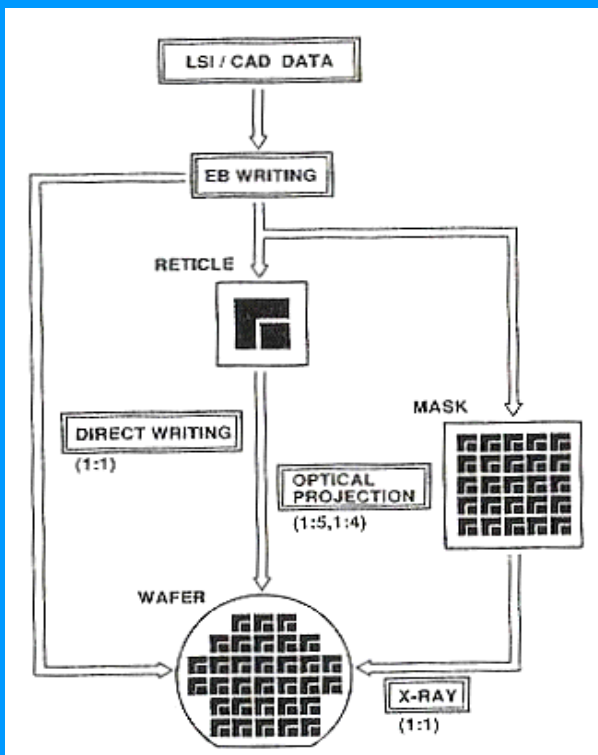
Development: MiBK-IPA 3:1 for 20 sec.

The step width is 20 μm and their mean height is ~100 nm.
The maximum resist height is 1.5 μm.

CNR-IESS - μFab Group

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Applications of electron beam lithography



Mainly employed for the fabrication of photomasks

Also used to write patterns directly on wafer

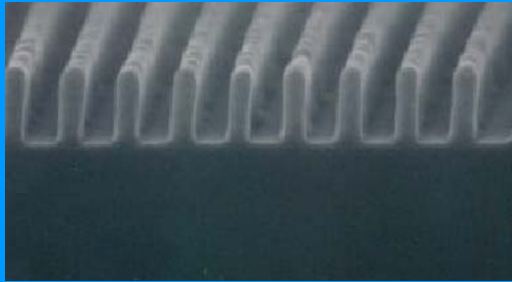
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L/S(Line & Space)Resist Pattern

HV : 30keV

Dose : 50 μ C/cm²

L/S = 50nm/70nm



L/S = 70nm/70nm



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L/S(Line & Space)Resist Pattern

HV : 50keV

Dose : 140 μ C/cm²

L = 50nm P = 100nm



L = 70nm P = 140nm



L = 90nm P = 200nm



L = 150nm P = 300nm

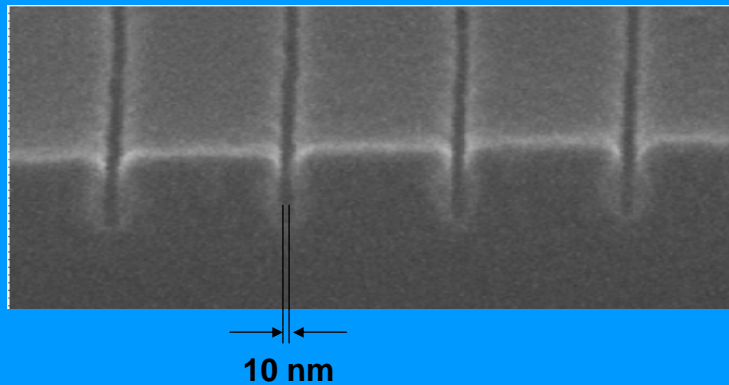


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10 nm Space Width Resist Pattern

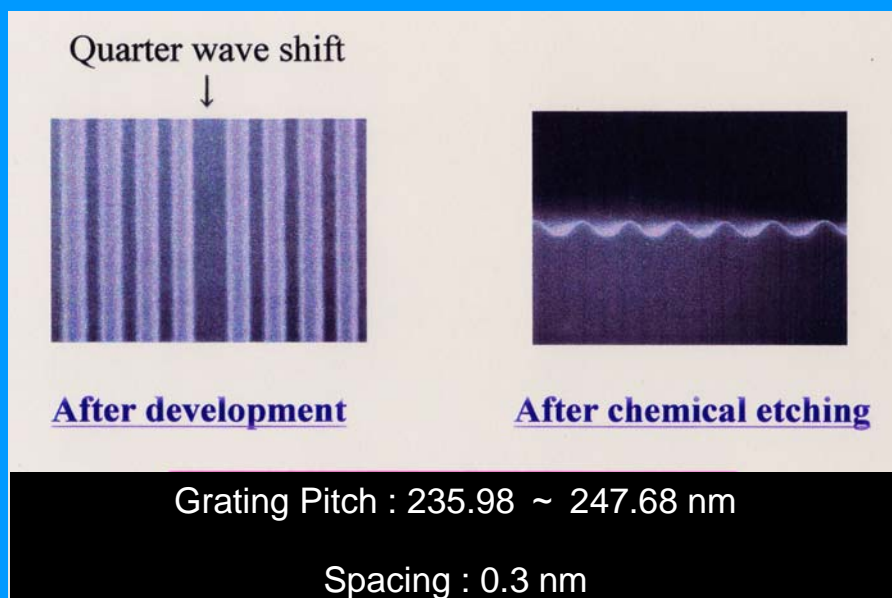
HV: 50kV

Resist : ZEP520



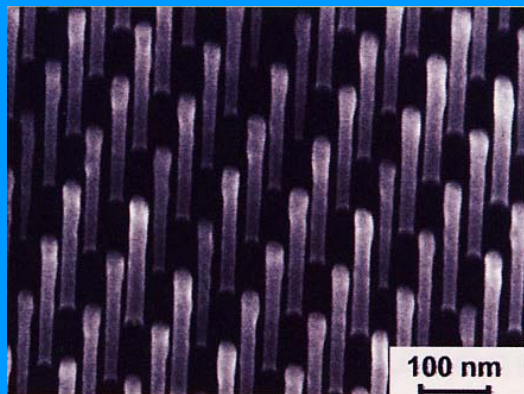
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Fabrication of Multi-Pitch Gratings

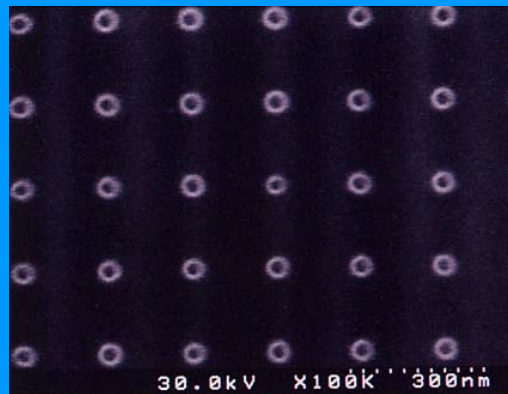


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Spot Scan Writing-Si Nanopillar for Photonic Crystal (by Spot Scan Writing)



Nano-pillar

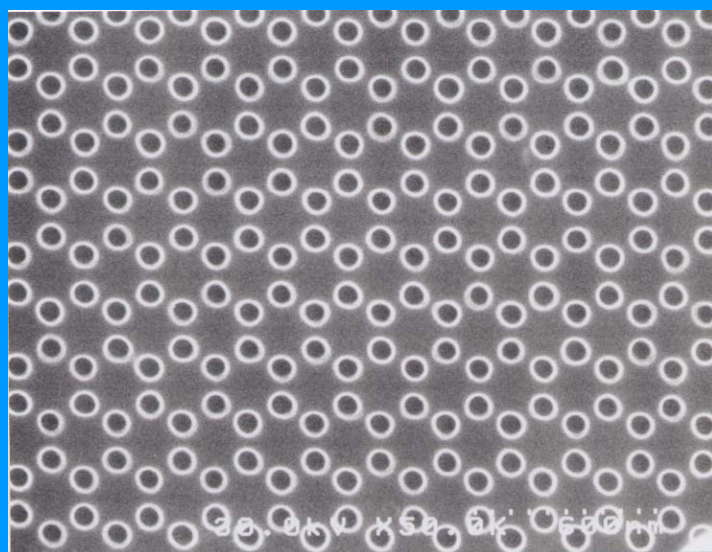


Dot array

The data supplied by Dr.T,Kanayama and Dr.T.Tada of JRCAT

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Hexagonal Grating (by Spot Scan Writing)



500 dots/100 μ m- length

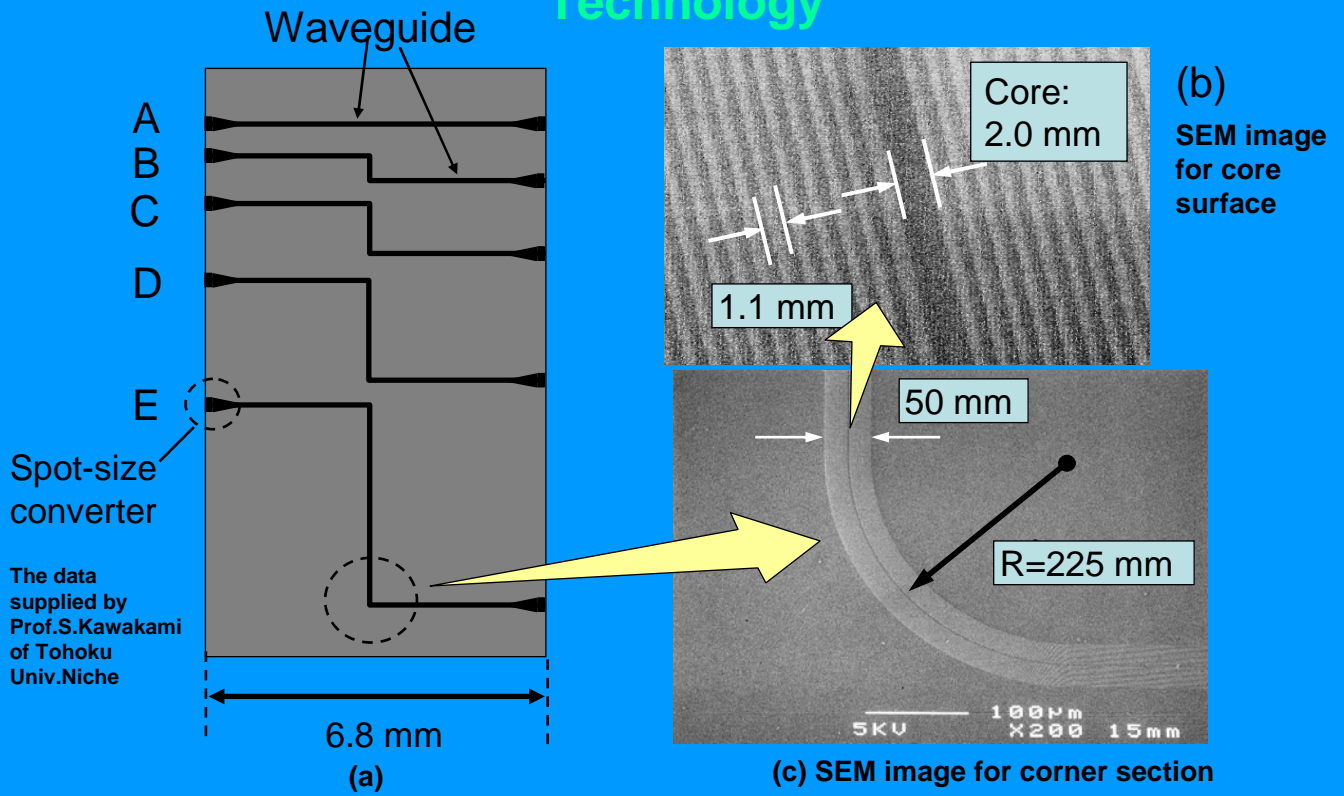
30kV

5×10^{-11} A

40 μ s/dot

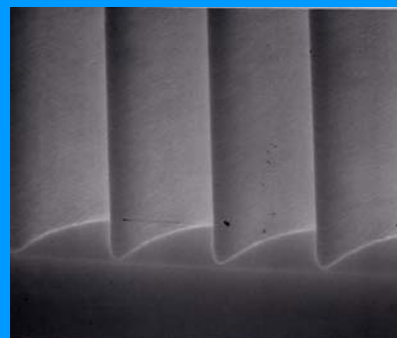
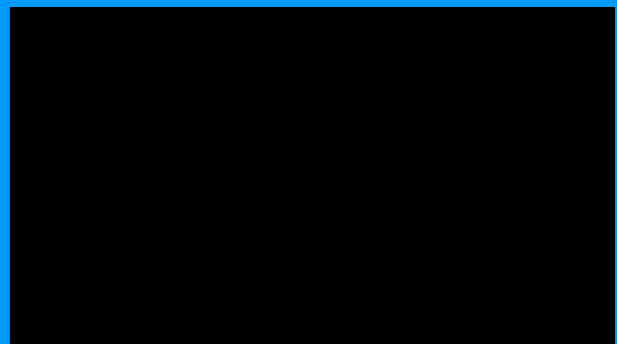
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Photonic Crystal Waveguides by the Autocloning Technology



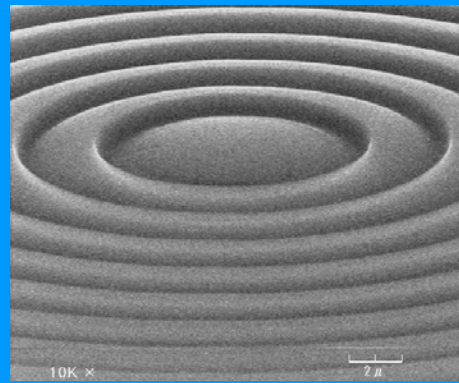
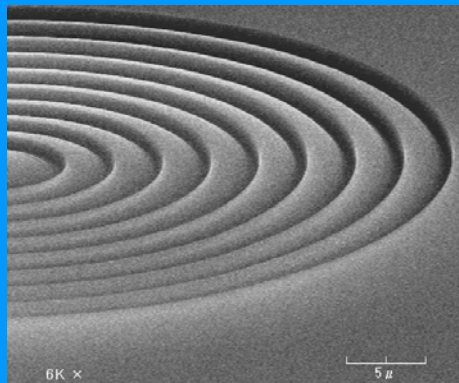
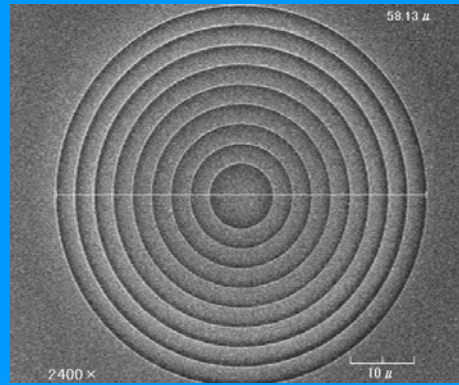
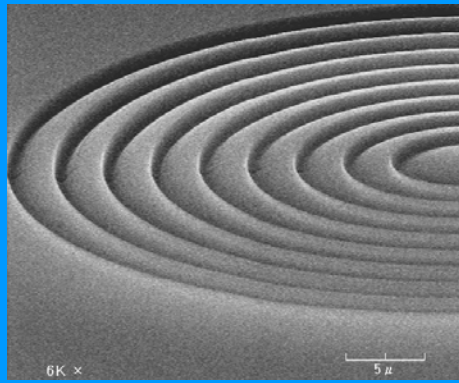
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Blazed Grating



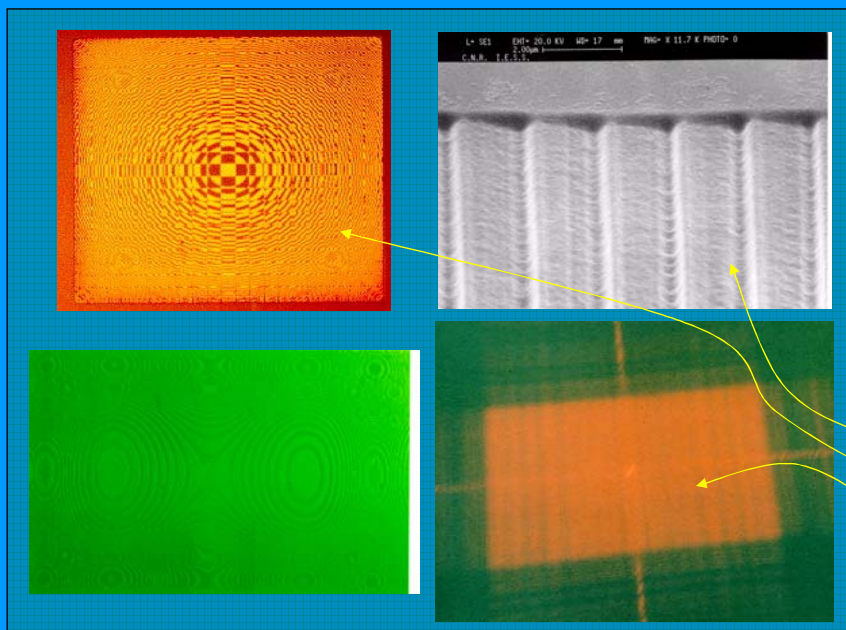
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3-D Concentric Circular Pattern



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Continuous profile holographic surfaces produced by e-beam methods

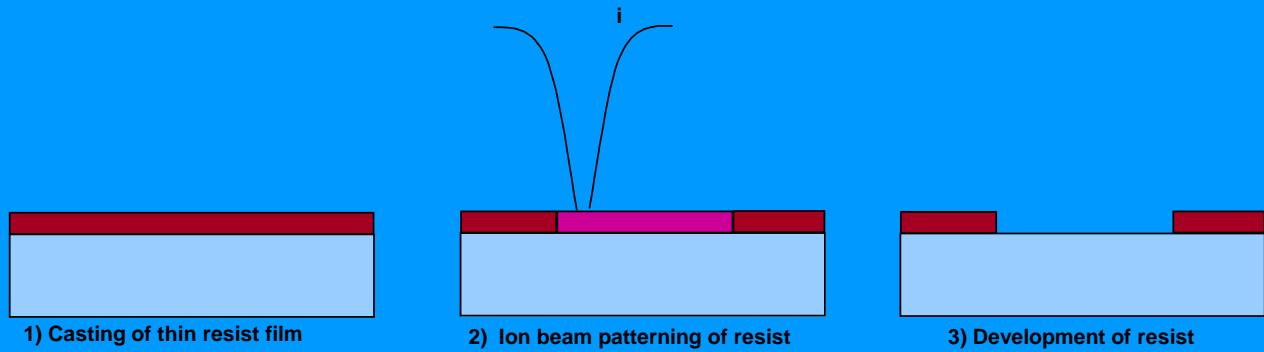


Continuous profile make it possible to design a wavefront transforming surface having the exact theoretical shape required to maximize efficiency.

- Continuous profile
- Overall pattern
- Uniform redistribution of laser light obtained by the innovative optical element

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Ion Beam Lithography



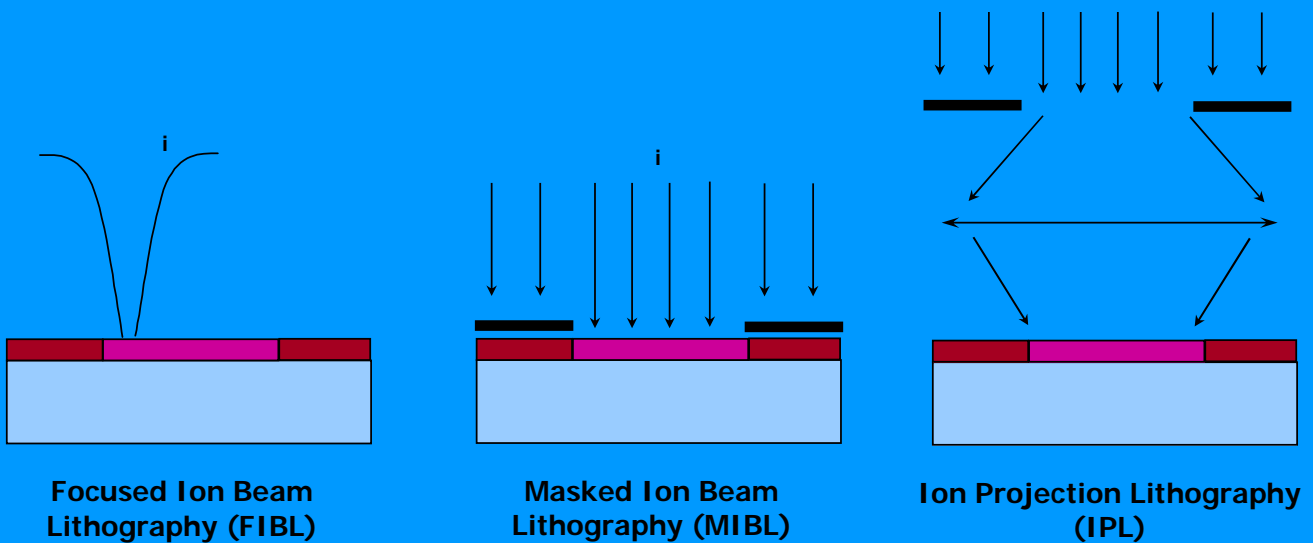
- Advantages of ion beams:

- Enhanced resists sensitivity
- Can be focused to narrower linewidth
- Reduced Scattering
- Allows hybrid processes such as ion-induced etching and implantation

[More ? Google it !](#)

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Ion beam lithography techniques



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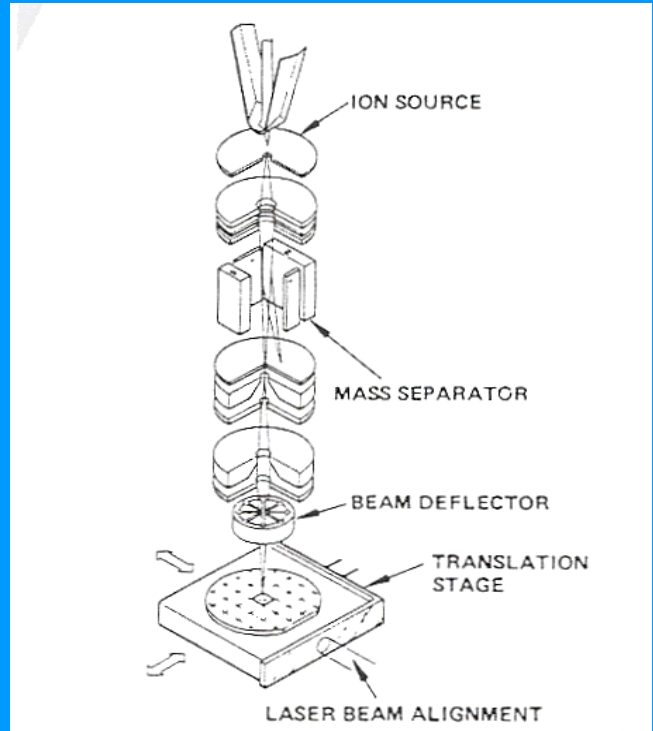
Focused Ion Beam Lithography

FIBL components:

- Ion source
- Ion optics column
- Sample displacement table

Specifications:

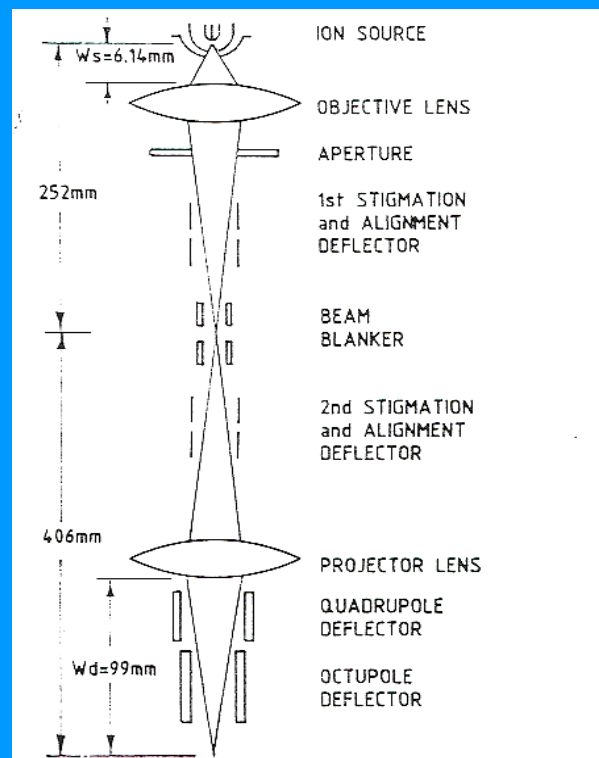
- Accelerating voltage 3-200 kV.
- Current density up to 10 A/cm².
- Beam diameter 0.5-1.0 μm.
- Ions: Ga⁺, Au⁺, Si⁺, Be⁺ etc.



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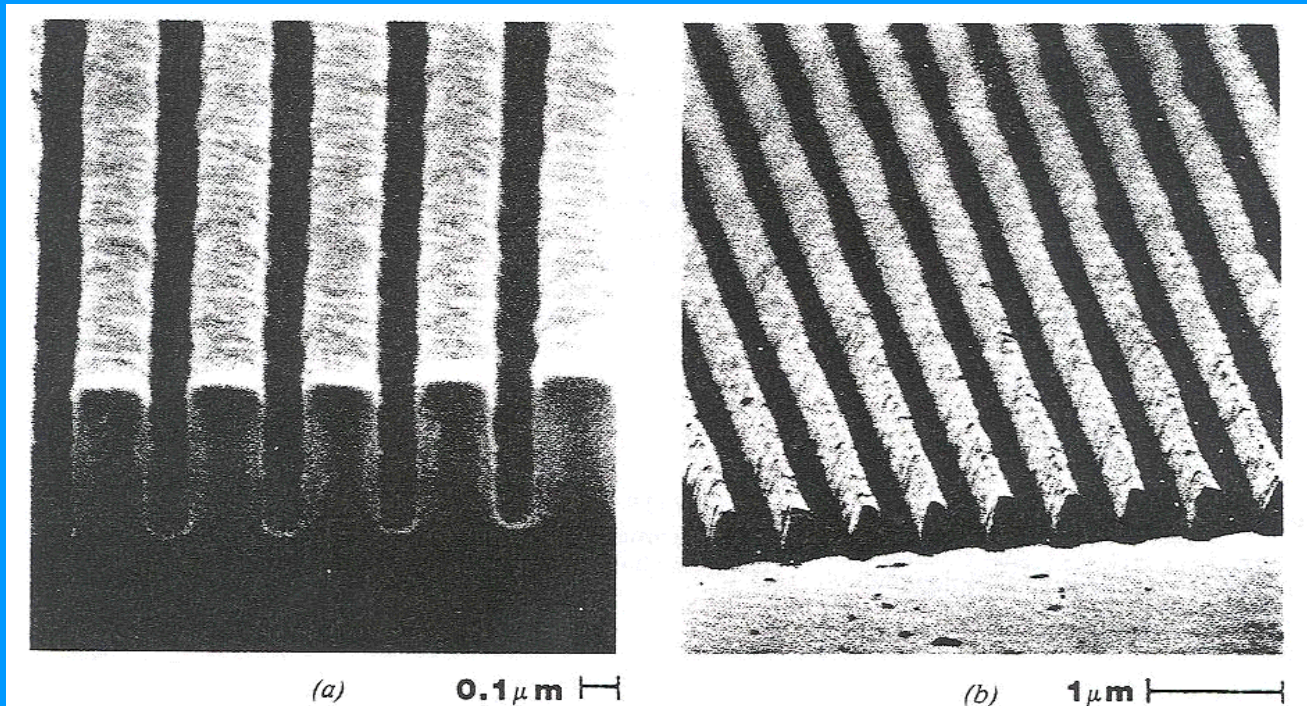
Ion optics

- Electrostatic lenses are employed due to large mass of ions
- Mass spectrometers are used to separate different species of ions



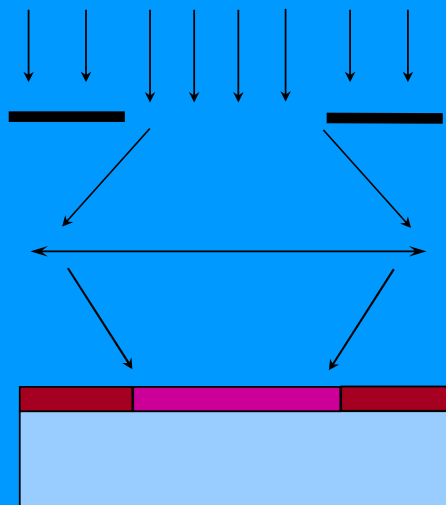
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FIB fabricated nanostructures

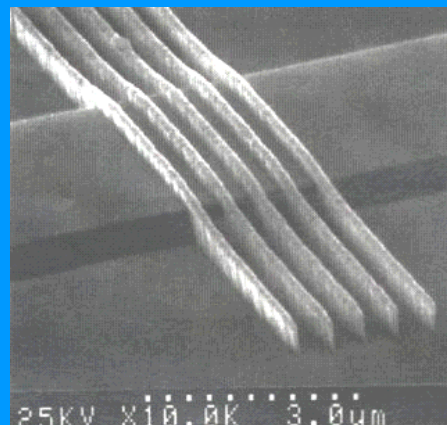
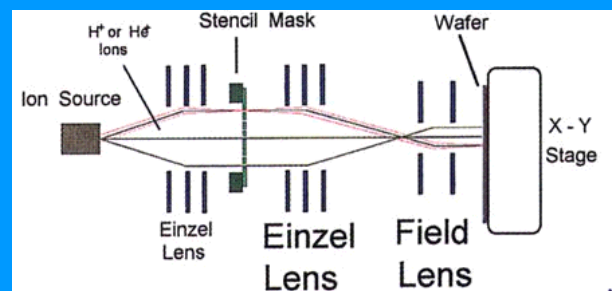


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Ion projection lithography



Ion Projection Lithography (IPL)



[Source: The Advanced Lithography Group](#)

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Alternate Nanolithography Techniques

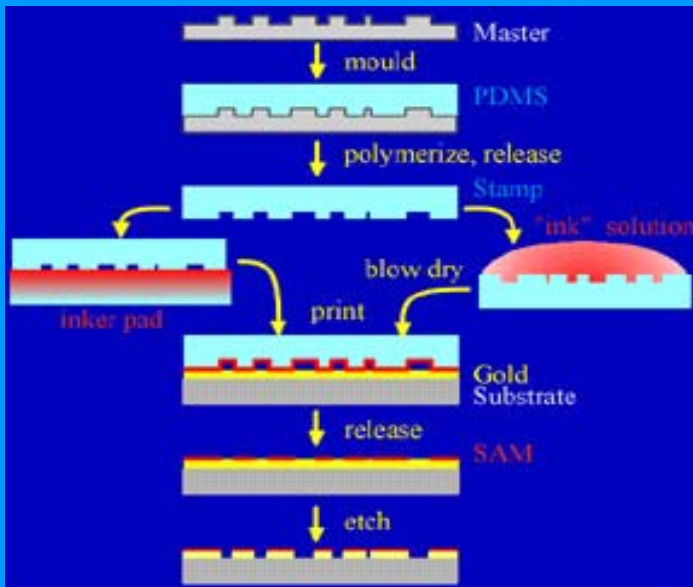
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Alternate Nanolithography Techniques

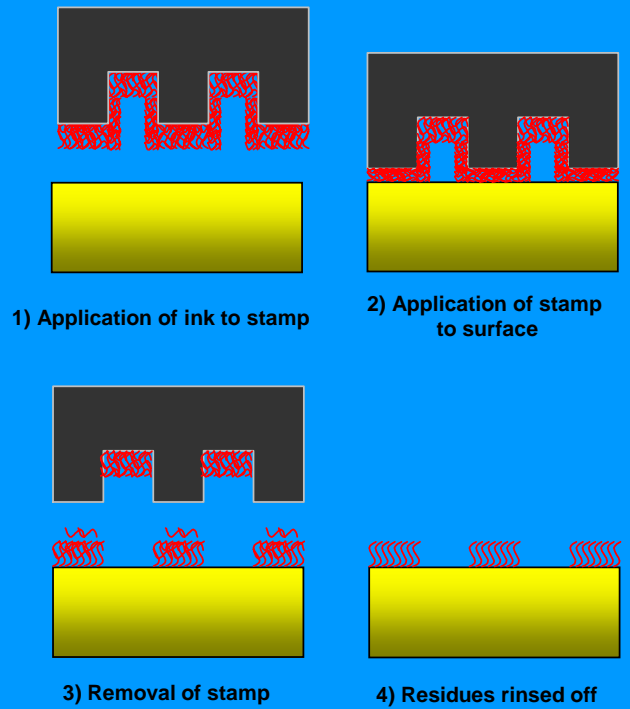
- Micro-contact Printing
- Nanoimprint Lithography
- Scanned Probe Lithography
- Dip-pen Lithography

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Micro-contact printing



Source: IBM Zurich



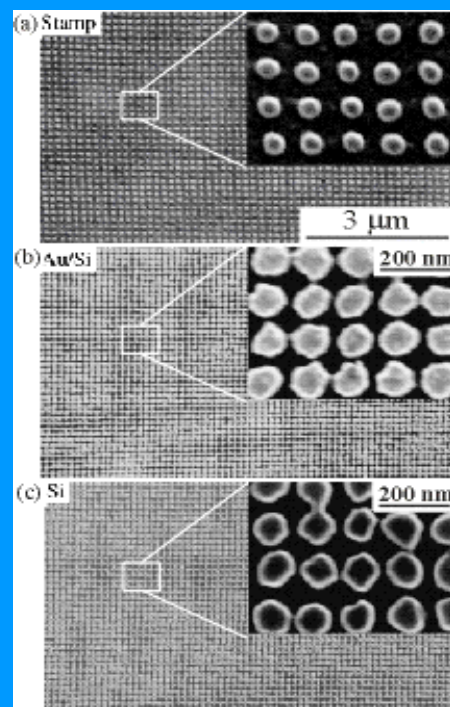
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Micro-contact printing



Printing of PDMS

Source: Winograd Group, Penn State

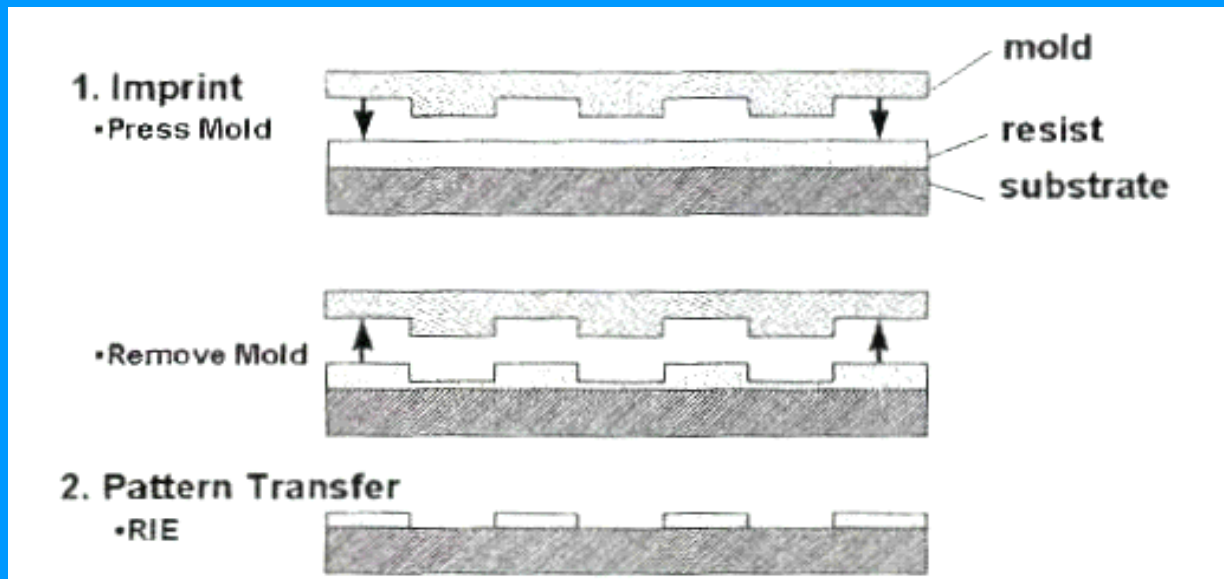


High-resolution μ CP of 60 nm dots

Source: IBM Zurich

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Nanoimprint Lithography



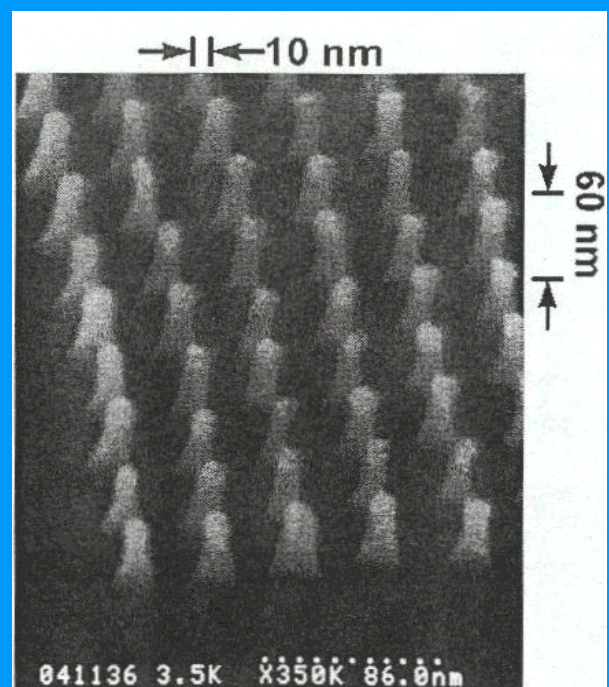
Consists of pressing a mold onto the resist above its glass transition temperature T_g

[More ? Check out S. Y. Chou, Princeton](#)

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NIL master

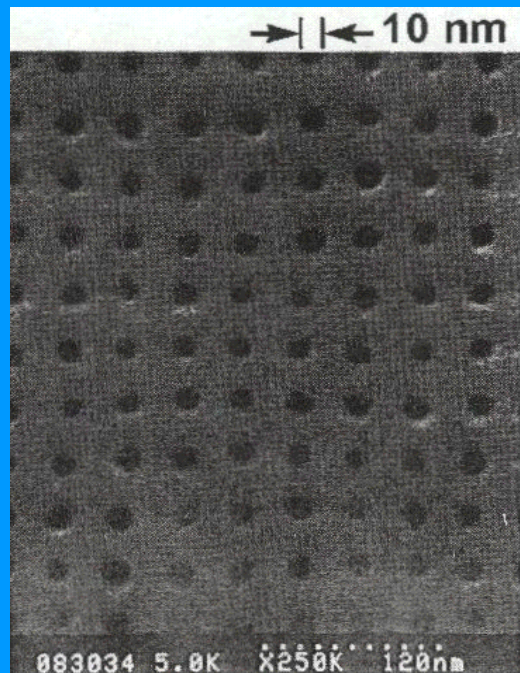
- SiO_2 pillars with 10 nm diameter, 40 nm spacing, and 60 nm height fabricated by e-beam lithography.
- Master can be used tens of times without degradation



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NIL pattern in PMMA

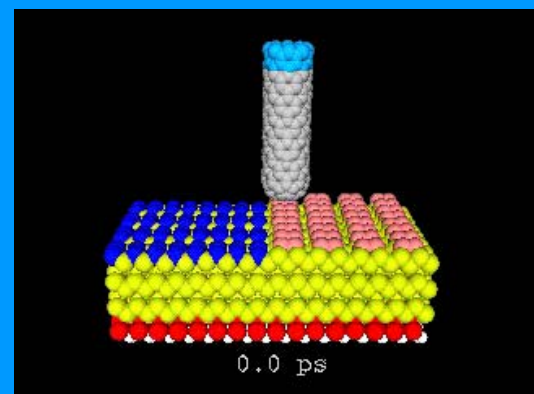
- Mask is pressed into 80 nm thick layer of PMMA on Si substrate at 175° C ($T_g=105^\circ\text{C}$), $P=4.4\text{ MPa}$.
- PMMA conforms to master patterng, resulting in ~10 nm range holes



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Carbon nanotubes for nanolithography

- A carbon nanotube can be used as a tip in an atomic force microscope (AFM). Such a tip in an AFM can be used to create nanoscale patterns i.e. nanolithography or to etch material away from a surface in the fabrication of semiconductor chips
- The videoclips show real-time dynamics of interaction between carbon nanotube tips and silicon and surfaces



[Ref. NASA, Ames Center](#)

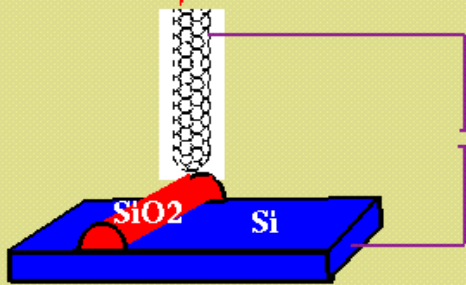
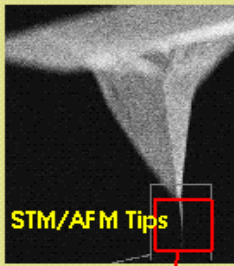
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Carbon nanotubes for nanolithography

Preliminary simulation and experiment show:

* the world's tiniest and strongest nanopencil

* never needs sharpening



TEM Image: SiO₂ lines (10 nm width) on Si Surface, written by a CNT tip

Ref: NASA, Ames Center

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