(a)

$$n_e = \frac{N_e}{V} = 2\frac{(2\pi m kT)^{3/2}}{h^3} e^{-(E_g - E_F)/kT}$$

$$n_v = \frac{N_v}{V} = \text{---}\,''\,\text{---}\; e^{-E_F/kT}$$

$$n_e = n_v \Rightarrow E_F = \frac{E_g}{2}$$

$$n_e n_v = n_i^2 = 4\frac{(2\pi m kT)^3}{h^6} e^{-E_g/kT}$$

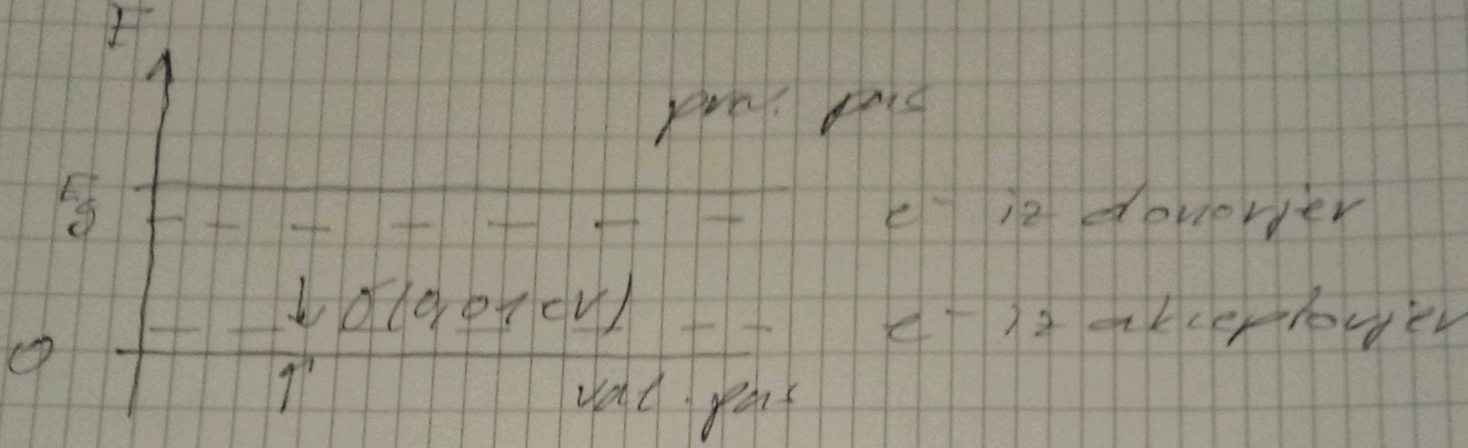
$$v_e = \mu_e E \qquad v_v = \mu_v E$$

$$j = e_0 n_i (v_e + v_v) = \underbrace{e_0 n_i (\mu_e + \mu_v)}_{\sigma} E$$

$$m_e \neq m_v \Rightarrow$$

$$\mu = \frac{E_g}{2} - \frac{3}{4} kT \ln \frac{m_e}{m_v}$$

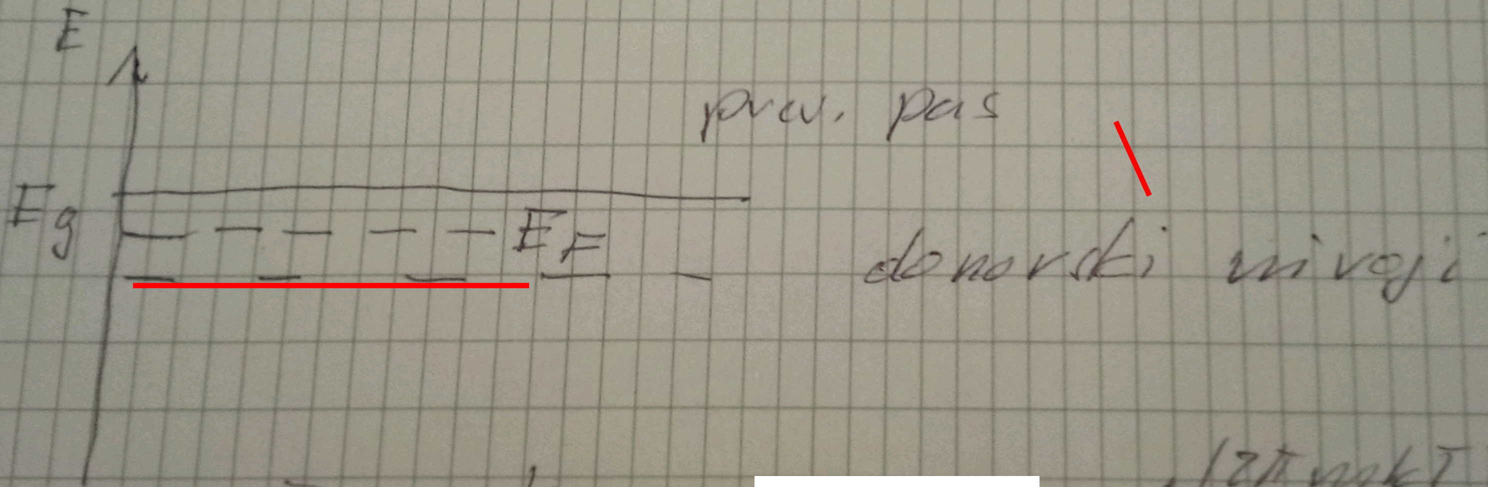
Dopirani polprevodniki



$E_g \sim O(1 eV)$

tipični donorji: As, P, Li

— II — akceptorji: B, Ga



še vedno $n_i^2 = 4\left(\frac{2\pi m kT}{h^2}\right)^3 \cdot e^{-E_g/kT}$

gostota prostih nosilcev naboja, ki izvirajo iz čistega polprev. - e^- iz valenčnega pasu in vrzeli iz prevodnega pasu

(ker $n_e n_v \neq f(E_F)$)

(c)

$$n_v + N_D = n_e + N_A$$

N_D — gost. donorskih atomov (+)

N_A — gost. akceptorskih atomov (−)

n-tip polprevodnika:

$$N_A = 0, \quad N_D \neq 0$$

$$n_e \gg n_v$$

$$n_e \approx N_D$$

p-tip polprevodnika:

$$N_D = 0, \quad N_A \neq 0$$

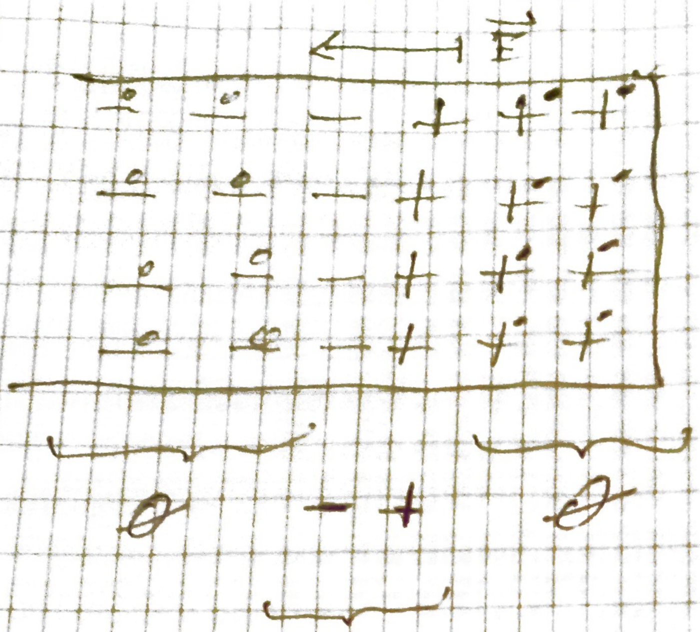
$$n_v \gg n_e$$

$$n_v \approx N_A$$

n-tip: $\sigma \approx e_0 N_D \mu_e$

p-tip: $\sigma \approx e_0 N_A \mu_v$

(e)



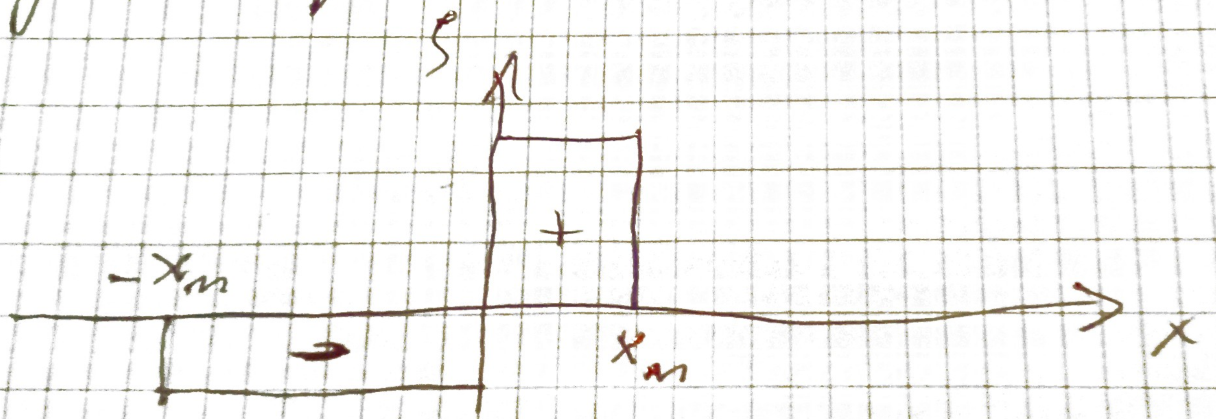
difuzija e^- in vrzeli je samoustavljajoč proces

prostorski naboj

↳ depletirana plast

depletirana: brez gibljivih nosilcev naboja (e^- in vrzeli)

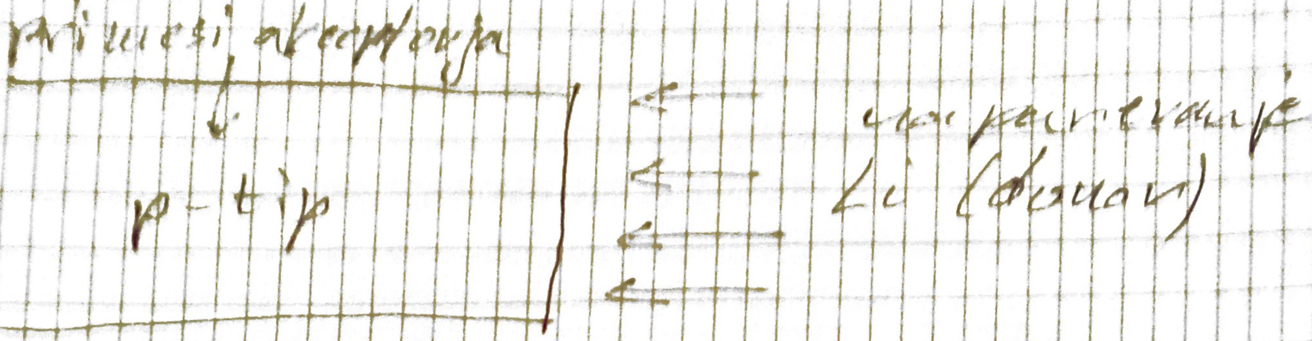
gostota prostorskega naboja:

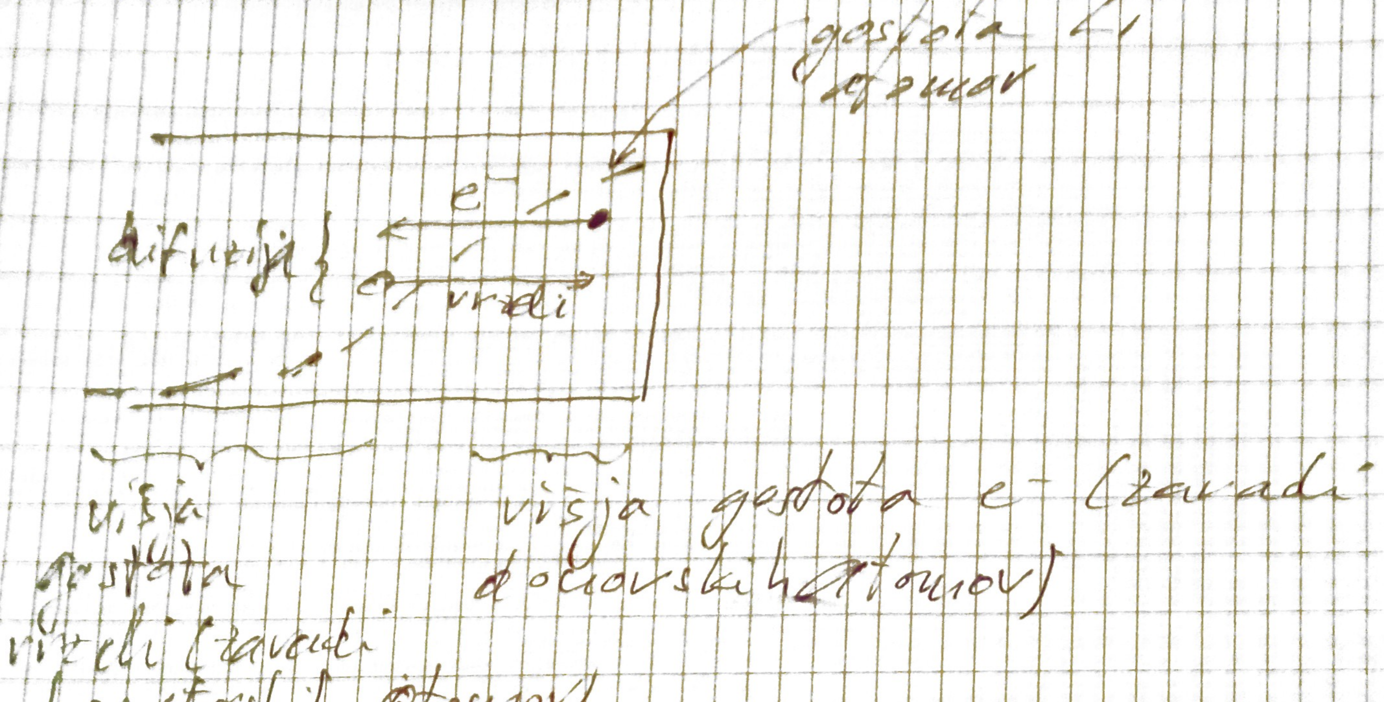


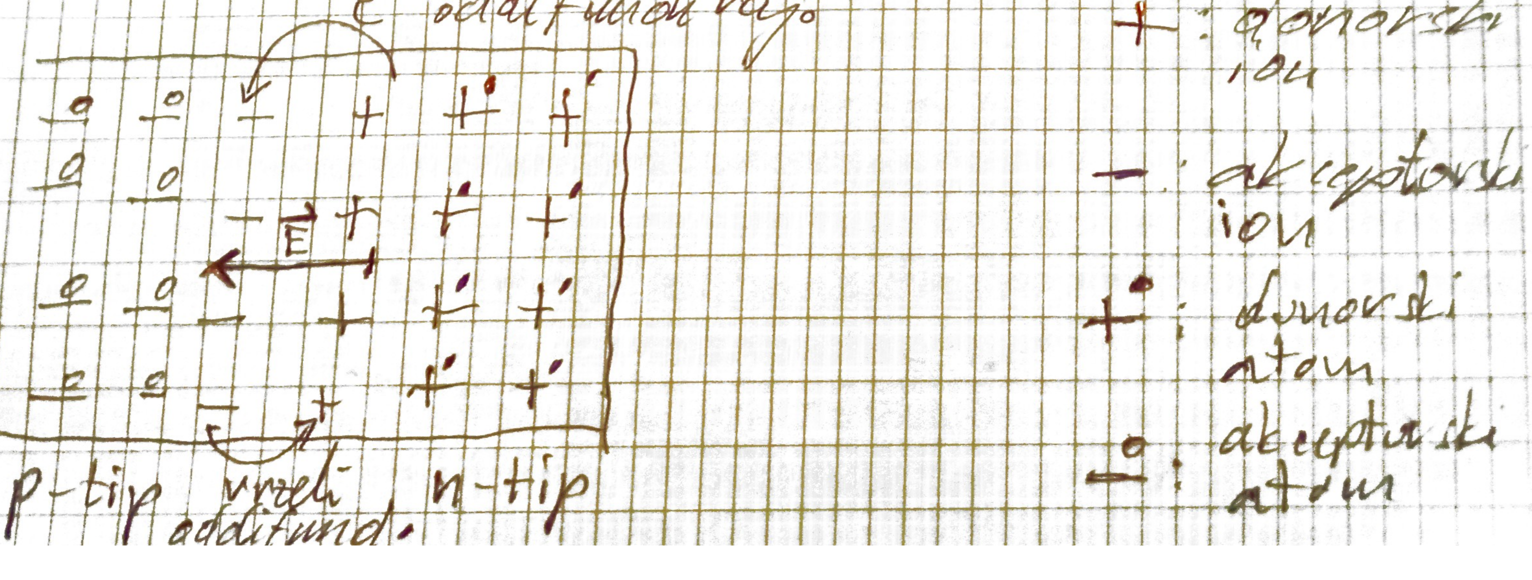
Maxwell-ova enačba:

$$\vec{\nabla} \vec{E} = \frac{\rho(\vec{r})}{\varepsilon \varepsilon_0}$$

p-n stik


primesi akceptorja
p-tip
implantiranje
Li (donor)


gostota Li
donor
e⁻
difuzija
vrzeli
višja gostota vrzeli (zaradi akceptorskih atomov)
višja gostota e⁻ (zaradi donorskih atomov)


e⁻ oddifundirajo
E
p-tip
vrzeli oddifund.
n-tip
+ : donorski ion
− : akceptorski ion
+• : donorski atom
−o : akceptorski atom

(4)

oz. v 1D:

$$\frac{\partial E}{\partial x} = \frac{\rho(x)}{\varepsilon\varepsilon_0}$$

$$\vec{E} = -\vec{\nabla} V$$ → potencial

$$E = -\frac{\partial V}{\partial x}$$

$$\frac{\partial^2 V}{\partial x^2} = -\frac{\rho(x)}{\varepsilon_0}$$ Poisson-ova en.

$$\rho(x) = \begin{cases} eN_D & 0 \leq x \leq x_n \\ -eN_A & -x_p \leq x < 0 \end{cases}$$

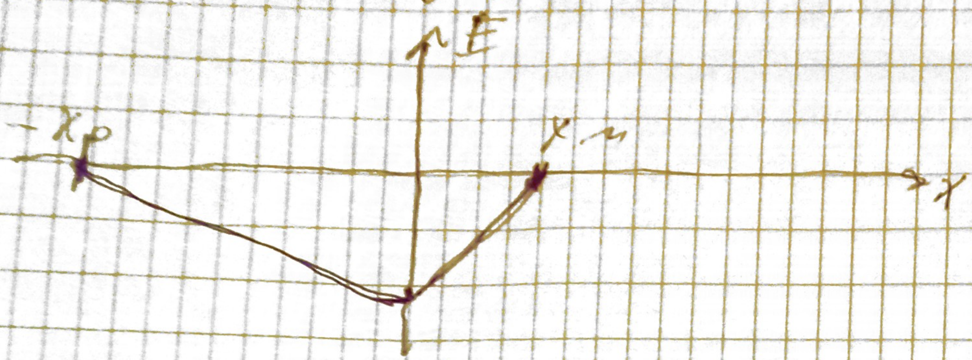
$$E = -\frac{\partial V}{\partial x} = \begin{cases} \frac{eN_D}{\varepsilon\varepsilon_0}(x - x_n) & 0 \leq x \leq x_n \\ -\frac{eN_A}{\varepsilon\varepsilon_0}(x + x_p) & -x_p \leq x < 0 \end{cases}$$

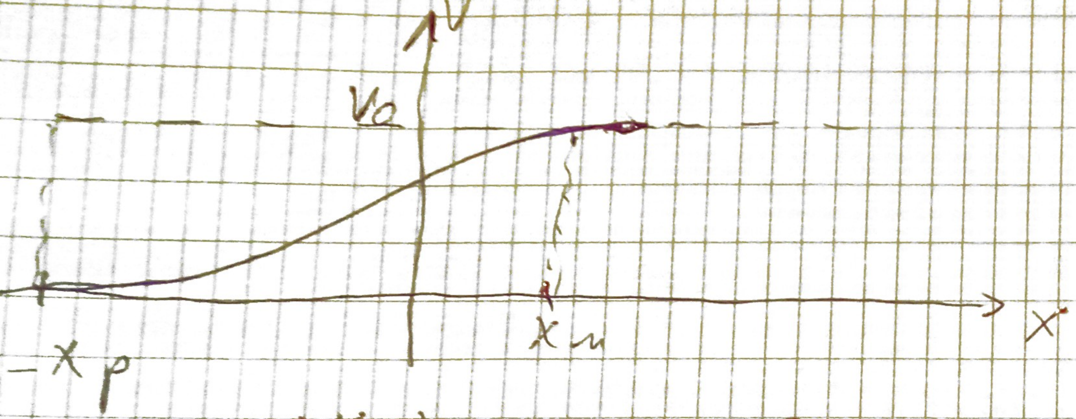
(robni pogoji: $E = 0$ za $x = x_n, -x_p$)

(1)

$$V(x) = \begin{cases} -\frac{e N_D}{2\varepsilon\varepsilon_0}(x - x_n)^2 + V_0 & 0 < x < x_n \\ \frac{e N_A}{2\varepsilon\varepsilon_0}(x + x_p)^2 & -x_p \le x < 0 \end{cases}$$

Robni pogoji: $V(x_n) = V_0$, $V(-x_p) = 0$





$V(x)$ zvezen pri $x = 0 \Rightarrow$

$$\Rightarrow \quad V_0 = \frac{e}{2\varepsilon\varepsilon_0}\left(N_D x_n^2 + N_A x_p^2\right)$$

poleg tega je spoj ravno elek. nevtralen $\Rightarrow$ $Q_+ = Q_-$ $\Rightarrow$

$$\Rightarrow \quad N_A x_p = N_D x_n$$

(4)

$$\Rightarrow x_n = \left[\frac{2\varepsilon\varepsilon_0 V_0}{e N_D (1 + N_D/N_A)}\right]^{1/2}$$

$$x_p = \left[\frac{2\varepsilon\varepsilon_0 V_0}{e N_A (1 + N_A/N_D)}\right]^{1/2}$$

celotna debelina depletirane plasti:

$$d = x_n + x_p = \left[\frac{2\varepsilon\varepsilon_0 V_0}{e} \frac{N_A + N_D}{N_A N_D}\right]^{1/2}$$

p stran močneje dopirana kot n stran

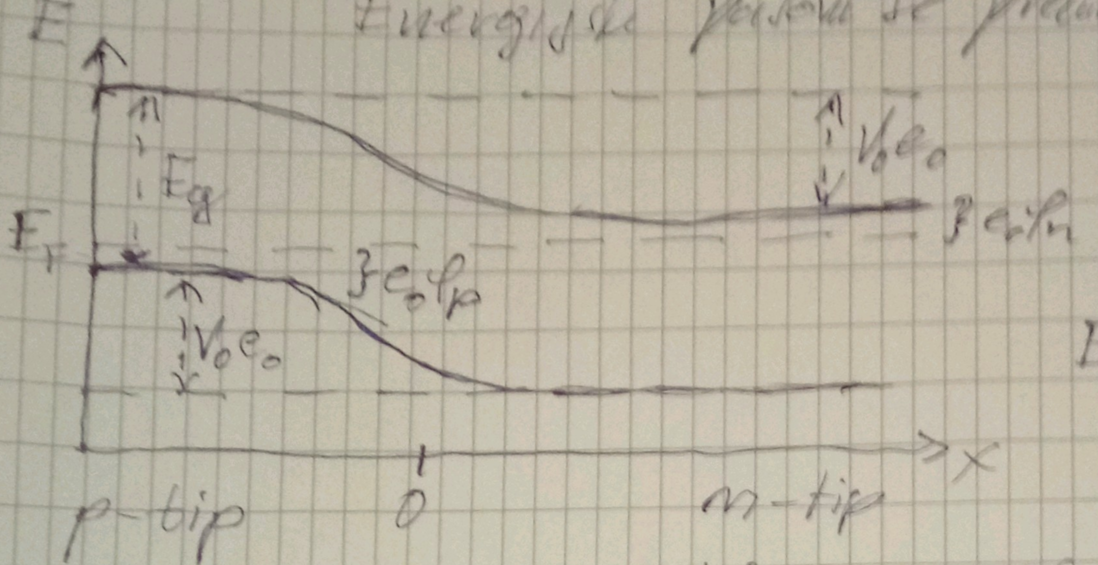
$$N_A \gg N_D \Rightarrow x_n \gg x_p \Rightarrow$$

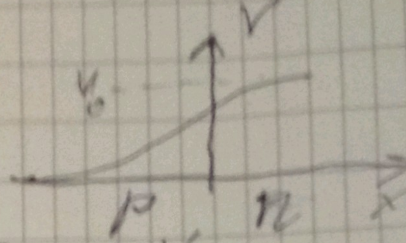
$$\Rightarrow d \approx x_p$$

in obratno...

Kaj pomeni kontaktna napetost V_0 za e^-?

Energijski pasovi se premaknejo:





$E = -e_0 V$

e^- (večinski gibljivi nosilci naboja v n-tipu) morajo premagati potencialni skok da preidejo iz n strani na p.

Čist polprev.: $n_e = n_0 e^{-(E_g - E_F)/kT}$

$$n_v = n_0 e^{-E_F/kT}$$

Dopiran polprev.:

$$n_e = n_0 e^{-e_0 \varphi_n/kT}$$

$$n_v = n_0 e^{-e_0 \varphi_p/kT}$$

(δ)

$$E_F + e_0\varphi_n + e_0 V_0 - E_g + e_0\varphi_p = E_F$$

$$V_0 = \frac{E_g}{e_0} - (\varphi_n + \varphi_p)$$

$$\varphi_{n,p} = \frac{kT}{e_0} \ln \frac{n_0}{n_{e,v}}$$

$$V_0 = \frac{E_g}{e_0} - \frac{kT}{e_0} \ln \frac{n_0^2}{n_e n_v}$$

$$n_i^2 = n_0^2 e^{-E_g/kT} \rightarrow n_0^2 = n_i^2 e^{E_g/kT}$$

$$V_0 = \frac{kT}{e_0} \ln \frac{n_e n_v}{n_i^2}$$

$$n_e \approx N_D \qquad n_v = N_A$$

$$V_0 = \frac{kT}{e_0} \ln \frac{N_D N_A}{n_i^2}$$

$N_{D,A} \sim 10^{17}/cm^3$ $\qquad$ $N_{at} \sim 10^{22}/cm^3$

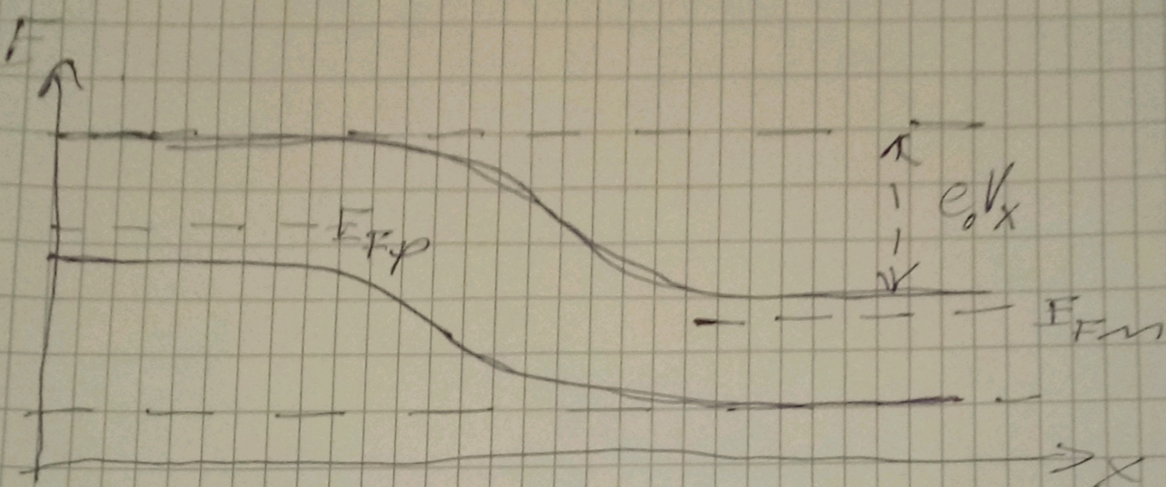
$n_i \sim 10^{10}/cm^3$

$T = 300K,\ N_A = N_D = 10^{17}/cm^3 \Rightarrow$

$\Rightarrow V_0^{Si} \approx 0{,}8\,V$

$V_0 = 0{,}8\,V \rightarrow d \approx 50\,\mu m$

Če dodamo zunanjo zaporno napetost (+ na n strani, − na p strani):



$E_{Fp} - E_{Fn} = e_0 V_b$

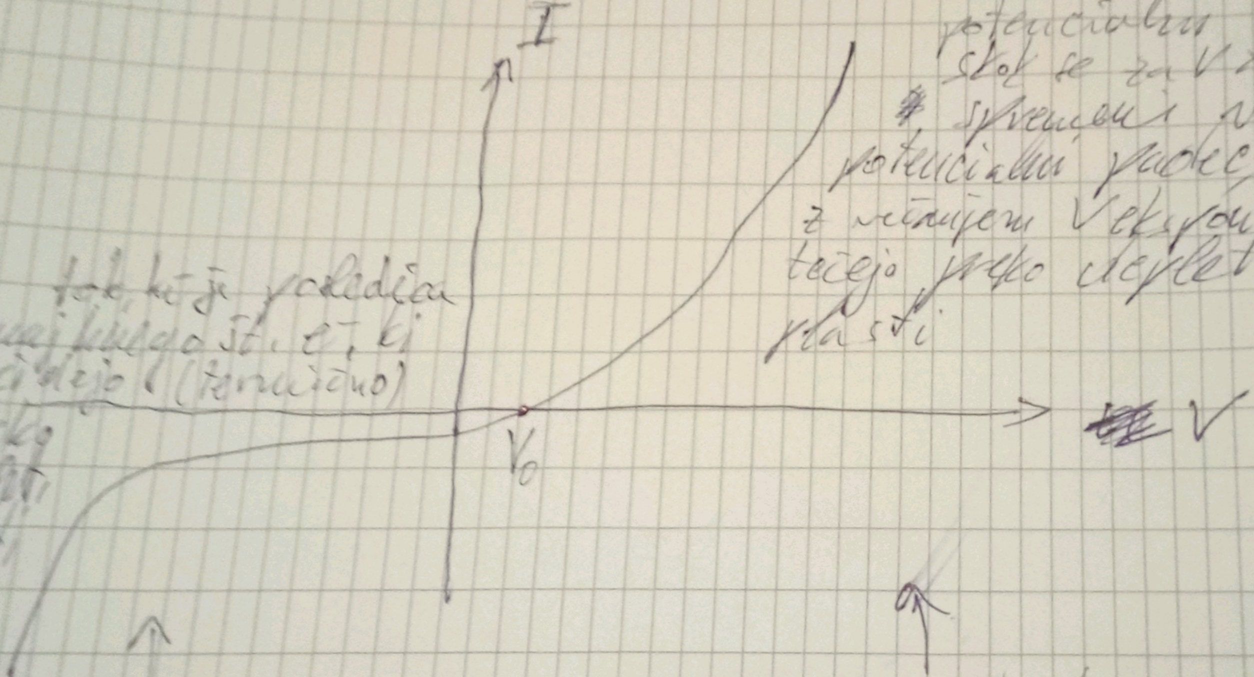
$E_{Fn} + e_0\varphi_n + e_0 V_x - E_g + e_0\varphi_p = E_{Fp}$

$$e_0 V_x = \underbrace{E_{Fp} - E_{Fn}}_{e_0 V_b} + \underbrace{E_g - e_0\varphi_n - e_0\varphi_p}_{e_0 V_0}$$

$\Rightarrow \quad V_x = V_b + V_0$

brez V_b: $d \propto \sqrt{V_0}$ z V_b: $d \propto \sqrt{V_b + V_0} \approx \sqrt{V_b}$

Polprevodniška dioda



zaporna napetost
(+ na n strani,
− na p strani)

napetost v prevodni smeri
(+ na p strani,
− na n strani)