微奈米光電製程

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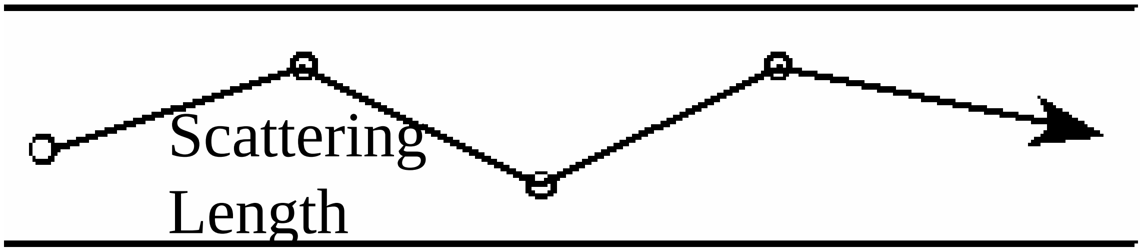
Outlines

1. 基本概念
2. Optical Lithography
3. E-Beam Lithography
4. Etching Techniques
5. Applications
6. Summary

基本概念(I)



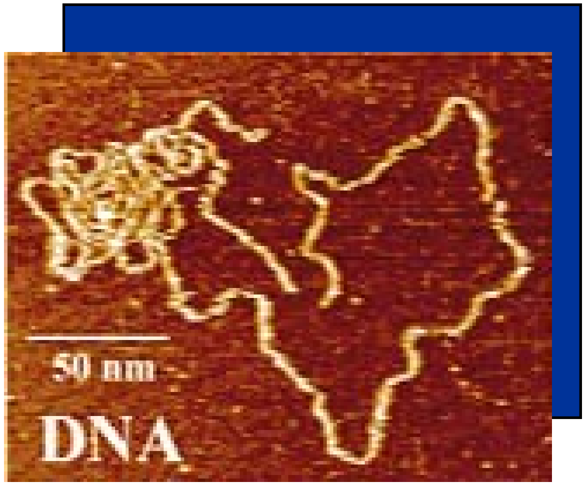
載子傳導並
遭遇散射

1.影響散射機制：雜質(低溫)及聲子振動(高溫)
2.室溫下，散射長度約小於100 nm
3.微米科技--在散射長度範圍外，無須考慮波動特性
4.奈米科技--在散射長度範圍內，載子行為必須考慮波動特性
5.尺寸在100 nm以下謂之奈米結構

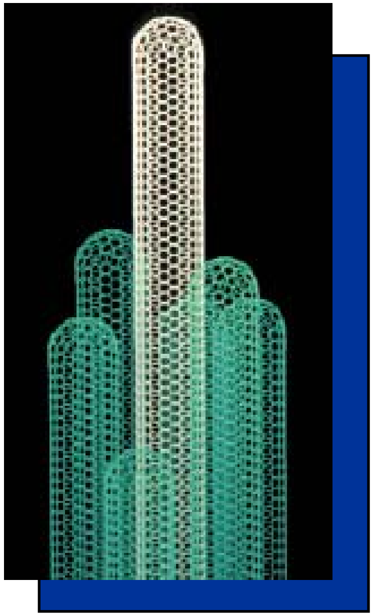
基本概念(II)

1. 微米尺度無法可預測奈米尺度
2. 奈米尺度的新現象：
— size confinement（空間限制效應）
— interfacial phenomena（表面或界面效應）

3.奈米結構的典例：
— carbon nanotubes
— protein, DNA

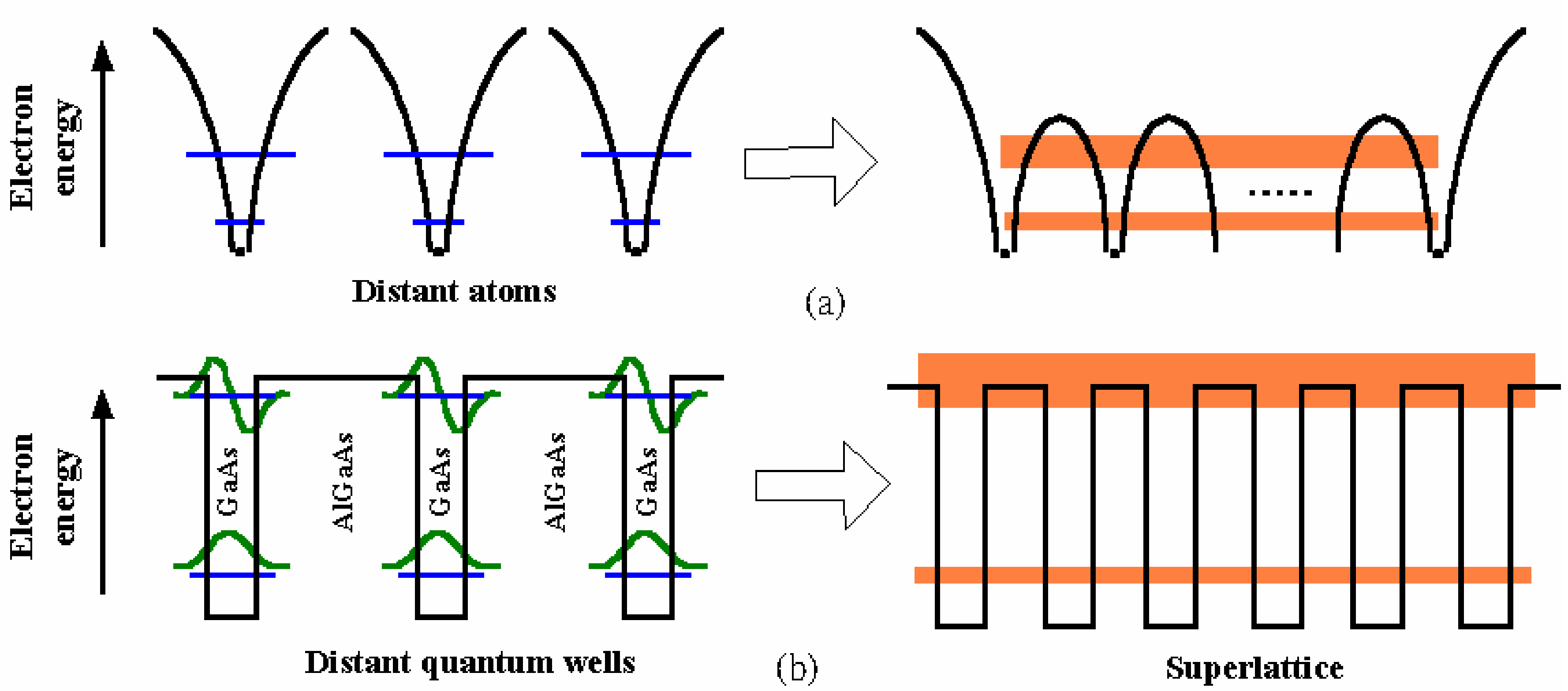


(NASA)



(carbon nanotube, NASA)

基本概念(III)



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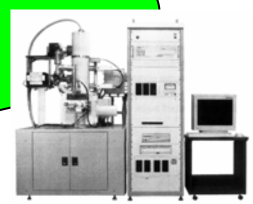
Patterning Technology--Lithography

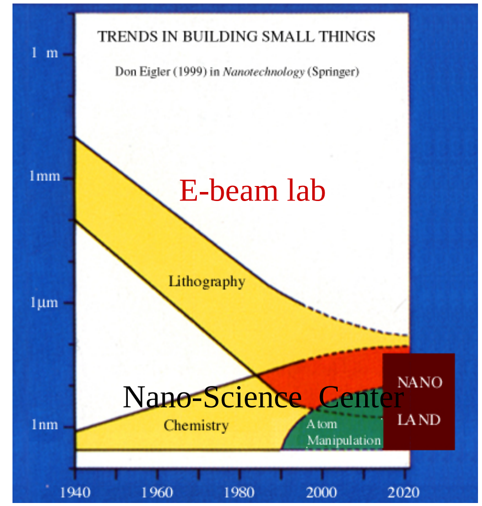
MBE, MOCVD, LPE

Growing nano-structures
in vertical direction

UV Lithography,
E-Beam Lithography



Fabricating nano-patterns
in horizontal direction



奈米中心與電子束實驗室共同發展互補的奈米科技

Wet Etching and
Dry Etch Technology

SEM. STM. AFM
For Observing

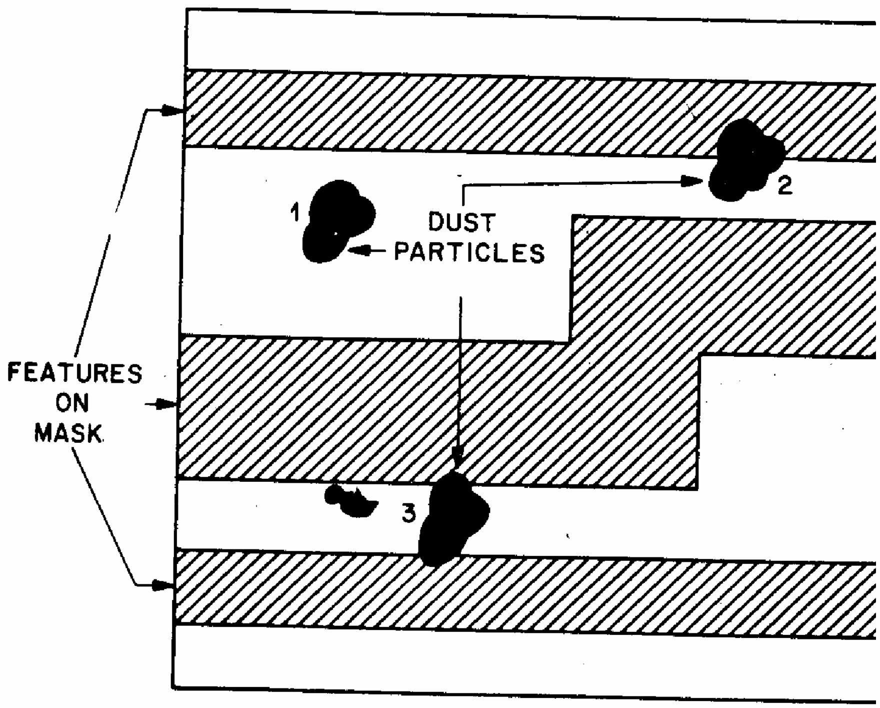
(Molecular)
Electronics

Optoelectronics

Biochip

NEMS

Cleaning Room – Environment Requirement



Various ways in which dust particles can interfere with photomask pat

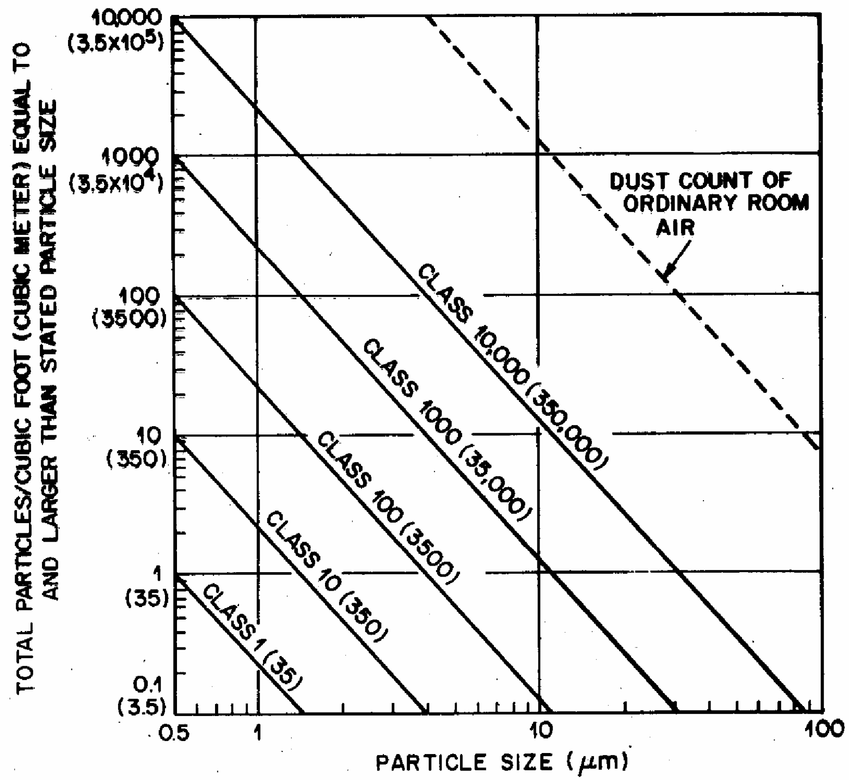
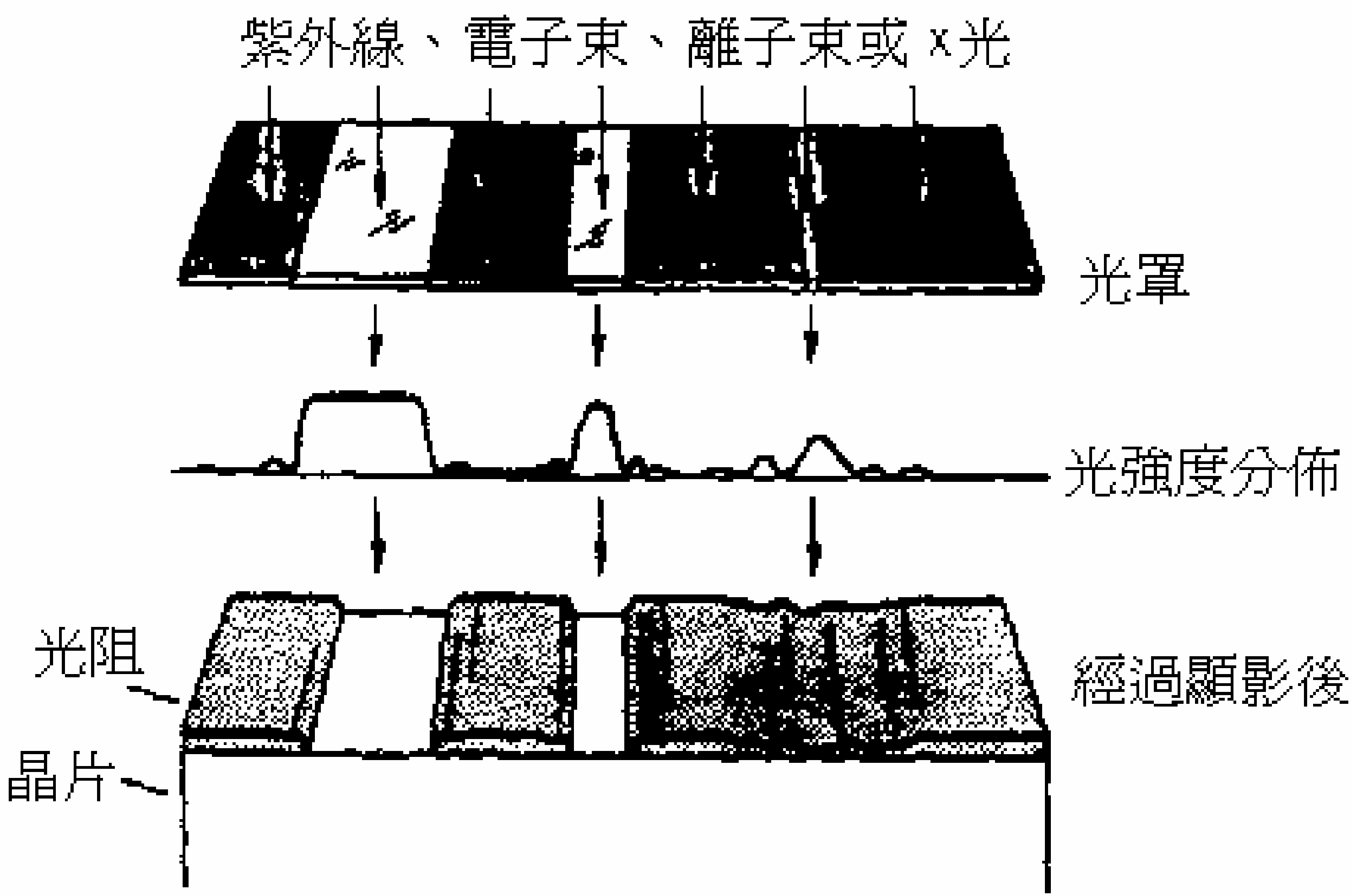


Fig. 2 Particle-size distribution curve.

製作奈米結構-顯影術



Optical (UV) Lithography

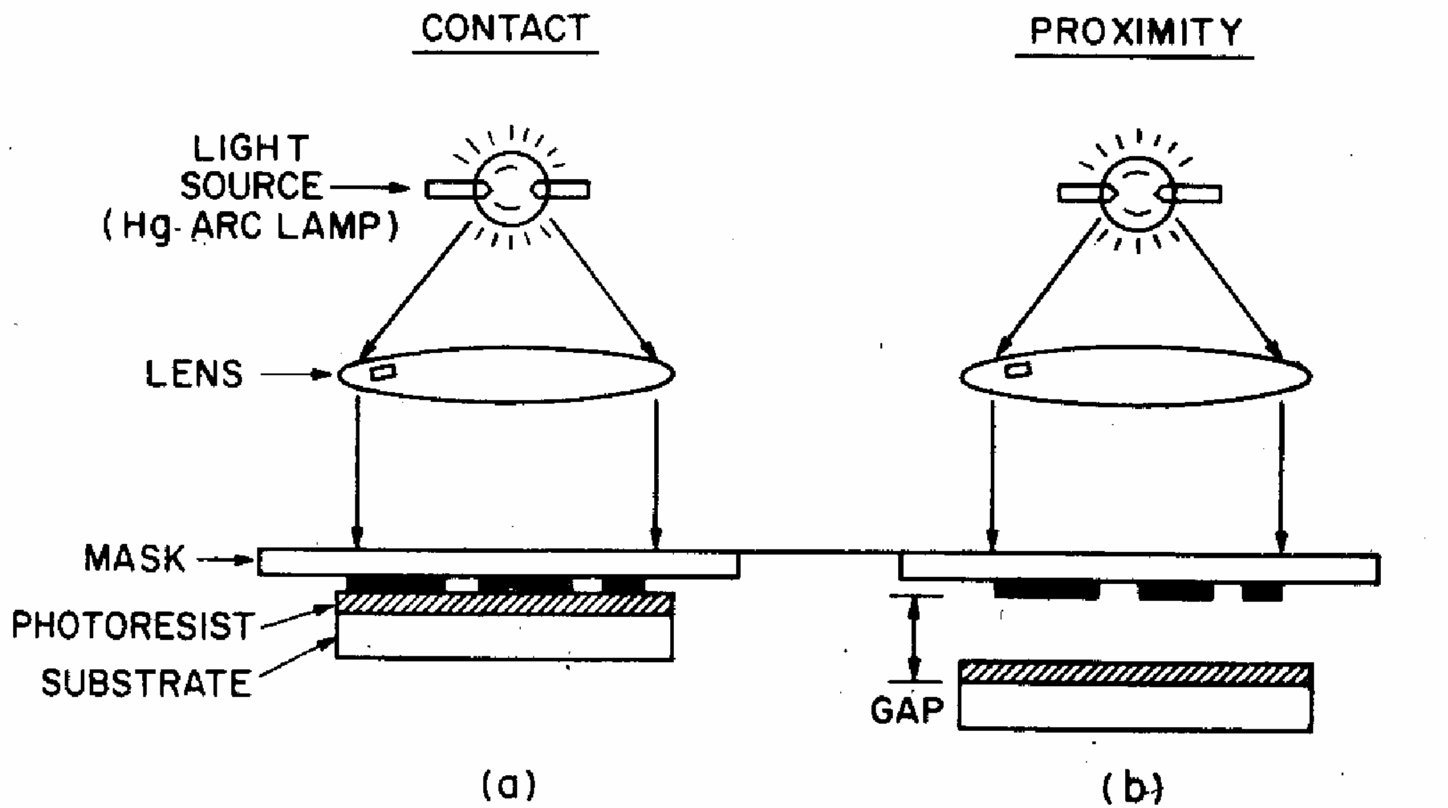
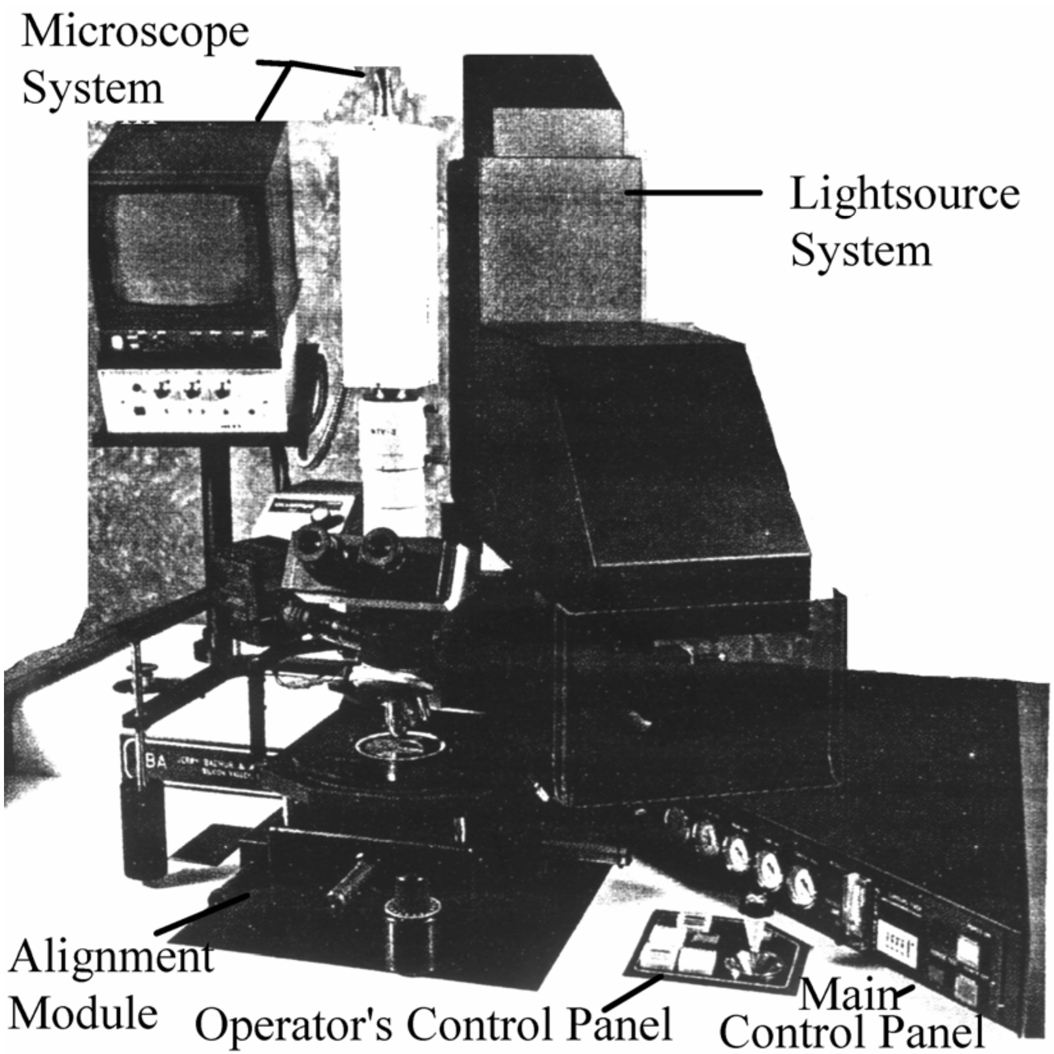
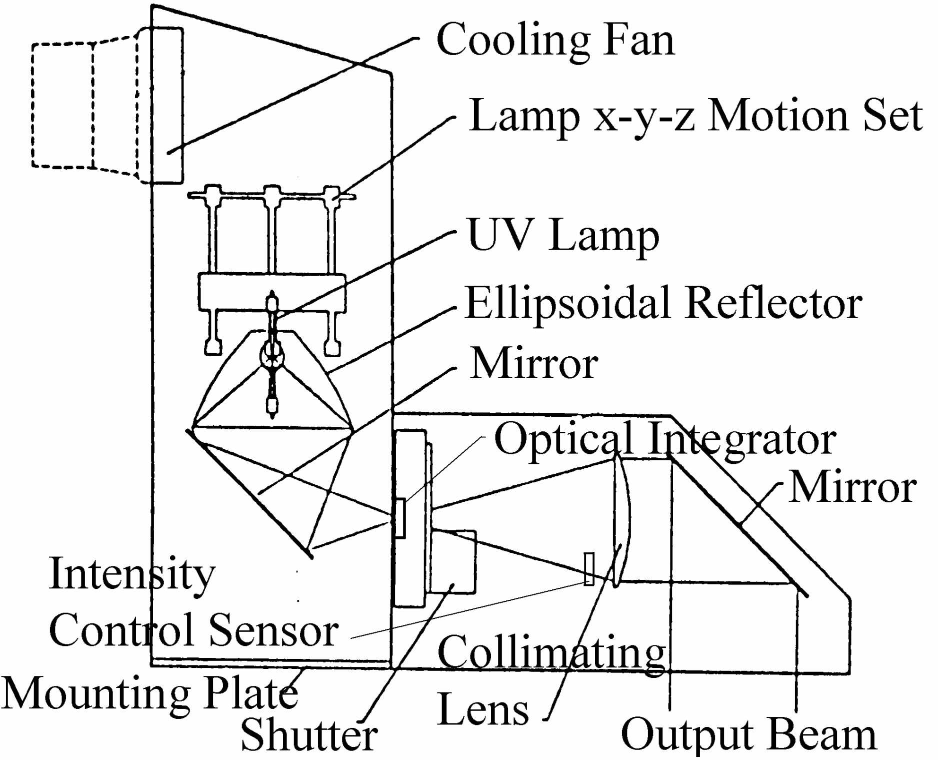


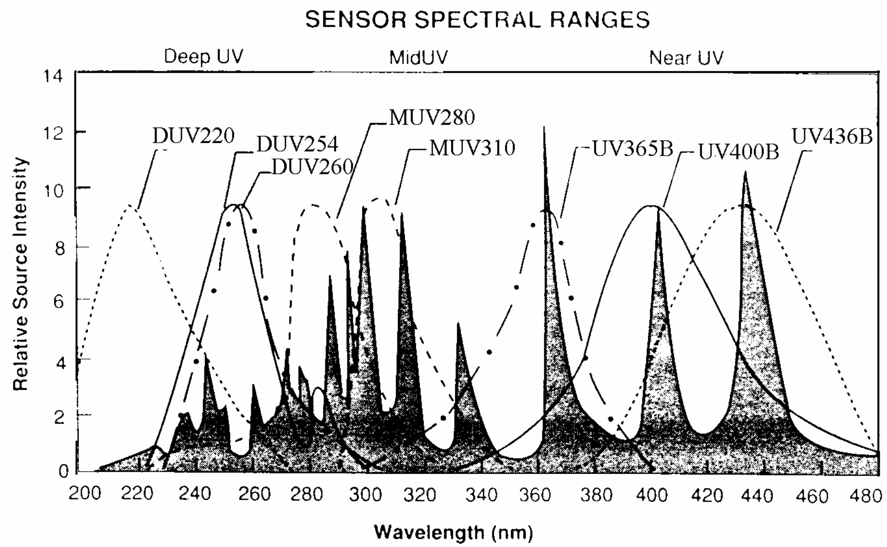
Fig. 3 Schematics of optical shadow printing techniques.[1] (*a*) Contact printing. (*b*) Proximity printing.

Mask Aligner

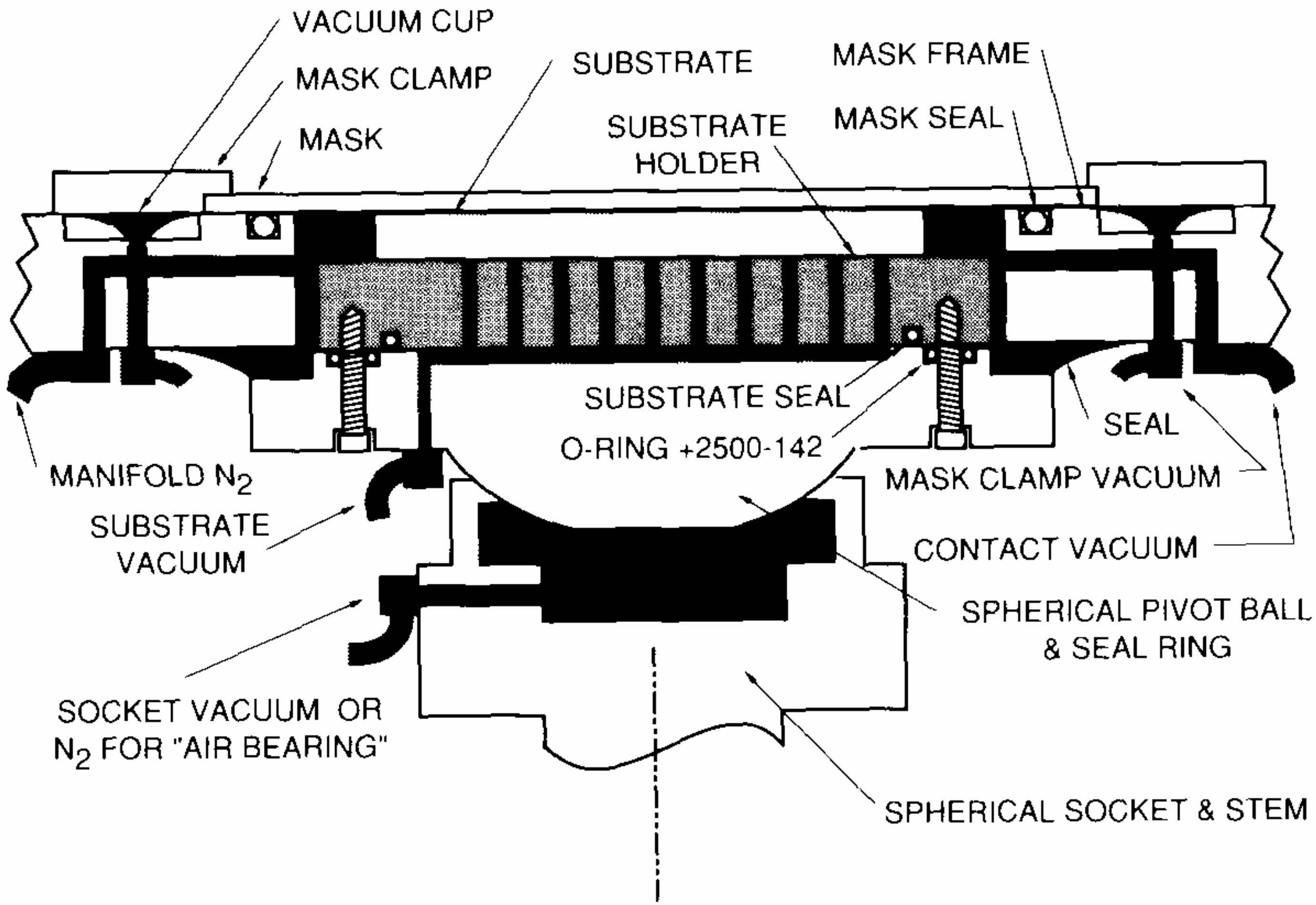


Light Source and Spectrum





Substrate Stage



Mask (光罩)

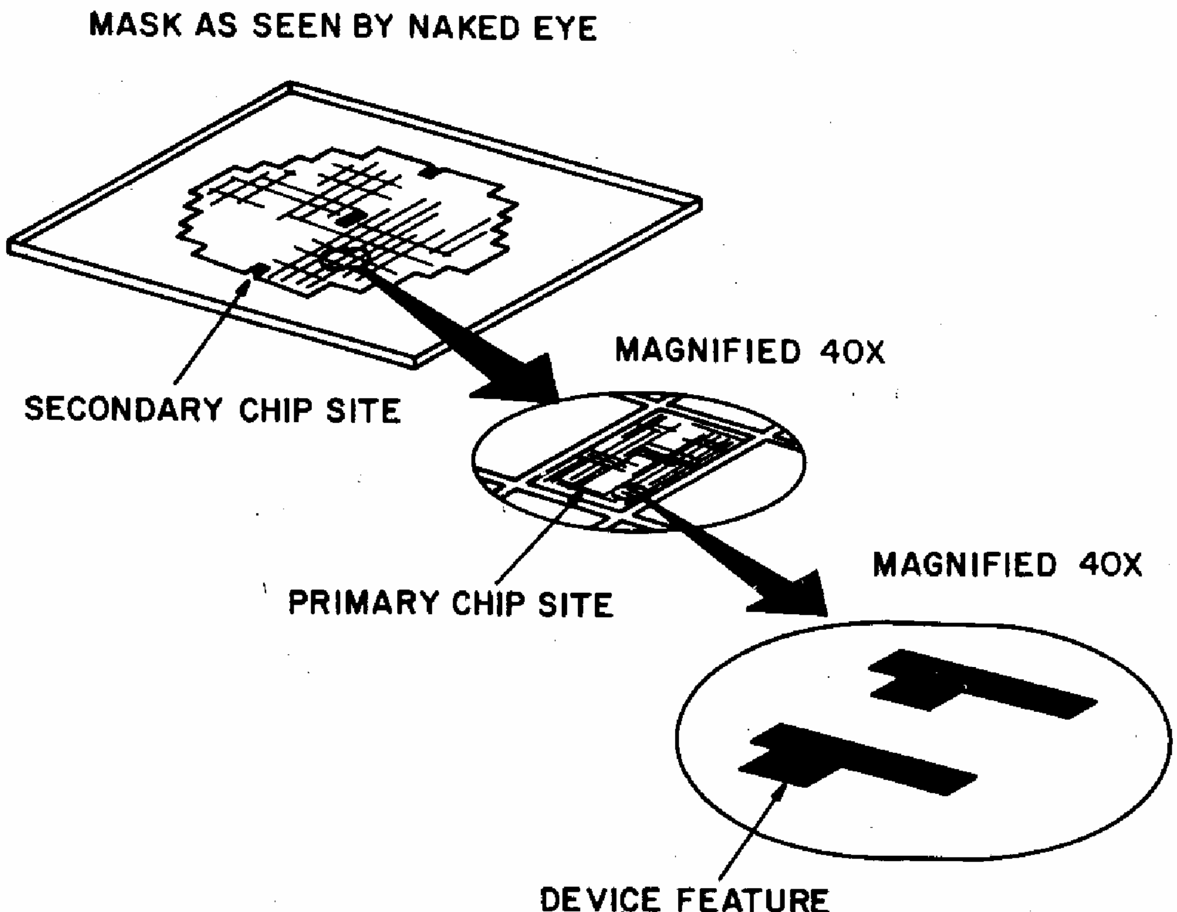


Fig. 6 A glass IC photomask.[1]

Photoresist (光阻)

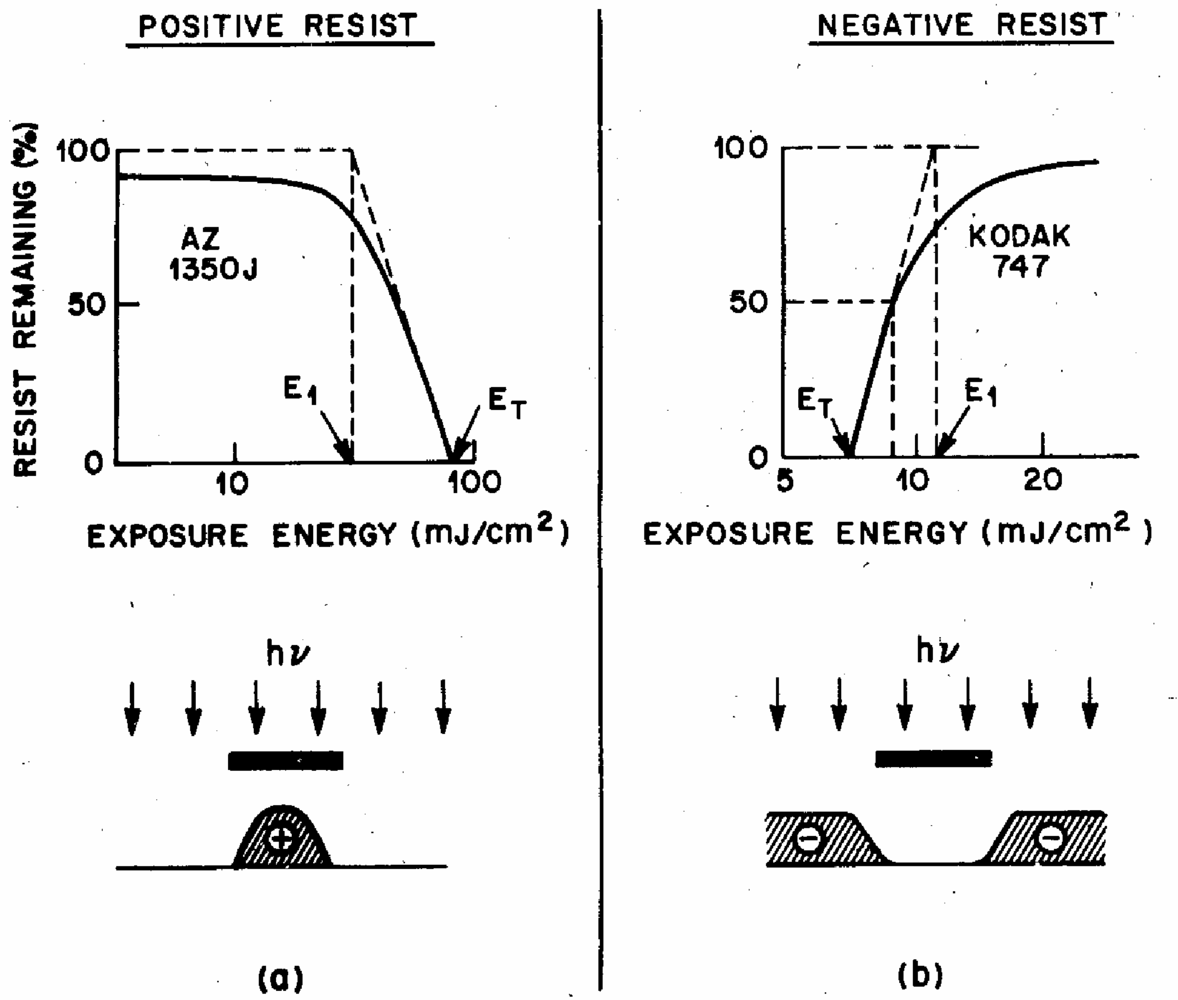


Fig. 8 Exposure response curve and cross section of the resist image after development.[1] (*a*) Positive photoresist. (*b*) Negative photoresist.

Resists for Various Lithography

Table 1 Negative and Positive Resists

Lithography	Name	Type	Sensitivity	γ
Optical	Kodak 747	Negative	9 mJ/cm^2	1.9
	AZ-1350J	Positive	90 mJ/cm^2	1.4
	PR102	Positive	140 mJ/cm^2	1.9
e-Beam	COP	Negative	0.3 $\mu C/cm^2$	0.45
	GeSe	Negative	80 $\mu C/cm^2$	3.5
	PBS	Positive	1 $\mu C/cm^2$	0.35
	PMMA	Positive	50 $\mu C/cm^2$	1.0
X-Ray	COP	Negative	175 mJ/cm^2	0.45
	DCOPA	Negative	10 mJ/cm^2	0.65
	PBS	Positive	95 mJ/cm^2	0.5
	PMMA	Positive	1000 mJ/cm^2	1.0

Pattern Transfer for Resists and Lift-off

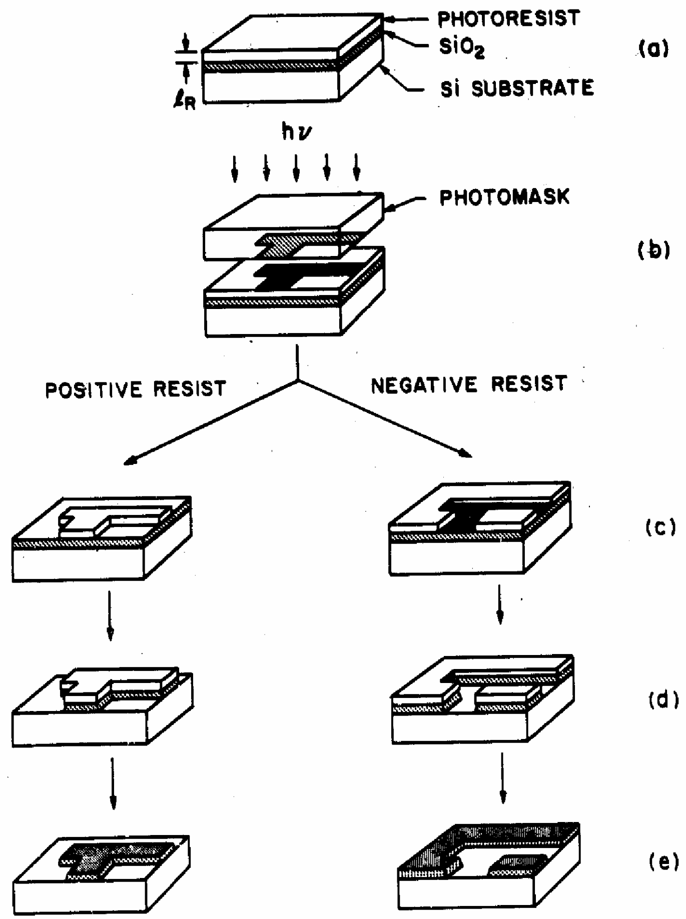


Fig. 10 Details of the optical lithographic transfer process.[10]

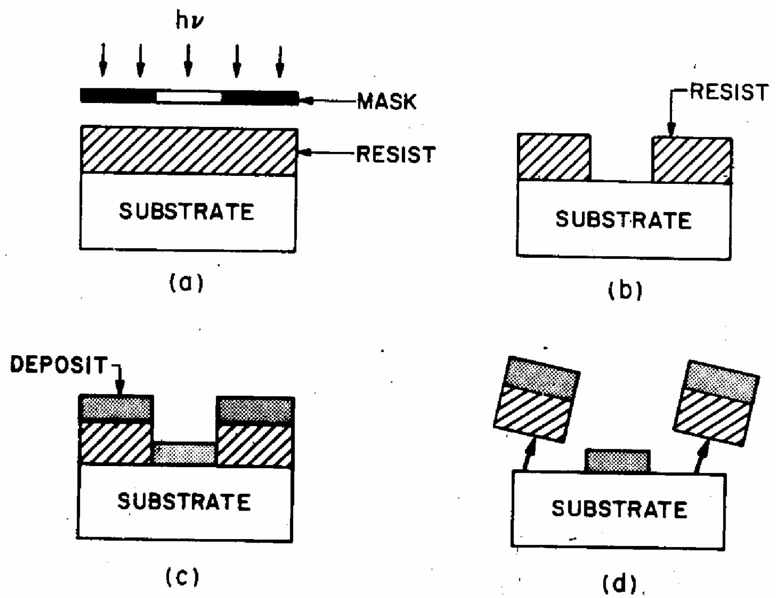


Fig. 11 Lift-off process for pattern transfer.

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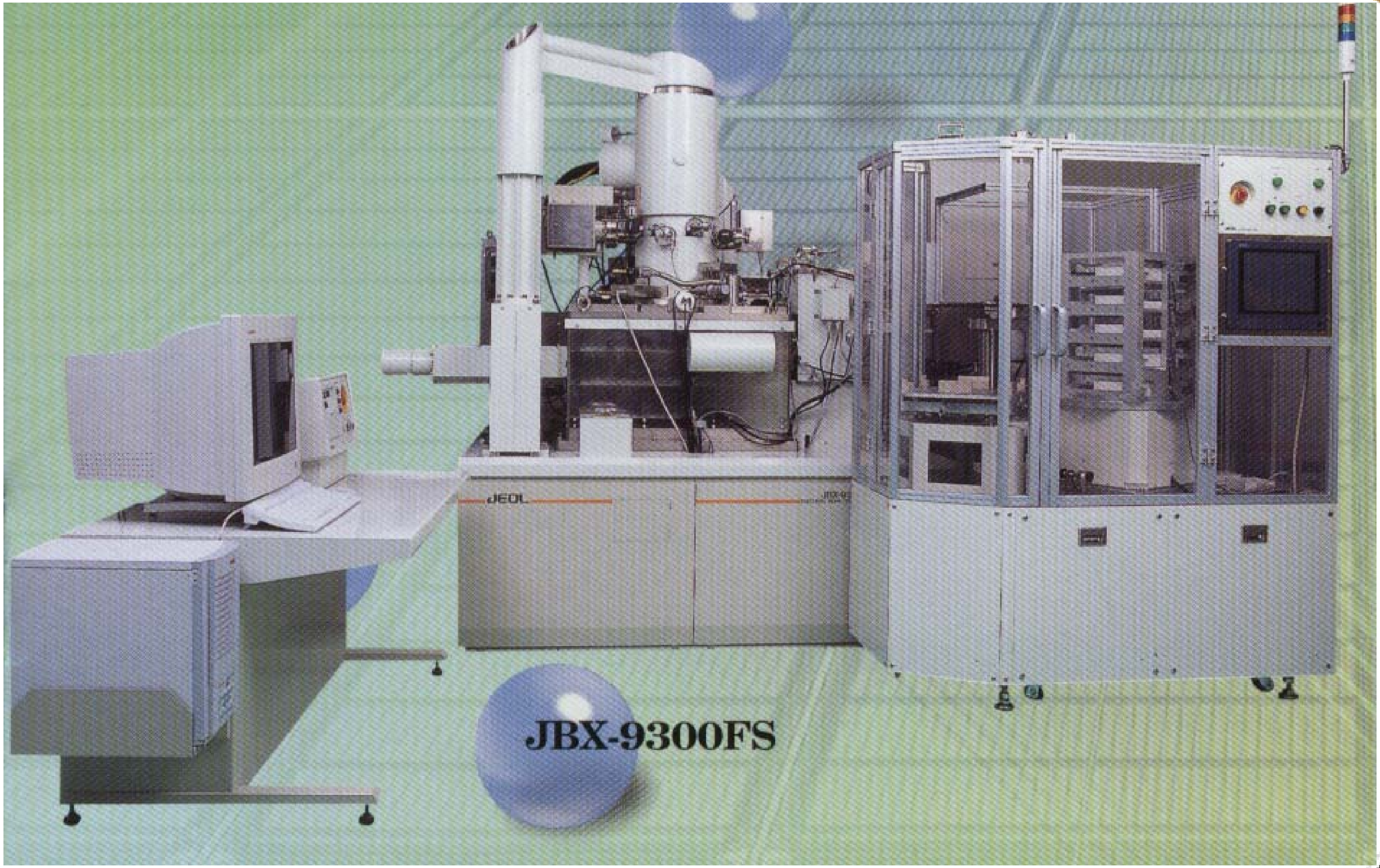
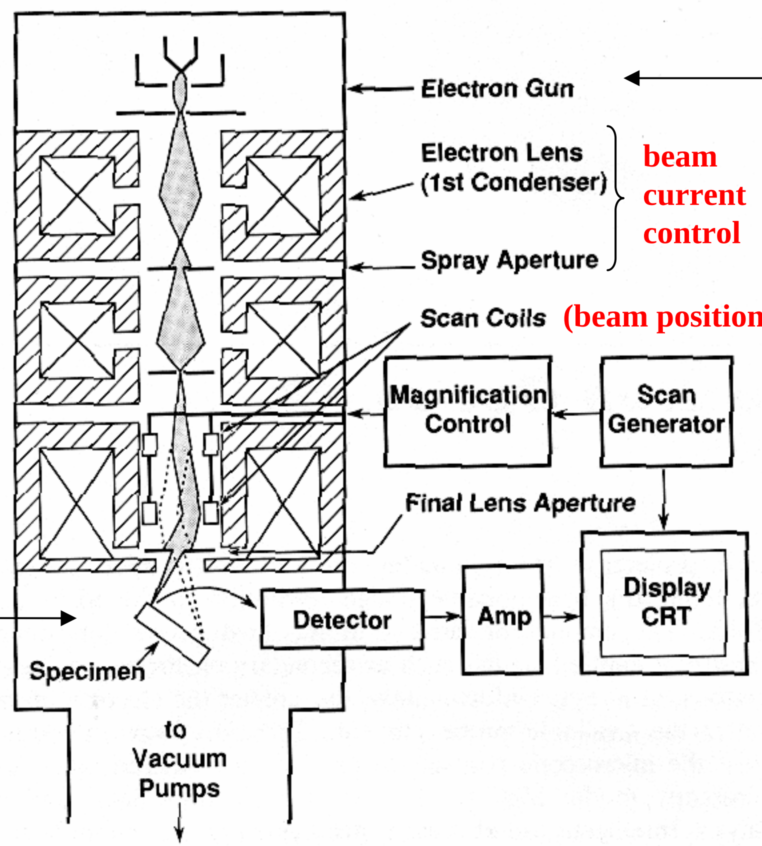
E Beam Lithography



Schematic Figure of E-Beam Writer



Source

beam current control

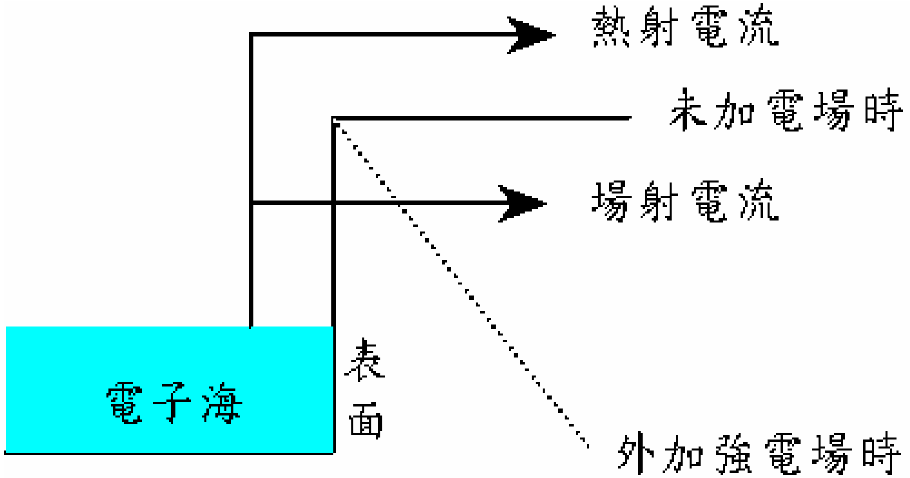
Focusing

(beam position control)

Deflecting

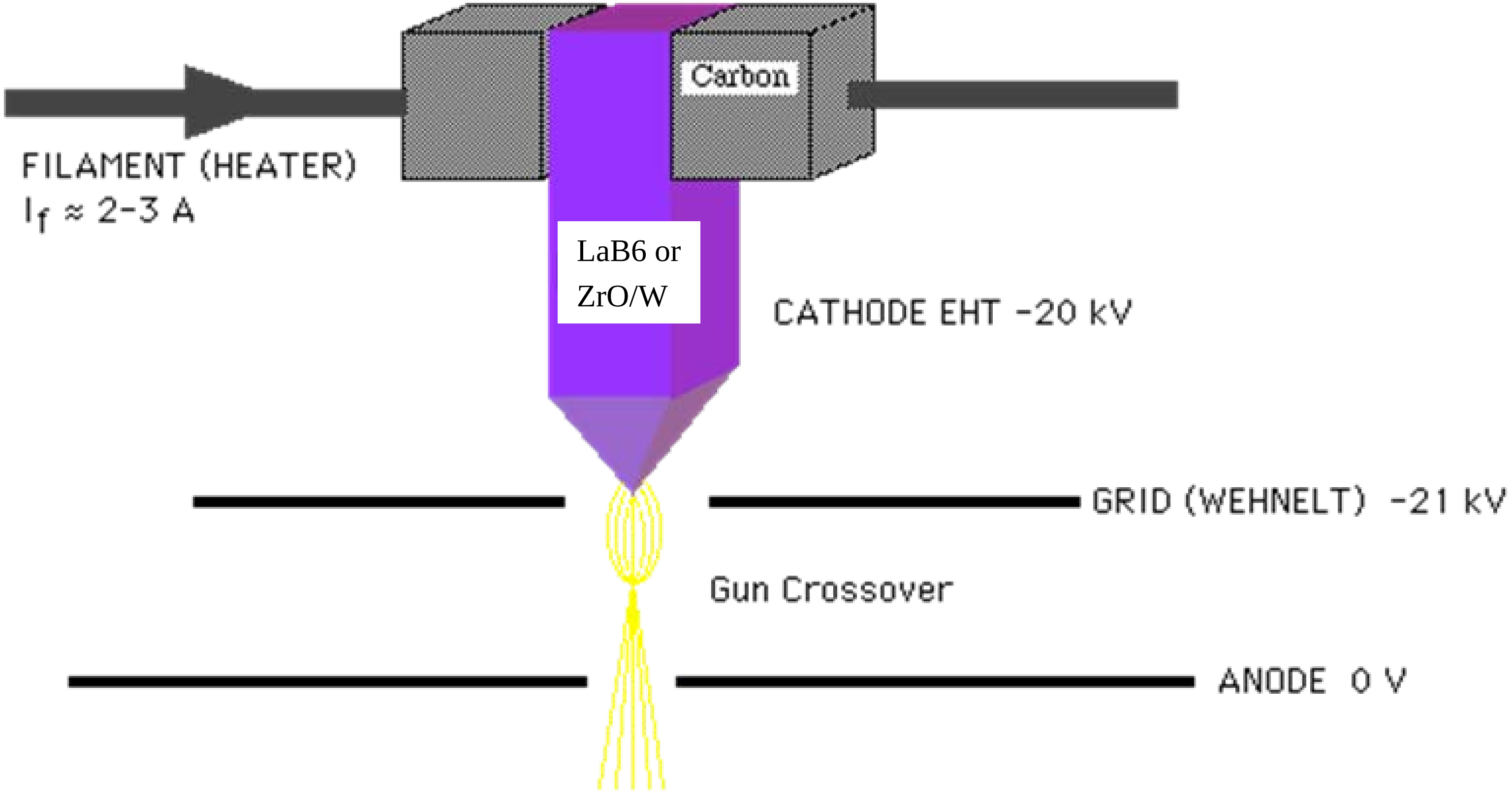
Working Stage

Variety of Electron Sources

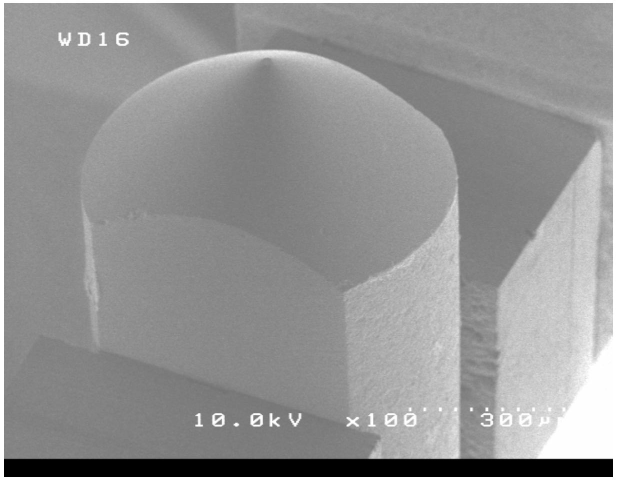


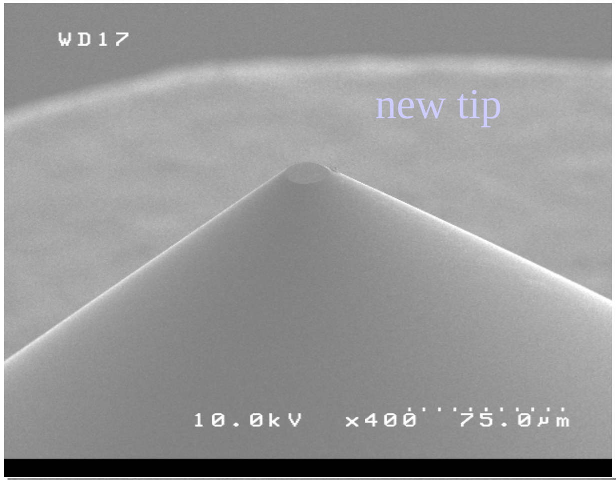
- 熱射型(LaB_6)：電子能量分佈大，解析度較低，但穩定性高
- 場射型：電子能量分佈小，解析度較高，但燈尖易受污染
- 熱場射型(ZrO/W)：解析度高，穩定性高，適合長時間使用

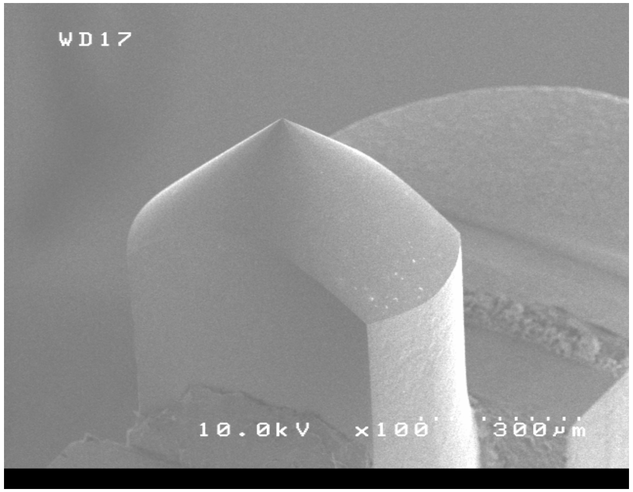
Gun of Electron Source



Gun Filament

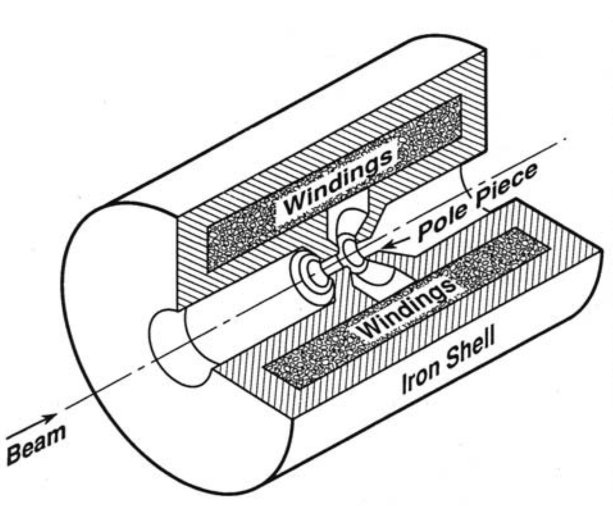


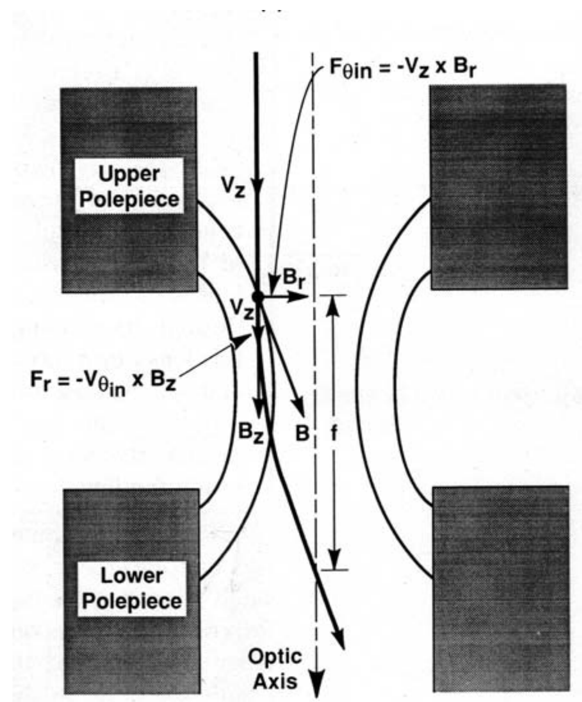




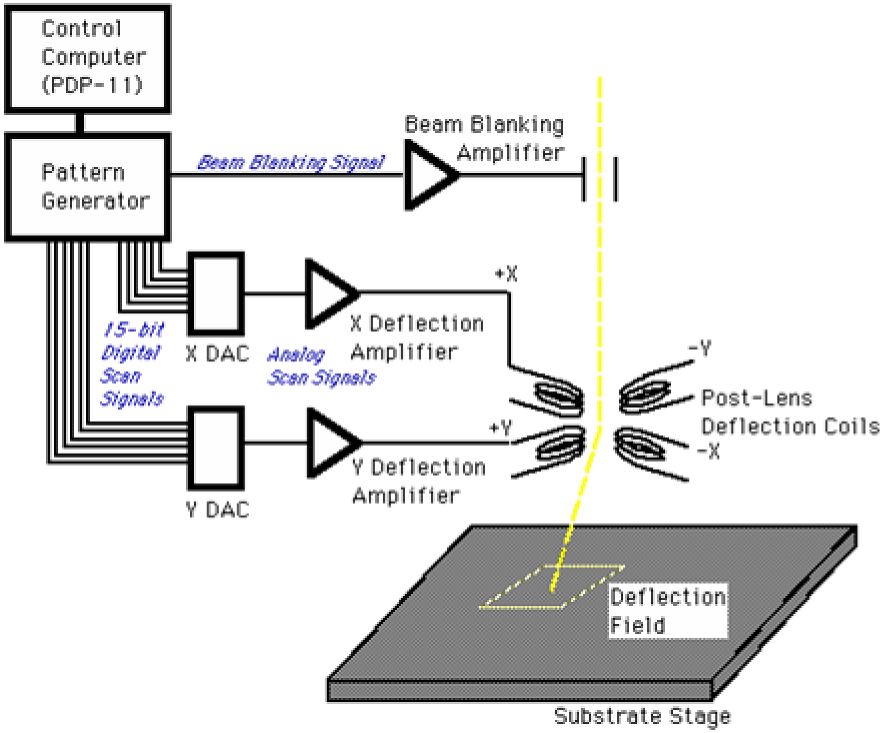
Focus System

- Electrostatic lenses
  - For positioning electrons in blanking and deflection systems
  - For focusing and accelerating electrons in electron gun
- Electromagnetic lenses
  - For condenser and objective lenses



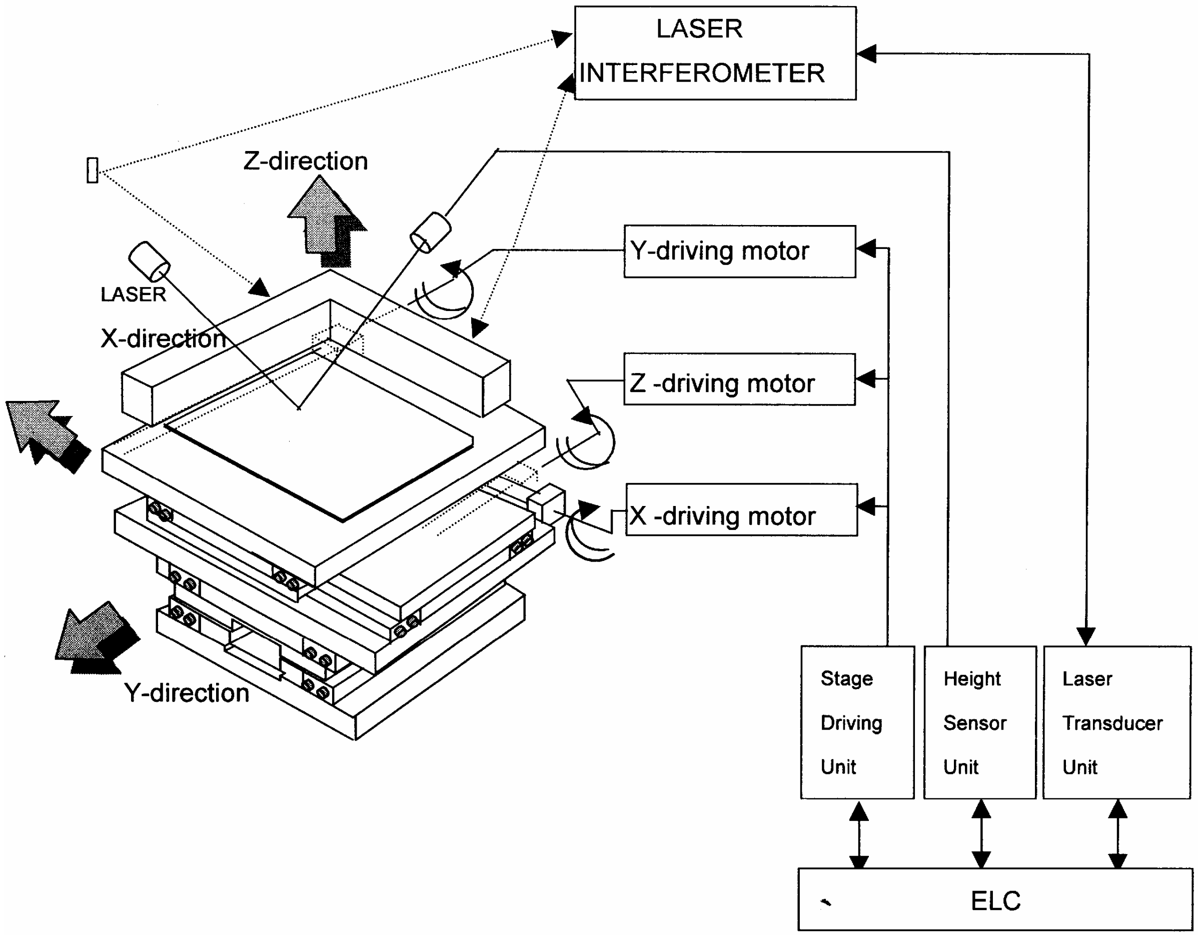


Deflection System



- Beam blanking amplifier turns the beam on and off
- Deflection coils change the beam position by varying an analog voltage applied to the coils
- The pattern in digitized form is converted to analog form for exposure

Working Stage

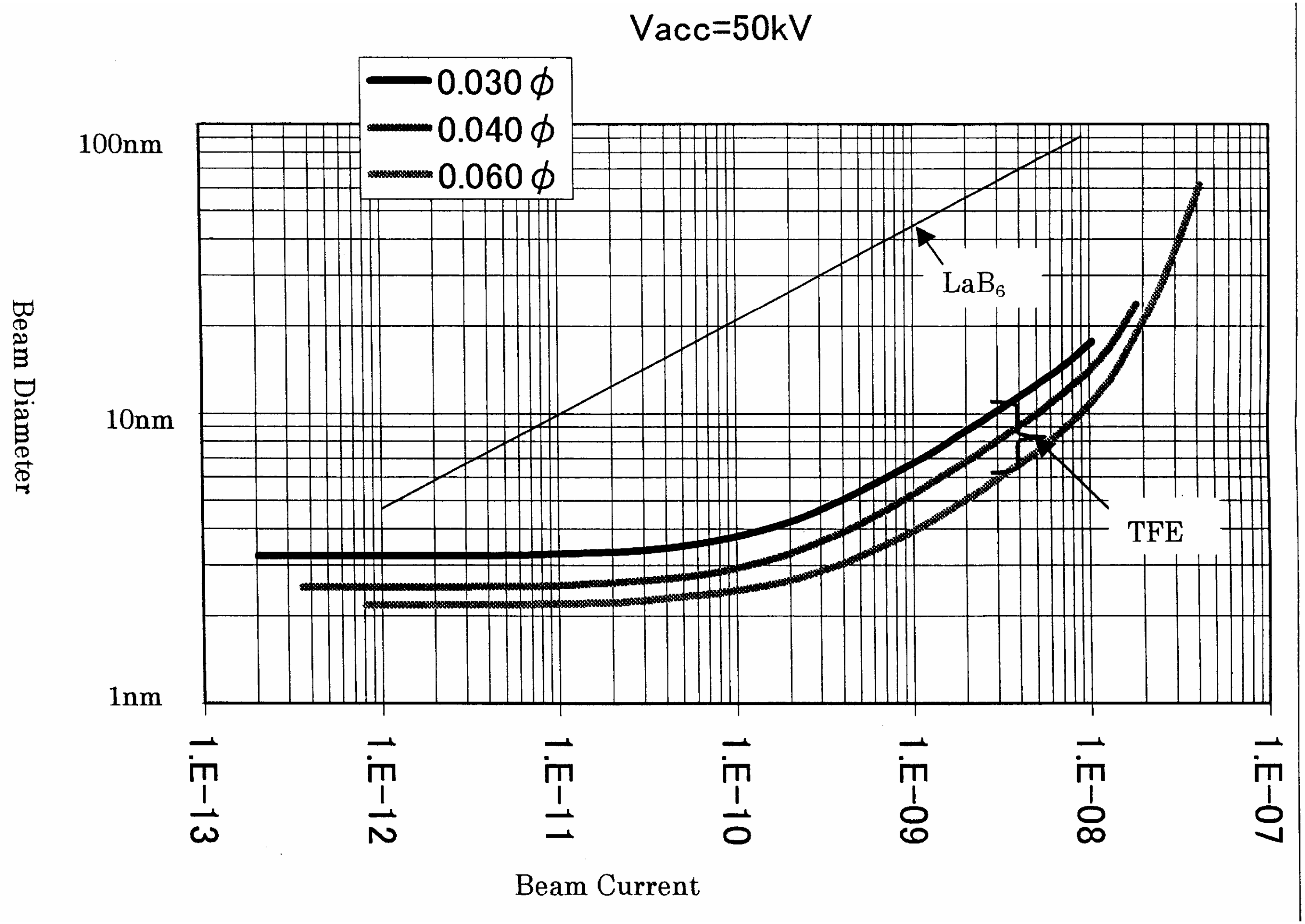


- A pair of laser interferometer measure the true position of stage.
- The beam is positioned by D/A converter and the interferometer to reach around 1 nm resolution

System Performance

- Beam Diameter v.s. Beam Current
- Beam Brightness
- Electrons and PMMA Interaction
- Electron Energy (Acceleration Voltage)
- Stitching Accuracy
- Overlay Accuracy and Alignment Marks
- Deflection Induced Aberration
- Defocus and Distortion
- Scanning Method
- Variable Shaped Beam Lithography
- Throughput of Shaped Beam System
- Development of E Beam Lithography

Beam Diameter v.s. Beam Current



Beam Brightness

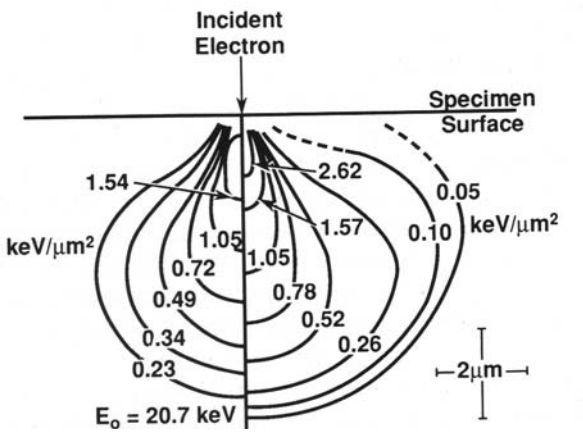
$$i_{beam} = KBd_{\min}^{8/3}$$

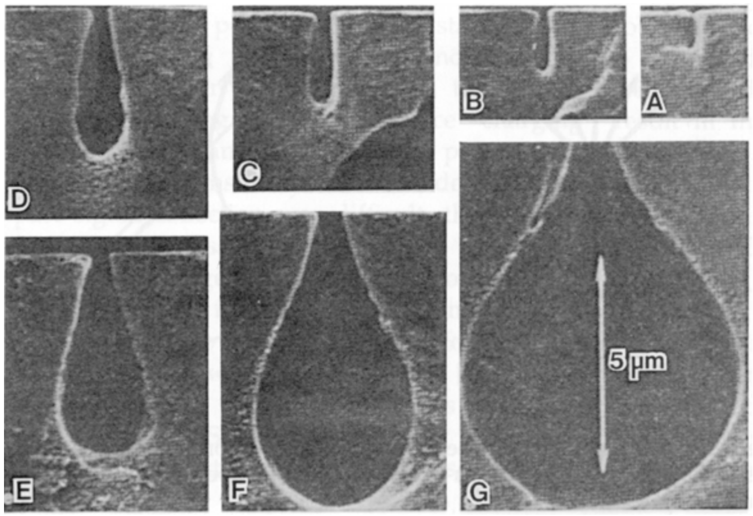
i_{beam} :beam current
K: constant
B:brightness of the gun
d_{min}:beam diameter

- Brightness is related to photoresist exposure
- The following factors need to be considered when selecting the beam current:
  - Total exposure time
  - Beam diameter
  - Ability to locate alignment marks, focus marks, etc.

Electrons and PMMA Interaction

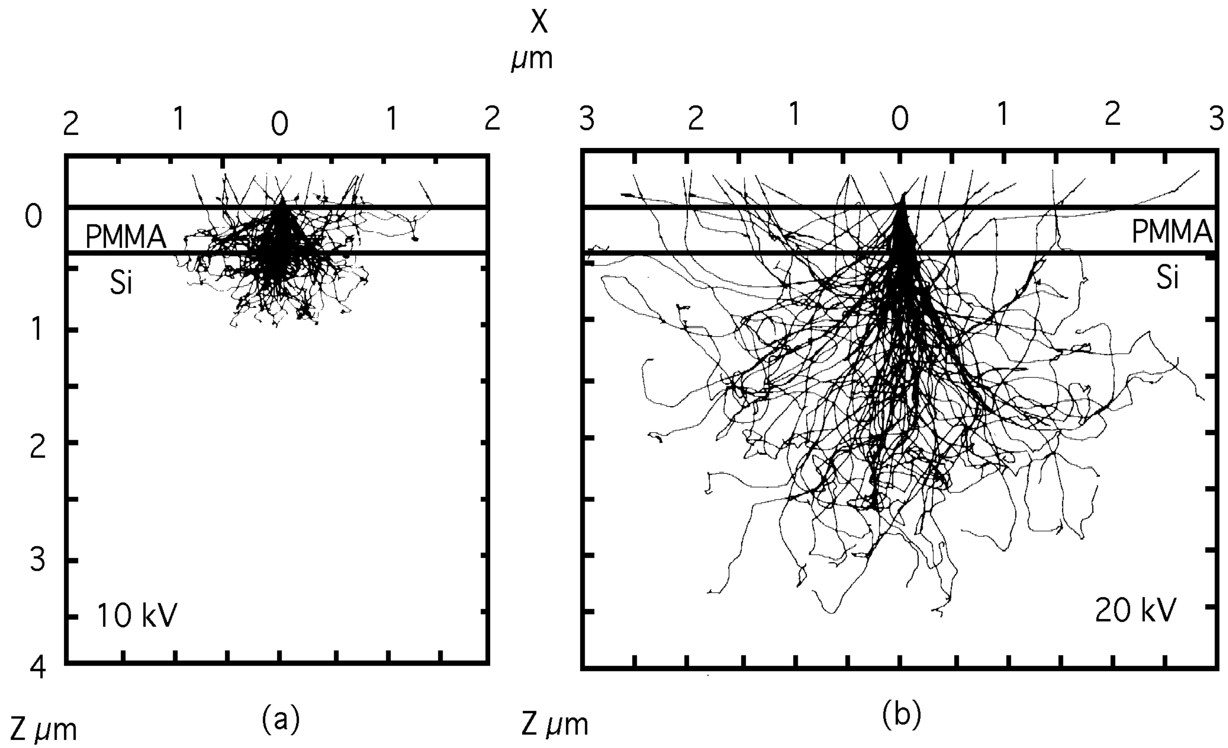
- Secondary electrons
  - Topography dependence
- Backscattered electrons
  - Atomic number dependence
- Interaction volume
  - Proximity effect





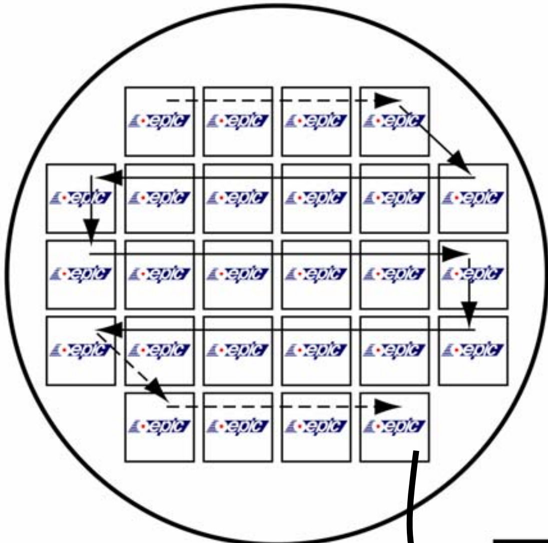
Same electron dosage with increased etching time
Adapted from Everhart et. al. 1972

Electron Energy(Acceleration Voltage)

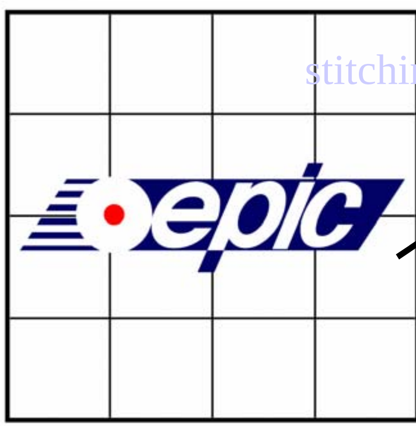


Monte Carlo simulation of electron scattering in resist on a silicon substrate at a) 10 kV and b) 20 kV. [From Kyser and Viswanathan 1975]

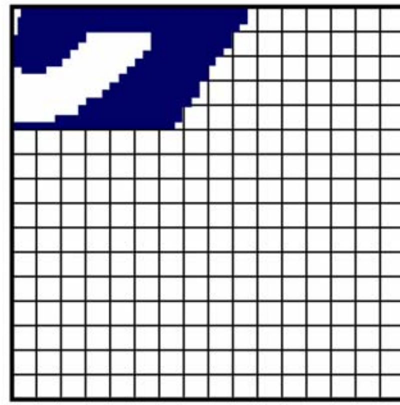
Stitching Accuracy



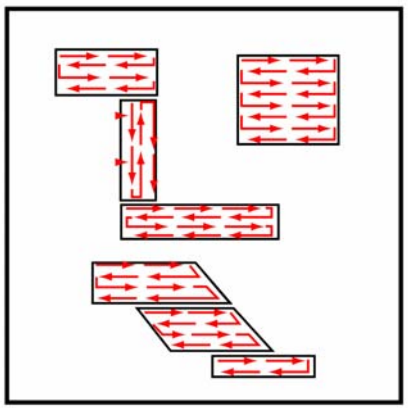
WAFER (Most wafers are made up of an array of chips, which are exposed in sequences.)



Chip (or Die)
Each chip usually forms a fundamental unit of wafer and is comprised of one or more e-beam fields



FIELD (An array of 32x32 subfields, each exposed in sequence without moving stage, but with different beam correction values in each subfield.)

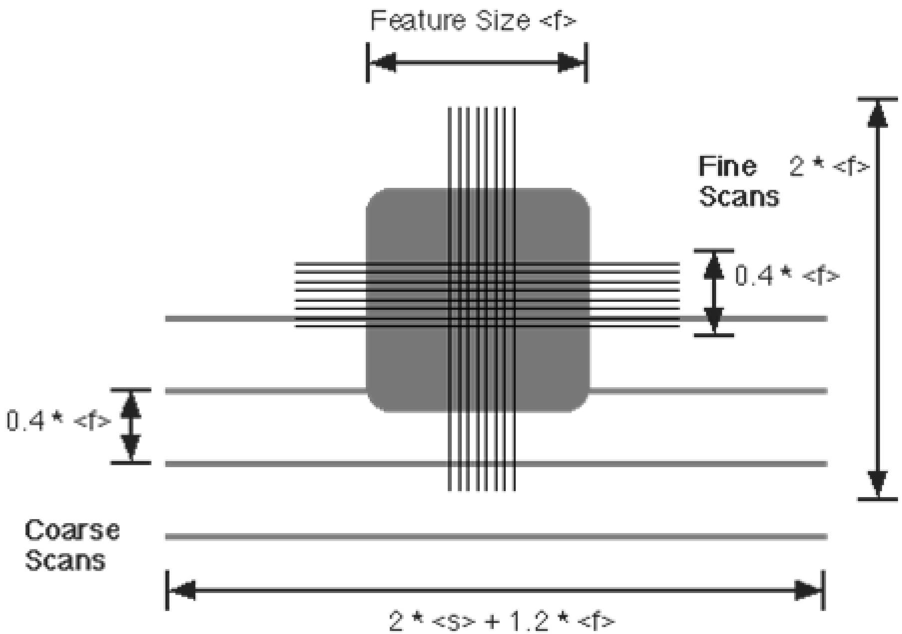


SUBFIELD (Each primitive shape in the subfield is exposed by rastering or vector-scanning the beam to fill the shape. The beam is blanked between shapes.)

Overlay Accuracy and Alignment Marks

Why Alignment marks?

Because the e-beam patterns need to be aligned with previously existing patterns

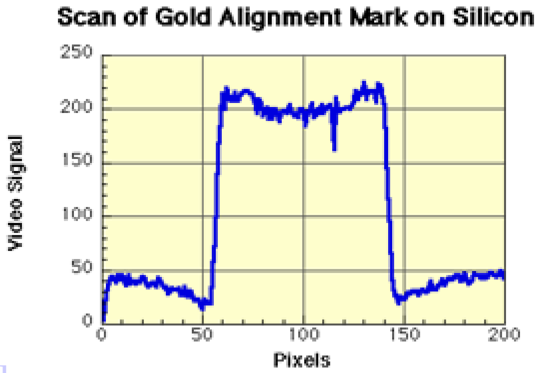


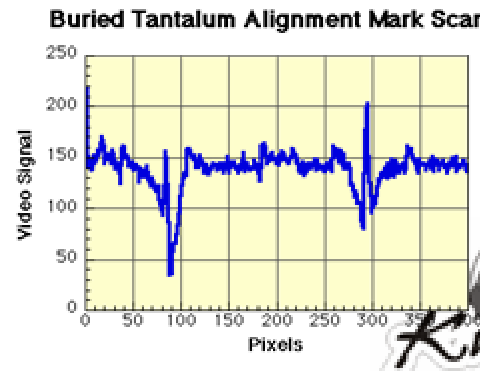
~ 20 μm

high

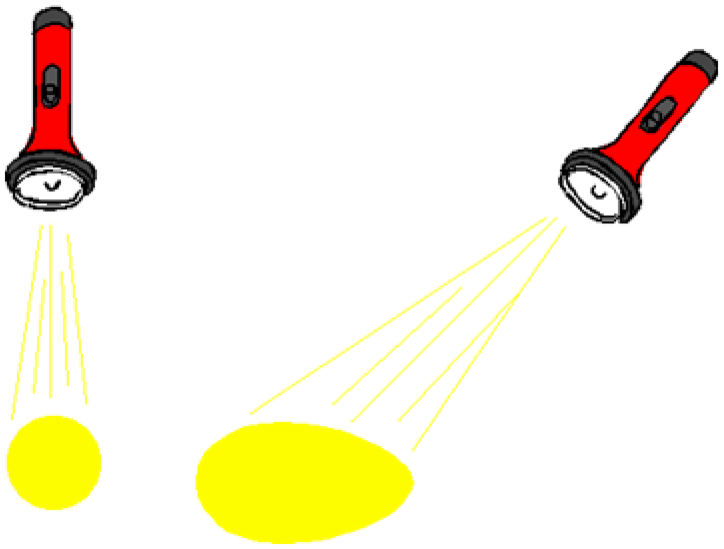
backscattered electron signal

low



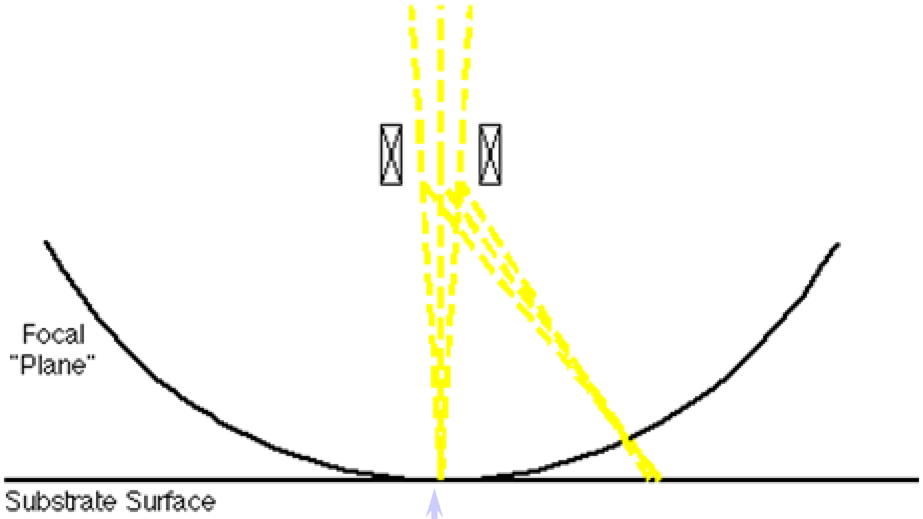


Deflection-induced Aberrations

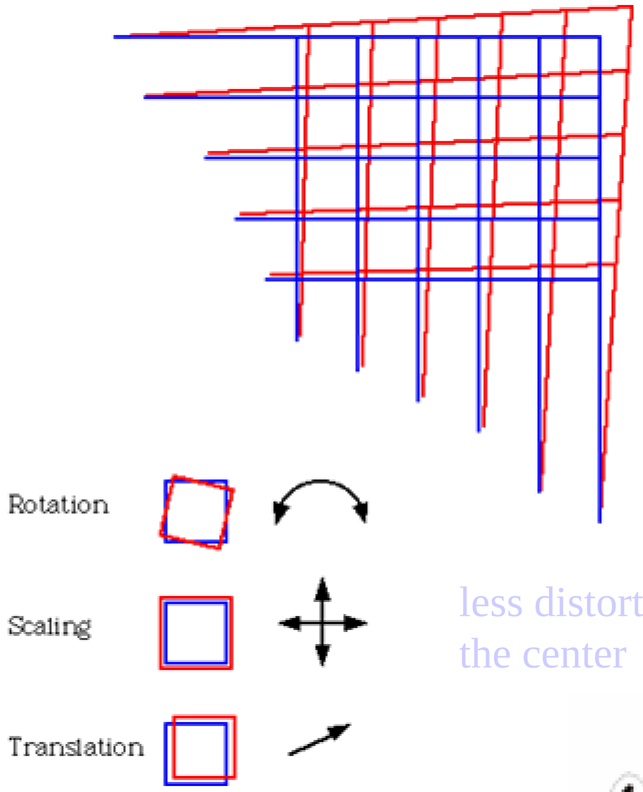


- Astigmatism
- Defocus
- Distortion

Defocus and Distortion



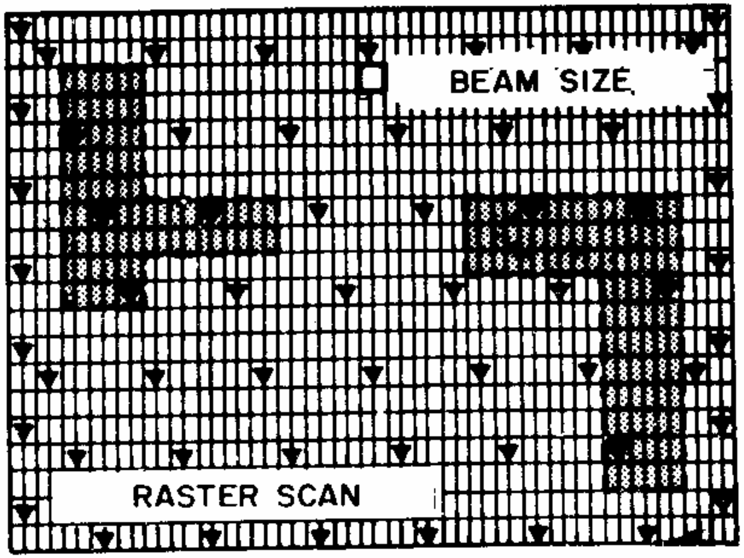
center is focused



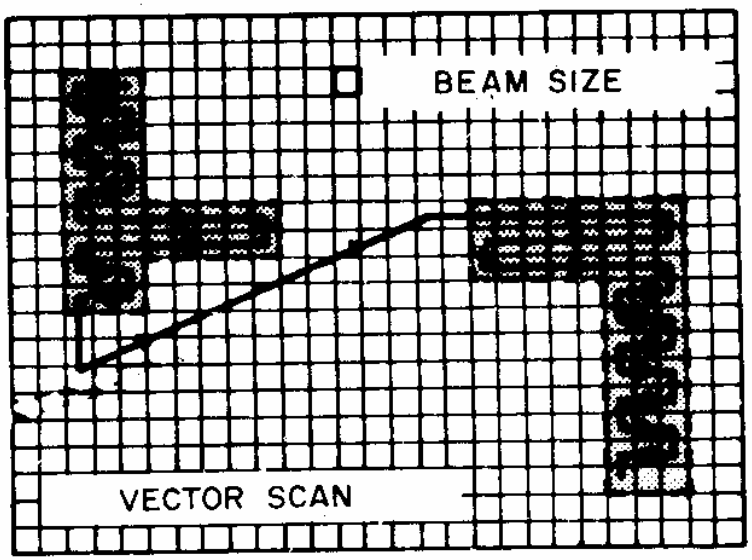
less distortion at the center

Scanning Method

-- Raster scan and Vector scan



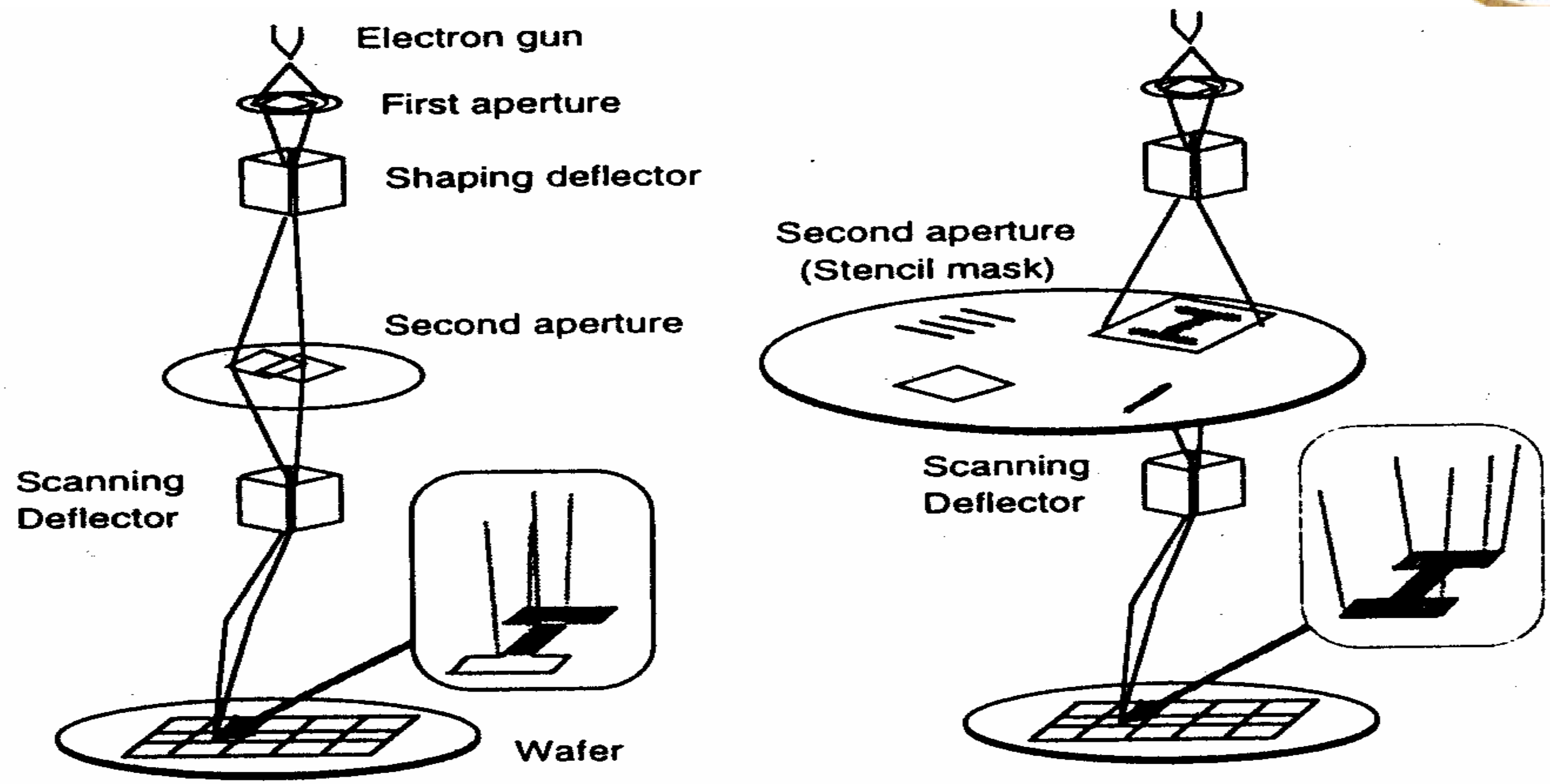
(a)



(b)

-- Shape scan

Variable Shaped Beam Lithography



(a) Variable shaped electron beam exposure system

(b) Cell projection electron beam exposure system

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Throughput of Shaped Beam System

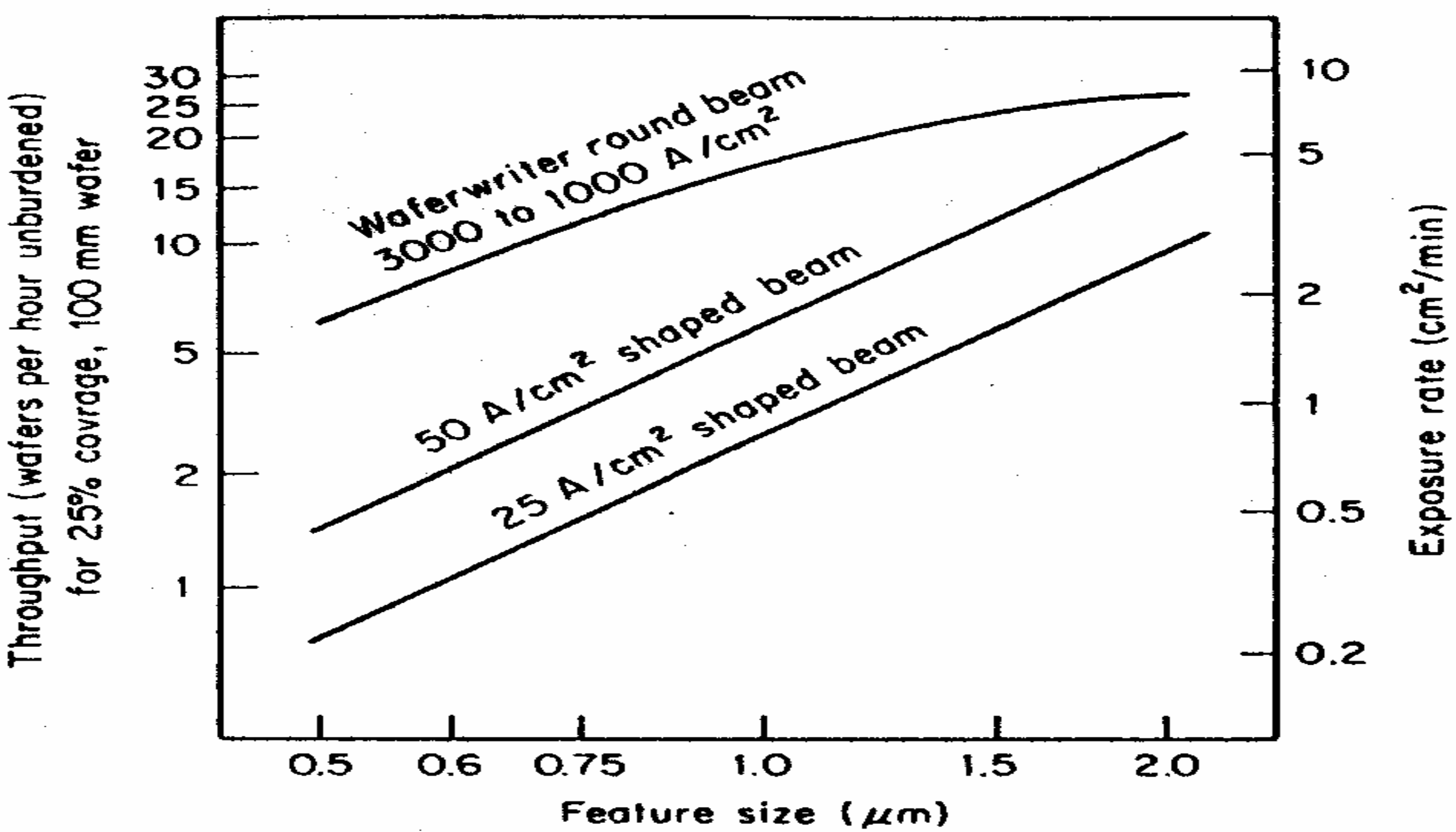

FIG. 4.44 **Shaped beam versus spot beam.**[9]

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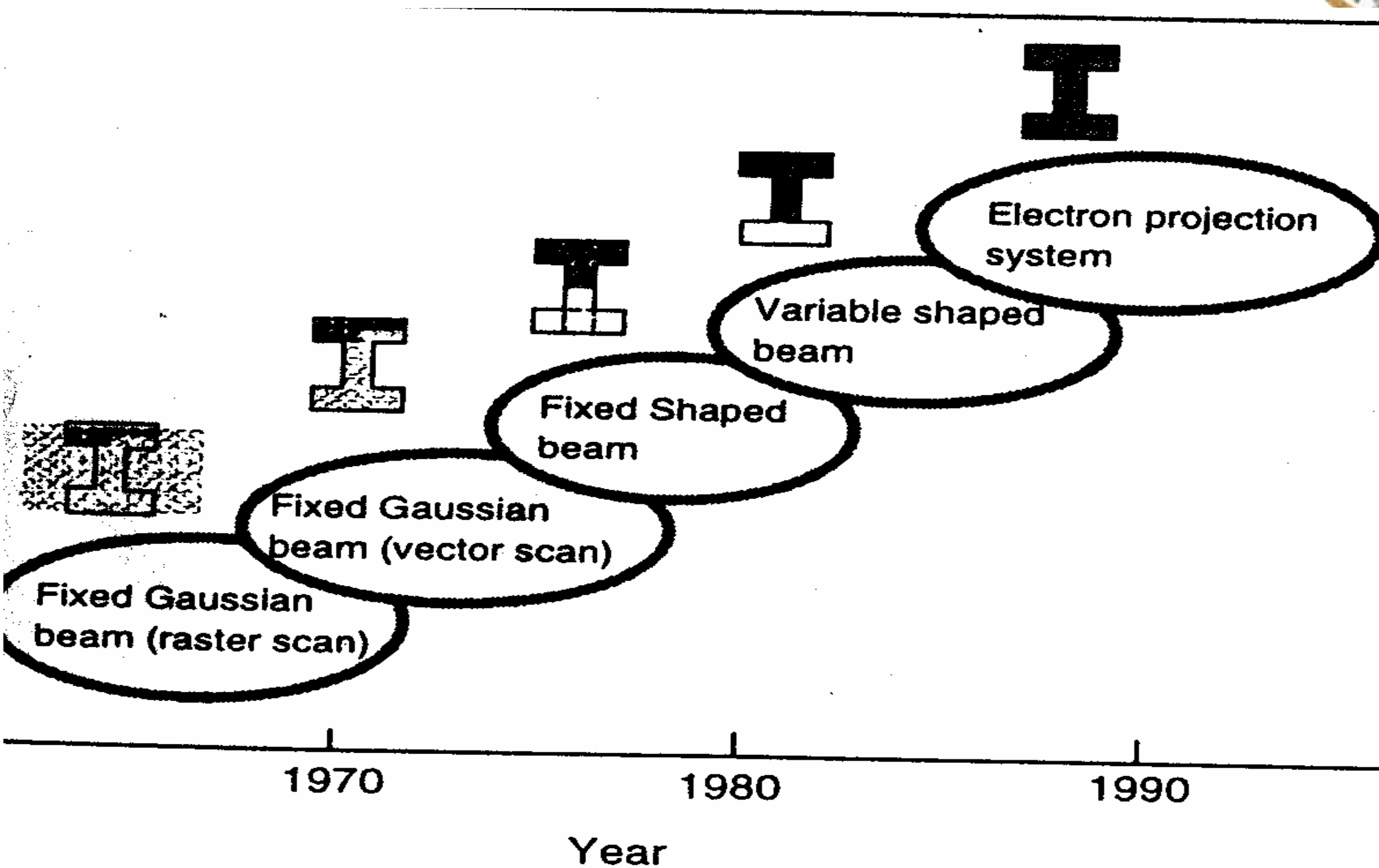
Development of E Beam Lithography



E Beam Photoresist

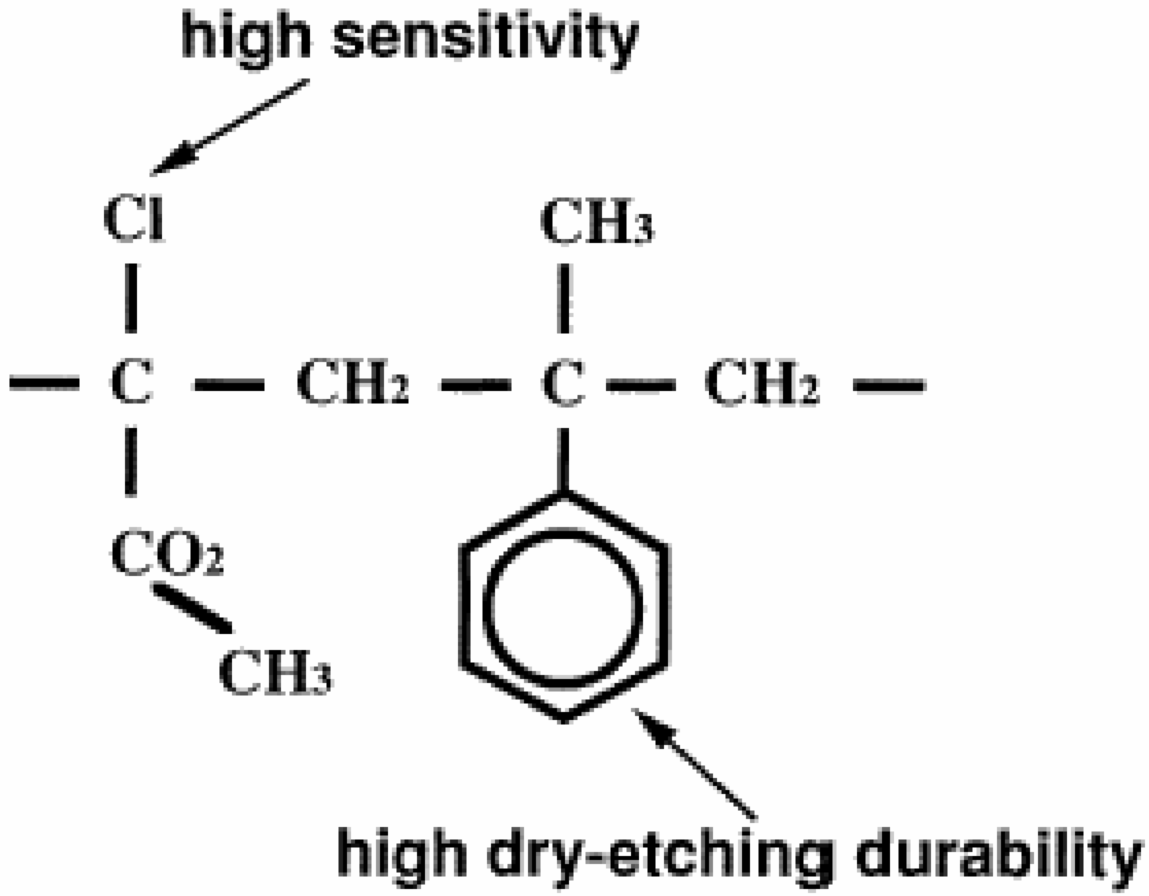
1. ZEP 529

2. PMMA -- Polymethylmethacrylate

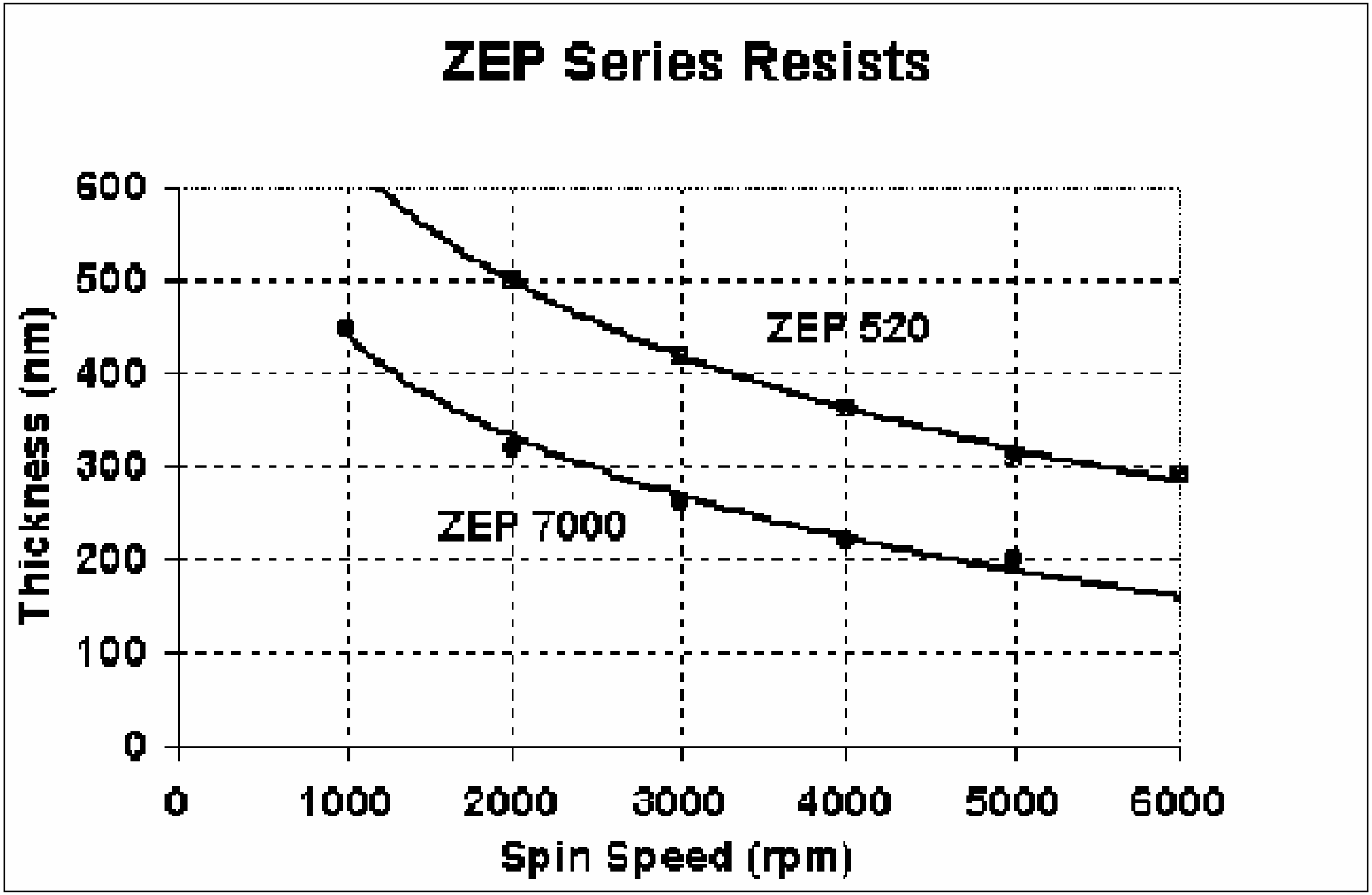
Basic Processing Procedure for ZEP Series

Surface Preparation	In general, no surface preparation (aside from normal cleaning) is necessary. Excellent adhesion to most surfaces.
Spin	Speed 1000-5000 rpm, 60 sec. (100-1000 nm)
Pre-bake	170˚C hotplate, 2 minutes
Expose	10 - 20% the dose requirement of PMMA
Develop	Solvent develop depending on resist
Rinse	With IPA
Dry	By spinning or dry N_2
Post-Bake	Not normally necessary.
Descum	RIE conditions: 30 sccm O_2, 30 mTorr total pressure, 90 W (0.25 W/cm²), 5 sec. or: Descum in barrel etcher, 0.6 Torr of oxygen, 150W, 1 min.
Stripping	Remover 1165 overnight @ RT, or 1165 @ 70˚(bath in PG room) for (30 minutes. O_2 plasma etches NEB very well. Remove residual resist with oxygen RIE: 30 sccm O_2, 30 mTorr total pressure, 0.25 W/cm², 5 min.

ZEP Chemical Structure



Thickness vs. Spin Speed for ZEP



ZEP520 Exposure Characteristics

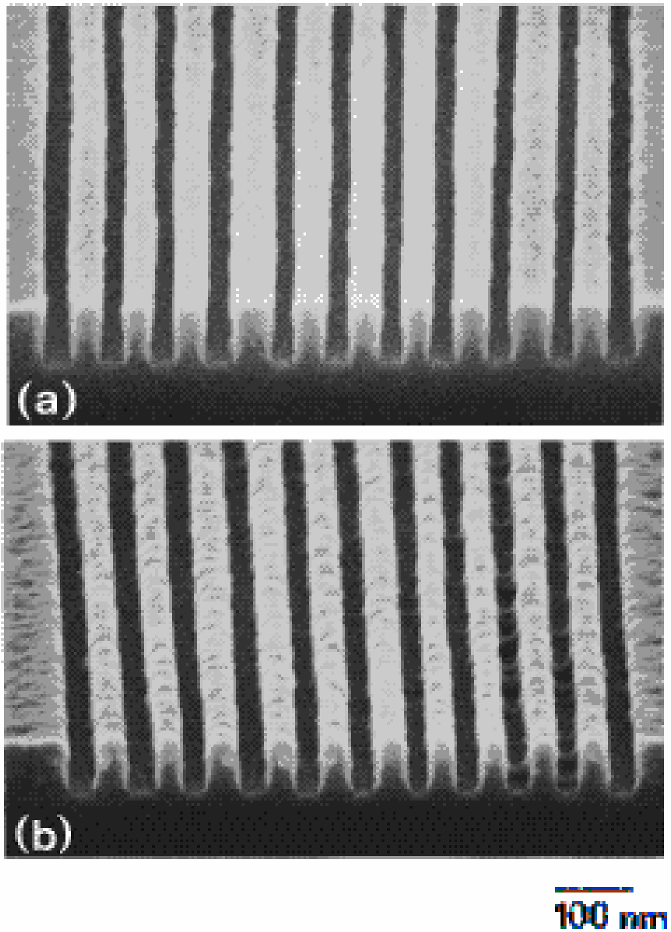


FIG. 2. Scanning electron micrographs (SEM) of ZEP-520 resist patterns after development. The developers were (a) hexyl acetate and (b) xylene.

Developing Solutions

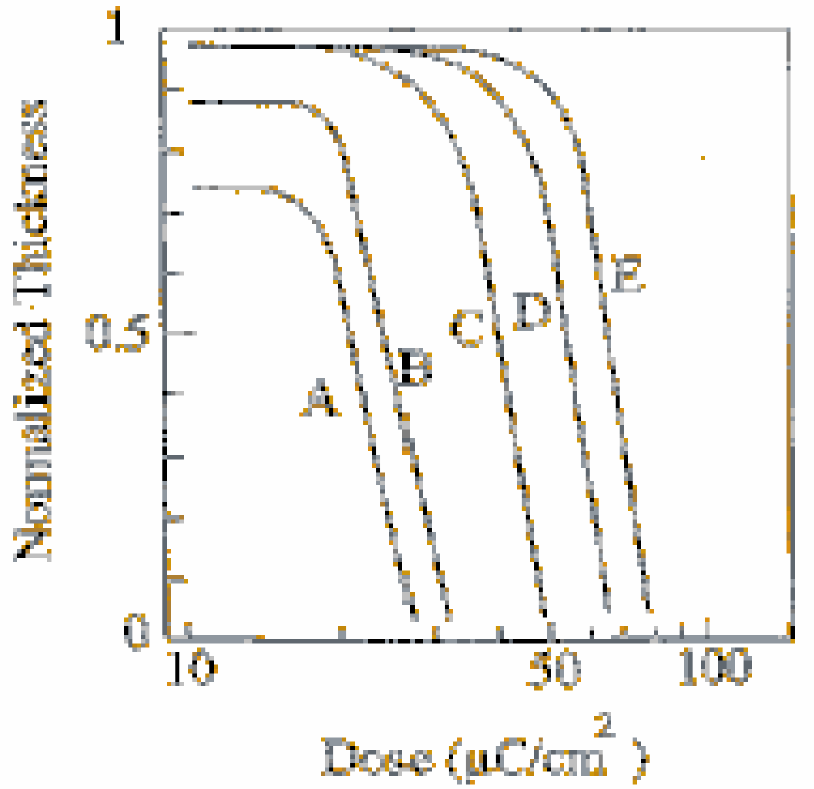
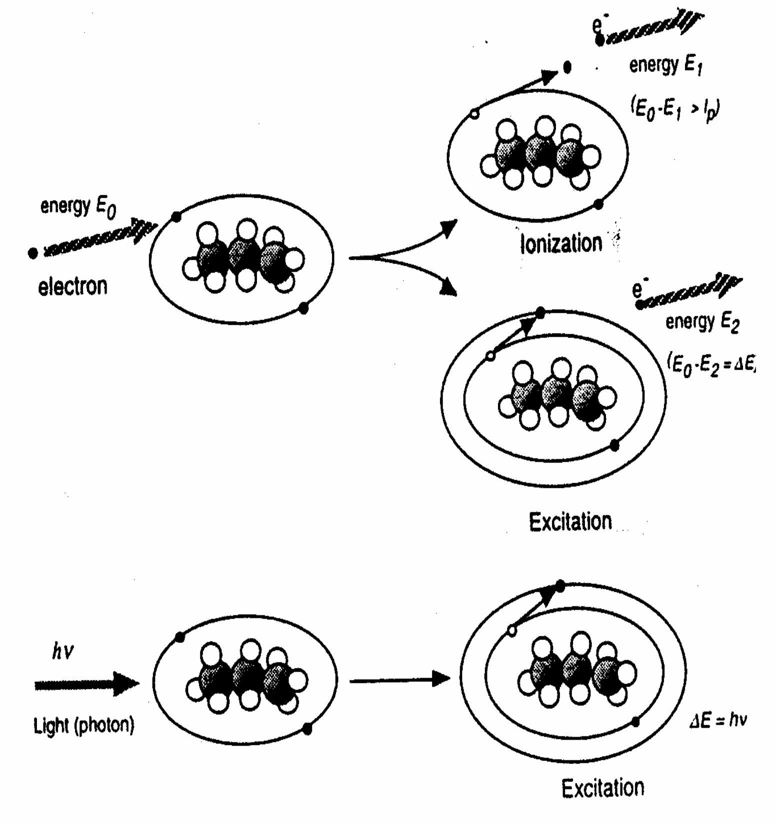


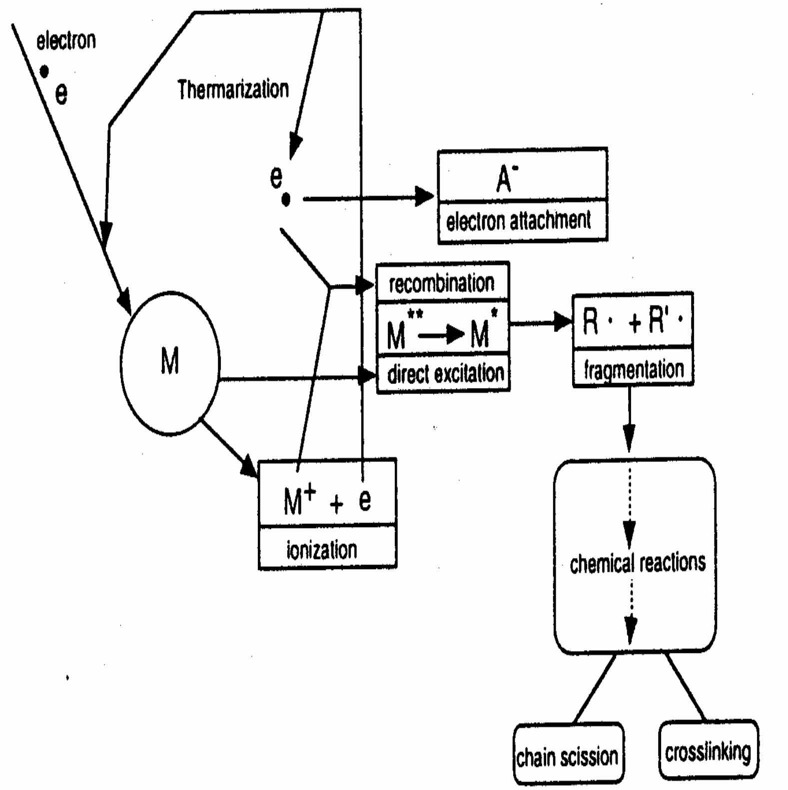
FIG. 1. Sensitivity curves of ZEP-520 resist developed in (A) xylene, (B) amyl acetate, (C) hexyl acetate, (D) heptyl acetate, and (E) octyl acetate. The resist thickness is 100 nm.

Basic Processing procedure for PMMA Resist

Surface Preparation	In general, no surface preparation (aside from normal cleaning) is necessary. Excellent adhesion to most surfaces.
Spin	Speed 1000-5000 rpm, 60 sec. (100-1000 nm)
Pre-bake	170˚C hotplate, 15 min., non-critical. Must be 150 < T < 200 degrees, for at least 10 minutes. May also be oven baked at 170˚C for 1 hour.
Expose	Dose around 170 uC/cm² at 40 kV.
Develop	1:1 MIBK:IPA, 1-2 minutes. (1:3 MIBK:IPA is an option, offering higher resolution, but lower sensitivity i.e. higher dose.)
Rinse	With IPA
Dry	By spinning or dry N_2
Post-Bake	Not normally necessary. Flow can begin as low as 120˚C. Does not seem to noticeably improve adhesion or etch resistance.
Descum	Light! (But necessary for good liftoff and clean etching.) PMMA etches very fast in oxygen. In an oxygen RIE, descum times are short, around 5 sec. In a barrel asher, times can be around 1 minute, but beware! Do not preheat the PMMA. Removal rates increase dramatically with temperature.
Stripping	Most solvents, including methylene chloride and acetone will strip PMMA, as will NMP (Remover 1165). It is removed very well by strong bases (KOH), and by acid normally hostile to organics, such as NanoStrip. Oxygen plasmas etch PMMA very well.

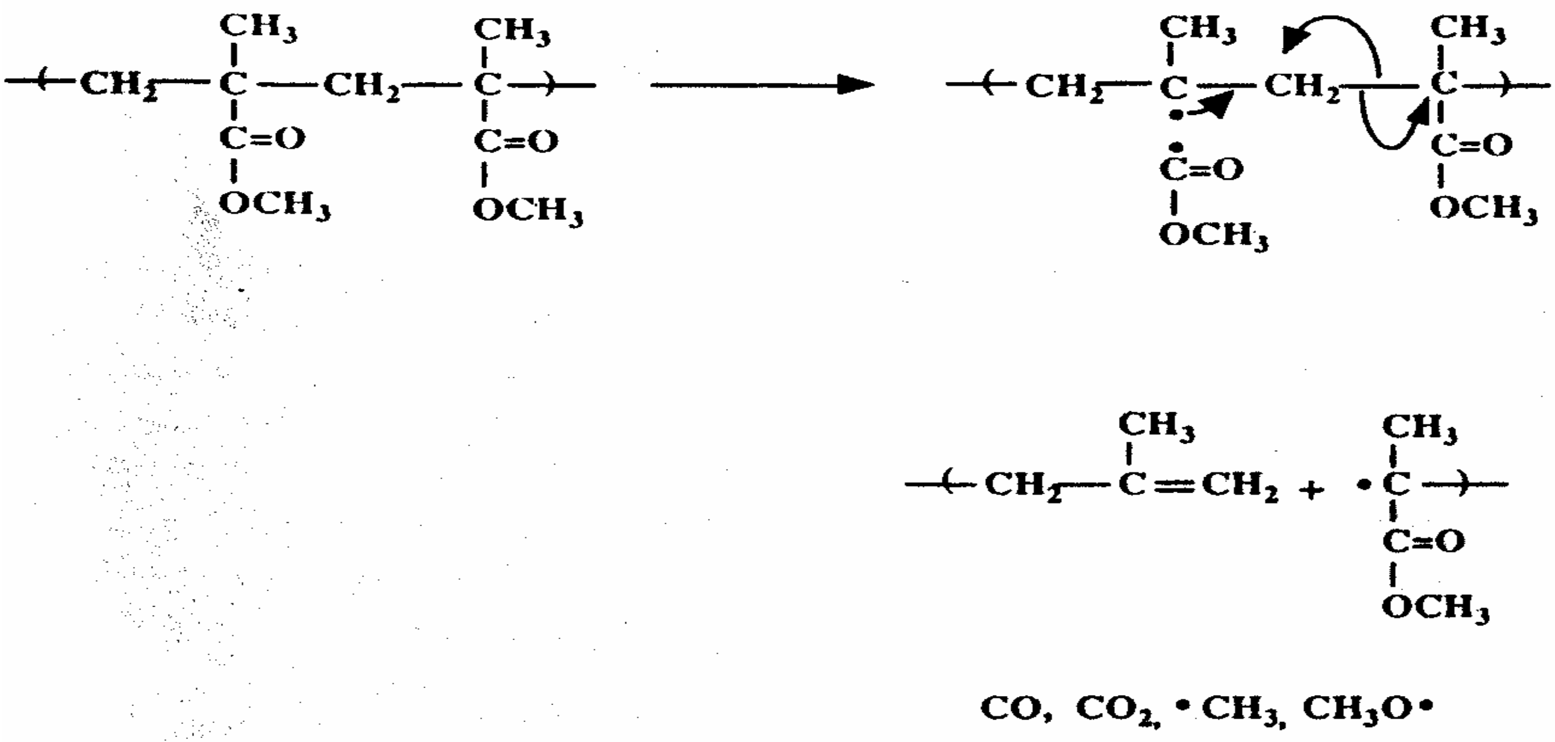
Interaction between Electrons and PMMA





PMMA Chemical Structure

Polymethylmethacrylate(PMMA)



Variety of PMMA

1. Unexposed PMMA --

2. PMMA with Moderate-dose electron irradiation
   – Positive Photoresist (low-molecular weight fragment)

3. PMMA with Heavy-dose electron irradiation (50-70 C/cm^2)
   -- Negative Photoresist (Cross-linked PMMA)

Combination of Positive and Negative PMMA

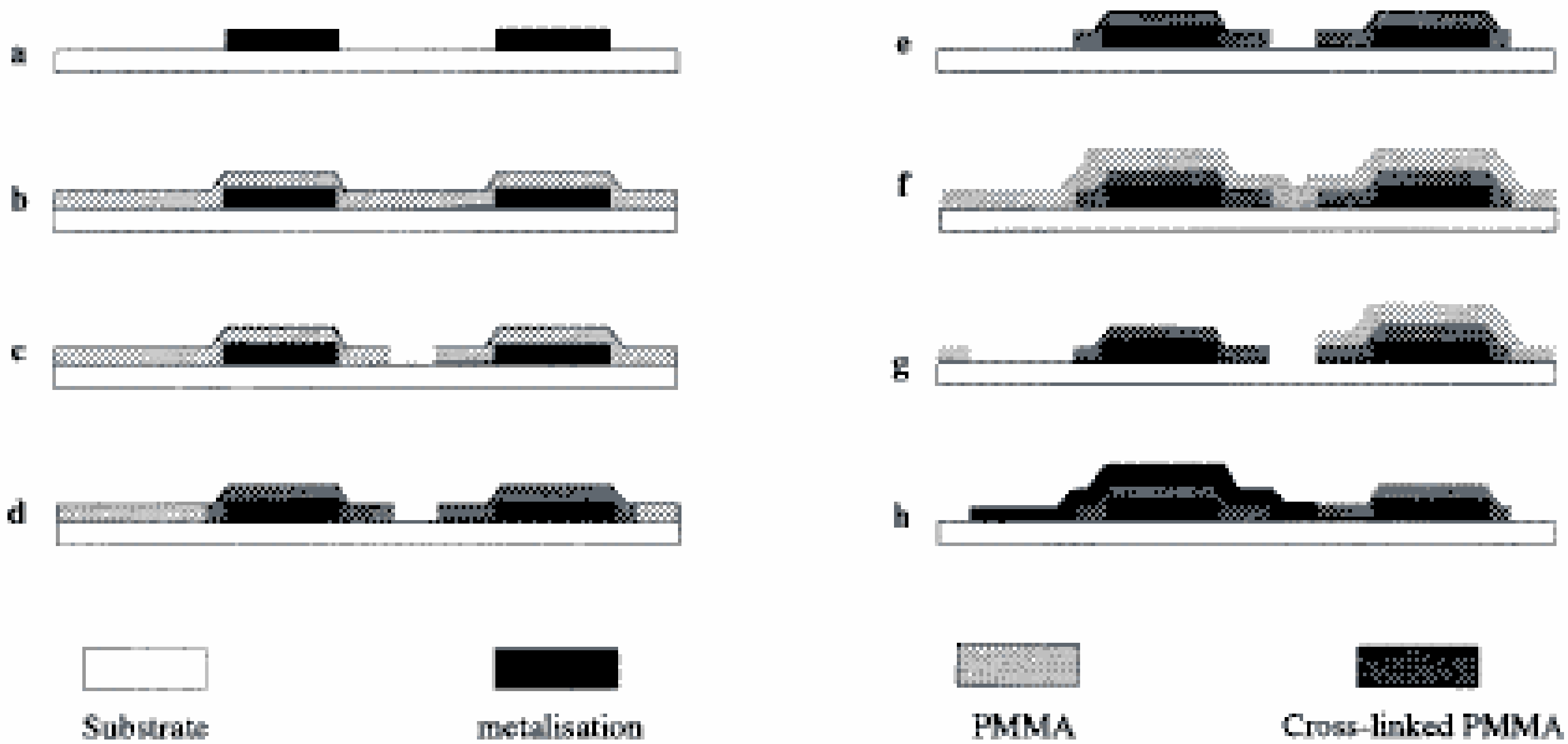
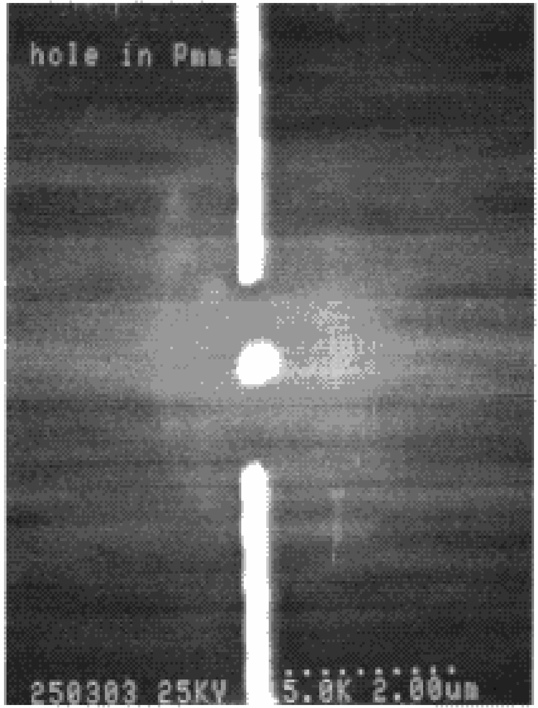
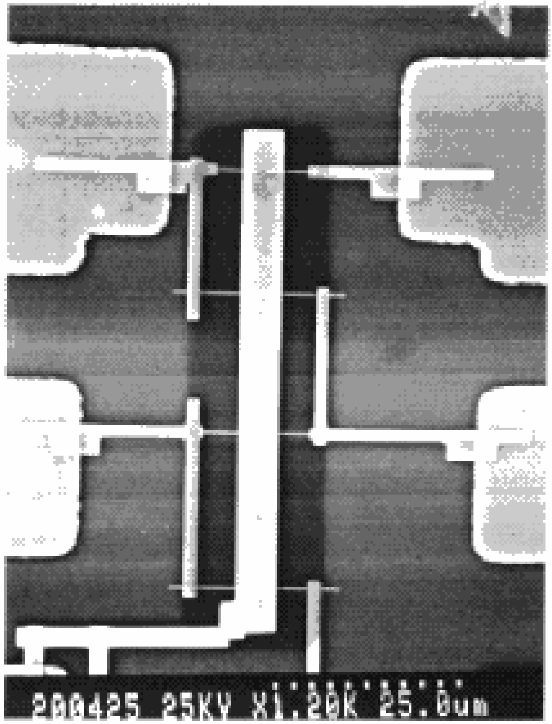


Figure 2. Schematic representation of the high-resolution negative resist process.

Crosslinked PMMA Applications



(*a*)



(*b*)

Figure 3. (*a*) A hole in crosslinked PMMA, in the middle of a split-gate gap. (*b*) The full device; the dark rectangle is a layer of crosslinked PMMA. The layer insulates the split-gate devices from the long top gate (horizontal bar) which connects to the central dot gate via the holes in the PMMA (see (*a*)).

Wet Etching for GaAs and Si

Table 2 Etchants for Silicon and Gallium Arsenide

Semi-Conductor	Etchant	Purpose	Composition	Etch Rate (μm/min)
Si	CP-4A	Polishing or lapping	3 ml HF 5 ml HNO_3 3 ml CH_3COOH	34.8
	CP-8	Polishing	1 ml HF 5 ml HNO_3 2 ml CH_3COOH 0.3 g I_2/250 ml solution	7.4
	Junction-staining etch	Measurement of Junction depth	HF + 0.1% HNO_3	–
	Orientation-dependent etch	Groove etching	23.4 wt% KOH 13.3 wt% Propyl alcohol 63.3 wt% H_2O	0.6 for <100> 6×10^{-3} for <111>
GaAs	H_2SO_4–H_2O_2–H_2O System	Polishing	8 ml H_2SO_4 1 ml H_2O_2 1 ml H_2O	0.8 for <111>-Ga 1.5 for all other
	H_3PO_4–H_2O_2–H_2O System	Polishing	3 ml H_3PO_4 1 ml H_2O_2 50 ml H_2O	0.4 for <111>-Ga 0.8 for all other

Orientation-Dependent Wet Etching

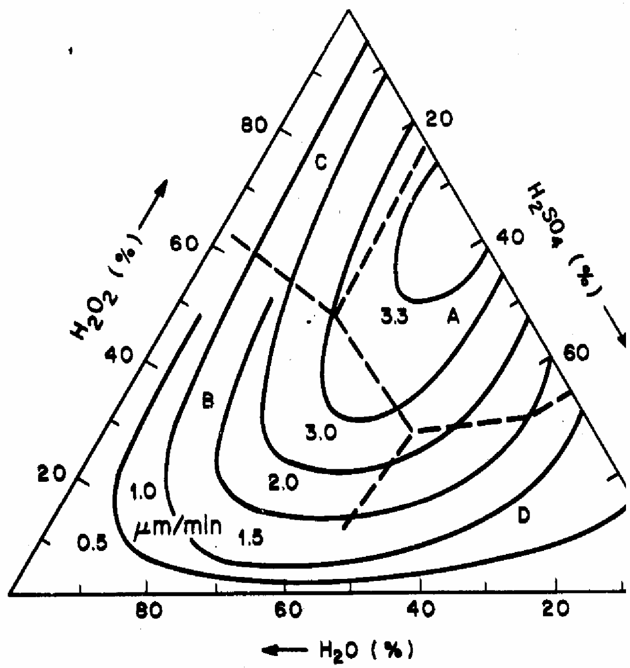


Fig. 23 Isoetch curves for GaAs (H_2SO_4:H_2O_2:H_2O system

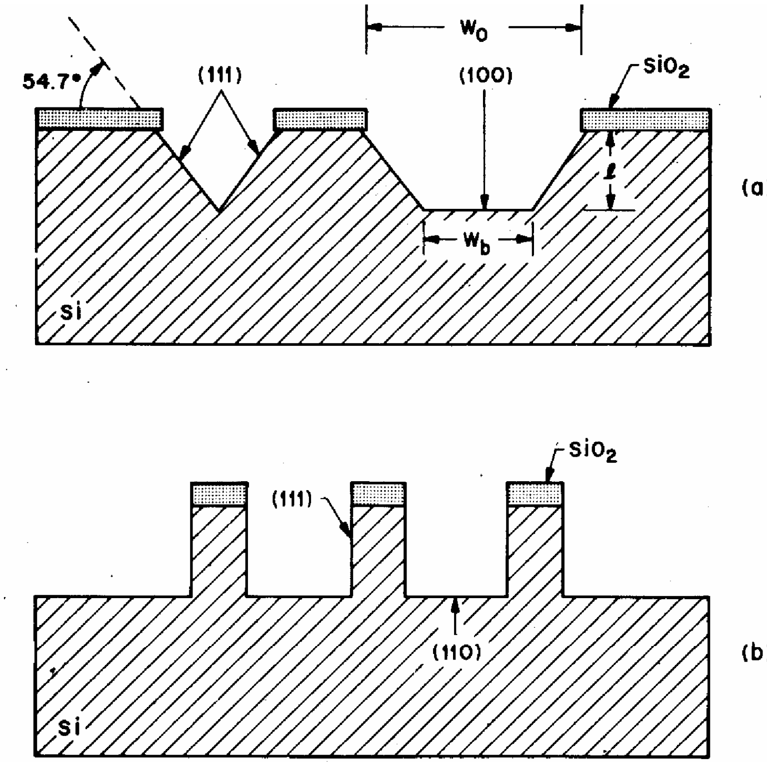


Fig. 24 Orientation-dependent etching. (*a*) Through window patterns on <100>-oriented silicon. (*b*) Through window patterns on <110>-oriented silicon.[20]

Wet Etching for Insulators and Conductors

Table 3 Etchants for Insulators and Conductors

Material	Etchant Composition	Etch Rate
SiO_2	28 ml HF, 170 ml H_2O, 113 g NH_4F (Buffered HF)	1000 Å/min
	15 ml HF, 10 ml HNO_3, 300 ml H_2O (P-Etch)	120 Å/min
Si_3N_4	Buffered HF	5 Å/min
	H_3PO_4	100 Å/min
Al	1 ml HNO_3, 4 ml CH_3COOH, 4 ml H_3PO_4, 1 ml H_2O	350 Å/min
Au	4 g KI, 1 g I_2, 40 ml H_2O	1 μm/min
Mo	5 ml H_3PO_4, 2 ml HNO_3, 4 ml CH_3COOH, 150 ml H_2O	0.5 μm/min
Pt	1 ml HNO_3, 7 ml HCl, 8 ml H_2O	500 Å/min
W	34 g KH_2PO_4, 13.4 g KOH, 33 g $K_3Fe(CN)_6$, H_2O to make 1 liter	1600 Å/min

Dry Etching with Plasma

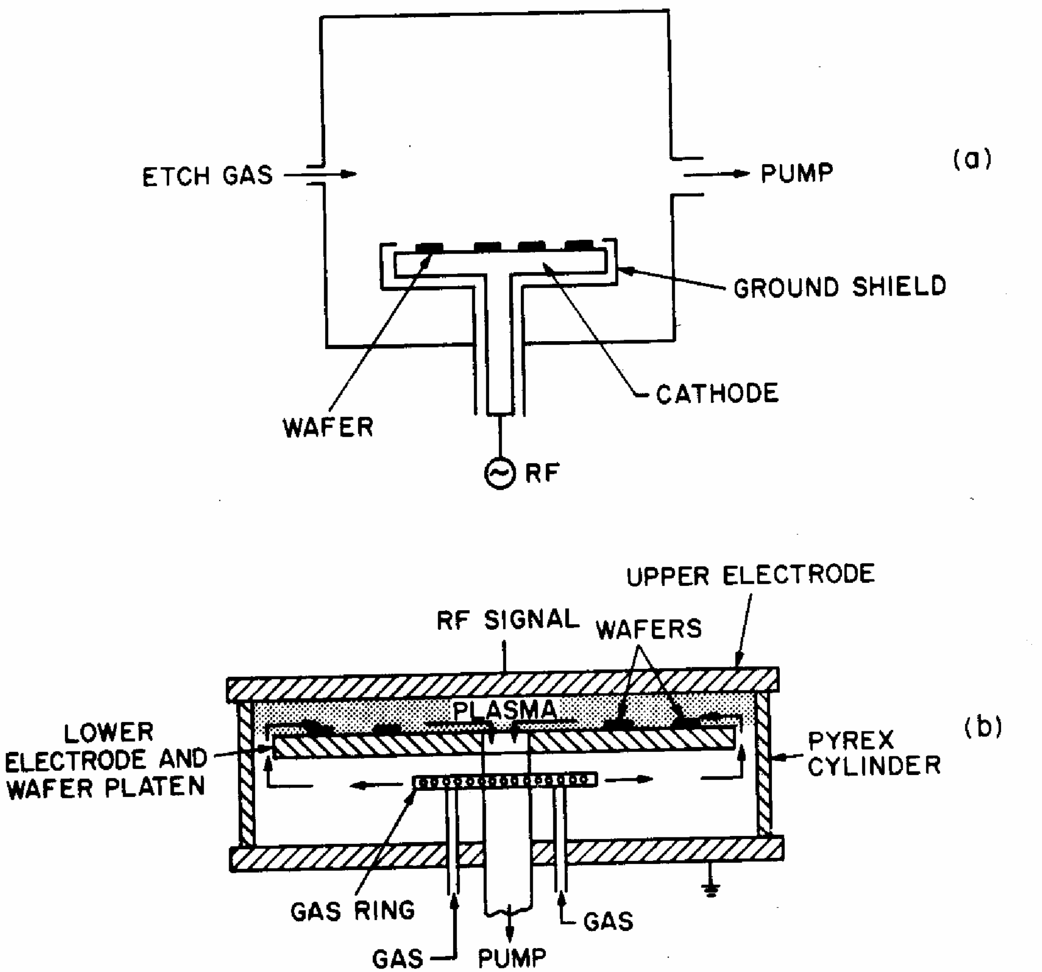


Fig. 27 (*a*) A sputtering-etching system. (*b*) A parallel-plate, plasma-etching system.[3]

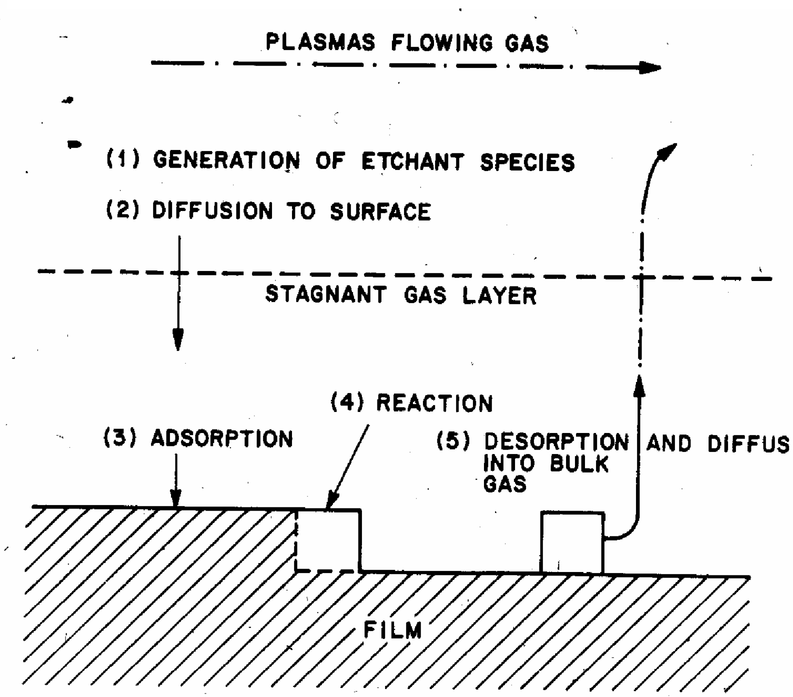


Fig. 28 Basic steps in a dry-etching processing.[23]

Comparison between Dry and Wet Etchings

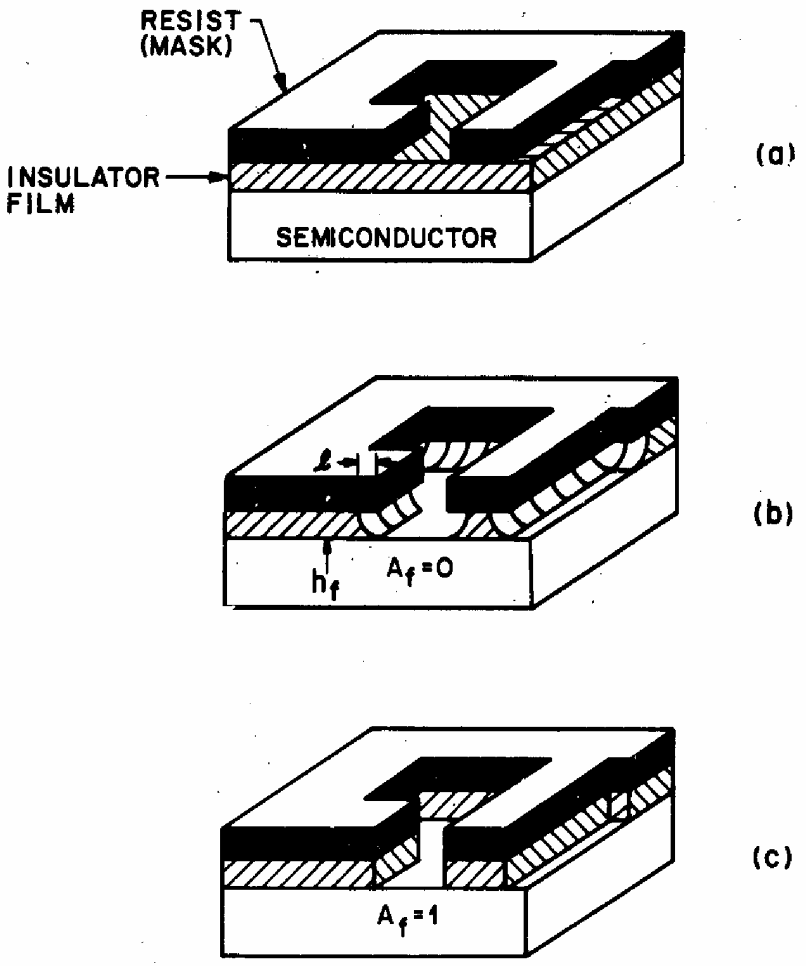
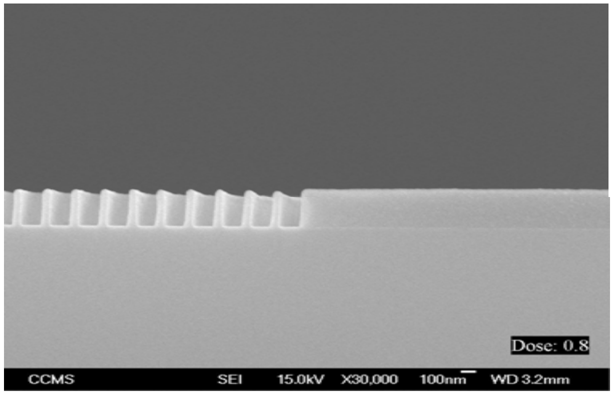


Fig. 26 Comparison of wet chemical etching and dry etching for pattern transfer.[22]

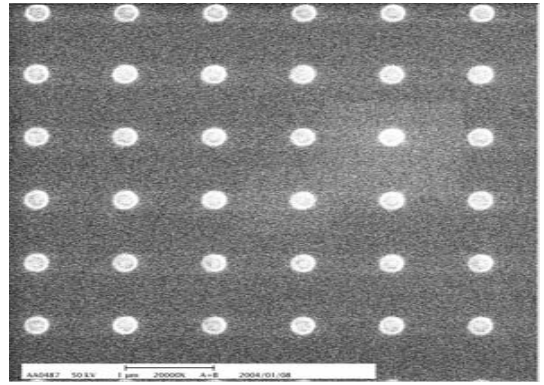
Various Applications

1. Nanostructures
2. Biology
3. Optoelectronics
4. Electronics
5. MENS

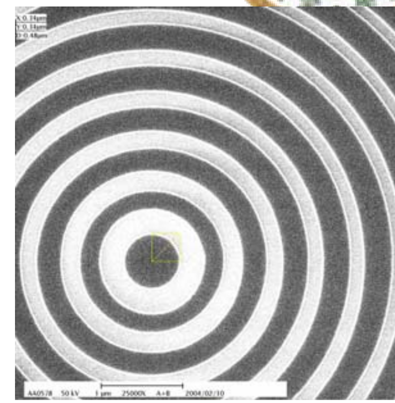
我們所製作的奈米結構



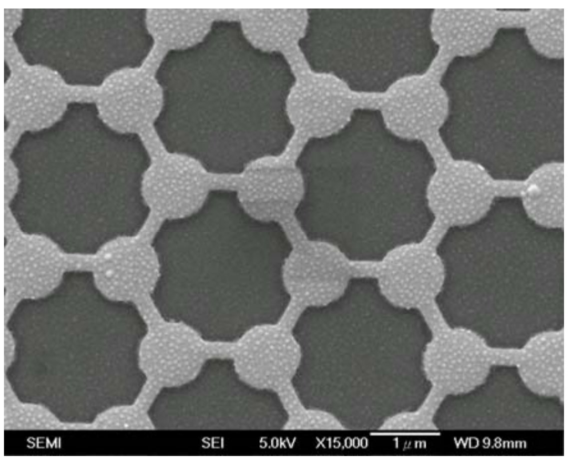
Selective Grating



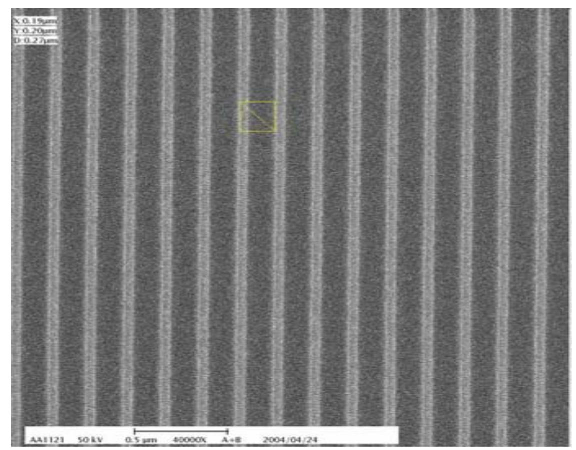
Quantum Dot Array
250 nm



Rings

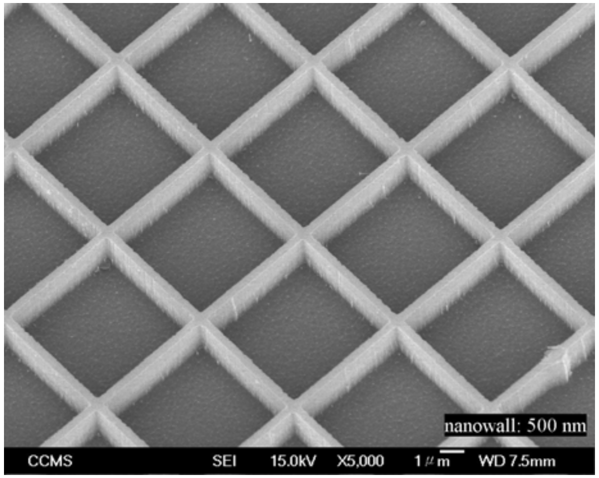


Au Hexgon

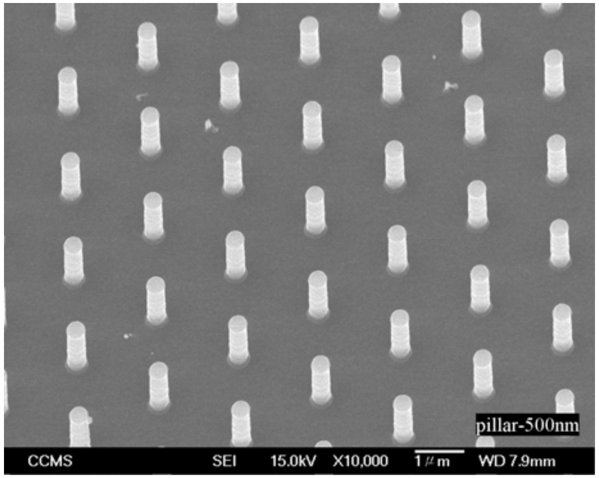


10 nm Lines

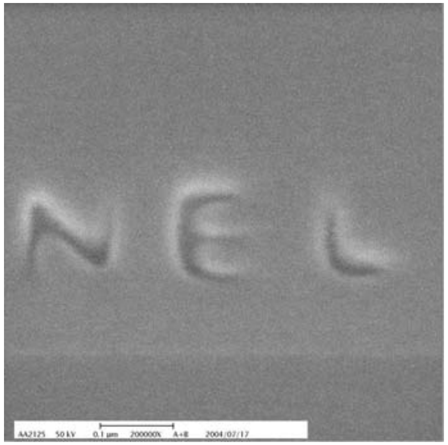
我們所製作的奈米結構



500 nm nanowalls



500 nm Pillar Array

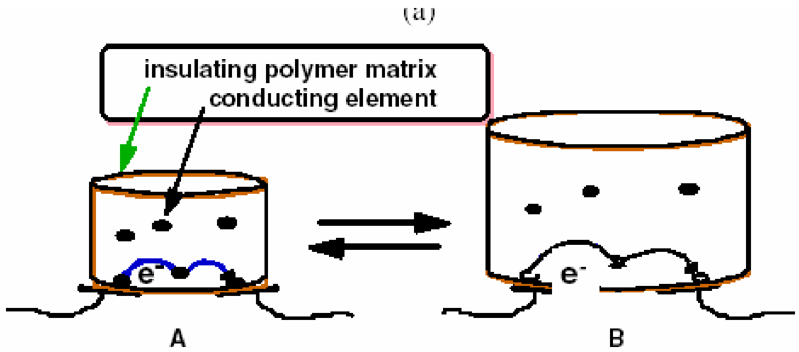


NEL (Nano Electronic Lab)
With 14 nm lines

NTUEE

Kuan

Biochip– Nose Chip



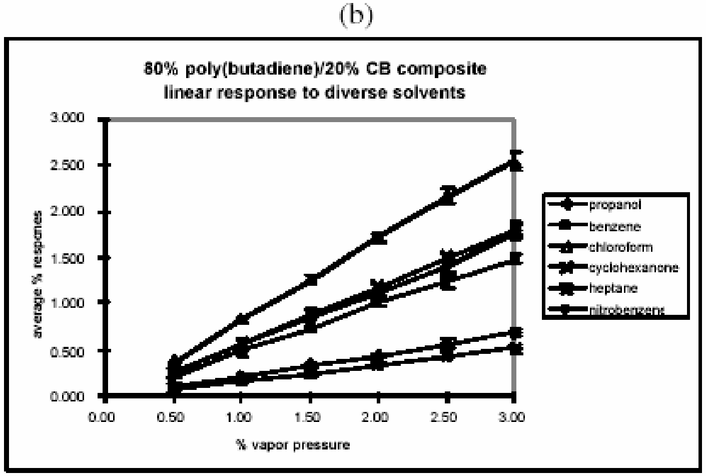
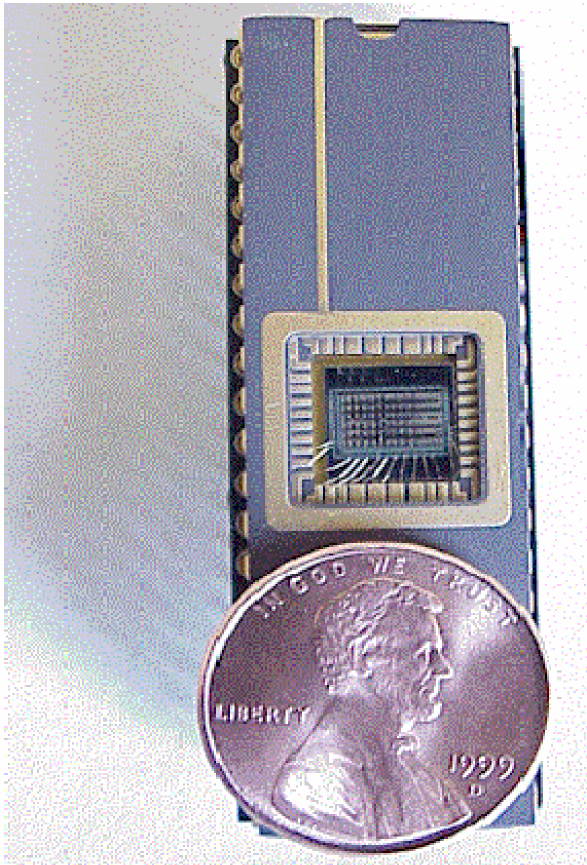


Fig. 1a Swelling occurs as an odorant partitions into the polymer. (b) A linear response of an individual sensor signal as a function of concentration is observed for a variety of analytes.



Photograph of a “nose-chip”, with 12 columns and 6 rows, each having a different polymeric sensor combination and each pixel having a switch under its pair of contact lines.

Biochip– Cochlear Auditory Prosthesis

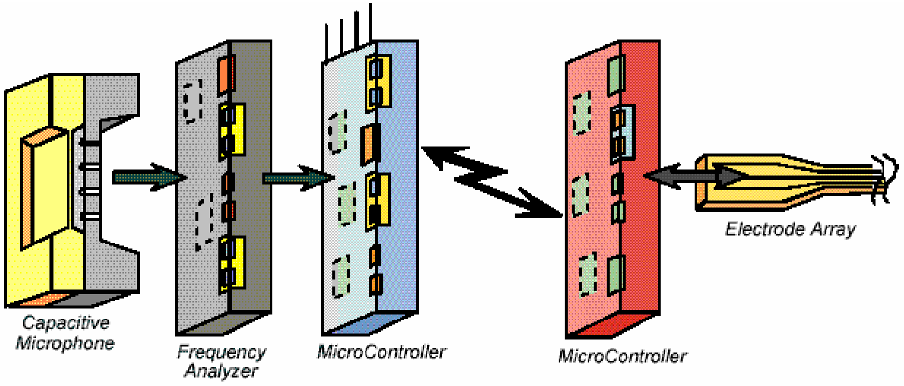
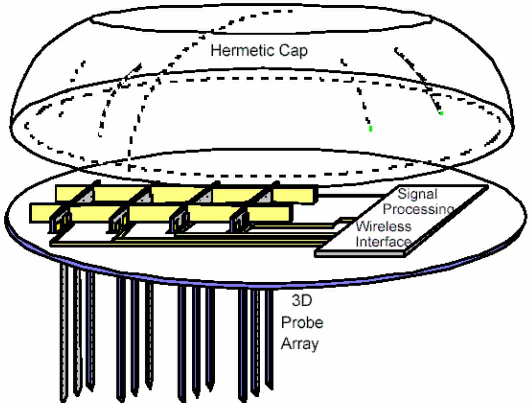
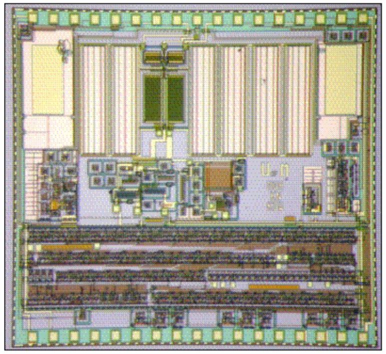


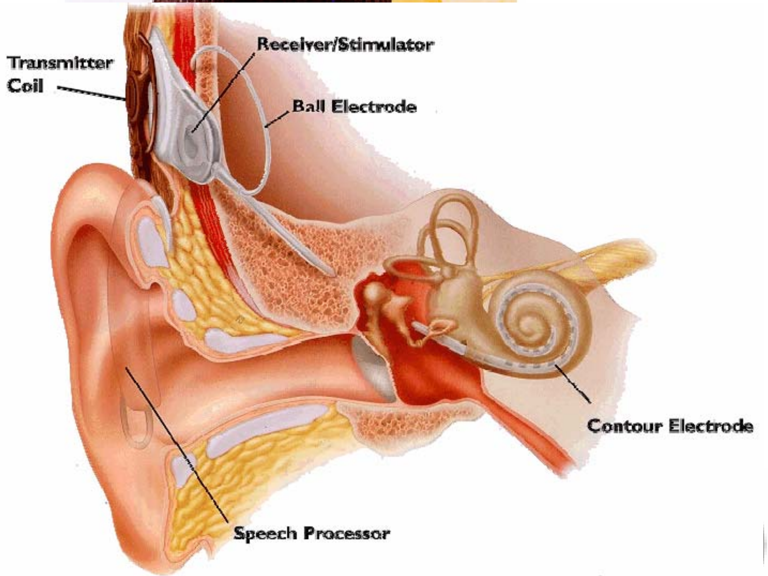
Fig. 1: Block diagram of a cochlear auditory prosthesis.



3D Si penetrating array



CMOS wireless interface
2 μm x 2 μm

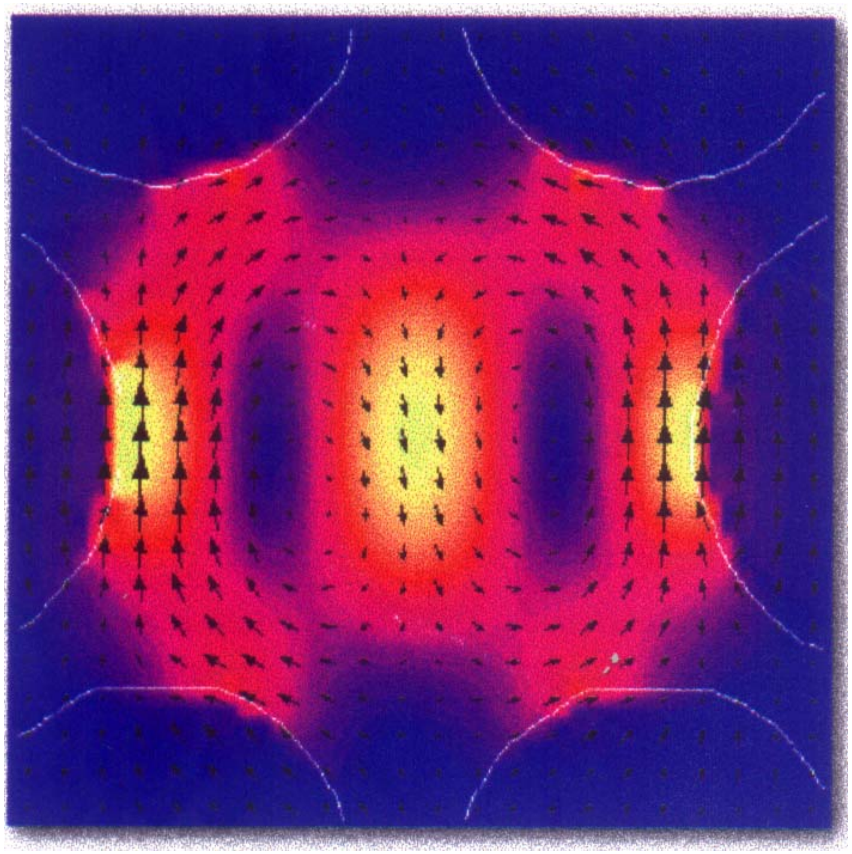


Optoelectronics--Photonic crystals

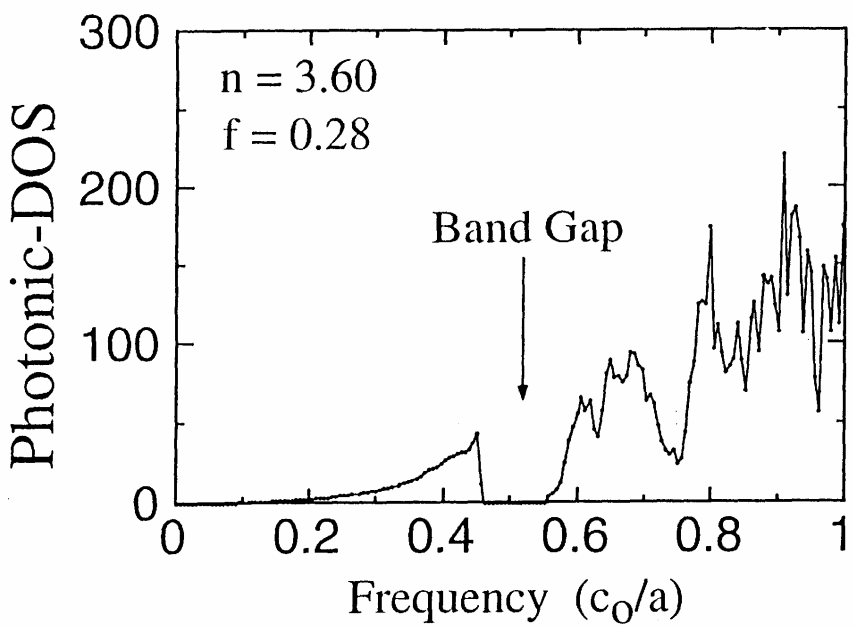
利用光子晶體可達到：

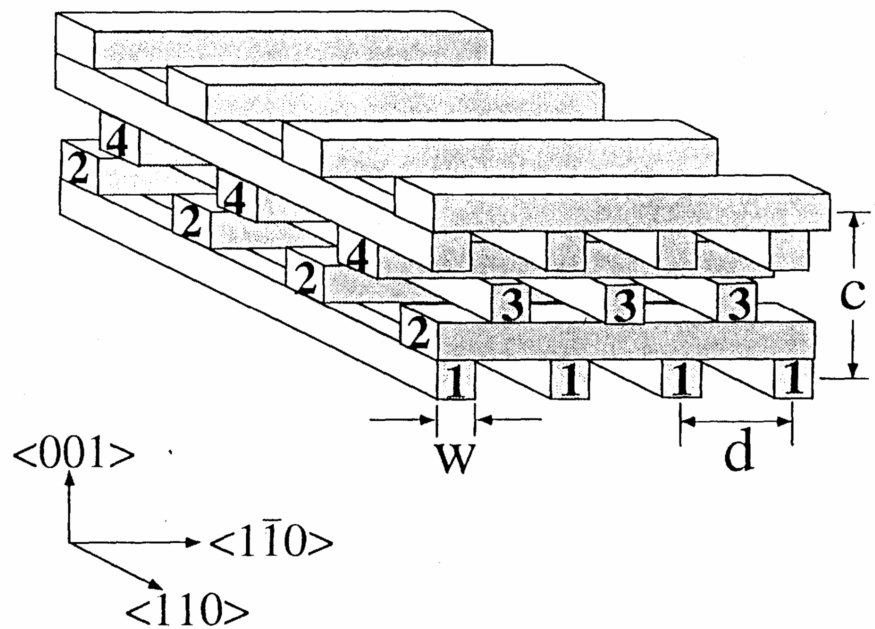
1.局限光子於有限空間中

2.抑制光子的產生

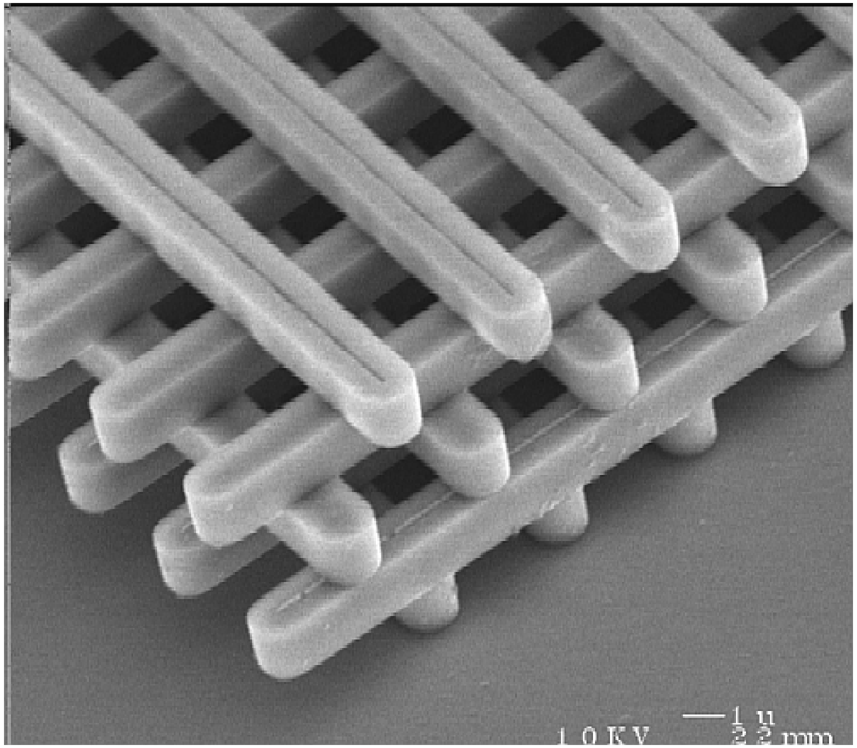


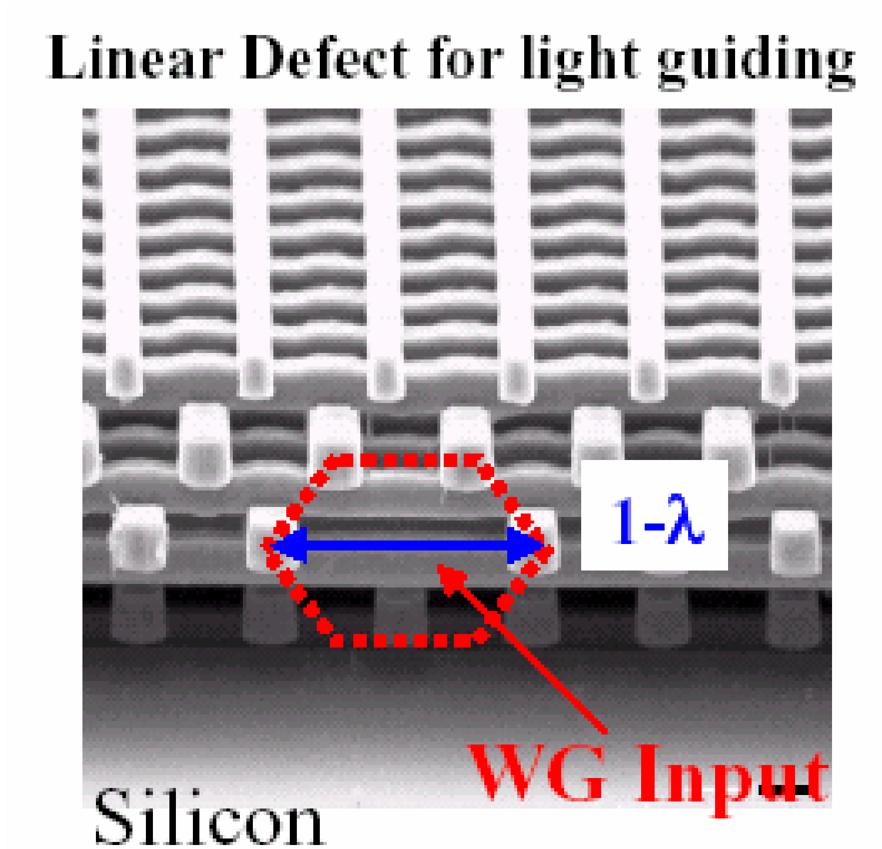
光子在光子晶體中的能帶結構





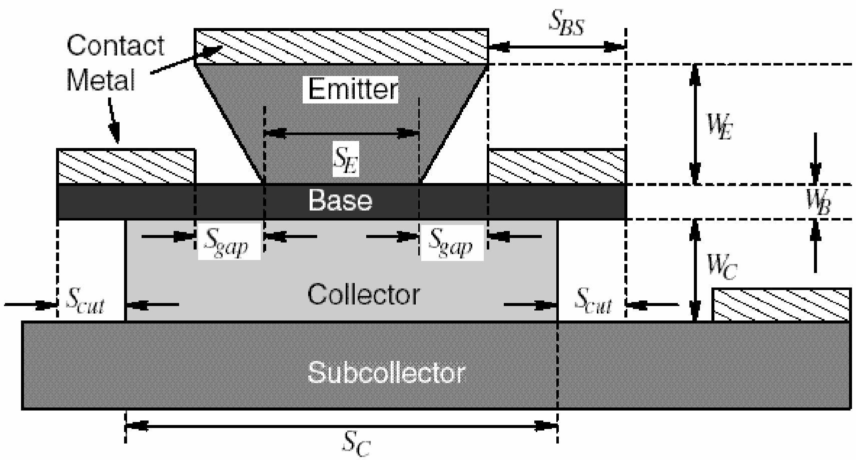
Photonic Crystal-實際範例





From American Institute of Physics and Sandia National Lab

InP Based SHBT



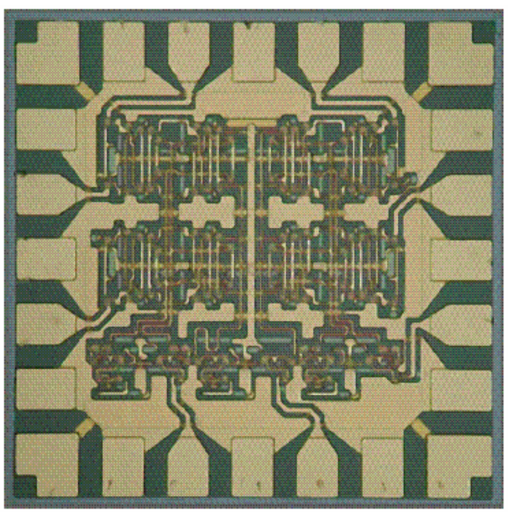


Figure 8: 40 Gb/s InP/InGaAs-SHBT 1:4 DEMUX

S_E [µm]	**1.2**	**0.75**	**0.5**	**0.25**
W_E [nm]	150	70	70	70
W_B [nm]	50	20	20	20
W_C [nm]	560	150	150	150
S_C [µm]	3	1	0.75	0.5
S_{BS} [nm]	700	300	300	300
S_{cut} [nm]	0	375	375	375
S_{gap} [nm]	200	200	200	200
f_t [GHz]	115 *	290	305	315
f_{max} [GHz]	170 *	405	525	755
t_g [ps]	n/a	2.6	2.3	1.9
BR [Gb/s]	n/a	115	130	160

25 nm CMOS Omega FETs

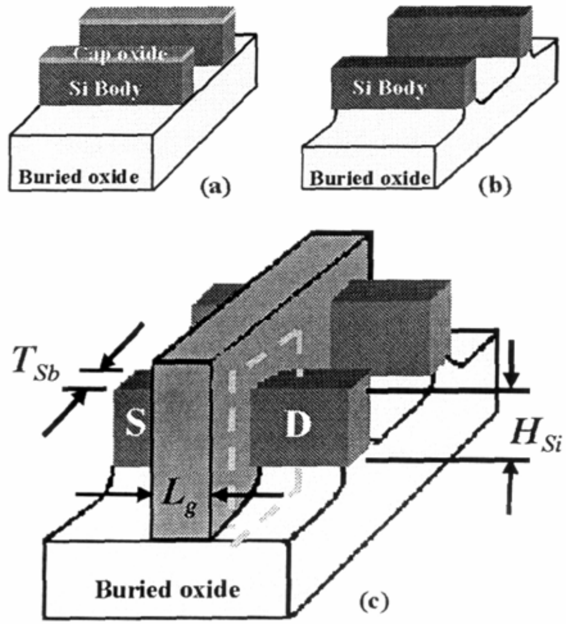


Figure 2. Schematic illustration of the fabrication of CMOS Ω-FETs, including:
(a) Si patterning for active area, with cap oxide on top of the Si body;
(b) Sacrificial oxide growth and sidewall silicon treatment for obtaining smooth surface; followed by cap oxide removal and the undercutting of buried oxide under silicon body; and
(c) Gate dielectric formation, gate deposition, and gate patterning. In this work, in-situ doped N+ poly silicon gate is adopted for 1.0 V version, and N+ and P+ dual-poly Si gates are adopted for 0.7 V version.

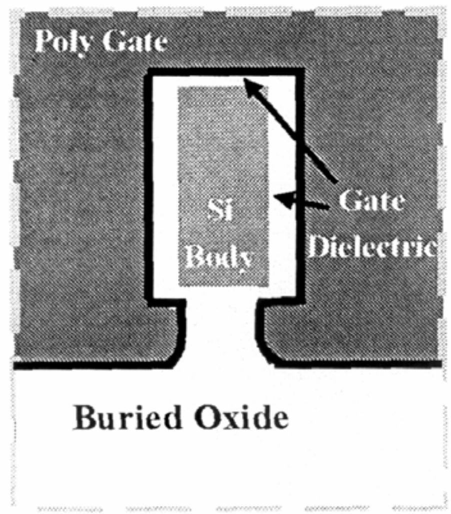
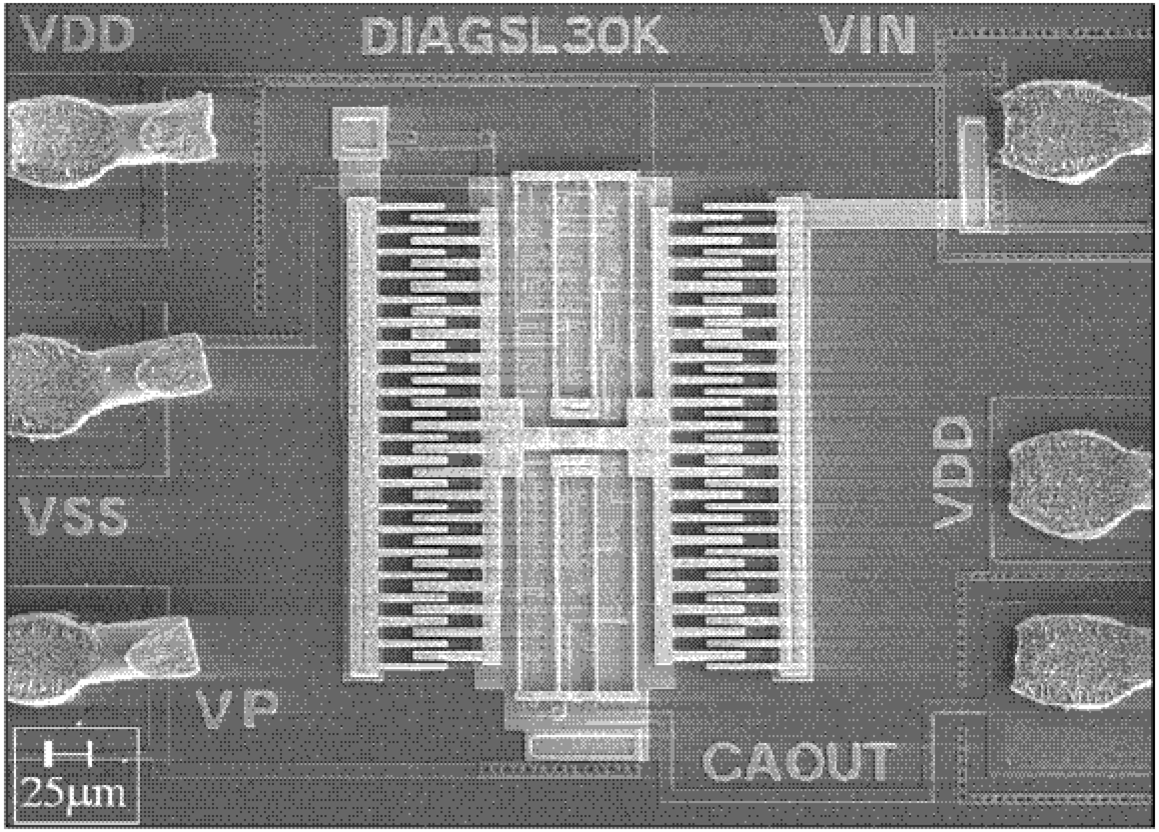


Figure 3. Schematic diagram showing the cross-section of the Ω-FET through the dashed square in Figure 2 (c). The silicon body is almost wrapped around by Ω-shaped gate except for the bottom center portion of the silicon body.

MENS– Comb Drive Resonator



A CMOS amplifier is under the resonator

A Promising Future
Is Based on
Micro Integrated Circuits and Nano-Technology

EXCITING TIMES ARE AHEAD OF US!