3.46 PHOTONIC MATERIALS AND DEVICES

Lecture 12: Crystal Growth

Lecture

Notes

Compound Semiconductor Crystal Growth

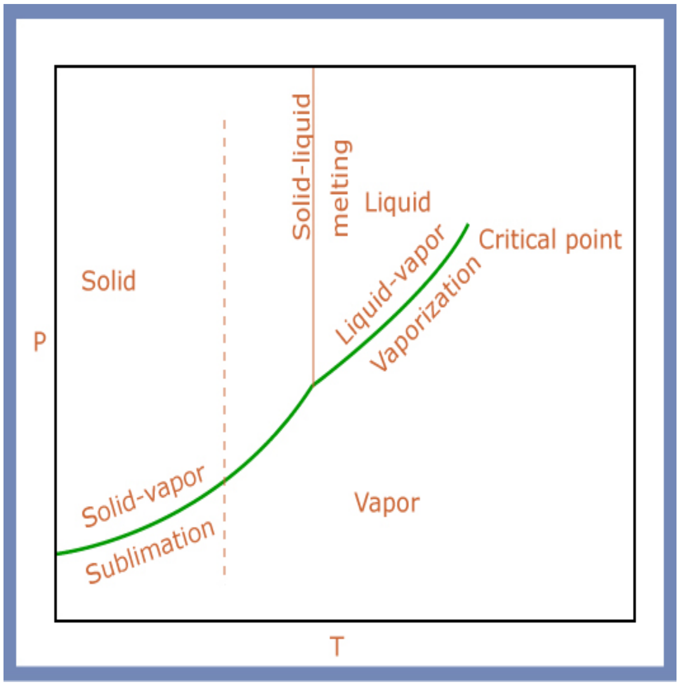
Intensive Variables

P, T, μ

Gibbs Phase Rule

$V = C - P + 2$

One Component System



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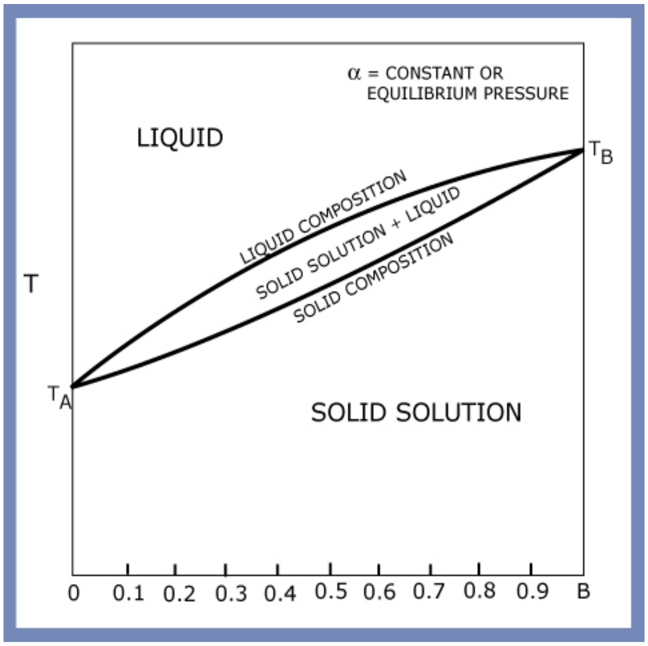
Two Component System

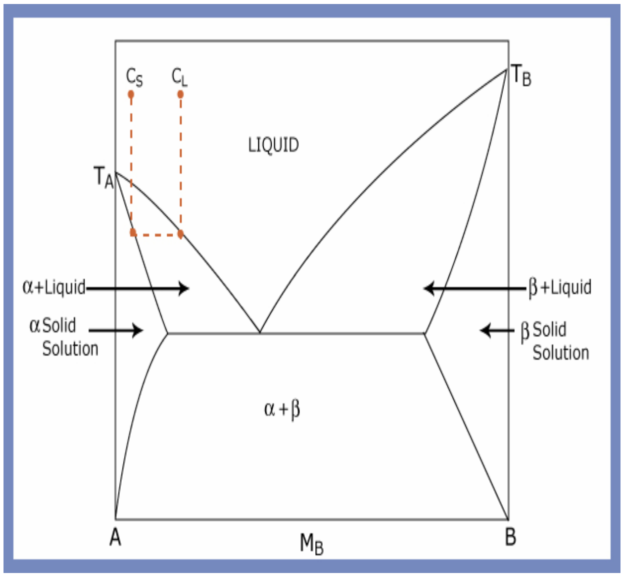


Solidification Crystalline State

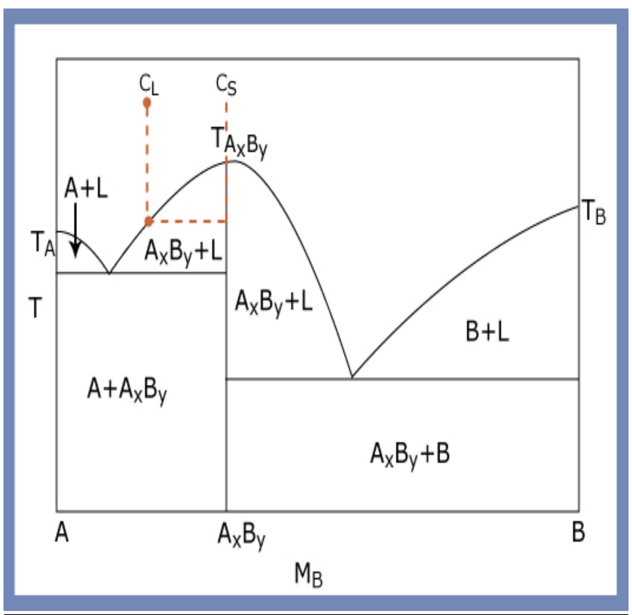
1) First order phase transition
   $\Delta G = \Delta U + PV - T\Delta S$
2) Composition C_s is richer in B than the liquid C_L.
3) ΔH_f latent heat of fusion is evolved.
4) Composition of solid varies continuously

Immiscible Systems

$$k = \frac{C_s}{C_L}$$



Compound formation



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Crystal Growth from the Melt

Requirements:

1) melts congruently
2) does not decompose before melting
3) no phase transition between T_{MP} and RT.

Methods:

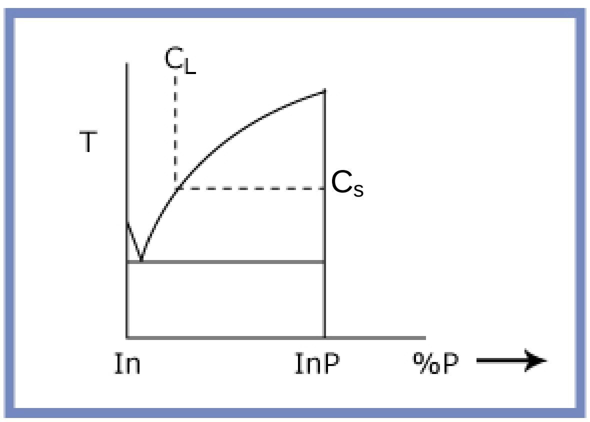
Czochrakski growth

- <u>seed</u>
- <u>melt</u> with crucible
- heat flow (ΔH_f)

Gradient freeze

- <u>boat</u> with <u>melt</u>
- traveling ∇T

Solution Growth



1) Diffusion of solute to S/L interface
2) Attachment of solute atom to crystal
3) Evolution of ΔH_f

Vapor Phase Growth

Molecule Beam Epitaxy MBE

Chemical Vapor Deposition CVD

Metal Organic Chemical Vapor Deposition MOCVD

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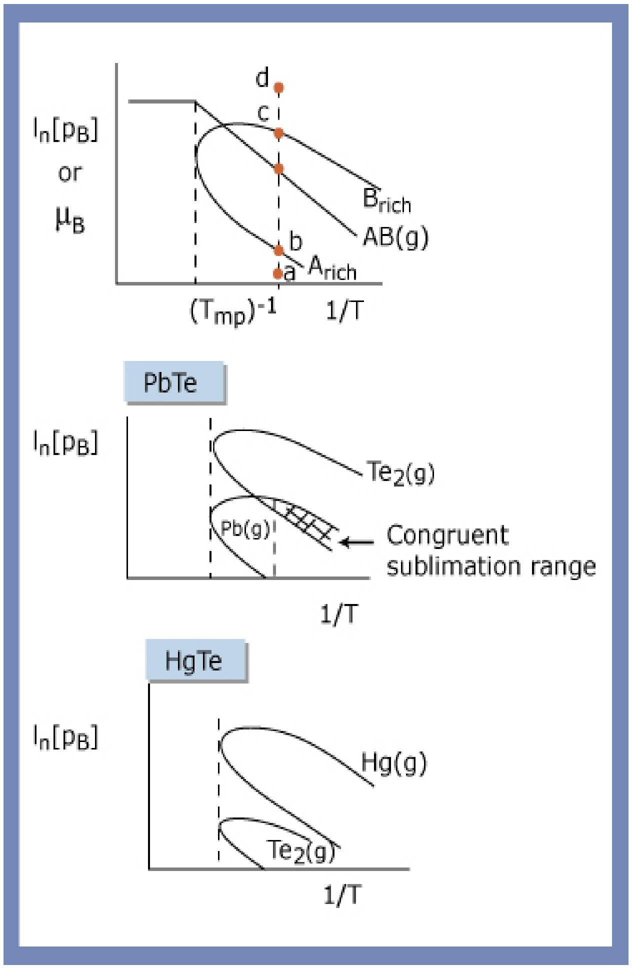
Vapor Phase Growth:

Gas Phase Equilibrium for AB compounds



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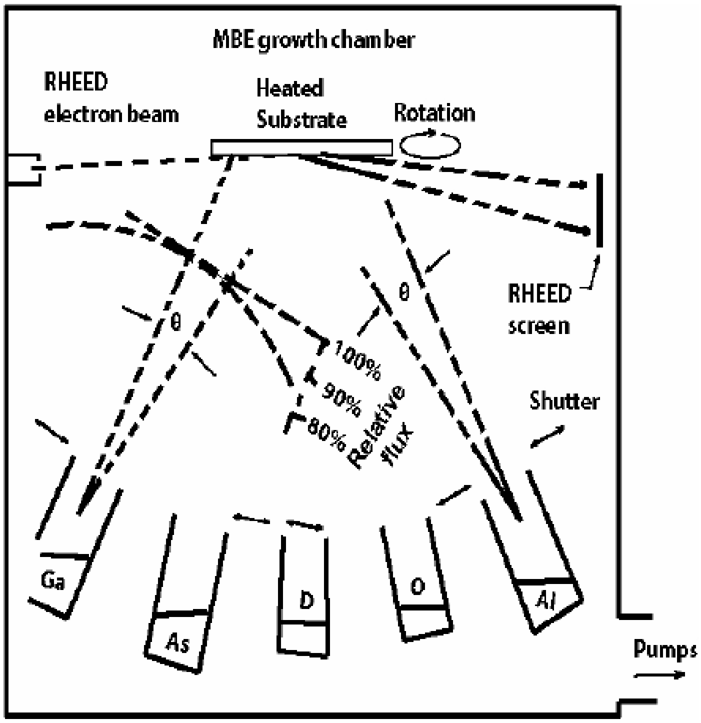
MBE Growth



- UHV $10^{-9} - 10^{-12}$ torr
- molecular flow MFP >> chamber size

$$\text{MFP} = \lambda = \left(\sqrt{2}\pi \underbrace{N}_{\text{molecule/cm}^2} \underbrace{d^2}_{\text{molecule diameter}}\right)^{-1}$$

$$\lambda_{300\ \text{K}} \simeq \frac{0.05\ \text{torr}\cdot\text{mm}}{P}$$

$$10^{-3}\,\text{T} \Rightarrow \lambda = 50\ \text{mm}$$

$$760\ \text{T} = 1\ \text{atm} \Rightarrow \lambda = 70\ \text{nm}$$

$$[P] \propto \exp\left[-E/kT\right]$$

$$\phi \propto P(MT)^{-\frac{1}{2}}$$

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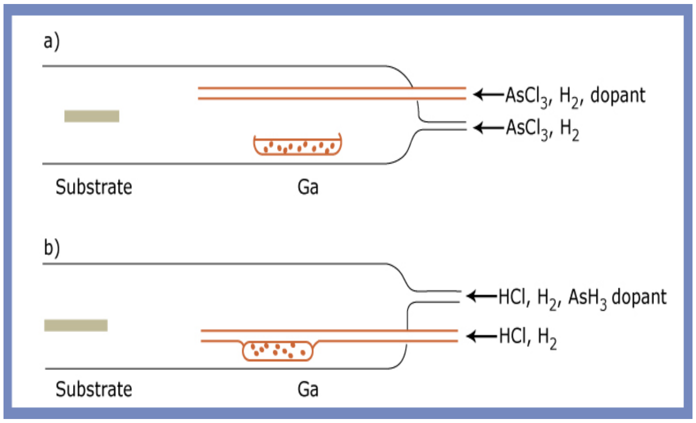
CVD Growth



- mass transport + source reaction
- gas phase diffusion
- homogenous gas phase reactions
- heterogeneous reaction at substrate

Source + transport

$$Ga + HCl \xrightarrow{H_2} GaCl + \frac{1}{2}H_2$$ halide + hydride

$$4AsCl_3 + 6H_2 \xrightarrow{H_2} As_4 + 12HCl$$ halide

$$4AsH_3 \xrightarrow{H_2} As_4 + 6H_2$$ hydride

Deposition

$$As_4 + 4GaCl + 2H_2 \rightarrow 4GaAs + 4HCl$$

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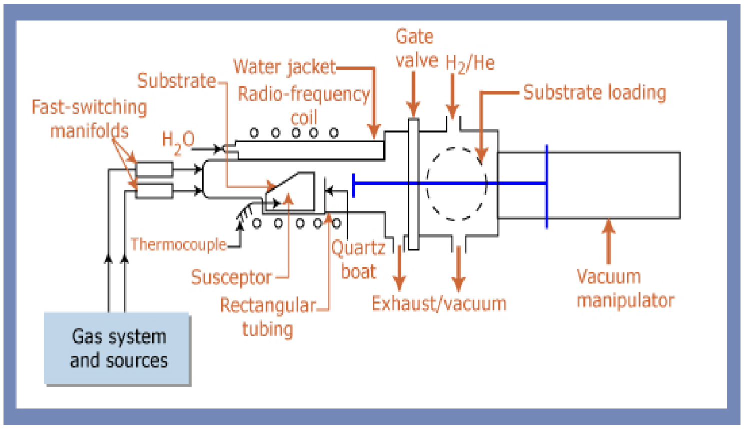
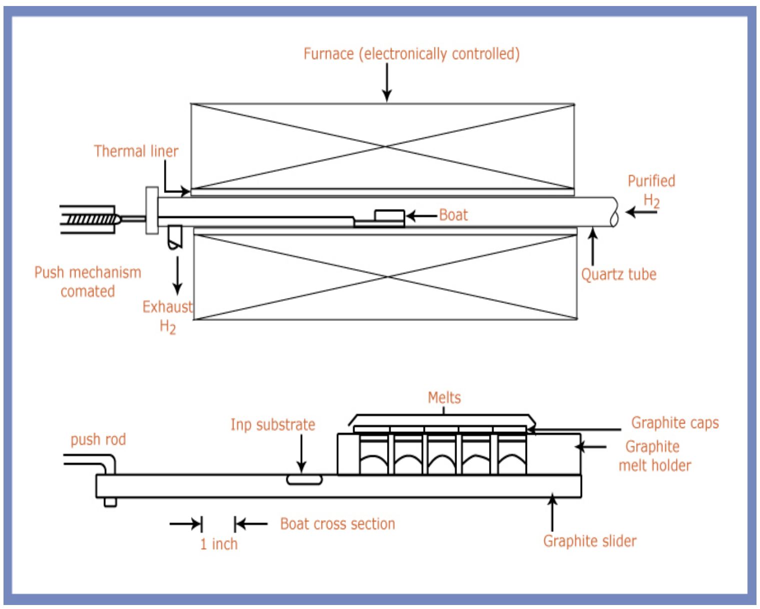
MOCVD Growth



- no source or transport reactions
- chemistry controlled by pyrolysis of $(CH_3)_3Ga$ adsorbed on substrate

$$(CH_3)_3Ga + AsH_3 \xrightarrow{H_2} GaAs + 3CH_4$$

LPE Growth



- In-rich side of phase diagram
- Lower T ⇒ super saturation
- Quartz reactor, H_2 (reduces slag)
- Solid composition determined by melt composition + T