

1. 电子带: $E = \frac{\hbar^2}{2} \left(\frac{k_x^2 + k_y^2}{m_e^*} + \frac{k_z^2}{m_z^*} \right) + E_c$

在 E 到 $E+dE$ 对应的等能面所包围的体积为

$$\frac{4}{3} \pi \cdot \left(\frac{2}{\hbar^2} m_e^* m_z^* \right)^{\frac{3}{2}} (E - E_c)^{\frac{3}{2}} = (E - E_c)^{\frac{3}{2}}$$

$$= \frac{4}{3} \pi \cdot 2 \sqrt{\frac{2}{\hbar^2} m_e^* m_z^*} (E - E_c) \cdot dE$$

$$\therefore \frac{dN}{dE} = \frac{2V}{(2\pi)^3} \cdot 2 \sqrt{\frac{2}{\hbar^2} m_e^* m_z^*} (E - E_c)$$

$$= \frac{V}{2\pi^2} \frac{2^{\frac{3}{2}} (m_e^* m_z^*)^{\frac{1}{2}}}{\hbar^3} \sqrt{E - E_c}$$

硅有 4 个相同导带底, 则

$$g(E) = \frac{2V}{\pi^2} \frac{2^{\frac{3}{2}} (m_e^* m_z^*)^{\frac{1}{2}}}{\hbar^3} \sqrt{E - E_c}$$

$$g(E) = \frac{V}{\pi^2} \frac{2^{\frac{5}{2}} (m_e^* m_z^*)^{\frac{1}{2}}}{\hbar^3} \sqrt{E - E_c}$$

价带: $E = E_v - \frac{\hbar^2}{2} (k_x^2 + k_y^2 + k_z^2)$

价带: $E = E_v - \frac{\hbar^2 k^2}{2m_p^*}$ (轻空穴带)

$$E = E_v - \frac{\hbar^2 k^2}{2m_{ph}^*}$$
 (重空穴带)

② 直接有 $g(E) = \frac{V}{2\pi^2} \frac{(2m_{pc}^*)^{\frac{3}{2}} + (2m_{ph}^*)^{\frac{3}{2}}}{\hbar^3} \sqrt{E_v - E}$

2. 使用非简并条件.

$$f(E_D) = g_D e^{-\frac{E_D - E_F}{k_B T}}$$

$$(1 - f(E_A)) = g_A e^{-\frac{E_F - E_A}{k_B T}}$$

受主能级电子数 $n = N_D g_D e^{-\frac{E_D - E_F}{k_B T}}$

受主能级空穴数 $p = N_A g_A e^{-\frac{E_F - E_A}{k_B T}}$

$$n = p = \sqrt{n_i^2} = \sqrt{N_A N_D g_D g_A} e^{-\frac{E_F - E_A}{k_B T}}$$

$$n = 2\sqrt{2} N_A e^{-\frac{E_F - E_A}{2k_B T}}$$

3. 300 K 时 $k_B T = 26 \text{ meV}$

$n_D = p_A = 5.6 \times 10^{-17}$, 即补偿率为 99.9...95%

(总共 16 个 9)

如果需要补偿率 99%, 即 $n_D = p_A = 0.01$, 此时 $T \sim 2085 \text{ K}$

说明通常情况下都能补偿

4. 设掺入磷的浓度为 N_D

$$p = \frac{n_i^2}{n} = \frac{A(1.7 \times 10^{13})^2}{10^{17}} \ll n$$

\therefore 处于低温施主激发区, 掺杂浓度 $N_D > 10^{17}$

$$n = \frac{N_D}{N_A} e^{\frac{E_C - E_D}{k_B T}} \approx 1$$

\therefore 处于强电离区, 中间电离区

$$n = \left(\frac{N_D N_A}{g_D} \right)^{\frac{1}{2}} e^{-\frac{E_C - E_D}{2k_B T}} = 10^{17}$$

得 $N_D =$

$$n = \frac{N_D}{2g_D} e^{-\frac{E_C - E_D}{k_B T}} \left(\sqrt{1 + \frac{4g_D N_D}{N_A}} e^{\frac{E_C - E_D}{2k_B T}} - 1 \right)$$

$$\text{得 } N_D = 4.03 \times 10^{17} \text{ cm}^{-3}$$

5. $\because p < n_i \ll N_A$

\therefore 三个温度都处于低温施主激发区

$$p = \frac{N_V}{2g_A} e^{-\frac{E_A - E_V}{k_B T}} \left(\sqrt{1 + \frac{4g_A N_A}{N_V}} e^{\frac{E_A - E_V}{2k_B T}} - 1 \right) \quad 1.02 \times 10^{10}$$

$$T = 300 \text{ K 时, } N_V = 2.5 \times 10^{19} \text{ cm}^{-3}, E_g = 1.12 \text{ eV}, N_i = 1.02 \times 10^{10} \text{ cm}^{-3}$$

$$\text{得 } p = 2.5 \times 10^{14} \text{ cm}^{-3} \quad 9.97 \times 10^{14}$$

$$n = \frac{n_i^2}{p} = 4.16 \times 10^{15} \text{ cm}^{-3}$$

$\therefore p \approx N_A$ 处于强电离区

$$T = 50 \text{ K 时, } N_V = \left(\frac{50}{300} \right)^{\frac{3}{2}} \times 1.1 \times 10^{19} = 7.48 \times 10^{17} \text{ cm}^{-3}$$

$$n_i = \left(\frac{50}{300} \right)^{\frac{3}{2}} \cdot \frac{e^{-\frac{E_g}{2k_B \cdot 50}}}{e^{-\frac{E_g}{2k_B \cdot 300}}} \times 1.02 \times 10^{10} \approx 0$$

$$\text{得 } p = 1.06 \times 10^{14} \text{ cm}^{-3} \quad 4.18 \times 10^{13} \text{ cm}^{-3}$$

$$n = \frac{n_i^2}{p} = 0$$

$$\therefore \frac{4g_A N_A}{N_V} e^{-\frac{E_A - E_V}{k_B T}} \gg 1 \quad \text{为弱电离区}$$

$$T = 350 \text{ K 时, } n_i = \left(\frac{350}{300} \right)^{\frac{3}{2}} \cdot \frac{e^{-\frac{E_g}{2k_B \cdot 350}}}{e^{-\frac{E_g}{2k_B \cdot 300}}} \times 1.02 \times 10^{10} \approx 2.58 \times 10^{10} \text{ cm}^{-3}$$

$$N_V = \left(\frac{350}{300} \right)^{\frac{3}{2}} \times 1.1 \times 10^{19} = 1.39 \times 10^{19} \text{ cm}^{-3}$$

$$\text{得 } p = 9.99 \times 10^{14} \text{ cm}^{-3} \approx 10^{15} = N_A$$

处于强电离区

$$n = \frac{n_i^2}{p} = 4.94 \times 10^6 \text{ cm}^{-3} \quad 6.7 \times 10^7 \text{ cm}^{-3}$$

8. 上正下负时 载流子^{*} 为空气

$$\eta = \frac{JB}{Eq}$$

$$= \frac{\frac{1}{3}B}{\frac{1}{2} \cdot q}$$

$$= \frac{JB}{uq} \cdot \frac{d}{s}$$

$$= \frac{1 \times 10^{-3} \times 2000 \times 10^{-4}}{1.6 \times 10^{-3} \cdot 1.6 \times 10^{-19}} \times \frac{1}{200 \times 10^{-6}}$$

$$= 3.9 \times 10^{11} \text{ m}^{-3}$$

7. 本征半导体费米能级 $E_F = \frac{E_v + E_c}{2} - \frac{1}{2} k_B T \ln \frac{N_c}{N_v} = \frac{1}{2} (E_c + E_v) + 0.031 \text{ eV}$

P型 \because 在 300K T. As & GaAs 处于强电离区

\therefore P型 GaAs $E_F = E_v + k_B T \ln \frac{N_v}{N_A} = E_v + 0.17 \text{ eV}$

N型 GaAs $E_F = E_c - k_B T \ln \frac{N_c}{N_D} = E_c - 0.099 \text{ eV}$