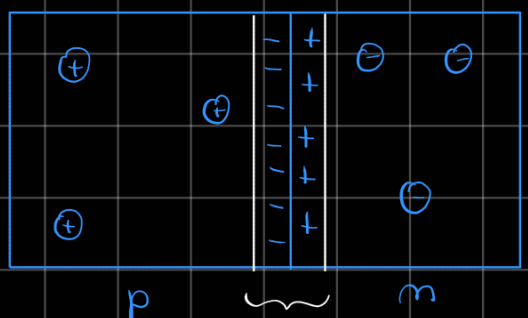
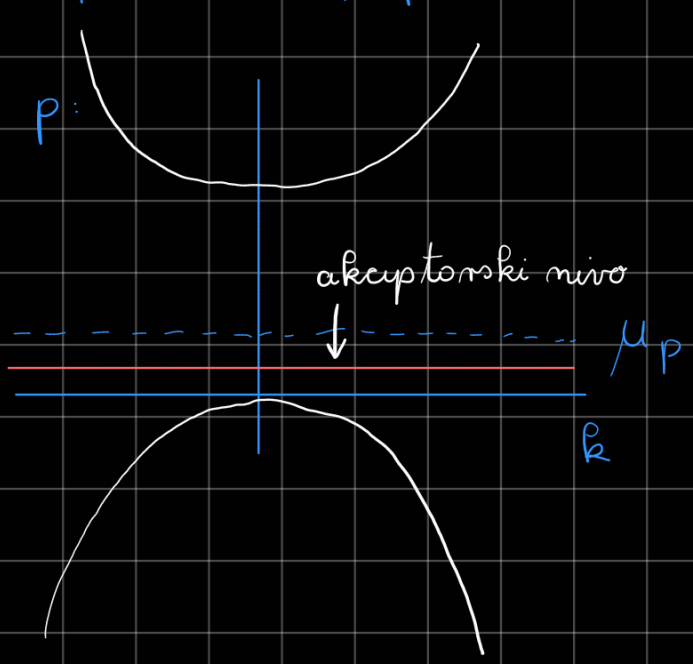
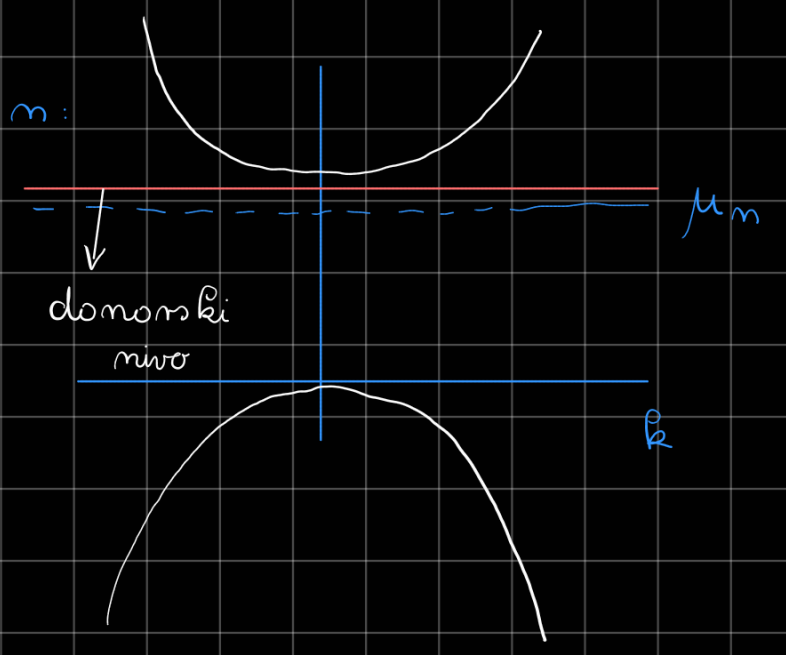
pn - stik



zaporna plast, ki nastane zaradi rekombinacije

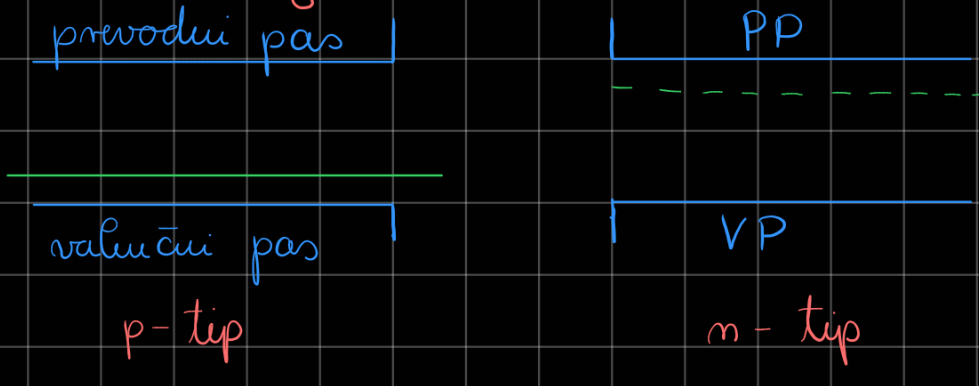
Ustacionarno stanje se vzpostavi, ko je $\vec{E}$, ki ga ustvarja zaporna plast, nasprotno enaka $\vec{E}$ zaradi razlike v p-n dopiranemu polprevodniku



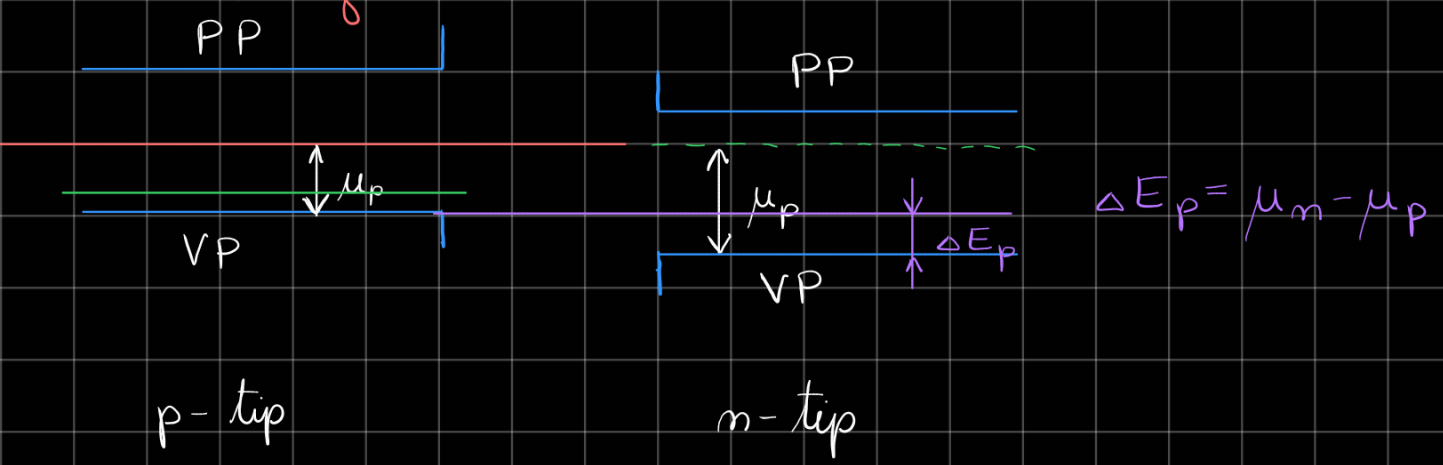


Analogno difuziji bodo e^- prehajali iz območja z višjim kem. potencialom na območje z nižjim.

začetno stanje



Končno stanje

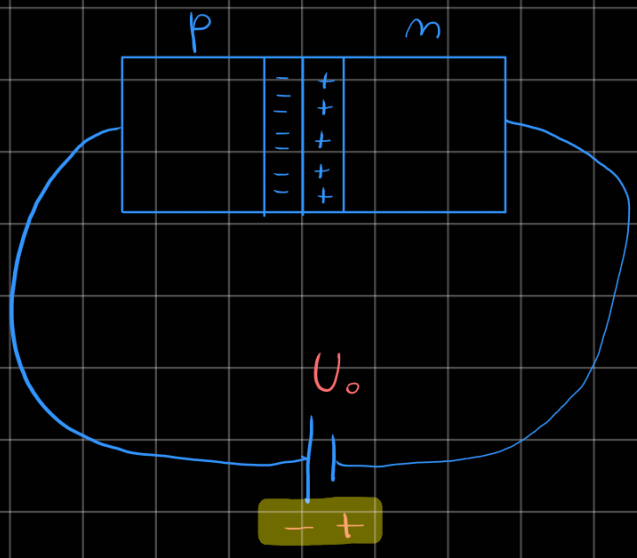


p - tip

n - tip

pn - stik pod napetostjo

a)

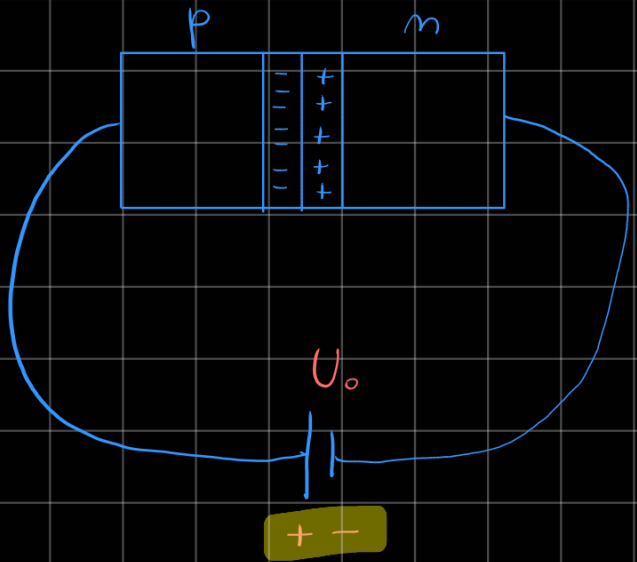


Proces se bo ustavil, ko bo U_0 enak napetosti na zaporni plasti

Zaporna plast se povečа.

analogno kondenzatorju

b)



Zaporna plast se zmanjša.

Topič V/43

$T_0 = 300K$ $\quad E_g = 0'67eV$ $\quad$ ozkoreža

$\xi_p = 0'01\,\Omega m$ $\quad m_e^* = 0'56\,m_0$ $\quad \eta_e = 0'39\ m^2/Vs$

$\xi_n = 0'001\,\Omega$ $\quad m_v^* = 0'35\,m_0$ $\quad \eta_v = 0'19\ m^2/Vs$

$\varepsilon = 15'8$ // dielektričnost germanija

$\Delta E_{pot} = ?$

$d_{zap.\ plast} = ?$

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

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

$$n_0 = 2\left(\frac{2\pi\sqrt{m_e^* m_v^*}\,k_B T}{h^2}\right) = 7'4 \cdot 10^{24}\ m^{-3}$$

n_e:

$\xi_p = \frac{1}{\beta_p}$ $\qquad \beta = \sum_j n_j \eta_j e_j$

$\xi_n = \frac{1}{\beta_n}$

$\beta_n = n_e \eta_e e_0 + n_v \eta_v e_0$ → ni veliko vrzeli

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

⛤ // izrazimo μ_N in vstavimo v enačbo n_e

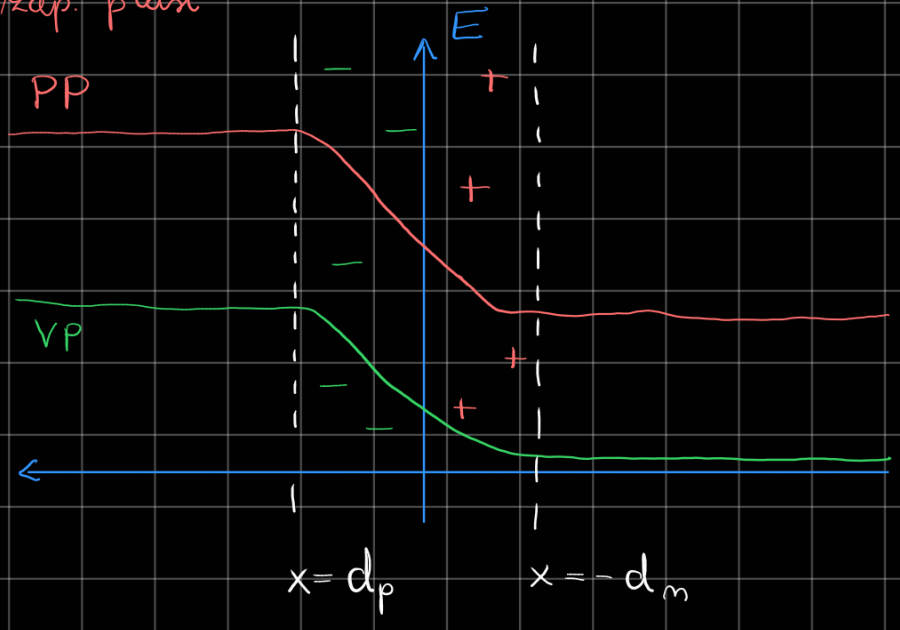
$$\mu_n = k_B T \left[\ln \frac{n_e}{n_0} + \frac{3}{4} \ln \frac{m_v^*}{m_e^*} \right] + E_g = 0'5\,V$$

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

$$n_v = \left(\xi_v \eta_v e_0\right)^{-1}$$

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

$d_{zap.\ plast}$

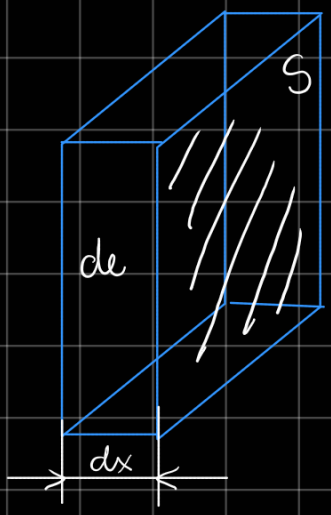


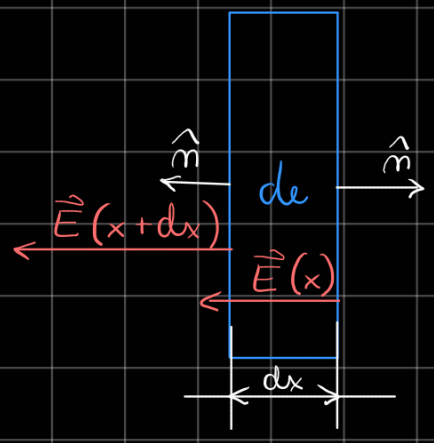
$d = d_p + d_n$

Izračunali bomo s pomočjo Gaussovega zakona in spremljanja 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 $\vec{E}$

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

$de = \varepsilon \varepsilon_0 \oint \left[E(x) + dE - E(x) \right] = n_d e_0 \, dV$ ($\oint dx$)

n_d ↓ # donorjev

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

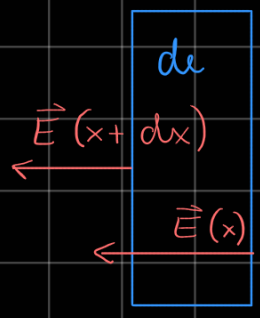
$E_n(x) = \frac{n_D e_0}{\varepsilon \varepsilon_0} x + A$

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)

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

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

BC je stik dveh režimov

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

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

$$n_d d_n = n_A d_p \qquad // d_n + d_p \text{ je debelina zaporne plasti}$$

Potrebujemo še eno enačbo

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

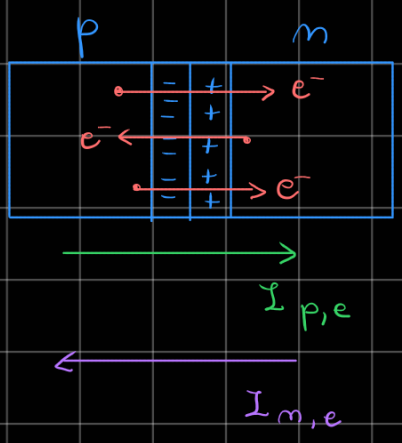
$$= \frac{e_0^2}{\varepsilon \varepsilon_0}\left[n_D \frac{d_n^2}{2} + n_A \frac{d_p^2}{2} \right] \qquad // \text{vstavimo prej dobljen } d_n \text{ notri}$$

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

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

$d = d_p + d_n = 446'6$ nm // majhna zaporna plast

Tokovi skozi p-n stik (karakteristika diode)



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

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

↳ manjši zaradi manjšega št. e^- (klub potencialu tobogan)

↳ večji zaradi večjega št. e^-

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

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

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

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

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

1) Zunanja napetost $U = \cancel{0}$

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

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

2) Zunanja napetost $U \neq \cancel{0}$

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

Dodatek

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

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

↗ prevodna smer → velik tok

↳ zaporna smer → majhen tok

Celoten tok

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

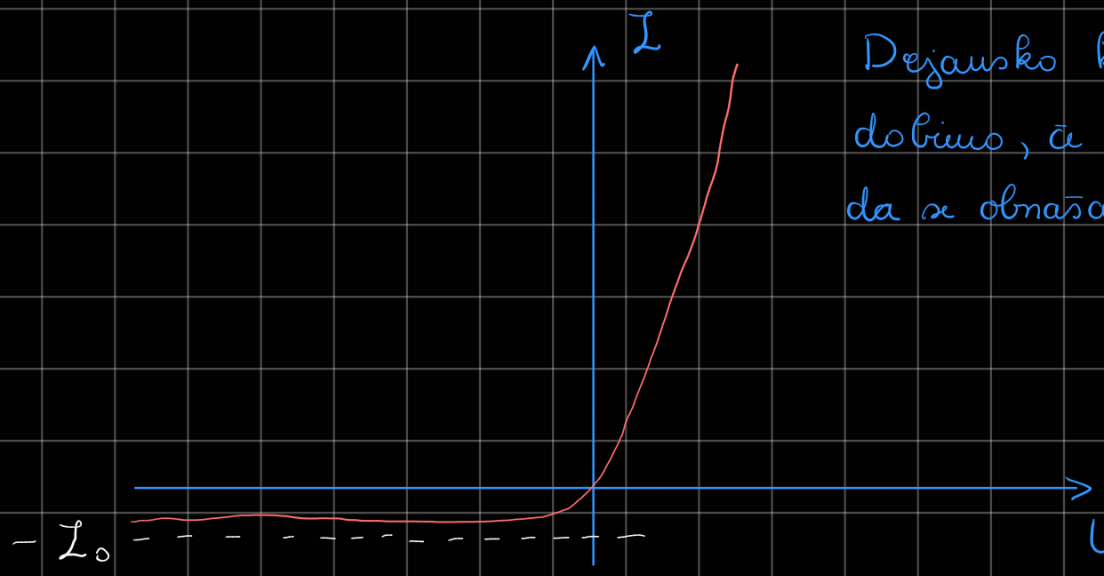
vzeli $I_v = I_{n,v} (e^{-\beta e_0 U_0} - 1)$

- prevodna smer

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

Dogovor: $U_0 > 0$ – prevodna smer

$U_0 < 0$ – zaporna smer



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