Semiconductor Device Theory:
Basic Operation of a PN Diode – Theoretical Exercise

Dragica Vasileska and Gerhard Klimeck
(ASU, Purdue)

1. A silicon *pn*-junction has a resistivity of 0.1 Ωcm and 2 Ωcm for the uniformly-doped *p* and *n* sections, respectively. If μ_n=1500 $cm^2/V\text{-}s$, μ_p=450 $cm^2/V\text{-}s$, and $n_i=1.45\times10^{10}$ cm^{-3} at room temperature:
   (a) Calculate the built-in voltage of the junction.
   (b) Calculate the diode saturation current at room temperature (τ_n=15 µs, τ_p=50 µs, A=0.05 cm^2).
   (c) Calculate and plot the temperature dependence of the saturation current, neglecting for simplicity the temperature dependence of mobility (E_g=1.12 eV for *Si*).

2. Consider a *pn*-junction diode. The concentration of holes in the *n*-section of the device is described by the continuity equation

$$D_p \frac{d^2 p_n}{dx^2} - \frac{p_n - p_{n0}}{\tau_p} = 0 \ .$$

   The concentration of shallow ionized donors in the *n*-section is equal to 10^{15} cm^{-3}. The intrinsic carrier concentration is 10^{10} cm^{-3}. The forward voltage applied to the diode is 0.5 *V*. Assuming that the length of the *n*-section, *L*, is much smaller than the diffusion length L_p, calculate and sketch the hole distribution in the *n*-section of the device. Also, assuming that D_p=12 cm^2/s and the lifetime τ_p=1 µs, how short does the *n*-section have to be to satisfy the condition that $L \ll L_p$ (use $L= L_p/10$ as a criterion)?

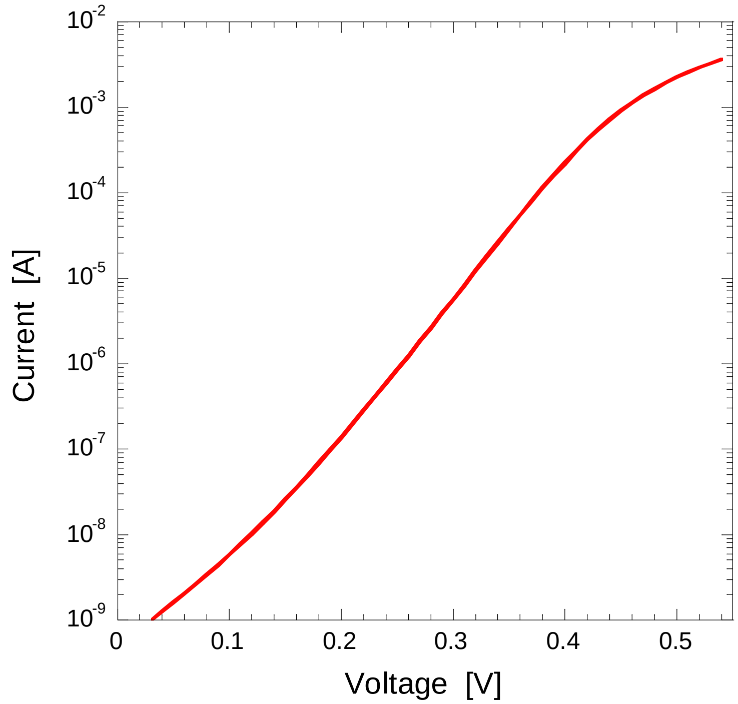
3. Find the total charge of electrons injected into the p-region of a n^+p silicon diode as a function of the bias voltage *V*. Doping density of the *p*-region is N_A, intrinsic carrier concentration is n_i, and the diode temperature is *T*. The length of the *p*-region is *L*, and the diffusion length of electrons in the *p*-region is L_n. Consider three cases:
   (a) Arbitrary relation between *L* and L_n.
   (b) $L \gg L_n$.
   (c) $L \ll L_n$.

   Assume that at the contacts, $n=n_{p0}$, where n_{p0} is the equilibrium concentration of electrons.

4. The forward *IV*-characteristics of a *pn*-diode are shown in the figure below.

(a) Explain the origins for the deviation of the measured *IV*-characteristics from the ideal model predictions.

(b) Calculate the series resistance of the diode. Explain how you arrived at your answer.



5. Consider a p^+-n-n^+ diode shown in the figure below. The doping of the three different regions, clearly illustrated on the figure, is N_A=N_{D2}=10^{20} cm^{-3} and N_{D1}=10^{16} cm^{-3}. The breakdown voltage for this diode is defined as being equal to the applied bias for which the maximum electric field reaches the critical field E_{crit}=2.5×10^5 V/cm.

(a) Calculate the breakdown voltage for the diode when L=20 μm. Sketch the electric field profile for this case.

(b) How will the magnitude of the breakdown voltage change if L is reduced to 0.5 μm. Explain qualitatively your reasoning. No actual calculation is needed for this case.

The intrinsic carrier concentration is $n_i = 1.5\times10^{10}$ cm^{-3} and the semiconductor permittivity equals to $k_s\varepsilon_0 = 1.05\times10^{-10}$ F/m.