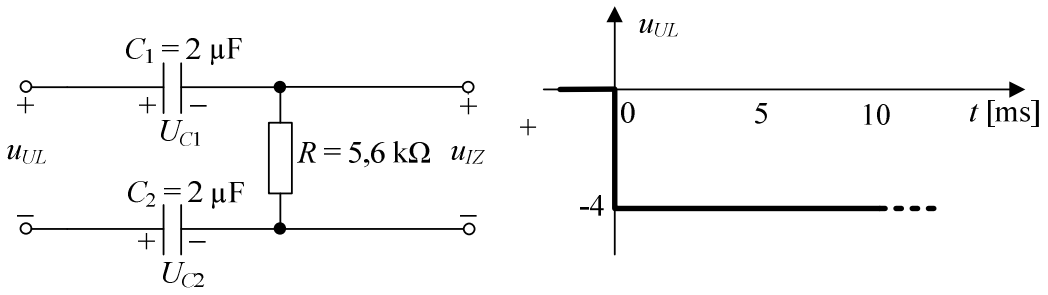
MEĐUISPIT IZ ELEKTRONIKE 1

ZADACI

ZADATAK 1. Za sklop na slici a) priključen je ulazni napon $u_{UL}(t)$ prema slici b). U t = 0 ms napon na kondenzatoru C_1 iznosi U_{C1} = 1.5 V dok na kondenzatoru C_2 iznosi U_{C2} = 1.5 V.

a) Napisati izraz za izlazni napon u intervalu $0 < t < \infty$ ms (**3 boda**).
b) Izračunati vrijednosti izlaznog napona u t = 0 ms i 5 ms (**2 boda**).
c) Na istom grafu nacrtati ulazni i izlazni napon (**1 bod**).



a) b)

ZADATAK 2. Silicij je dopiran donorima $N_D = 2 \cdot 10^{16}$ cm^{-3}. Odrediti:

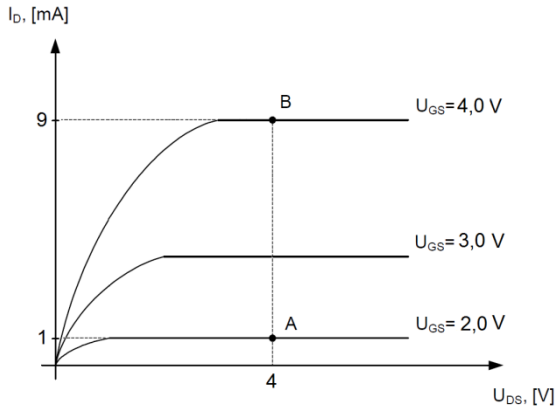
a) položaj Fermijeve energije na temperaturi T = 300 K (**2 boda**),
b) tip i iznos koncentracije primjesa koju treba dodati da bi na T = 400 K Fermijeva energija bila na istoj udaljenosti od vrha vodljivog pojasa kao pod a) (**4 boda**).

ZADATAK 3. Koncentracije primjesa na n i p strani silicijske diode iznose $N_D = 4 \cdot 10^{15}$ cm^{-3} i $N_A = 2 \cdot 10^{17}$ cm^{-3}. Parametri manjinskih nosilaca su $\mu_n = 800$ cm^2/Vs, $\mu_p = 300$ cm^2/Vs, $\tau_n = 0{,}5$ µs i $\tau_p = 0{,}8$ µs. Površina pn spoja iznosi S = 1 mm^2. Širine n i p strane diode su W_n = 350 µm i W_p = 0,8 µm. Napon propusne polarizacije pn-spoja je U_D = 0,55 V. Vrijedi T = 300 K. Pretpostaviti m = 1.

a) Nacrtati raspodjele manjinskih nosilaca, izračunati i označiti rubne te ravnotežne koncentracije (**6 bodova**).
b) Izračunati struju zasićenja I_S (**2 boda**).
c) Izračunati iznos struje kroz diodu I_D (**1 bod**).
d) Ako serijski otpor neutralnih p i n strana iznose redom 5 i 7 Ω, koliki je napon na stezaljkama diode U (**1 bod**)?

ZADATAK 4. Izlazna karakteristika nekog MOSFET-a prikazana je na slici. Faktor modulacije dužine kanala λ je približno jednak nuli.

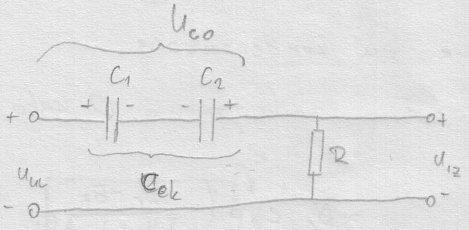
a) Uz obrazloženje, odrediti tip MOSFET-a (n ili p kanalni, obogaćeni ili osiromašeni) (**1 bod**).
b) Izračunati napon praga U_{GS0} (**3 boda**).
c) Izračunati debljinu oksida upravljačke elektrode t_{ox} ako je omjer širine i duljine kanala W/L = 20, te pokretljivost nosilaca µ=350 cm^2/Vs (**2 boda**).
d) Nacrtati prijenosnu karakteristiku i na njoj označiti položaj točaka A i B. (**2 bod**).



ELE1 - MEĐUISPIT 2013.

1. $u_{UL} = u_{C1} + u_{iz} - u_{C2} =$

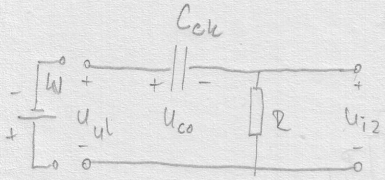
$= u_{C1} - u_{C2} + u_{iz}$



$u_{C0} = u_{C10} - u_{C20}$

$C_{ek} = \left[\frac{1}{C_1} + \frac{1}{C_2}\right]^{-1} = \left\{C_1 = C_2 = C\right\} = \left[\frac{1}{C} + \frac{1}{C}\right]^{-1} = \frac{C}{2} = \frac{2}{2} = 1\mu F$

$\tau = C_{ek} \cdot R = 10^{-6} \cdot 5{,}6 \cdot 10^{3} = 5{,}6 \cdot 10^{-3}\,s = 5{,}6\,ms$



$u_{C0} = u_{C10} - u_{C20} = 1{,}5 - 1{,}5 = 0$

$t = 0^- \Rightarrow u_{iz}(0^-) = 0$

$t = 0^+ \Rightarrow u_{iz}(0^+) = -4V$

$u_{C0} = u_{C\tau} = 0$

$u_{ek} = -4V$

$u_{iz}(t) = u_R(t) = U_R(0^+) \exp\frac{-t}{\tau}$

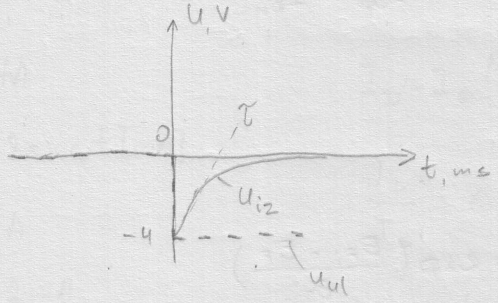
b) $u_{iz}(0^-) = 0$

$u_{iz}(0^+) = -4V$

$u_{iz}(t = 5ms)$

$u_{iz} = -4 \exp\frac{-5 \cdot 10^{-3}}{5{,}6 \cdot 10^{-3}} = -1{,}64\,V$

c)

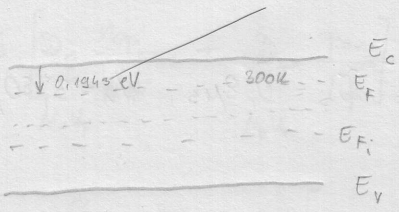


② $N_D = 2 \cdot 10^{16}\ cm^{-3}$

a) $T = 300K$

$E_F = ?$

b) $T = 400K$



a) $n_{on} = N_c \cdot \exp \frac{E_F - E_c}{E_T} \Rightarrow E_F = E_c + E_T \ln \frac{n_{on}}{N_c}$

$N_D = 2 \cdot 10^{16}\ cm^{-3} \qquad n_i = 1{,}45 \cdot 10^{10}\ cm^{-3} \Rightarrow N_D \gg n_i \Rightarrow$ EKSTRINZIČAN

$n_{on} = N_D = 2 \cdot 10^{16}\ cm^{-3}$

$N_c = C \cdot T^{\frac{3}{2}} = 7{,}07 \cdot 10^{15} \cdot (300)^{\frac{3}{2}} = 3{,}67 \cdot 10^{19}\ cm^{-3}$

$E_F = E_c + E_T \ln \frac{n_{on}}{N_c} = E_c + \frac{300}{11600} \ln \frac{2 \cdot 10^{16}}{3{,}67 \cdot 10^{19}} = E_c - 0{,}1943\ eV$

b) $T \uparrow \Rightarrow E_F \Rightarrow E_{Fi}$, $E_F \uparrow \Rightarrow N_D{+}{+}$

$N_{Duk} = N_{D1} + N_{D2}$

$T = 400K$

$N_c = C \cdot T^{\frac{3}{2}} = 7{,}07 \cdot 10^{15} \cdot 400^{\frac{3}{2}} = 5{,}66 \cdot 10^{19}\ cm^{-3}$

$n_i(400K) = C_1 T^{\frac{3}{2}} \exp \frac{-E_{G0}}{2kT} = 7{,}22 \cdot 10^{12}\ cm^{-3}$

$E_c - E_F = 0{,}1943\ eV \Rightarrow E_F - E_c = -0{,}1943\ eV$

$n_{on2} = N_c \exp \frac{E_F - E_c}{E_T} = 5{,}66 \cdot 10^{19} \exp \frac{-0{,}1943\ eV}{\frac{400}{11600}} = 1{,}02 \cdot 10^{17}\ cm^{-3}$

$n_{on2} \gg n_i \Rightarrow$ EKSTRINZIČAN

$n_{on2} \simeq N_{Duk} = N_{D1} + N_{D2} \Rightarrow N_{D2} = n_{on2} - N_{D1}$

$N_{D2} = 1{,}82 \cdot 10^{17}\ cm^{-3}$

③ n-stran

$N_D = 4 \cdot 10^{15}\ cm^{-3}$, $\mu_p = 300\ cm^2/Vs$, $\tau_p = 0,8\mu s$, $W_n = 3,50\mu m = 350 \cdot 10^{-4}\ cm$

p-strana

$N_A = 2 \cdot 10^{17}\ cm^{-3}$, $\mu_n = 800\ cm^2/Vs$, $\tau_n = 0,5\mu s$, $W_p = 0,8\mu m = 0,8 \cdot 10^{-4}\ cm$

$S = 1mm^2 = 10^{-2}\ cm^2$

a) RAVNOTEŽNE KONC.

$$p_{on} = \frac{n_i^2}{n_{on}} = \frac{n_i^2}{N_D} = \frac{(1,45 \cdot 10^{10})^2}{4 \cdot 10^{15}} = 5,26 \cdot 10^4\ cm^{-3}$$

$$n_{op} = \frac{n_i^2}{p_{op}} = \frac{n_i^2}{N_A} = \ldots = 1,05 \cdot 10^3\ cm^{-3}$$

RUBNE KONC.

$$p_{no} = p_{on} \exp \frac{U_D}{m U_T} = 5,26 \cdot 10^4 \exp \frac{0,55 \cdot 11600}{1 \cdot 300} = 9,06 \cdot 10^{13}\ cm^{-3}$$

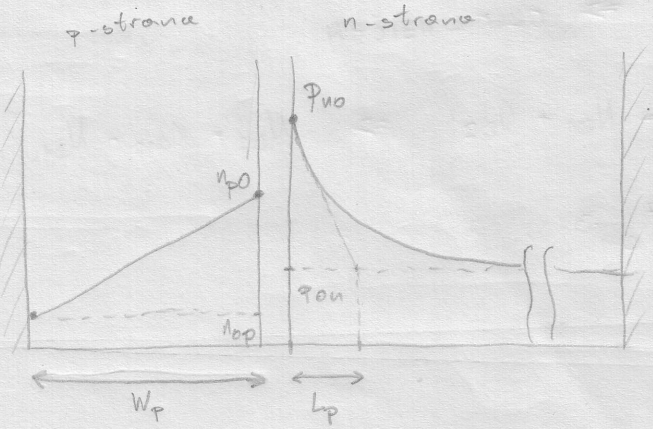
$$n_{po} = n_{op} \exp \frac{U_D}{m U_T} = \ldots = 1,81 \cdot 10^{12}\ cm^{-3}$$

$$L_n = \sqrt{D_n \tau_n} = \sqrt{\mu_n U_T \cdot \tau_n} = \sqrt{800 \cdot \frac{300}{11600} \cdot 0,5 \cdot 10^{-6}} = 32,2\mu m = 32,2 \cdot 10^{-4}\ cm$$

$$L_p = \sqrt{D_p \tau_p} = \sqrt{\mu_p \cdot U_T \cdot \tau_p} = \ldots = 24,9\mu m = 24,9 \cdot 10^{-4}\ cm$$

$W_p \ll L_n \Rightarrow$ USKA P-STRANA

$W_n \gg L_p \Rightarrow$ ŠIROKA N-STRANA



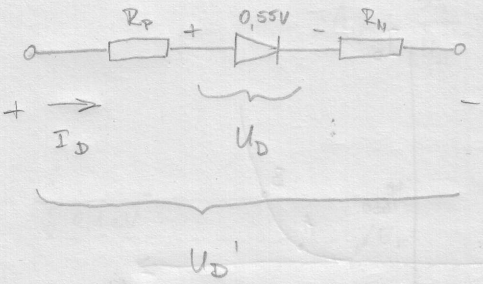
b) $I_S = I_{SN} + I_{SP} = qS\left[\underbrace{D_n}_{\mu_n U_T}\frac{n_{op}}{W_P} + \underbrace{D_P}_{\mu_P U_T}\frac{p_{on}}{L_P}\right] = qSU_T\left[\mu_n\frac{n_{op}}{W_P} + \mu_P\frac{p_{on}}{L_P}\right] =$

$= 1{,}6\cdot10^{-19}\cdot10^{-2}\,\frac{300}{11600}\left[800\,\frac{1{,}05\cdot10^{3}}{0{,}8\cdot10^{-4}} + 300\,\frac{5{,}26\cdot10^{4}}{24{,}9\cdot10^{-4}}\right] =$

$= 0{,}7\cdot10^{-12}\,A = 0{,}7\,pA$

c) $I_D = I_S\left[\exp\left(\frac{U_D}{mU_T}\right) - 1\right] = 0{,}7\cdot10^{-12}\left[\exp\left(\frac{0{,}55\cdot11600}{1\cdot300}\right) - 1\right] = 1{,}2\,mA$

d)



$U_D' = U_D + I_D(R_P + R_N) = 0{,}55 + 1{,}2\cdot10^{-3}(5+7)$

$U_D' = 0{,}564\,V$

P1

1.

(4.) a) U_{GS} pozitivan $\rightarrow$ $I_D \uparrow$ $\Rightarrow$ NMOS

- moramo znati U_{GSO}

b) A: $I_{DA} = 1mA$ B: $I_{DB} = 9_m A$

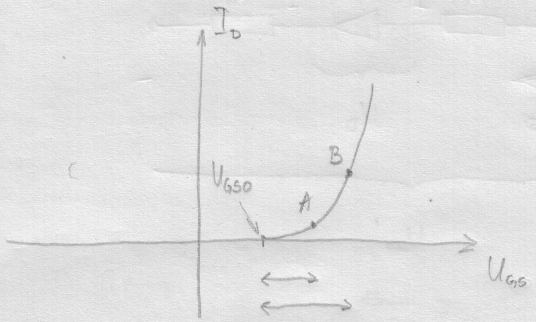
$U_{GSA} = 2V$ $U_{GSB} = 4V$

A i B u zasićenju

$$I_{DA} = \frac{K}{2}(U_{GSA} - U_{GSO})^2 \qquad I_{DB} = \frac{K}{2}(U_{GSB} - U_{GSO})^2$$

$$\frac{I_{DB}}{I_{DA}} = \frac{(U_{GSB} - U_{GSO})^2}{(U_{GSA} - U_{GSO})^2} \quad / \sqrt{\ }$$

$$\pm\sqrt{\frac{I_{DB}}{I_{DA}}} = \frac{U_{GSB} - U_{GSO}}{U_{GSA} - U_{GSO}}$$



2.

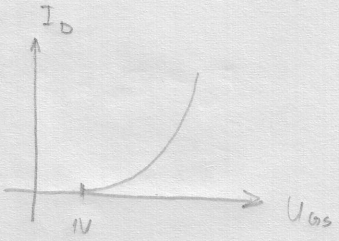
$$3 = \frac{U_{GSB} - U_{GSO}}{U_{GSA} - U_{GSO}}$$

$(U_{GSB} - U_{GSO})$ i $(U_{GSA} - U_{GSO})$ imaju isti predznak

(i u A, i u B imamo kanal)

$$3(U_{GSA} - U_{GSO}) = U_{GSB} - U_{GSO} \Rightarrow U_{GSO} = \frac{3U_{GSA} - U_{GSB}}{2} = \frac{3 \cdot 2 - 4}{2} = 1V$$

$$K = \frac{2 I_{DO}}{(U_{GSA} - U_{GSO})} = \ldots = 2\ mA V^{-2}$$

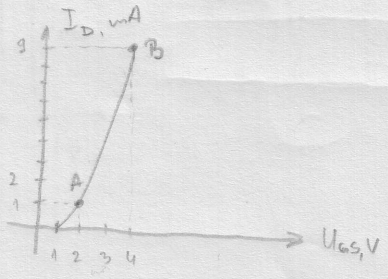


3.

u $U_{GS} = 0V \Rightarrow I_D = 0 \Rightarrow$ OBOGAĆENI SLOJ

$$K = \mu_n C_{ox} \frac{W}{L} = \mu_n \frac{\varepsilon_0 \varepsilon_{rox}}{t_{ox}} \cdot \frac{W}{L} \Rightarrow t_{ox} = \frac{\mu_n \varepsilon_0 \varepsilon_{rox}}{K} \cdot \frac{W}{L}$$

$$t_{ox} = \frac{350 \cdot 8{,}854 \cdot 10^{-14} \cdot 3{,}9}{2 \cdot 10^{-3}} \cdot 20 = 1{,}21 \cdot 10^{-6}\ cm \quad 12{,}1\ nm$$

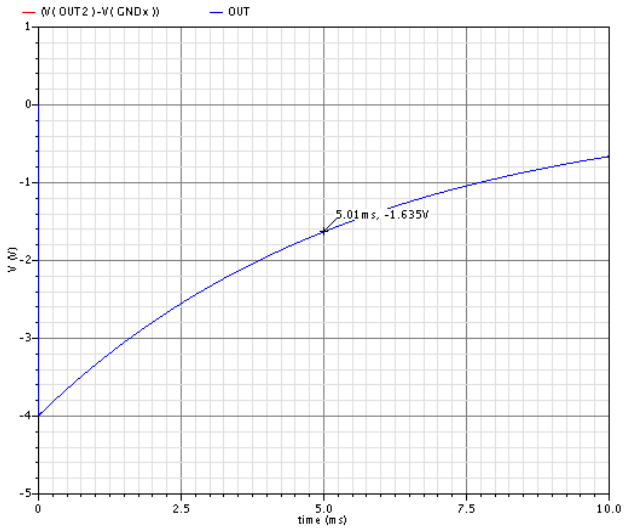


RJEŠENJA MEĐUISPITA IZ ELEKTRONIKE 1

ZADACI

ZADATAK 1.

$$u_{IZ}\left(0\ \text{ms} < t < \infty\ \text{ms}\right) = u_{IZ}\left(0\ \text{ms}\right)^{+} \cdot e^{-\frac{t}{\tau}}$$
$$u_{IZ}\left(t = 3\ \text{ms}\right) = -1{,}96\ \text{V}$$
$$u_{IZ}\left(t = 5\ \text{ms}\right) = -1{,}64\ \text{V}$$



ZADATAK 2.

$E_F = E_C$ - 0,1943 eV (2 boda)
$E_F = E_{Fi}$ + 0,36 eV

$n_{02} = 2{,}02 \cdot 10^{17}\ cm^{-3}$ (2 boda)

$N_{D2} = 1{,}82 \cdot 10^{17}\ cm^{-3}$ (2 boda)

ZADATAK 3.

$n_{0p} = 1051{,}25\ \text{cm}^{-3}$
$D_n = 20{,}7\ \text{cm}^2/\text{s}$
$L_n = 3{,}22 * 10^{-3}\ \text{cm} = 32{,}2\ \text{um}$

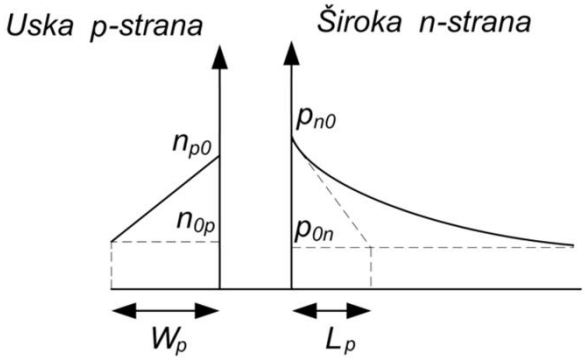
$p_{0n} = 52\,562{,}5\ \text{cm}^{-3}$
$D_p = 7{,}76\ \text{cm}^2/\text{s}$
$L_p = 2{,}49 * 10^{-3}\ \text{cm} = 24{,}9\ \text{um}$

$p_{n0} = 9{,}07 * 10^{13}\ \text{cm}^{-3}$
$n_{p0} = 1{,}81 * 10^{12}\ \text{cm}^{-3}$

$I_S = 0{,}7\,pA$

I = 1,2 mA

$U = U_D + I * R_S = 0{,}56\ \text{V}$

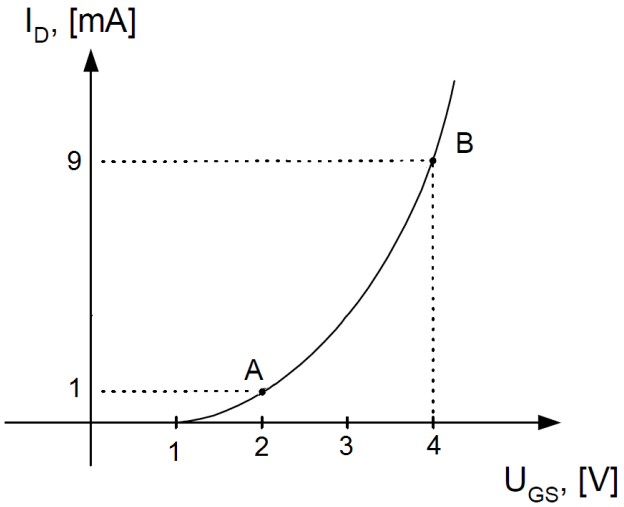


ZADATAK 4.

n-kanalni MOSFET obogaćenog tipa

U_{GS0} = 1 V

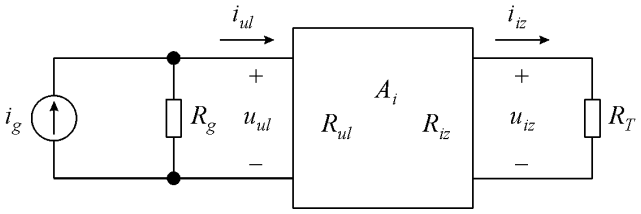
t_{ox} = 12,1 nm



PITANJA

1. Pojačalo na slici ima strujno pojačanje uz kratkospojen izlaz $A_i = 150$, ulazni otpor $R_{ul} = 1$ kΩ i izlazni otpor $R_{iz} = 4$ kΩ. Uz koji će otpor trošila R_T strujno pojačanje biti $A_I = i_{iz}/i_{ul} = 100$? Koliko je pri tome naponsko pojačanje $A_V = u_{iz}/u_{ul}$ (**2 boda**)?

a) $R_T = 8$ kΩ, $A_V = 200$
b) $R_T = 2$ kΩ, $A_V = 50$
c) $R_T = 8$ kΩ, $A_V = 100$
d) $R_T = 2$ kΩ, $A_V = 200$
e) $R_T = 8$ kΩ, $A_V = 50$



2. U siliciju dopiranom samo jednom primjesom koncentracije N, Fermijeva energija na T=300 K nalazi se 0,1 eV od dna vodljivog pojasa. Na temperaturi T=400 K vrijedi da je $N >> n_i$. Za primjesu N te specifičnu vodljivost na T=400 K u odnosu na T=300 K vrijedi (**2 boda**):

a) N su donori, σ pada
b) N su akceptori, σ raste
c) N su donori, σ raste
d) N su akceptori, σ pada
e) N su donori, σ se ne mijenja

3. *pn*-dioda sa širokim stranama ima *n*-stranu 1000 puta jače dopiranu od *p*-strane i spojena je na napon U_D=0,6 V. Da li je uz rub osiromašenog područja veća koncentracija manjinskih nosilaca na p-strani ili na n-strani? Ako se *p*-strana suzi na vrijednost $W_p = L_n/10$, što se dešava sa strujom diode (**2 boda**):

a) Veća je koncentracija manjinskih nosilaca na n-strani; struja raste.
b) Veća je koncentracija manjinskih nosilaca na p-strani; struja raste.
c) Veća je koncentracija manjinskih nosilaca na n-strani; struja pada.
d) Veća je koncentracija manjinskih nosilaca na p-strani; struja pada.
e) Veća je koncentracija manjinskih nosilaca na p-strani; struja ostaje približno ista.

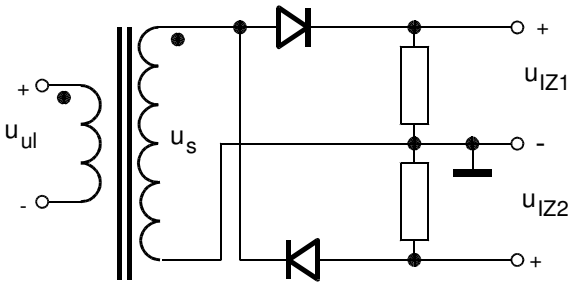
4. Kroz diodu koja ima struju zasićenja I_S=10 fA teče struja i_D=1+0,2sinωt [mA]. Uz zanemarenje serijskog otpora neutralnih strana te pretpostavku U_T=25mV, napon na diodi ima sljedeći oblik (**2 boda**):

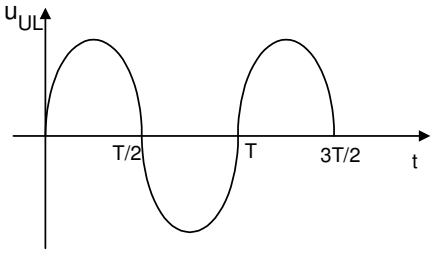
a) u_D=630+5·sinωt, [mV]
b) u_D=700+25·sinωt, [mV]
c) u_D=700+5·sinωt, [mV]
d) u_D=550+5·sinωt, [mV]
e) u_D=630+25·sinωt, [mV]

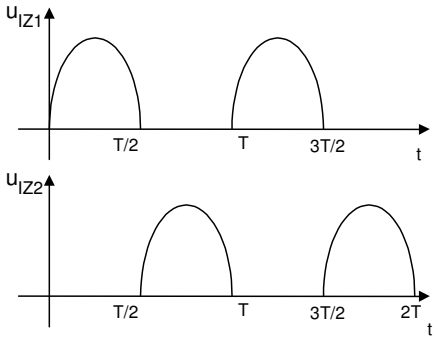
5. Koliku će valnu duljinu upadnog zračenja detektirati fotodioda sa širinom zabranjenog pojasa od 2,1 eV i kakva mora biti polarizacija fotodiode za tu detekciju (**2 boda**)?

a) $\lambda = 0{,}59$ μm, zaporna polarizacija,
b) $\lambda = 1{,}7$ μm, ne mora biti polarizirana
c) $\lambda = 1{,}7$ μm, zaporna polarizacija
d) $\lambda = 1{,}7$ μm, propusna polarizacija
e) $\lambda = 0{,}59$ μm, propusna polarizacija

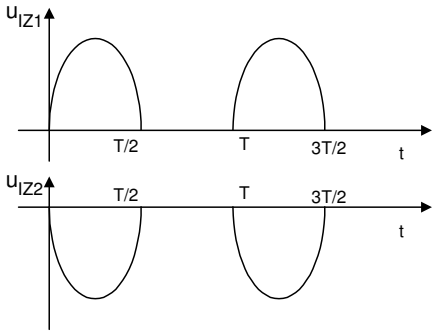
6. Na ulaz sklopa ispravljača priključen je sinusni ulazni napon. Kako izgledaju izlazni naponi (**2 boda**)?



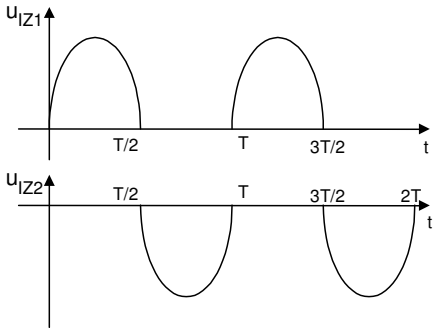




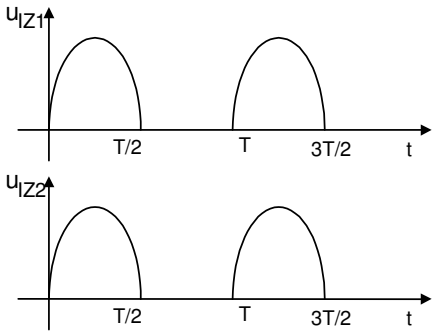
a)



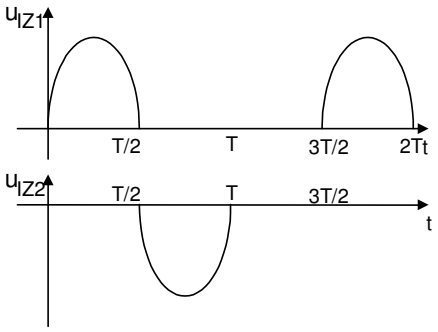
b)



c)

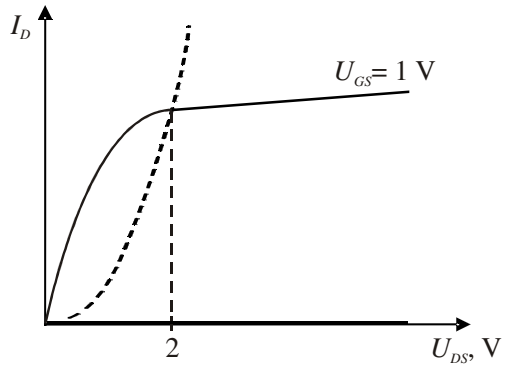


d)



e)

7. Na slici su prikazane izlazne karakteristike tranzistora. Za tip tranzistora vrijedi (**2 boda**):



a. *n*-kanalni MOSFET obogaćenog tipa,
b. *p*-kanalni MOSFET obogaćenog tipa,
c. *n*-kanalni MOSFET osiromašenog tipa,
d. *p*-kanalni MOSFET osiromašenog tipa,
e. *p*-kanalni MOSFET u triodnom području.

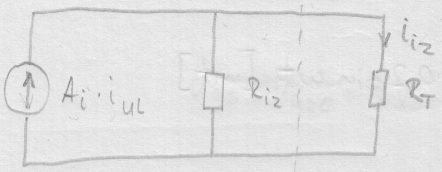
PITANJA

1. $A_i = 150$

$R_{ul} = 1\,k\Omega$

$R_{iz} = 4\,k\Omega$

$A_I = \frac{i_{iz}}{i_{ul}} = 100$

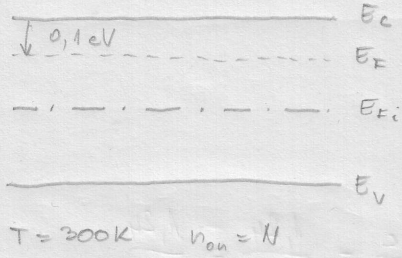


$$A_I = \frac{i_{iz}}{i_{ul}} = \frac{A_i \cdot i_{ul} \frac{R_{iz}}{R_{iz}+R_T}}{i_{ul}} \Rightarrow \frac{A_i}{A_I} = \frac{R_{iz}+R_T}{R_{iz}}$$

$$R_T = R_{iz}\left[\frac{A_i}{A_I} - 1\right] = 4\left[\frac{150}{100} - 1\right] = 2\,k\Omega$$

$$A_v = \frac{u_{iz}}{u_{ul}} = \frac{i_{iz} R_T}{i_{ul} R_{ul}} = A_I \frac{R_T}{R_{ul}} = 100 \cdot \frac{2}{1} = 200$$

2.



$T = 300K \quad n_{on} = N$

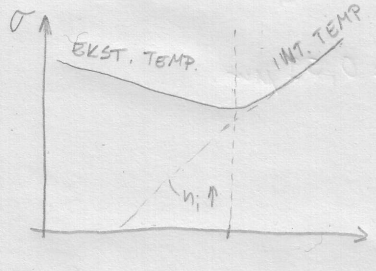
$E_F > E_{Fi} \Rightarrow$ n-tip $\quad N = N_D$

$T = 400K$

$N \gg n_i \Rightarrow n_{on} = N$

$\sigma = \sigma_N = q \mu_n \cdot n_{on}$ ← KONST.

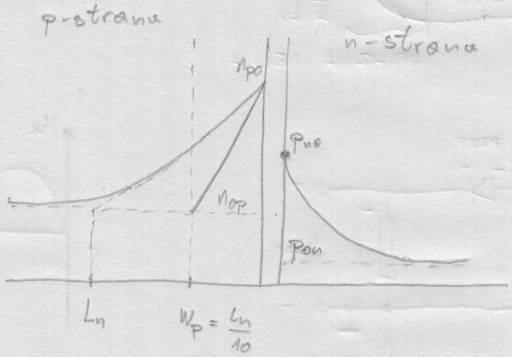
$T \uparrow \Rightarrow \mu_n \downarrow \Rightarrow \sigma \downarrow$



3. $N_D = 1000\, N_A$

$p_{on} = \frac{n_i^2}{N_D} \ll n_{op} = \frac{n_i^2}{N_A}$

n-strana $\quad$ p-strana



1) ŠIROKA

$$I_{D1} = I_{DP} = q S D_n \frac{dn}{dx} = q S D_n \frac{n_{po}}{L_n}$$

2) $$I_{P2} = I_{DP} = q S D_n \frac{n_{po}}{W_p}$$

STRUJA RASTE

$$\frac{I_{D2}}{I_{D1}} = \frac{L_n}{W_p} = \frac{L_n}{\frac{L_n}{10}} = 10$$

4. $I_S = 10\,fA = 10 \cdot 10^{-15}\,A$

$i_D = I_D + I_{dm} \cdot \sin \omega t = 1 + 0{,}2 \sin \omega t\ [mA]$

$I_D = 1\,mA$

$I_{dm} = 0{,}2\,mA$

$I_D \doteq I_S \exp \frac{U_D}{U_T} \Rightarrow U_D = U_T \ln \frac{I_D}{I_S} = 25 \cdot \ln \frac{10^{-3}}{10 \cdot 10^{-15}} = 633\,mV \approx 630\,mV$

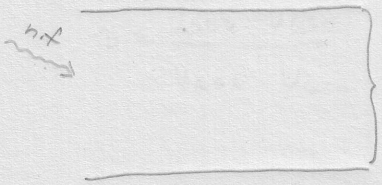
- MALI SIGNAL VIDI DINAMIČKI OTPOR

$r_d = \frac{U_T}{I_D} = \frac{25}{1} = 25\,\Omega$

$U_{dm} = r_d I_{dm} = 25 \cdot 0{,}2 \cdot 10^{-3} = 5 \cdot 10^{-3}\,V = 5\,mV$

$u_D = U_D = U_D + U_{dm} \sin \omega t = 630 + 5 \sin \omega t\ [mV]$

5.

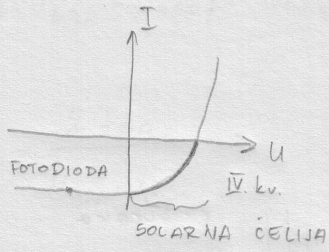


$h \cdot f > E_G$

$h \cdot \frac{c}{\lambda}$

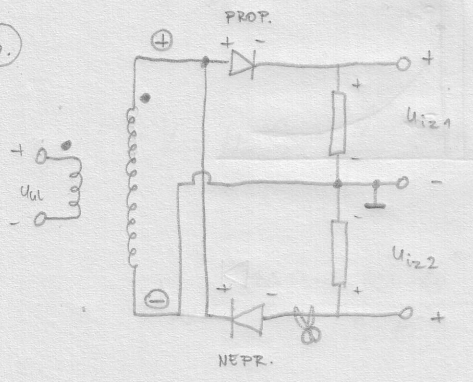
$\lambda = \frac{hc}{E_G} = \frac{1{,}24}{E_G} = \frac{1{,}24}{2{,}1}$

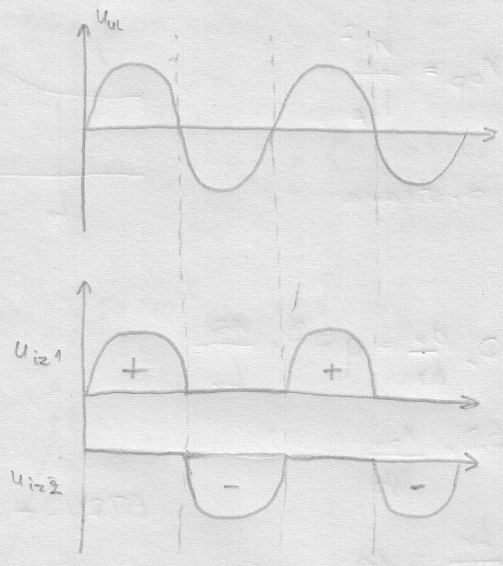
$\lambda = 0{,}59\,\mu m$



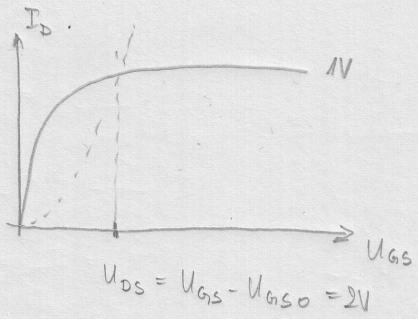
REVERZNO POL.

6.





7. $U_{DS} > 0 \Rightarrow$ NMOS

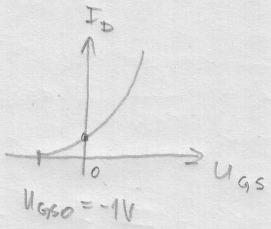


$U_{GS} - U_{GSO} = 2V$

$U_{GSO} = U_{GS} - 2 = 1 - 2 = -1V$

NMOS
$U_{GSO} < 0$ } OSIROMAŠENO

iz $U_{GSO} = 0 \Rightarrow |I_D| > 0$ OSIROMAŠENO



PITANJA

	A	**B**	**C**	**D**
1	D	B	E	C
2	A	D	B	E
3	B	E	C	A
4	A	D	B	E
5	A	D	B	E
6	C	D	B	B
7	C	A	D	B