Name:- Kaushik jaiswal
Batch:- A2
Roll no:. 16ucc046.

Assignment- 04
Subject:- Physics-2.

Q what is Kronig - Penny model? What does it represent?

Ans:. It is the model for electron in one-dimensional periodic potential. The possible states that the e⊖ can occupy are determined by Scrödinger equation.

It represents simple one-dimensional periodic potential yields energy bands as well as energy band gaps.

The Potential assume is $u(x) = \begin{cases} 0 & , 0 < x < a \\ u_0 & , -b < x < 0. \end{cases}$

We need to solve Schroedinger equation

$$-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2} + V(x)\,\phi_{nk}(x) = E_{nk}\,\phi_{nk}(x).$$

(Q) what is effective mass? How is mass defined in E vs K diagram?

(Ans) $F_{total} = F_{ext} + F_{int} = mA$

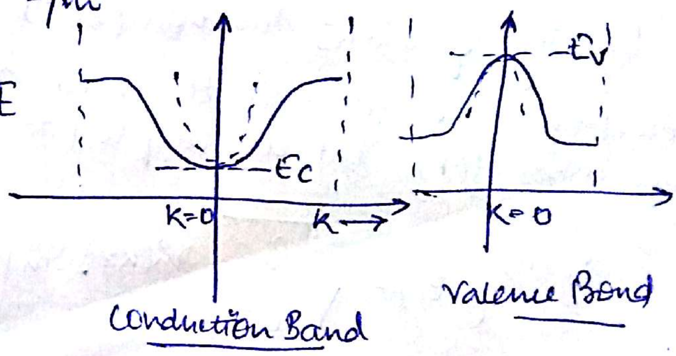
$F_{ext} = m^* a.$

here m^* is effective mass, looks into account the particle mass and also the effect of internal forces

$$\frac{1}{\hbar^2}\cdot\frac{d^2E}{dk^2} = 1/m$$

$$f = ma = -eE$$

$$a = -\frac{eE}{m}$$



E v/s K diagram

$$\frac{d^2E}{dk^2} = 2C_1$$

$$\Rightarrow \frac{1}{\hbar^2}\cdot\frac{d^2E}{dk^2} = \frac{2C_1}{\hbar^2}$$

$$\Rightarrow \left[\frac{1}{\hbar^2}\cdot\frac{d^2E}{dk^2} = \frac{2C_1}{\hbar^2} = \frac{1}{m^*}\right]$$

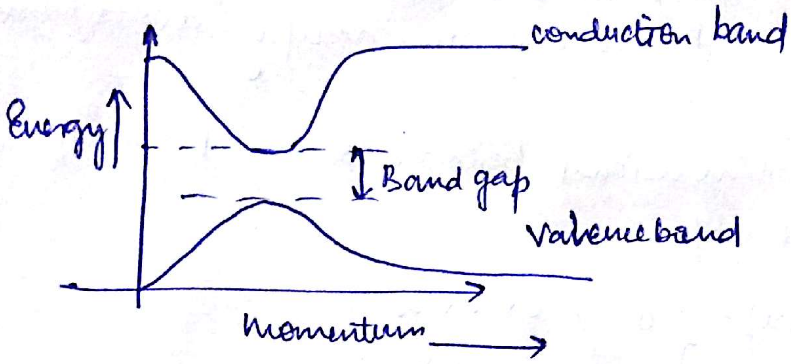
$$a = -\frac{eE}{m^*_n}$$

Scanned by CamScanner

③ What is direct & indirect band gap semiconductor?

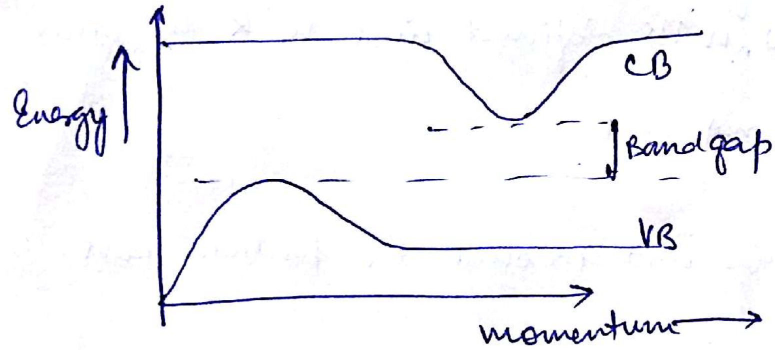
Ans:- Direct bandgap semiconductor.

In direct bandgap semiconductor, top of valence band and bottom of conduction band occur at same value of ~~same~~ momentum.



Indirect band gap semiconductor.

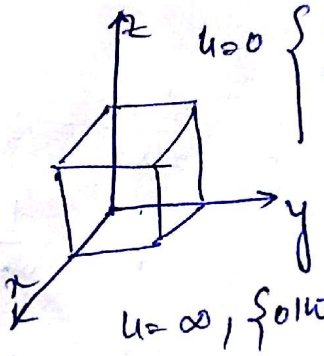
The maximum energy of valence band occurs at different value of momentum to the minimum in conduction band energy.



④ Density of states function (DOS)

Electrons are allowed to move relatively freely in conduction band of semiconductor, but are confined to crystal.

$$\Psi(x,y,z) = \sqrt{\frac{q}{L^3}}\,\sin(Kx)\,\sin(Ky)\,\sin(Kz)$$

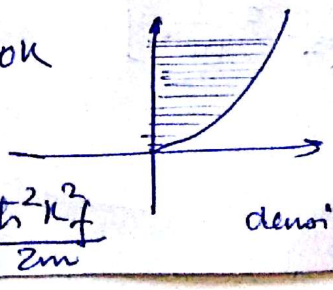


$u=0$ $\begin{cases} 0<x<L \\ 0<y<L \\ 0<z<L \end{cases}$

$u=\infty$, {otherwise}

$$E = \frac{\hbar^2\pi^2}{2mL^2}\left(n_x^2 + n_y^2 + n_z^2\right)$$

fermi-level at T=0K



max value of energy for filled states is known as E_F

$$E_F = \frac{\hbar^2 K_F^2}{2m}$$

density of filled states $= \frac{N}{V} = \frac{1}{3\pi^2}\left(\frac{2mE_F}{\hbar^2}\right)^{3/2}$.

Pag. 10:-03

(5) Relation between DOS and Energy

$$g(E) = \frac{4\pi (2m)^{3/2}}{h^3} \sqrt{E}$$ → It is the density of quantum state per unit volume of the crystal.

(6) Fermi Dirac probability function.

max of 1 particle is allowed in each quantum state (by Pauli exclusion principle). There are g_i ways of choosing where to place the first particle, $(g_i - 1)$ ways for second particle and so on. where

Total no of ways of arranging N_i particle in ith level $N_i \leq g_i$) →

$$g_i (g_i - 1) \cdots (g_i (N-1) = \frac{g_i!}{(g_i - N_i)!}$$

Actual number of independent ways of arranging N_i particles in ith level is

$$W_i = \frac{g_i!}{N_i! \, (g_i - N_i)!}$$

(7) Fermi energy

The energy below which all states are filled with electrons and above which all the states are empty at $T=0K$.

(8) Effective mass

$$m^* = \left(\frac{1}{\hbar^2} \frac{d^2E}{dk^2} \right)^{-1}$$

$\frac{d^2E}{dk^2}$ of curve A > $\frac{d^2E}{dk^2}$ of curve B

⇒ m^* of curve A < m^* of curve B

So, B will have heavier effective mass.

(9)

$$E_V - E = \frac{K^2 \hbar^2}{2m}$$

$k = 0.08 (A^\circ)^{-1} = 0.08 \times 10^{10} = 8 \times 10^8 m.$

from curve A →

$$(0.025) \times (1.6 \times 10^{-19}) = \frac{(8 \times 10^8)^2 (1.054 \times 10^{-34})^2}{2m}$$

$$m = \frac{(8\times10^{8})^2(1.054\times10^{-34})^2}{2\times0.025\times1.6\times10^{-19}}$$

$$= \frac{7.1\times10^{-51}}{0.08\times10^{-19}} = 88.75\times10^{-32}$$

$$m = 8.88\times10^{-31}\,kg$$

$$\Rightarrow m/m_0 = \frac{8.8\times10^{-31}}{9.1\times10^{-31}} = 0.975.$$

for curve B →

$$(0.3)(1.6\times10^{-19}) = \frac{(8\times10^{8})^2(1.054\times10^{-34})^2}{2m}$$

$$m = \frac{(8\times10^{8})^2\,(1.054\times10^{-34})^2}{2\times0.3\times(1.6\times10^{-19})}.$$

$$= 7.4\times10^{-32}\,Kg.$$

$$\frac{m}{m_0} = \frac{7.4\times10^{-32}}{9.1\times10^{-31}} = 0.74.$$

(10) fermi energy level = 6.25 eV

T = ?

1% Probability ~~energy~~ level will not contain an $e^{\ominus}$ = $6.25-0.30 = 5.95$ eV

0.30 eV below fermi ~~f~~ energy level will not contain $e^{\ominus}$ ⇒

Probability that it will not contain $e^{\ominus}$ ⇒

$$1-f_F(E) = 1-\frac{1}{1+e^{\frac{E-E_f}{KT}}}.$$

$$0.01 = 1-\frac{1}{1+e^{(5.95-0.25)/KT}}$$

$$\frac{1}{1+e^{-0.3/KT}} = 0.99$$

$$1+e^{-\frac{0.3}{KT}} = 1/0.99$$

$$KT = 0.06529\,eV.$$

$$T = \frac{0.0652}{k}$$

$$T = 7\cancel{1}60K.$$

(11) $T = 300\,K$

$3KT$ above fermi energy

$$f_F(E) = \frac{1}{1+e^{\frac{E-E_F}{KT}}} = \frac{1}{1+e^{3KT/KT}}$$

$$f_F(E) = \frac{1}{1+20.09} = 0.04474$$

$$= 4.74\,\%.$$

(12) no. of Quantum states = ?

between E_c + $E_c - KT$ at $T = 300K$

Si →

$$g_c(E)\,dE = \frac{4\pi(2m_n^*)^{3/2}}{h^3} \int_{E_c}^{E_c+KT} \sqrt{E-E_c}\,dE$$

$$= \frac{4\pi(2m^*)^{3/2}}{h^3} \left(2/3\right)(E-E_c)^{3/2} \Big|_{E_c}^{E_c+KT} dE$$

(14) DOS per unit volume

$$\int_0^1 g(E)\,dE = \frac{4\pi(2m)^{3/2}}{h^3} \int_0^1 \sqrt{E}\,dE$$

$$N = \frac{4\pi(2m)^{3/2}}{h^3} \times 2/3\; E^{3/2}$$

$$N = 4.5 \times 10^{27}\,m^{-3}$$

$$N = 4.5 \times 10^{21} \text{ states/cm}^3.$$

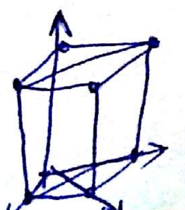
$$\Rightarrow N = 4.5 \times 10^{21}$$

(15) lattice constant = a

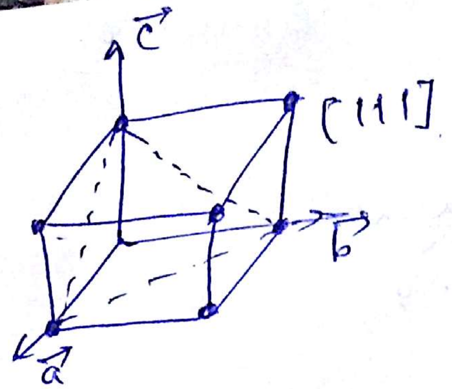
(i) 110
(ii) 111
(iii) 220
(iv) 321
(v) ~~E0~~ $\bar{1}00$
(vi) $\bar{1}11$.

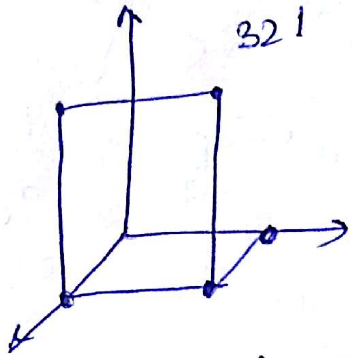
(16) [110] [111] [220] [321]

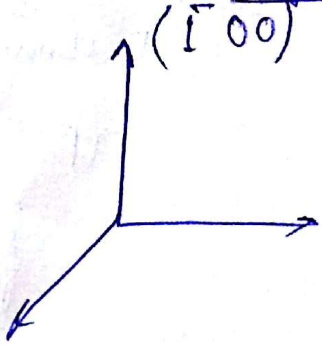
(1) [110]



P.T.O.







(17) Surface density of atoms (Si)

Surface density = No. of atom/lattice point ÷ Area of LP

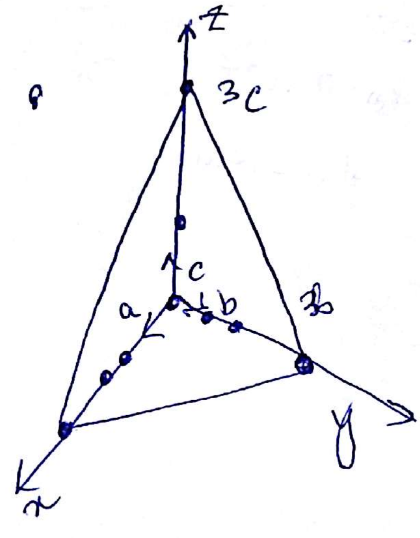
(a) (100) plane (b) (110) plane (c) (111) plane

(a) (100) plane ; $S\cdot D = \dfrac{2\text{ atoms}}{(5.43\times10^{-8})^2} = 6.78\times10^{14}\,cm^{-2}$.

(b) (110) plane ; $S\cdot D = \dfrac{4\text{ atom}}{\sqrt{2}\,(5.43\times10^{-8})^2} = 9.59\times10^{14}\,cm^{-2}$.

(c) (111) plane ; $S\cdot D = \dfrac{4\text{ atoms}}{\sqrt{3}\,(5.43\times10^{-8})^2} = 7.83\times10^{14}\,cm^{-2}$.

(18)



(a) Miller indices :- [3, 3, 3]

(b) Miller indices = [3, 2, 2].

Scanned by CamScanner