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Exercise for Solid State Physics for Nanoscience
SS 2019
Exercise sheet 4

4.1 Intrinsic Carrier concentration vs. Temperature

The density of free electrons n (holes p) is given below:

$$n = 2(\frac{2\pi m_n kT}{h^2})^{\frac{3}{2}} e^{-\frac{E_C - E_F}{kT}}; \qquad p = 2(\frac{2\pi m_p kT}{h^2})^{\frac{3}{2}} e^{-\frac{E_F - E_V}{kT}}$$

E_c, E_v and E_F are the conduction, valance and Fermi energy levels. For intrinsic semiconductors the number of electrons is equal to the number of holes ($n=p=n_i$).

Scale the intrinsic carrier concentrations for germanium, silicon and GaAs from room temperature (T = 300 K) to 0 ◦C and liquid nitrogen temperature (T = 77 K) using the data below:

	Si	**Ge**	**GaAs**
E_G[eV]	1.12	0.67	1.35
$\frac{dE_G}{dT}$ [eV/K]	-2.3x10^{-4}	-3.7x10^{-4}	-5.0x10^{-4}
n_i(300K)[cm^{-3}]	1.45x10^{10}	2.4x10^{13}	1.79x10^{6}

4.2 Space charge region of pn-Junction

a) Find the built-in voltage for a silicon p-n junction at room temperature with doping concentrations $N_A = 10^{16} cm^{-3}$ (acceptor) and $N_D = 10^{12} cm^{-3}$(donor).

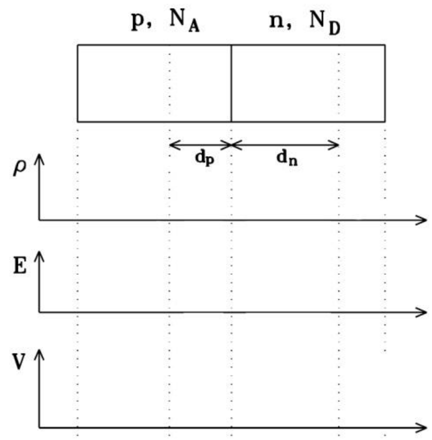
b) Derive the width of the natural space-charge region and the maximum electric field ε_{max} for an abrupt p-n junction as a function of the doping concentration N_A and N_D. Calculate the width for a very highly doped ($N_A=10^{16}$ cm^{-3}) p-type junction on n-type detector-grade material with $N_D=10^{12}$ cm^{-3}.

4.3 Structure of Bands

(a) Draw a pn diode junction in thermal equilibrium with its parts separated. Indicate on the sketch the levels of the valance band energy, conduction band and Fermi energy for both the p and n type semiconductors.

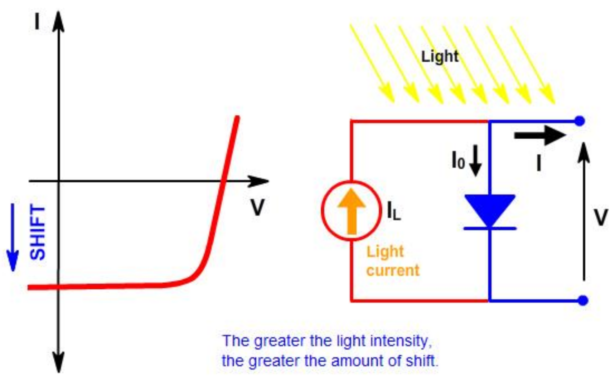
(b) Repeat part (a) when the two semiconductors are braught togather.

(c) see 4.2b For different doping concentration of the p and n type materials, plot the change of the electric field E, the potential V and the charge density p along the depleted area. Use figure below.



Exercise 4: Solar Cell

A biased pn-junction is a basic element of silicon solar cells. It function can be understood by means of the I-V characteristics curve of a pn-junction shifted by I_L along the current axis (towards



negative current), where I_L is the radiation induced current. Determine the effective working point (I_W, V_W) providing maximum power harvest of the solar cell. Neglect any other losses and suppose that Voc is known (open circuit).