Lecture 21: Photocurrent generation

Photocurrent generation requires

- A material with an *energy gap* (to extract electrons with $\Delta\mu > 0$)
- A preferred *direction* for electron extraction

- A *semiconductor* provides the band gap
- Different *doping* at the contacts (*pn* or *np* junction) gives preferred direction for charge collection

Simple model of a PV cell:

- *n-p* junction with very thin *n* region, *p* region with thickness *d*,
- electron diffusion coefficient D_n, electron lifetime t_n
- spatially uniform generation rate *G*
- electrons collected only through *n* contact ($x = 0$):

Continuity equation for electrons: $\frac{1}{e}\frac{dJ_n}{dx} + G - R = 0$

Boundary conditions: $n(0) = 0 \qquad J_n(d) = 0$

Substituting for J_n and R: $D_n \frac{d^2 n}{dx} - \frac{n}{t_n} = -G$

This second order inhomogeneous DE has $n = \text{Complementary function} + \text{Particular integral}$

CF: $n = Ae^{x/L} + Be^{-x/L}$ PI: $n = Gt_n$

$$n = Ae^{x/L} + Be^{-x/L} + Gt_n$$

$$J_n = eD_n \frac{dn}{dx} = \frac{eD_n}{L}\left(Ae^{x/L} - Be^{-x/L}\right)$$

Applying boundary conditions:

$$J_n(d) = 0 \quad \Rightarrow \quad B = Ae^{2d/L}$$

$$n(0) = 0 \quad \Rightarrow \quad A = \frac{-Gt_n}{\left(1 + e^{2d/L}\right)} = \frac{-Gt_n e^{-d/L}}{2\cosh(d/L)} \quad \Rightarrow \quad B = \frac{-Gt_n e^{d/L}}{2\cosh(d/L)}$$

$$n = Gt_n - \frac{Gt_n e^{(x-d)/L}}{2\cosh(d/L)} - \frac{Gt_n e^{-(x-d)/L}}{2\cosh(d/L)} = Gt_n\left\{1 - \frac{\cosh((x-d)/L)}{\cosh(d/L)}\right\}$$

$$J_n = eD_n Gt_n \frac{1}{L}\frac{\sinh((d-x)/L)}{\cosh(d/L)} = eGL\frac{\sinh((d-x)/L)}{\cosh(d/L)}$$

Photocurrent collected at x = 0: $J_{SC} = J_n(0) = eGL\tanh(d/L)$

J_{SC} limited by:
(i) Generation rate. i.e. photon flux density, optical depth of slab
(ii) thickness of slab relative to electron diffusion length

For large J_{SC} require $L >> 1/\alpha \Rightarrow$ very high purity material!