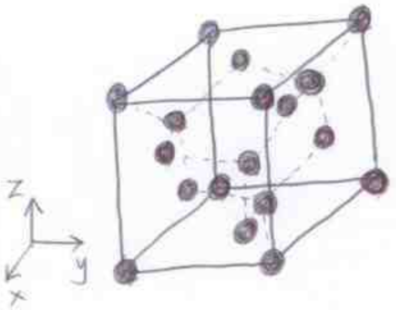
Homework ※5. Solution

1. Si structure = FCC + 1/2 tetrahedral site (총 8개 중 4개)
(inversely occupied)




(000, 100, 010, 001
110, 101, 011, 111
$\frac{1}{2}\frac{1}{2}0$, $0\frac{1}{2}\frac{1}{2}$, $\frac{1}{2}0\frac{1}{2}$, $\frac{1}{2}\frac{1}{2}1$
$1\frac{1}{2}\frac{1}{2}$, $\frac{1}{2}1\frac{1}{2}$, $\frac{1}{4}\frac{1}{4}\frac{1}{4}$, $\frac{3}{4}\frac{3}{4}\frac{1}{4}$
$\frac{3}{4}\frac{1}{4}\frac{3}{4}$, $\frac{1}{4}\frac{3}{4}\frac{3}{4}$

* $a_{Si} = 5.431\ \text{Å}$

cell 당 atom 수 = 8

∴ density (atoms/cm³)

$$= 8 \times \frac{1}{(5.431 \times 10^{-10})^3}$$

$$= \underline{4.994 \times 10^{22}/cm^3}$$

Textbook (6.4 & 8.2 참조할것)

2. $dN^* = N(E)\,dE$

$$N(E) = 2Z(E)\cdot F(E)$$

$$Z(E) = \frac{V}{4\pi^2}\left(\frac{2m}{\hbar^2}\right)^{3/2} E^{1/2}$$

$$F(E) = \frac{1}{\exp\left(\frac{E-E_F}{k_B T}\right)+1} \simeq \exp\left[-\left(\frac{E-E_F}{k_B T}\right)\right]$$

$(\because E-E_F \doteq 0.5\,eV,\quad k_B T = 10^{-2}\,eV \text{ at } T_{room})$

$$N^* = \frac{V}{2\pi^2}\left(\frac{2m}{\hbar^2}\right)^{3/2}\int_0^\infty E^{1/2}\exp\left[-\frac{E-E_F}{k_B T}\right]dE$$

$$= \frac{V}{2\pi^2}\cdot\left(\frac{2m}{\hbar^2}\right)^{3/2}\exp\left(\frac{E_F}{k_B T}\right)\int_0^\infty E^{1/2}\exp\left(-\left(\frac{E}{k_B T}\right)\right)dE$$

$$\left(\because \int_0^\infty x^{1/2} e^{-nx}dx = \left(\frac{1}{2n}\right)\sqrt{\frac{\pi}{n}}\right)$$

$$N^* = \frac{V}{2\pi^2}\left(\frac{2m}{\hbar^2}\right)^{3/2}\exp\left(\frac{E_F}{k_B T}\right)\cdot\frac{k_B T}{2}(\pi k_B T)^{1/2}$$

$$= \frac{V}{4}\cdot\left(\frac{2mk_B T}{\pi\hbar^2}\right)^{3/2}\exp\left(\frac{E}{k_B T}\right)$$

$$\left(\because E_F = -\frac{E_g}{2},\ m_e^*/m_0 \text{ relation},\ N_e = N^*/V\right)$$

$$N_e = \frac{1}{4}\left(\frac{2mk_B}{\pi\hbar^2}\right)^{3/2}\left(\frac{m_e^*}{m_o}\right)^{3/2} T^{3/2} \exp\left[-\frac{E_g}{2k_BT}\right]$$

$$\frac{1}{4}\left(\frac{2mk_B}{\pi\hbar^2}\right)^{3/2} \fallingdotseq 4.84\times10^{15} \quad (cm^{-3}\cdot k^{-3/2})$$

$$\therefore N_e = 4.84\times10^{15} \left(\frac{m_e^*}{m_o}\right)^{3/2} T^{3/2} \exp\left[-\frac{E_g}{2k_BT}\right]$$

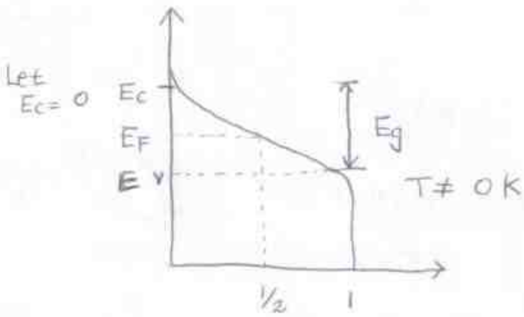
4. $N_e = 4.84 \times 10^{15} \left(\frac{m_e^*}{m_0}\right)^{3/2} T^{3/2} \exp\left[-\left(\frac{E_g}{2k_B T}\right)\right]$

$\frac{m_e^*}{m_0} = 1$, $E_{g,300K} = 1.12\,eV$, $k_B = 8.616 \times 10^{-5}\,eV/k$

$\therefore N_e = 4.84 \times 10^{15} (300)^{3/2} \cdot \exp\left(-\frac{1.12}{2 \times 8.616 \times 10^{-5} \times 300}\right)$

$= \underline{9.81 \times 10^{9}\ /cm^3}$

5.




Let $E_c = 0$ $\quad E_v = -E_g$.

$$F(E) = \frac{1}{\exp\left(\frac{E-E_F}{k_B T}\right)+1}$$

$$F(E_v) + F(E_c) = 1 = \frac{1}{\exp\left(\frac{E_v-E_F}{k_B T}\right)+1} + \frac{1}{\exp\left(\frac{E_c-E_F}{k_B T}\right)+1}$$

$$= \frac{1}{\exp\left(\frac{-E_g-E_F}{k_B T}\right)+1} + \frac{1}{\exp\left(\frac{-E_F}{k_B T}\right)+1}$$

$$\exp\left(\frac{-E_g-E_F}{k_B T}\right) \cancel{+1} = \cancel{1} + \frac{\exp\left(-\frac{E_g+E_F}{k_B T}\right)+1}{\exp\left(-\frac{E_F}{k_B T}\right)+1}$$

$$\exp\left(\frac{-E_g-2E_F}{k_B T}\right) + \cancel{\exp\left(\frac{-E_g-E_F}{k_B T}\right)} = \cancel{\exp\left(-\frac{E_g+E_F}{k_B T}\right)} + 1$$

$$E_g + 2E_F = 0$$

$$\boxed{\therefore E_F = -\frac{1}{2} E_g}$$

6. $N_e = 4.84 \times 10^{15} \left(\frac{m_e^*}{m_0}\right)^{3/2} T^{3/2} \exp\left(-\frac{E_g}{2k_B T}\right)$

$N_e = 10^{22}\ /cm^3$ , $E_g = 1eV$ , $k_B = 8.616 \times 10^{-5} eV/k$

$\frac{m_e^*}{m_0} = 1$

by using calculator ; $\underline{T = 19735.13K}$

7. Eq.(8.14)

$$\sigma = \underset{\sim\sim\sim\sim}{4.84 \times 10^{15} \left(\frac{m^*}{m_0}\right)^{3/2}} T^{3/2} e \underset{\sim\sim\sim}{(\mu_e + \mu_h)} \exp\left(-\frac{E_g}{2k_B T}\right)$$

$$= A T^{3/2} \exp\left(-\frac{E_g}{2k_B T}\right)$$

$$\left(\begin{array}{l} \sigma = 1 , \quad 1/T = 0.8 \times 10^{-2} \\ \sigma = 10 , \quad 1/T = 0.7 \times 10^{-2} \end{array}\right.$$ 대입.

$$1 = A \left(1/_{0.8\times10^{-2}}\right)^{3/2} \cdot \exp\left(-\frac{E_g}{2k_B} \cdot 0.8\times10^{-2}\right) \cdots ①$$

$$10 = A \left(1/_{0.7\times10^{-2}}\right)^{3/2} \cdot \exp\left(-\frac{E_g}{2k_B} \cdot 0.007\right) \cdots ②$$

$$①/② \quad \left(\frac{7}{8}\right)^{3/2} \exp\left(\frac{E_g}{2k_B}(0.007 - 0.008)\right) = \frac{1}{10}$$

$$\therefore E_g = \frac{2 \times 8.616 \times 10^{-5}}{0.007 - 0.008} \ln\left(\frac{1}{10} \cdot \left(\frac{8}{7}\right)^{3/2}\right) = 0.362eV$$

8.

$\sigma = N_{de} \cdot \mu_e \cdot e$

$= 5 \times 10^{16}\ atoms/cm^3 \times e \times 0.39\ m^2/V \cdot s$

$= 3.12 \times 10^{-3}\ electrons/cm^3 \cdot C \cdot m^2/V \cdot s$

$= \underline{31.2\ (\Omega \cdot cm)^{-1}}$

$$\frac{N^*}{V} = \frac{1}{4}\left(\frac{2mk_BT}{\pi\hbar^2}\right)^{3/2} \exp\left(\frac{E_F}{k_BT}\right)$$

$$= 5\times10^{22}/m^3 \qquad \left(\begin{matrix} m_e = 9.11\times10^{-31}\,kg & T = 298k \\ k_B = 1.381\times10^{-23}\,J/k & \hbar = 1.054\times10^{-34}\,J\cdot s \end{matrix}\right)$$

$$\therefore E_F = -0.1595\,eV$$

9. (a) at 300k 대부분의 donor 전자가 excited 된다.
(상온이상)

$N_e = 10^{13}$ electrons / $cm^3$

(b) $N_e = 4.84\times10^{15}\left(\frac{m_e^*}{m_0}\right)^{3/2}\cdot T^{3/2}\cdot \exp\left(-\frac{E_g}{2k_BT}\right)$

$\frac{m_e^*}{m_0} = 1$, $T = 300k$, $k_B = 8.616\times10^{-5}\,eV/k$, $E_g = 1eV$

$N_e = 9.9907\times10^{10}$ electrons / $cm^3$

(c) extrinsic electron의 기여가 100 배정도 크다.

10. $$E = \frac{m^*e^4}{2(4\pi\varepsilon_0\cdot\hbar)^2\cdot\varepsilon^2} = \frac{0.8\times9.11\times10^{-31}\times(1.602\times10^{-19})^4}{2\times(4\pi\times8.854\times10^{-12}\times6.582\times10^{-16})^2\times16^2}$$

$$= 0.0425\,eV$$

$$= 42.5\,meV$$

이는 n-type Si 의 Ionization E와 비슷하다.

Si (Donor

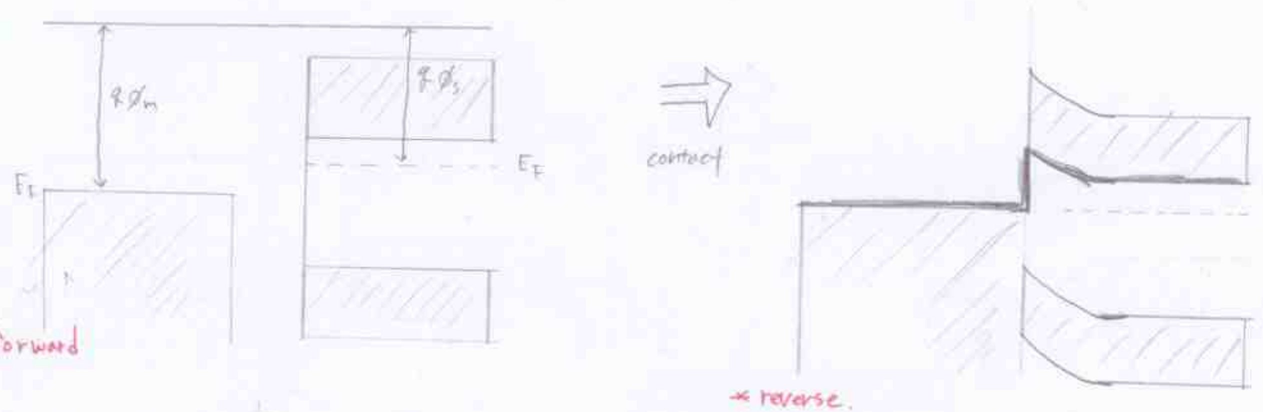
| | | |
|---|---|---|
| Sb | : | 0.039eV |
| P | : | 0.045eV |
| As | : | 0.054eV |

∴ 가정이 resonable 함을 알 수 있다.

답안을 잘 작성해준 학생의 모범 답안입니다.

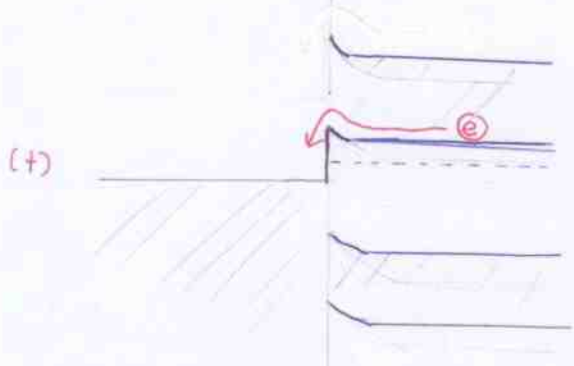
* 3

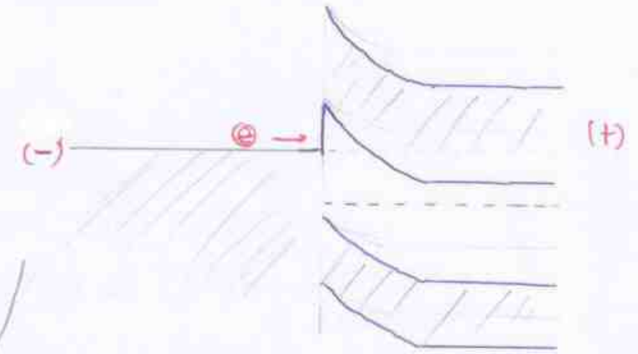
(a) N-type , $q\phi_m > q\phi_s$

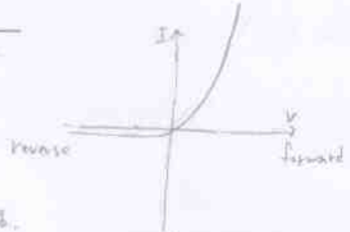



* forward

* reverse.




· V의 크기가 클수록 depletion width 및 potential barrier 감소

· 전자의 diffusion current (semi-conductor → metal) 우세.

- rectifying contact.

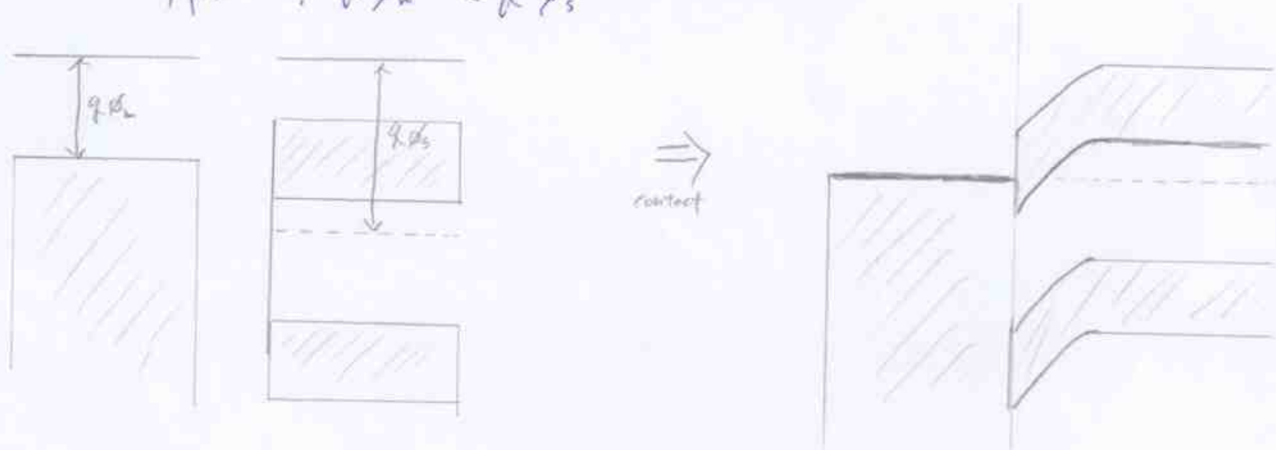
(reverse 전압은 전기가 거의 흐르지 않고 forward면 빠르게 흐르므로!)

V의 크기가 클수록 depletion width 및 potential barrier 증가.

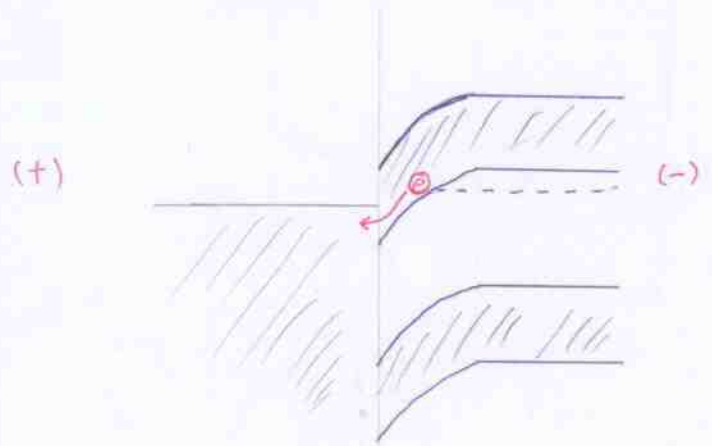
· 전자의 diffusion current 감소. (약해짐)

· 약간의 drift current 만이 존재

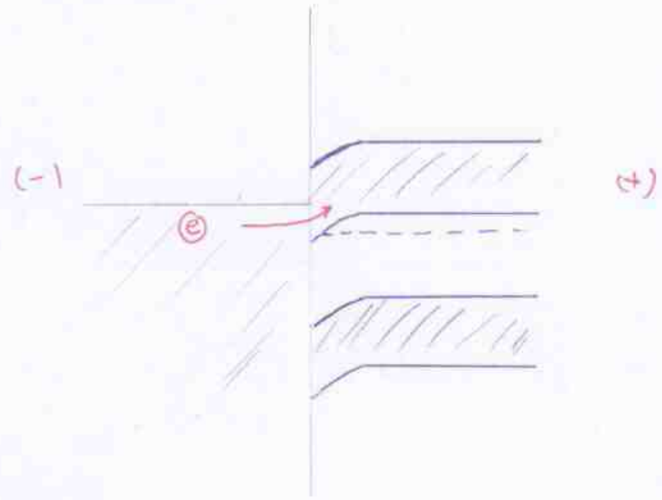
(b) N-type , $q\phi_m < q\phi_s$

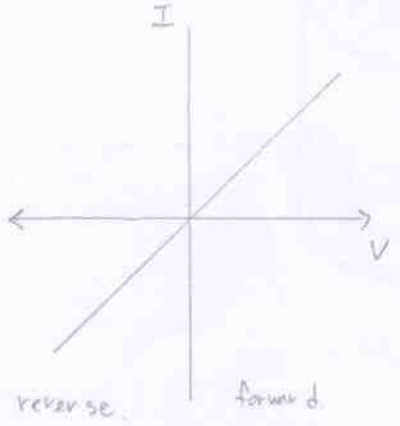


* forward




* reversed



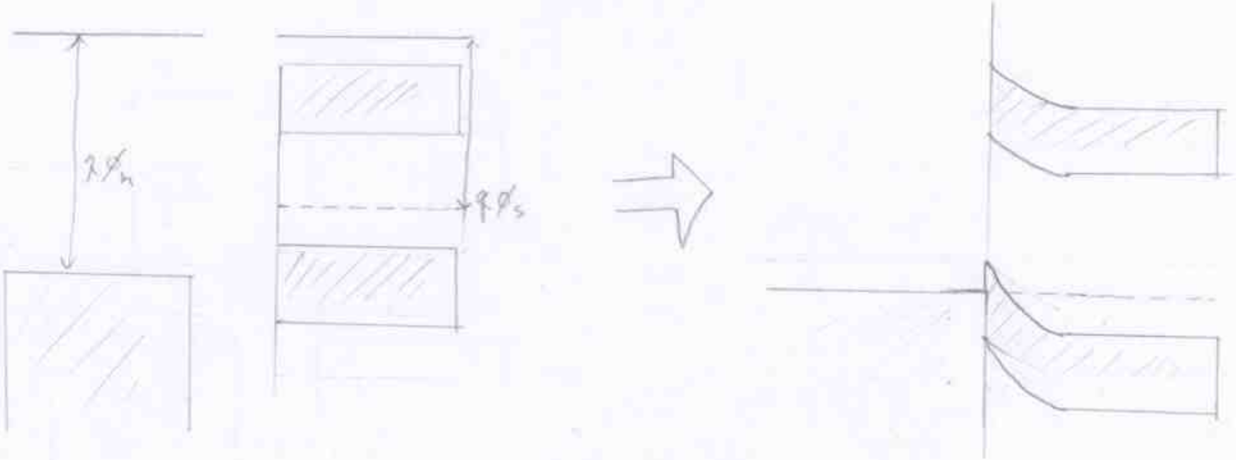

외부에서 걸어준 전압이 증가함에 따라

linearly 전류도 증가 ( ohm's law)

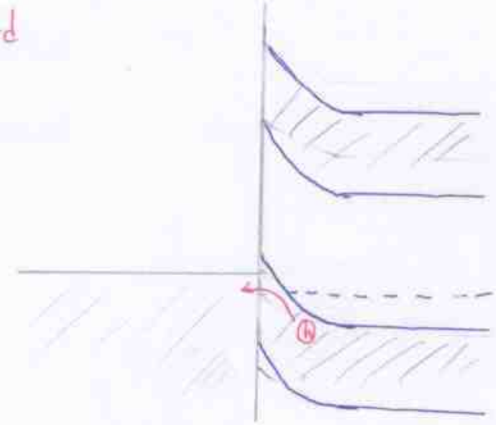
forward 및 reverse 모두 전류가 잘 흐른다
(전자가 major charge carrier)

∴ ohmic contact.

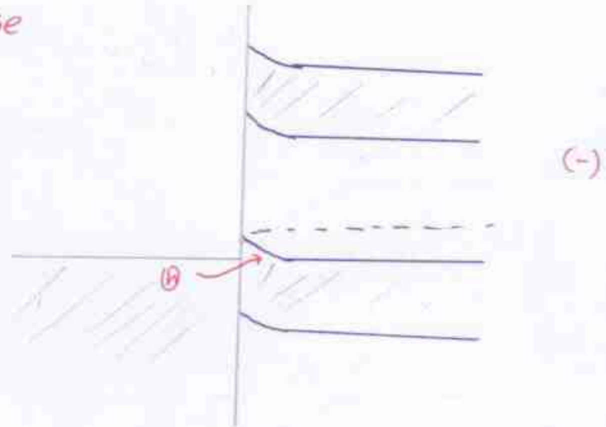
(c) P - type , $q\phi_m > q\phi_s$

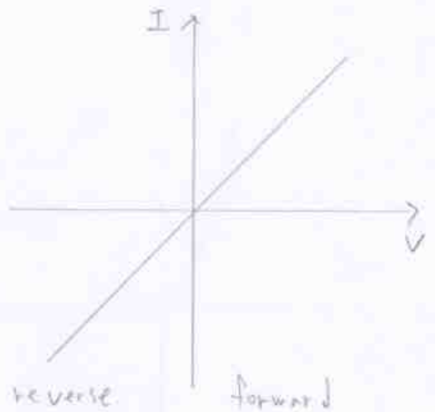



* forward




* reverse

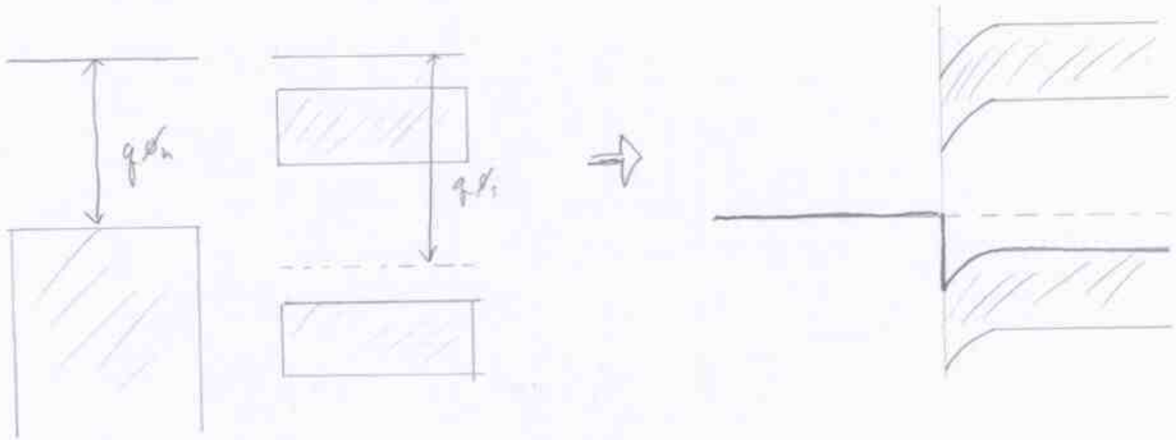



hole이 major charge carrier로서
forward 와 reverse 모두 전류가 잘 흐른다.

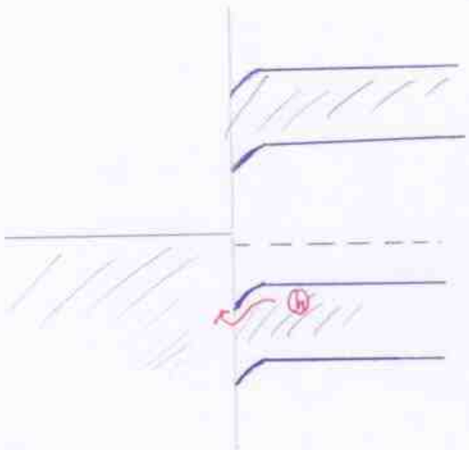
∴ ohmic contact.

(d) p-type , $q\phi_m < q\phi_s$




× forward

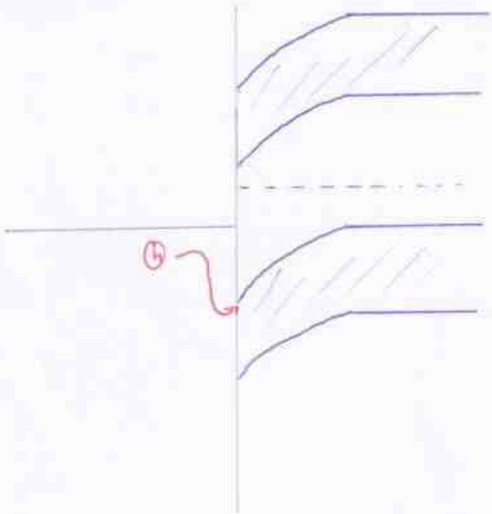
(-)




(+)

× reverse

(+)

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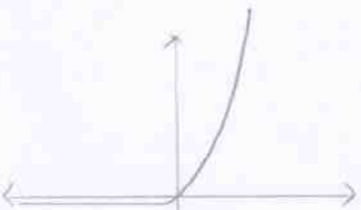

reverse forward

· hole이 major charge carrier

· forward bias 인 경우, 전압의 크기가 증가할수록 charge barrier가 감소하고 depletion width도 감소하므로 hole의 이동이 쉬워져서 흐르는 전류의 세기 증가.

· reverse bias 인 경우 charge barrier가 있으므로 diffusion current가 미미함

∴ rectifying contact.