ZZV

VJ.1. silicij.

$T = 300K \rightarrow p = 5 \cdot 10^{15} cm^{-3} = N_A$

↳ $T_1 = 300K$ i $T_2 = 350K$ $n, p = ?$

$n_i = 1.45 \cdot 10^{10} cm^{-3}$ poluvodič tipa p jer je

$N_A = p >> n_i$

$p \approx N_A = 5 \cdot 10^{15} cm^{-3}$

$n = \frac{n_i^2}{p} = 4.2 \cdot 10^{4} cm^{-3}$ ✓

za $T_2 = 550K$

$n_{i2} = C_1 T_2^{\frac{3}{2}} e^{-\frac{E_{G0}}{2kT}} = 1.32 \cdot 10^{15} cm^{-3}$ ✓

$p = \frac{N_A + \sqrt{N_A^2 + 4n_{i2}^2}}{2} = 5.32 \cdot 10^{15} cm^{-3}$ ✓

$n = \frac{n_i^2}{p} = 3.27 \cdot 10^{14} cm^{-3}$

VJ2. $T = 350K$ $N_A = 10^7 cm^{-3}$

↳ $n, p = ?$ $T_1 = 350K$ $T_2 = 550K$

za $T_1 = 350K$

$n_{i1} = 4.96 \cdot 10^{11} cm^{-3}$ poluvodič je tipa n

$n = \frac{n_{i1}^2}{p} = 2.46 \cdot 10^{16} cm^{-3}$ $p = 1 \cdot 10^7 cm^{-3}$

za $T_2 = 550K$

$n_{i2} = 1.318 \cdot 10^{15} cm^{-3}$

$n = 2.46 \cdot 10^{16} cm^{-3}$

poluvodič je tipa n

$p = \frac{n_{i2}^2}{n} = 7.07 \cdot 10^{13} cm^{-3}$

VJ3. $T = 500K \quad p = 1 \cdot 10^{15} = N_A$

↳ $T_1 = 300K$ i $T_2 = 500K$

za $T_2 = 500K$ poluvodič je tipa p

$n_{i2} = 3.228 \cdot 10^{14} cm^{-3}$ $N_A > n_{i2}$ $p = 1 \cdot 10^{15}$

$p = \frac{N_A + \sqrt{N_A^2 + 4n_i^2}}{2} = 1.09 \cdot 10^{15} cm^{-3}$

$n = \frac{n_{i2}^2}{p} = 1.04 \cdot 10^{14} cm^{-3}$

za $T_1 = 300K$

$n_{i1} = 1.45 \cdot 10^{10} cm^{-3}$ $N_A > n_{i1}$ poluvodič tipa p

$p = 1 \cdot 10^{15}$ $n = \frac{n_{i1}^2}{p} = 2.1 \cdot 10^{5} cm^{-3}$

VJ4. $T = 450K \Rightarrow N_D = 1 \cdot 10^{12} cm^{-3}$

↳ $T_1 = 300K$ i $T_2 = 450K$ $(n, p) = ?$

za $T_2 = 450K$

$n_{i2} = 5.92 \cdot 10^{13}$ $N_D < n_{i2}$ što znači da je ovo poluvodič tipa p

$p = \frac{n_{i2}^2}{n} = 3.5 \cdot 10^{15} cm^{-3}$ $n = 1 \cdot 10^{12} cm^{-3}$

za $T_1 = 300K$

$n_{i1} = 1.45 \cdot 10^{10} cm^{-3}$ $p = 3.5 \cdot 10^{15} cm^{-3}$

$n = \frac{n_{i1}^2}{p} = 6 \cdot 10^{4} cm^{-3}$

V15. $T = 450K$ $n = 10^{11} cm^{-3} = N_D$

tip poluvodiča je P

$n_i = C_1 T^{\frac{3}{2}} e^{-\frac{E_{G0}}{2E_T}} = 5.92 \cdot 10^{13} cm^{-3}$

dodana prinjesa $N_A = 3.5 \cdot 10^{16} cm^{-3}$ AKCEPTOR

$p = \frac{n_i^2}{n^2} = 3.5 \cdot 10^{16}$

V16. $T = 350K$ $n = 10^{17} cm^{-3} = N_D$

tip i konc. dodane prinjese

$n_i < N_D$ - donor

$n_i = C_1 T^{\frac{3}{2}} e^{-\frac{E_{G0}}{2E_T}} = 4.963 \cdot 10^{11} cm^{-3}$

$p = \frac{n_i^2}{n} = 2.46 \cdot 10^{6} cm^{-3}$

dodana je prinjesa DONOR $N_D = 1 \cdot 10^{17} cm^{-3}$

V17. $T = 200°C = 473K$ $p = 10^{13} cm^{-3}$

$n_i = C_1 T e^{-\frac{E_{G0}}{E_T 2}} = 1.35 \cdot 10^{14} cm^{-3}$

$n = \frac{n_i^2}{p} = 1.82 \cdot 10^{15} cm^{-3}$

dodana prinjesa je donor $N_D = 1.82 \cdot 10^{15} cm^{-3}$

VJ8. $N_A = 10^{15} cm^{-3}$ i $N_D = 1.25 \cdot 10^{15} cm$

$N_D > N_A$ $N_D - N_A = 2.5 \cdot 10^{14}$

n, p na $T_1 = 300K$ i $T_2 = 473K$

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za $T_1 = 300K$

$N_D - N_A = 2.5 \cdot 10^{14} cm^{-3}$

n-tip poluvodiča

$n_{i_1} = 1.45 \cdot 10^{10} cm^{-3}$

$(N_D - N_A) \gg n_{i_1}$

$n = (N_D - N_A) = 2.5 \cdot 10^{14} cm^{-3}$

$$p = \frac{n_{i_1}^2}{n} = 8.4 \cdot 10^{5} cm^{-3}$$

za $T_2 = 473K$

$(N_D - N_A) = 2.5 \cdot 10^{14} cm^{-3}$

$n_{i_2} = 1.35 \cdot 10^{14} cm^{-3}$

$$n = \frac{(N_D - N_A) + \sqrt{(N_D - N_A)^2 + 4 n_{i_2}^2}}{2} = 3.089 \cdot 10^{14} cm^{-3}$$

$$p = \frac{n_{i_2}^2}{n} = 5.9 \cdot 10^{13} cm^{-3}$$

VJ9. $N_A = 1.5 \cdot 10^{15}\,cm^{-3}$

$N_D = 1 \cdot 10^{15}\,cm^{-3}$

$n, p = ?$ $T_1 = 300K$ $T_2 = 450K$

za $T_1 = 300K$

$N_A - N_D = 5 \cdot 10^{14}\,cm^{-3}$

$n_{i1} = 1.45 \cdot 10^{10}\,cm^{-3}$

p-tip poluvodiča

$(N_A - N_D) \gg n_{i1}$ $\boxed{p = 5 \cdot 10^{14}\,cm^{-3}}$

$$\boxed{n = \frac{n_{i1}^2}{p} = 4.2 \cdot 10^5\,cm^{-3}}$$

za $T_2 = 450K$

$N_A - N_D = 5 \cdot 10^{14}\,cm^{-3}$

$n_{i2} = 5.92 \cdot 10^{13}\,cm^{-3}$

p-tip poluvodiča

$$p = \frac{(N_A - N_D) + \sqrt{(N_A - N_D)^2 + 4n_{i2}^2}}{2} = 5.07 \cdot 10^{14}\,cm^{-3}$$

$$\boxed{n = \frac{n_{i2}^2}{p} = 6.91 \cdot 10^{12}\,cm^{-3}}$$

VJ10. $T = 300K$ $n = 5 \cdot 10^7\,cm^{-3}$

$\hookrightarrow T = 450K \Rightarrow n = 5 \cdot 10^7\,cm^{-3}$

poluvodič je tipa p

$n_i = 1.45 \cdot 10^{10}\,cm^{-3}$

$$p_2 = \frac{n_i^2}{n} = 4.2 \cdot 10^{12}\,cm^{-3}$$

za $T_2 = 450K$

$n_i = 5.92 \cdot 10^{13}\,cm^{-3}$ $n = 5 \cdot 10^7$

$$p_1 = \frac{n_i^2}{n} = 7.00 \cdot 10^{13}\,cm^{-3}$$

trebamo dodati akceptore

$$\boxed{N_A = p_2 - p_1 = 6.99 \cdot 10^{13}\,cm^{-3}}$$

VJ.11. silicij

$T_1 = 300K \quad p = 10^{15} cm^{-3}$

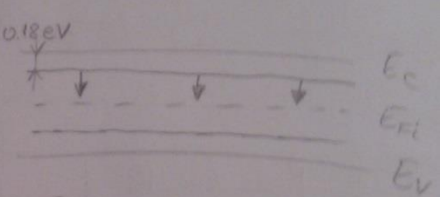
↳ $T_2 = 550K \Rightarrow p = 10^{15} cm^{-3}$

$n_{i1} = 1.43 \cdot 10^{10} cm^{-3}$ $\qquad$ $n_{i2} = 1.318 \cdot 10^{15} cm^{-3}$

$n_1 = \frac{n_{i1}^2}{p} = 2.1 \cdot 10^5 cm^{-3}$ $\qquad$ $n_2 = \frac{n_{i2}^2}{p} = 1.74 \cdot 10^{15}$

$\Delta N_D = n_2 - n_1 = 1.74 \cdot 10^{15}$

VJ12. $E_F = E_c - 0.18 eV$ $\quad T = 300K$



$E_F = \frac{E_c + E_v}{2} = E_c - \frac{E_G}{2} = E_c - \frac{1.12}{2} = E_c - 0.56 eV$

tip prinjese je donor N_D

$N_c = 3.67 \cdot 10^{19} cm^{-3}$

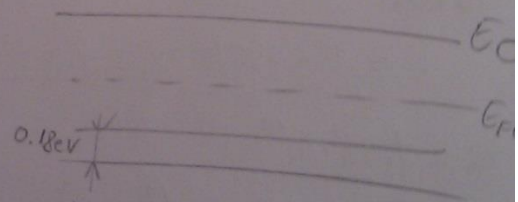
$n = N_c e^{\frac{E_F - E_c}{E_T}} = 3.67 \cdot 10^{19} e^{\frac{-0.18 \cdot 11600}{300}} = 3.48 \cdot 10^{16}$

$\boxed{N_D = 3.48 \cdot 10^{16} cm^{-3}}$

da bude $E_F = E_v + 0.18 eV$ novi položaj

$p = N_v e^{\frac{E_v - E_F}{E_T}}$

$p = 3.67 \cdot 10^{19} \cdot e^{\frac{-0.18 \cdot 116}{3}} = 3.483 \cdot 10^{16}$



no trebaro eliminirati donore N_D pa će ukupno akceptora N_A biti podrebno da bi se došlo u stanje $E_F = E_v + 0.18 eV$

$N_A = N_D + p = 6.966 \cdot 10^{16} cm^{-3}$

VJ.13. $T = 27°C = 300K$

↳ $n = 10^{15}\,cm^{-3} = N_D$

$\sigma = ?$ na $T_2 = 250°C = 523K$ $\quad \mu_{n2} = 450 \frac{cm^2}{Vs}$ $\quad \mu_{p2} = 220 \frac{cm^2}{Vs}$

$n_i = 1.45 \cdot 10^{10}\,cm^{-3}$ $\quad p = \frac{n_i^2}{n} = 2.1 \cdot 10^5\,cm^{-3}$

$\sigma = q(n\mu_{2n} + p\mu_{2p})$

$n_{i2} = 6.377 \cdot 10^{14}$ $\quad n = \frac{N_D + \sqrt{N_D^2 + 4n_{i2}^2}}{2} = 1.31 \cdot 10^{15}\,cm^{-3}$

$p = \frac{n_{i2}^2}{n} = 3.1 \cdot 10^{14}\,cm^{-3}$

$\sigma = 1.609 \cdot 10^{-19} \cdot (1.31 \cdot 10^{15} \cdot 450 + 3.1 \cdot 10^{14} \cdot 220) = 0.1058 \frac{S}{cm}$

VJ14. $T_1 = 300K$

$n = 1 \cdot 10^{-4}\,cm^{-3} = N_D$

↳ $\sigma = ?$ na $T_2 = 400K$ $\quad \mu_{n2} = 800 \frac{cm^2}{Vs}$ $\quad \mu_{p2} = 320 \frac{cm^2}{Vs}$

$n_{i1} = 1.45 \cdot 10^{10}\,cm^{-3}$ $\quad p = \frac{n_{i2}^2}{n} = 2.1 \cdot 10^{16}\,cm^{-3}$

$n_{i2} = 7.22 \cdot 10^{12}\,cm^{-3}$ $\quad N_D > n_{i2}$ $\quad \boxed{p = 2.1 \cdot 10^{16}\,cm^{-3}}$

$n = \frac{n_{i2}^2}{p} = 2.4 \cdot 10^{9}\,cm^{-3}$

$\sigma = q(\mu_n n + \mu_p \cdot p)$ $\quad p << n$

$\sigma = q(\mu_p \cdot p) = 1.08 \frac{S}{cm}$

VJ 15. $T_1 = 525K \Rightarrow n = N_D = 10 N_p = 10p$

$\sigma = ?$ na $T_2 = 300K$ $\mu_{n_2} = 900 \frac{cm^2}{Vs}$ $\mu_{p_2} = 350 \frac{cm^2}{Vs}$

$n_{i_1} = 6.74 \cdot 10^{14} cm^{-3}$ $p = \frac{n_{i_1}^2}{n} = \frac{n_{i_1}^2}{10p}$

$\frac{n}{10} = \frac{n_{i_1}^2}{n} \Rightarrow n^2 = 10 n_{i_1}^2$

za T_2 $n = 2.13 \cdot 10^{15}$

$n = N_D >> n_{i_2} \Rightarrow N_D = n$

$n_{i_2} = 1.45 \cdot 10^{10} cm^{-3}$

$p = \frac{n_{i_2}^2}{n} = 9.8 \cdot 10^4 cm^{-3}$

$\sigma = q(\mu_{n_2} n + \mu_{p_2} p) = q \mu_{n_2} \cdot n = 0.3 \frac{S}{cm}$

VJ. 16. $T_1 = 400K$

$\hookrightarrow N_D = \frac{N_A}{10^5}$

$\delta = ?$ na $T_2 = 300$ $\mu_{n_2} = 900$ $\mu_{p_2} = 350$

$n_{i_1} = 7.22 \cdot 10^{12}$ $p = \frac{n_{i_1}^2}{n} = \frac{n_{i_1}^2}{N_A} \cdot 10^5$

$n_1 = 2.28 \cdot 10^{10} cm^{-3}$ $\Leftarrow$ $p^2 = 10^5 \cdot n_{i_1}^2 \Rightarrow p = 2.28 \cdot 1$

$n_{i_2} = 1.45 \cdot 10^{10} cm^{-3}$ za $T_2 = 300K$

$n = \frac{n_{i_2}^2}{p} = 9.2 \cdot 10^4 cm^{-3}$

$\sigma = q(\mu_{n_2} n + \mu_{p_2} \cdot p) = q \mu_{p_2} \cdot p = 0.128$

$\delta = \frac{1}{\sigma} = 7.788 \Omega cm$

VJ17. $T_1 = 550K$ Dopiran je Dororiva $N_D > N_P$

$\sigma_1 = 0.28 \frac{S}{cm}$

$T_2 = 300K$ $(\sigma_2 = 0.28 \frac{S}{cm})$ $\mu_{n2} = \mu_{n1} = 900$ $\mu_{p1} = \mu_{p2} = 300$

$n_{i1} = 1.318 \cdot 10^{15} cm^{-3}$ $p = \frac{n_{i1}^2}{n} =$ $p_1 = 1.11 \cdot 10^{15}$ ~~$p_2 = 4.7 \cdot 10^{15}$~~

$\sigma_1 = q(\mu_{n1} \cdot n + \mu_{p1} \cdot p) = q(\mu_{n1} \cdot n + \mu_{p1} \cdot \frac{n_{i1}^2}{n})$

$\mu_{n1} \cdot n^2 - \frac{\sigma_1}{q} n + \mu_{p1} \cdot n_{i1}^2 = 0$ $900 n^2 - 1.74 \cdot 10^{18} n + 5.211 \cdot 10^{32} = 0$ $\Delta = 1.0285 \cdot 10^{36}$

$n_{1,2} = \frac{1.74 \cdot 10^{18} \pm \sqrt{3.0285 \cdot 10^{36} - 1.876 \cdot 10^{36}}}{1800}$

$n_1 = 1.56 \cdot 10^{15}$ ~~$n_2 = 3.7 \cdot 10^{14}$~~

$n_{i2} = 1.45 \cdot 10^{10} cm^{-3}$

$p = \frac{n_{i2}^2}{n} = 1.3 \cdot 10^5$

$\sigma_2 = q(\mu_{n1} \cdot n + \mu_{p1} \cdot p)$

$\boxed{N_D = 1.56 \cdot 10^{15} cm^{-3}}$

VJ18. $N_A = 10^{15} cm^{-3}$ $N_D > N_A$ $\mu_{n1} = 900$ za T_2 -15%
$N_D = 1.1 \cdot 10^{15} cm^{-3}$ $\mu_{p1} = 350$

$T_1 = 300K$ $T_2 = 450K$

$\sigma_{T1} = ?$ $\sigma_{T2} = ?$

$N_D - N_A = 1 \cdot 10^{14} cm^{-3} \Rightarrow n_{i1}$

$n_{i1} = 1.45 \cdot 10^{10} cm^{-3}$ Poluvodič tipa n

$n = 1 \cdot 10^{14}$

$\sigma_{T1} = q(\mu_{n1} n + \mu_{p1} p)$ $p = \frac{n_{i1}^2}{n} = 2.1 \cdot 10^6 cm^{-3}$

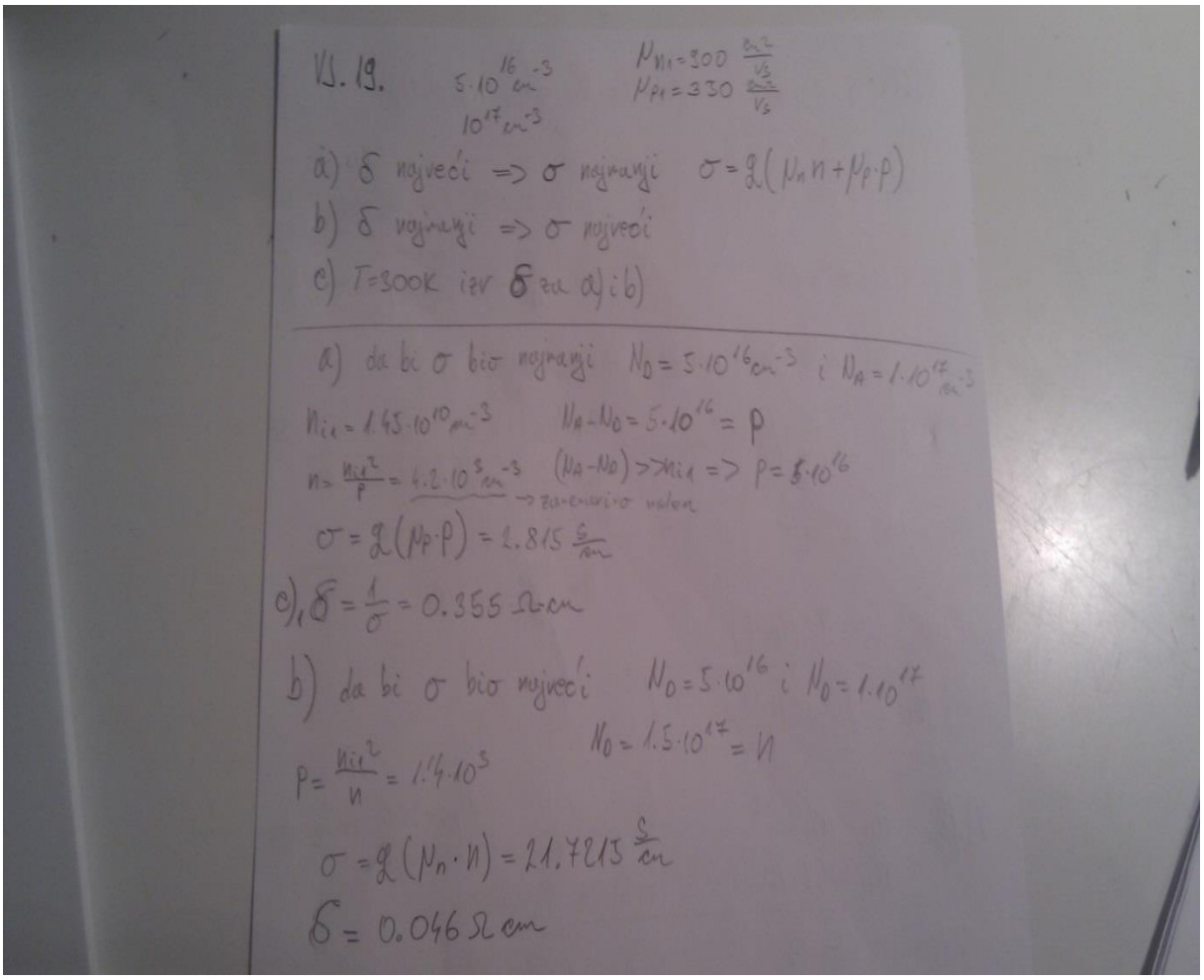
$\sigma_{T1} = 0.0144 \frac{S}{cm}$

za $T_2 = 450K$ $\mu_{n2} = 765$
$\mu_{p2} = 255$ $n = \frac{N_D - N_A + \sqrt{(N_D - N_A)^2 + 4 n_{i2}^2}}{2} = 1.27 \cdot 10^{14} cm^{-3}$

$n_{i2} = 5.9 \cdot 10^{13} cm^{-3}$

$p = \frac{n_{i2}^2}{n} = 2.74 \cdot 10^{13}$

$\sigma_{T2} = 0.0167 \frac{S}{cm}$



VJ. 19. $5 \cdot 10^{16}\,cm^{-3}$ $10^{17}\,cm^{-3}$ $\mu_{n1} = 300\ \frac{cm^2}{Vs}$ $\mu_{p1} = 330\ \frac{cm^2}{Vs}$

a) δ najveći $\Rightarrow$ σ najmanji $\sigma = q(\mu_n n + \mu_p \cdot p)$

b) δ najmanji $\Rightarrow$ σ najveći

c) $T = 300K$ izr δ za a) i b)

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a) da bi σ bio najmanji $N_D = 5 \cdot 10^{16} cm^{-3}$ i $N_A = 1 \cdot 10^{17} cm^{-3}$

$n_{i1} = 1.45 \cdot 10^{10} cm^{-3}$ $N_A - N_D = 5 \cdot 10^{16} = p$

$n = \frac{n_{i1}^2}{p} = 4.2 \cdot 10^{3} cm^{-3}$ $(N_A - N_D) >> n_{i1} \Rightarrow p = 5 \cdot 10^{16}$

→ zanemarivo malen

$\sigma = q(\mu_p \cdot p) = 1.815\ \frac{S}{cm}$

c) $\delta = \frac{1}{\sigma} = 0.355\ \Omega cm$

b) da bi σ bio najveći $N_D = 5 \cdot 10^{16}$ i $N_D = 1 \cdot 10^{17}$

$N_D = 1.5 \cdot 10^{17} = n$

$p = \frac{n_{i1}^2}{n} = 1.4 \cdot 10^{3}$

$\sigma = q(\mu_n \cdot n) = 21.7813\ \frac{S}{cm}$

$\delta = 0.046\ \Omega cm$

BY MATAN