Detection of Light: Exercise 5

Set: Fri 9th Mar 2018,
Due: Before the start of class Fri 16th Mar 2018
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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.

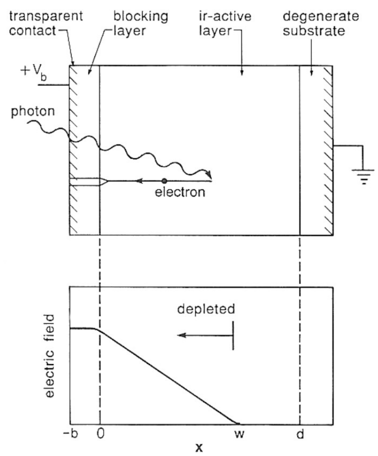

Figure 1: Diagram of a BIB depletion region.

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, when the detector is operated under the critical bias voltaqe?

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]