18.1-1 Determine the factor $1-R$ in the expr. for the quantum efficiency.

Normal incidence

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2 \qquad n_1 = \text{air} = 1$$
$$n_2 = \text{semiconductor}$$

Tabel 16.2-1
$n_{Si} = 3,5$
$n_{GaAs} = 3,6$
$n_{InSb} = 4,2$

$\Longrightarrow \quad R_{Si} = 31\% \quad \Rightarrow \quad (1-R)_{Si} = 69\%$

$R_{GaAs} = 32\% \quad (1-R)_{GaAs} = 68\%$

$R_{InSb} = 34\% \quad (1-R)_{InSb} = 62\%$

18.1-2 Responsivity

Find maximum responsivity for an ideal photodetector (unity quantum efficiency η and unity gain G)

$$\eta = (1-R)\,\zeta\,(1-e^{-\alpha d}) = 1$$

$$\mathcal{R} = \frac{\eta \cdot e}{h\nu} = \eta \cdot \frac{\lambda_0}{1240} \quad [A/W\ ;\ \lambda_0 \text{ in nm}]$$

$$\mathcal{R}_{Si} = 1 \cdot \frac{\lambda_0^{E_g,Si}}{1240}$$

...

Tabel 16.1-2

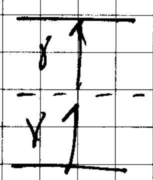
$$\left.\begin{aligned} \lambda_{Si} &= 1{,}11\,\mu m \\ \lambda_{GaAs} &= 0{,}873\,\mu m \\ \lambda_{InSb} &= 7{,}29\,\mu m \end{aligned}\right\} \Rightarrow \begin{aligned} \mathcal{R}_{Si} &= 0{,}88 \\ \mathcal{R}_{GaAs} &= 0{,}70 \\ \mathcal{R}_{InSb} &= 5{,}88 \end{aligned}$$

18.1-5 ~~Two photon detector~~

Beam of photons $h\nu$, photon flux density ϕ (#/cm²-s)

$h\nu < E_g < 2h\nu$

(in S8T ϕ = photon flux
$P = h\cdot\nu\cdot\phi$)



Current density $= J_p \equiv \zeta\cdot\phi^2$; ζ is constant

Show that the responsivity (A/W) is given by

$$\mathcal{R} = \left[\zeta/(h\cdot c_o)^2\right]\cdot\lambda_o^2\cdot P/A$$

Physically explain λ_o^2 and P/A

$$\left.\begin{aligned}\mathcal{R} &= i/P \\ J_p &= \zeta\cdot\phi^2\end{aligned}\right\} \Rightarrow \mathcal{R} = i/P = \frac{i/A}{P/A} = J_p/_{P/A} = \frac{\zeta\cdot\phi^2}{P/A}$$

We can write optical power P as $P = h\nu\,(\phi\cdot A) \Rightarrow$

photon flux density !!

$$\Rightarrow \begin{cases}\mathcal{R} = \zeta\cdot\phi^2/_{P/A} \\ \phi = \dfrac{P/A}{h\cdot\nu} = \dfrac{P/A\cdot\lambda}{h\cdot c}\end{cases}$$

since $h\nu = \dfrac{h\cdot c}{\lambda} \Rightarrow \dfrac{1}{h\nu} = \dfrac{\lambda}{h\cdot c}$

$$\Rightarrow \mathcal{R} = \zeta\,\frac{(P/A)^{\cancel{2}}\cdot\lambda^2}{(h\cdot c)^2}\,\frac{1}{\cancel{P/A}} = \underline{\underline{\zeta\,\frac{\lambda^2}{(h\cdot c)^2}\cdot P/A}}$$

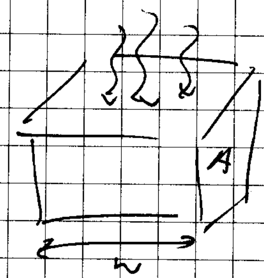
18.2-2 Photoconductivity

$n_i = 1{,}5 \cdot 10^{10}\ cm^{-3}$

recombination lifetime $\tau = 10\,\mu s$

optical power density $1\,mW/cm^3$ at $\lambda = 1\,\mu m$

$$\left.\begin{aligned} R &= \eta \cdot \phi / w \cdot A \\ R &= \Delta n / \tau \end{aligned}\right\} \Rightarrow$$



$$\Delta n = \eta \cdot \tau \cdot \phi / w \cdot A = \eta \cdot \tau \,(P/w \cdot A) / h \cdot \nu$$

$$\Rightarrow \frac{\Delta \sigma}{\sigma} = \frac{\Delta n}{n_i} = \frac{\eta \cdot \tau \cdot (P/wA) \cdot \lambda / h \cdot c}{n_i} =$$

$$= / \text{si unit} / = \frac{1/2 \cdot 10 \cdot 10^{-6} \cdot 1 \cdot 10^{3} \cdot 1 \cdot 10^{-6} / h \cdot c}{1{,}5 \cdot 10^{10}} = \underline{\underline{167\%}}$$

18.3-1 Quantum efficiency PDs p-i-n

Light pulse 6×10^{12} photons, $\lambda_0 = 1550nm$

$\Rightarrow$ $2\times10^{12} e^-$ collected at the terminal

Determine quantum efficiency η and responsivity $\mathcal{R}$ of the PD.

$\phi = 6\cdot10^{12}$ photons

$$\left.\begin{aligned} i_p &= e\cdot\phi\,\eta \\ i_p &= 2\times10^{12}\,e^- \end{aligned}\right\} \Rightarrow \eta = \frac{2}{6} = \underline{\underline{\frac{1}{3}}}$$

$$\text{Responsivity} = \frac{\eta\cdot e}{h\nu} = \eta\cdot\frac{\lambda_0}{1240} = \frac{1}{3}\cdot\frac{1550}{1240} =$$

$$= \underline{\underline{0{,}42\ A/W}}$$

18.4-1 APD $\bar{G} = 20$ $\lambda_0 = 1550\,nm$

1) If $R = 12\,A/W$, calculate η

2) i_p at output if $\phi = 10^{10}$ photons/s at this wavelength?

Devices with gain | $\boxed{R = \frac{\eta \cdot G \cdot e}{h\nu} = \eta \cdot G \frac{\lambda_0}{1240}}$ (A/W λ_0 in nm.)

1) $\Rightarrow \eta = \frac{1240 \cdot R}{\lambda_0} \frac{1}{G} = \frac{1240 \cdot 12}{1550} \cdot \frac{1}{20} = \underline{\underline{0{,}48}}$

2) $i_p = \eta \cdot e \cdot \phi = \cancel{0{,}53\,nA}$ ~~530 pA~~

$= \underline{\underline{0{,}77\,nA}}$