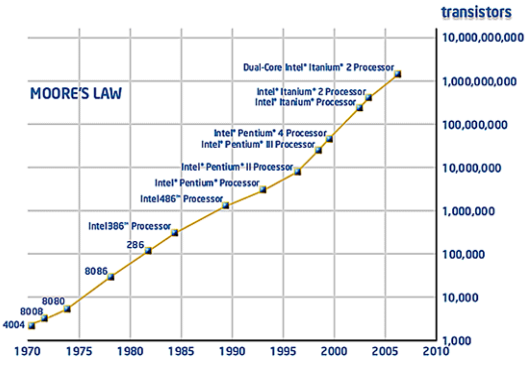
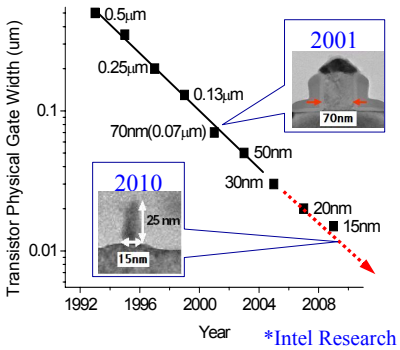
Ch 6: Lithography

Challenges – Moore's Law

The number of transistors on a microchip will double every 18 months.



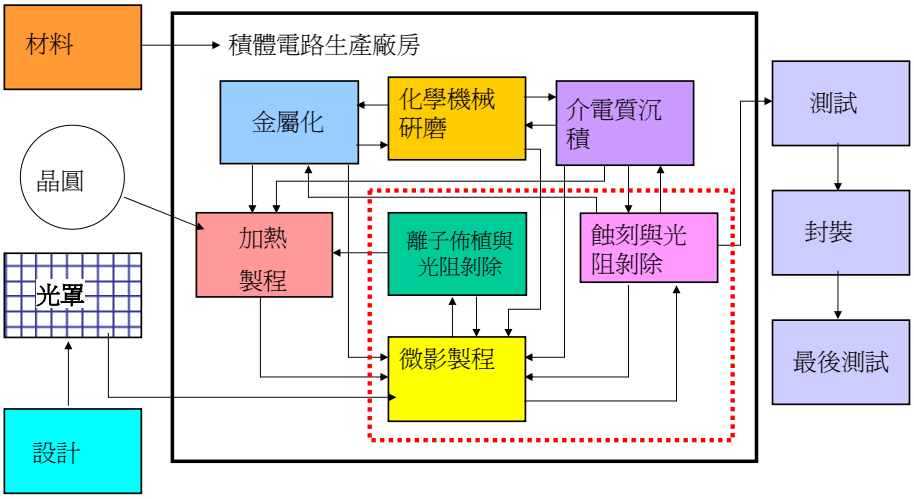
*Intel Research



*Intel Research

Currently more than 1 billion transistors per microchip

積體電路製程流程



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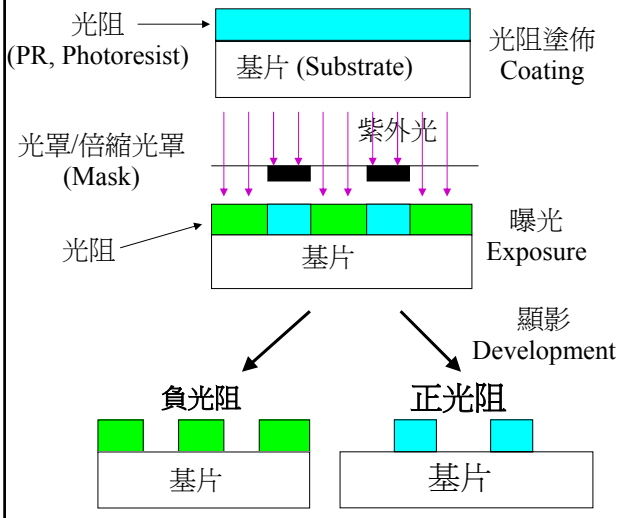
微影製程 (Lithography)



- 暫時在晶圓上塗佈光阻劑
- 將設計圖案轉移至光阻劑
- 爲IC製程中最重要之步驟
- 占晶圓總製程時間的40 ~50%

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光阻劑 (Photoresist, PR)

- 光敏感物質
- 暫時塗佈在晶圓上表面
- 經由曝光製程將設計圖案轉移其上
- 非常類似於塗佈在照相機上的光敏感物質

負光阻

- 經曝光後變不可溶
- 經顯影製程，未曝光部分溶解
- 較便宜

正光阻

- 經曝光後變可溶
- 經顯影製程，曝光部分溶解
- 解析度較佳

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光阻成分

- 高分子
- 溶劑
  1. 溶解高分子
  2. 允許光阻藉由旋轉塗佈而成薄層以進行應用
- 感光劑
  1. 決定曝光時間及強度
- 添加劑

6

PR Considerations

- PR Considerations
  - _____
  - _____ (decrease of thickness when CD decreases)
  - _____
  - Sensitive wavelengths
- Area ChE are most desired:
  - Good resolution, good resistance, and good adhesion
  - The thinner, the better resolution, but worse resistance.

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光阻--負光阻與正光阻

負光阻

- 大部分負光阻爲聚異戊二烯 (polyisoprene)橡膠
- 經曝光之光阻變成交連之高分子，交連之高分子有較佳之抗化學蝕刻能力
- 未曝光部分溶於顯影劑

缺點

- 由於光阻膨脹使解析度較差
- 環境及安全因素--主要溶劑爲二甲苯

正光阻

- 酚醛（Novolac）樹脂
- 醋酸型溶劑
- 感光劑在樹脂中進行交連
- 光分解感光劑且切斷交連，在鹼性液中樹脂溶解性變更佳
- 較高之解析度 (< 3 μm)
- 價格昂貴
- IC製程常用

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基本步驟

- 晶圓清洗
- 脫水烘烤
- 底漆層及光阻塗佈
- 軟烘烤
- 對準及曝光
- 顯影
- 圖案檢視
- 硬烘烤

光阻塗佈

顯影

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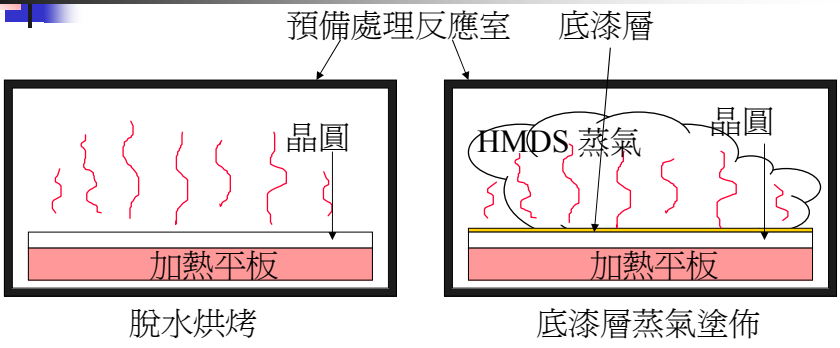
預烘烤及底漆層蒸氣塗佈



脫水烘烤　　底漆層蒸氣塗佈

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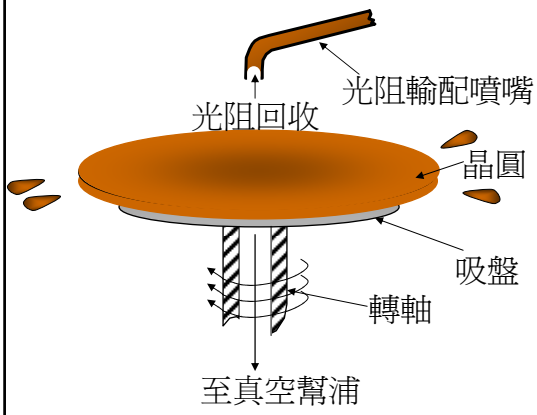
光阻旋轉塗佈

Rotation speed vs. thickness:

Special considerations:



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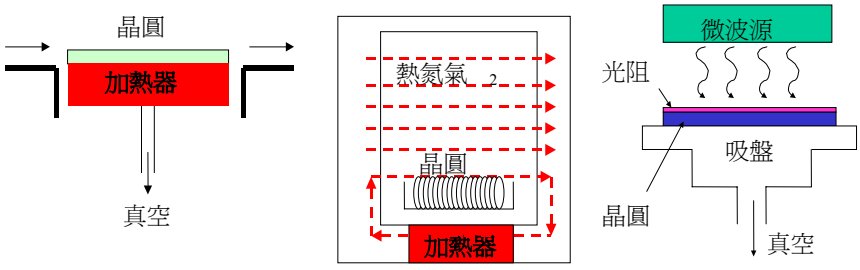
烘烤系統



加熱平板　　對流烤箱　　微波爐

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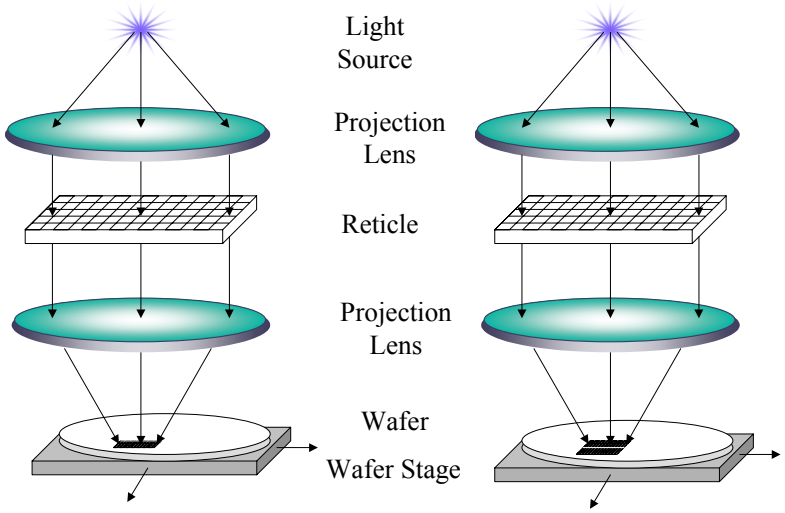
步進式對準/曝光



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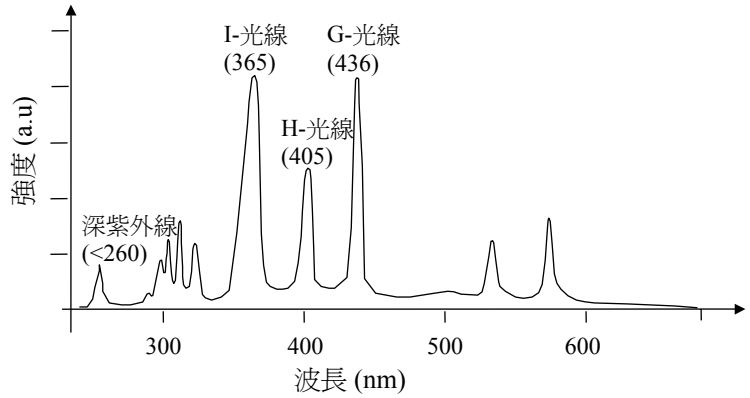
水銀燈之光譜



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波長與光源種類

	名稱	波長 (nm)	所應用的圖形尺寸 (μm)
水銀燈	G-line	436	0.50
	H-line	405	
	I-line	365	0.35 to 0.25
準分子雷射	XeF	351	
	XeCl	308	
	KrF (DUV)	248	0.25 to 0.15
	ArF	193	0.18 to 0.13
氟雷射	F_2	157	0.13 to 0.1

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顯影

- 顯影劑溶解光阻軟化之部分，並將光罩或倍縮光罩上的圖案轉到光阻上
- 三個基本步驟: 顯影, 洗滌, 旋乾

	正光阻	負光阻
顯影劑	TMAH	二甲苯
洗滌	去離子水	乙酸丁脂

•TMAH ((CH3)4NOH).

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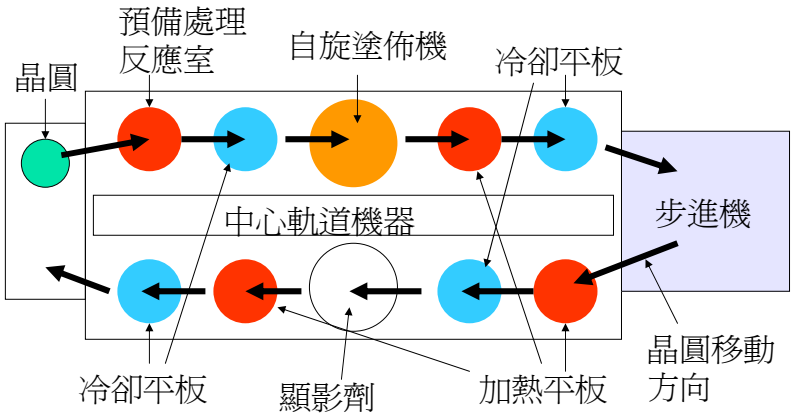
晶圓軌道機-步進機整合系統



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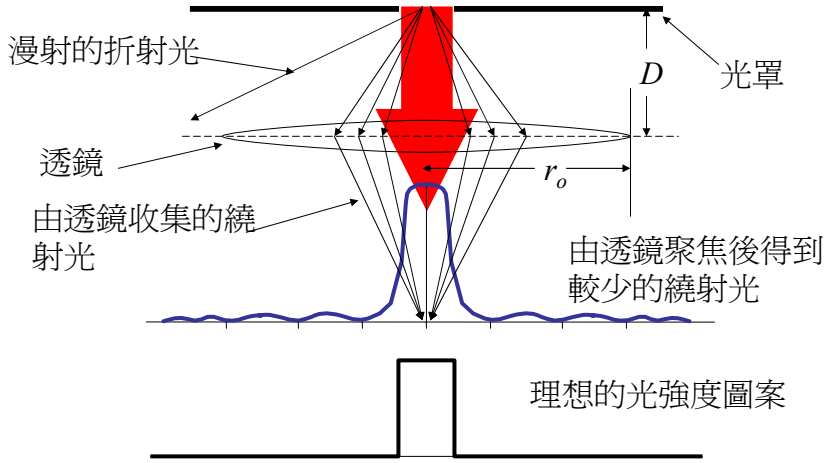
經透鏡的繞射光



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Resolution Considerations

數值孔徑 (Numeric aperture, NA)

- *NA* 代表一透鏡收集繞射光之能力
- $NA = 2\, r_0 / D$
  - r_0 : 透鏡之半徑
  - D ：光罩與透鏡兩物體間的距離
- 具有較大 *NA之透鏡能捕捉* 較高階的繞射光並 獲得較清晰的影像

解析度(Resolution)

- 可達到且可重複之最小圖案尺寸
- 解析度可表示爲 $R = \frac{K_1 \lambda}{NA}$

*K*1 爲系統常數, *l* 爲光波長, *NA* = 2 *ro/D*, 爲數值孔徑

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改善解析度

- 增加 NA
  - 更大的透鏡, 可能太貴或是不實際
  - 減少 DOF 及造成製程困難度
- 降低波長
  - 需開發新光源，光阻及設備
  - 降低波長的限制
  - UV 到 DUV, 到 EUV, 甚至 X-Ray
- 降低 K_1
  - 相轉移光罩

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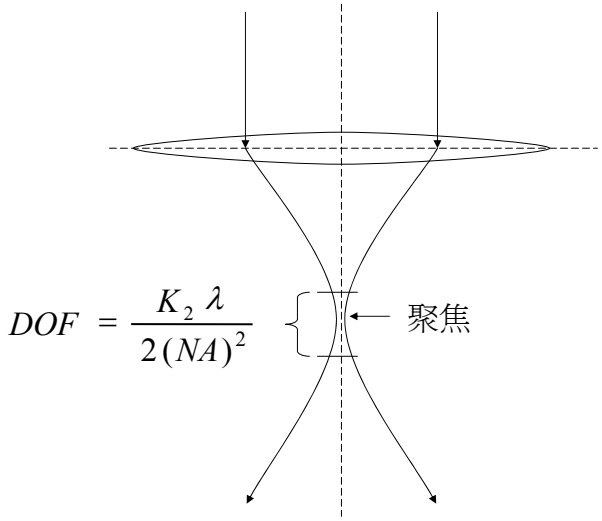
景深 (Depth of Focus)



表面平坦化之要求

- 較高的解析度需要
  - 更短的 λ
  - 更大的*NA*.
- 兩者皆減少 *DOF*
- 晶圓表面必須高度平坦化
- 對0.25 μm 圖案，CMP 是必須的

I-光線及深紫外線

- 水銀 I-光線， 365 nm
  - 通常在 0.35 μm 微影使用
- DUV KrF 準分子雷射，248 nm
  - 0.25 μm, 0.18 μm 及 0.13 μm 微影
- ArF準分子雷射，193 nm
  - 應用: < 0.13 μm
- F_2準分子雷射， 157 nm
  - 仍處 R&D， < 0.10 μm 應用

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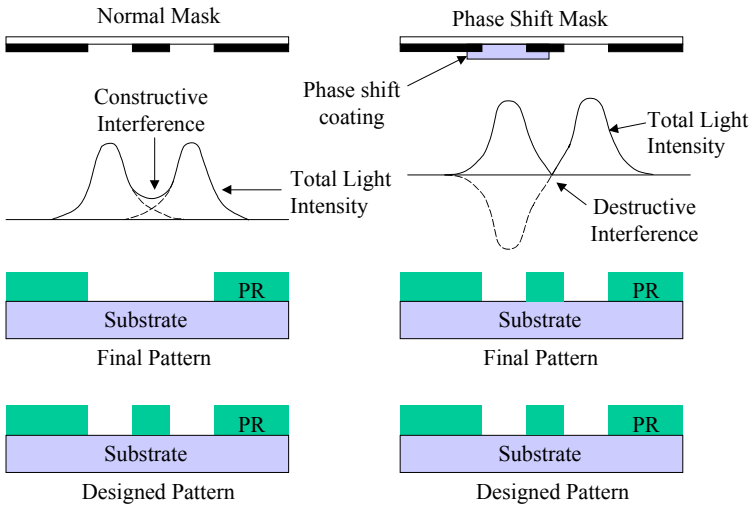
相位移光罩圖案化



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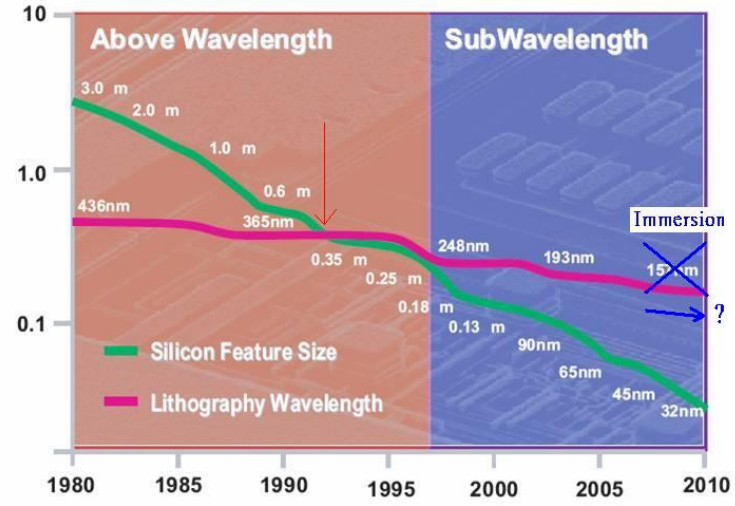
Past and Future



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ITRS

(International Technology Roadmap for Semiconductors)

Table 2a Lithographic-Field and Wafer-Size Trends—Near-term Years

Year of Production	2005	2006	2007	2008	2009	2010	2011	2012	2013
DRAM ½ Pitch (nm) (contacted)	80	70	65	57	50	45	40	36	32
MPU/ASIC Metal 1 (M1) ½ Pitch (nm) (f)	90	78	68	59	52	45	40	36	32
MPU Physical Gate Length (nm)	32	28	25	23	20	18	16	14	13
Lithography Field Size									
Maximum Lithography Field Size—area (mm^2)	858	858	858	858	858	858	858	858	858
Maximum Lithography Field Size—length (mm)	33	33	33	33	33	33	33	33	33
Maximum Lithography Field Size—width (mm)	26	26	26	26	26	26	26	26	26
Maximum Substrate Diameter (mm)—High-volume Production (>20K wafer starts per month)									
Bulk or epitaxial or SOI wafer	300	300	300	300	300	300	300	450	450

Table 2b Lithographic-Field and Wafer Size Trends—Long-term Years

Year of Production	2014	2015	2016	2017	2018	2019	2020
DRAM ½ Pitch (nm) (contacted)	28	25	22	20	18	16	14
MPU/ASIC Metal 1 (M1) ½ Pitch (nm) (f)	28	25	22	20	18	16	14
MPU Physical Gate Length (nm)	11	10	9	8	7	6	6
Lithography Field Size							
Maximum Lithography Field Size—area (mm^2)	858	858	858	858	858	858	858
Maximum Lithography Field Size—length (mm)	33	33	33	33	33	33	33
Maximum Lithography Field Size—width (mm)	26	26	26	26	26	26	26
Maximum Substrate Diameter (mm)—High-volume Production (>20K wafer starts per month)							
Bulk or epitaxial or SOI wafer	450	450	450	450	450	450	450

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Year of Production	2005	2006	2007	2008	2009
DRAM ½ Pitch (nm) (contacted)	80	70	65	57	50
MPU/ASIC Metal 1 (M1) ½ Pitch (nm) (f)	90	78	68	59	52
MPU Physical Gate Length (nm)	32	28	25	23	20
Lithography Field Size					
Maximum Lithography Field Size—area (mm^2)	858	858	858	858	858
Maximum Lithography Field Size—length (mm)	33	33	33	33	33
Maximum Lithography Field Size—width (mm)	26	26	26	26	26
Maximum Substrate Diameter (mm)—High-volume Production (>20K wafer starts per month)					
Bulk or epitaxial or SOI wafer	300	300	300	300	300

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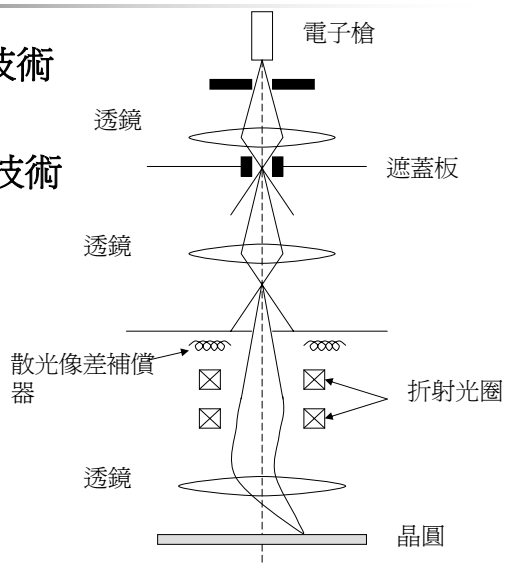
- 極紫外線 (EUV)微影技術
- X光微影技術
- 電子束 (E-beam)微影技術



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Novel Techniques

- Currently Used
  - Immersion Lithography
  - Double Exposure
  - Photoresist Trimming
- Possible for Future Processes
  - Scanning Probe Lithography
  - Nanoimprint Lithography
  - ….many more

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