Detection of Light: Exercise 4

Set: Fri 6th Mar 2015,
Due: Fri 13th Mar 2015

1 Diffusion in photodiodes [7 marks]

In a photodiode, the diffusion length L_n can be understood as the average distance a carrier can move (or diffuse) in the neutral p-type and n-type regions, before it recombines. This is defined as:

$$L_n = (D\tau)^{1/2}$$

where

$$D = \frac{kT\mu}{q}$$

is the diffusion coefficient and τ is the recombination time.

a In order to increase detectability of photogenerated carriers, what condition should therefore be imposed on the thickness l of the neutral absorber layer overlying the depletion region, in terms of the impurity concentration N_I? Assume that the variation of the mobility μ with impurity concentration is negligible and that $\tau \propto N_I^{-1}$.

b Test your condition by calculating the detector quantum efficiency η for three values of l about the limit determined in part a (eg. the limiting value itself and a factor of 2 either way), where

$$\eta = \frac{2b}{e^{l/L_n} + e^{-l/L_n}}$$

and b is the fraction of incident photons available for absorption to produce carriers. What do you conclude?

c On the other hand, what is the requirement on the thickness l in terms of N_I in order to guarantee good photon absorption rates? Is it possible to meet these two conditions simultaneously in an extrinsic photoconductor?

2 Well Capacity in Charged Coupled Devices (CCDs) [3 marks]

When a voltage V_g is applied on the electrode of a single element of a CCD, photoelectrons produced in the semiconductor substrate will collect near the semiconductor-oxide interface, because they can not penetrate the insulator. The number of electrons Q_W that the resulting Metal-Oxide Semiconductor (MOS) capacitor can hold is the well capacity:

$$Q_W = C_0(V_g - V_T)$$

where V_T is the threshold voltage for the formation of a storage well and the capacitance C_0 is that of a plane parallel capacitor with area A and separation d:

$$C_0 = \frac{A\kappa_0\epsilon_0}{d}$$

The dielectric constant of silicon dioxide is $\kappa_0 = 4.5$.

a How many electrons can be collected in a MOS if the thickness of the oxide layer is 0.2 μm and the elctrode dimensions are 18 μm $\times$ 18 μm? Assume that a voltage difference of $V_g - V_T = 3.5V$ is applied.

b Conceptually, what prevents MOS capacitor from accumulating more electrons?

3 Application of CCD Readout: Exoplanet Transits [10 marks]

To search for a transient planet we observe the nearby star η-Leidensis with a new IR imager based on the Teledyne Hawaii-2RG array, which we operate with four readout channels in double-correlated sampling mode. Our star η-Leidensis is quite bright, and the incoming photon flux is 500,000 photons per second, which will be evenly spread across the four central detector pixels.

For this question, refer to the Hawaii-2RG data table from the lecture slides. Assume a detector ADU gain of unity and ignore photon shot noise.

1. What would be the minimum clocking frequency required to read out the array (i.e. moving the readout from pixel to pixel) required to avoid saturation? Can this be achieved with this detector?

2. Unfortunately, the expected signatures in the light curve of η-Leidensis from a transient planet are very weak: model estimates suggest that the maximum transit depth is 10 magnitudes smaller than the flux from η-Leidensis itself. Our readout electronics digitizes the output signals using a 12-bit analog-to-digital (A/D) converter. Could a transient signal of that magnitude be detected? If not, what would be the obvious solution?

3. In addition we also investigate the nearby companion star ξ-Leidensis, which is 3 magnitudes fainter than η-Leidensis. We would like to reduce the read noise by a factor of three (compared to part a) by performing multiple non-destructive readouts of the illuminated pixels. Is this feasible if the maximum frame rate is limited to 1 frame/second (to minimise noise), or would we saturate?