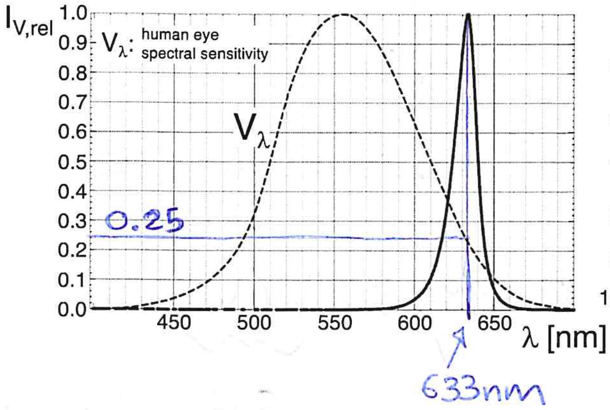
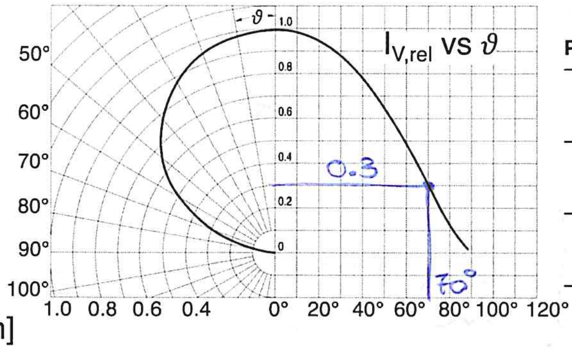
SOLUZIONI ESAME 29-06-18

ES 1

Osram LR G6SP





PARAMETER	VALUE
Luminous Intensity	I_V = 5600 mcd
Forward voltage	V_F = 2.1 V
Forward current	I_F = 140 mA

a) Calcolare E_{GAP}

$E_{PH} = E_{GAP} + \frac{kT}{2}$, $T = 25\ °C = 298.15\ K$

$E_{PH} = \frac{hc}{\lambda}$

Dal grafico $\lambda \simeq 633\ nm \rightarrow E_{PH} = 1.959\ eV$

$\rightarrow E_{GAP} = E_{PH} - \frac{kT}{2} = 1.946\ eV$

b) Verificare l'emissione Lambertiana, calcolare η_{LE} e η_{PCE}

ϑ	I_V grafico	$I_V = I_{V,0} \cos\vartheta$
30°	$\sim 0.88\ I_{V,0}$	$0.87\ I_{V,0}$
45°	$\sim 0.65\ I_{V,0}$	$0.7\ I_{V,0}$
60°	$\sim 0.5\ I_{V,0}$	$0.5\ I_{V,0}$

$\rightarrow$ La caratteristica di emissione è ben approssimata dalla legge di Lambert del coseno: $I_V(\vartheta) = I_{V,0} \cos\vartheta$

Dalla tabella $I_{V,0} = 5.6\ cd$

$\rightarrow$ Flusso luminoso $\Phi_V = \pi \cdot I_{V,0} = 17.6\ lm$

efficacia luminosa $\eta_{LE} = \dfrac{\Phi_v}{V_F I_F} = 59.9 \dfrac{lm}{W}$

efficienza di conversione elettro-ottica $\eta_{PCE} = \dfrac{\Phi_r}{V_F I_F}$

→ Si deve calcolare il flusso radiante Φ_r (= potenza ottica emessa)

$$\Phi_v = 683 \frac{lm}{W} \int_0^\infty \underbrace{\Phi_{r,\lambda}}_{\text{flusso radiante spettrale} \simeq \Phi_r \delta(\lambda-\lambda_0)} V(\lambda)\, d\lambda = 683 \frac{lm}{W} \Phi_r \underbrace{V(\lambda_0)}_{0.25,\ \text{dal grafico}}$$

$$\Phi_r = \frac{\Phi_v}{683 \frac{lm}{W} \cdot 0.25} = 103\ mW$$

$$\eta_{PCE} = \frac{\Phi_r}{V_F I_F} = 35\%$$

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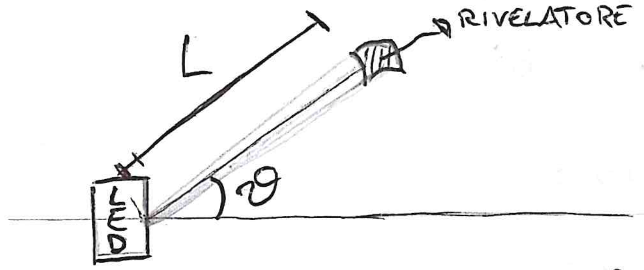
c) ϑ_{MAX} per avere $P_{riv} \geq 0.5\ nW$



$P_{riv} = I_r(\vartheta)\, \Omega_{riv}$

I_r: intensità radiante

Ω_{riv}: angolo solido "visto" dal LED

$P_{riv} = k\, I_{r,0}\, \Omega_{riv}$; $k = \dfrac{I_r(\vartheta)}{I_{r,0}}$

$$\Omega_{riv} = \frac{A}{L^2} = 50\ nsr$$

$$I_{r,0} = \frac{\Phi_r}{\pi} = 32.8 \frac{mW}{sr}$$

$k\, I_{r,0}\, \Omega_{riv} \geq 0.5\ nW \rightarrow k \geq 0.3 \rightarrow I_r(\vartheta) \geq 0.3\, I_{r,0}$

$\Rightarrow \vartheta_{MAX} = 70°$, dal grafico

ES 2

Laser He-Ne

$m_{He} = 0.66 \times 10^{-26}$ kg , $m_{Ne} = 3.35 \times 10^{-26}$ kg

$\lambda_0 = 632.8$ nm

cavità Fabry-Perot $L = 50$ cm

$R_1 = 96\%$ $R_2 = 99.9\%$

$\tau_{PU} = 30$ ns

$B_{21} = 1.52 \times 10^{20} \frac{m}{kg}$

$T = 160\,°C$

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1) Calcolare il numero di modi oscillanti

$$M = \frac{\Delta\nu_{Doppler, FWHM}}{\Delta\nu_{FSR}}$$

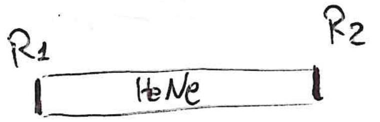
$$\Delta\nu_{D,FWHM} = 2\nu_0 \sqrt{\frac{kT \cdot 2\ln(2)}{M_{Ne} \cdot c^2}}$$

$$\nu_0 = \frac{c}{\lambda_0} = 474 \text{ THz}$$

$T = 433$ K

$\Delta\nu_{D,FWHM} = 1.57$ GHz

cavità



condizione di risonanza $L = m \frac{\lambda}{2n}$, $n \simeq 1$

modi di cavità: $\nu_m = m \frac{c}{2L}$

$$\rightarrow \Delta\nu_{FSR} = \frac{c}{2L} = 300 \text{ MHz}$$

$M \cong 5$ modi

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b) Determinare α_s

$$\tau_{ph} = 30\,ns = \frac{n^{\simeq 1}}{c\,\alpha_T} \longrightarrow \alpha_T = \frac{1}{c\,\tau_{ph}} = 0.111\ m^{-1}$$

$$\alpha_T = \alpha_s + \frac{1}{2L}\ln\left(\frac{1}{R_1 R_2}\right)$$

$$\Rightarrow \alpha_s = \alpha_T - \frac{1}{2L}\ln\left(\frac{1}{R_1 R_2}\right) = 0.069\ m^{-1}$$

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c) $(N_2 - N_1)_{th}$

coefficiente di guadagno: $g \triangleq \frac{dP}{P\,dx} = \frac{dN_{ph}}{N_{ph}\,\frac{c}{n}\,dt} = \frac{1}{N_{ph}\,c}\frac{dN_{ph}}{dt}$ $\quad (n = 1)$

$$\frac{dN_{ph}}{dt} = (\text{rate emissioni stimolate}) - (\text{rate assorbimento})$$

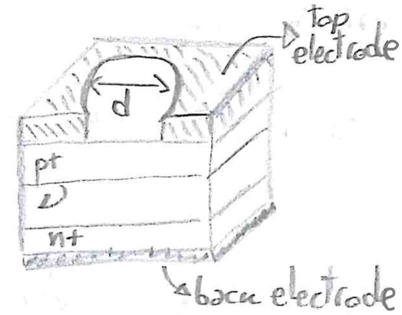
$$= N_2 B_{21}\rho(\nu) - N_1 B_{12}\rho(\nu) \underset{B_{21}=B_{12}}{=} (N_2 - N_1) B_{21}\rho(\nu)$$

$$\rho(\nu) \sim \frac{N_{ph}(h\nu_0)}{\Delta\nu_{Doppler,\,FWHM}}$$

$$\Longrightarrow g_{th} = \frac{1}{N_{ph}} \cdot \frac{1}{c} \cdot (N_2 - N_1)_{th} \cdot B_{21} \cdot \frac{N_{ph}(h\nu_0)}{\Delta\nu_{FWHM}}$$

$$(N_2 - N_1)_{th} = c \cdot \underbrace{g_{th}}_{=\alpha_T \text{ in regime stazionario}} \cdot \frac{1}{B_{21}} \cdot \frac{\Delta\nu_{FWHM}}{h\nu_0} = 1.1 \times 10^{15}\ m^{-3}$$

ES 3



Fotodiodo pin in Si.

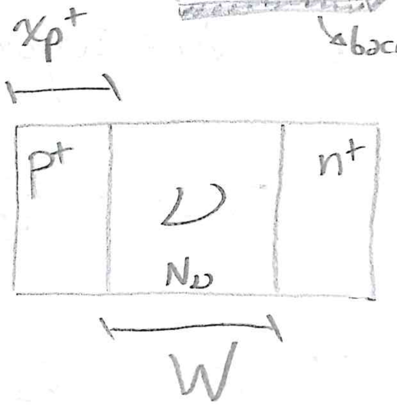
$x_{p^+} = 150\ \text{nm}$

regione quasi-intrinseca $N_D = 2\times10^{13}\ \text{cm}^{-3}$

diametro sup. fotosensibile $d = 1.6\ \text{mm}$

$I_d = 1.5\ \text{nA}$

$R_L = 50\ \Omega$



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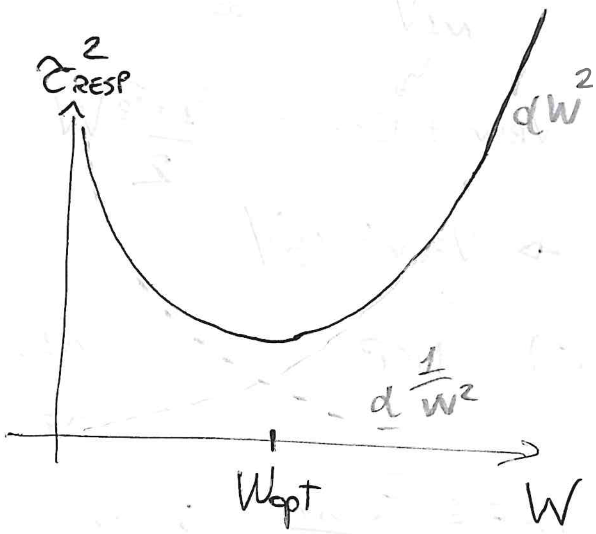
2) W_{opt}, $\tau_{RESP,opt}$, $\tau_{RESP}\big|_{W=20\mu m}$

$$\tau_{RESP} = \sqrt{\tau_{transit}^2 + \tau_{RC}^2}$$

$$\tau_{transit} = \frac{W}{v_{DRIFT}} = \frac{W}{v_{SAT}}$$

hyp: $F \geq F_{sat}$ in tutta la regione ν

(W: estensione della regione ν)



$$\tau_{RC} = C_{DEP} R_L = \varepsilon_0 \varepsilon_r \frac{A}{W} R_L$$

minimizzo τ_{RESP}: $\dfrac{d(\tau_{RESP}^2)}{dW} = 0$

$$\frac{2W_{opt}}{v_{SAT}^2} - \frac{2(\varepsilon_0\varepsilon_r A R_L)^2}{W_{opt}^3} = 0$$

$$W_{opt}^4 = (\varepsilon_0\varepsilon_r v_{SAT} A R_L)^2 \rightarrow W_{opt} = \sqrt{\varepsilon_0\varepsilon_r v_{SAT} A R_L} \simeq 32\ \mu m$$

pongo $W = W_{opt}$:

$$\tau_{transit,opt} = \sqrt{\frac{\varepsilon_0\varepsilon_r A R_L}{v_{SAT}}} = 323\ ps \quad ; \quad \tau_{RC,opt} = \sqrt{\frac{\varepsilon_0\varepsilon_r A R_L}{v_{SAT}}} = 323\ ps$$

$\tau_{tr,opt} = \tau_{RC,opt}$ → Il tempo di risposta del fotodiodo è minimo quando le due costanti di tempo sono uguali.

$\tau_{RESP,opt} = 456\ ps$

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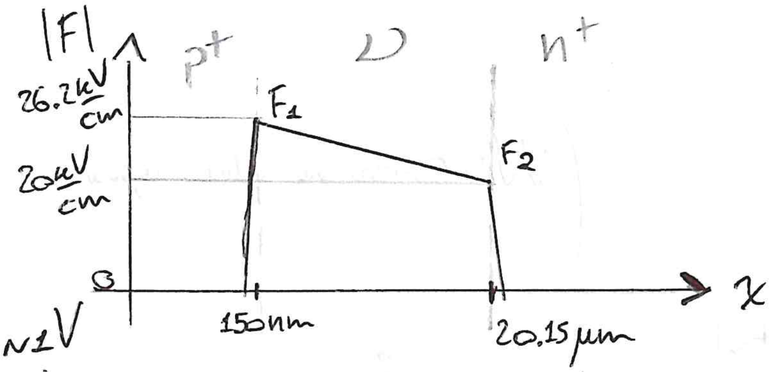
b) V_{REV} per avere saturazione di velocità in ν, e grafico $F(x)$ vs. x



Devo porre $F_2 \geq F_{SAT}$

→ $F_2 = F_{SAT} = 20\ \frac{kV}{cm}$

$$F_1 = F_2 + \frac{qN_\nu W}{\varepsilon_0 \varepsilon_r} = 26.2\ \frac{kV}{cm}$$

$\approx 1V$

$$V_{REV} + \Phi_{BI} = \frac{F_1 + F_2}{2} W$$

→ $V_{REV} \simeq 45V$

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c) NEP a $\lambda_1 = 400\ nm$ $(\alpha_1 = 9.52 \times 10^4\ cm^{-1})$

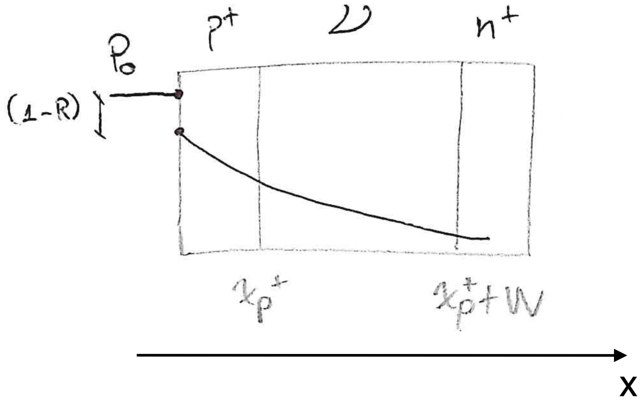
$$NEP \triangleq \frac{P_{o,min}}{\sqrt{BW}} \; ; \; P_{o,min} = \frac{I_{ph,min}}{\Re} = \frac{\sqrt{2q(I_{ph,min} + I_d)BW}}{\Re}$$

responsivity

$$NEP = \frac{\sqrt{2qI_D}}{\Re}$$

[hyp: $I_{ph,min} \ll I_{dark}$]

$$P(x) = P_0(1-R)\,e^{-\alpha x}$$



$$\mathcal{R} = \eta \frac{q\lambda}{hc}$$

$$\eta = (1-R)\, e^{-\alpha x_p} \left(1 - e^{-\alpha W}\right)$$

$n_{Si} = 3.42$

$$R = \left(\frac{n_0 - n_{Si}}{n_0 + n_{Si}}\right)^2 = 0.3$$

$$\eta_1 = 0.7 \cdot 0.2338 \cdot 1 = 0.168$$

$$\mathcal{R}_1 = \eta_1 \frac{q\lambda_1}{hc} = 54.2 \ \frac{mA}{W}$$

$$NEP_1 = 4 \times 10^{-13} \ \frac{W}{\sqrt{Hz}}$$

La NEP dipende da λ per la dipendenza di $\mathcal{R}$ da λ