IC製造業與光電產業之介紹

Dr. 陳 柏 穎

W 01 上課資料

義守大學　通訊工程系

Sept./12/2007

Agenda

- New Concept for Worldwide
- IC Manufacturing History
- IC Manufacturing Introduction
- IC Process Flow Introduction
- The Strategy for the IC Development
- The Reliability test for IC Process
- Quality Control
- Ford 8-D

Agenda

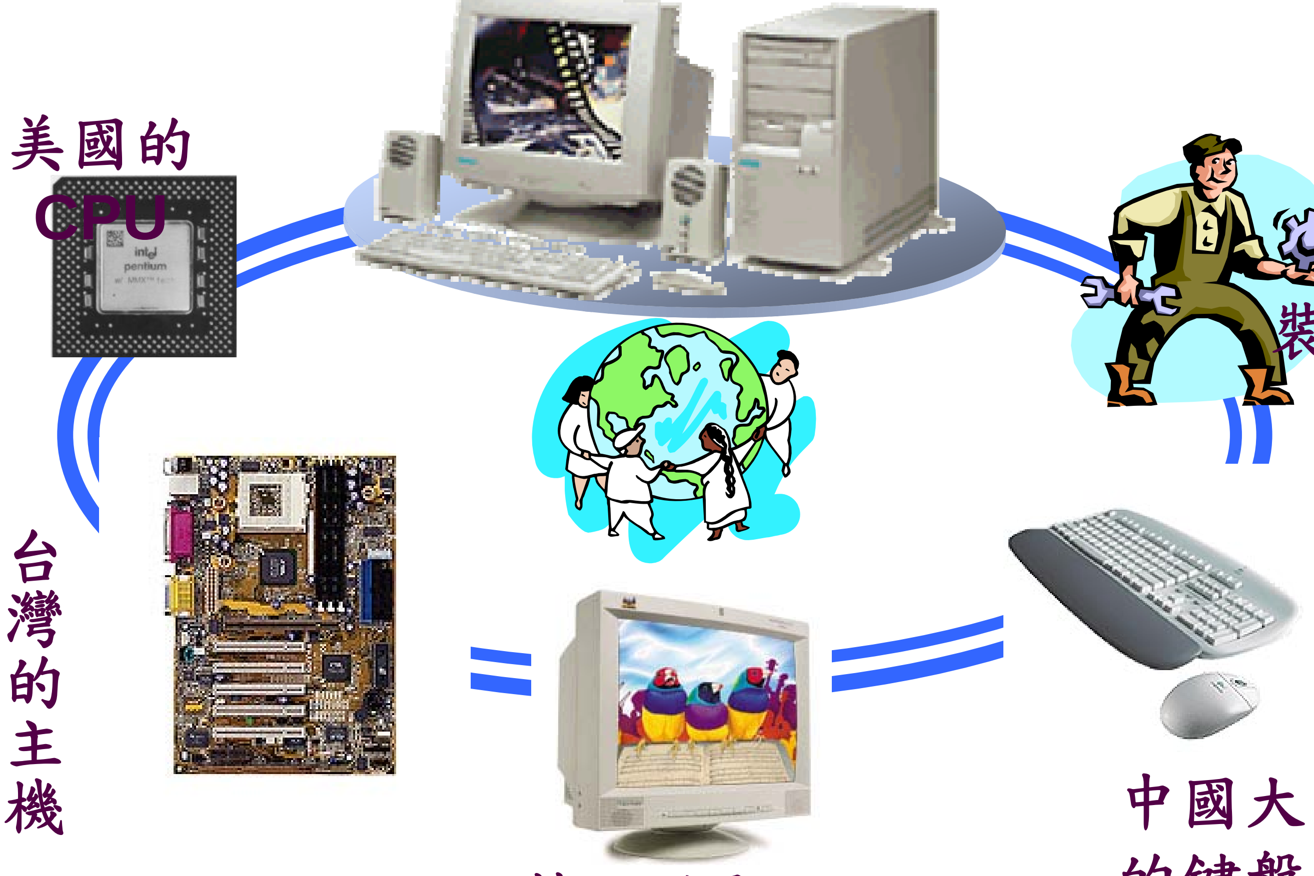
- New Concept for Worldwide
- IC Manufacturing History
- IC Manufacturing Introduction
- IC Process Flow Introduction
- The Strategy for the IC Development
- The Reliability test for IC Process
- Quality Control
- Ford 8-D

New Concept for world-wide

- 生產無疆界
- 國際化成驅勢
- 知識傳遞快速
- 電子產品演進快速
- 快速生產降低成本
- 生活品質降低
- 電化製品依賴性增加
- 越來越強調企業競爭力
- 越來越依靠E-化來提升企業競爭力

New Concept for world-wide

- 生產線上無疆界



美國的CPU

墨西哥的組裝

台灣的主機板

韓國的顯示器

中國大陸的鍵盤與滑鼠

New Concept for world-wide

- Low life quality

GettyImages/TDI

New Concept for world-wide

- 電化製品依賴性增加

New Concept for world-wide

- 越來越強調企業競爭力

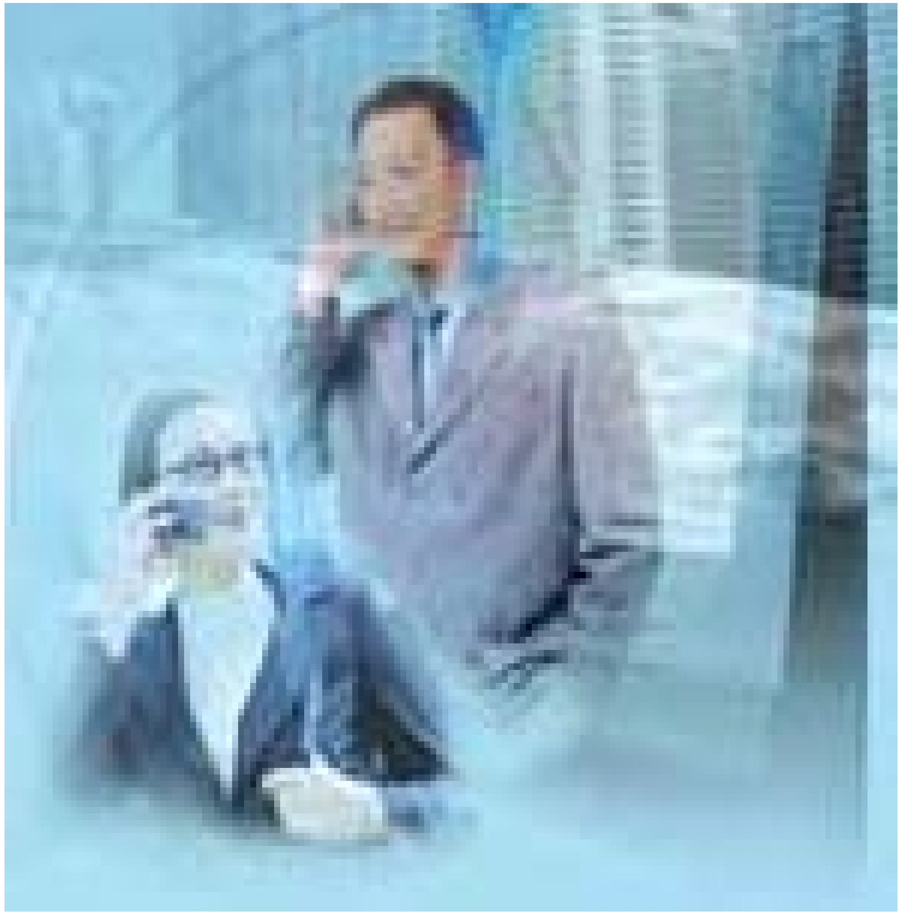
企業競爭力

New Concept for world-wide

- 國與國之距離在**E-**化後縮短

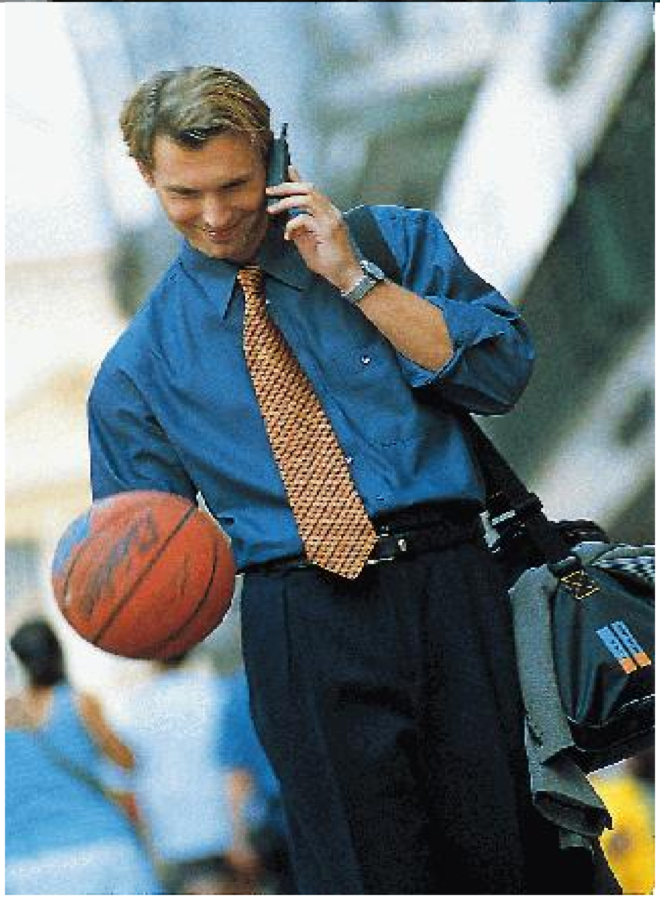
New Concept for world-wide

- Wireless become major



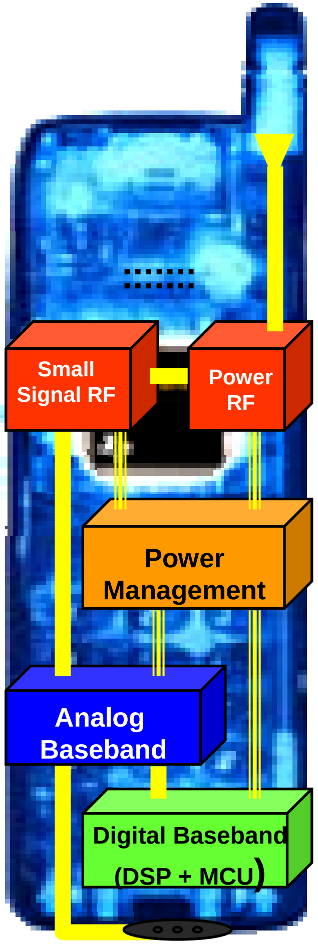
New Concept for world-wide

Cell Phone



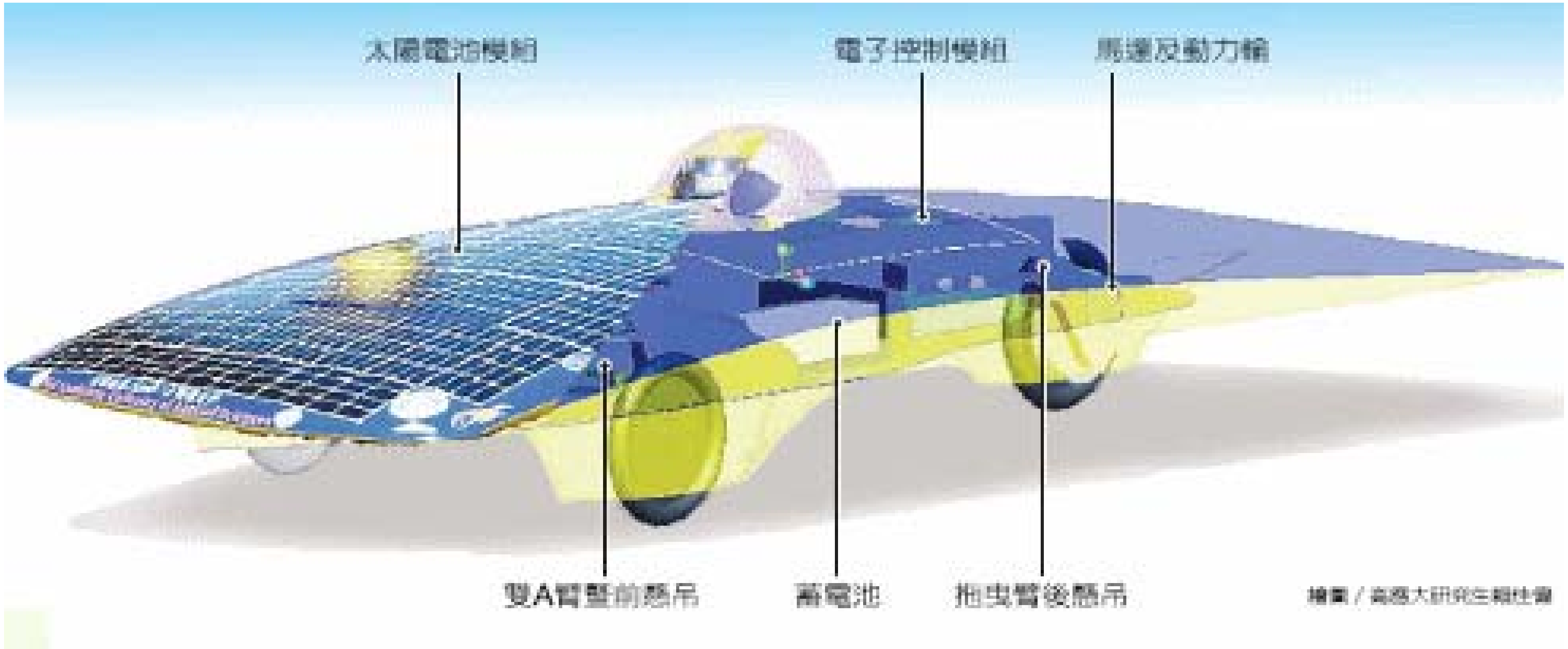
1996	1997	1998	1999	2000
48M	86M	162M	260M	435M

Units



New Concept for world-wide

- 能源與環保會被重視



New Concept for world-wide

◆ 追求速度

Agenda

New Concept for Worldwide

IC Manufacturing History

IC Manufacturing Introduction

IC Process Flow Introduction

The Strategy for the IC Development

The Reliability test for IC Process

Quality Control

Ford 8-D

IC製造業與光電產業之介紹

Dr. 陳 柏 頴

W 02 上課資料

義守大學　通訊工程系

Sept./19/2007

IC Manufacturing History

What is VLSI ?

- VLSI為Very Large Scale Integration之縮寫
- 整合(integration)什麼?
  - 整合電路(circuits)
- 什麼是電路?
  - 電晶體(transistors)和金屬線(wires)
  - 電阻(resistors)、電容(capacitors)和電感(inductors)
- IC & VLSI
  - 積體電路(Integrated circuits-ICs)：許多電晶體、金屬線及被動元件在一顆晶片(chip)上
  - 超大型積體電路(Very Large Scale Integration-VLSI)：非常多電晶體、金屬線及被動元件在一顆晶片上
- 為什麼要使用IC來製造電子電路
  - Printed a circuit, like you print a picture
    - Create components in parallel, cost no longer dependent on # of devices
  - 價格便宜、操作速度快及低功率消耗

IC Manufacturing History

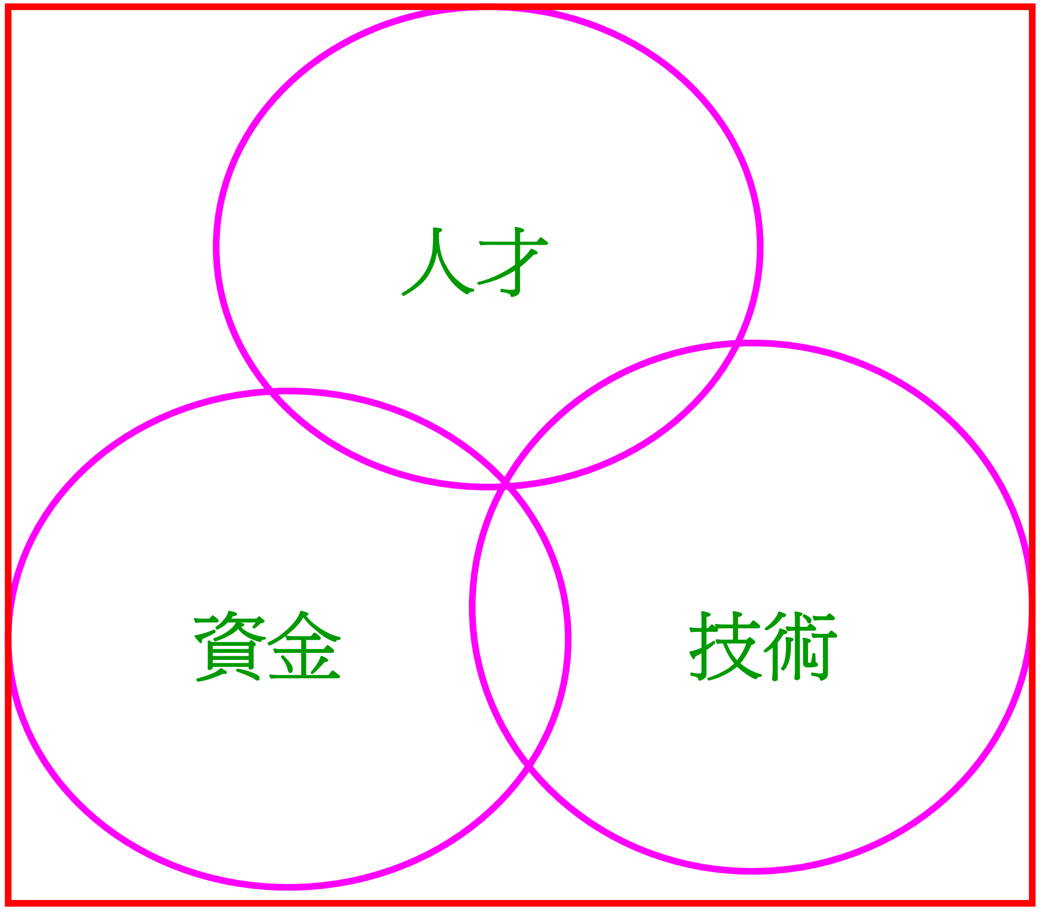
IC introduction-

Why Si ?

- ◆ **Single Crystal Structure**
  -Periodic and predictable
- ◆ **Semiconductor- all electronic components but inductor**
  -Diode (Asymmetric resistor), Transistor (Switch), Resistor, Cpactor
- ◆ **Abundant and cheap- made of sand**
- ◆ **Easy to transform to other materials**
  -conductor (doping and anneal)
  - insulator by oxidation (SiO2)

IC Manufacturing History

IC value:



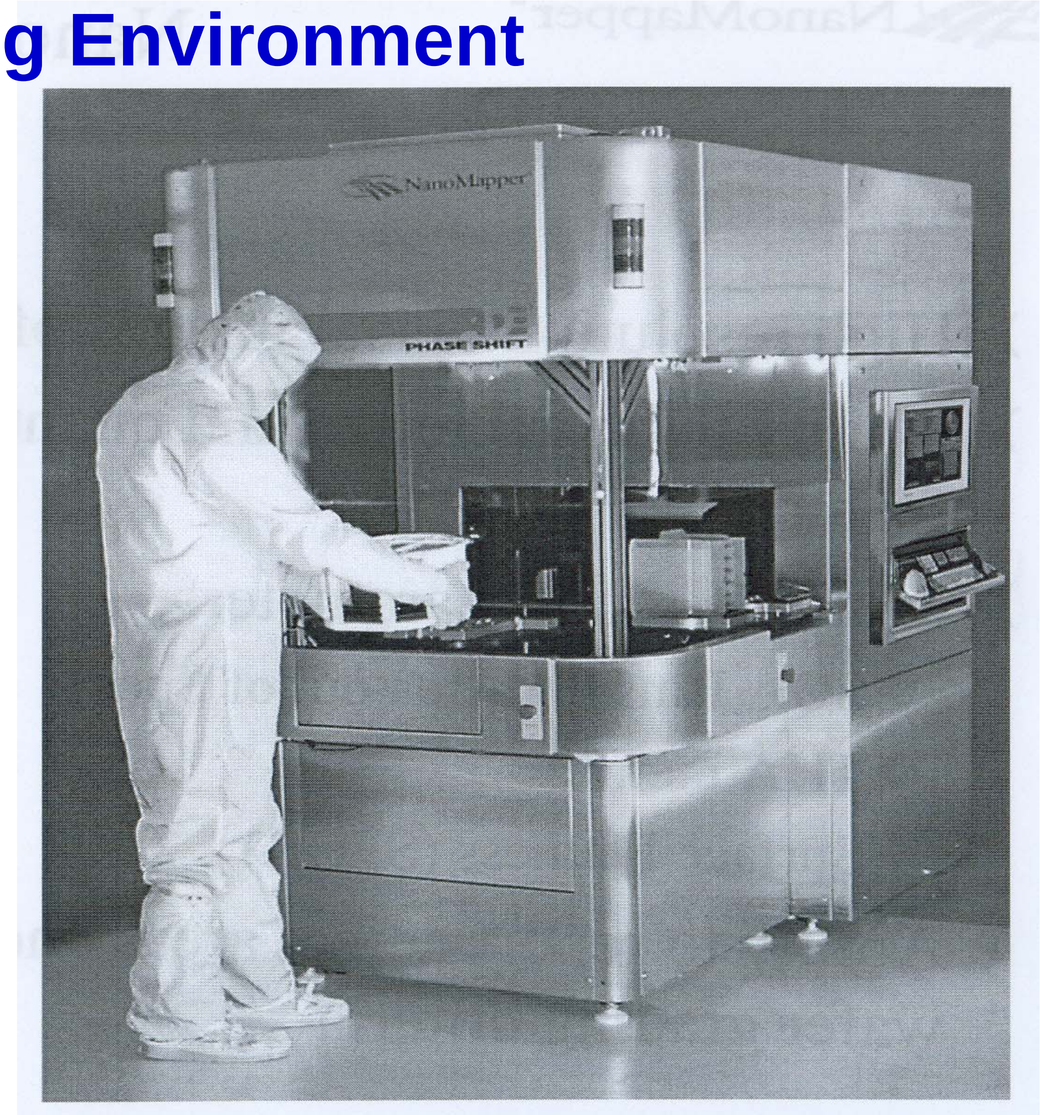
人才

資金

技術

IC Manufacturing History

IC Manufacturing Environment



IC Manufacturing History

IC的前身是真空管：

1. 真空管體積
2. 真空管散熱問題
2. 真空管操作電壓問題

Radiotron UV202 transmitting valve (1921).

IC Manufacturing History

IC的前身是真空管：

Plate power: 35 W (max). Plate voltage: 1500 V (max). Maximum frequency: 100 MHz.

IC Manufacturing History

- The beginning of the information age: invention of integrated circuit or IC about 40 years ago.

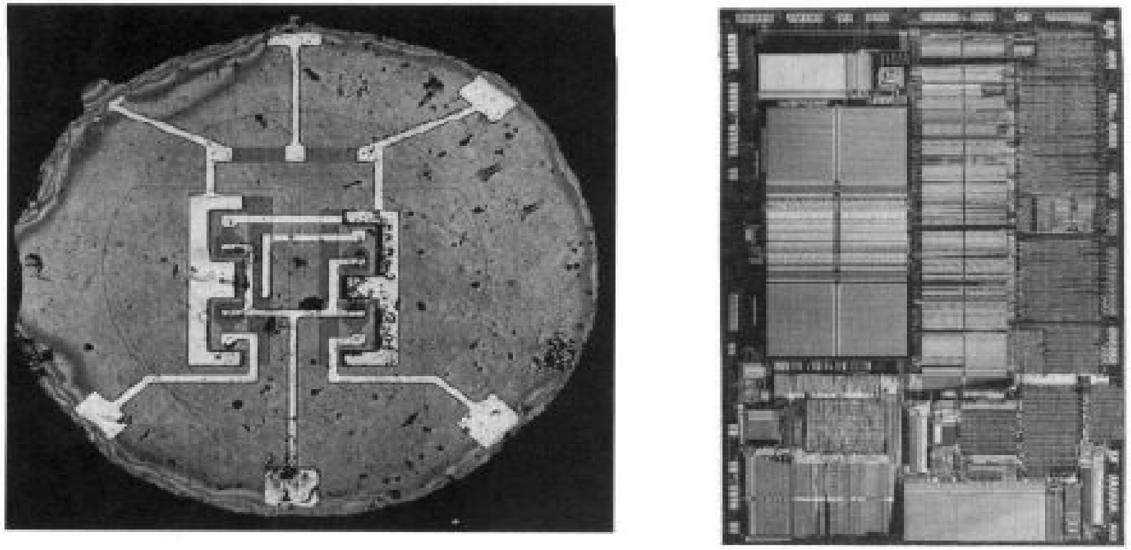


Figure 1-1 Photomicrographs of state-of-the-art ICs manufactured in the early 1960s (left) and in the early 1990s (right). The 1960s IC contains four bipolar transistors and several resistors. The 1990s chip contains over a million MOS transistors.

IC Manufacturing History

- The beginning of the information age: invention of integrated circuit or IC about 40 years ago.

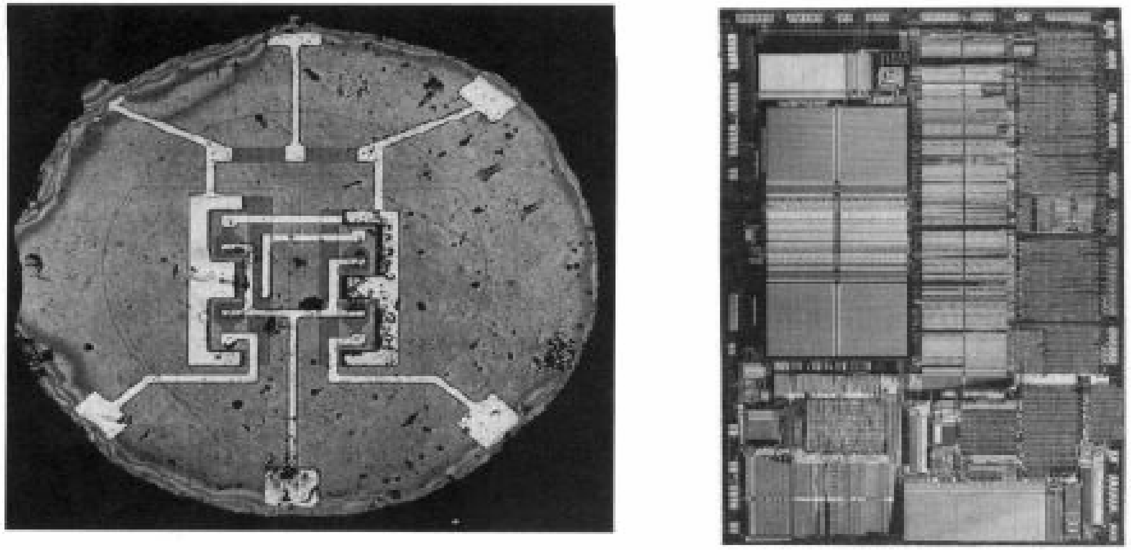
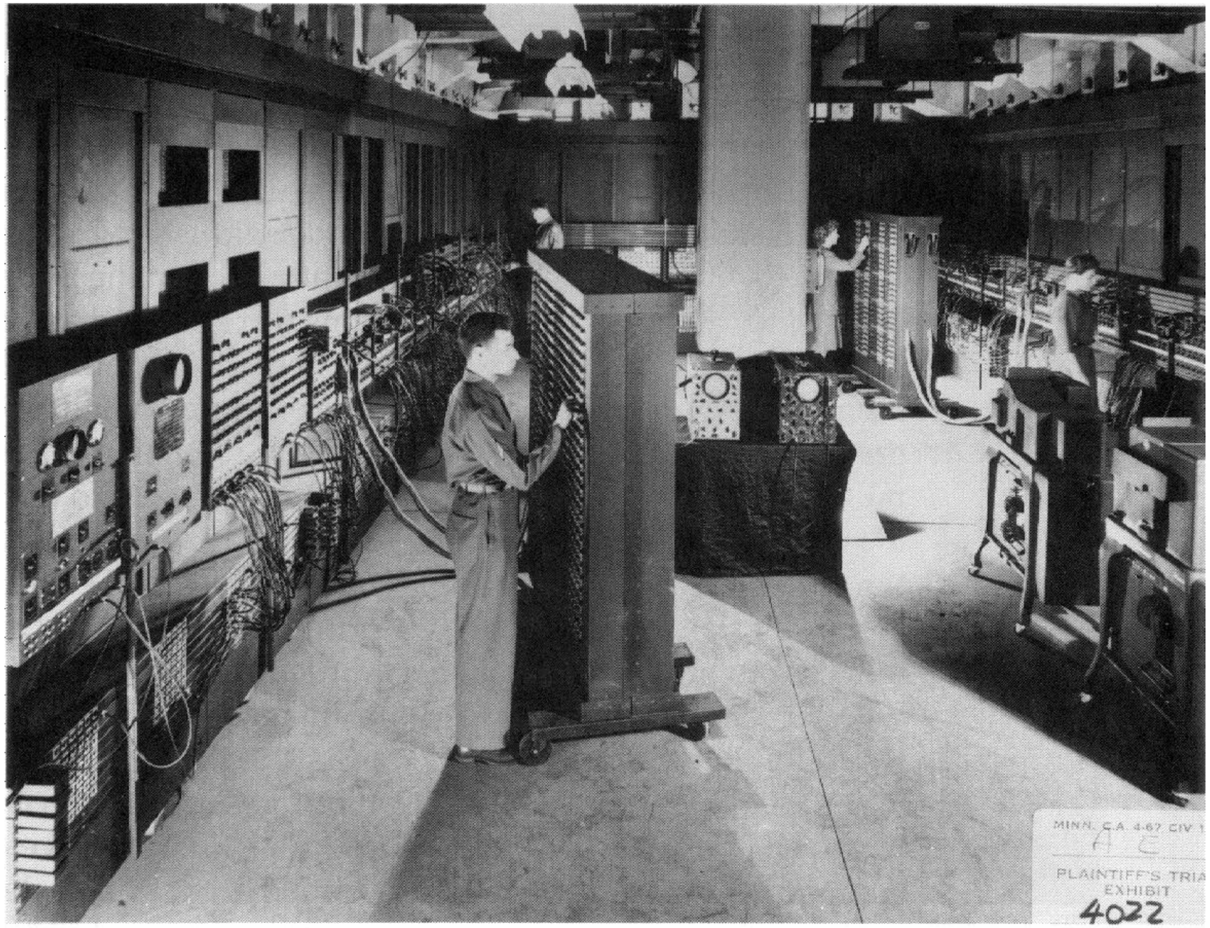


Figure 1–1 Photomicrographs of state-of-the-art ICs manufactured in the early 1960s (left) and in the early 1990s (right). The 1960s IC contains four bipolar transistors and several resistors. The 1990s chip contains over a million MOS transistors.

IC Manufacturing History

The first electronic computer (1946)



IC Manufacturing History

真空管電腦 – 第 1 代電腦 (1946 ~ 1953)

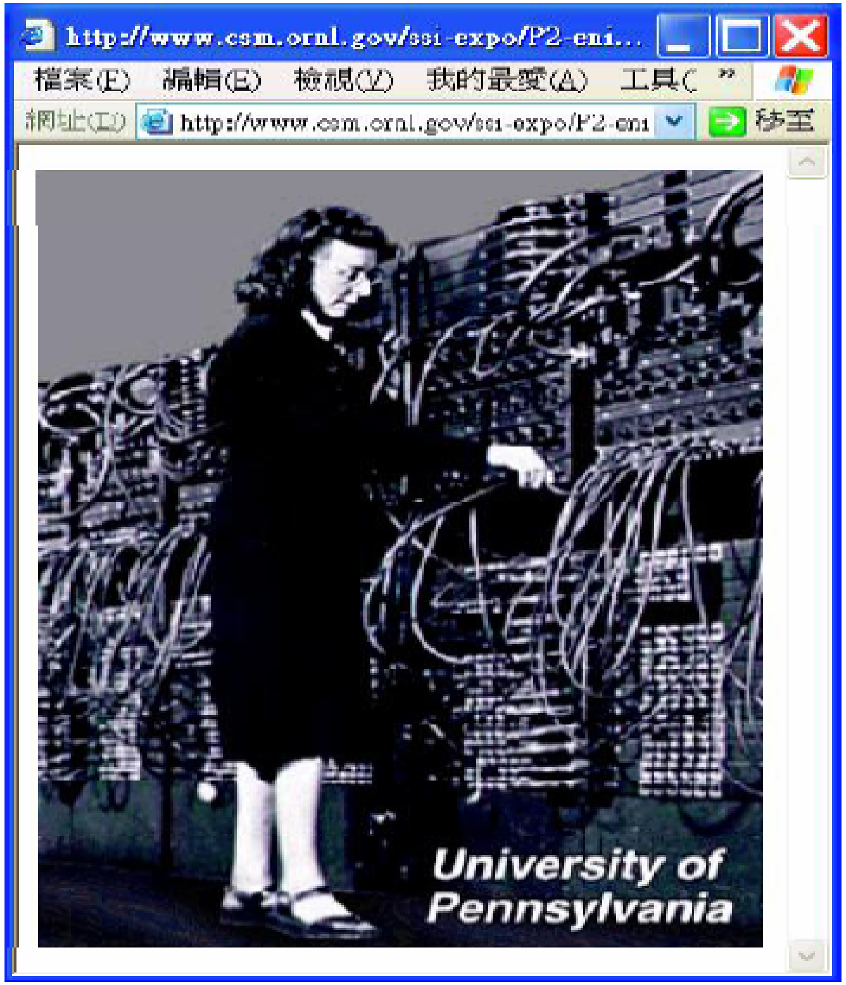
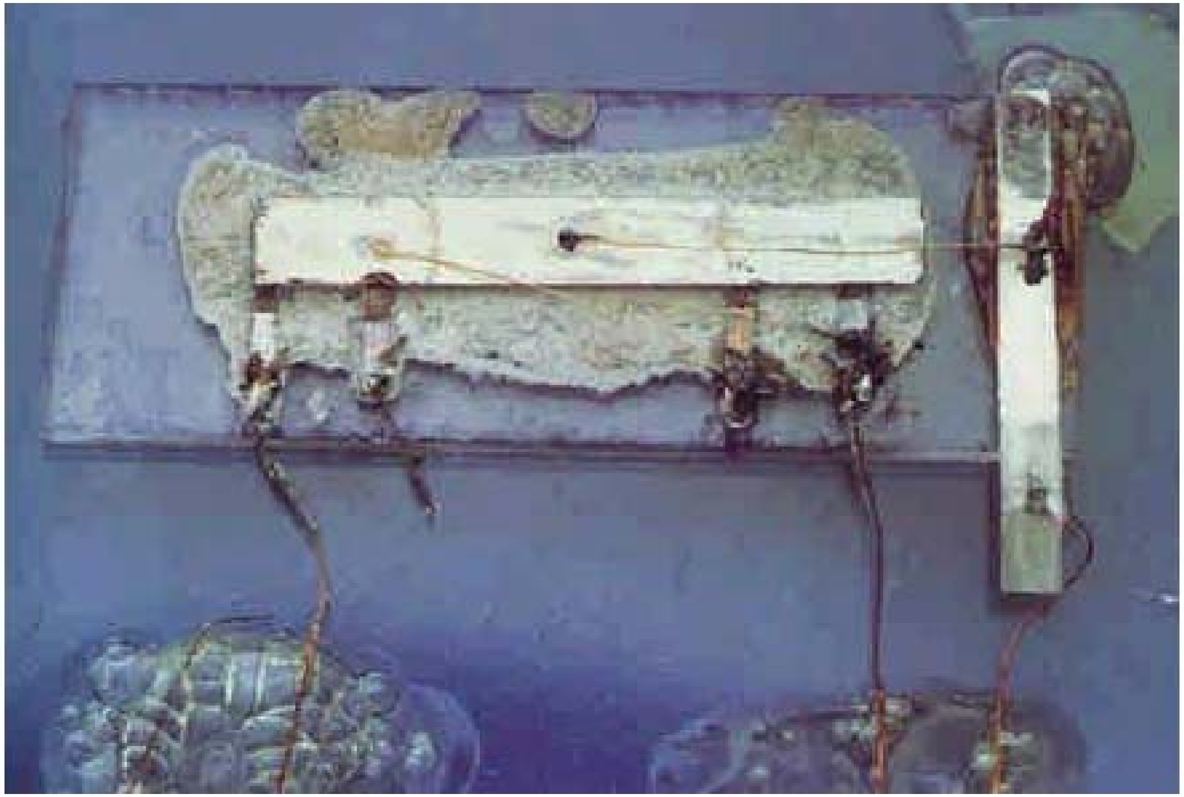


圖 1-5 人類第一部電腦 — ENIAC

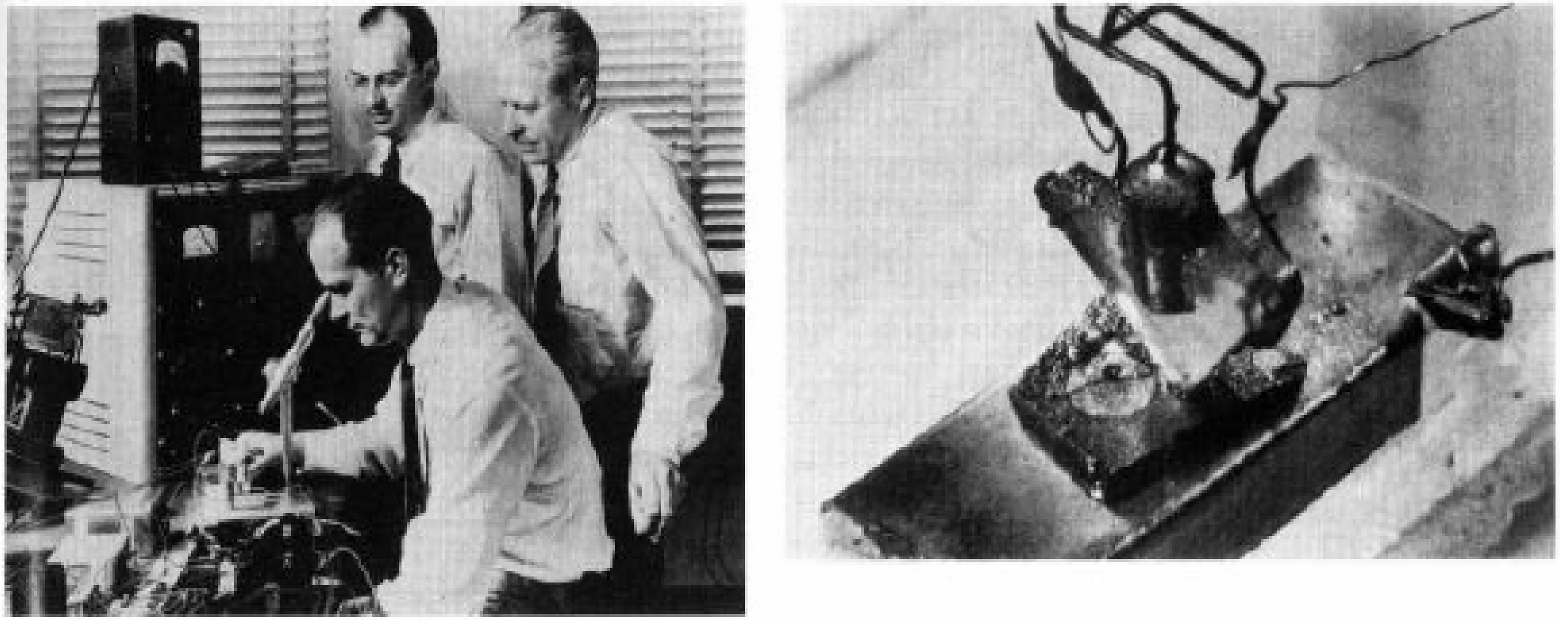
IC Manufacturing History

First transistor Bell Labs, 1948



IC Manufacturing History

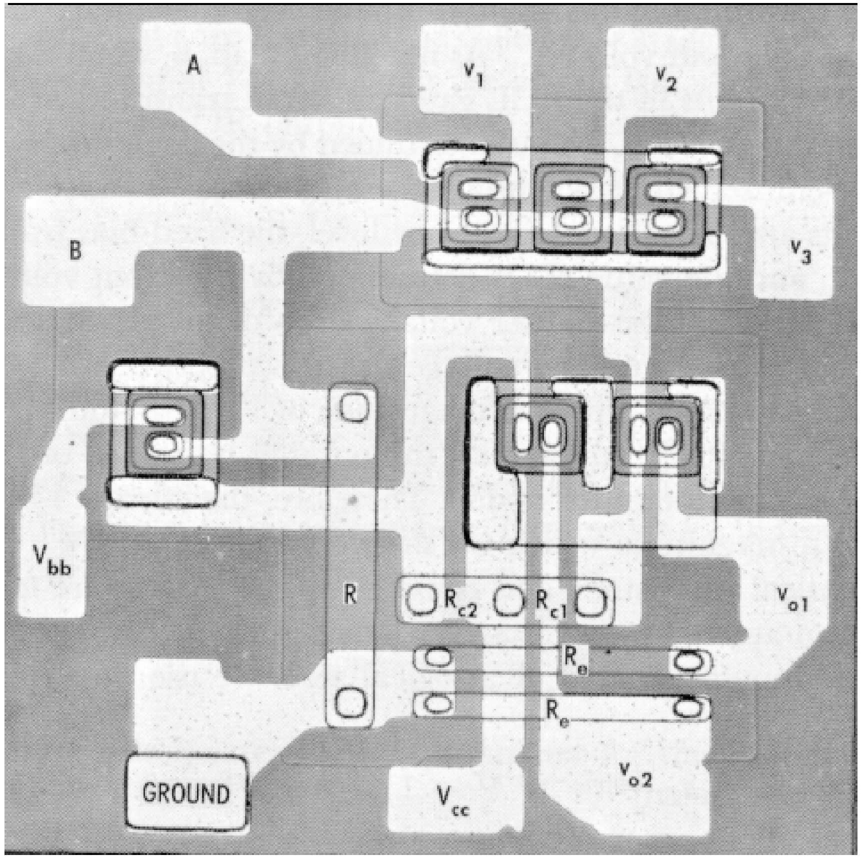
First transistor Bell Labs, 1948



- 1947: the point contact transistor on polycrystalline Ge invented at Bell Lab by Bardeen, Brattain, and Shockley
- 1953: Bardeen and Brattain found the surface properties of semiconductors could be controlled by exposing them to oxygen, water, or ozone.
- Single crystal (controllable, stable, and reproducible) and SiO_2 are the two

IC Manufacturing History

The First Integrated Circuits

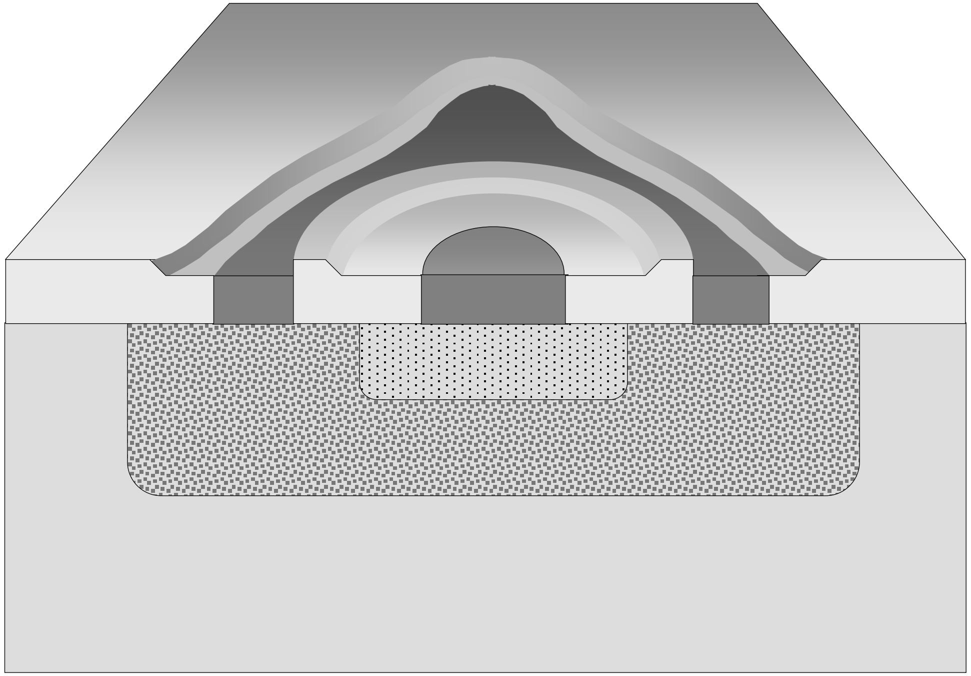


Bipolar logic 1960's

ECL 3-input Gate
Motorola 1966

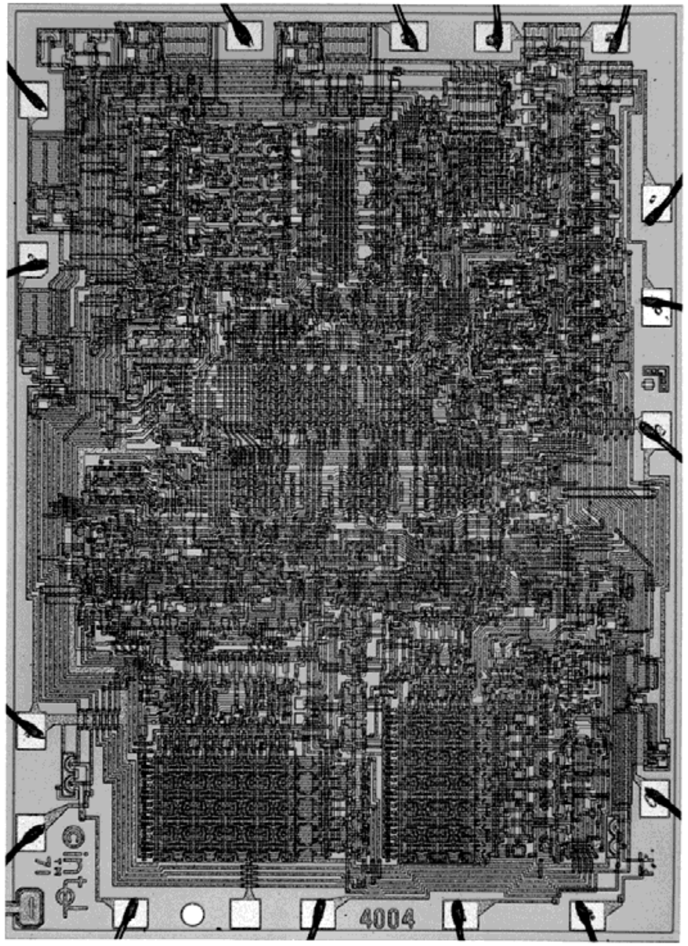
IC Manufacturing History

第一平面式電晶體



IC Manufacturing History

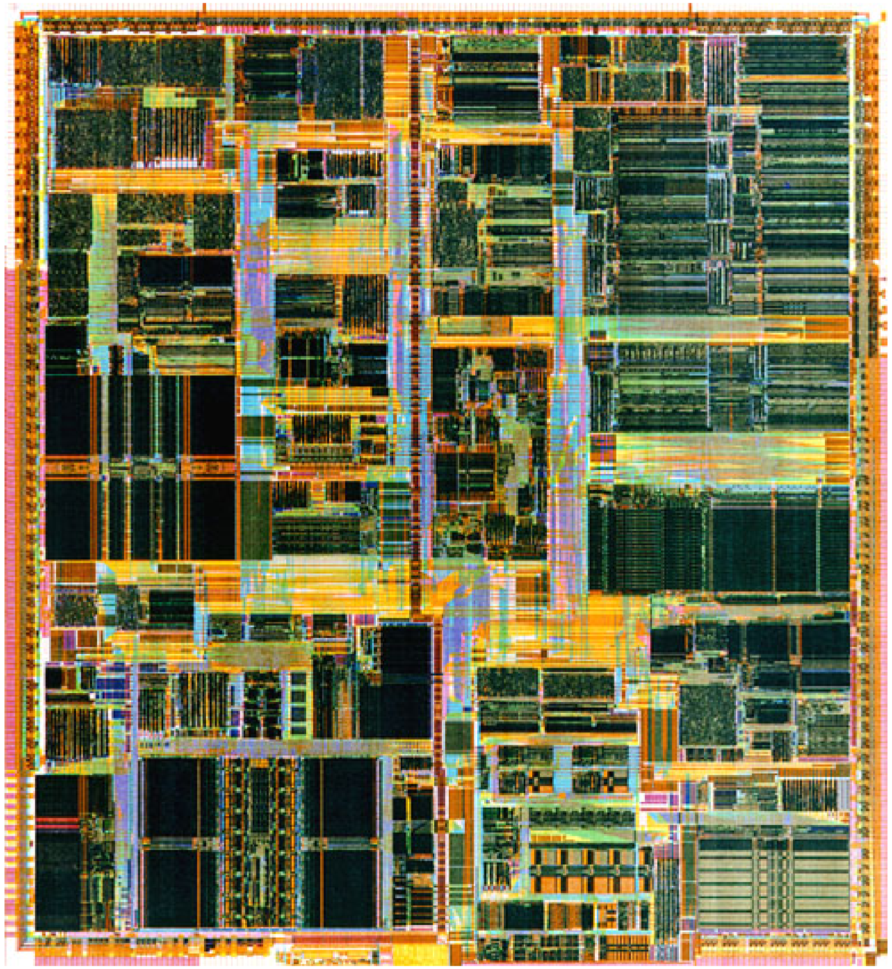
Intel 4004 Micro-Processor



1971
1000 transistors
1 MHz operation

IC Manufacturing History

Intel Pentium (IV) microprocessor



IC Manufacturing History

IC 發展歷程記實

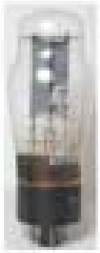
- 20世紀前半世紀 : 真空管
- 1925年 : FET理論被發表- by J. Lienfeld
- 1935年 : 現代FET結構被發表- by O. Heli
- 1947年 : BJT結構被發表- by Brattin,

  Bardin, & Schockley→ got Nobel Prize
- 1958年 : 第一顆積體電路, by Jack Kiby (Texas Instruments)
- 1959年 : 矽平面製程, Process similar to current, by Robert

  Noyce (Fairchild)
- 1960s年 :PMOS process, BJT
- 1970s年 :NMOS process, BJT
- 1980s年 :CMOS process, BJT
- 1990s年 :CMOS, BiCMOS, BJT

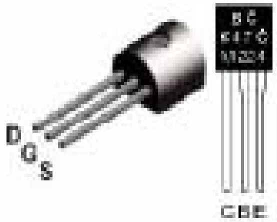
IC Manufacturing History

IC 發展之路程:



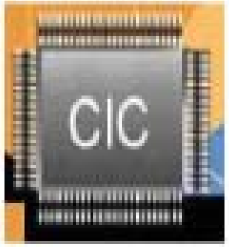
1906 ~ now

John A. Fleming



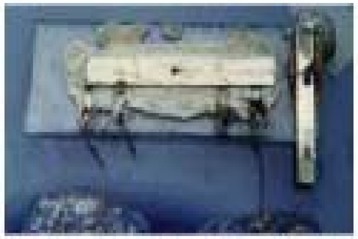
1947~now

John Bardeen, Walter Brattain,
and William Shockley

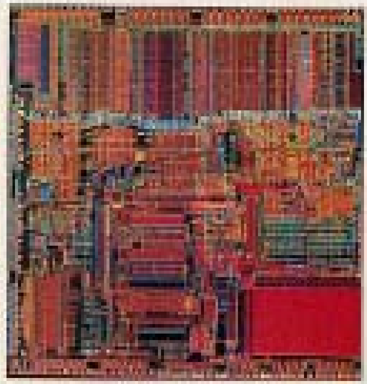


1958~now

Jack Kilby and
Robert Noyce



Texas Instruments' first IC

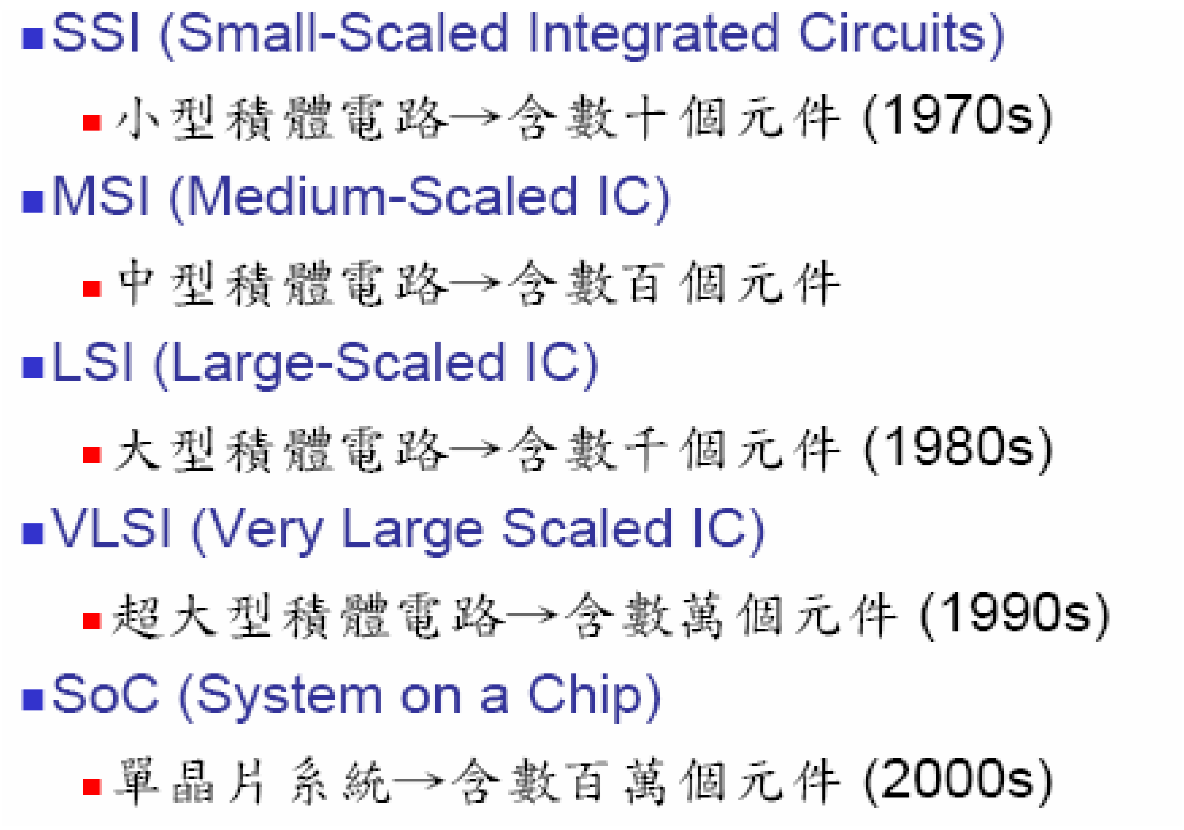


386

4004

IC Manufacturing History

20世紀後半世紀之 IC 發展:



- SSI (Small-Scaled Integrated Circuits)
  - 小型積體電路→含數十個元件 (1970s)
- MSI (Medium-Scaled IC)
  - 中型積體電路→含數百個元件
- LSI (Large-Scaled IC)
  - 大型積體電路→含數千個元件 (1980s)
- VLSI (Very Large Scaled IC)
  - 超大型積體電路→含數萬個元件 (1990s)
- SoC (System on a Chip)
  - 單晶片系統→含數百萬個元件 (2000s)

IC Manufacturing History

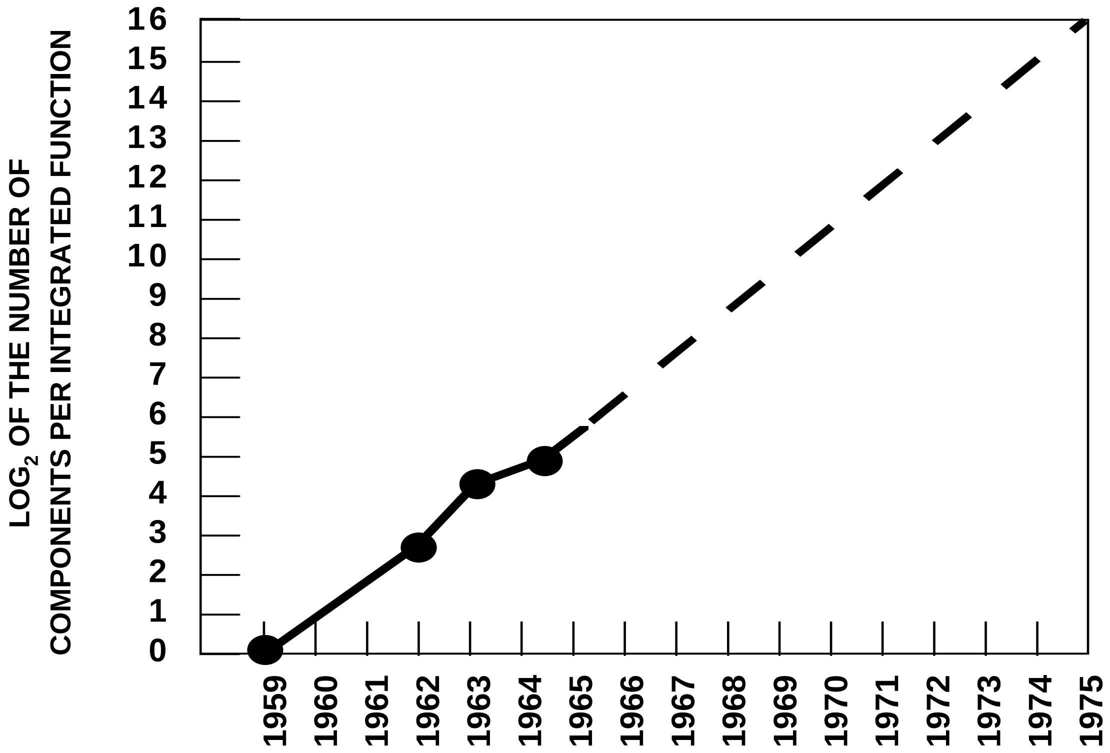
Moore’s Law

③ In 1965, Gordon Moore noted that the number of transistors on a chip doubled every 18 to 24 months.

③ He made a prediction that semiconductor technology will double its effectiveness every 18 months

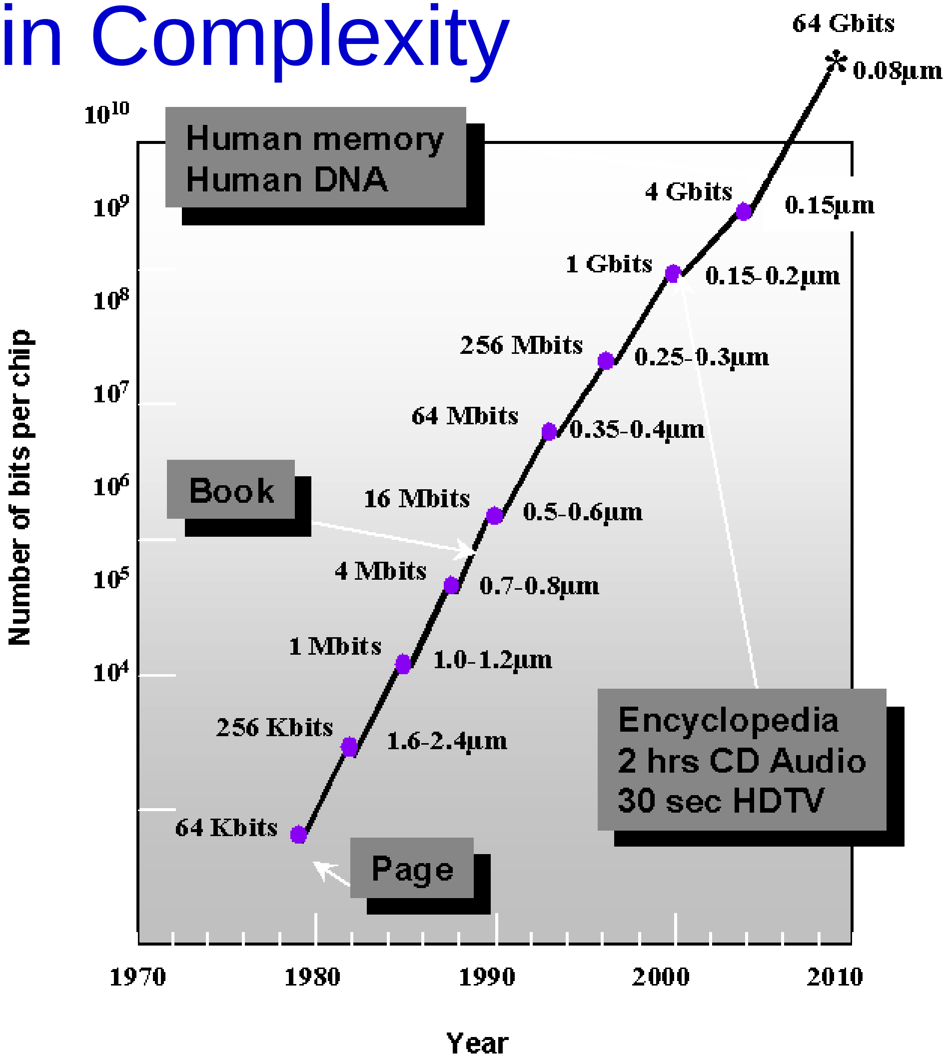
IC Manufacturing History

Moore's Law



IC Manufacturing History

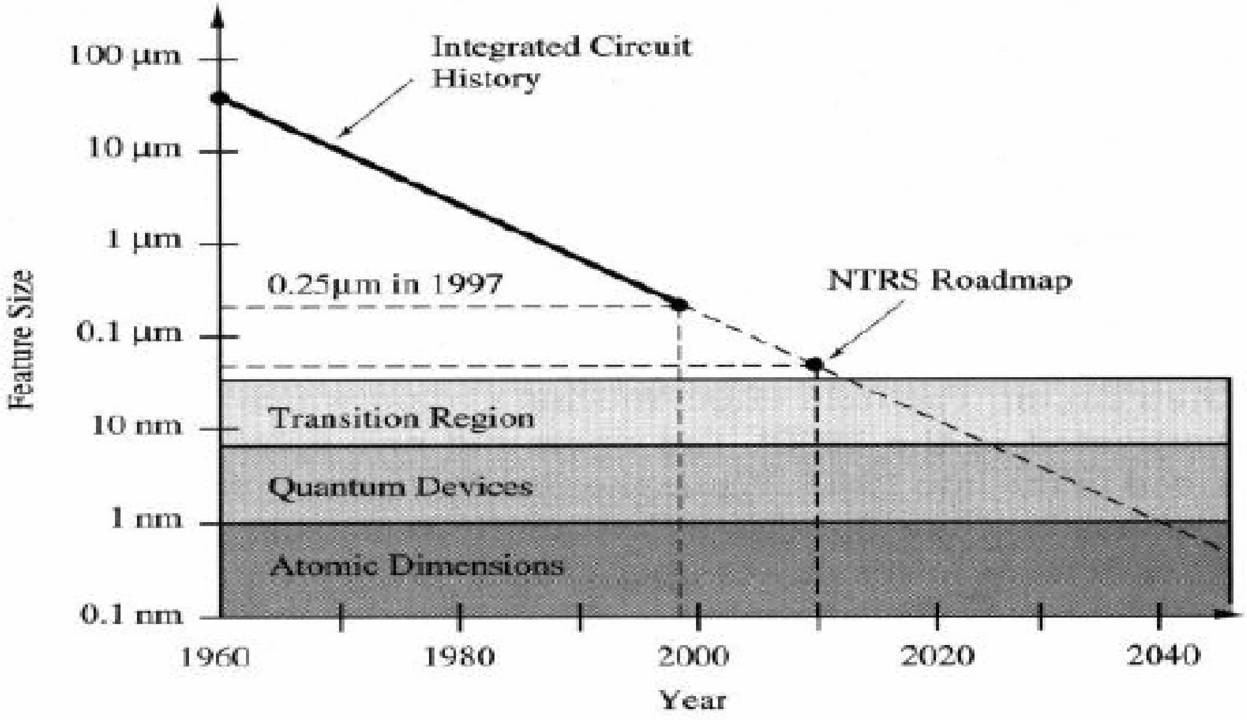
Evolution in Complexity



IC Manufacturing History

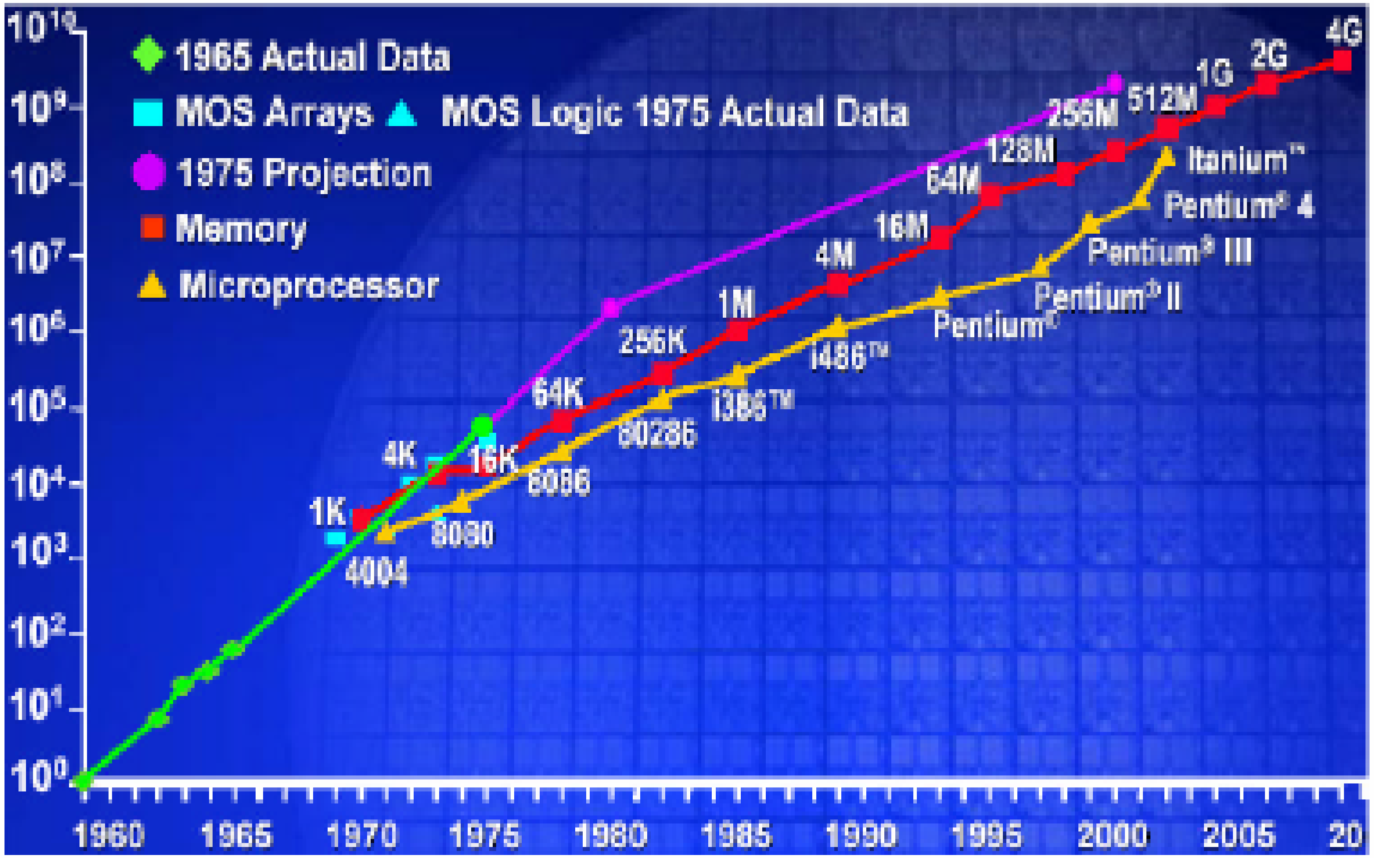
Moore's Law

Doubling of the number of transistors on a chip roughly every two years.



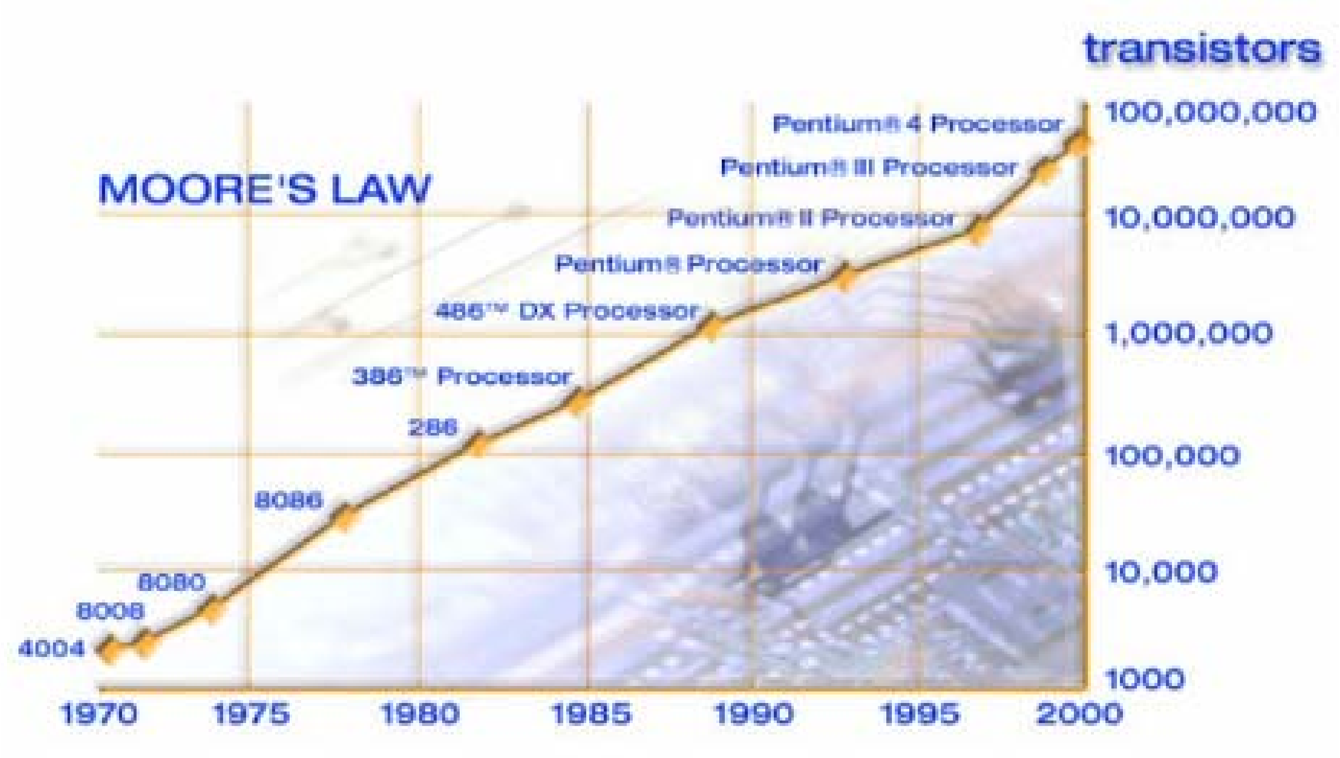
IC Manufacturing History

Moore's Law



IC Manufacturing History

Moore’s Law



IC Manufacturing History

Roadmap of IC

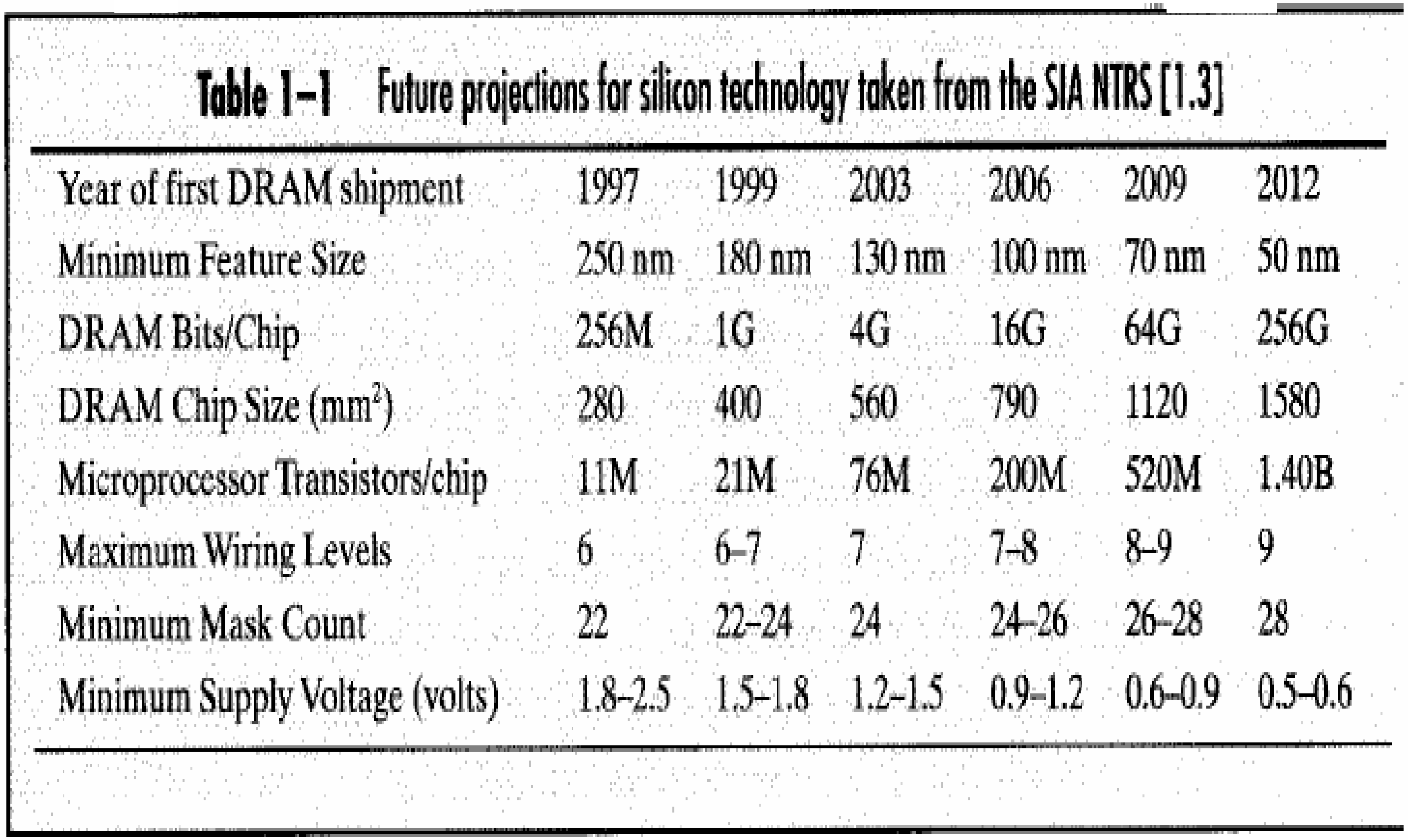
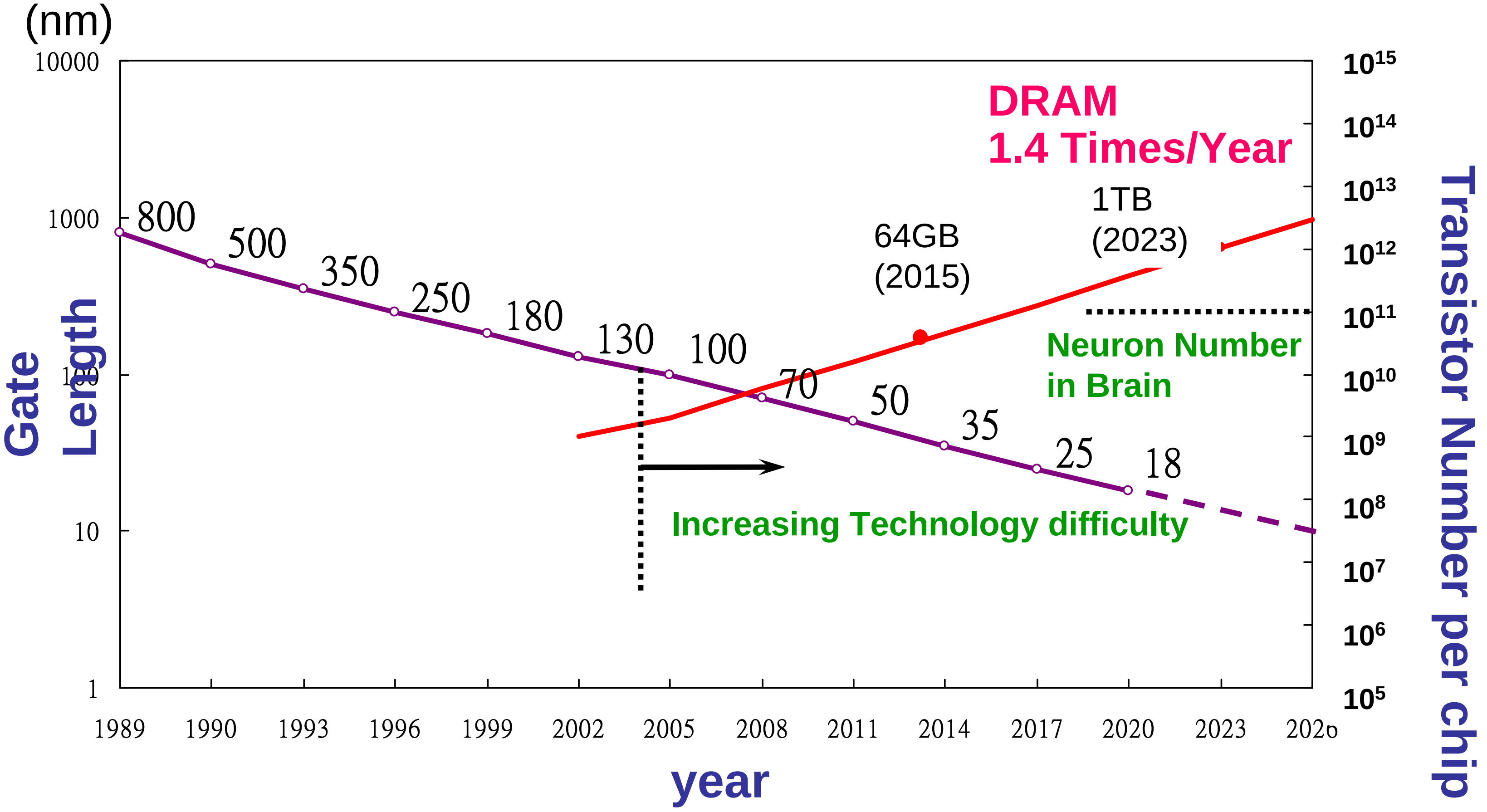


Table 1–1 Future projections for silicon technology taken from the SIA NTRS [1.3]

Year of first DRAM shipment	1997	1999	2003	2006	2009	2012
Minimum Feature Size	250 nm	180 nm	130 nm	100 nm	70 nm	50 nm
DRAM Bits/Chip	256M	1G	4G	16G	64G	256G
DRAM Chip Size (mm^2)	280	400	560	790	1120	1580
Microprocessor Transistors/chip	11M	21M	76M	200M	520M	1.40B
Maximum Wiring Levels	6	6–7	7	7–8	8–9	9
Minimum Mask Count	22	22–24	24	24–26	26–28	28
Minimum Supply Voltage (volts)	1.8–2.5	1.5–1.8	1.2–1.5	0.9–1.2	0.6–0.9	0.5–0.6

IC Manufacturing History

Silicon Story



IC Manufacturing History

Roadmap of IC

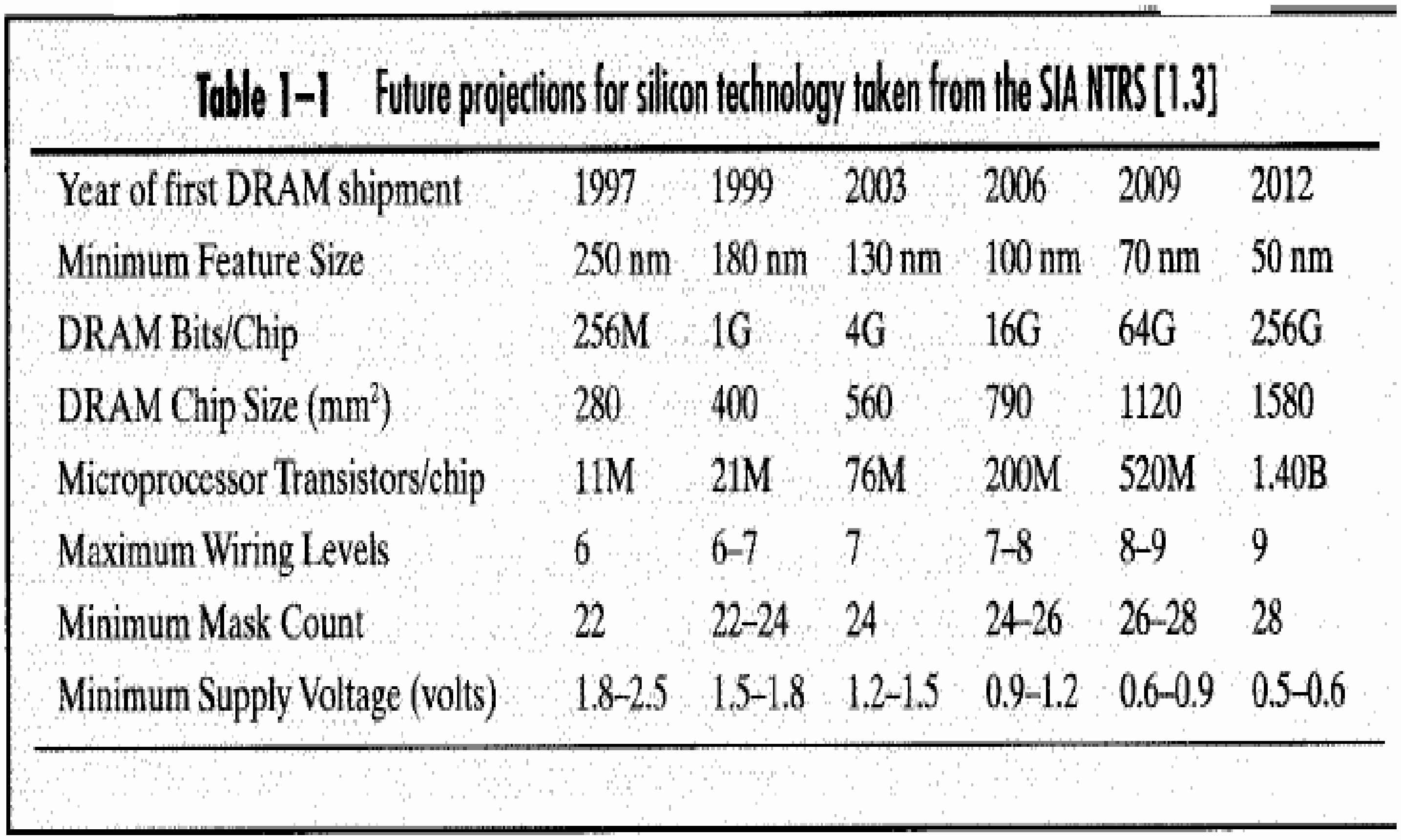
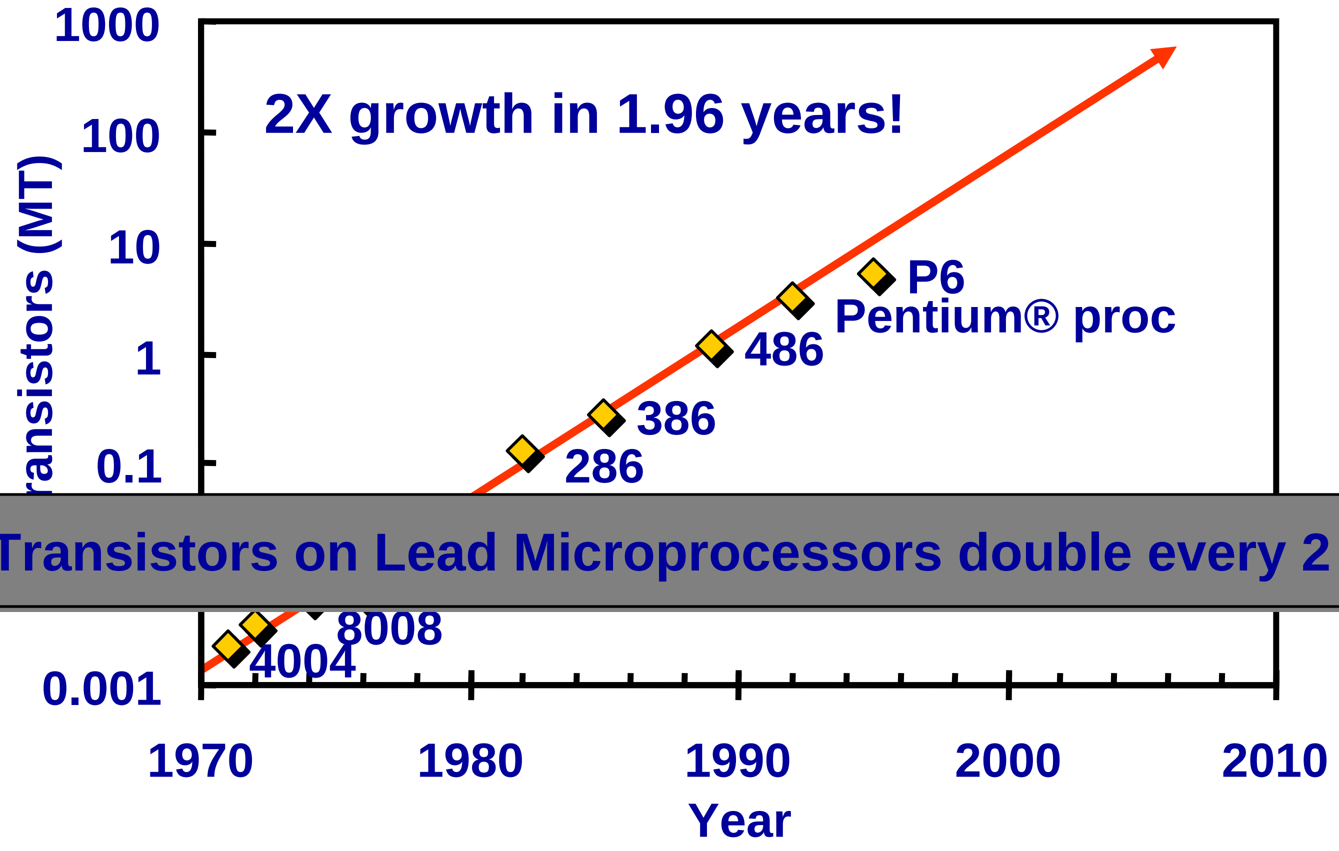


Table 1–1 Future projections for silicon technology taken from the SIA NTRS [1.3]

Year of first DRAM shipment	1997	1999	2003	2006	2009	2012
Minimum Feature Size	250 nm	180 nm	130 nm	100 nm	70 nm	50 nm
DRAM Bits/Chip	256M	1G	4G	16G	64G	256G
DRAM Chip Size (mm^2)	280	400	560	790	1120	1580
Microprocessor Transistors/chip	11M	21M	76M	200M	520M	1.40B
Maximum Wiring Levels	6	6–7	7	7–8	8–9	9
Minimum Mask Count	22	22–24	24	24–26	26–28	28
Minimum Supply Voltage (volts)	1.8–2.5	1.5–1.8	1.2–1.5	0.9–1.2	0.6–0.9	0.5–0.6

IC Manufacturing History

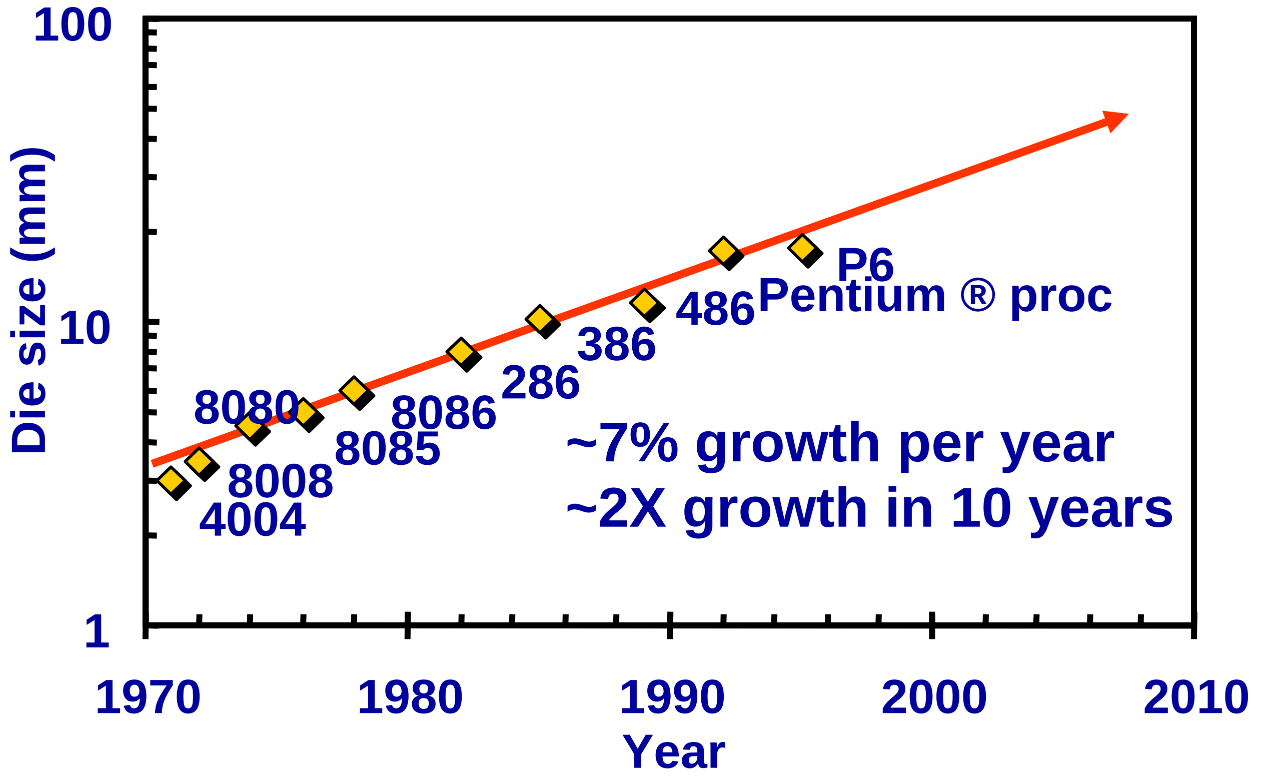
Moore’s law in Microprocessors



Transistors on Lead Microprocessors double every 2 years

IC Manufacturing History

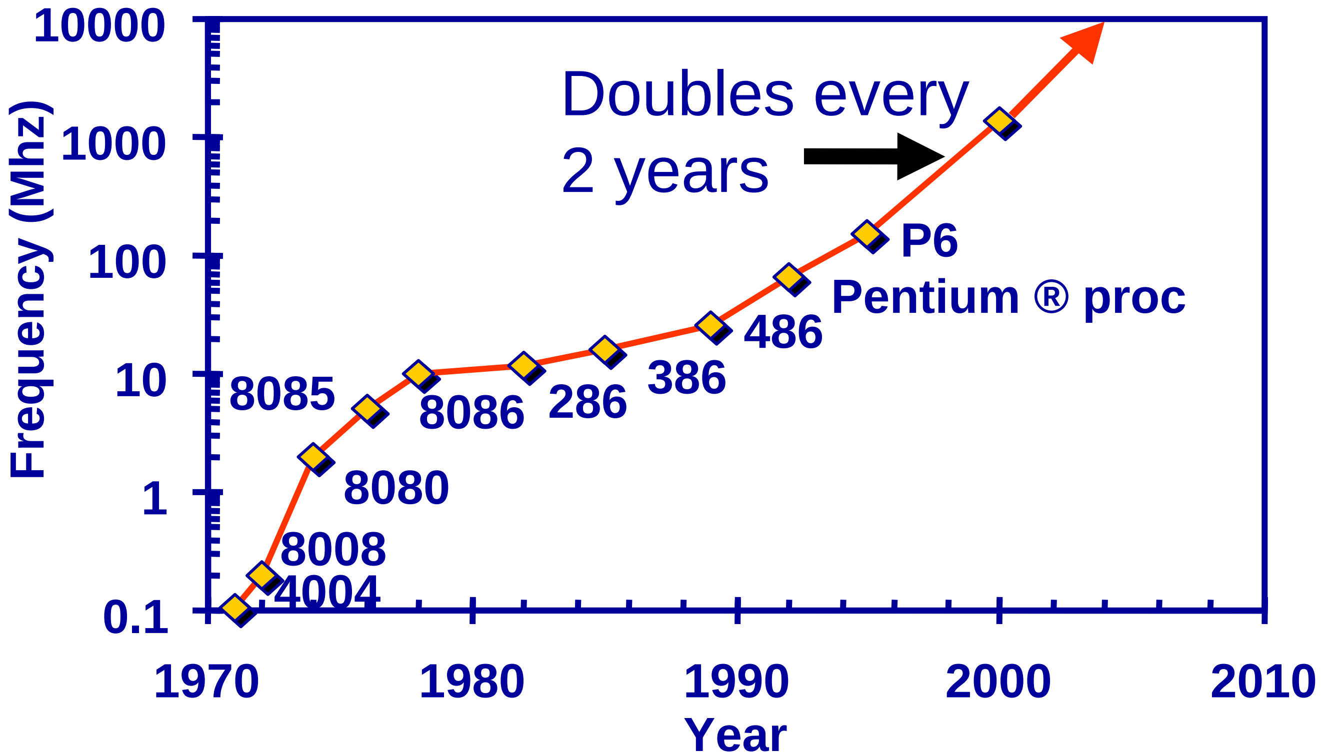
Die Size Growth



Die size grows by 14% to satisfy Moore's Law

IC Manufacturing History

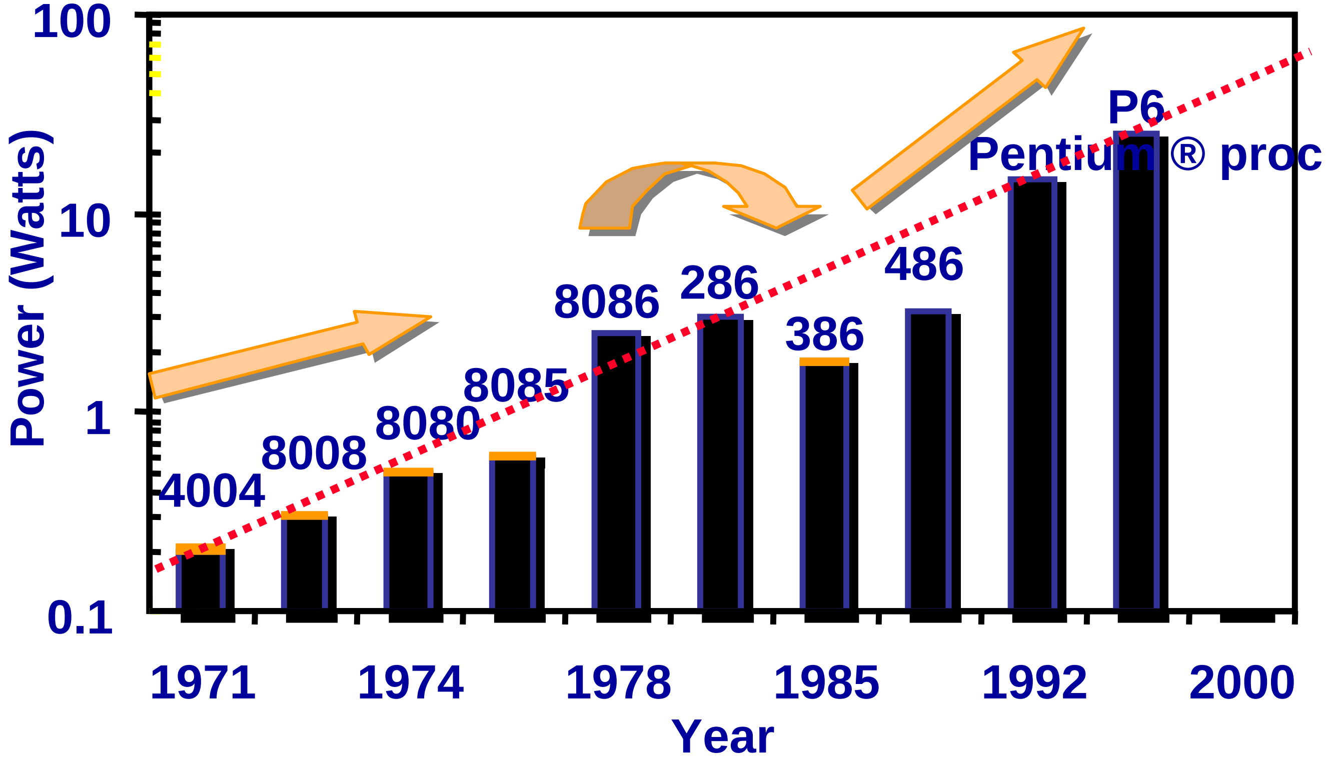
Frequency



Lead Microprocessors frequency doubles every 2 years

IC Manufacturing History

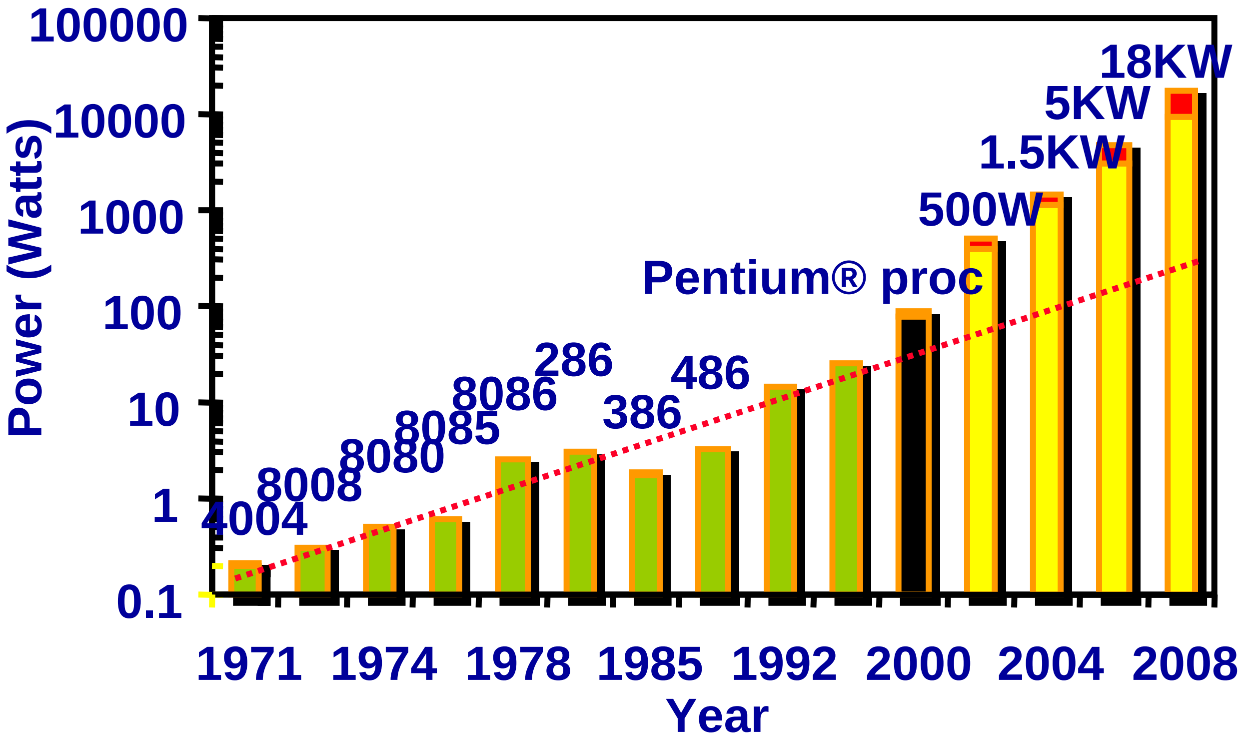
Power Dissipation



Lead Microprocessors power continues to increase

IC Manufacturing History

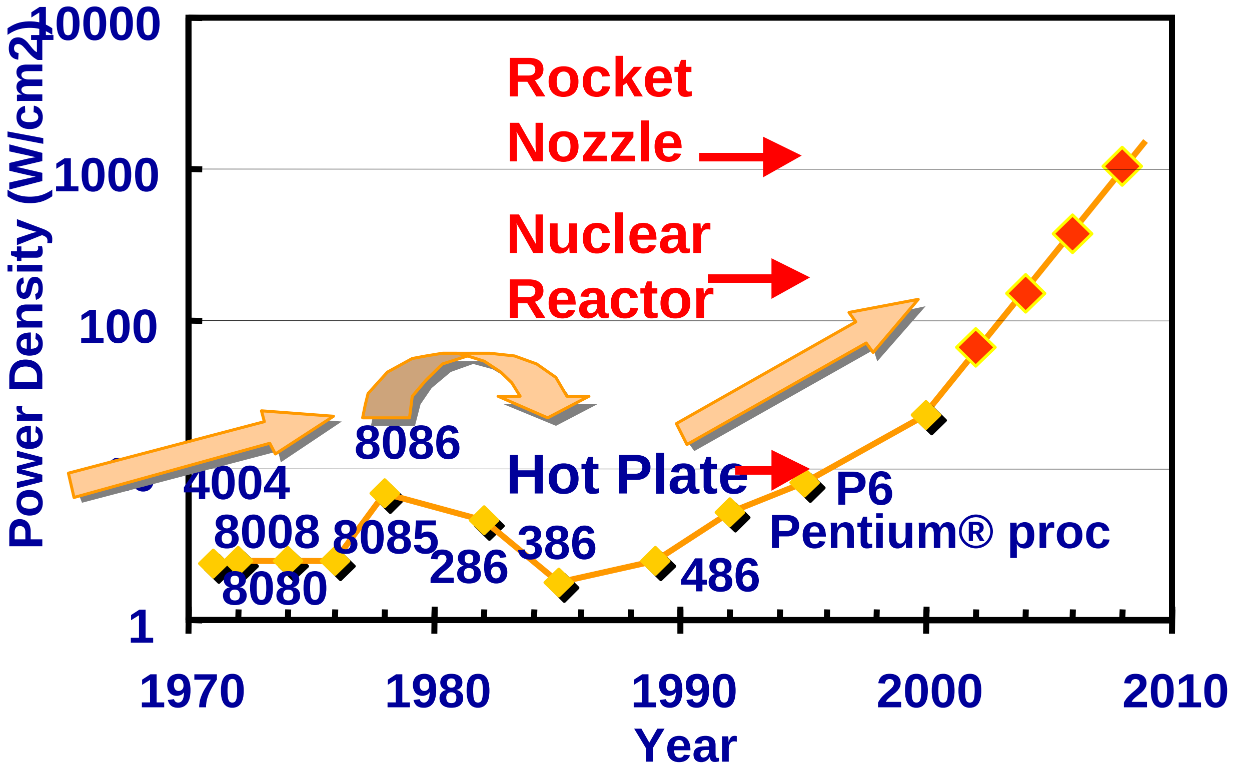
Power will be a major problem



Power delivery and dissipation will be prohibitive

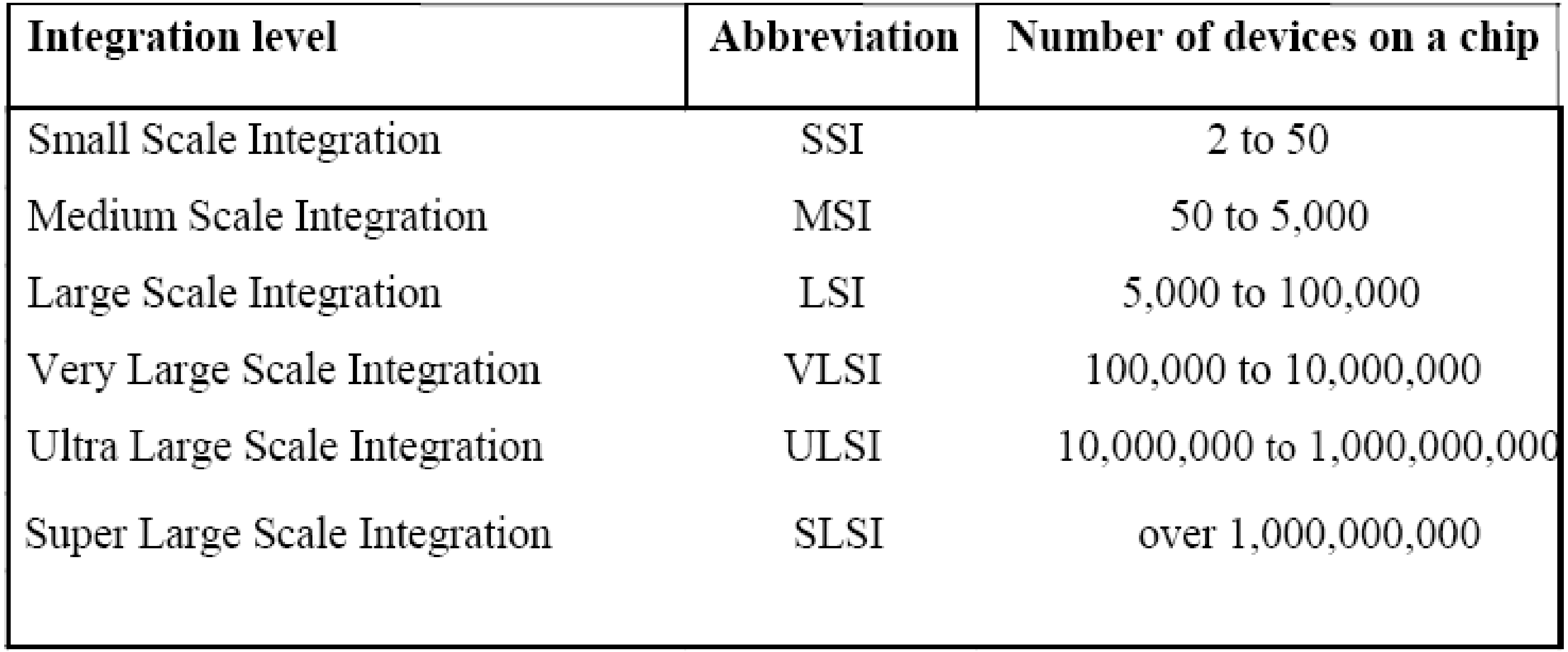
IC Manufacturing History

Power density



Power density too high to keep junctions at low temp

IC Manufacturing History



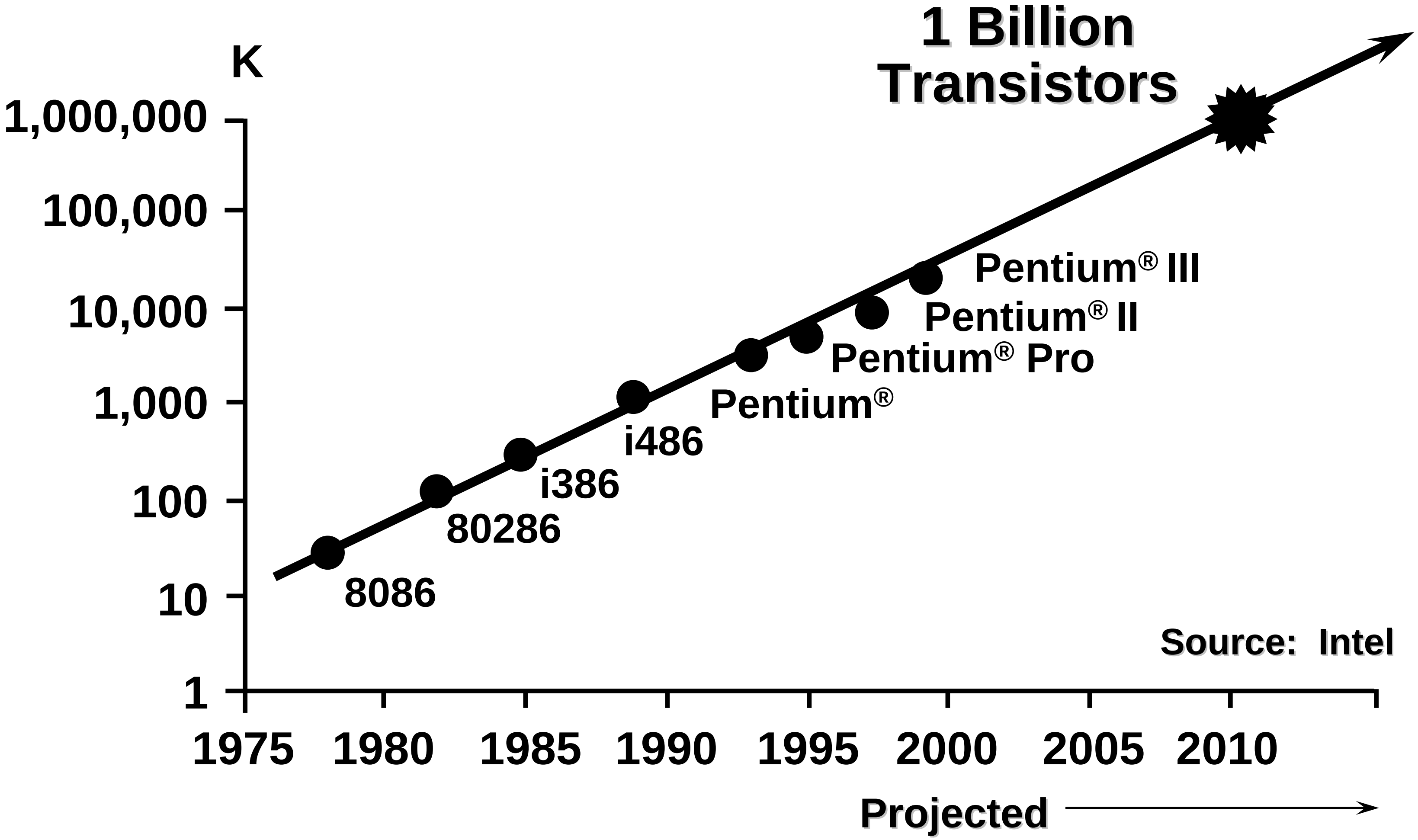
Integration level	Abbreviation	Number of devices on a chip
Small Scale Integration	SSI	2 to 50
Medium Scale Integration	MSI	50 to 5,000
Large Scale Integration	LSI	5,000 to 100,000
Very Large Scale Integration	VLSI	100,000 to 10,000,000
Ultra Large Scale Integration	ULSI	10,000,000 to 1,000,000,000
Super Large Scale Integration	SLSI	over 1,000,000,000

IC Manufacturing History

20世紀後半世紀之 IC 發展年代紀實:

- 1958 : Single transistor 1
- 1962+: SSI 10
- 1967 : MSI (Medium) 100
- 1972 : LSI 1000
- 1978 : VLSI 10^5-10^6
- 1990 : ULSI (Ultra) $>10^6$
- 2000 : SoC (System on Chip)

IC Manufacturing History



Source: Intel

IC Manufacturing History

Why Scaling?

Technology shrinks by 0.7/generation

With every generation can integrate 2x more functions per chip; chip cost does not increase significantly

Cost of a function decreases by 2x

But …

How to design chips with more and more functions?

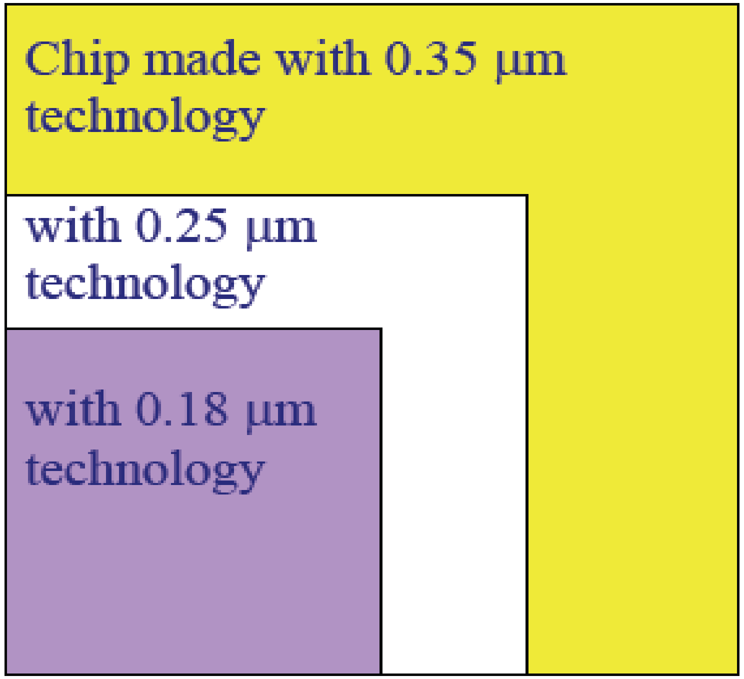
Design engineering population does not double every two years…

Hence, a need for more efficient design methods

Exploit different levels of abstraction

IC Manufacturing History

Why Scaling?



Chip made with 0.35 µm technology

with 0.25 µm technology

with 0.18 µm technology

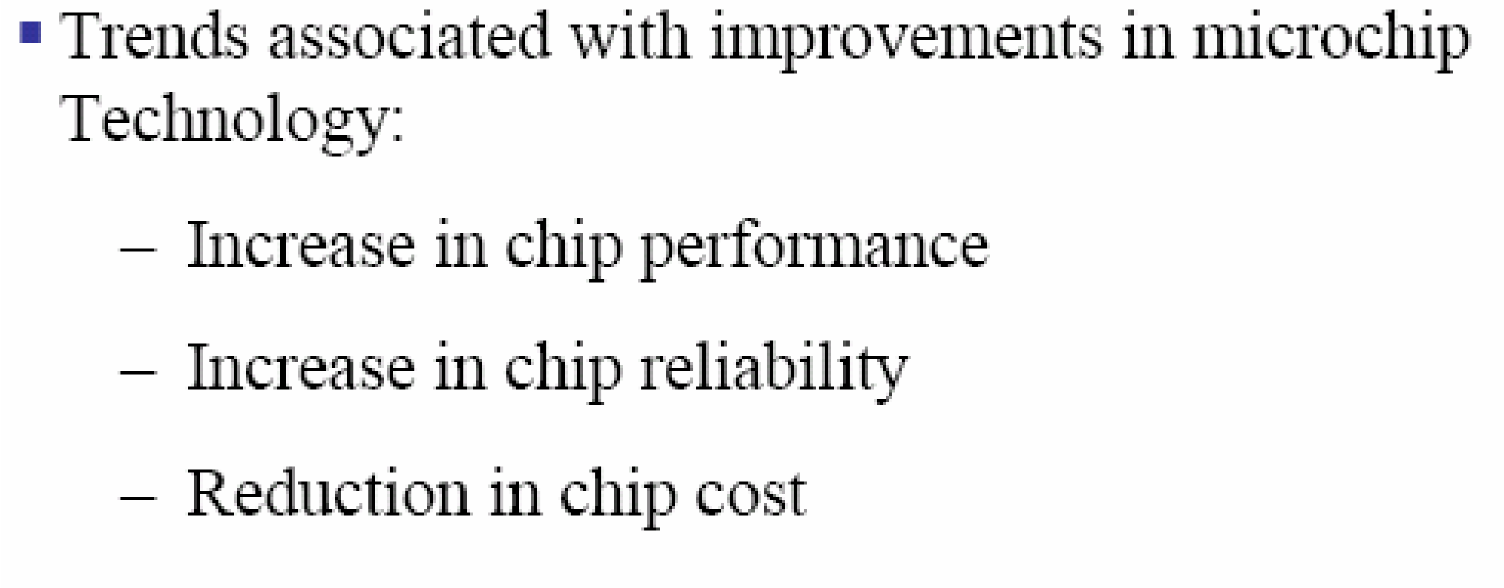
IC Manufacturing History

Why Scaling?

Applications

IC Manufacturing History

The trend of Semiconductor



- Trends associated with improvements in microchip Technology:
  - Increase in chip performance
  - Increase in chip reliability
  - Reduction in chip cost

IC Manufacturing History

Why Scaling?

rapid advancement in technology

miniaturization, low cost

cheaper, smaller, faster systems

greater market needs

Moore's Law

IC Manufacturing History

The trend of Semiconductor

Year			1986	1990	1993	1997	2001	2003
記憶體		(bit)	1M	4M	16M	64M	256M	1G
製程線寬		(um)	1.2	0.8	0.5	0.25	0.18	0.13
金屬不純物	規格	(ppt)	10000	1000	500	100	10	5
	實測值	(ppt)	5000	500	100	10	1	0.5
微粒子 Particle	規格	(um)	0.5	0.5	0.3	0.2	0.1	0.05
		(pcs/ml)	50	50	200	100	100	10
	實測值	(um)	0.5	0.5	0.3	0.2	0.1	0.05
		(pcs/ml)	30	10	50	30	30	5

IC Manufacturing History

積體電路之重要觀念

- 積體電路(Integration circuit, IC)是把電晶體、電阻、電容...等電子元件整合做在一個晶方(chip)內稱之。
- 自從1958年第一顆IC被應用在第二代電腦以來, 後續的研究發現,而這些電路如果作三度空間等比例的縮小其結果功能相仿, 僅需調整電子通道在次表面(sub-micro)的電場結構(architecture)作部份修正即可作到與上一代完全相同的功能但積集度卻大幅增加的新世代 。
- 這個項重大發現造就一個明星產業就是半導體積體電路, 而且從美國矽谷(silicon valley)一路往亞洲的日本、韓國、臺灣有如雁鴉飛行路線般地在移動且在各地都有開花結果。

IC Manufacturing History

積體電路之重要觀念　積木遊戲

堆積木，是用幾種基本的小木塊 (基底木塊) 堆出複雜的作品；若基底木塊的種類愈多，作品愈有趣且多樣化；反之若只有一兩種，受限較多就難有吸引人的成果

向量觀念類似堆積木。平面上任一向量A都可以用一組所謂的基底(basis)來表示，例如：

$$A = a\hat{x} + b\hat{y}$$

$\hat{x}$、$\hat{y}$ = x 軸和y 軸的單位向量

a、b = x、y軸上的分量

$\hat{x}$、$\hat{y}$：基底木塊 ； A：組合出來的作品

IC Manufacturing History

積體電路之重要觀念 積木遊戲

同理,積木堆出來的城堡也可以看作一個向量。以方程式來表示為:

城堡=27 方形木塊+ 45 三角形木塊+

一個城堡由27個方形木塊、45個三角形木塊、等所組成

「27」、「45」: 表示城堡在方形基底木塊和三角形基底木塊上的分量。

IC Manufacturing History

積體電路之重要觀念

積木遊戲

◆ 基底向量未必互相垂直，理論上任何兩個不同方向的向量，皆可以構成平面上的一組基底向量

◆ 通常選擇的基底向量爲互相垂直

「垂直」的數學意義：兩向量彼此沒有分量在對方方向

「垂直」的深層意義：它們是「完全不同」的向量

垂直基底使數學形式簡單，且容易認清複雜向量的背後涵義

◆ 只要發現更多垂直基底，就可以拓展更多樣化的向量空間。

IC Manufacturing History

- 電路仔細拆解後，總會發覺是由幾個基本的元件組成：電阻(R)、電感 (L)、電容(C)、二極體(D)和電晶體(T)
    - 對應於向量，電路A可表示爲：
      電路A = a1R + a2L + a3C + a4D + a5

- R、L、C、D、T也就是電子電路的基本木塊

IC Manufacturing History

電阻

- 電阻的可貴之處，在於V、I 間的簡單比例關係。若其V、I 的關係爲 $V = RI^2 + R^2\sqrt{I}$ ，電路設計將會十分複雜。因此歐姆定律有極高的重要性。
- 許多人都會利用歐姆定律「計算」題目 ，但很少想它背後的涵義。以後我們將利用電阻決定適當的電壓或電流，使電路設計成想要的模式，希望慢慢能體會電阻好用之處

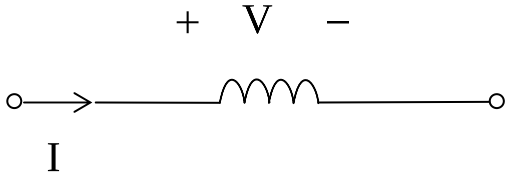
IC Manufacturing History

電感

◆ R是電子電路向量空間的第一個基底向量，其V和I呈線性關係(linear relationship) 。

◆找尋新的元件是電子工程師一直以來努力的目標，元件相當於電子電路向量空間的基底向量，越多，電子電路的變化就越豐富。

◆我們發現，一銅線繞成線圈，可以產生一個獨特的新元件—電感 (Inductor)；符號見右圖



IC Manufacturing History

電感

- 根據法拉第定律，由於線圈磁場感應產生電場，其V-I 關係如下

$$V = L \cdot \frac{dI}{dt}$$

V和I的微分成正比

比例常數L稱爲電感量(inductance)

- 電感(L)的V-I呈微分關係，不論如何組合，線性關係的R都無法呈現L的微分關係；以向量觀點，L是和R完全垂直的全新基底向量。因此電子電路將由R所建構的一維空間進入(R，L)的二維空間 。

IC Manufacturing History

電感

電感的兩大特點：

一. $Z_L \propto w$ ，阻抗會隨著頻率而改變，表示電感是「frequency sensitive」 的元件，對頻率有選擇性

應用：濾波器(filter) —— 從一群不同頻率的信號中將要的信號濾出。

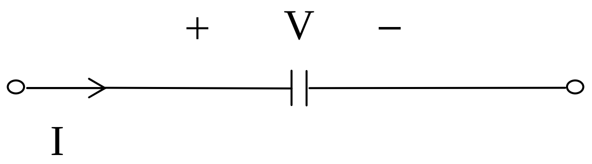
例如：電視機或收音機的選台器

二. 電感的電壓與電流之間的相位差90°，這個特性可以改變信號的相位 。

IC Manufacturing History

電容

- 電容(capacitor)的構造簡單，爲兩片金屬之間夾著一塊絕緣體，符號如下圖：



V-I 關係 ： $V = \frac{1}{C}\cdot\int Idt$

- 電壓和電流的積分呈線性關係其中比例常數C稱爲電容量 。

IC Manufacturing History

電容

- 電容C的特性和R、L完全不同，以向量空間的觀點，三者互爲垂直的基底，將電子電路推展爲R、L、C的三維空間 。
- 電容界定了積分關係，配合電阻的線性及電感的微分關係後，基本數學功能備齊，即可以電子電路完成大多數學方程式表示的功能 。

IC Manufacturing History

電容

電容的阻抗特性爲和頻率成反比，剛好和電感相反，若巧妙運用，可做出許多有用的電路。

LC帶通濾波器(bandpass filter) 就是利用 電感/電容 阻抗分別隨頻率 遞增/遞減的特性來選擇頻率 。

電容的電壓與電流之間有相位差90°，可用來改變信號的相位 。

IC Manufacturing History

二極體 (The Diode)

- R、L 、 C構成的電路缺點：無法改變頻率

- 原因：對弦波信號，不管作微分、積分或乘上一個常數(此三者數學上稱爲線性運算，linear operation)，結果仍是一個弦波信號，其中振幅、相位可以被改變，但頻率永遠不變。

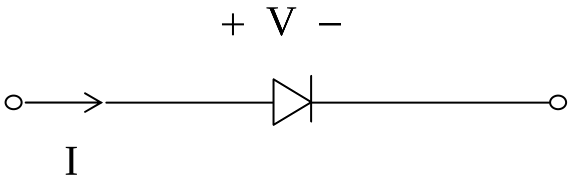
→ 結論：尋找新元件

IC Manufacturing History

二極體 (The Diode)

- 二極體(Diode, D)，是有方向性的元件。
  R、L、C是沒有方向性的元件，它們的V-I特性是左右對稱的。

二極體的電路符號
如右圖

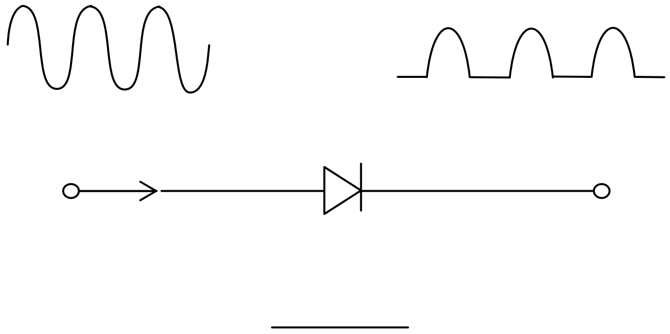


- 「+」端是陽極，「−」端是陰極。當陽極電壓高於陰極時，其電流很大；加同樣電壓使陰極電壓高於陽極時，其電流趨近於零。
  → 左右兩端特性不對稱 → 方向性

IC Manufacturing History

二極體 (The Diode)

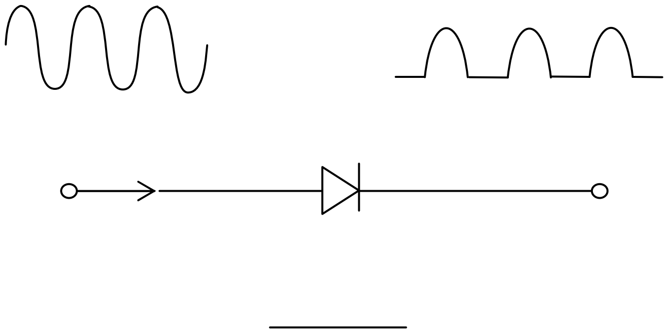
- Diode的方向性可將交流信號轉爲直流電壓，或產生不同頻率的弦波信號。
  如下圖，將一個cos wt弦波信號的下半部「截掉」，成爲半波信號



IC Manufacturing History

二極體 (The Diode)

- Diode的方向性可將交流信號轉爲直流電壓，或產生不同頻率的弦波信號。
  如下圖，將一個cos wt弦波信號的下半部「截掉」，成爲半波信號



IC Manufacturing History

二極體 (The Diode)

由數學上著名的傅立葉轉換得知 $s(t)$ 一個頻率爲w的半波信號 ，可以表示爲

$$s(t)=a_0+a_1\cos(wt+\theta_1)+a_2\cos(2wt+\theta_2)+a_3\cos(3wt+\theta\ +\ldots$$

$$=\sum_{n=0}^{\infty} a_n\cos(nwt+\theta_n)$$

$s(t)$

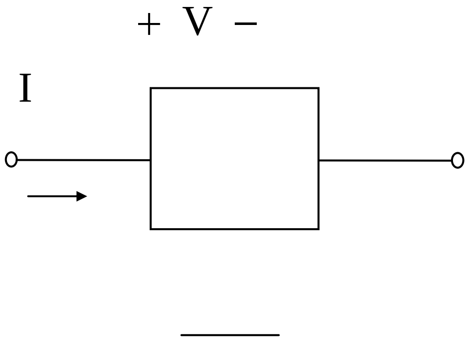
a_n 和 θ_n 由 的波形所決定

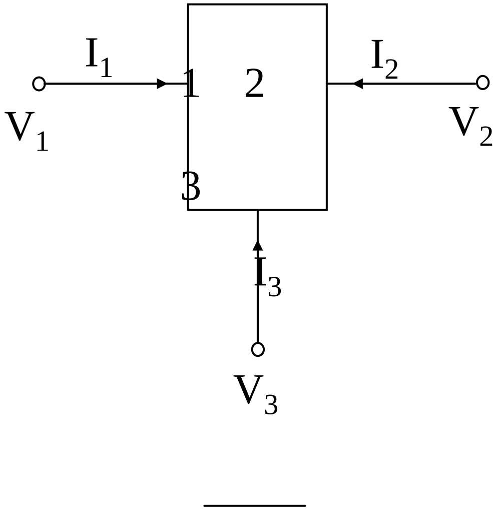
上式表明半波信號包含由直流信號(a_0)，及w的各個倍頻信號(coswt，cos2wt，…)，只要加上濾波器，就可得到與輸入端不同頻率的輸出

IC Manufacturing History

電晶體 (The Transistor)

- R、C、L、D都是兩端元件，僅有一個端電壓(V)及一個電流(I) ，本身不具有放大機制。很難組成放大訊號的電路
- 三端元件，有三個端電壓(V1，V2，V3)及三個端電流(I1，I2，I3)。假如這些
  - 電壓電流存在特別的關係(例：I2 = kV1或V2 = kV1，k > 1)，那麼元件本身就存在放大機制，就可以輕易做出放大器。





IC Manufacturing History

電晶體 (The Transistor)

電晶體(Transistor, T)，是三端元件。分成

一. 雙極性界面電晶體
(Bipolar Junction Transistor, BJT)

二. 場效電晶體 (Field Effect Transistor, FET)

兩者皆利用半導體以不同結構製作而成，元件本身都存在放大機制

電晶體的應用：
一. 放大器的製作

二. 作爲開關元件(switching device)

例如室溫到達設定值能自動打開冷氣機的電路，或門窗被破壞時能自動啓動警報器的電路

Agenda

New Concept for Worldwide

IC Manufacturing History

IC Manufacturing Introduction

IC Process Flow Introduction

The Strategy for the IC Development

The Reliability test for IC Process

Quality Control

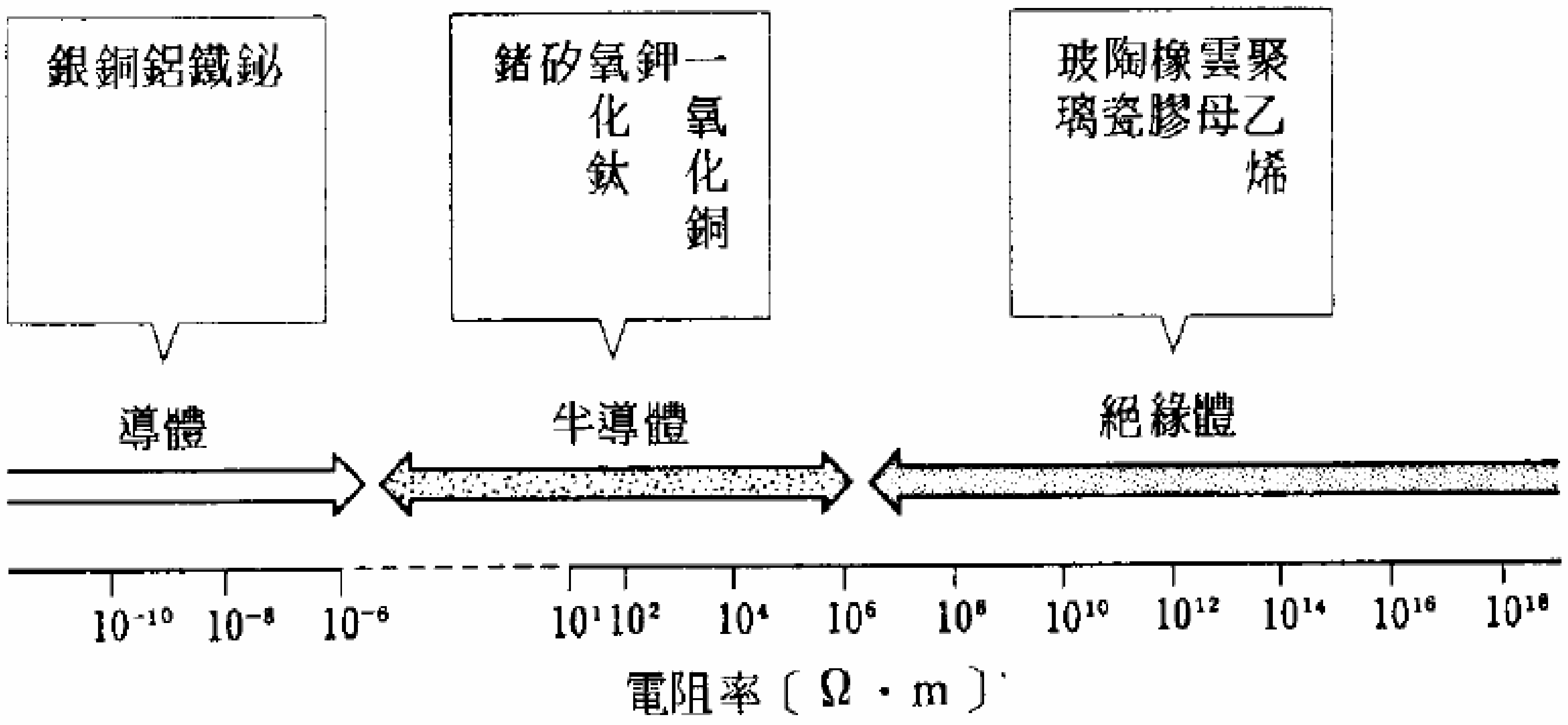
Ford 8-D

物質依照導電能力的分類

物質依照導電能力來區分，可將其分成三類：

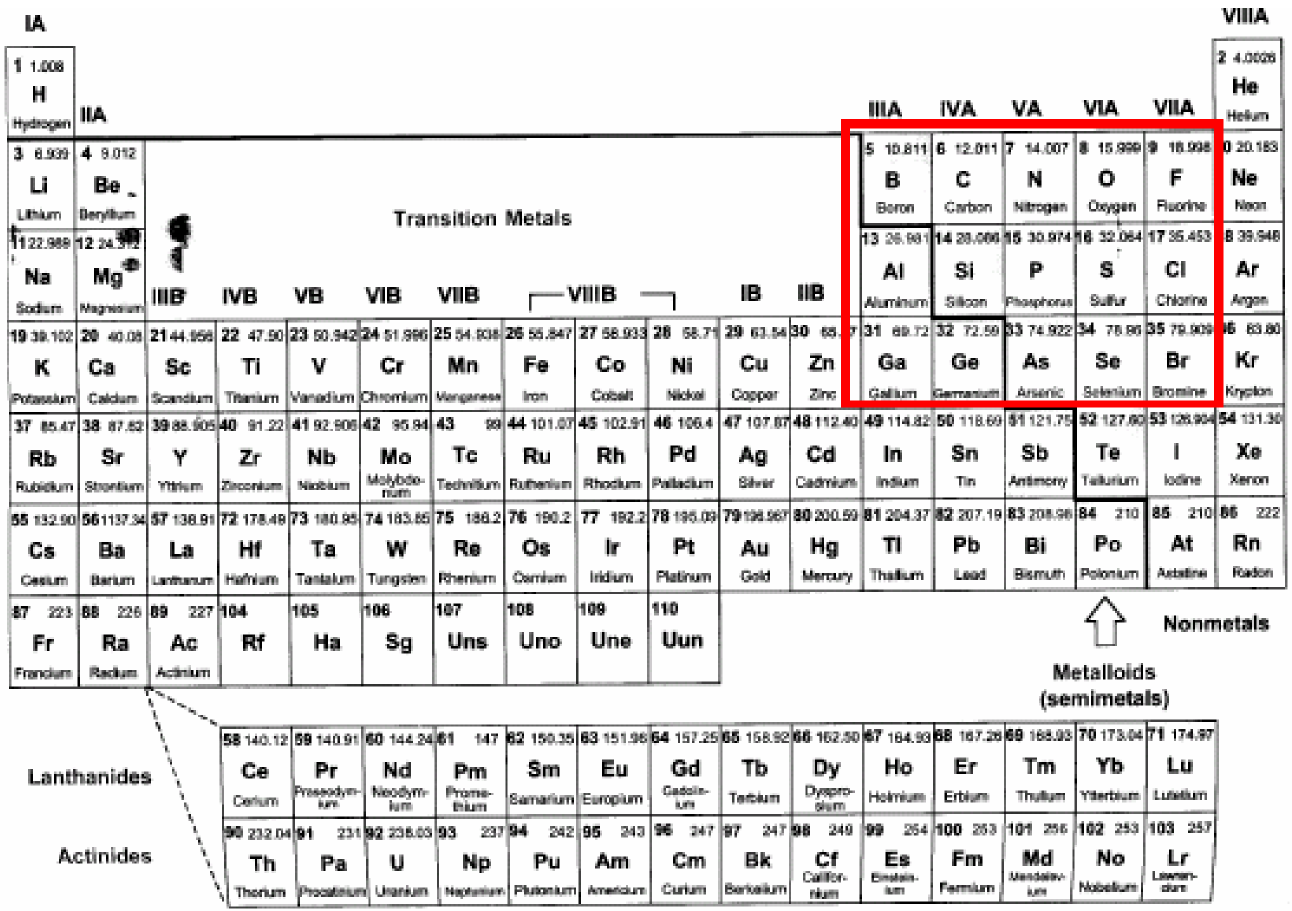
1. 導體
2. 絕緣體
3. 半導體

何謂半導體？



各種物質的電阻率

The Periodic Table



IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 1.008 H Hydrogen																	2 4.0026 He Helium
3 6.939 Li Lithium	4 9.012 Be Beryllium											5 10.811 B Boron	6 12.011 C Carbon	7 14.007 N Nitrogen	8 15.999 O Oxygen	9 18.998 F Fluorine	10 20.183 Ne Neon
11 22.989 Na Sodium	12 24.312 Mg Magnesium											13 26.981 Al Aluminum	14 28.086 Si Silicon	15 30.974 P Phosphorus	16 32.064 S Sulfur	17 35.453 Cl Chlorine	18 39.948 Ar Argon
19 39.102 K Potassium	20 40.08 Ca Calcium	21 44.956 Sc Scandium	22 47.90 Ti Titanium	23 50.942 V Vanadium	24 51.996 Cr Chromium	25 54.938 Mn Manganese	26 55.847 Fe Iron	27 58.933 Co Cobalt	28 58.71 Ni Nickel	29 63.54 Cu Copper	30 65.[illegible]7 Zn Zinc	31 69.72 Ga Gallium	32 72.59 Ge Germanium	33 74.922 As Arsenic	34 78.96 Se Selenium	35 79.909 Br Bromine	36 83.80 Kr Krypton
37 85.47 Rb Rubidium	38 87.62 Sr Strontium	39 88.905 Y Yttrium	40 91.22 Zr Zirconium	41 92.906 Nb Niobium	42 95.94 Mo Molybdenum	43 99 Tc Technitium	44 101.07 Ru Ruthenium	45 102.91 Rh Rhodium	46 106.4 Pd Palladium	47 107.87 Ag Silver	48 112.40 Cd Cadmium	49 114.82 In Indium	50 118.69 Sn Tin	51 121.75 Sb Antimony	52 127.60 Te Tellurium	53 126.904 I Iodine	54 131.30 Xe Xenon
55 132.90 Cs Cesium	56 137.34 Ba Barium	57 138.91 La Lanthanum	72 178.49 Hf Hafnium	73 180.95 Ta Tantalum	74 183.85 W Tungsten	75 186.2 Re Rhenium	76 190.2 Os Osmium	77 192.2 Ir Iridium	78 195.09 Pt Platinum	79 196.967 Au Gold	80 200.59 Hg Mercury	81 204.37 Tl Thallium	82 207.19 Pb Lead	83 208.98 Bi Bismuth	84 210 Po Polonium	85 210 At Astatine	86 222 Rn Radon
87 223 Fr Francium	88 226 Ra Radium	89 227 Ac Actinium	104 Rf	105 Ha	106 Sg	107 Uns	108 Uno	109 Une	110 Uun								

Transition Metals

Nonmetals

Metalloids (semimetals)

Lanthanides	58 140.12 Ce Cerium	59 140.91 Pr Praseodymium	60 144.24 Nd Neodymium	61 147 Pm Promethium	62 150.35 Sm Samarium	63 151.96 Eu Europium	64 157.25 Gd Gadolinium	65 158.92 Tb Terbium	66 162.50 Dy Dysprosium	67 164.93 Ho Holmium	68 167.26 Er Erbium	69 168.93 Tm Thulium	70 173.04 Yb Ytterbium	71 174.97 Lu Lutetium
Actinides	90 232.04 Th Thorium	91 231 Pa Protactinium	92 238.03 U Uranium	93 237 Np Neptunium	94 242 Pu Plutonium	95 243 Am Americium	96 247 Cm Curium	97 247 Bk Berkelium	98 249 Cf Californium	99 254 Es Einsteinium	100 253 Fm Fermium	101 256 Md Mendelevium	102 253 No Nobelium	103 257 Lr Lawrencium

各種物質的電阻率

常溫下不同材料的電阻

物質		電阻率（resistivity）（Ω-m）
導體	銀	1.6×10^{-8}
	銅	1.7×10^{-8}
	金	2.3×10^{-8}
	鋁	2.8×10^{-8}
半導體	矽	0.03-0.04
	鍺	0.46
絕緣體	純水	2.5×10^{5}
	木頭	$10^{8}-10^{11}$
	玻璃	$10^{10}-10^{14}$
	橡膠	$10^{13}-10^{16}$

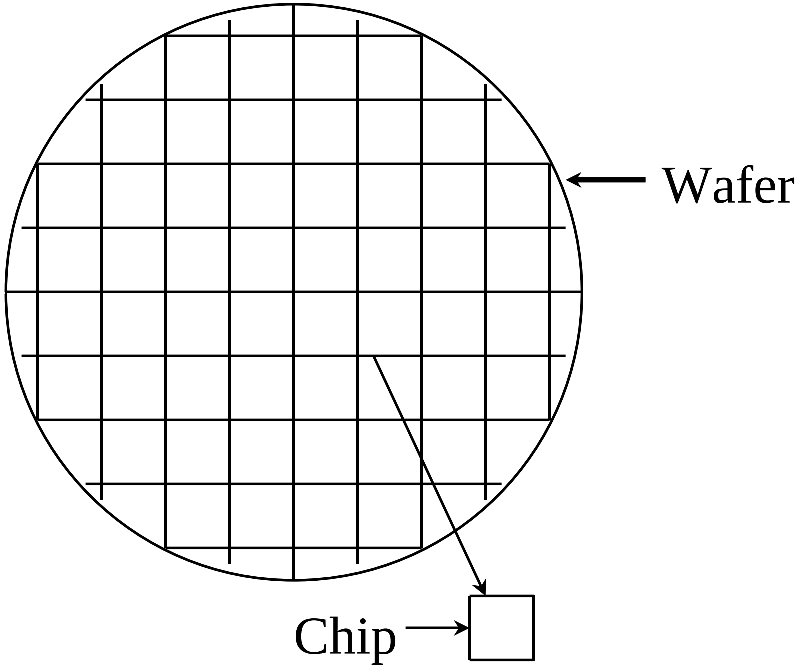
半導體

- 半導體(semiconductor)材料的導電性恰介於導體與絕緣體之間, 它們的導電能力比不上導體, 但比絕緣體還要好. 常見的半導體材料有矽、鍺和砷化鎵.

IC Manufacturing Introduction

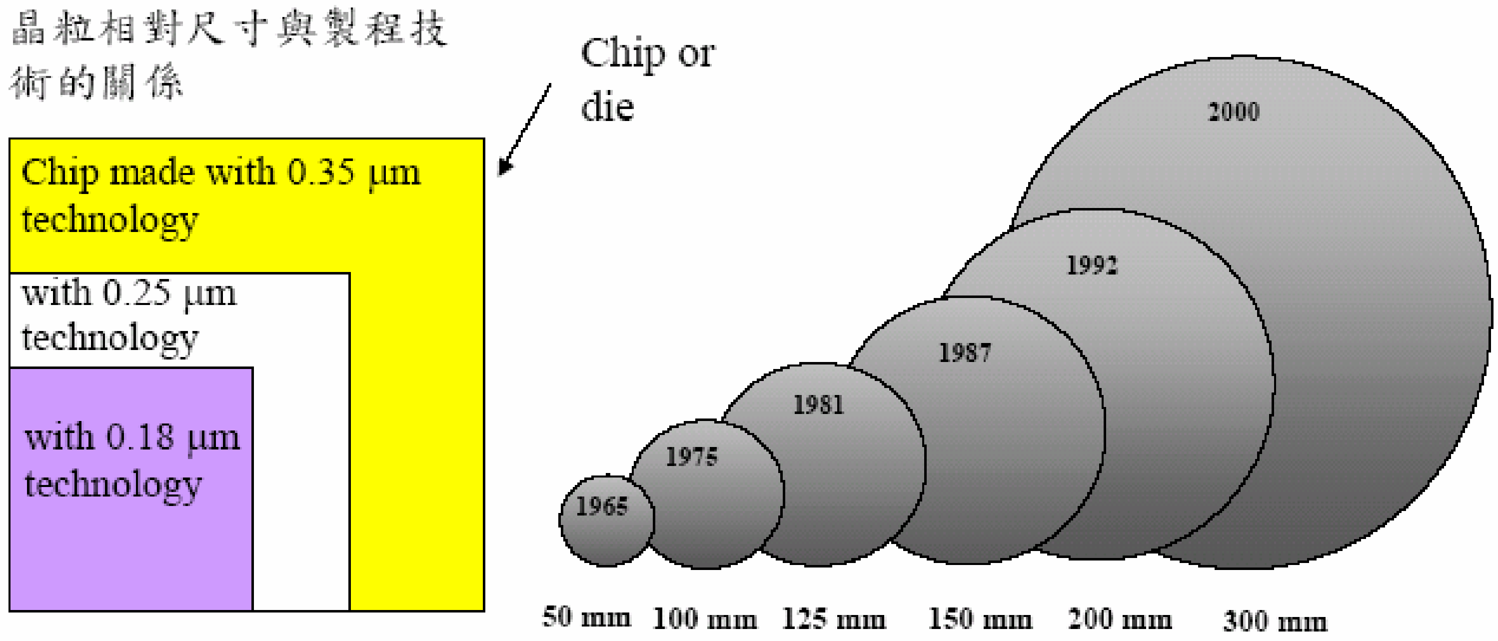
Wafer v.s. Chip

- Sketch of a wafer showing repeated chips



IC Manufacturing Introduction

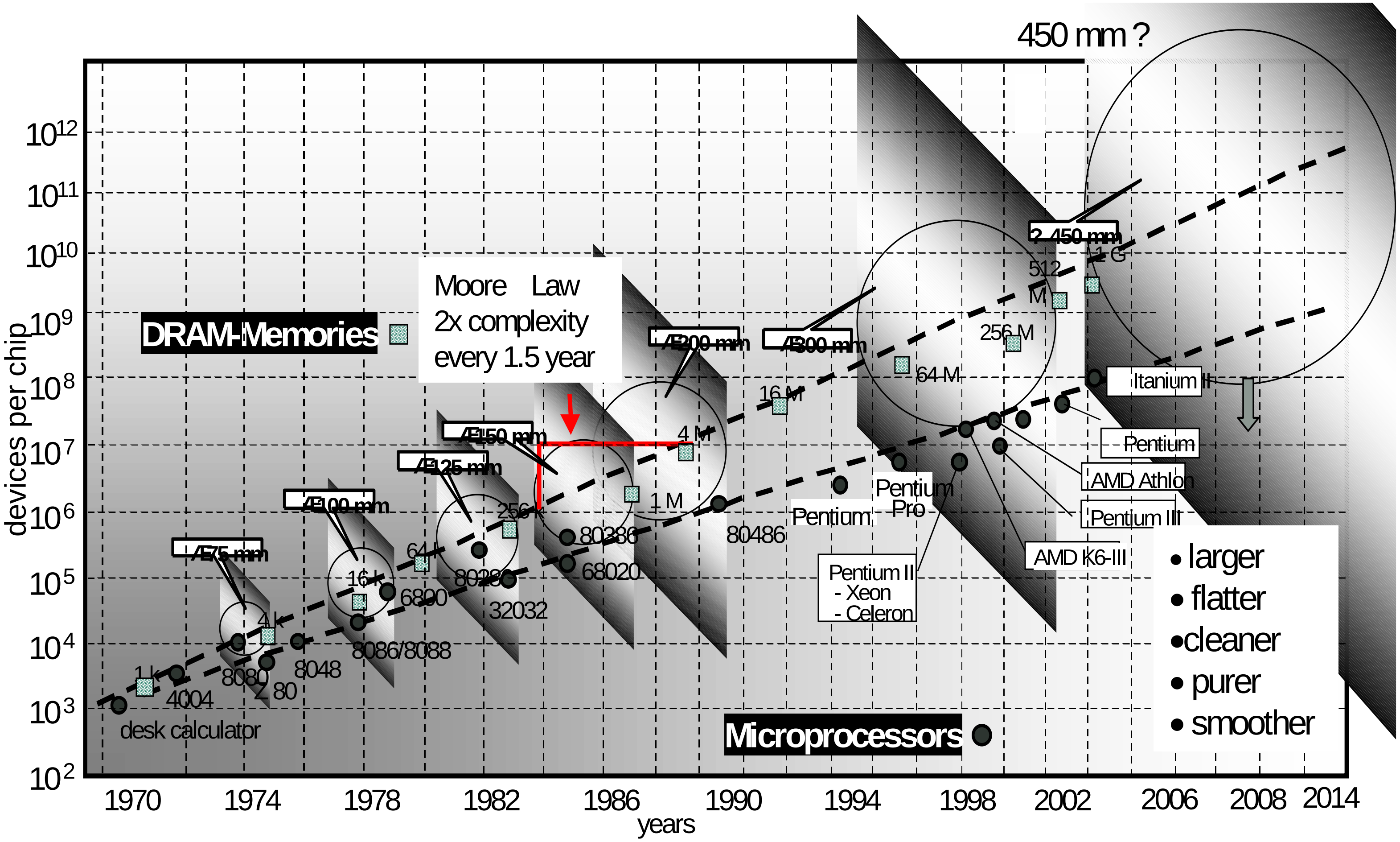
矽晶圓尺吋演進



晶粒相對尺寸與製程技術的關係

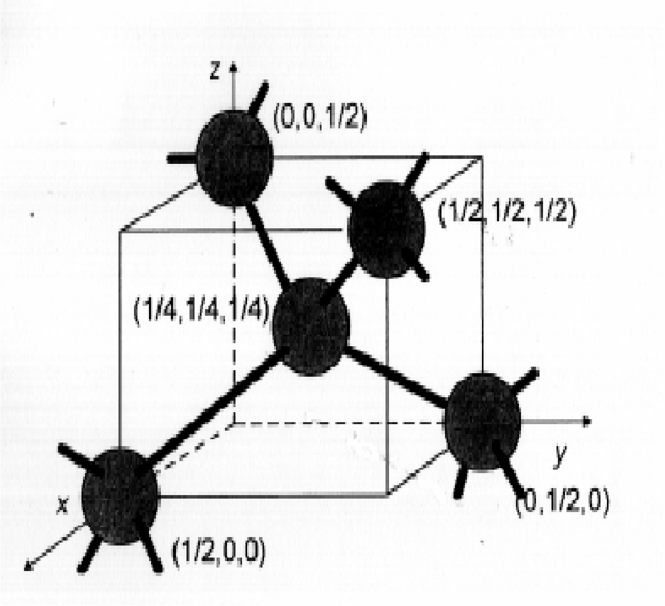
IC Manufacturing Introduction

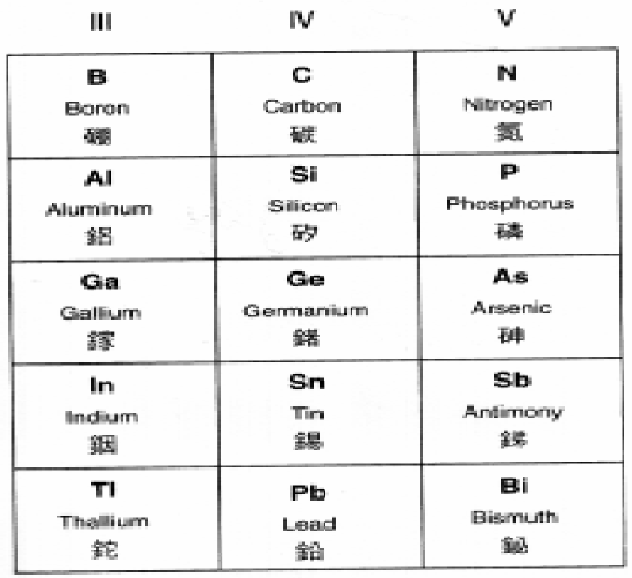
-- A larger wafer size increasing the productivity (cost) is mandatory



何謂半導體 ？

- 元素半導體由單一元素組成，如矽、鍺等
- 共價鍵結合
- 屬於鑽石晶格結構–面心立方
- 屬於週期表 **II-VI** 價元素

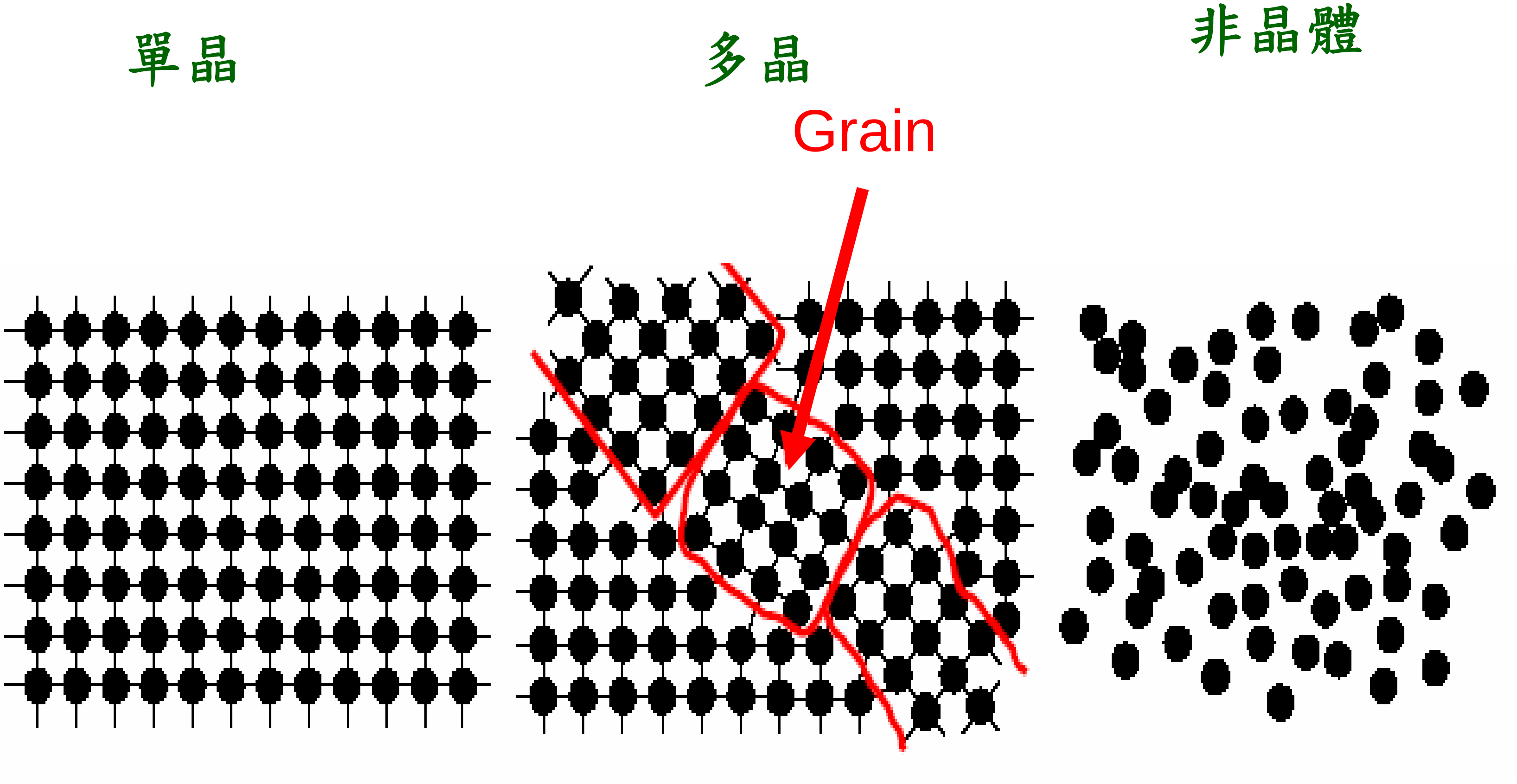




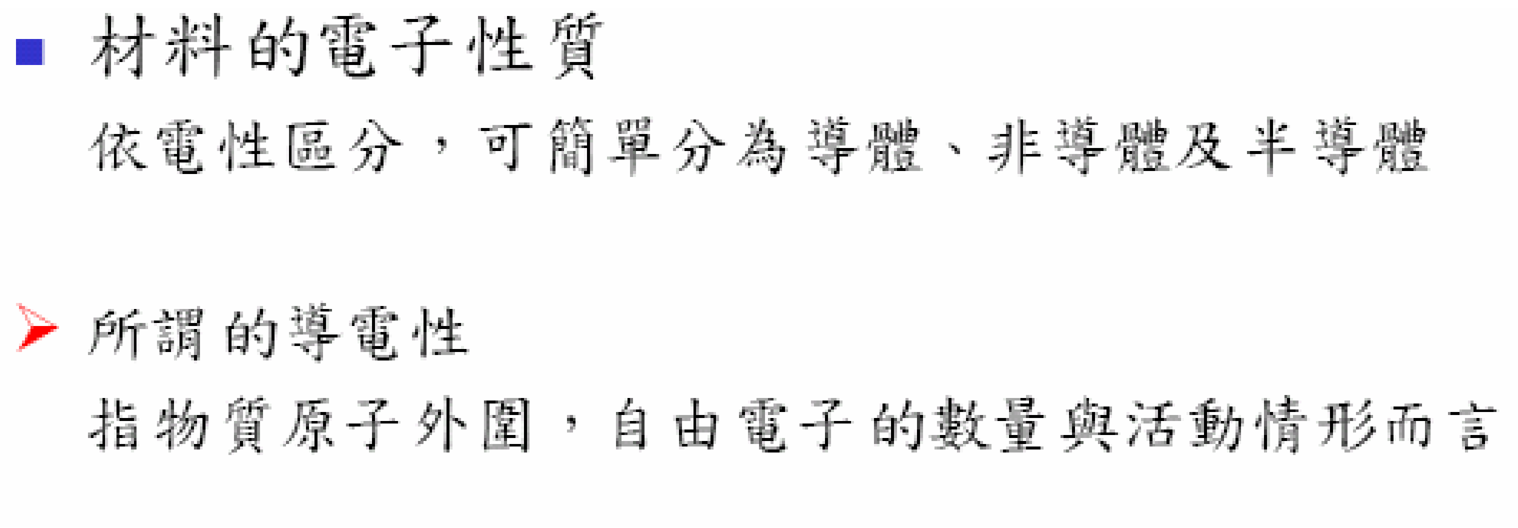
III	IV	V
B Boron 硼	**C** Carbon 碳	**N** Nitrogen 氮
Al Aluminum 鋁	**Si** Silicon 矽	**P** Phosphorus 磷
Ga Gallium 鎵	**Ge** Germanium 鍺	**As** Arsenic 砷
In Indium 銦	**Sn** Tin 錫	**Sb** Antimony 銻
Tl Thallium 鉈	**Pb** Lead 鉛	**Bi** Bismuth 鉍

IC Manufacturing Introduction

單晶. 多晶. 非晶體



材料種類



- 材料的電子性質

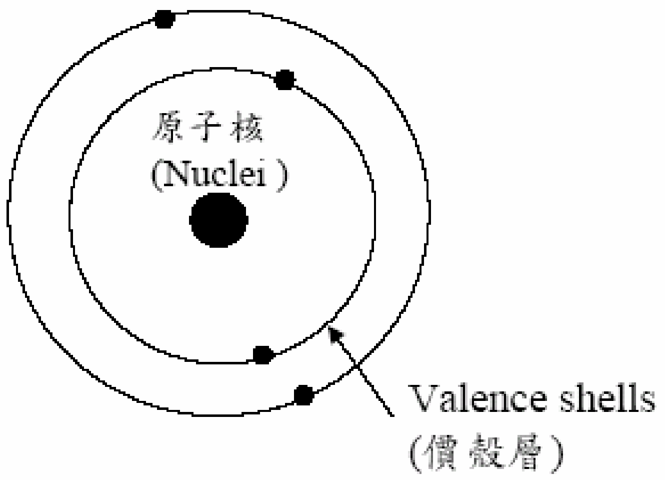
  依電性區分，可簡單分為導體、非導體及半導體

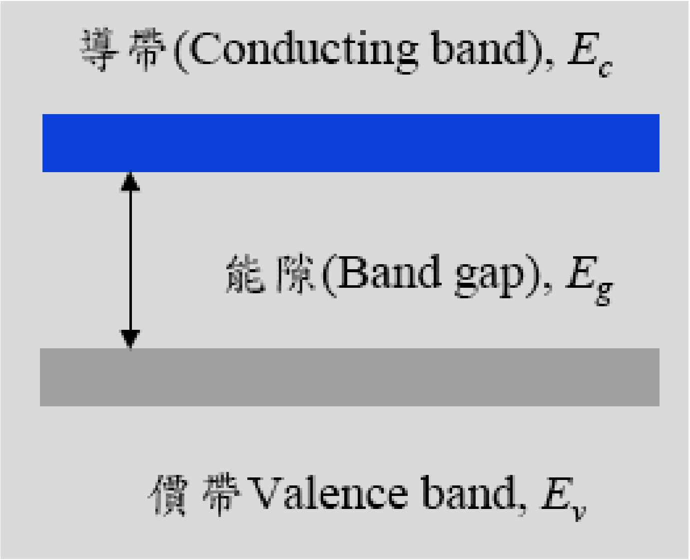
➢ 所謂的導電性

  指物質原子外圍，自由電子的數量與活動情形而言

電子能階

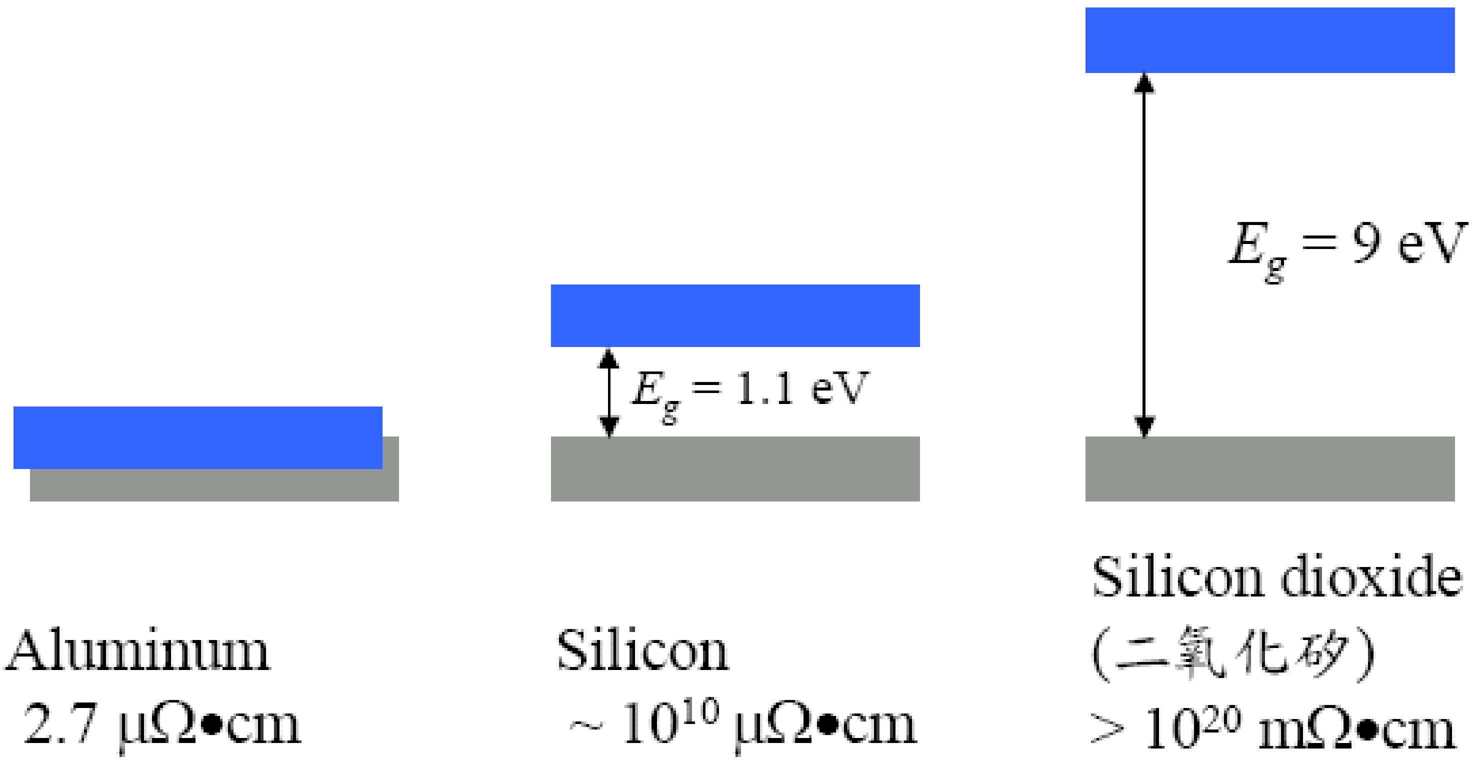
- 電子能階的特性
  - 電子所能接受的能量為不連續式的
  - 能階的轉換需要有外來能量
  - 能階與能階間存在一能隙(Gap)





材料的能階

- Al(導體)、矽(半導體)與SiO_2(非導體)電子能階的比較



IC Manufacturing Introduction

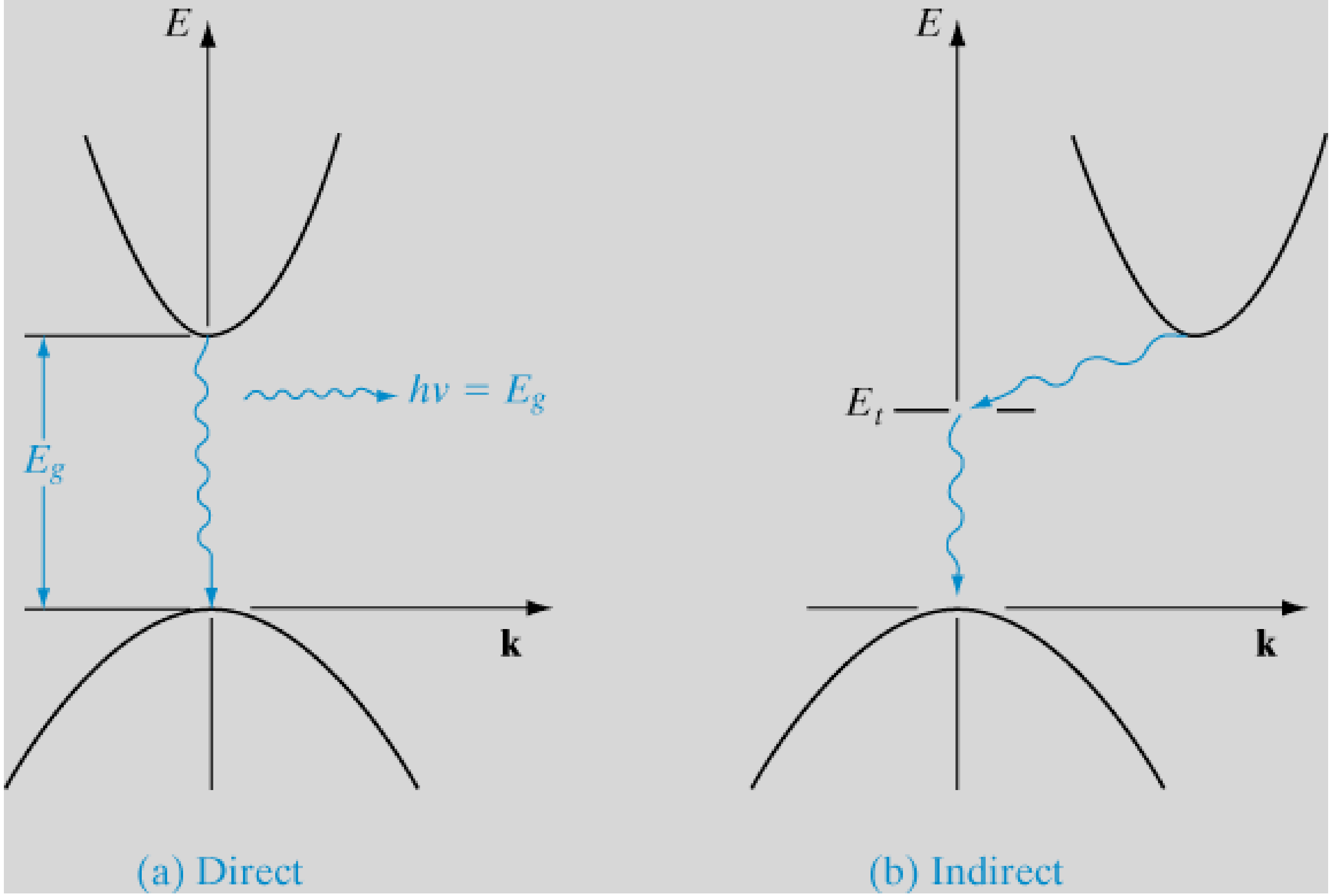
- 半導體 — 一種電子能隙介於導體與非導體之物質

半導體與絕緣體的能隙

基本電性	材料名稱	能隙(eV)
半導體	Si	1.10
	Ge	0.68
	GaAs	1.40
	InP	1.25
	ZnSe	2.60
絕緣體	SiO_2	9.00
	SiN4	5.00

IC Manufacturing Introduction

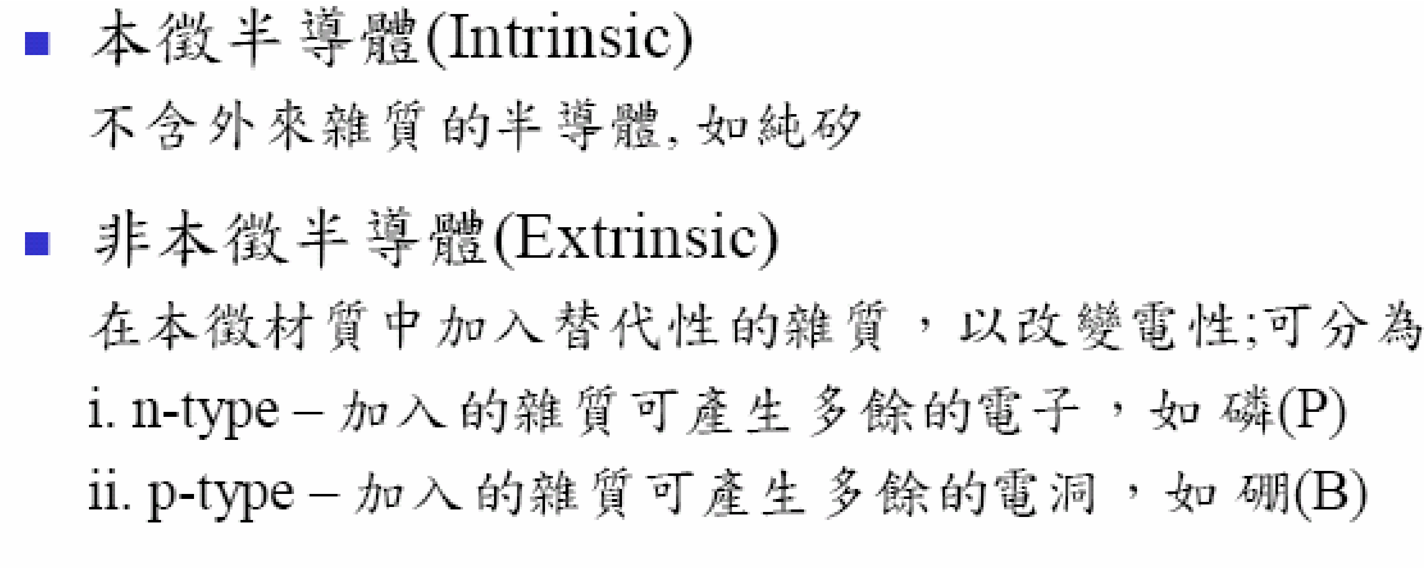
Direct and indirect electron transitions in semiconductors



(a) Direct

(b) Indirect

IC Manufacturing Introduction



- 本徵半導體(Intrinsic)

  不含外來雜質的半導體, 如純矽

- 非本徵半導體(Extrinsic)

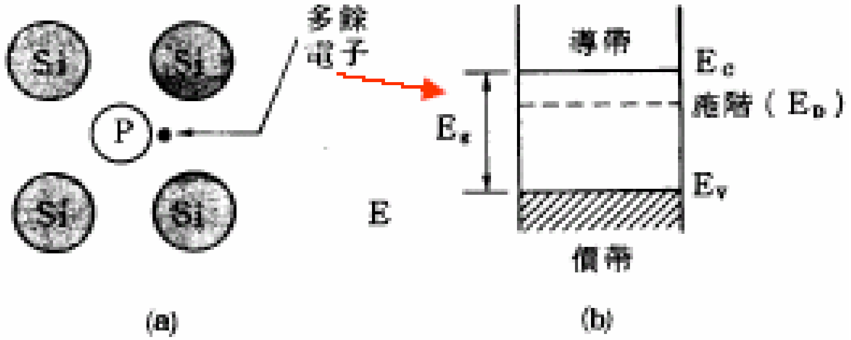
  在本徵材質中加入替代性的雜質，以改變電性;可分為

  i. n-type – 加入的雜質可產生多餘的電子，如 磷(P)

  ii. p-type – 加入的雜質可產生多餘的電洞，如 硼(B)

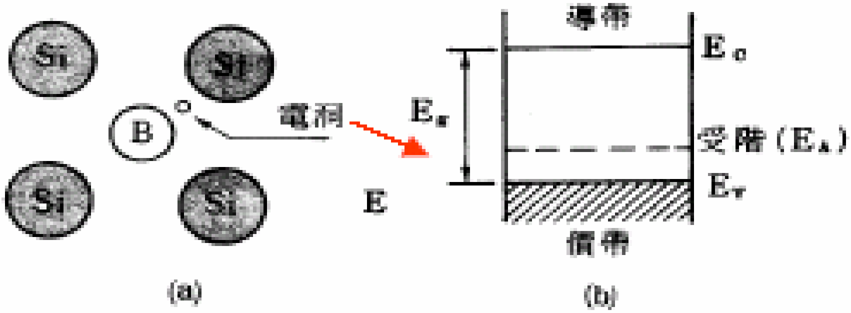
IC Manufacturing Introduction

- n-type



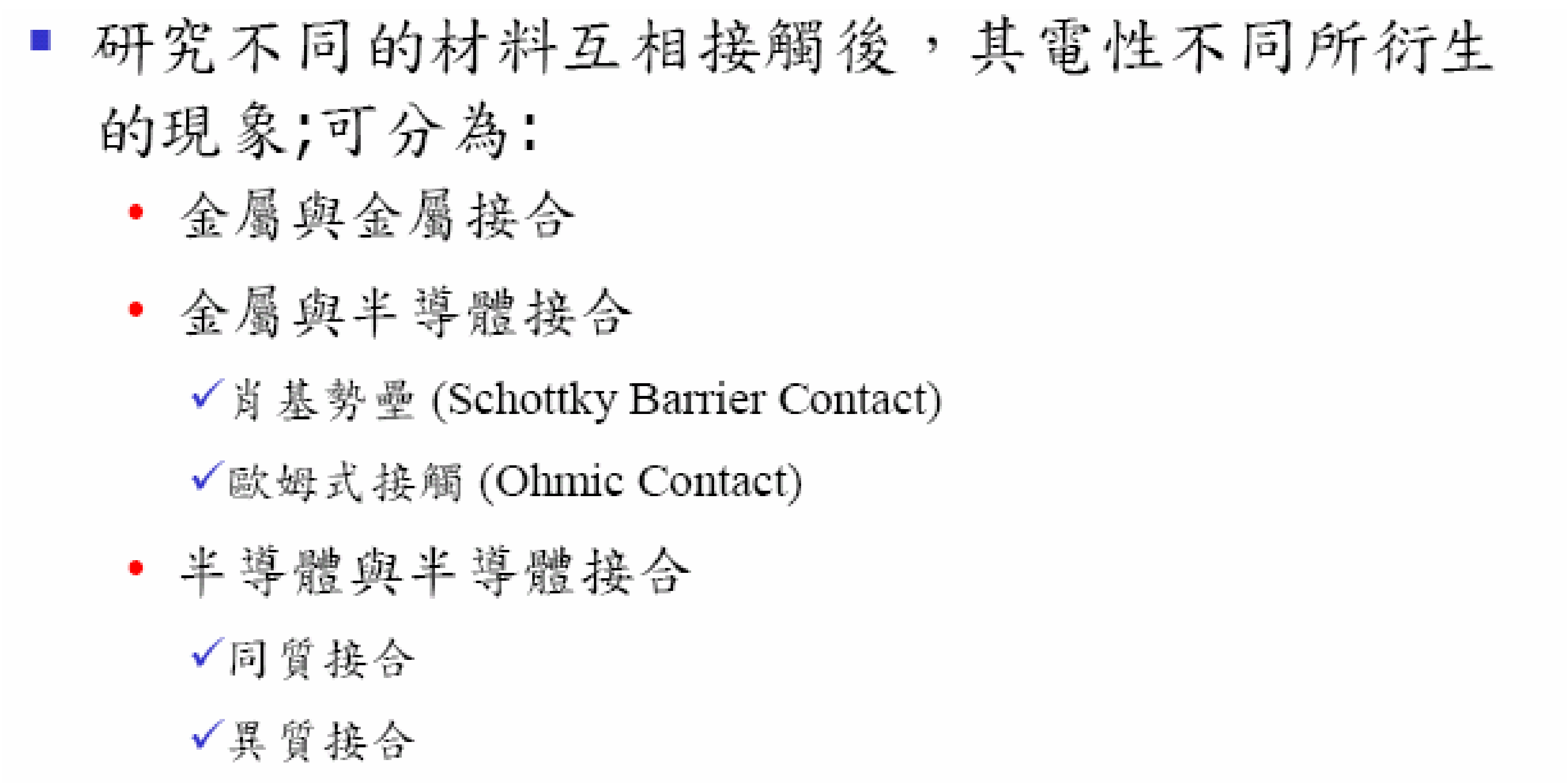
四價矽加入五價磷後的結果因多餘電子使
得能隙導電帶能量附近產生所謂施階

- p-type



四價矽加入三價硼後的結果因多餘電洞使
得能隙價電帶能量附近產生所謂受階

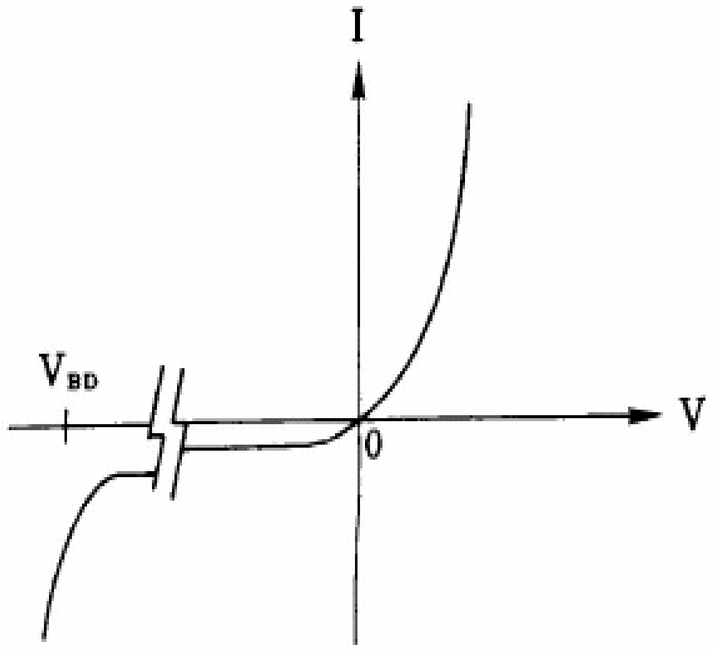
IC Manufacturing Introduction



- 研究不同的材料互相接觸後，其電性不同所衍生的現象;可分為:
  - 金屬與金屬接合
  - 金屬與半導體接合
    - ✓肖基勢壘 (Schottky Barrier Contact)
    - ✓歐姆式接觸 (Ohmic Contact)
  - 半導體與半導體接合
    - ✓同質接合
    - ✓異質接合

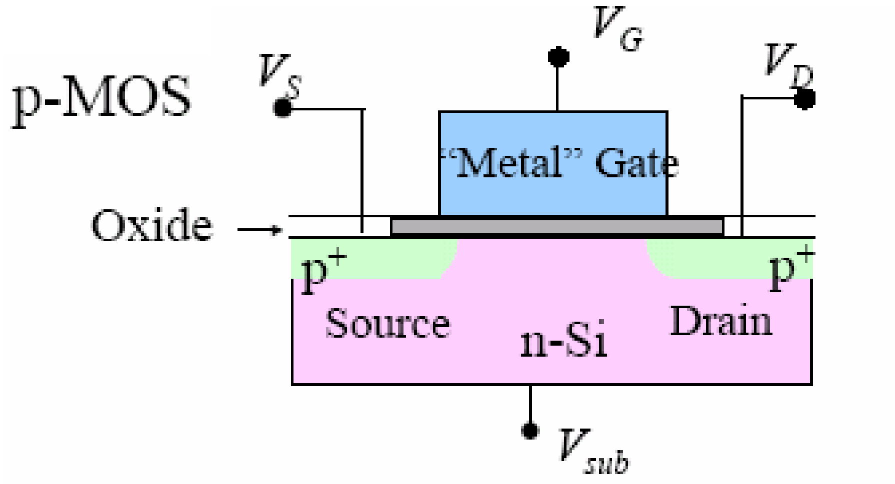
PN二極半導體的接合

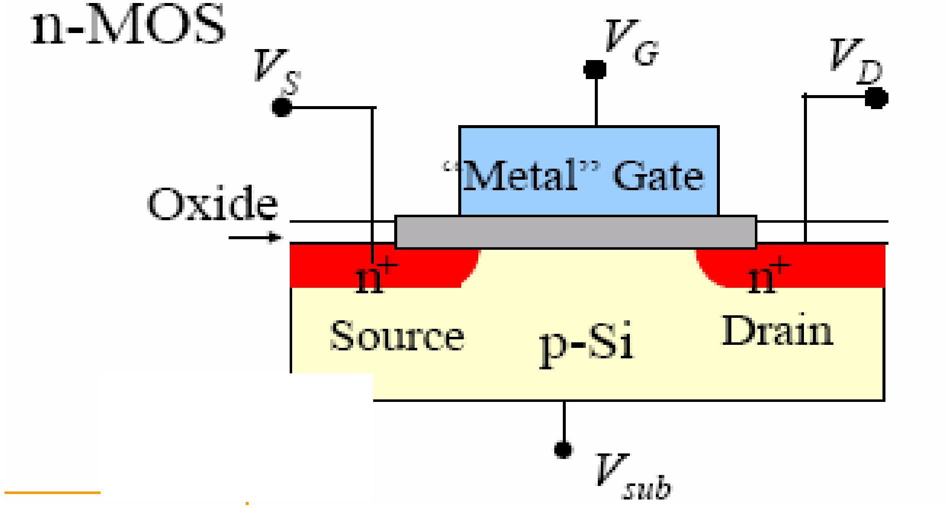
- pn二極體在施加的電壓是順向時才有電流流過(右側)
- 若施加的逆向偏壓太高，且過於一臨界值，二極體的逆向電流Jr將急劇上升，此一現象稱為崩潰(Breakdown)，原因為電子獲致足夠的動能將價帶的電子激發到導帶所致



V_{BD}為發生崩潰現象時的逆向偏壓大小

NMOS v.s. PMOS


p-MOS
V_S
V_G
V_D
"Metal" Gate
Oxide
p^+
p^+
Source
n-Si
Drain
V_{sub}


n-MOS
V_S
V_G
V_D
"Metal" Gate
Oxide
n^+
n^+
Source
p-Si
Drain
V_{sub}

IC Manufacturing Introduction

Si Wafer Manufacturing

- **Pure Si Preparation**

$$SiO_2 + 2C \xrightarrow{1500\text{-}2000^{o}C} Si + 2CO$$

(Black Powder 98-99%)

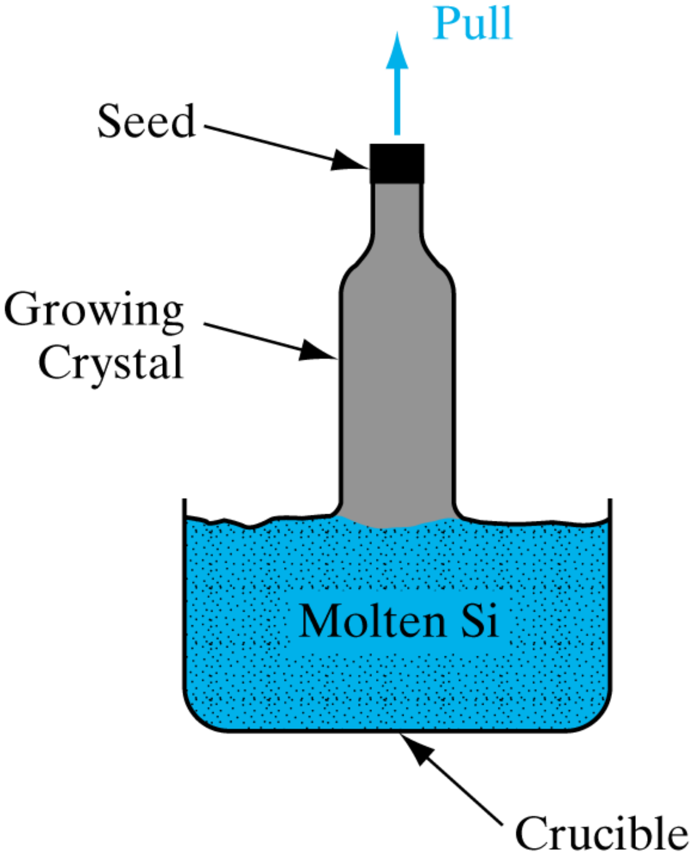
$$Si + 2HCl_{(g)} \xrightarrow{300^{o}C} SiHCl_3 + H_2$$

$$SiHCl_3 + H_2 \xrightarrow{1100^{o}C} Si + 3HCl$$

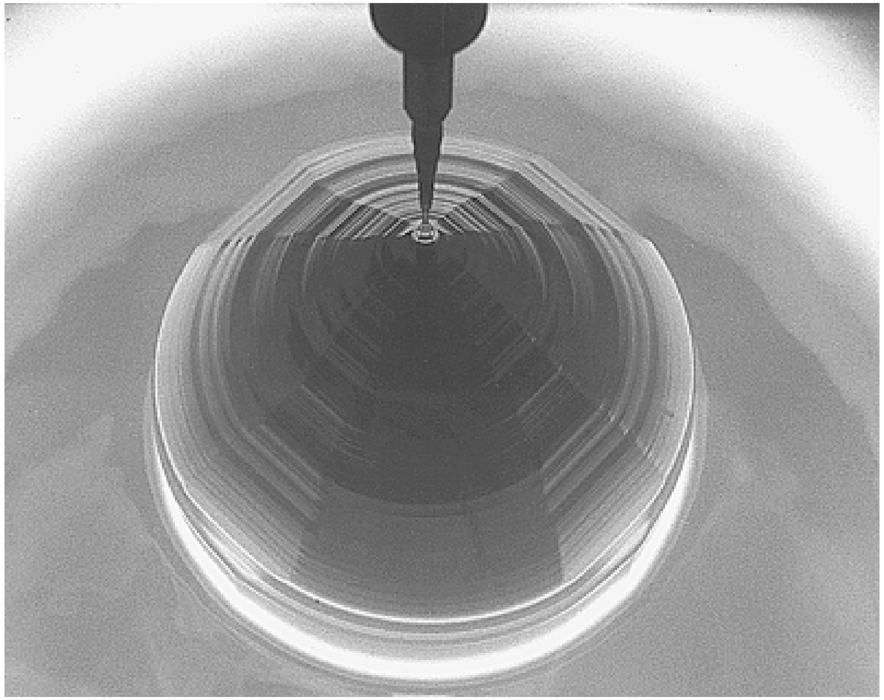
Polysilicon (purity: 99.999999999%)

IC Manufacturing Introduction

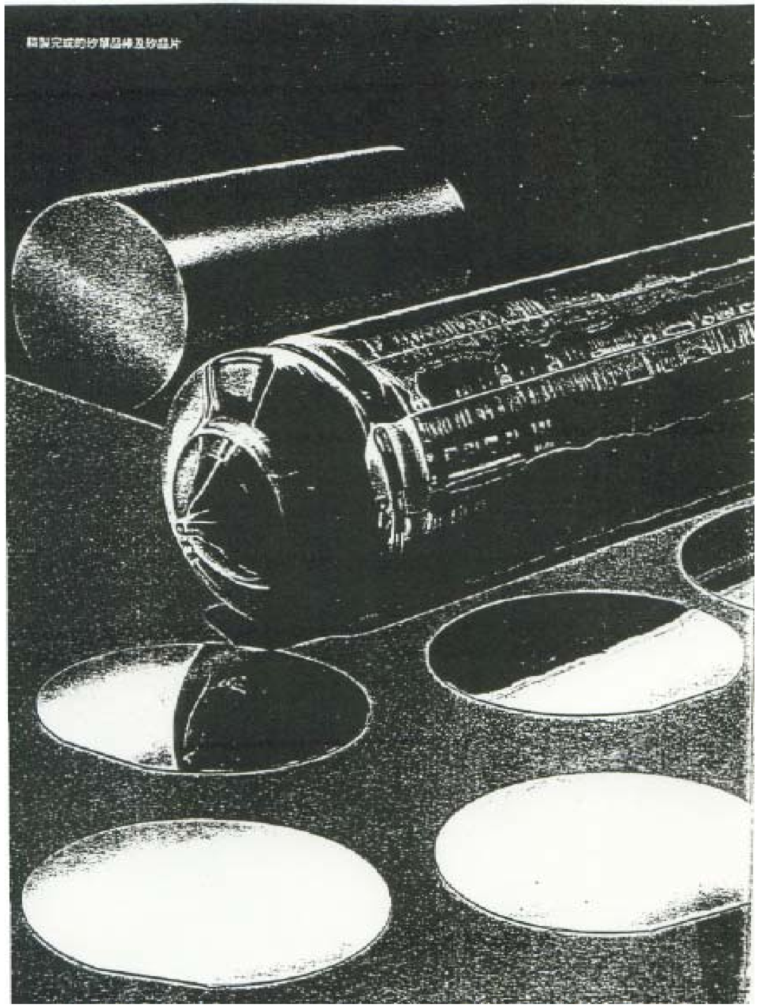
(Czochralski method):



(a)

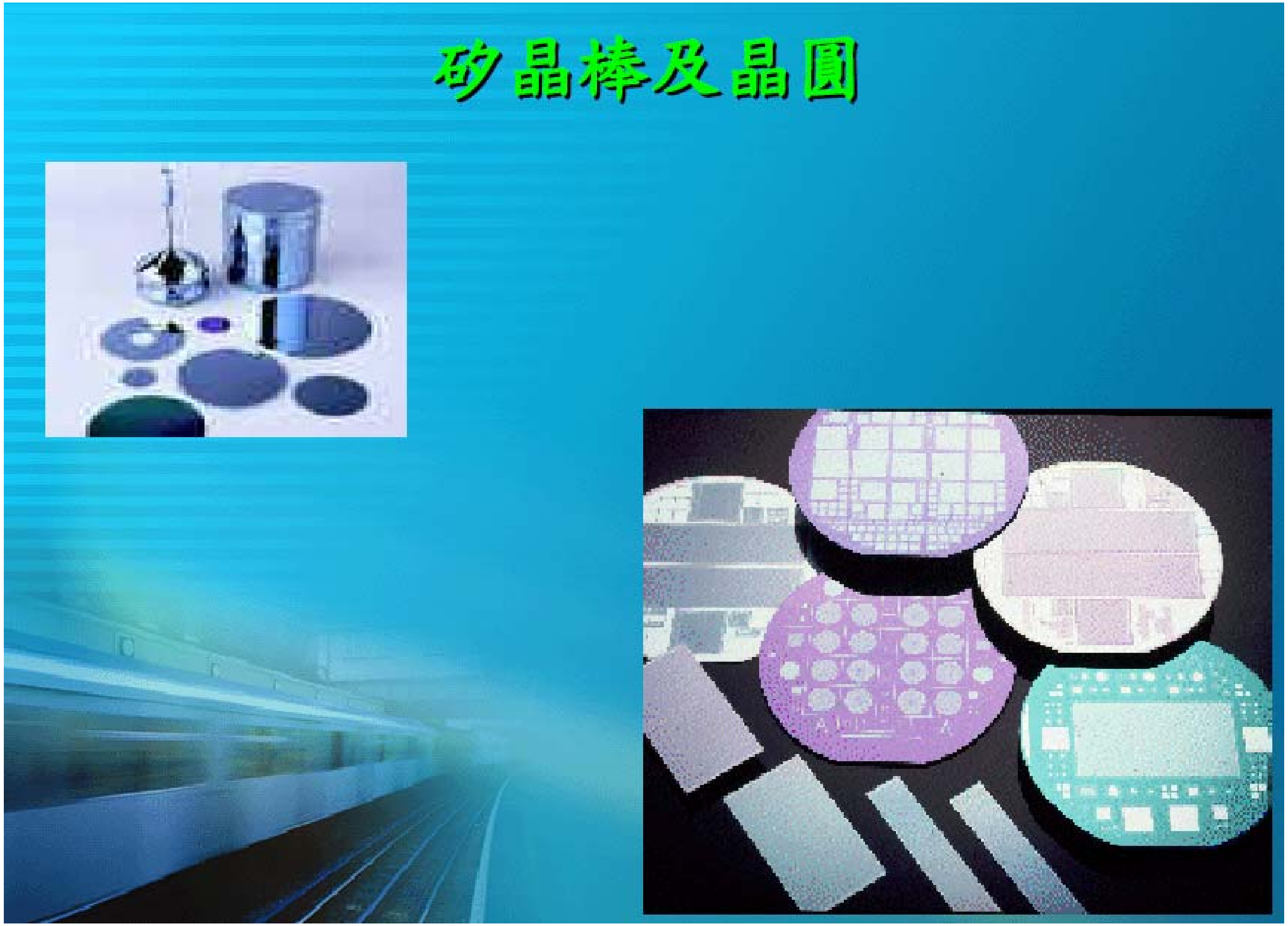


IC Manufacturing Introduction



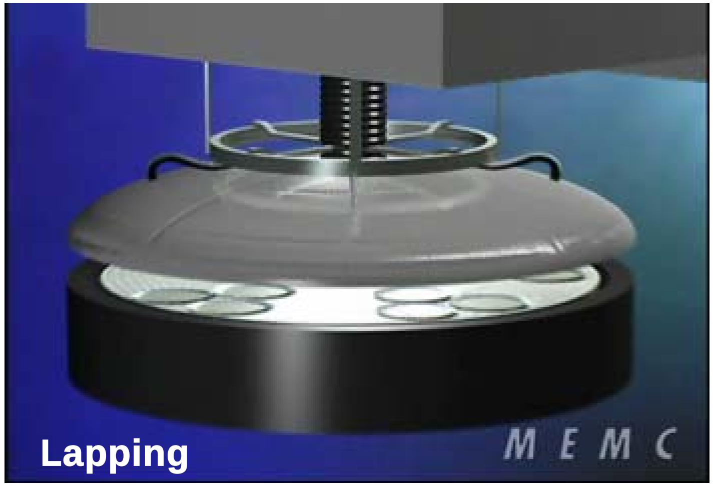
IC Manufacturing Introduction

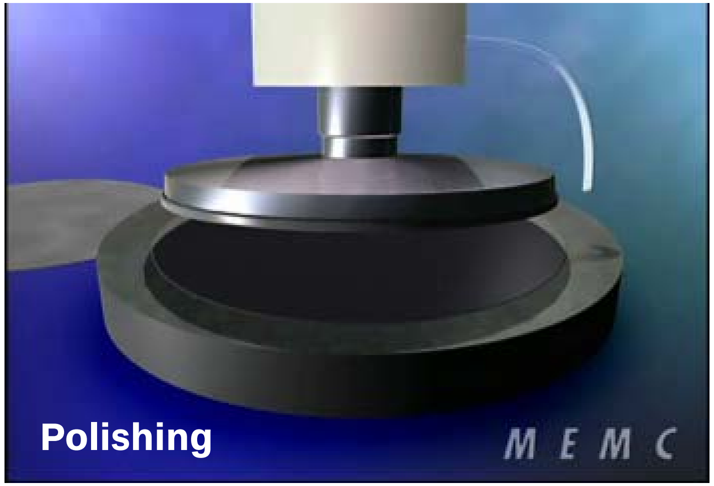
IC Manufacturing Introduction

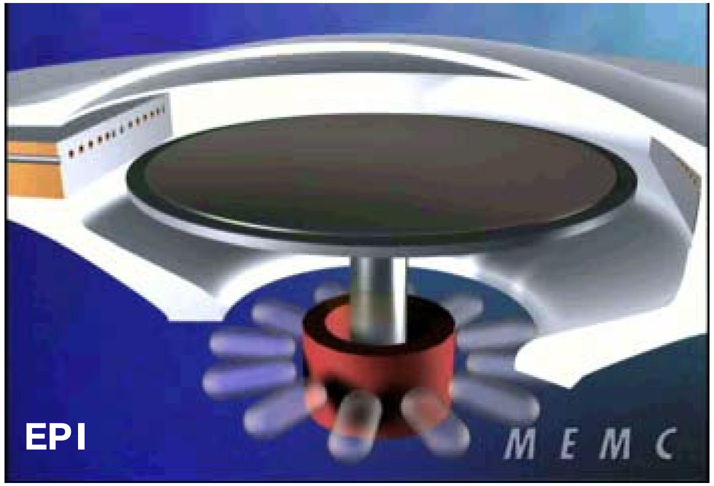


矽晶棒及晶圓

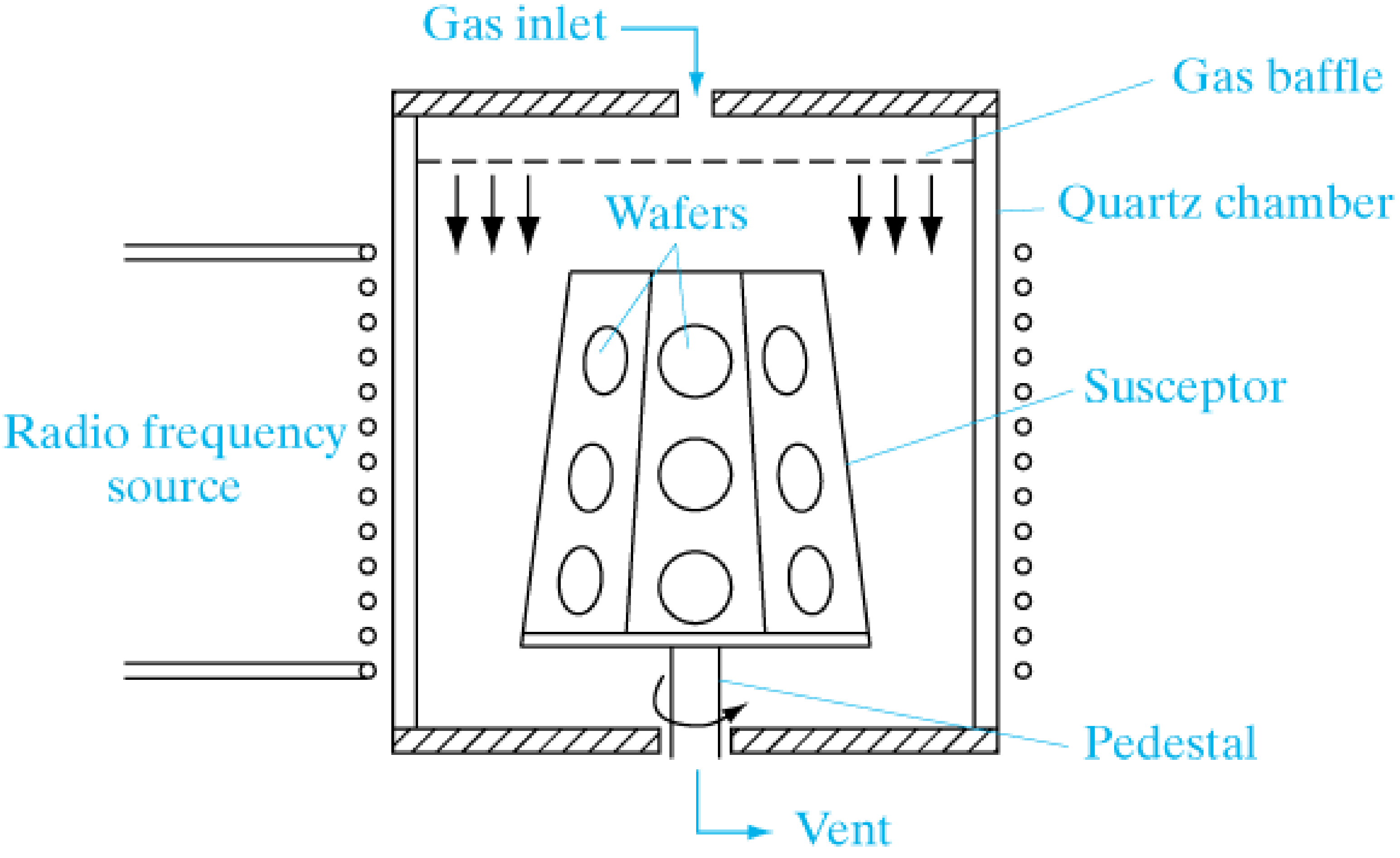
IC Manufacturing Introduction





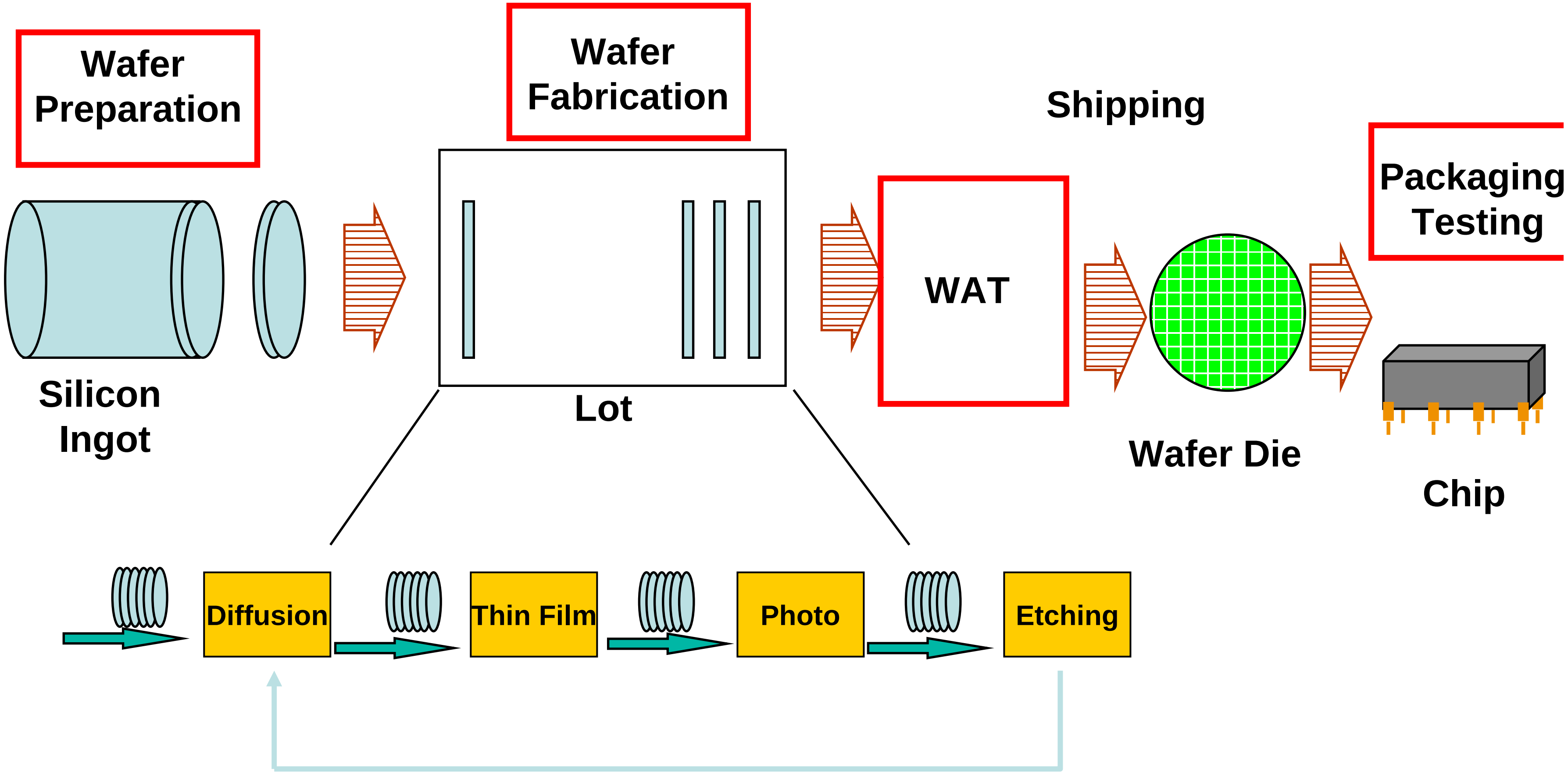


A barrel-type reactor for Si VPE

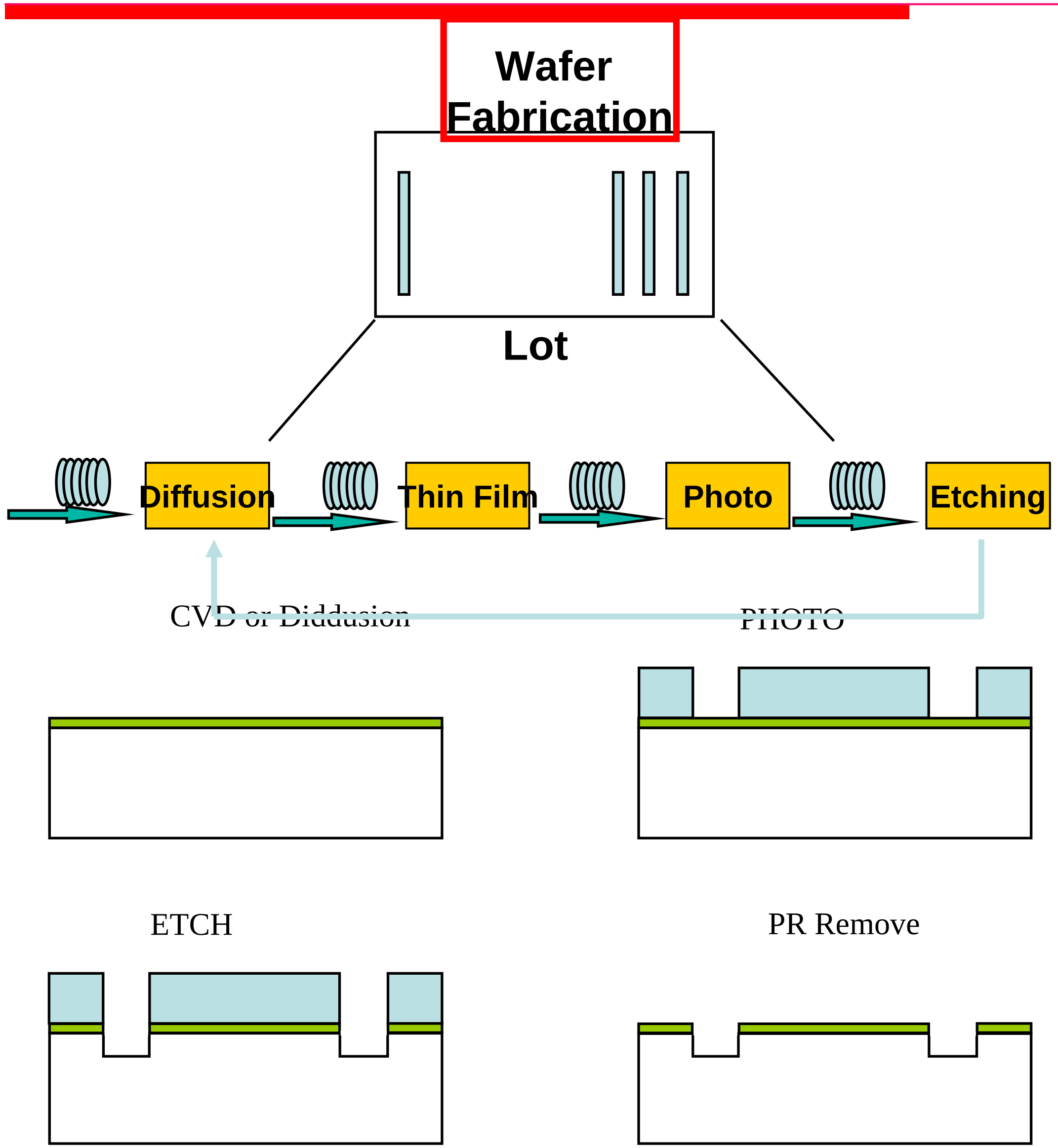


IC Manufacturing Introduction

IC Process



IC Manufacturing Introduction



Wafer Fabrication

Lot

Diffusion

Thin Film

Photo

Etching

CVD or Diddusion

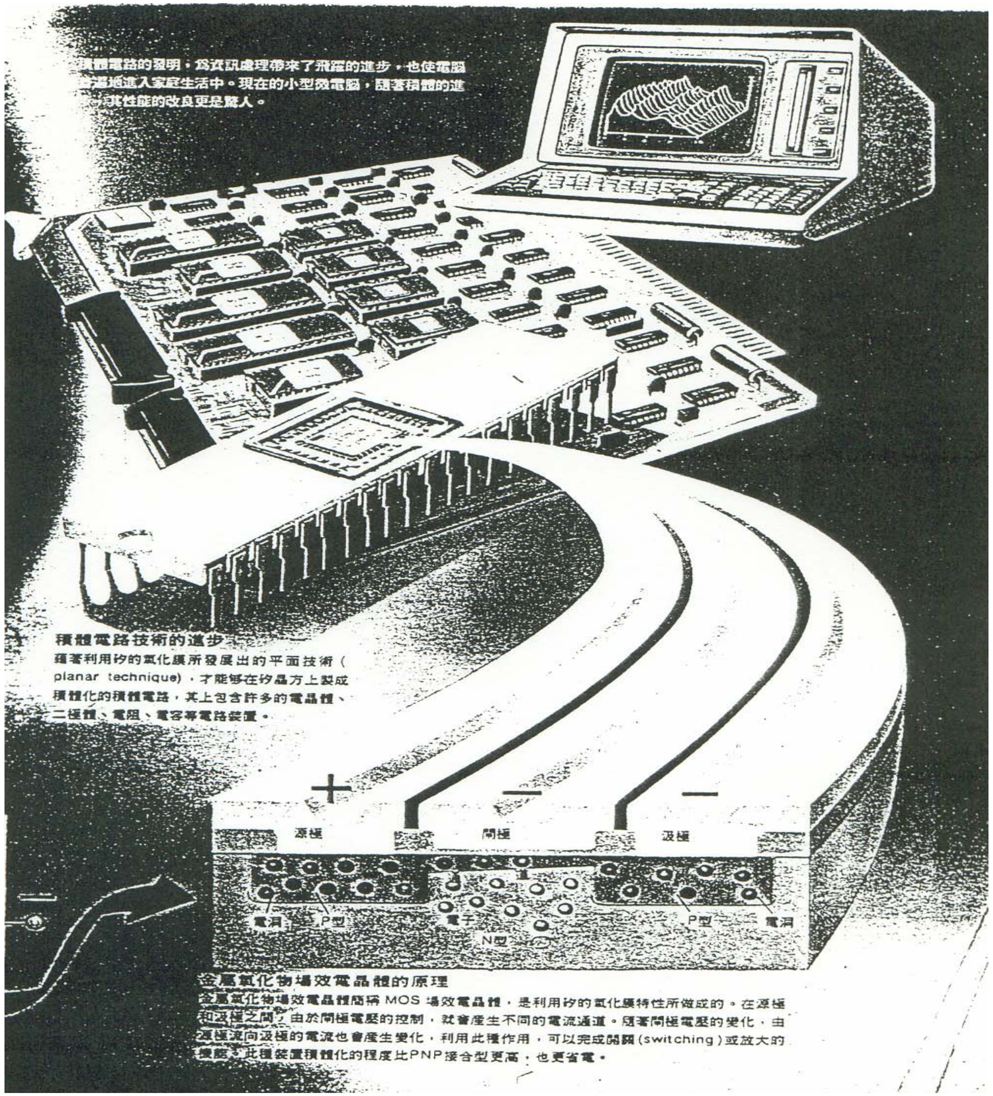
PHOTO

ETCH

PR Remove

IC Manufacturing Introduction

MOS transistor



積體電路的發明，爲資訊處理帶來了飛躍的進步，也使電腦遍地進入家庭生活中。現在的小型微電腦，隨著積體的進，其性能的改良更是驚人。

積體電路技術的進步

藉著利用矽的氧化膜所發展出的平面技術（planar technique），才能夠在矽晶方上製成積體化的積體電路，其上包含許多的電晶體、二極體、電阻、電容等電路裝置。

金屬氧化物場效電晶體的原理

金屬氧化物場效電晶體簡稱 MOS 場效電晶體，是利用矽的氧化膜特性所做成的。在源極和汲極之間，由於閘極電壓的控制，就會產生不同的電流通道。隨著閘極電壓的變化，由源極流向汲極的電流也會產生變化，利用此種作用，可以完成開關(switching)或放大的機能。此種裝置積體化的程度比PNP接合型更高，也更省電。

IC Manufacturing Introduction

Vertical furnace

The silica wafer holder is loaded with eight-inch Si wafers and moved into the furnace above for oxidation, diffusion, or deposition operations.

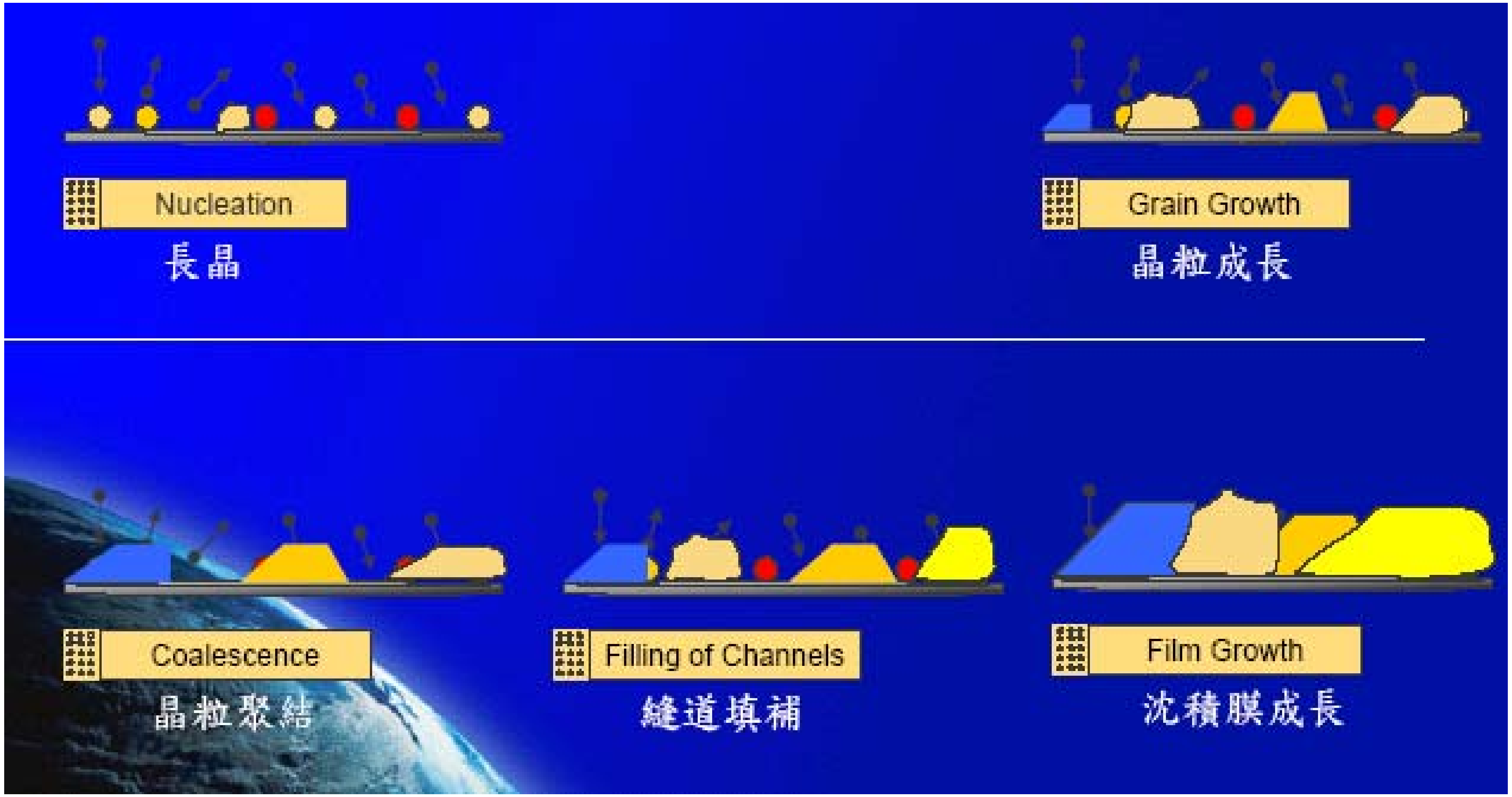
物理/化學氣相沉積法

(PVD/CVD) Deposition

- 利用低壓化學氣相沉積（LPCVD）的技術，沉積一層氮化矽，用來做為離子佈植的罩幕及後續製程中，定義P型井的區域。

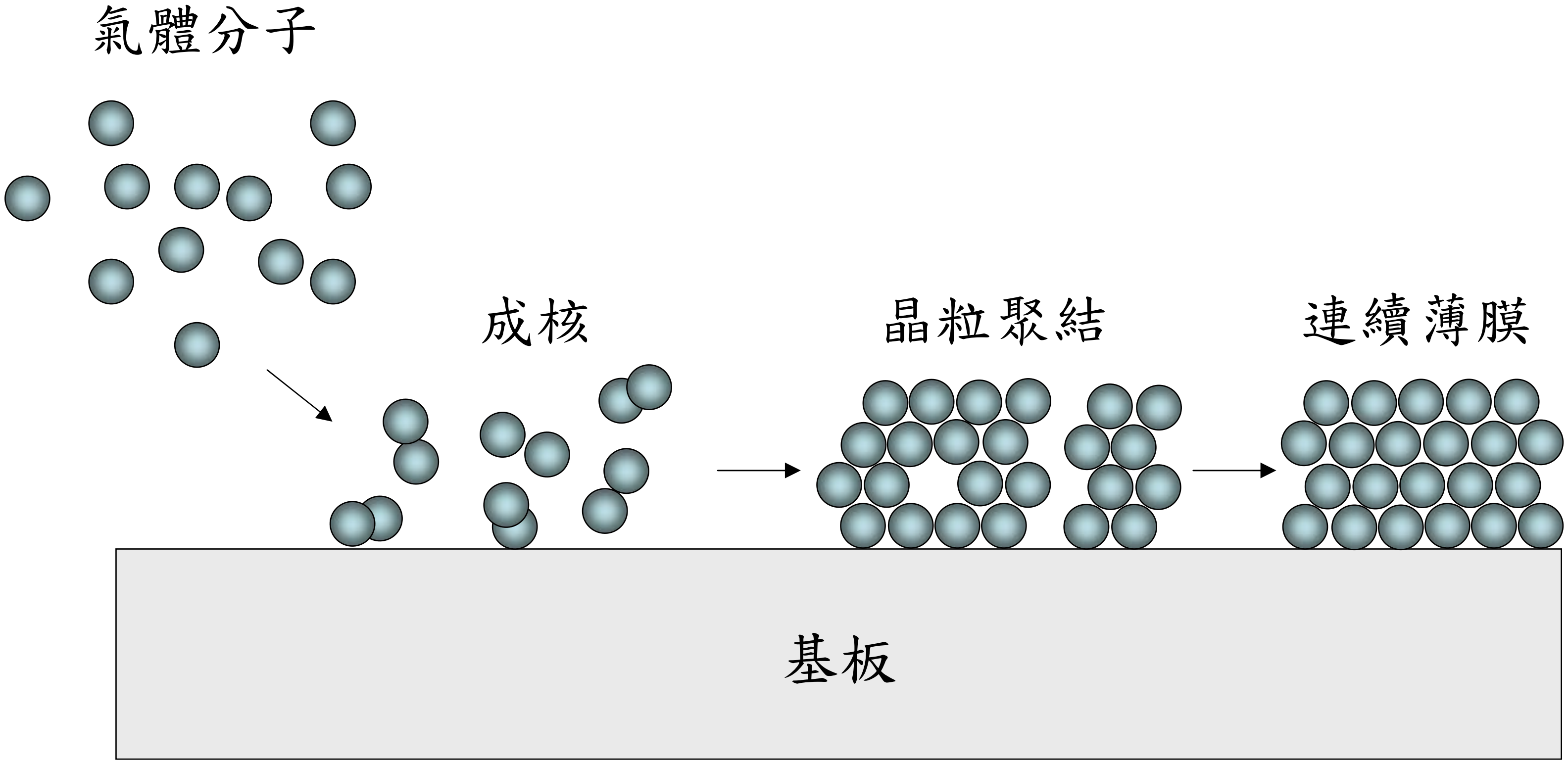
IC Manufacturing Introduction

CVD films



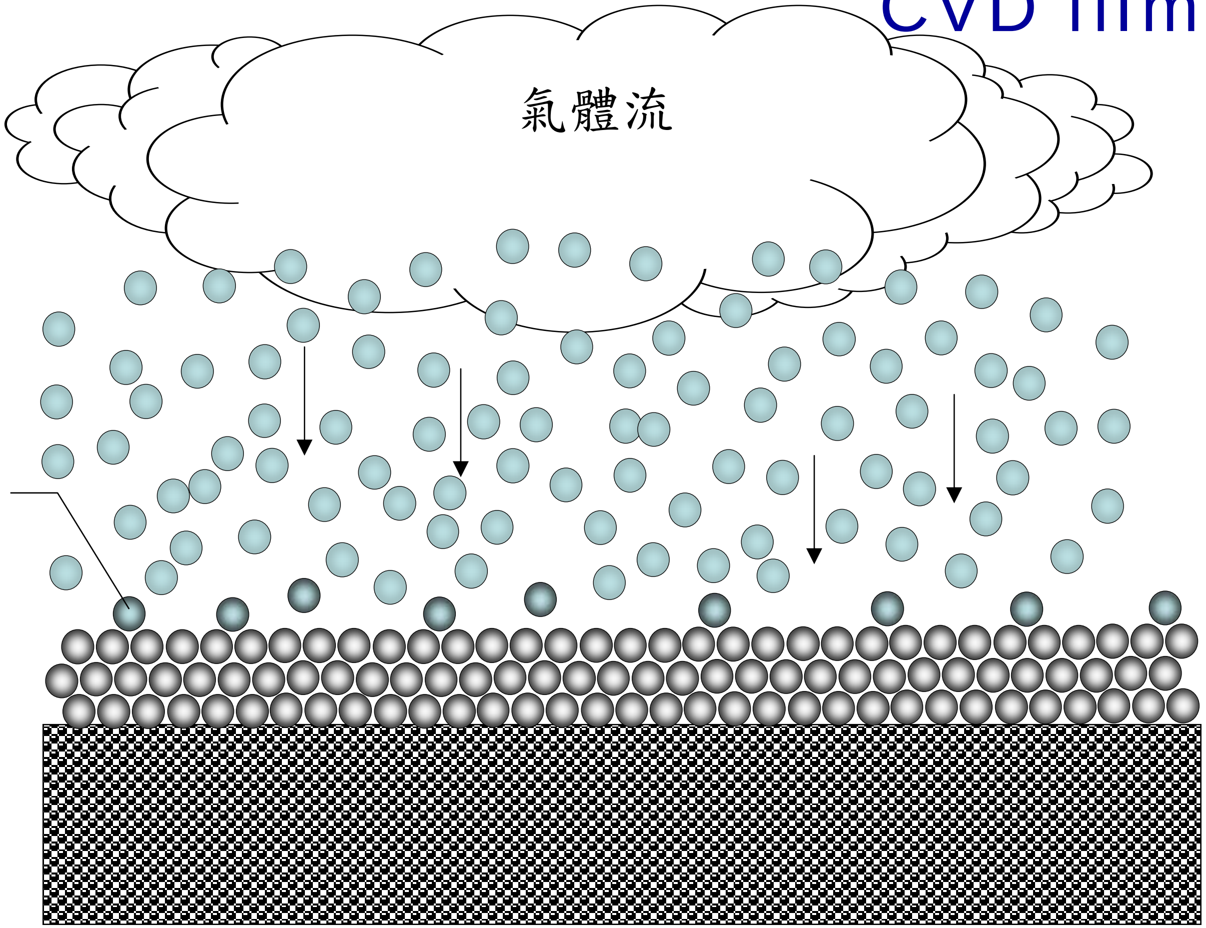
IC Manufacturing Introduction

CVD films



CVD之氣體流

CVD films

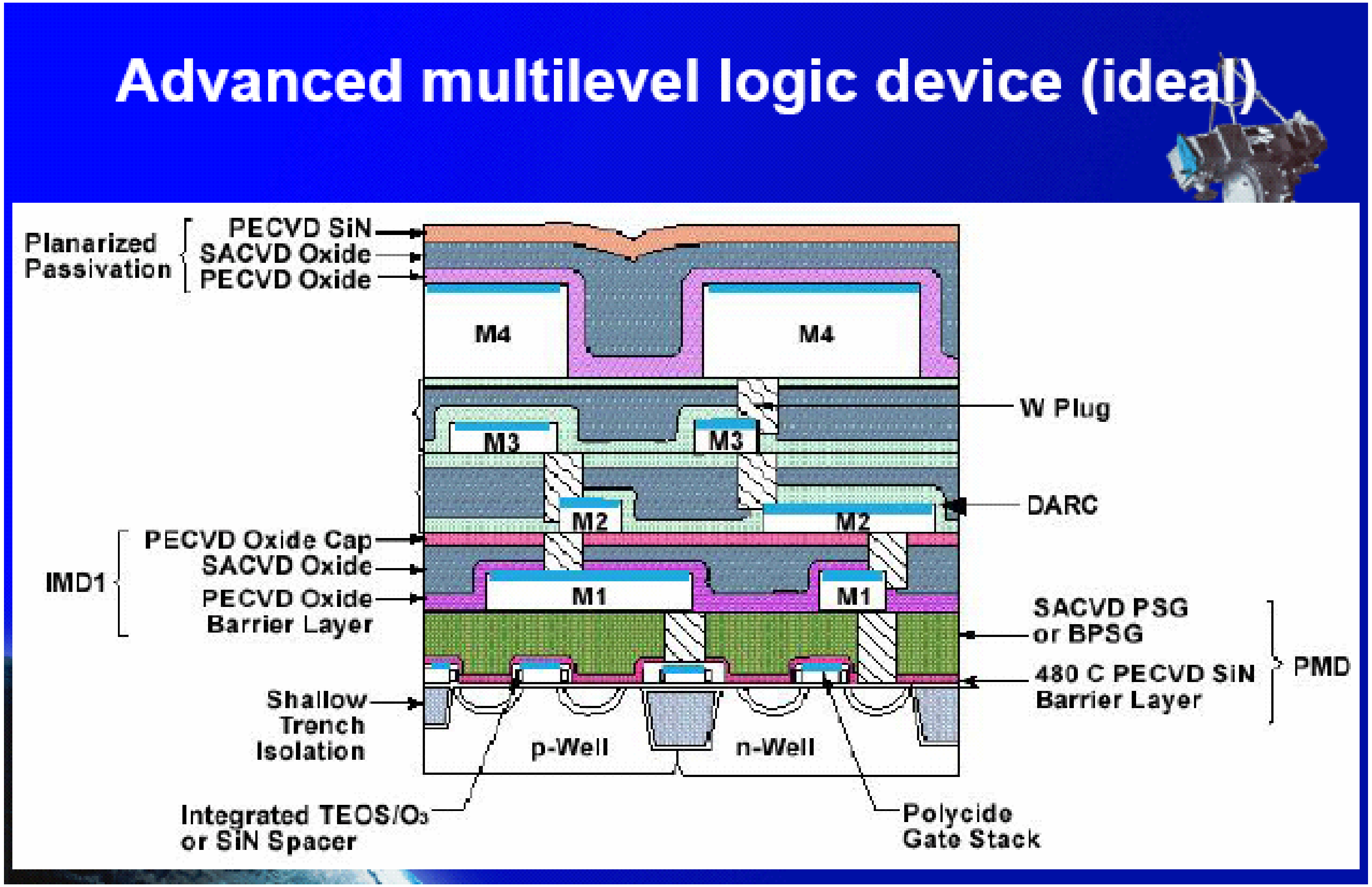


CVD films

電性	機械性	熱性	化學性	製程	金屬化
低介電常數	附著性	熱穩定	抗酸及鹼	圖案化能力	接觸電阻低
低介電損耗	低收縮	熱延展係數低	選擇性蝕刻	填溝佳	低電遷移（腐蝕）
低漏電	抗破裂	高傳導率	雜質低	平坦化	低應力
高可靠度	低應力		無腐蝕性	針孔少	小丘（平滑表面）
	硬度佳		低水氣吸收	微粒少	適於阻障層金屬(Ta, TaN, TiN等）
			儲存有效期長		

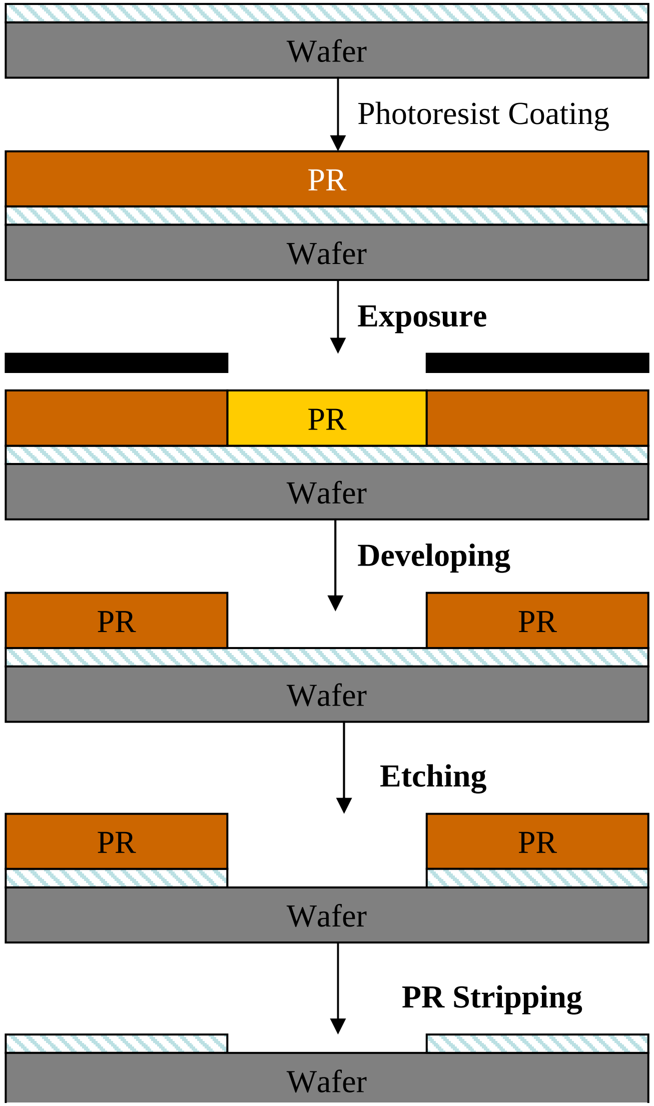
IC Manufacturing Introduction

CVD films



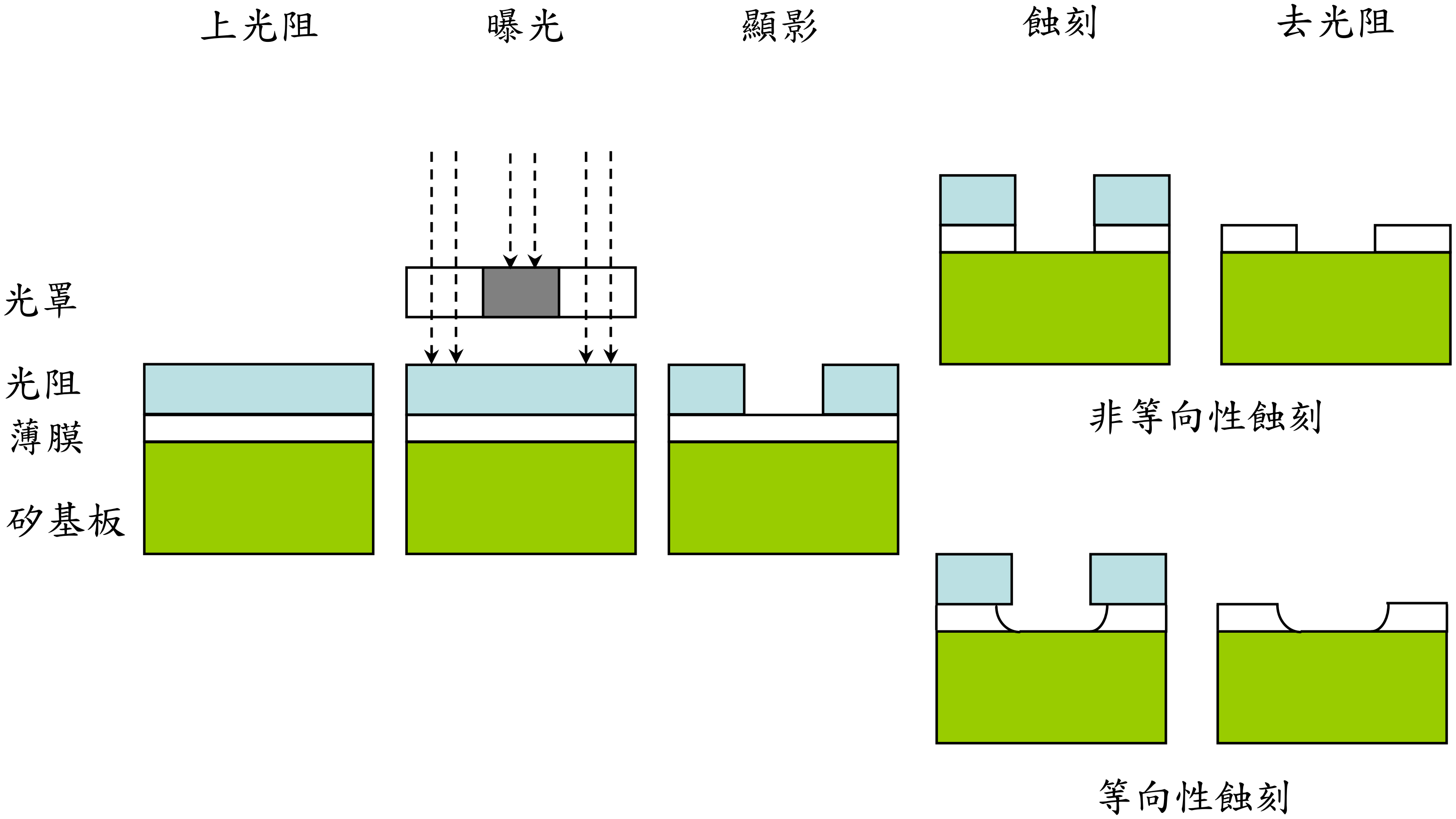
IC Manufacturing Introduction

- **Photo Process**



Photolithography (黃光製程)

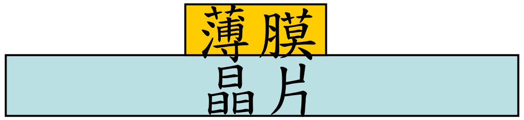
黃光微影及蝕刻



IC Manufacturing Introduction

Etching (蝕刻)

- 何謂蝕刻 (etch)
  - 以化學反應或是物理作用的方式，將光罩圖案轉移至微影製程前所沉積的薄膜。



- 何謂乾、溼蝕刻 (dry etch & wet etch)

  - **濕蝕刻**: 將晶圓浸泡於(或噴灑)特定之化學品中利用化學反應蝕刻晶圓表面物質

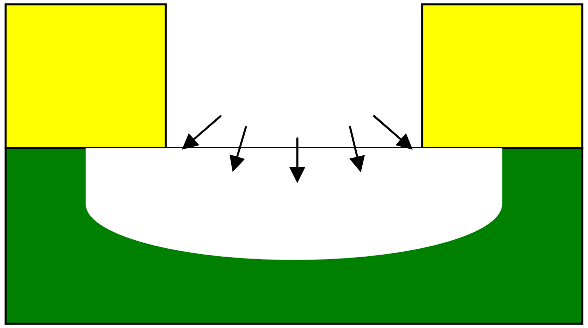
  - **乾蝕刻**: 使用特定或混合之氣體在真空(vacuum)及高能量(RF/Microwave)之激發下產生電漿(plasma)以物理反應或化學反應蝕刻晶圓表面物質

IC Manufacturing Introduction

Etching

濕蝕刻

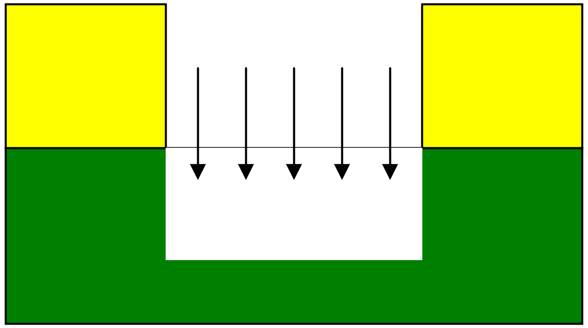
chemical



等向性蝕刻
Isotropic etch

乾蝕刻

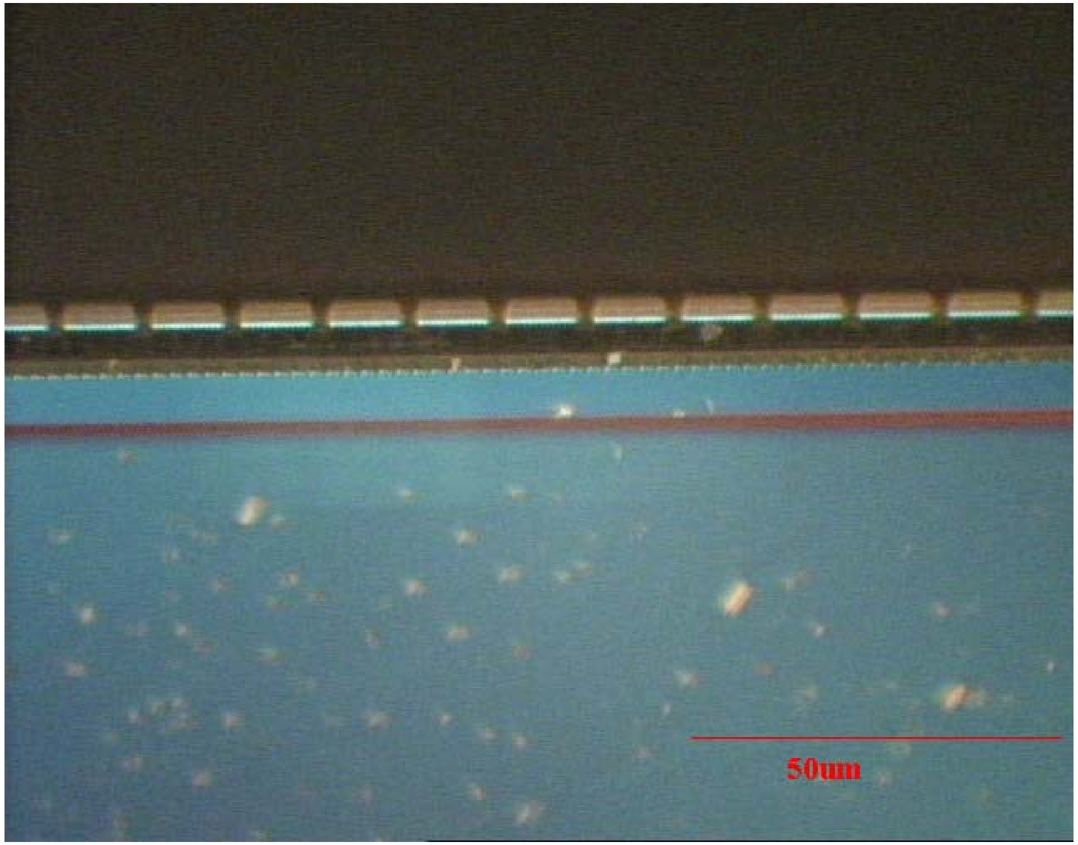
plasma



非等向性蝕刻
Anisotropic etch

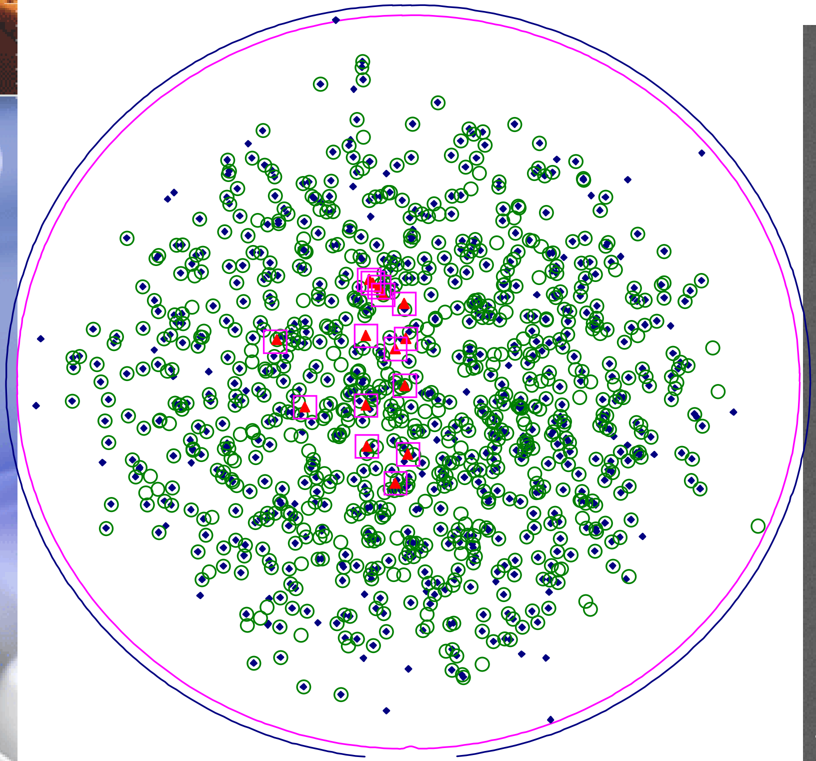
IC Manufacturing Introduction

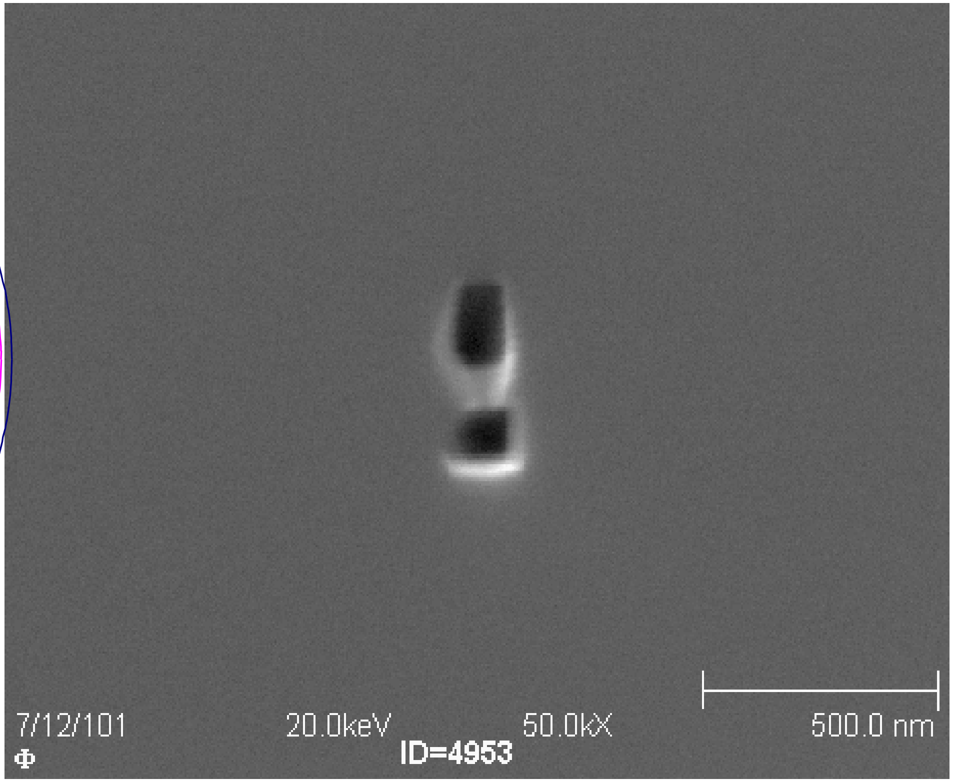
BMD



IC Manufacturing Introduction

Crystal-originated particle (COP)



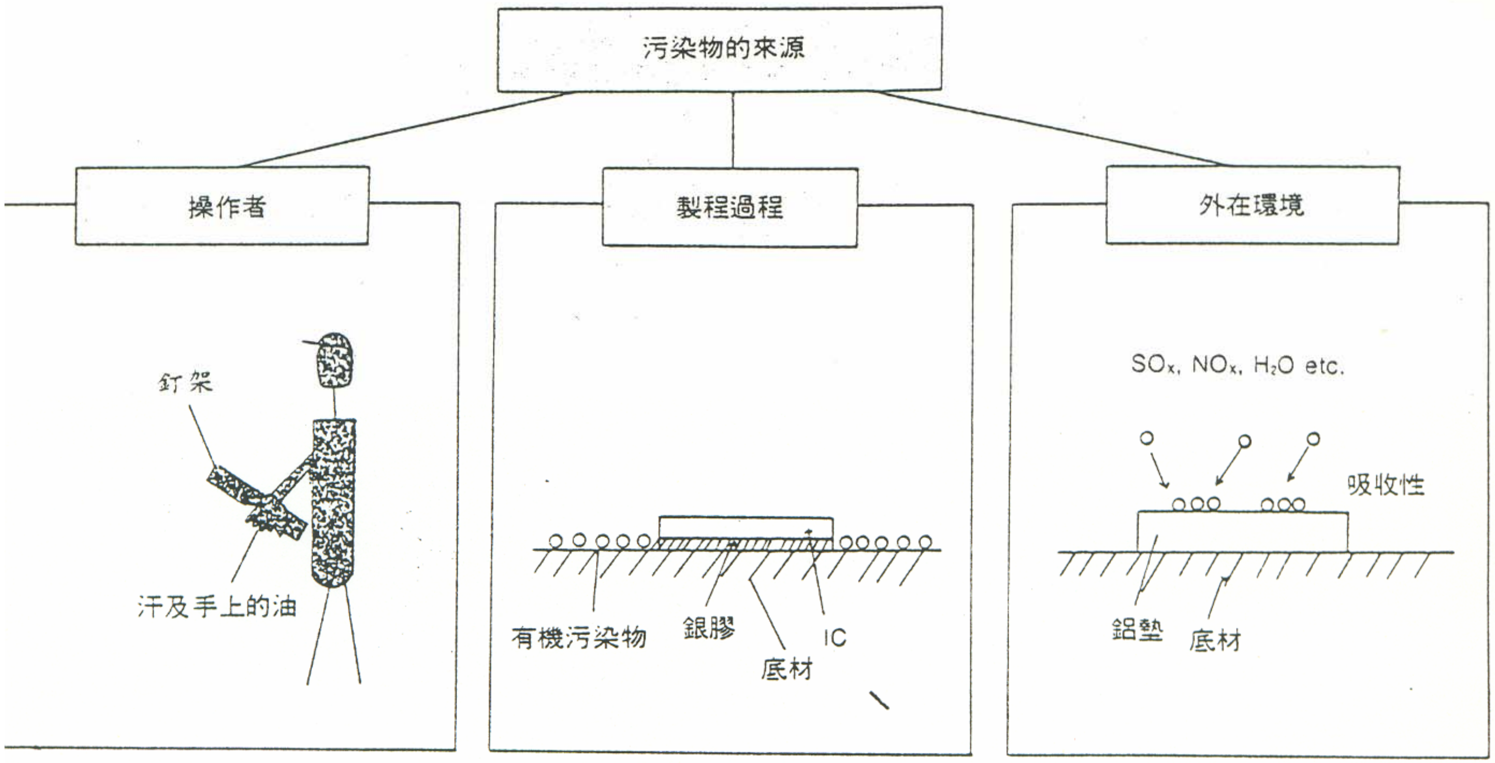


IC Manufacturing Introduction

Clean room

IC Manufacturing Introduction

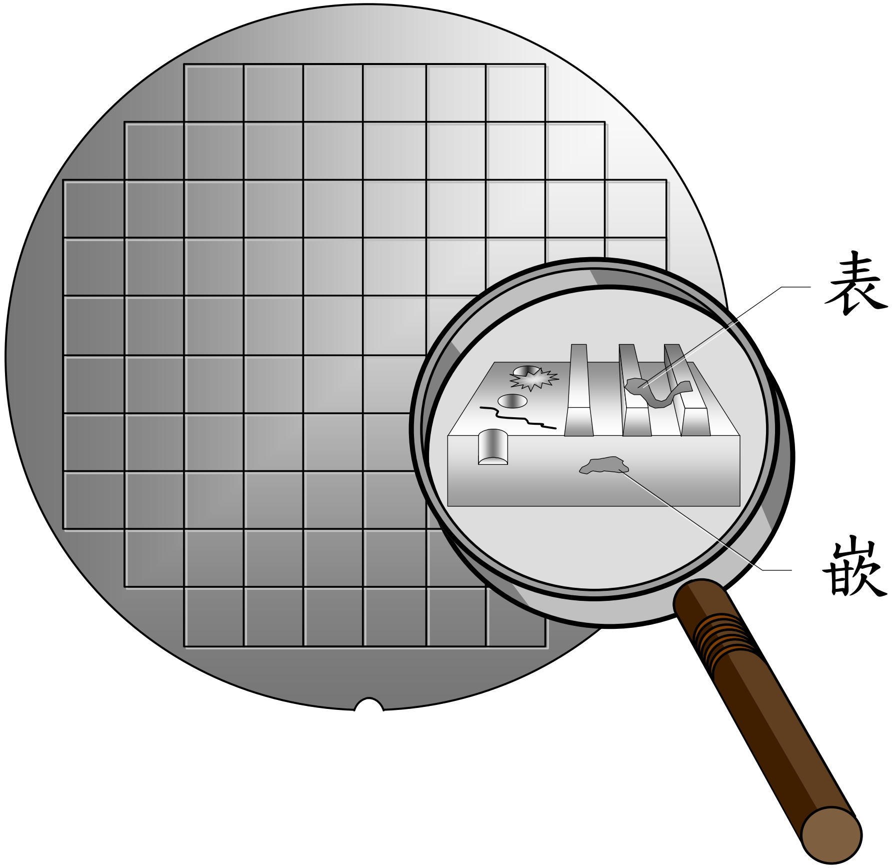
Particle resource



造成污染物之來源（摘自Kyusyu Matsushita Electric Co.）

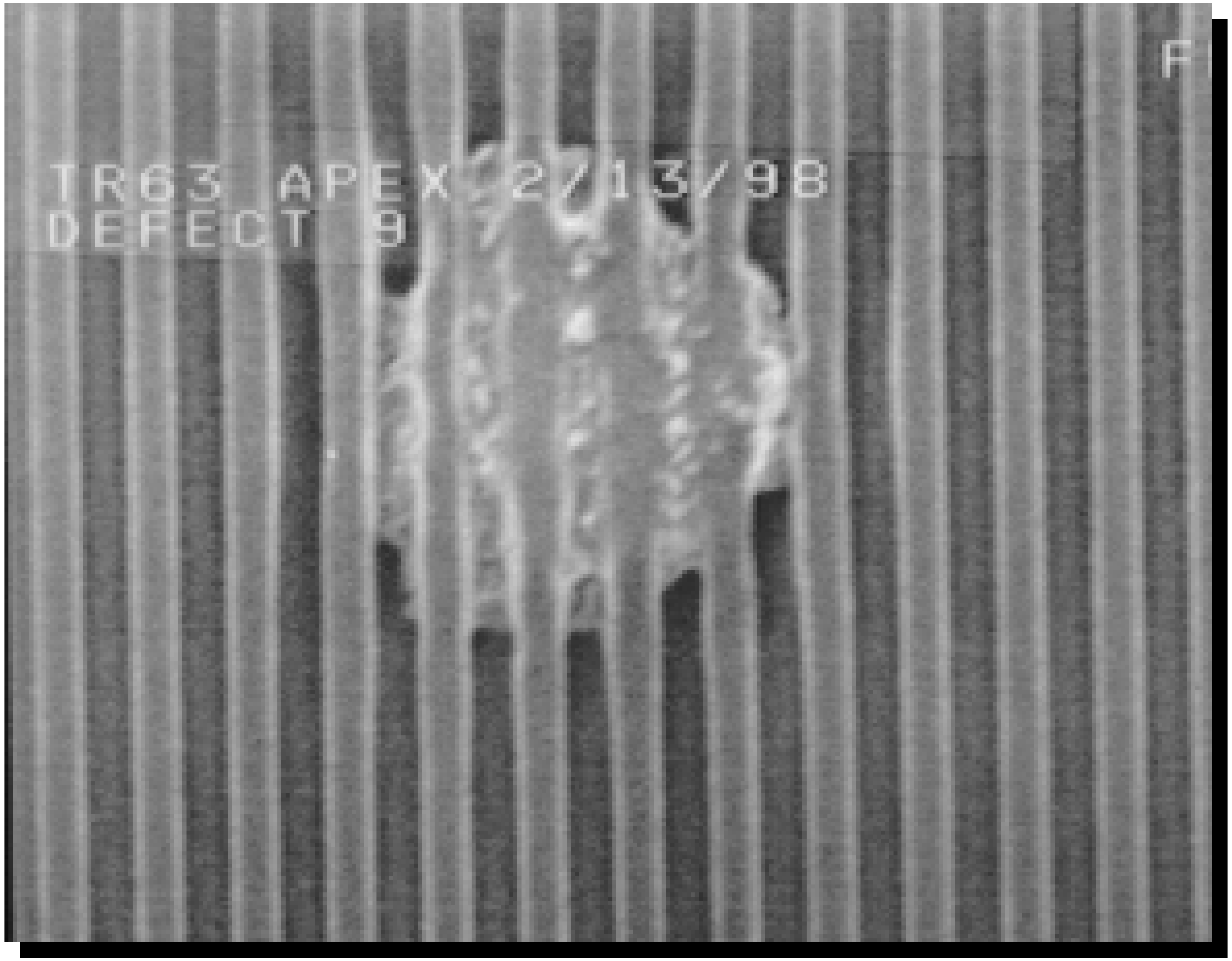
IC Manufacturing Introduction

Particle resource 晶圓污染物



Particle resource

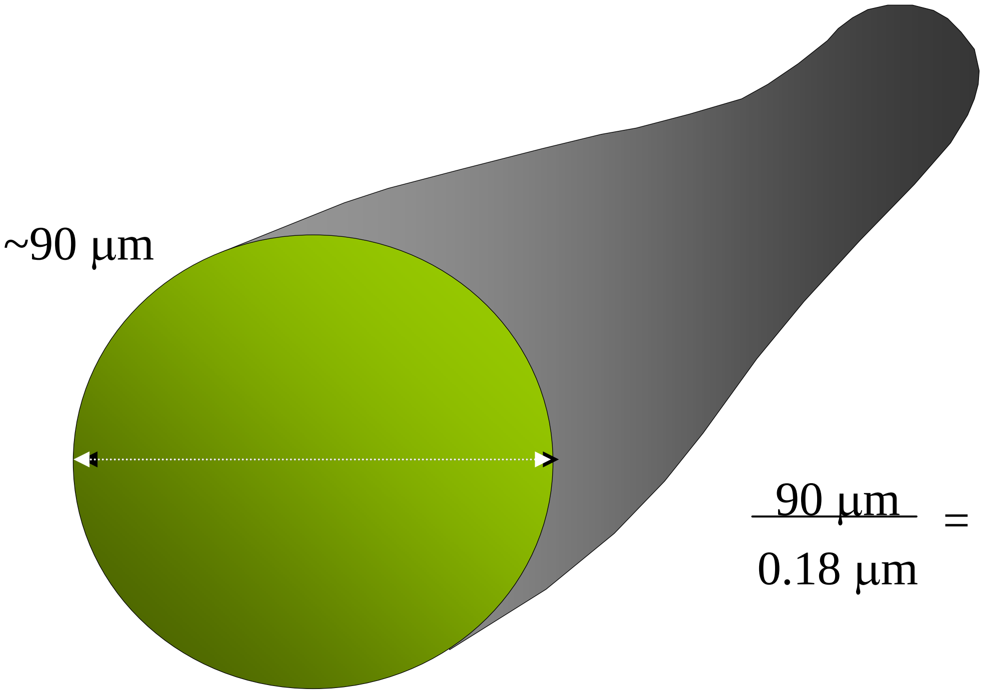
微粒造成的缺陷



Particle resource

微粒造成的缺陷

人類頭髮對0.18μm微粒的相對大小

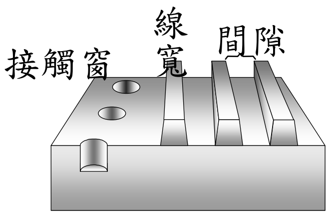


人類頭髮的橫切面

人類頭髮的相對尺寸大約是在IC裡最小特徵尺寸的500倍

最小IC特徵尺寸 = 0.18μm

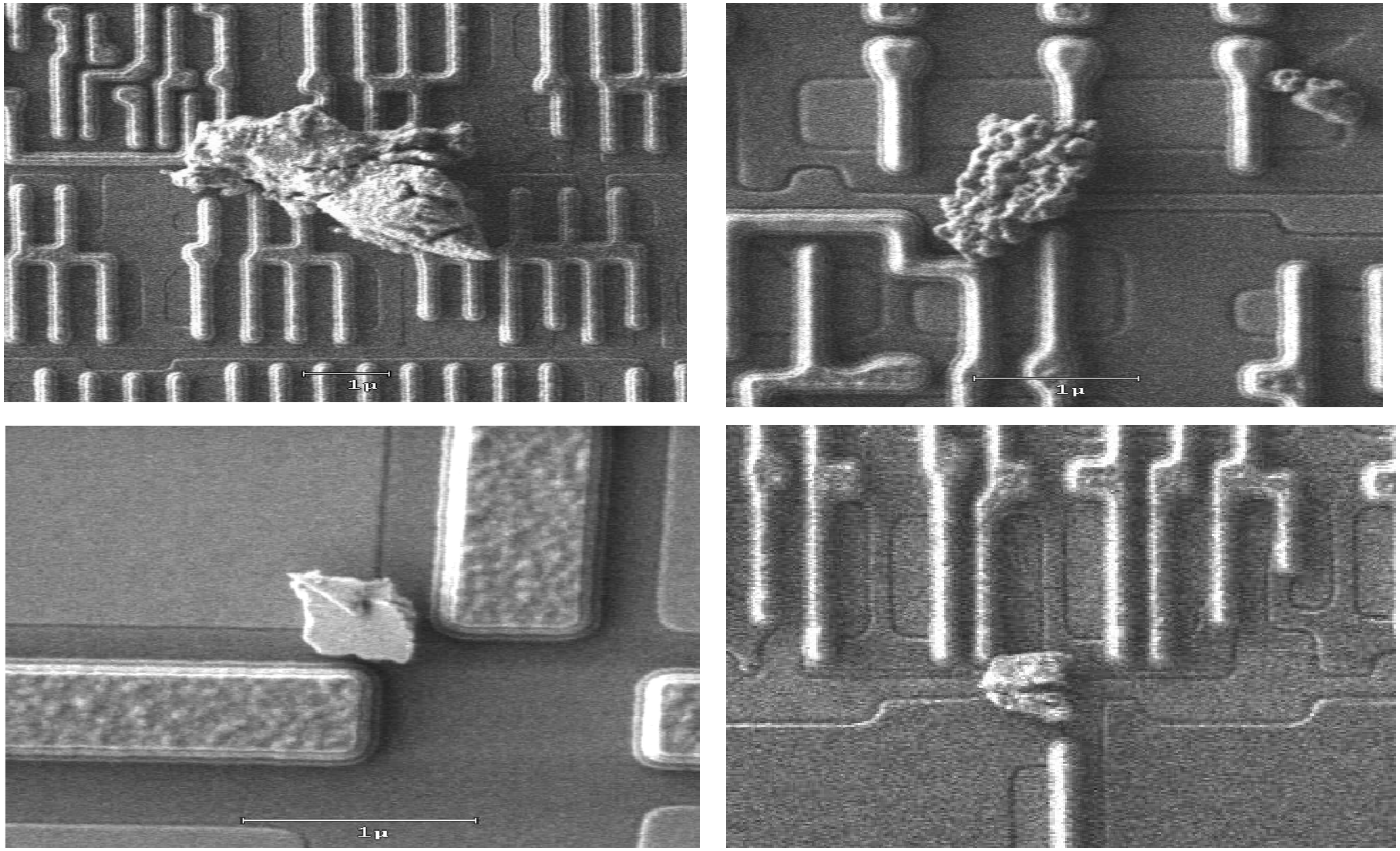
$$\frac{90\ \mu\text{m}}{0.18\ \mu\text{m}} = 500$$



一較大IC的一小部分例子

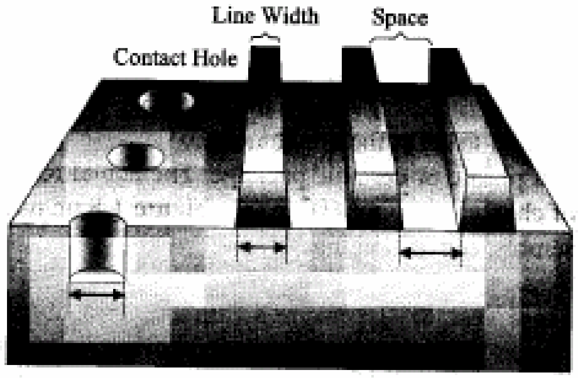
IC Manufacturing Introduction

Particle resource



The CD (Critical Dimension)

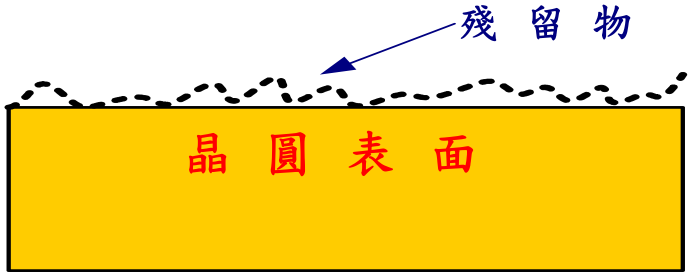
- Feature size – the physical dimension of a feature on a chip, or circuit geometry
- Critical dimension (CD) – minimum feature size on a wafer



	1988	1992	1995	1998	2000	2002	2005	2008
CD (µm)	1.0	0.5	0.35	0.25	0.18	0.13	0.10	0.07

IC Manufacturing Introduction

Clean



- 初始清洗就是將晶圓放入清洗槽中，利用化學或物理的方法將在晶圓表面的塵粒或雜質去除，防止這些雜質塵粒，對後續的製程造成影響，使得元件無法正常工作。

Particle remove mechanisms

* Particle removal model

Particle oxidative model

Figure (a) : shows the oxidation of a particle and make it soluble. We can see the particle dissolute and disappeared.

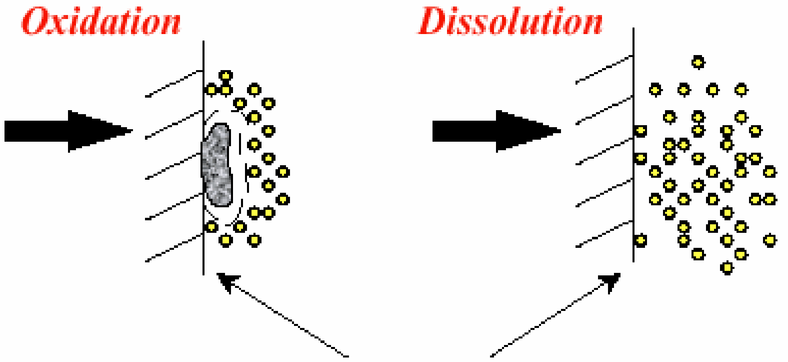


fig. (a) **Silicon wafer surface**

Electrical repulsion model

Figure (b) : shows the particle being removed by the electric repulsion due to induced charge.

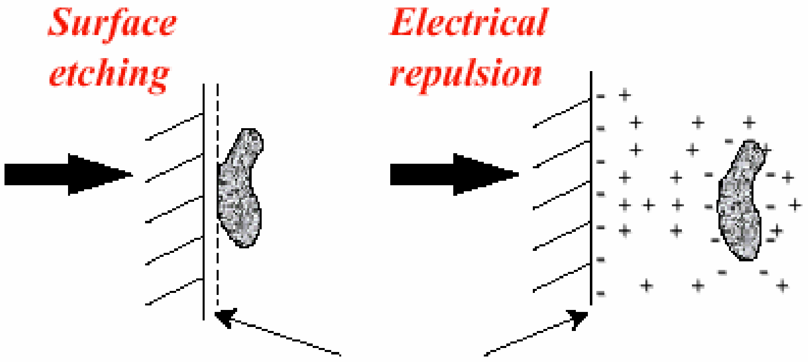


fig. (b) **Silicon wafer surface**

標準清洗步驟

	化學溶劑	清洗溫度	清除之污染物
1	$H_2SO_4+H_2O_2$(4:1)	120°C	有機污染物
2	D.I. H_2O	室溫	洗清
3	$NH_4OH+H_2O_2+H_2O$ (1:1:5) (SC1)	70 - 80°C	P微塵
4	D.I. H_2O	室溫	洗清
5	$HCl+H_2O_2+H_2O$ (1:1:6) (SC2)	70 - 80°C	金屬離子
6	D.I. H_2O	室溫	洗清
7	$HF+H_2O$ (1:50)	室溫	原生氧化層
8	D.I. H_2O	室溫	洗清

Agenda

New Concept for Worldwide

IC Manufacturing History

IC Manufacturing Introduction

IC Process Flow Introduction

The Strategy for the IC Development

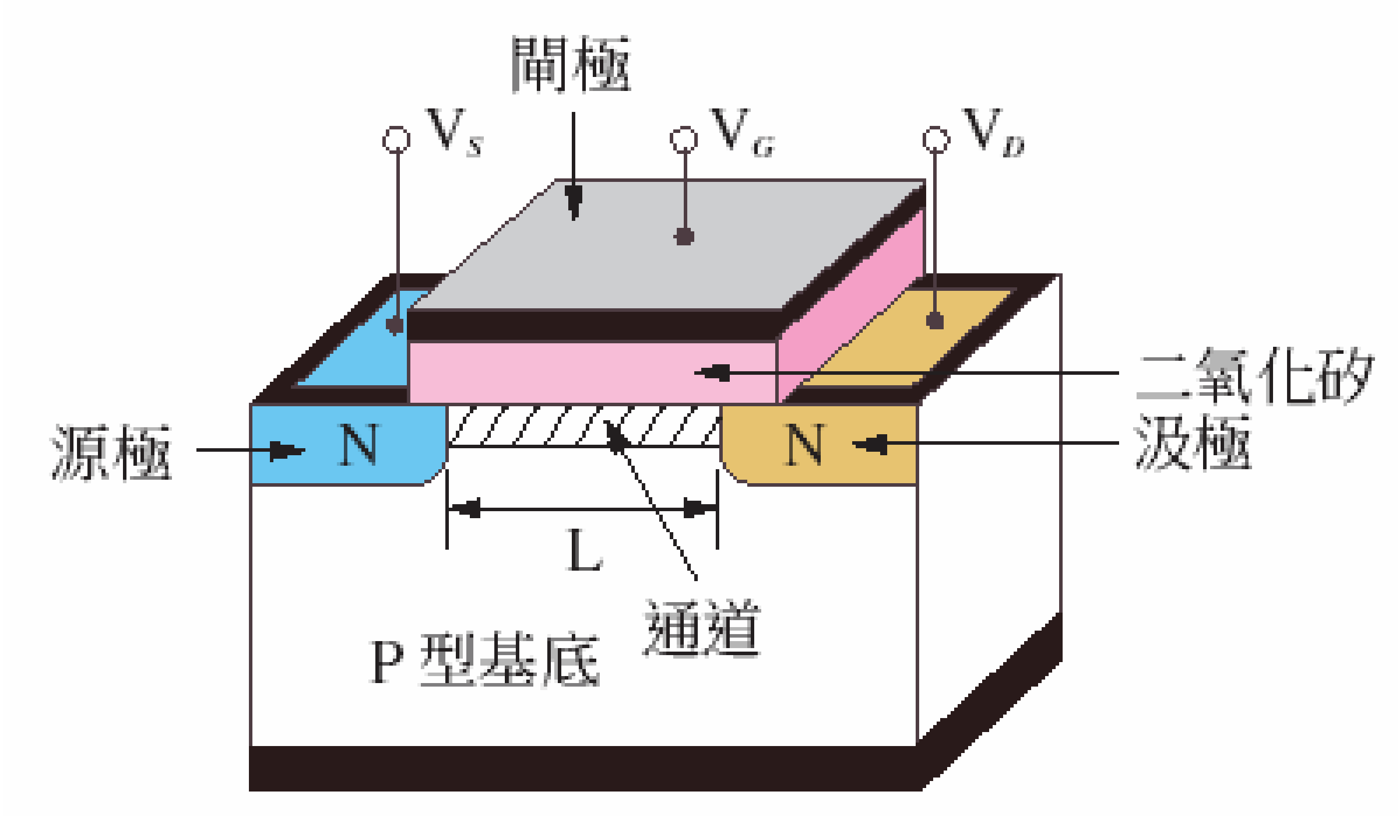
The Reliability test for IC Process

Quality Control

Ford 8-D

IC Process Flow

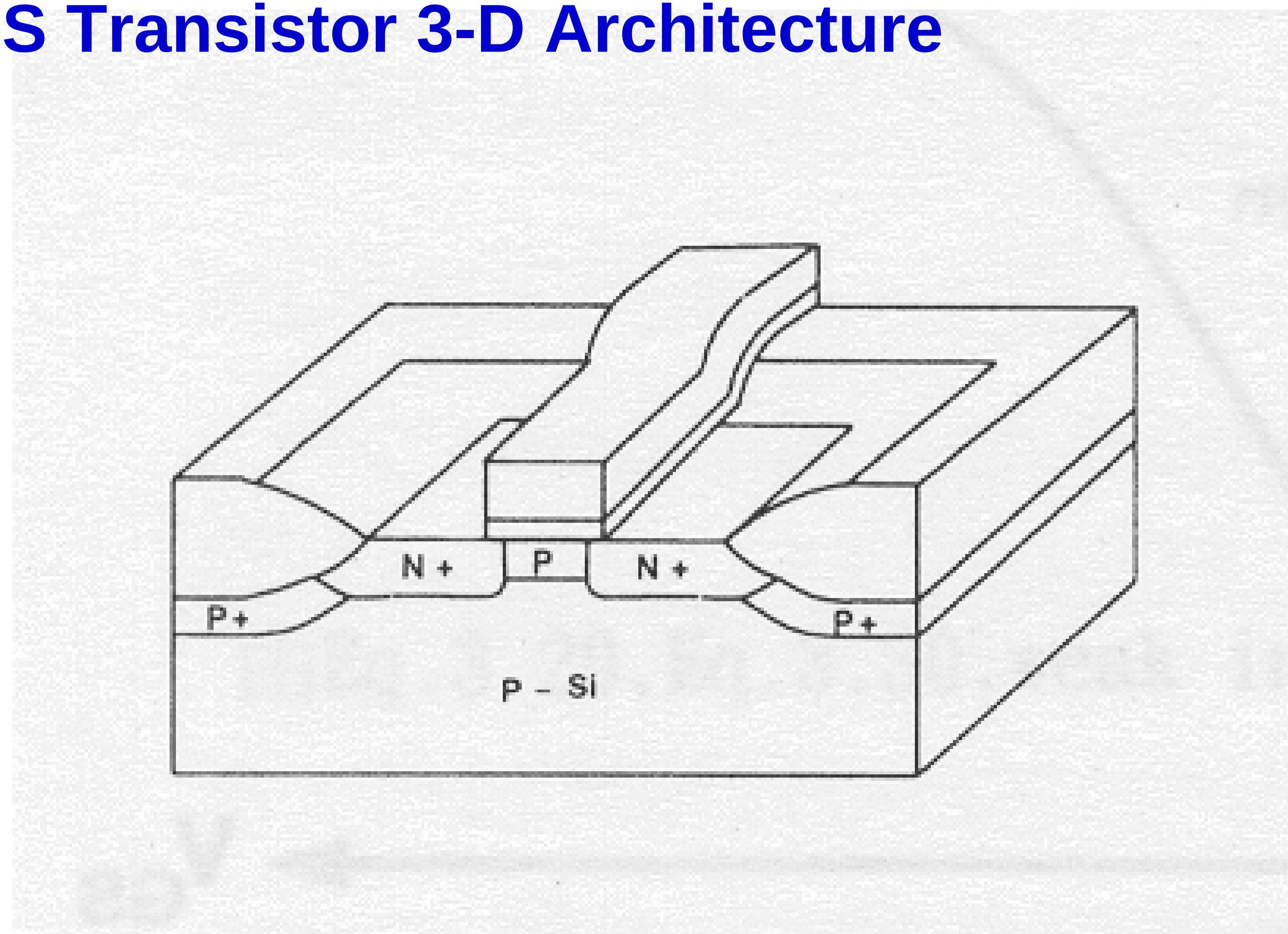
金氧半場效電晶體 (Metal-Oxide-Semiconductor Field-Effect Transistor)，縮寫爲MOSFET 。



N 型 MOSFET 的透視圖

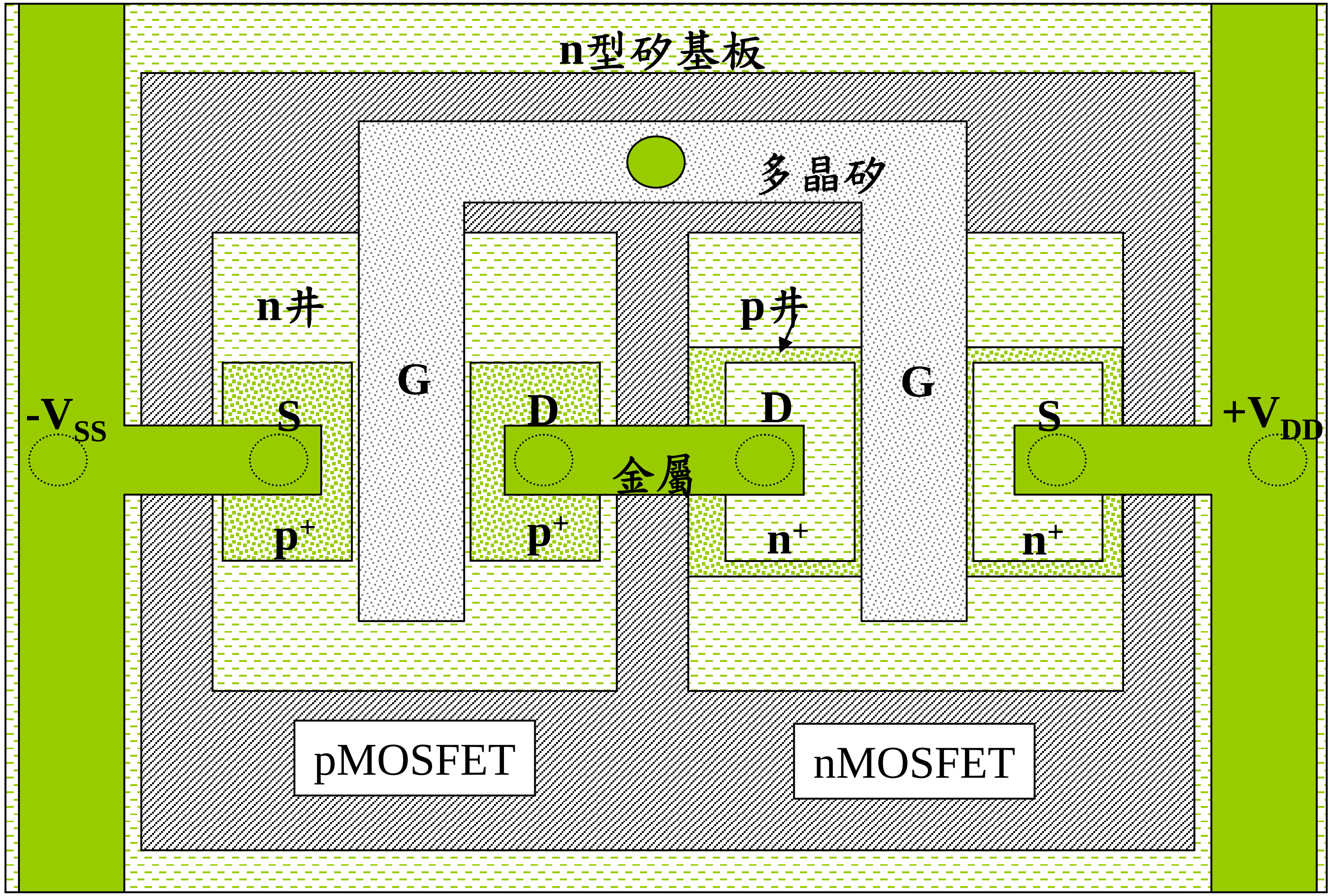
IC Process Flow

MOS Transistor 3-D Architecture



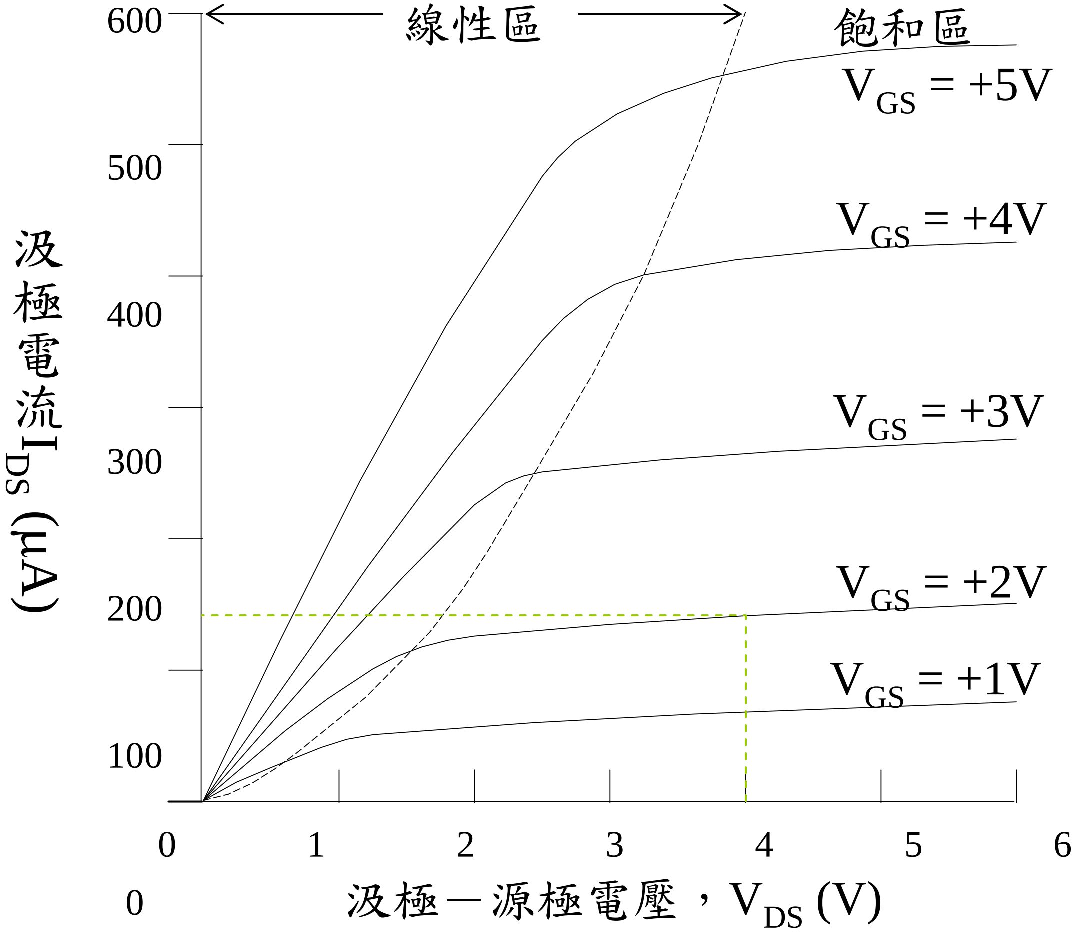
IC Process Flow

CMOS反相器俯視圖



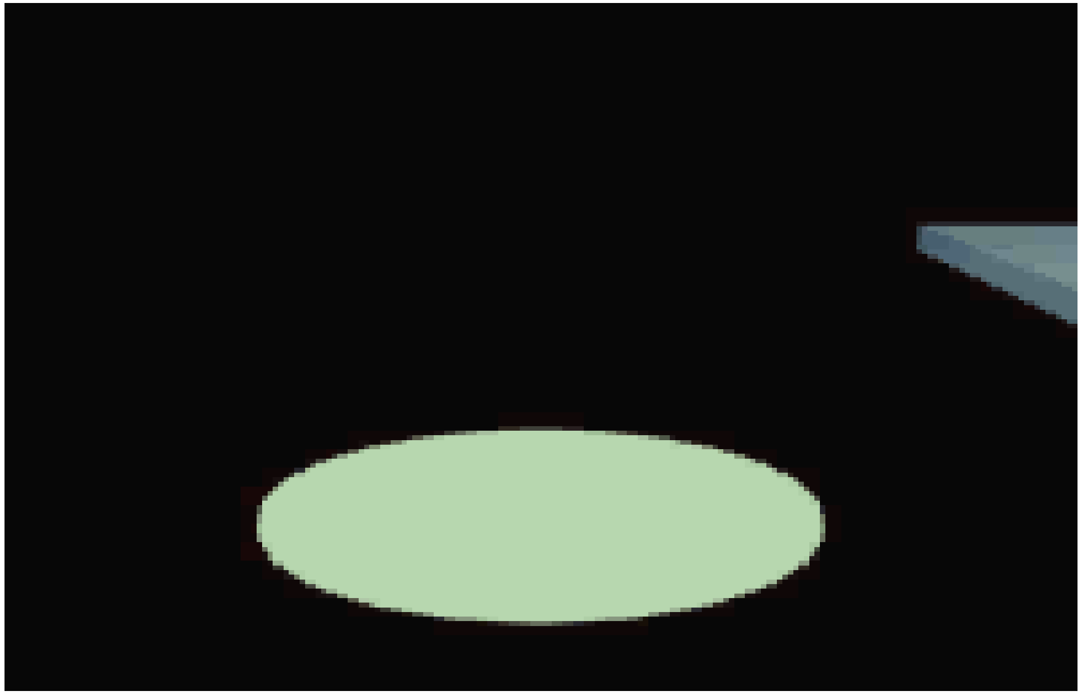
IC Process Flow

n通道MOSFET的特性曲線



IC Process Flow

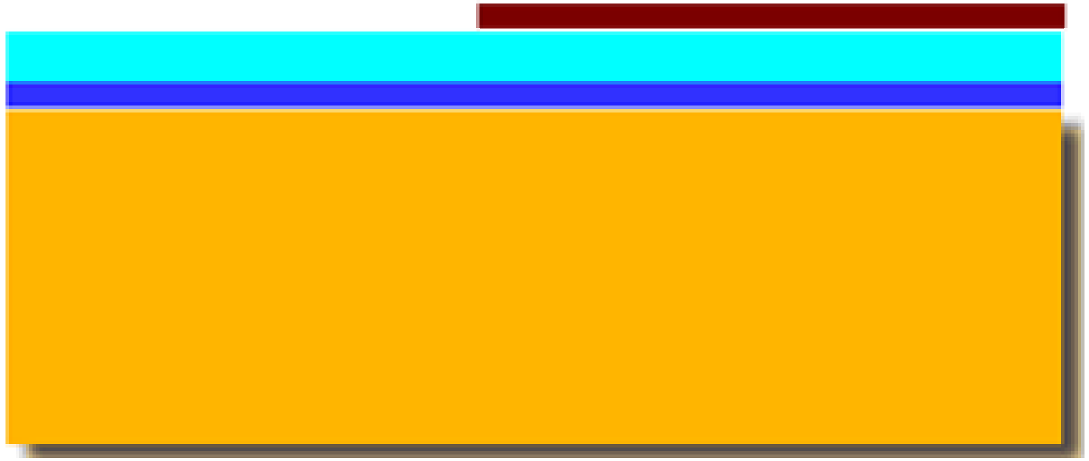
微影



- 微影製程的要素:光源,光罩,和光阻.
- 微影技術: (1) X光微影(X-ray lithography),(2) 電子束微影(electron bean lithography),(3) 離子束微影(ion bean lithography).

IC Process Flow

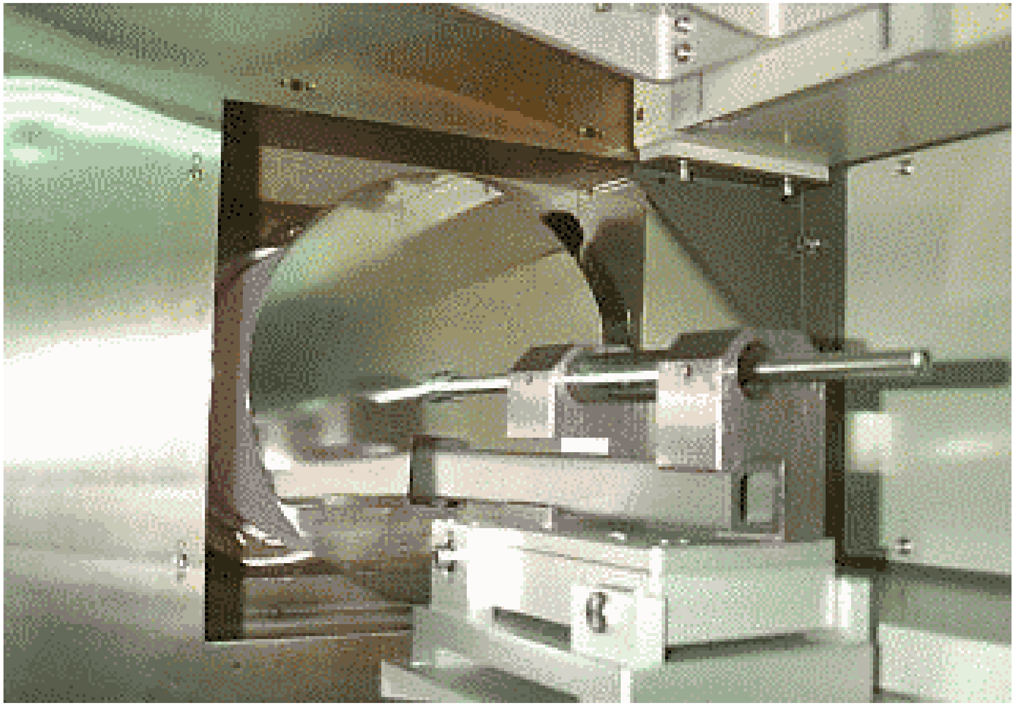
去除氮化矽



- 將晶圓表面的氮化矽，利用乾式蝕刻的方法將其去除掉。

IC Process Flow

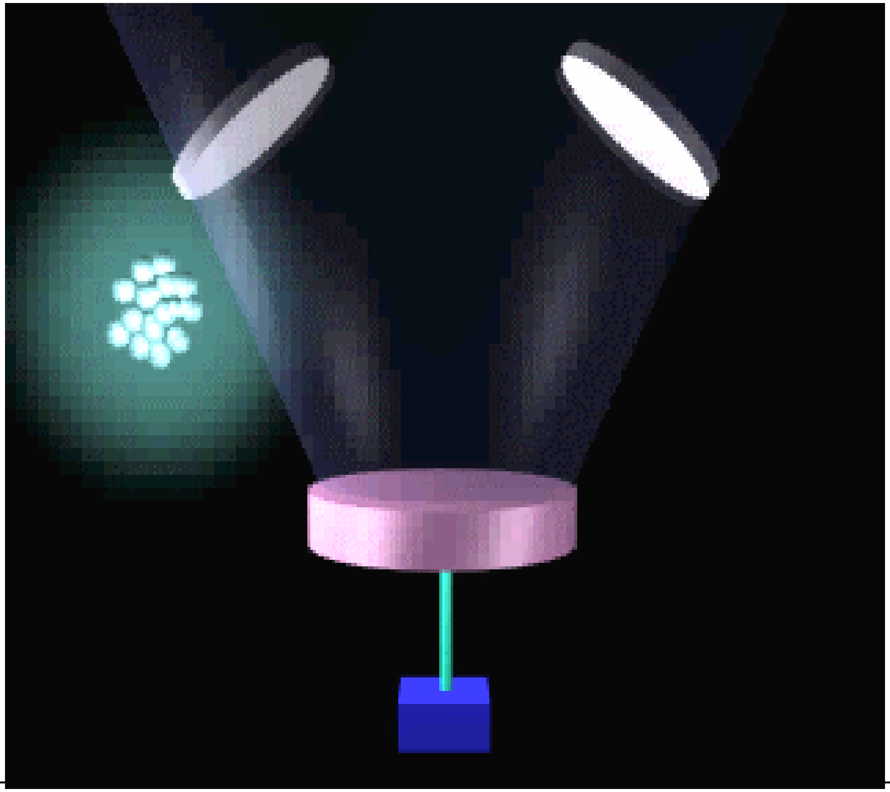
n型井的退火



- 離子佈植之後會嚴重地破壞矽晶圓晶格的完整性。所以摻雜離子佈植之後的晶圓必須經過適當的處理以回復原始的晶格排列。退火就是利用熱能來消除晶圓中晶格缺陷和內應力，以恢復晶格的完整性。同時使植入的摻雜原子擴散到矽原子的替代位置，使摻雜元素產生電特性。

IC Process Flow

濺鍍法 (sputter)



- 利用高能量的粒子(經由電場加速的正離子)轟擊固態靶的表面，靶原子與這些高能粒子交換能量後，由表面飛出，沈積在矽晶圓上，形成薄膜，這種方法稱為濺鍍。