Detection of Light: Exercise 2

Set: Fri 12th Feb 2016,
Due: Fri 19th Feb 2016
Questions: wilby@strw.leidenuniv.nl

1 Carrier Mobility [4 marks]

a Calculate the conductivity of intrinsic Si at room temperature (T=293K). What is the fractional contribution of holes to this value?

Take the intrinsic carrier density at this temperature to be $n_i = 4.8 \times 10^9\,\mathrm{cm}^{-3}$ and the relative mobilities of electrons and holes to be $\mu_n = 1.35 \times 10^3\,\mathrm{cm}^2\,\mathrm{V}^{-1}\,\mathrm{s}^{-1}$, $\mu_p = 480\,\mathrm{cm}^2\,\mathrm{V}^{-1}\,\mathrm{s}^{-1}$ respectively.

[2 marks]

b What is the electron mobility in the same photodetector cooled to T=150K? State the physical reason for this temperature dependence.

[2 marks]

2 Design of an intrinsic photoconductor [16 marks]

Consider an intrinsic silicon photoconductor operating at 1 μm and constructed as shown in Fig. 1. Let its surface area $wl = 1\,\mathrm{mm}^2$ in a square pixel configuration, operating at room temperature. Assume the detector breaks down when the bias voltage, V_b, exceeds 50 mV.

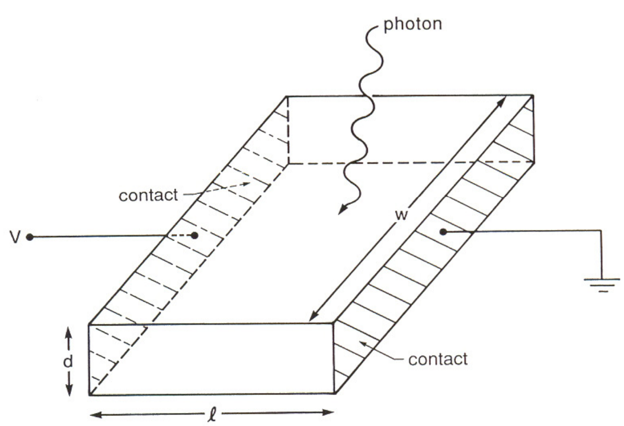

Figure 1: Photoconductor with transverse contacts.

a The minimum detector thickness required for good quantum efficiency corresponds to one absorption length (photon mean free path length) in the material.

i) Use the data in Fig. 2 to estimate the minimum detector thickness d for this detector. What is the corresponding quantum efficiency η of this detector, if reflection is neglected?

[3 marks]

ii) What is a more realistic value of η, if reflection is now taken into account? Assume normal photon incidence on the detector surface and a refractive index for Si of $n = 3.4$.

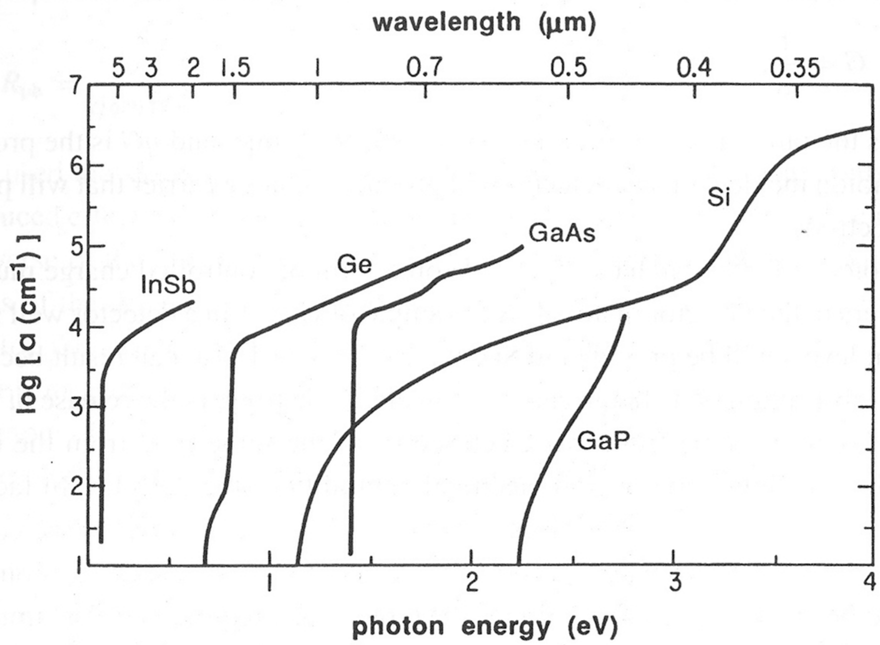

Figure 2: Linear absorption coefficients a for various semiconductors (on $\log_{10}$ scale).

[1 marks]

b Calculate the responsivity S using your value of η in part a.ii, explicitly stating the units of your answer. The recombination time for Si under the given conditions is $\tau = 1 \times 10^{-4}$ s. Assume the detector is operated at 10 mV below the breakdown voltage. What is the probability of any given photon reaching the detector contact?

[3 marks]

c Calculate i) The dark resistance and hence the dark current, and ii) the photo-current of the detector when illuminated by an astrophysical source with a photon flux of $\phi = 10^5\,\gamma/s$. Again, take the electron concentration in Si to be $n_i = 4.8 \times 10^9$ cm^{-3}.

[3 marks]

d The variance of the detected signal is dominated by two factors: the thermal Johnson (kTC) noise associated with dark current

$$\langle I_J^2 \rangle = \frac{4kT}{R_d}\Delta f$$

where R_d is the (dark) resistance of the detector, and the G-R noise associated with the photo-current

$$\langle I_{G-R}^2 \rangle = 4q^2\phi\eta G^2\Delta f$$

where $\Delta f = 1/(2\Delta t_{int})$ is the frequency bandwidth of the observation. Calculate the signal-to-noise ratio our photoconductor obtains for a 0.5s exposure of the source in part c). State the factor limiting detector performance in this scenario, and suggest how this may be improved.

[6 marks]