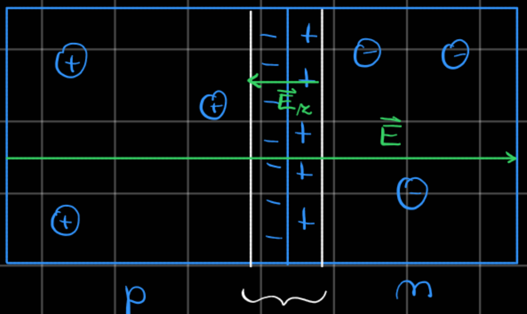
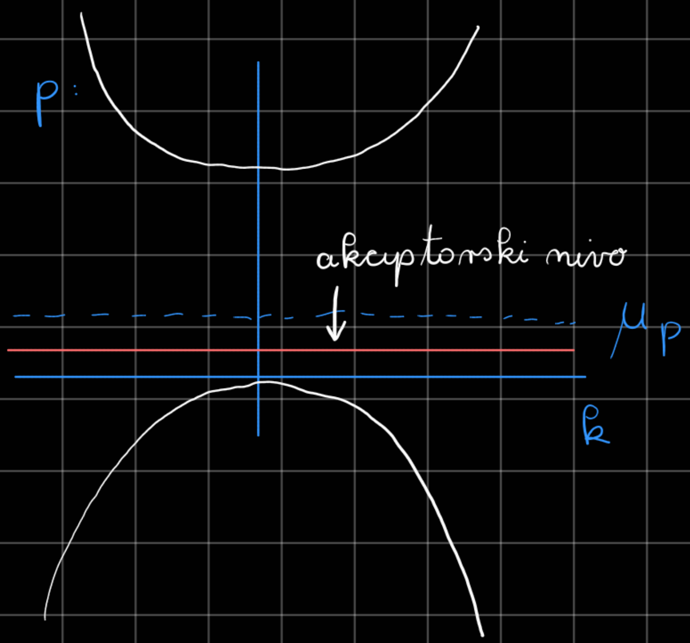
pn - stik

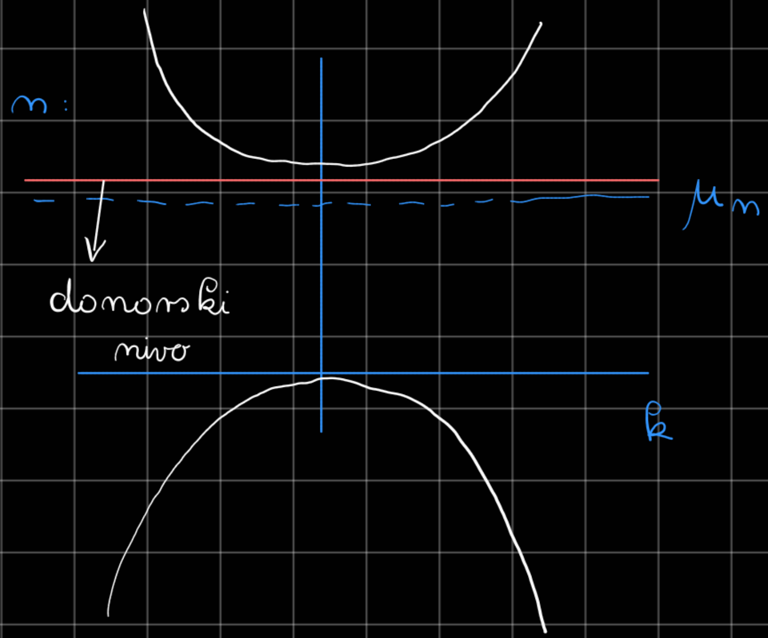


zaporna plast, ki nastane zaradi rekombinacije

Stacionarno stanje se vzpostavi, ko je $\vec{E}$, ki ga generira zaporna plast, nasprotno enaka $\vec{E}$ zaradi razlike v p-n dopiranemu polprevodniku

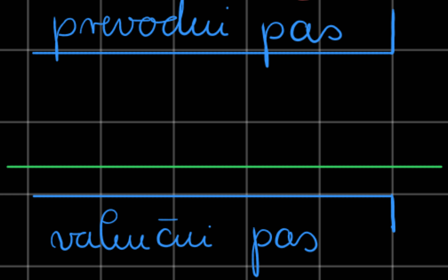
olp



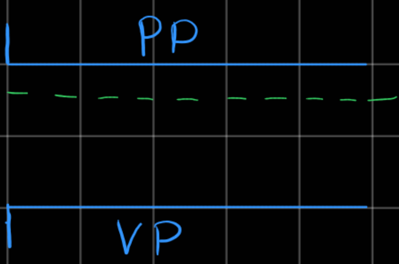


Analogno difuziji bodo e^- prehajali iz območja z višjim kem. potencialom na območje z nižjim.

začetno stanje

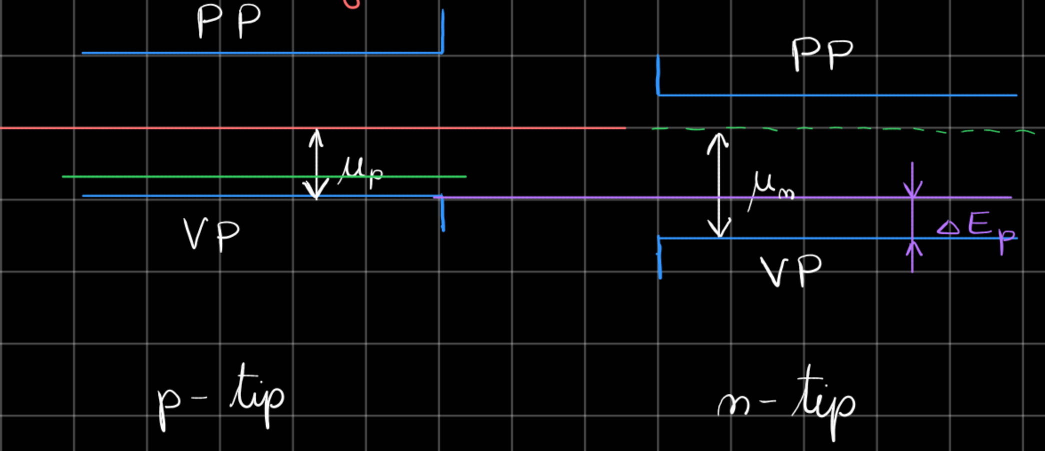


p- tip



n - tip

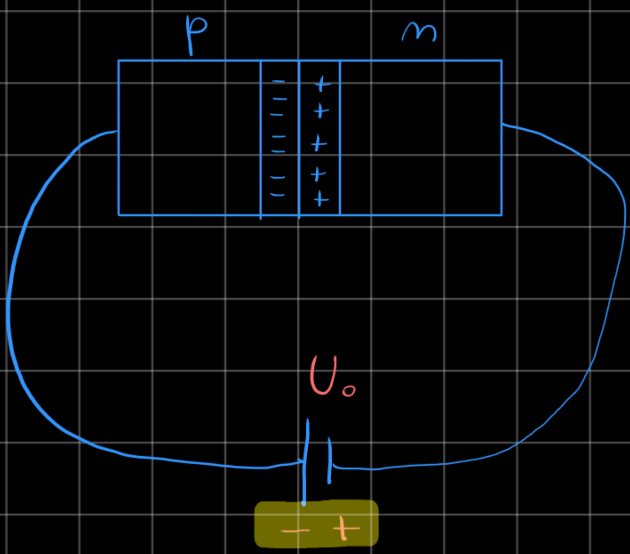
končno stanje



$$\Delta E_p = \mu_n - \mu_p$$

pn - stik pod napetostjo

a)

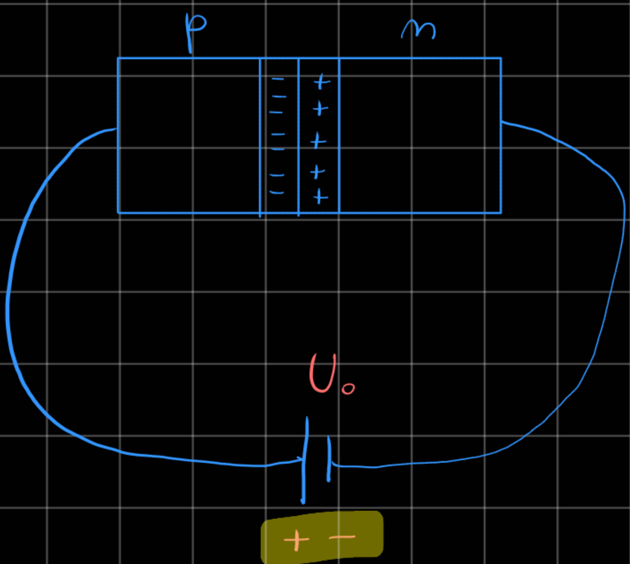


Proces se bo ustavil, ko bo U_0 enak napetosti na zaporni plasti

Zaporna plast se poveča.

analogno kondenzatorju

b)



Zaporna plast se zmanjša.

Topic V/43

$T_0 = 300K$ $E_g = 0{,}67 eV$ gibljivost

$\zeta_p = 0{,}01 \Omega m$ $m_e^* = 0{,}56\, m_0$ $\eta_e = 0{,}39\, m^2/Vs$

$\zeta_n = 0{,}001 \Omega$ $m_v^* = 0{,}35\, m_0$ $\eta_v = 0{,}19\, m^2/Vs$

$\varepsilon = 15{,}8$ // dielektričnost germanija

$\Delta E_{pot} = ?$

$d_{zap.\ plast} = ?$

$\Delta E_{pot} = \mu_N - \mu_p$

$$\mu_n : \quad n_e = \underbrace{n_0 \left(\frac{m_e^*}{m_v^*}\right)^{\frac{3}{4}}}_{n_{0e}} e^{-\beta(E_g - \mu_n)} \quad \star$$

$$n_0 = 2\left(\frac{2\pi\sqrt{m_e^* m_v^*}\, k_B T}{h^2}\right) = 7{,}4 \cdot 10^{24}\, m^{-3}$$

n_e :

$$\zeta_p = \frac{1}{\sigma_p} \qquad \sigma = \sum_j n_j \eta_j e_j$$

$$\zeta_n = \frac{1}{\sigma_n} \qquad \sigma_n = \eta_e (n_D + n_e^v) e_0$$

ni veliko vrzeli

$$\sigma_n = n_e \eta_e e_0 + \cancel{n_v \eta_v e_0}$$

$$\Rightarrow n_e = \frac{\sigma_n}{\eta_e e_0} = \left(\xi_n \eta_e e_0\right)^{-1}$$

$\cancel{A}$ // izrazimo μ_N in vstavimo v enačbo n_e

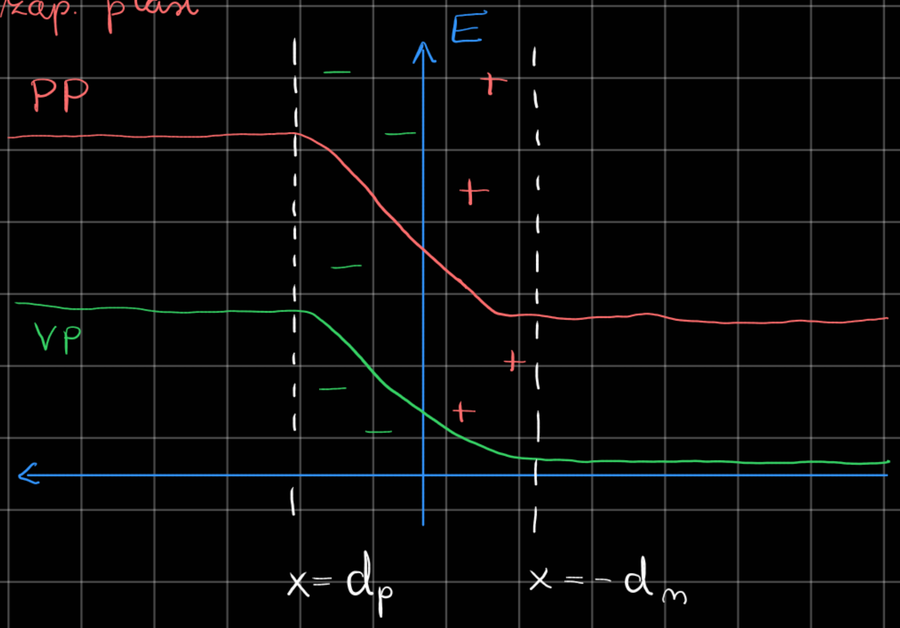
$$\mu_n = k_B T \left[\ln \frac{n_e}{n_0} + \frac{3}{4} \ln \frac{m_v^*}{m_e^*}\right] + E_g = 0'5V$$

$$\mu_p: \quad n_v = n_0 \left(\frac{m_v^*}{m_e^*}\right)^{\frac{3}{4}} e^{-\beta \mu_p}$$ // izpeljali smo jih zadnjič

$$n_v = \left(\xi_v \eta_v e_0\right)^{-1} \qquad \sigma_p = e_0 \left(n_A + n_v^{\,e}\right)$$

$$\Rightarrow \mu_p = k_B T \left[\ln \frac{n_v}{n_0} + \frac{3}{4} \ln \frac{m_e^*}{m_v^*}\right] = 0'31$$

$d_{zap.}$ plast

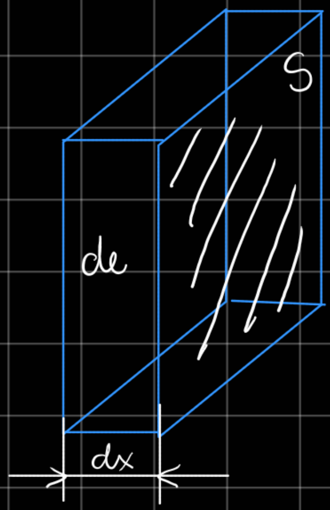


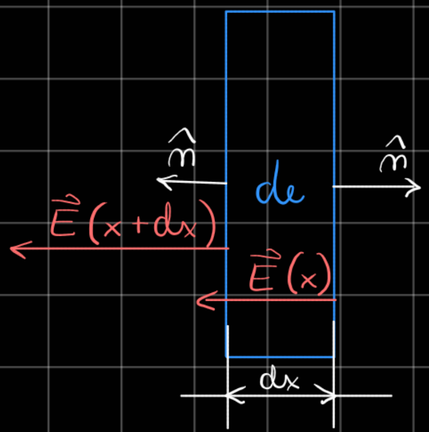
$d = d_p + d_n$

Izračunali bomo s pomočjo Gaussovega zakona in spreminjanja el. polja

a) n-stik

Gaussov zakon: $e = \oint \vec{D}\, d\vec{S} = \oint \varepsilon \varepsilon_0 \vec{E}\, d\vec{S}$





$\vec{E}(x+dx) = \vec{E} + d\vec{E}$

Bolj levo je več pozitivnega naboja in zato večje $\vec{E}$

$d\vec{S} = \hat{n}\, dS$

$de = \varepsilon \varepsilon_0 \cancel{S} \left[E\cancel{(x)} + dE - E\cancel{(x)} \right] = \underbrace{n_d}_{\#\text{ donorjev}}\, e_0\, dV$, $dV = \cancel{S}\, dx$

$\frac{dE}{dx} = \frac{n_D e_0}{\varepsilon \varepsilon_0}$ // integriramo nedoločeno

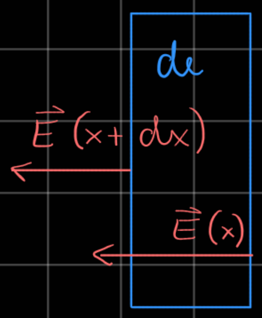
$E_n(x) = \frac{n_D e_0}{\varepsilon \varepsilon_0} x + A$

BC $E_n(x = -d_n) = 0$

$A = \frac{n_D e_0}{\varepsilon \varepsilon_0} d_n$

$\Rightarrow E_n(x) = \frac{n_D e_0}{\varepsilon \varepsilon_0} (x + d_n)$

b) p-stik



$$\vec{E}(x+dx) = \vec{E} - d\vec{E}$$

//analogno a)

$$E_p = -\frac{e_0 n_A}{\varepsilon\varepsilon_0} x + B \quad \text{in BC} \quad E_p(x=d_p) = 0$$

$$E_p(x) = \frac{e_0 n_A}{\varepsilon\varepsilon_0}\left(d_p - x\right)$$

BC je stik dveh režimov

$$E_n(x=0) = E_p(x=0)$$

$$\frac{n_D e_0}{\varepsilon\varepsilon_0} d_n = \frac{n_A e_0}{\varepsilon\varepsilon_0} d_p$$

$$n_d d_n = n_A d_p$$ //$d_n + d_p$ je debelina zaporne plasti

Potrebujemo še eno enačbo

$$\Delta E_p = \mu_n - \mu_p = \int_{-d_n}^{d_p} e_0 \vec{E} d\vec{s} = e_0 \int_{-d_n}^{0} E_n dx + e_0 \int_{0}^{d_p} E_p dx$$

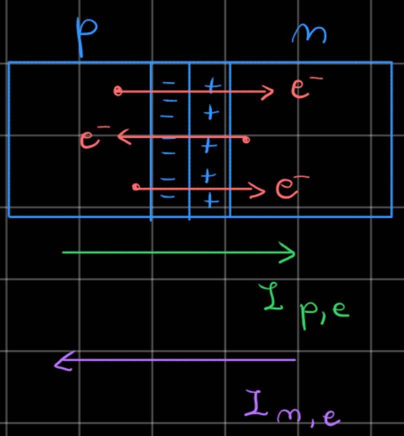
$$= \frac{e_0^2}{\varepsilon\varepsilon_0}\left[n_D \frac{d_n^2}{2} + n_A \frac{d_p^2}{2}\right]$$ //vstavimo prej dobljen d_n notri

$$d_n = \sqrt{\frac{2 \Delta E_p \varepsilon \varepsilon_0}{e_0^2 \left[n_D + \frac{n_D^2}{n_e}\right]}} = 76'4 \text{ nm}$$

$$\Rightarrow d_p = \frac{n_D}{n_A} d_n = 370'2 \text{ nm}$$

$$d = d_p + d_n = 446'6 \text{ nm}$$ // majhna zaporna plast

Tokovi skozi p-n stik (karakteristika diode)



// tokova sta posledici e^- iz p/n dela

$$I_e = I_{p,e} + I_{n,e}$$

↳ ($I_{n,e}$) manjši zaradi manjšega št. e^- (kljub potencialnemu toboganu)

↳ ($I_{p,e}$) večji zaradi večjega št. e^-

$$\boxed{I_{n,e} = A_e \cdot n_{e,n}}$$, $n_{e,n}$ ... št. gostota v n delu

A_e ... lastnosti gibanja e^- v prevod. pasu

$$\boxed{I_{p,e} = A_e \, n_{e,p}}$$

$$I_{p,e} = A_e n_{e,0} \, e^{-\beta(E_g - \mu_n)}$$

$$I_{n,e} = \underbrace{A_e n_{e,0} \, e^{-\beta(E_g - \mu_p)} \cdot e^{-\beta \Delta E_{pot}}}_{I_{p,e}}$$

1) Zunanja napetost $U = \emptyset$

$$I_e = 0 \quad (I_v = 0)$$

$$I_{e,n} = I_{e,p} \Rightarrow \Delta E_p = \mu_n - \mu_p$$

2) Zunanja napetost $U \neq \emptyset$

$$I_e = I_{e,n} - I_{e,p}$$

Dodatek

$I_{n,e} = A_e n_{e,0} \, e^{-\beta(E_g - \mu_p)} e^{-\beta U_0 e_0}$ ob zunanji napetosti

---

$$\Delta E_p' = \Delta E_p \pm e_0 U_0 = \mu_n - \mu_p \pm e_0 U_0$$

$\nearrow$ prevodna smer $\rightarrow$ velik tok

$\hookrightarrow$ zaporna smer $\rightarrow$ majhen tok

Celoten tok

$$I = I_e + I_v = I_0 \left(e^{-\beta e_0 U_0} - 1\right), \quad I_0 = I_{p,e} + I_{n,v}$$

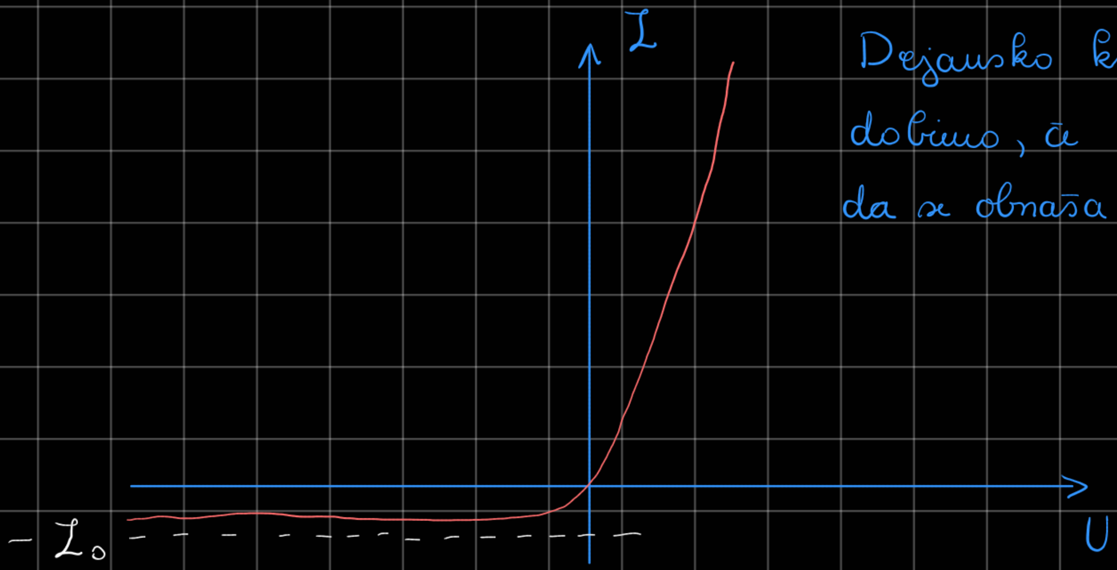
vrzeli $\quad I_v = I_{n,v} \left(e^{-\beta e_0 U_0} - 1\right)$

• prevodna smer

$$I = I_0 \left(e^{\beta e_0 U_0} - 1\right)$$

Dogovor: $U_0 > 0$ – prevodna smer

$U_0 < 0$ – zaporna smer



Dejansko karakteristiko diode dobimo, če upoštevamo še, da se obnaša kot upornik