Detection of Light: Exercise 5

Set: Thurs 9th Mar 2017,
Due: Thurs 16th Mar 2017
Questions: wilby@strw.leidenuniv.nl

1 BIB Detectors [10 marks]

Consider the Blocked Impurity Band (BIB) photoconductor shown in Fig. 1, consisting of a highly-doped Si:As (n-type) infrared-active layer with a small but non-negligible fraction of p-type impurities, which is overlaid with a high-purity Si blocking layer to which a positive bias voltage V_b is applied. A depletion region of width w is formed in which photons may be absorbed and subsequently detected with high efficiency.

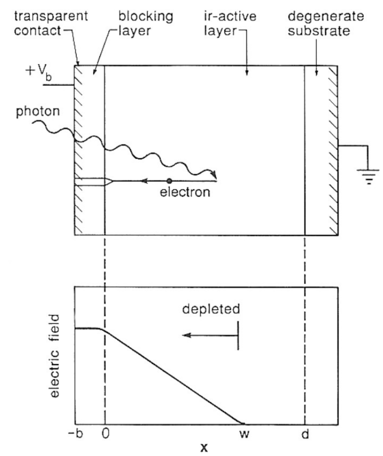

Figure 1: Diagram of a BIB depletion region.

For this question take the blocking and IR-active layer widths to be $t_B = 4.5\,\mu$m and $t_A = 15.0\mu$m respectively, and the densities of of n-type dopants and p-type impurities are $N_D = 5\times10^{17}\,\text{cm}^{-3}$, $N_A = 10^{13}\,\text{cm}^{-3}$. The dielectric constant $\kappa_0 = 11.8$ for Si at room temperature, and the permittivity of free space $\epsilon_0 = 8.854 \times 10^{-12}$ F m^{-1}.

a Sketch an energy-level diagram for this BIB detector as a function of position x along the detector. With reference to this explain:

i) What is meant by "hopping" in over-doped extrinsic semiconductors, and how does the BIB band structure help overcome this problem?

ii) What is meant by the depletion region of the detector, and why does it have a finite extent within the IR-active layer?

[3 marks]

b i) By solving the one-dimensional Poisson equation

$$\frac{\mathrm{d}E}{\mathrm{d}x} = \frac{\rho}{\epsilon_0 \kappa_0},$$

obtain an expression for the electric field E as a function of distance x from the inner edge of the blocking layer, depletion layer width w and acceptor density N_A.

ii) Hence show that the width of the depletion region as a function of the bias voltage V_b and thickness of the blocking layer t_B is given by:

$$w = \left(\frac{2\kappa_0 \epsilon_0}{q N_A} |V_b| + t_B^2 \right)^{\frac{1}{2}} - t_B$$

[Hint: Use the boundary condition $V(x = -t_B) = |V_b|$ at the outer edge of the blocking layer.]

[4 marks]

c What is the value of the critical bias voltage in this detector for which the thickness of the depletion region is the same as the thickness of the IR-active layer, t_A?

[1 mark]

d Consider photo-electrons accelerated near the boundary of the blocking layer, where the mean-free path length is $\langle l \rangle \sim 0.3\ \mu$m.

i) On average how much energy will these electrons gain in between collisions?

ii) Given that the ionisation energy of arsenic in Si:As is $E_i = 54$ meV, explain briefly how gains of $G > 1$ may be obtained in BIB detectors. In what part of the detector does this occur, and why?

[2 marks]