3.46 PHOTONIC MATERIALS AND DEVICES

Lecture 14: Defects and Strain

Lecture

Perfection

- LRO (Long Range Order)
- SRO (Short Range Order)

Imperfection

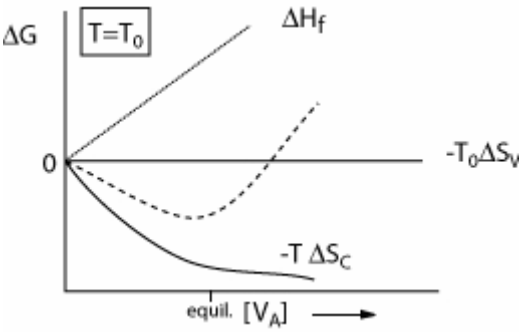
- Vibrating atom
- Electronic change
- Chemical impurity
- Point defect (I, V)
- 1D defect (dislocation)
- 2D defect (grain boundary)
- 3D defect (precipitate)

Defect Chemistry

$$\Delta G_f = \Delta H_f - T\left(\Delta S_V + \Delta S_C\right)$$

Vacancy Equilibria

$$A_A \rightleftarrows V_A + A_A$$



Notes

Charge Carriers as Defects

$$e^- + h^+ \rightleftarrows \text{bond}$$

$$[e^-][h^+] = np = K_{np}$$

$$= \exp\left(-\frac{\Delta G}{k_B T}\right)$$

$$= \exp\left(\frac{\Delta S}{k_B}\right) \exp\left(-\frac{\Delta H}{k_B T}\right)$$

$$= N_C N_V \exp\left(-\frac{E_g}{k_B T}\right)$$

Point Defect Equilibria in Compounds

$$bB + cC \rightleftharpoons dD + eE$$

$$K = \frac{[D]^d [E]^e}{[B]^b [C]^c}$$

AB_x Compounds

Schottky Defect (vacancy pair)

$$A_A + xB_B \rightleftharpoons V_A + xV_B + A_A + B_B$$

$$K_S = [V_A][V_B]^x$$

Frenkel Pair

$$A_A \rightarrow A_I + V_A$$

$$K_{FP}(A) = [A_I][V_A]$$

$$K_{FP}(B) = [B_I][V_B]$$

Anti-Site Defect

$$A_A + B_B \rightleftharpoons A_B + B_A$$

$$K_{AS} = [A_B][B_A]$$

Nonstoichiometry

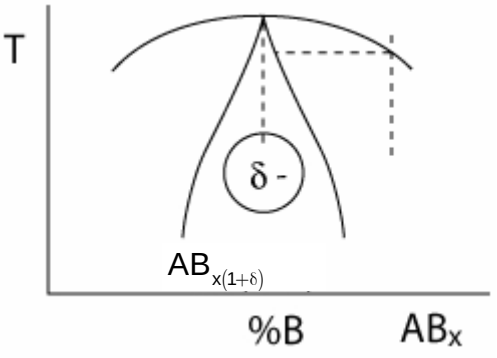
AB_x

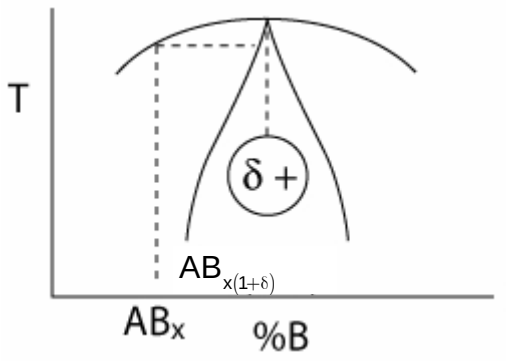
$$\frac{[A]}{[B]} \neq \frac{1}{x}$$

$$\Rightarrow AB_{x(1+\delta)}$$

for a volatile component “B”

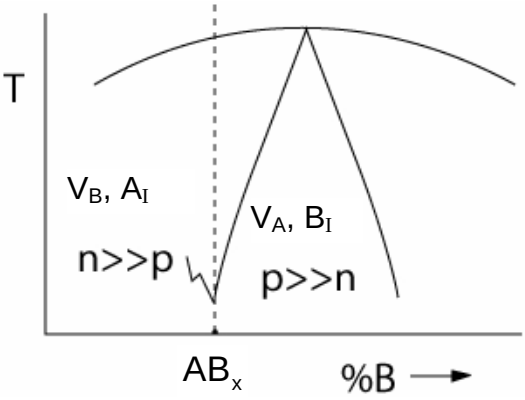
$$x\delta = [A_I] - [V_B] + [A_B]$$





Electrical Properties: Defect Ion Approximation

A (metal)	B (non-metal)
excess A ($\delta < 0$)	excess B ($\delta > 0$)
V_B (donor)	V_A (acceptor)
A_I (donor)	B_I (acceptor)
A_B (acceptor)	B_A (donor)



Defect-Carrier Equilibria

$$D \rightleftharpoons D^{z+} + ze^-$$

$$A \rightleftharpoons A^{z-} + zh^+$$

$$\Rightarrow \text{solubility} \equiv f(E_F)$$

example: Li in Si (B)

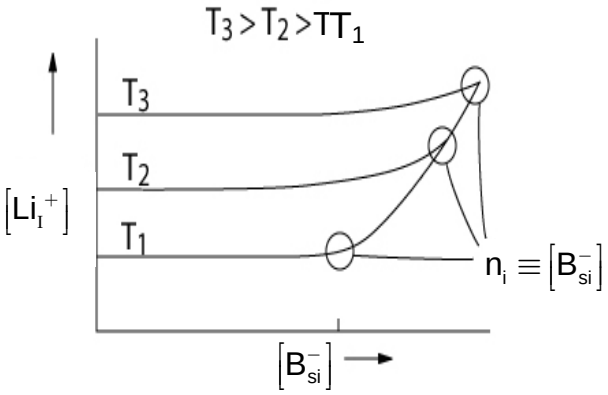
$$B_{Si} \rightleftarrows B_{Si}^- + h^+$$

$$Li(ext) \rightleftarrows Li_I^+ + e^-$$

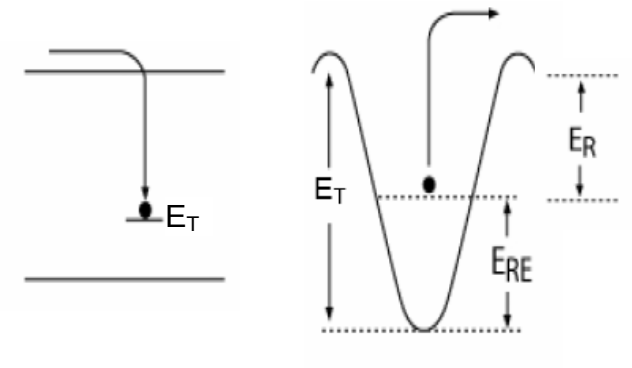
$$e^- + h^+ \rightleftharpoons \text{bond}$$

$$\left[B_{Si}^-\right] + n = \left[Li_I^+\right] + p$$

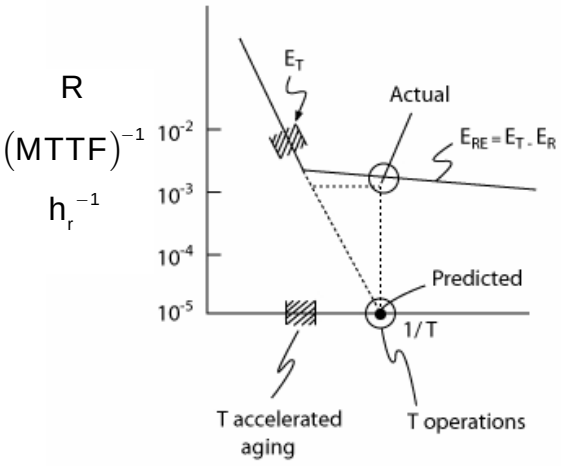
Lecture



Consequences: Laser reliability



$$\frac{R_{RE}}{R_T} = \frac{\eta R_R}{\nu_L} \exp\left[\frac{E_R}{k_B T}\right]$$



Notes

E_R: Recombination Energy
E_T: Transition Energy
E_{RE}: Reaction Enhanced Energy