微影製程

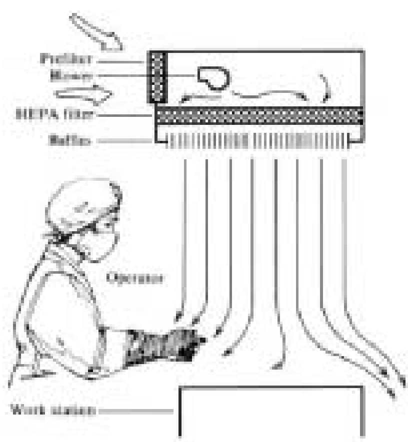
Lithography

余 志 成
高雄第一科技大學機械系

Department of Mechanical and Automation Engineering
National Kaohsiung First University of Science and Technology

Clean Room

- Particles
- Humidity
- Vibration
- Pressure
- Electromagnetic wave
- Static
- De-Ionized water



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無塵室等級

- 塵粒控制
  - HEPA過濾
  - 洗手→戴口罩→戴無塵帽→穿無塵衣→穿無塵鞋→戴塑膠手套→用空氣清洗

日本：每立方英呎室內之空氣所含有大於或等於0.1μm之微塵粒子顆數		美國：每立方英呎室內之空氣所含有大於或等於0.5μm之微塵粒子顆數	
級別 1	不超過10^1顆	Class 1	不超過1顆
級別 2	不超過10^2顆	Class 10	不超過10顆
級別 3	不超過10^3顆	Class 100	不超過100顆
級別 4	不超過10^4顆	Class 1000	不超過1000顆

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無塵室的控制項目

- 溫度：22°±2°，濕度50 ±5%
- 振動：增加廠房質量以吸收能量
- 水的控制：去除雜質以避免短路、缺陷，控制水中離子濃度(DI water)以避免與化學藥品或晶圓直接發生反應。
- 氣體控制：製程使用氣體（N_2, Ar, O_2, H_2, SiH_4）若含有不純物可能造成元件漏電或破壞氧化薄膜。
- 電磁波：可能造成設備功能失常，可採用電磁遮蔽的金屬包覆空間以隔絕電磁波
- 靜電：靜電會吸附顆粒，造成晶圓線路短路，而靜電放電會引爆可燃氣體

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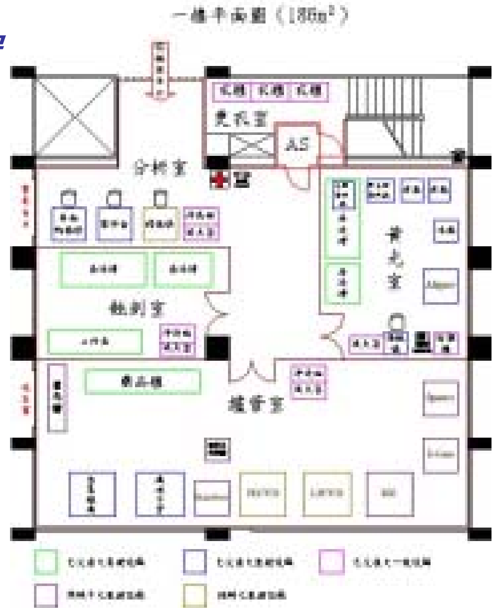
無塵室的典型配置

- 北區微機電中心平面圖
- 黃光區class 1000
  - 光阻塗佈、光罩對準曝光、顯影
- 其他區域class10000
  - 化學蝕刻室
  - 鍍膜蝕刻區
  - 分析區



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無塵室常見的污染源

- Location: a clean room near a refinery, smokestack, sewage plant, or cement plant spells big trouble.
- Construction: the floor is an important source of contamination. Also, items such as light fixtures must be sealed, and room construction tolerances must be held very tight.
- Wafer handling: transfer box.
- Process equipment: never use fiberglass duct liner, always use 100% polyester filters; eliminate all nonessential equipment.
- Chemicals: residual photoresist or organic coatings, metal corrosion.
- Attire: wear only proper attire and dress only in the anteroom.
- Electrostatic discharge: clean room must have a conductive floor.
- Furniture: use only clean room furniture.
- Stationary: use a ballpoint pen instead of a lead pencil, only approved clean room paper.
- Operator: no eating, drinking, smoking, chewing gum, or makeup of any kind.

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Lithography

- 微影製程的步驟與所需之儀器設備
  - 晶片清洗—化學清洗槽、去離子水、氮氣槍
  - 去水烘烤—烤箱
  - 塗底—通常以旋鍍機塗佈HMDS
  - 光阻塗佈—通常以旋鍍機
  - 預烤—軟烤箱或熱墊板
  - 對準及曝光—光罩對準曝光機
  - 顯影—化學清洗槽
  - 硬烤—硬烤箱或熱墊板
  - 薄膜蝕刻—化學清洗槽（溼蝕刻）或RIE（乾蝕刻）
  - 去除光阻—化學清洗槽、超音波震盪器

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晶片清洗與塗底

- 晶片清洗
  - 使用去離子水清除晶片上的雜質、以氮氣槍吹乾晶片
- 去水烘烤
  - 在烤箱烘烤去除晶片表面的水分子
- 塗底
  - 通常以旋鍍機塗佈HMDS，以增加光阻與晶片表面附著力

化學清洗槽

Spin Coater (光阻塗佈機)

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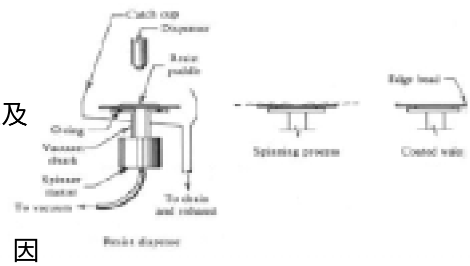
上光阻與預烤

- 上光阻
  - 以旋鍍機(Spin Coating)
  - 影響旋鍍厚度的因素
    - 滴入的光阻液的量
    - 旋鍍機的轉速與時間
    - 光阻液的性質（黏滯性及粒子含量）



- 預烤
  - 降低光阻液中的溶劑含量，因而會減少光阻厚度約10~20%
  - 有回火的效果，使光阻平坦化

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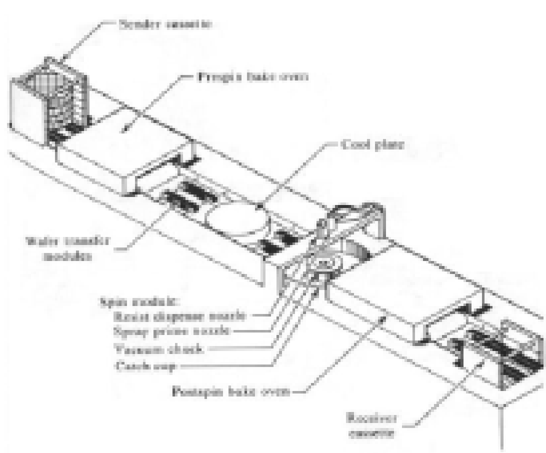
量產方式的光阻塗佈

- An Automated Spin Coater for Photoresist



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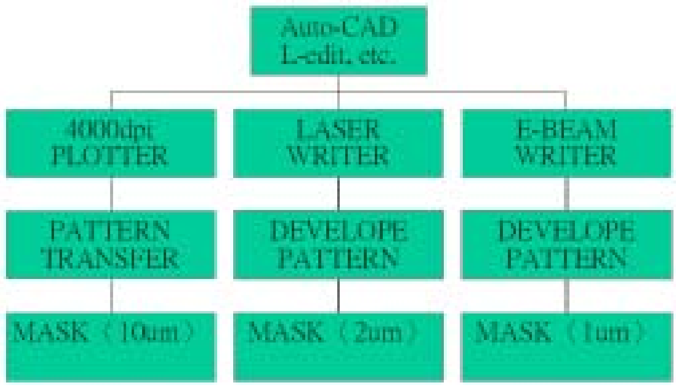
光罩(Mask)製作

- 一般以平坦透明之石英、玻璃，再以鉻（~800Å）當作阻擋層



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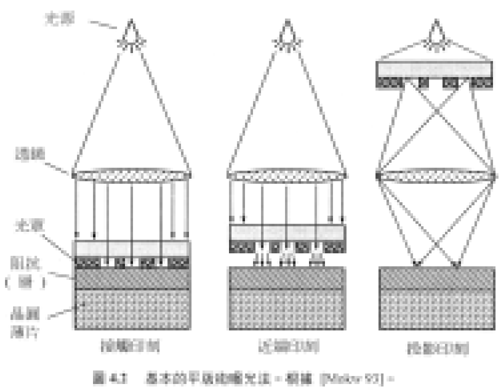
曝光方式

- Contact：可達1微米的結構解析，多用於學校、不適合量產，因接觸易傷害光罩
- In proximity：光罩與晶片保持20-50微米的間隙，受光繞射影響解析度受限於2微米
- Optical projection：解析度約0.5微米，但成本高



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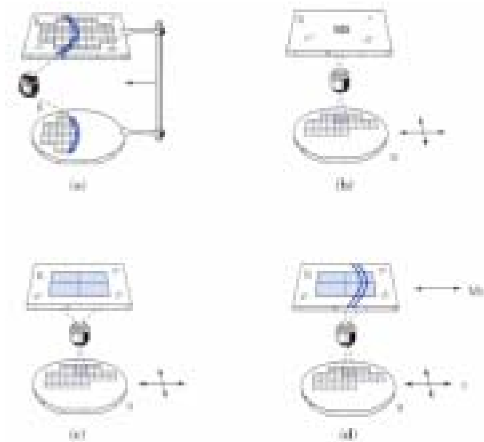
Projection Printing



(a) Annual-field wafer scan

(b) 1:1 step and repeat（重複步進式）

(c) M:1 reduction step and repeat

(d) M:1 reduction step and scan

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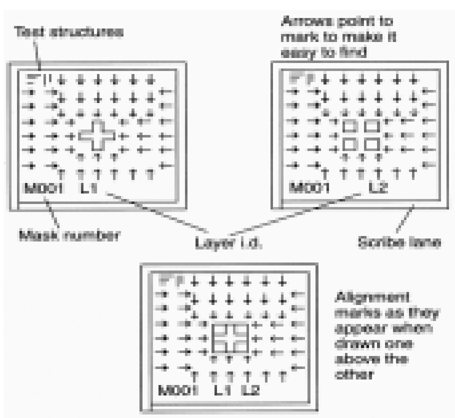
光罩對準記號的設計

■ 設計於光罩的四個角落



A very simple alignment design for two layers (example only, not to scale)

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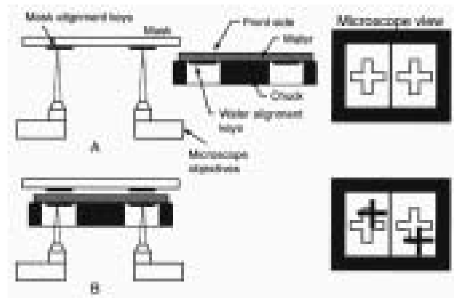
光罩的對準

- 雙面對準
  - 儲存晶片背面的的對準記號
  - 利用曝光機移動晶圓，直至光罩上的對準記號與背面之記號重合

Union PEM800 雙面光罩對準機



曝光光源

- 汞燈(Hg)
  - G-line 波長436 nm（常用於學校）
  - I-line 波長365 nm（常用於0.35微米的IC製程中）
- KrF產生深紫外光(Deep UV)，用於0.25微米的IC製程
- Excimer laser（準分子雷射）
  - KrF 波長248 nm
  - ArF 波長193 nm：用於0.18微米的IC製程
- E-beam（電子物質波）：價錢高，量產中
- X光：能量需求高，價錢昂貴，多用於LIGA製程

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不同光阻對光波長的敏感度

離像術	光阻名稱	正/負光阻	敏感度或感光度
光學	AZ-1350	正光阻	90 mJ/cm^2
	PR102	正光阻	140 mJ/cm^2
	SU8-2（1.5 μm）	負光阻	85-100 mJ/cm^2
	SU8-5（5 μm）	負光阻	120-130mJ/cm^2
電子束	GeSe	負光阻	80 μc/ cm^2
	PBS	正光阻	1 μc/ cm^2
	PMMA	正光阻	50 μc/ cm^2
X 光	COP	負光阻	175 mJ/cm^2
	PBS	正光阻	95 mJ/cm^2
	PMMA	正光阻	1000 mJ/cm^2

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Critical Dimension

- Critical Dimension (CD)

$$CD \propto \sqrt{\lambda g}$$

- λ 光源波長
- g 光罩與晶圓間隙

Ex: λ = 0.4 micron

g = 50 micron

CD ~ 4.5 micron

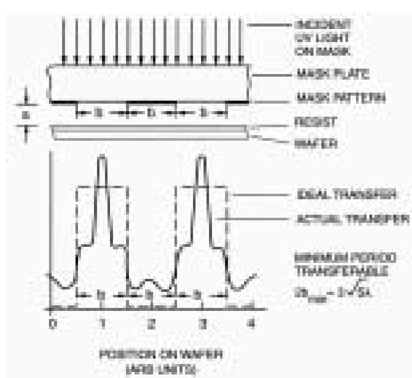

Figure 1.12 Light distribution profiles on a photoresist surface after light passes through a mask containing an equal line and space grating. (From C.G. Willson in Introduction to Microlithography, L. F. Thompson, C.G. Willson, and M.J. Bowden, Eds., American Chemical Society, Washington, D.C., 1994." Reprinted with permission.)

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正光阻與負光阻

- 正光阻：分子鍵在曝光後被打斷，在顯影時會被溶去
- 負光阻：分子鍵在曝光後被交鏈，在顯影時為曝光部分會被溶去

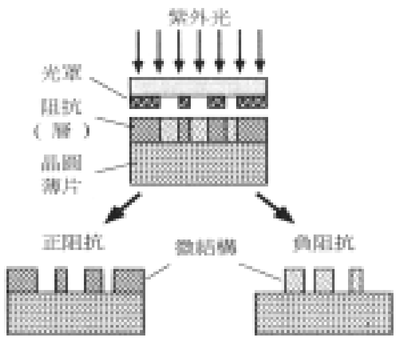

圖 4.3　不同的顯像步驟。

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正光阻與負光阻的比較

Characteristic	Resist type: Positive	Resist type: Negative
Adhesion to Si	Fair	Excellent
Available compositions	Many	Vast
Contrast γ	Higher, e.g., 2.2	Lower, e.g., 1.5
Cost	More expensive	Less expensive
Developer	Aqueous based (ecologically sound)	Organic solvent
Developer process window	Small	Very wide, insensitive to overdeveloping
Influence of oxygen	No	Yes
Lift-off	Yes [usually with multiple-layer resist (MLR)]	Yes, with new types of negative resists [single-layer resist (SLR)]
Minimum feature	0.5 μm and below	± 2 μm
Opaque dirt on clear portion of mask	Not very sensitive to it	Causes printing of pinholes
Photospeed	Slower	Faster
Pinhole count	Higher	Lower
Pinholes in mask	Prints mask pinholes	Not so sensitive to mask pinholes

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正光阻與負光阻的比較（續）

Characteristic	Resist type: Positive	Resist type: Negative
Plasma etch resistance	Very good	Not very good
Proximity effect	Prints isolated holes or trenches better	Prints isolated lines better
Residue after development	Mostly at <1 μm and high aspect ratio	Often a problem
Sensitizer quantum yield Φ	0.2 to 0.3	0.5 to 1
Step coverage	Better	Lower
Strippers of resist over		
Oxide steps	Acid	Acid
Metal steps	Simple solvents	Chlorinated solvent compounds
Swelling in developer	No	Yes
Thermal stability	Good	Fair
Wet chemical resistance	Fair	Excellent

*Newer resist systems are discussed under ***Photolithography Resolution Enhancement Technology***, page 32.

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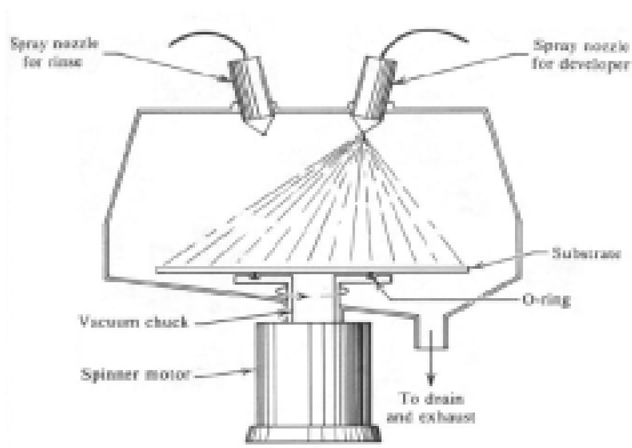
Development



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硬烤

- 以高於光阻的玻態轉變溫度(Glass transition)加熱(120~200°C)
  - 降低光阻的溶劑含量
  - 增加附著
  - 增加對酸的抵抗
  - 使邊緣平坦化、減少缺陷孔隙。

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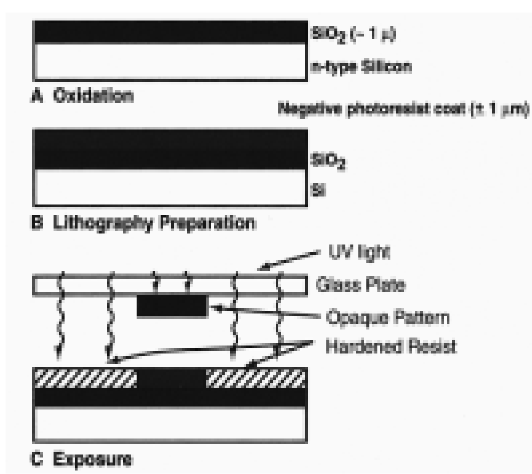
Lithography of Silica Pattern - 1

- 氧化層
- 上光阻
- 對準曝光



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Lithography of Silica Pattern - 2

- 光阻顯影（負光阻）
- 蝕刻裸露之二氧化矽圖形
- 去除光阻

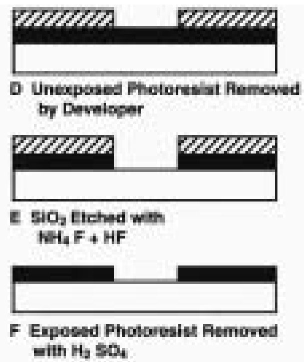

Figure 1.1 Basic photolithography and pattern transfer. Example uses an oxidized Si wafer and a negative photoresist system. Process steps include exposure, development, oxide etching, and resist stripping. Steps A through F are explained in the text.

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灰階平版術

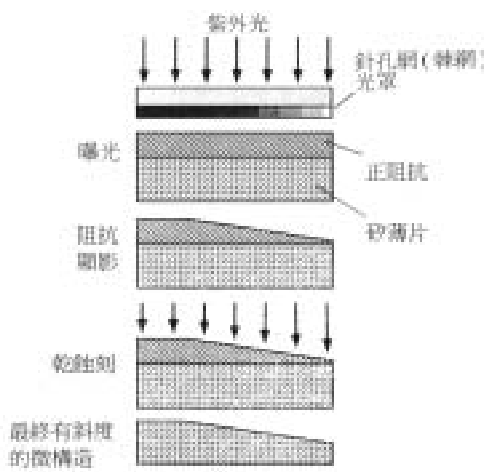

圖 4.4 灰階平版術的原理。根據 [Weng 94]。

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灰階平版術的應用

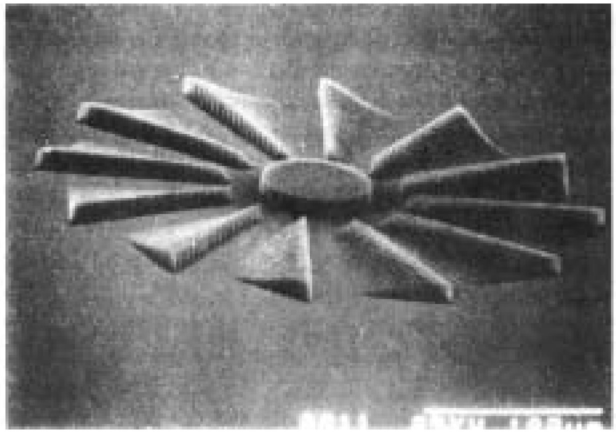

圖 4.5　由使用灰階平版術所製成之微構造。感謝 the Fraunhofer-Institute for Silicon Technology, Itzehoe。

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Reference

- *Fundamentals of Microfabrication*, Marc Madou, 2nd Ed., CRC Press (2002) – Chapter 1
- *Microsystem Technology and Microrobotics*, Fatikow and Rembold,Springer, (1997) – Chapter 3
- *Semiconductor Devices*, S.M. Sze, 2nd Ed., John Wiley & Sons (2002) – Chapter 12
- 微機電系統，陳炳輝，五南，（2001）- 第二章