2. 晶體成長與量測

- 單晶成長
- 磊晶成長
- 晶體量測
- 其他的晶體成長方法

2.1 單晶成長

1. 柴可拉斯基長晶法

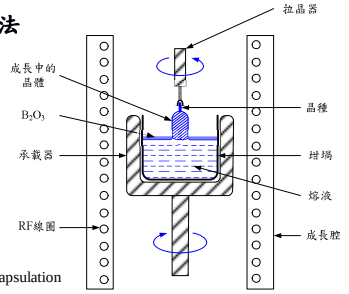
Pre-process

- Starting from raw material to form metallurgical-grade Si
  - $SiO_2 + 2C \rightarrow (2000\ ^\circ C)\ Si + 2CO\uparrow$
- Metallurgical-grade Si to form Trichlorosaline
  - $Si + nHCl \rightarrow (300\ ^\circ C)\ SiHCl_3 + MCl_x$
- Trichlorosaline to form polysilicon
  - $2SiHCl_3 + 2H_2 \rightarrow 2Si + 6HCl$
- Ready for CZ growth

2.1 單晶成長

1. 柴可拉斯基長晶法

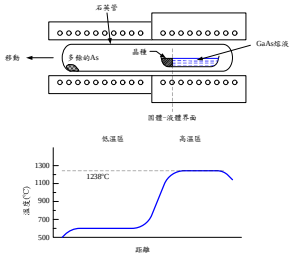
成長單晶最重要的技術之一就是柴可拉斯基(Czochralski)在1917年提出的長晶法，稱為柴可拉斯基長晶法。



液封式柴可拉斯基(Liquid Encapsulation Czochralski, LEC)長晶系統。

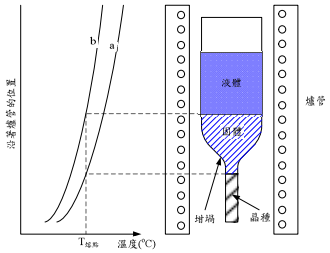
2.1 單晶成長

2. Bridgman Method



2.1 單晶成長

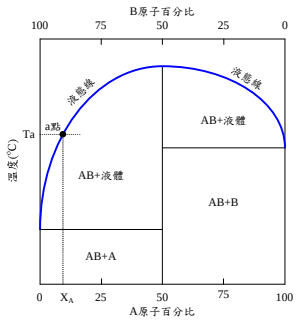
3. Vertical Gradient Freeze (VGF) Method



2.2 磊晶成長

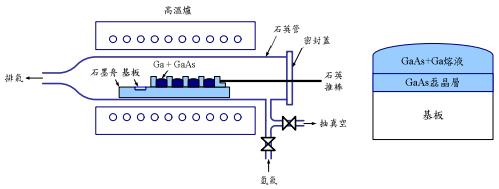
1. 液相磊晶法

- Phase Diagram



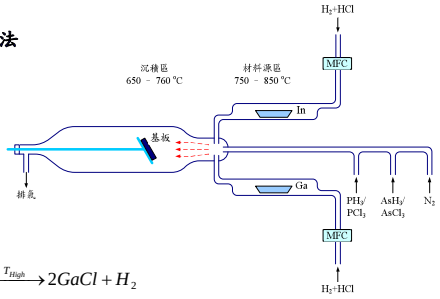
2.2 磊晶成長

1.2 液相磊晶系統



2.2 磊晶成長

2.1 氣相磊晶法



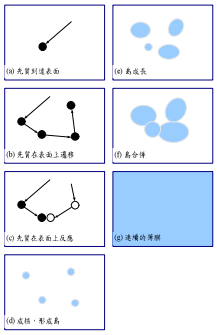
-- 例如: GaAs

$$2Ga + 2HCl \xrightarrow{T_{High}} 2GaCl + H_2$$

$$3GaCl + 3AsH_3 \xrightarrow{T_{Low}} 3GaAs + 3HCl + 3H_2$$

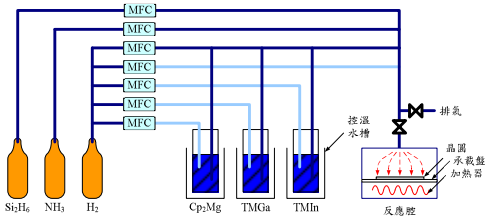
2.2 磊晶成長

2.2 膜的形成



2.2 磊晶成長

3.1 有機金屬化學氣相沉積 (MOCVD)法



2.2 磊晶成長

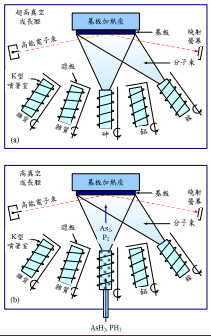
3.2 實例----$In_xGa_{1-x}N$的成長反應式

$$y\left[(CH_3)_3In\right] + (1-y)\left[(CH_3)_3Ga\right] + NH_3 \xrightarrow{\sim 1050^\circ C} In_xGa_{1-x}N + 3CH_4$$

2.2 磊晶成長

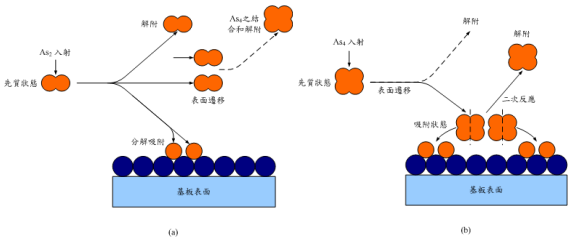
4.1 分子束磊晶法

雖然使用固體源之分子束磊晶法已成功用於成長GaAs和AlGaAs等化合物半導體，但是含磷之III-V族化合物半導體很難用固體源之分子束磊晶法成長。因為元素的固體磷包含具有不同蒸氣壓之同素異形的形式(P2和P4)，所以通量很難控制。1980年，Panish提出分子束磊晶法加AsH3和PH3分解的方法成長GaAs和InP。其係將AsH3和PH3分別裂解成As2和P2。此種技術稱為氣體源分子束磊晶法(Gas Source Molecular Beam Epitaxy, GSMBE)。



2.2 磊晶成長

4.2 成長機制



2.2 磊晶成長

四種磊晶法的比較結果

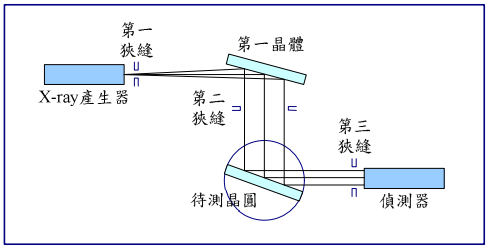
	LPE	VPE	MOCVD	MBE
真空(Torr)	760	760	10^{-2}	$\leq 10^{-9}$
成本	低	貴	昂貴	昂貴
成長速率	快	快	慢	很慢
磊晶品質	很好	好	很好	很好
表面形態	差	佳	佳	佳
應用性	差	差	佳	佳

2.3 晶體量測

- X-ray Diffraction
- Absorption Spectrum
- Photoluminescence (PL)
- Hall Measurement

2.3 晶體量測

- X-ray Diffraction



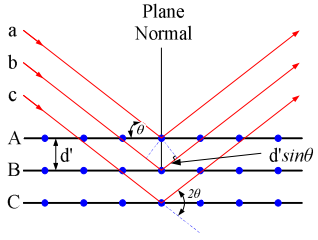
2.3 晶體量測

- X-ray Diffraction

$$m\lambda = 2d\sin\theta, m = 1,2,3,...$$

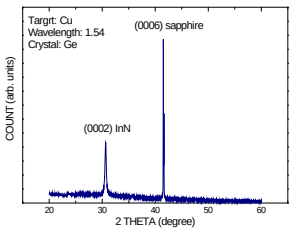
$$\frac{1}{d^2} = \frac{\left(h^2+k^2+l^2\right)}{a^2}$$

$$\frac{1}{d^2} = \frac{4}{3}\left(\frac{h^2+hk+k^2}{a^2}\right)+\frac{l^2}{c^2}$$



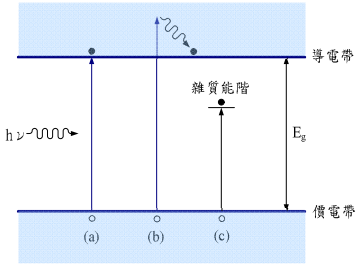
2.3 晶體量測

- X-ray Diffraction $\frac{\Delta a}{a_{epi}} = \frac{a_{epi}-a_{sub}}{a_{epi}} = 1-\frac{\sin\theta_{epi}}{\sin\theta_{sub}} = 1-\frac{\sin 15.32}{\sin 20.76} = 25.46\%$



2.3 晶體量測

- Absorption Spectrum

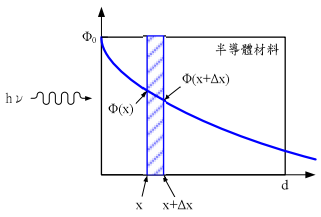


2.3 晶體量測

- Absorption Spectrum

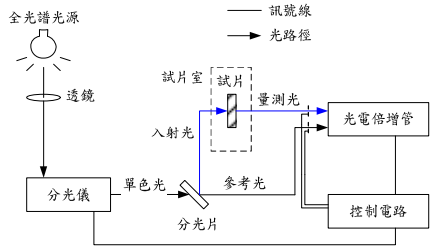
$$\frac{d\Phi(x)}{dx} = -\alpha\Phi(x)$$

$$T = \frac{\Phi(d)}{\Phi_0} = e^{-\alpha d}$$



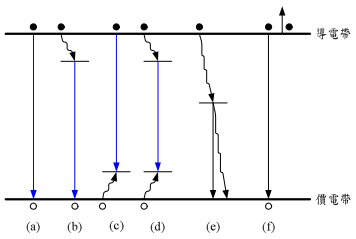
2.3 晶體量測

- Absorption Spectrum



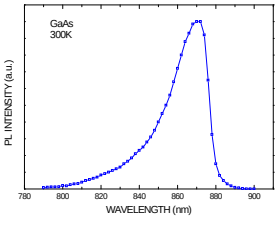
2.3 晶體量測

- Photoluminescence (PL)



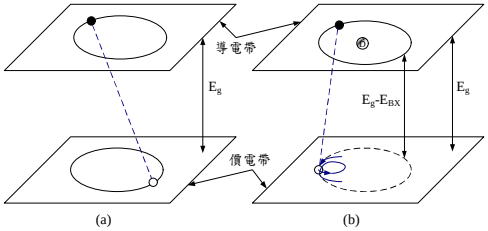
2.3 晶體量測

- Photoluminescence (PL)



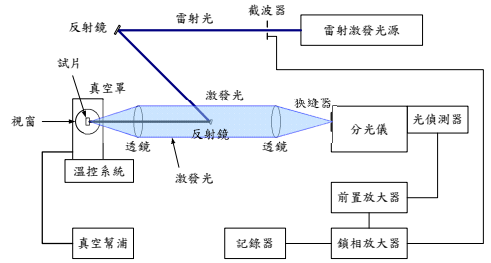
2.3 晶體量測

- Photoluminescence (PL)



2.3 晶體量測

- Photoluminescence (PL)



2.3 晶體量測

- Hall Measurement

$$q\bar{v}\times\bar{B}=-\bar{a}_y qv_x B_z$$

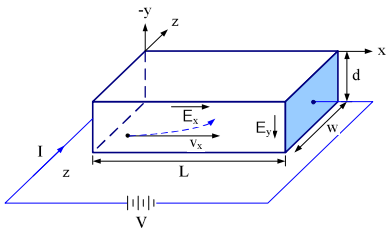
$$q\mathcal{E}_y=+qv_x B_z$$

$$\mathcal{E}_y=\frac{V_H}{d}$$

$$J=\frac{I}{A}=qpv_x$$

$$p=\frac{dIB_z}{qAV_H}$$

$$\rho=\frac{1}{qp\mu_n}$$



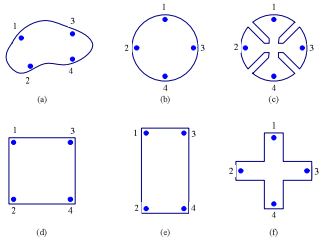
2.3 晶體量測

- van der Pauw 法

$$\rho=\frac{\pi d}{\ln 2}\frac{(R_{12,34}+R_{23,41})}{2}F$$

$$\frac{R_r-1}{R_r+1}=\frac{F}{\ln 2}\cosh^{-1}[\frac{\exp(\ln 2/F)}{2}]$$

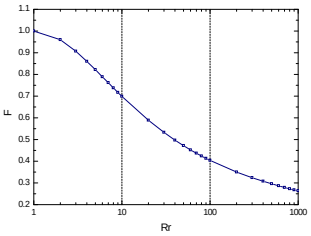
$$R_r=\frac{R_{12,34}}{R_{23,41}}$$



2.3 晶體量測

- 校正因子

$$\frac{R_r-1}{R_r+1}=\frac{F}{\ln 2}\cosh^{-1}[\frac{\exp(\ln 2/F)}{2}]$$

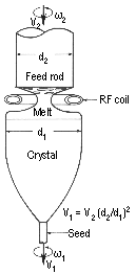


2.4 補充

- Growth of single crystals
  - Float-zone (FZ)長晶法

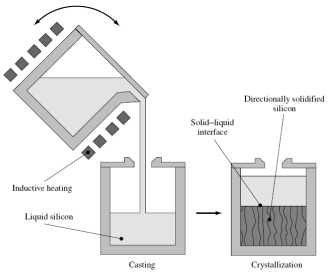
此種長晶法係將RF加熱器掃瞄過整個複晶棒。





2.4 補充

- Growth of polycrystals
  - Block casting



2.4 補充

- Growth of polycrystals
  - Block casting

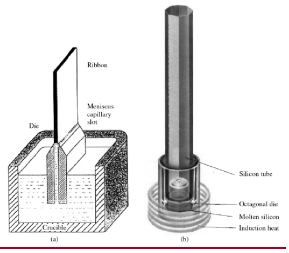


Treatment of Silicon Bricks
- characterization
  life time, resistivity, size
- surface grinding
- chamfer grinding
- cutting of top and bottom

2.4 補充

- Ribbon technnques
  - Edge defined film fed growth (EFG-growth)

利用毛細作用，經石墨做成的鑄模槽孔（slotteddie）將矽帶從矽液中拉長出來的。由Mobil Tyco公司研究發展，目前已可同時拉長5條5公分寬的矽帶，製成的太陽電池最高效率已達12.4%。EFG法的最大優點是生長率高，但缺點是無法控制均一性的晶粒品質，故仍待改進。

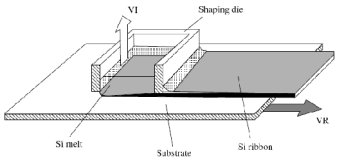


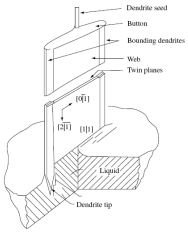


ASE Americas' production line for EFG crystal growth.

2.4 補充

- Ribbon technnques
  - Ribbon Growth on a Substrate (RGS)
  - Dendritic web growth

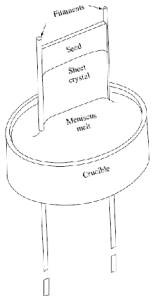




2.4 補充

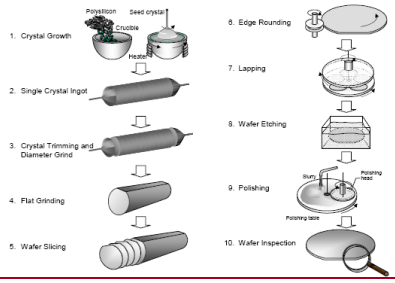
- Ribbon technnques
  - String Ribbon (STR) growth





2.4 補充

- Preparation of wafers



2.4 補充

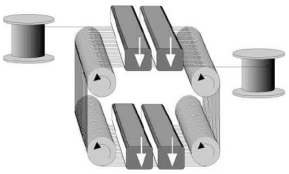
❑ Slicing machine





2.4 補充

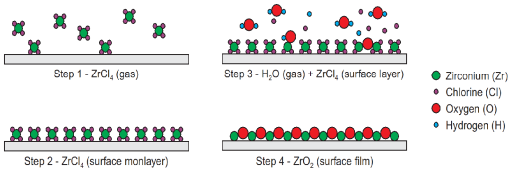
❑ Slicing machine





2.4 補充

✹ Atomic Layer Deposition (ALD)



2.4 補充

✹ Atomic Layer Deposition (ALD)

