Detection of Light: Exercise 6

Set: Fri 16th Mar 2018,
Due: Before the start of class Fri 23rd Mar 2018
Questions, please e-mail to: dorval@strw.leidenuniv.nl

1 Charged Coupled Devices (CCDs) [10 marks]

Consider a Metal-Oxide Semiconductor (MOS) CCD composed of pixels with square dimensions 20 μm, each separated from the readout electrode by a SiO_2 insulating oxide layer of thickness 2.0 μm. When a readout voltage V_g is applied to the electrode of a single pixel element, photoelectrons produced in the semiconductor substrate will collect near the semiconductor-oxide interface because they cannot penetrate the insulator, as shown in Fig. 1.

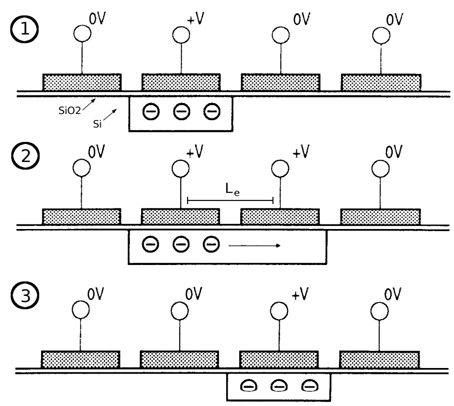

Figure 1: Schematic representation of the charge shuffling readout process in a CCD.

a Calculate the full-well electron capacity Q_W of the pixel, when V_g is 3.0 V greater than the threshold voltage V_T required to form a storage well. What prevents MOS capacitor from accumulating more electrons?

The dielectric constant of SiO_2 is $\kappa_0 = 4.5$.

[2 marks]

When considering charge transfer efficiency from pixel to pixel in a CCD, the dominant mechanism when there is a large amount of accumulated charge is the self-induced drifting of electrons due to their mutual electrostatic repulsion. We can derive an approximate time constant for this process if we calculate the average time that it takes for the charge to drift through the separation L_e between two neighbouring electrodes when the readout voltage is applied.

b Show that the time constant for self-induced charge transfer between pixels is given approximately by:

$$\tau_{\mathrm{SI}} \approx \frac{L_e^2 C_0}{\mu q N_0}$$

where μ is the electron mobility. Assume that there are initially N_0 electrons on one electrode and that the neighbouring electrode is completely empty.

[2 marks]

The Hawaii-2RG detector consists of an array of 2048 x 2048 pixels with the properties stated above, and pixels may be read out in a 4-quadrant, 2-phase clocking arrangement at frequencies ranging from 100kHz - 50MHz. We wish to read out the center-most 4 pixels, which are imaging a bright star at half the detector saturation level.

c i) Calculate the charge transfer inefficiency for a single pixel, if we read out the chip at the fastest possible rate. How many electrons get left behind on average by this single transfer event?

(You may assume that electrostatic repulsion is the dominant charge shuffling mechanism. Take the electron mobility in Si to be $\mu = 1350\,\mathrm{cm^2\,V^{-1}\,s^{-1}}$.)

ii) Calculate the total transfer uncertainty associated with reading out these center-most pixels, and hence the error (in %) on the stellar signal due to this effect.

iii) What main factor can cause the charge transfer uncertainty to be larger than your result, in practice?

[6 marks]