University of Technology
Department of Laser& Optoelectronics Engineering
Final Examination 2011-2012

Subject: Optical detectors
Division: Optoelectronics Eng.
Examiner: Dr. Mehdi Munshid Shellal

Class: 3^{rd} *year*
Time:3 hours
Date: 4 / 6 /2012

Answer only five questions

All questions have same weights (10 marks)

Q1:(a) What are the main requirements for a photodetector ?

(b) For a photoconductive detector if the energy hυ of incident photons exceeds the band gap energy, an electron-hole pair is generated. Derive the quantum efficiency η using the responsivity R concept?

(c) Show that $R \approx \frac{\eta\lambda}{1.24}$, where R is responsivity figure of merit of the detector in A/W unit.

(d) Let we have a semiconductor slab of absorption coefficient α. It is assumed that the facets of this slab have antireflection coating, then the power transmitted through the slab of width w is $P_{tr} = P_{in}e^{-\alpha w}$. Show that $\eta_{abs} = 1 - e^{-\alpha w}$

Q2:(a)There two photoconductive processes. What are they? Explain each one?

(b) If the photocurrent of a photovoltaic detector is $i_{so} = \frac{\eta q P_\lambda \lambda}{hc}$. Using the current-voltage characteristic of a diode at zero bias. Show that the open circuit photovoltage, i.e., the photovoltaic signal v_{so} is given by

$$v_{so} = \frac{\eta \lambda P_\lambda \beta kT}{hcI_s}.$$

(c) For quantum (photo) detectors, there are three principal effects. What are they? Then state only one of them?

Q3: **(a)** All detectors are limited in the minimum radiant power which they can detect by some form of noise. This noise may arise from three possibilities, what are they?

(b) In absence of electrical bias, the absolute minimum noise exists, termed Johnson" noise, "Nyquist" noise or "thermal" noise. This form of noise arises from the random motion of the current carriers within any resistive material. There are three principal forms of excess noise exist. What are they?

(c) Write the short circuit G-R noise current i_N and the open circuit G-R noise voltage v_N for a simple one-level extrinsic photoconductor which appear only in the presence of a bias current I_B? Explain each parameter used here?

"اقلب الصفحة رجاءا"

(1)

Q4:(a) Show that at zero bias that, shot noise current is equivalent to the Johnson noise current?

(b) What is the general expression for the noise current of 1/f power law noise? Explain all its parameters?

(c) Let you have a phototransistor, voltage comparator, battery of 12 volt, LED and some resistors. Design a basic phototransistor detector circuit?

(d) Let you have a photocell, voltage comparator, battery of 12 volt, LED and some resistors. Design a basic cds photocell detector circuit?

Q5: **(a)** Explain the thermal resistances for thermal detectors corresponding to the three mode of heat transfer, conduction, convection, and radiation?

(b) If we add heat at the rate $q\,J/s$ for time Δt and the resulting Temperature rise is Δt, then we can define the thermal capacitance to be $C_{th} = \frac{q\,\Delta t}{\Delta T}$. If the temperature rises from value T_o at time t_o to T_1 at time t_1, then we can write $T_1 - T_O = \Delta T(t) = \frac{1}{C_{th}}\int_{t_o}^{t_1} q(t)dt$.

Show the heattransfer $q(t)$ in the differential form?

Q6: If $\frac{d}{dt}(\Delta \mathrm{T}) + \frac{G_{th}}{C_{th}}\Delta \mathrm{T} = \frac{\eta}{C_{th}} P_{\omega} e^{j\omega t}$, using integrating factor. Show that

$$\Delta \mathrm{T}_{\omega} = \frac{\eta P_{\omega}}{G_{th}(1+\omega^2\tau_{th}^2)^{1/2}} \quad ?$$

Good luck

حلول نموذج رقم (١)

Q1 (a) It should have high:
① Sensitivity ② fast response ③ low noise ④ low cost and ⑤ high reliability. It size should be Compatible with the fiber-core size. These requirements are best met by photodetectors made of Semiconductor materials.

(b)
The photocurrent I_p is directly proportional to the incident optical power P_{in},

$$I_p \propto P_{in}$$
$$I_p = R P_{in}$$

quantum efficieny $= \eta = \dfrac{\text{electron generation rate}}{\text{Photon incidence rate}}$

$$= \frac{I_p/q}{P_{in}/h\nu} = \frac{I_p \, h\nu}{q \, P_{in}} = \frac{R h\nu}{q}$$

(C) $\longrightarrow \therefore \quad \eta = \dfrac{R h c}{q \lambda}$

$$\therefore \quad R = \frac{\eta q \lambda}{h c}$$

$$= \frac{\eta \lambda}{1.24} \quad \text{where} \quad \frac{q}{hc} = \frac{1}{1.24}$$

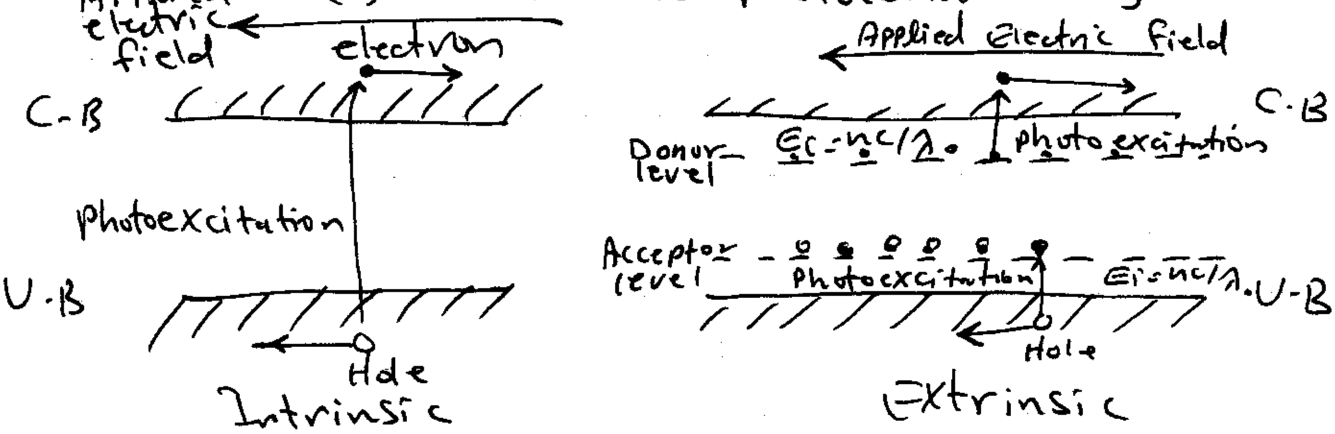
(d)

$$P_{abs} = P_{in} - P_{tr}$$
$$= P_{in} - P_{in} e^{-\alpha w} = P_{in}(1 - e^{-\alpha w})$$
$$\eta_{abs} = \frac{P_{abs}}{P_{in}} = \frac{\cancel{P_{in}}(1 - e^{-\alpha w})}{\cancel{P_{in}}}$$
$$= 1 - e^{-\alpha w}$$

Q_2 (a)

(1) Intrinsic photoconductivity

(2) Extrinsic Photoconductivity



$$h\nu \geq E_g \Rightarrow \frac{hc}{\lambda} \geq E_g \Rightarrow \lambda \leq \frac{hc}{E_g}$$

$$\lambda_o = \frac{1.24}{E_g(eV)}$$

(b) The I-V characteristic of a diode is given by

$$I_d = I_s\left[\exp(qV/\beta kT) - 1\right]$$

$$\frac{1}{R} = \left.\frac{dI_d}{dV}\right|_{V=0} = \left. I_s \frac{q}{\beta kT} e^{qV/\beta kT}\right|_{V=0}$$

$$= I_s \frac{q}{\beta kT}$$

$$\therefore \quad R = \frac{\beta kT}{I_s q}$$

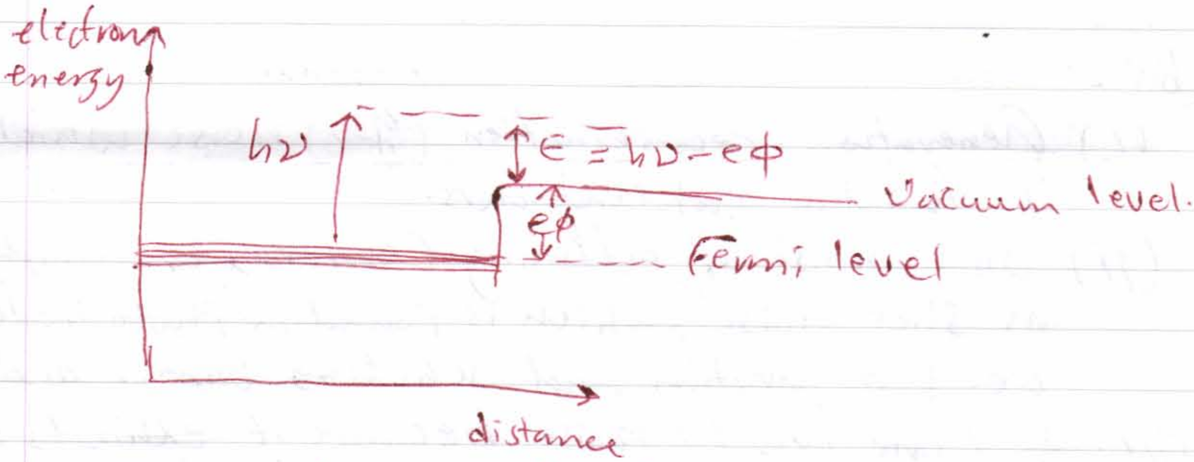
$$V_{so} = i_{so} R = \frac{\eta P_\lambda \cancel{q} \lambda}{hc} * \frac{\beta kT}{I_s \cancel{q}}$$

$$= \frac{\eta P_\lambda \lambda \beta kT}{hc I_s}$$

Q2

(c) (1) photoconductive Effect
(2) photovoltaic Effect
(3) Photoemissive Effect

Photoemissive Effect



ϕ = surface work function
e = electron charge
E = electron kinetic energy
$h\nu$ = photon energy

Q3 (a) (i) in the detector itself.
(ii) in the radiant energy to which the detector responds, or
(iii) in the electronic system following the detector

(b)
(i) Generation-recombination (g-r) noise which is found in photoconductors.
(ii) Shot noise of diffusing carriers, or simply as shot noise, which is found in photodiodes, i.e. p-n junction and schottky barrier diodes.
(iii) $\frac{1}{f}$ (one over f) noise because it exhibits a $1/f$ power law spectrum to a close approximation. It also ~~has~~ been called flicker noise, a term carried over from a similar power law form of noise in vacuum tubes.

(c) Write the short circuit G-R noise current i_N and the open circuit G-R noise voltage V_N, which appear only in the presence of a bias current I_B.

$$i_N = 2 I_B \left[\frac{\tau \Delta f}{N_0 (1+\omega^2 \tau^2)} \right]^{1/2}$$

$$V_N = 2 I_B R \left[\frac{\tau \Delta f}{N_0 (1+\omega^2 \tau^2)} \right]^{1/2}$$

Q4

(a) $$i_N = \left[(2qI + 4qI_0)\Delta f\right]^{1/2}$$

The diode equation is

$$I = I_0\left[e^{qV/kT} - 1\right]$$

$$\frac{1}{R} = \frac{dI}{dV} = I_0 \frac{q}{kT} \Rightarrow R = \frac{kT}{I_0 q} \equiv$$

at zero bias $I = 0$ $$\Rightarrow \boxed{I_0 = \frac{kT}{qR}}$$

$$\therefore i_N = \left[\left(0 + 4\cancel{q}\frac{kT}{\cancel{q}R}\right)\Delta f\right]^{1/2}$$

$$\therefore i_N = \left[\frac{4kT\Delta f}{R}\right]^{1/2}$$

$\equiv$ Johnson Noise.

(b) $$i_N = \left(\frac{K_1 I_B^{\alpha} \Delta f}{f^{\beta}}\right)^{1/2}$$

$K_1 \equiv$ proportionality factor

$I_B \equiv$ bias Current

$\Delta f \equiv$ The ~~measurement~~ measurement bandwidth.

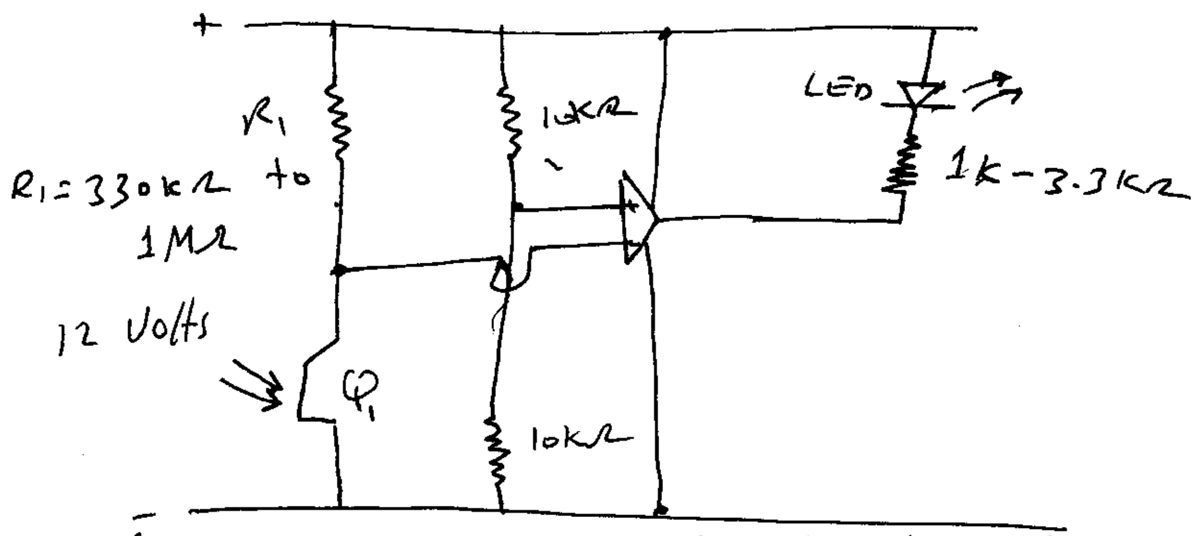
$f \equiv$ frequency of radiation

$\alpha \equiv$ a Constant of a value of two.

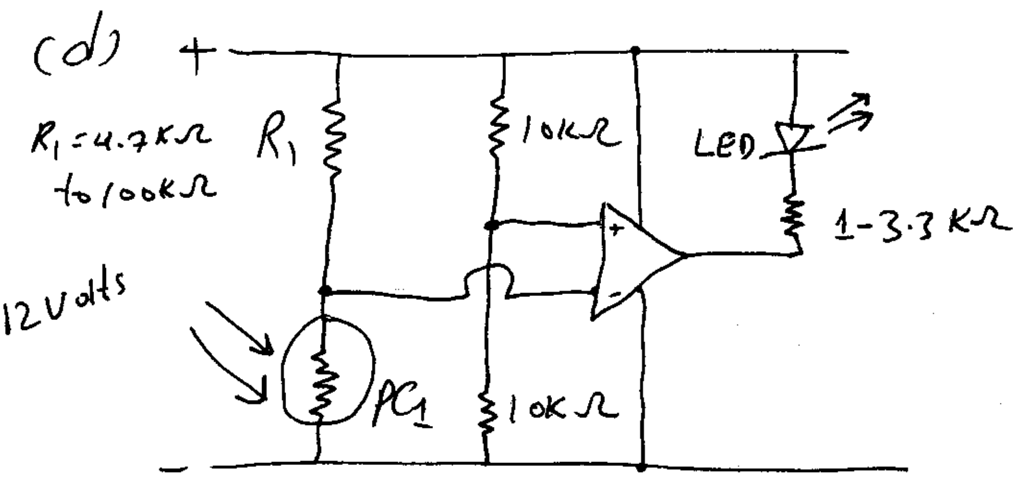
$\beta \equiv$ a Constant whose value is about unity.

Q4

(c) i-



The LED is on when the phototransistor is dark.?



The LED is on when the photocell is DARK.

In ~~these~~ this ccts, when the light falling on the photocell is blocked, its resistance will increase and the voltage across PC1 will rise. when the voltage rises above $\frac{1}{2}$ of the supply voltage, the output of the comparator will turn ON and the LED will be lit.

Q_5 (a)

* Fourier's law for one-dimensional heat conduction is given by

$$q = AK\left(\frac{T_1 - T_2}{L}\right) = \frac{T_1 - T_2}{\underbrace{L/AK}_{R_{th}}} \quad \text{——— (1)}$$

where q = heat flow rate, kcal/sec.
A = area normal to heat flow, m^2,
K = Thermal conductivity of the detecting material, kcal/msec°C;
L = Thickness of that material, m.

Equation (1) is analogous to ohm's law in electricity relating the across and through variables for a resistance. Hence, thermal resistance due to conduction is defined by $R_{th} = L/AK$

* Heat transfer by convection is described by Newton's law of cooling as

$$q = Ah(T_1 - T_2) = \frac{T_1 - T_2}{1/Ah} \quad \text{——— (2)}$$

where h = convection coefficient of heat transfer kcal/m^2 sec °C.

The thermal resistance due convection is defined as

$$R_{th} = 1/Ah$$

* The net heat flux by radiation between two bodies at absolute temperatures T_1 & T_2, respectively, is given by Stefan-Boltzmann law as

$$q = \sigma F_e F_{12} A_1 (T_1^4 - T_2^4) \quad \text{——— (3)}$$

where σ = Stefan-Boltzmann Constant = $5.67 \times 10^{-8}\ W/m^2K^4$,

F_e = emissivity factor,

F_{12} = Geometric View factor, and

A_1 = Surface area of the first body.

(noting that $F_{12}A_1 = F_{21}A_2$)

To linearize eqn.(3), we multiply and divide by $(T_1 - T_2)$ to obtain

$$q = \sigma F_e F_{12} A_1 (T_1^4 - T_2^4)\frac{(T_1-T_2)}{(T_1-T_2)},$$

Then, thermal resistance due to radiation is defined by

$$R_{th} = \frac{T_1 - T_2}{\sigma F_e F_{12} A_1 (T_1^4 - T_2^4)}$$

(b) $$\Delta T(t) = \frac{1}{C_{th}} \int_{t_0}^{t_1} q(t)\,dt$$

$$C_{th}\Delta T(t) = \int_{t_0}^{t_1} q(t)\,dt$$

by differentiating, we get

$$C_{th}\frac{d\,\Delta T(t)}{dt} = q(t)$$ where $\frac{d}{dt}$ vanishes $\int_{t_0}^{t_1}$

Q6

$$\frac{d}{dt}(\Delta T) + \frac{G_{th}}{C_{th}}\Delta T = \frac{\eta}{C_{th}} P_{w} e^{j\omega t} \quad (1)$$

$$I.F = e^{\int P dt} = e^{\int \frac{G_{th}}{C_{th}} dt} = e^{\frac{G_{th}}{C_{th}} t}$$

بضرب طرفي (1) في ال I.F

$$e^{\frac{G_{th}}{C_{th}}}\left[\frac{d}{dt}\Delta T + \frac{G_{th}}{C_{th}}\Delta T = \frac{\eta}{C_{th}} P_w e^{j\omega t}\right] \quad (2)$$

$$e^{\frac{G_{th}}{C_{th}}t}\frac{d}{dt}\Delta T + e^{\frac{G_{th}}{C_{th}}}\frac{G_{th}}{C_{th}}t\,\Delta T = e^{\frac{G_{th}}{C_{th}}t} P_w e^{j\omega t}$$

which can ~~be~~ written to be

$$\frac{d}{dt}\left(e^{\frac{G_{th}}{C_{th}}}\Delta T\right) = \frac{\eta P_w}{C_{th}} e^{\left(\frac{G_{th}}{C_{th}}+j\omega\right)t} \quad (3)$$

Integrating both sides of (3), we obtain

$$e^{\frac{G_{th}}{C_{th}}t}\Delta T = \frac{\eta P_w}{(G_{th}+j\omega C_{th})} e^{\left(\frac{G_{th}}{C_{th}}+j\omega\right)t} + C$$

$$\therefore \Delta T = Ce^{-t/\tau_{th}} + \frac{\eta P_w e^{j\omega t}}{(G_{th}+j\omega C_{th})}$$

(where $\tau_{th} = \frac{C_{th}}{G_{th}}$

$$|\Delta T| = \Delta T_\omega e^{j\omega t}$$

$$\Delta T_\omega = \frac{\eta P_w}{(G_{th}^2+\omega^2 C_{th}^2)^{1/2}}$$