# I. PROBLEM SESSION 13

## A. Problem 13.1

**P-n junctions:**
The p-n junction is formed by joining P-type and N-type semiconductors together in very close contact. The term junction refers to the boundary interface where the two regions of the semiconductor meet. If they were constructed of two separate pieces this would introduce a grain boundary, so p-n junctions are usually created in a single crystal of semiconductor by doping, for example by ion implantation, diffusion of dopants, or by epitaxy (growing a layer of crystal doped with one type of dopant on top of a layer of crystal doped with another type of dopant).

P-n junctions are elementary building blocks of almost all semiconductor electronic devices such as diodes, transistors, solar cells, LEDs, and integrated circuits; they are the active sites where the electronic action of the device takes place.

Junctions with different properties can also be made at interfaces between all possible combinations of metals, semiconductors and superconductor. As an example p-n junction(Schottky junction) can also be made at the interface of a semiconductor and a metal, where the metal serves the role of the n-doped side.

We will in this problem look at the space charge distribution in p-n junctions: Consider a silicon-based junction as shown schematically in a fig.1 below. Derive and sketch charge density, electric field, and potential within the space

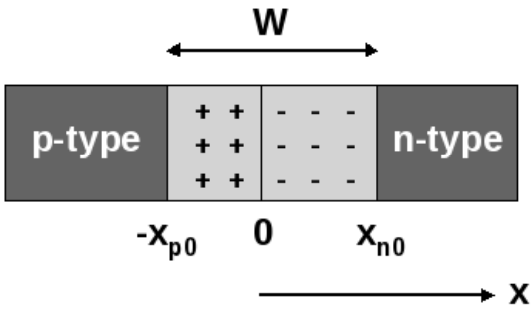


Figure 1: A p-n junction

charge region $W$ of the junction. Assume donor and acceptor concentrations of $1 * 10^{16}$ and $4 * 10^{17} cm^{-3}$ in the n- and p-type sides of the junction. Assume the contact area $A$ of $2 * 10^{3} cm^{-2}$ and room temperature operation (i.e the intrinsic carrier concentration is $10^{10} cm^{-3}$). Calculate: a) The in-build potential b) The depth of the space charge region as well as $x_{p0}$ and $x_{n0}$ c) The charge associated with $x_{p0}$ and $x_{n0}$ d) The maximum amount (in terms of its absolute value) of the field

## B. Problem 13.2

**Solar cell:**
Current and voltage in illuminated junctions. A solar cell is typically made up of a p-n heterojunction at the surface of a semiconductor crystal(see e.g. fig.2). The design and improvement of a solar cell depends on a wide spectrum of solid state physics knowledge. We need to have a good knowledge of the band structure of the semiconductor(s), a solid knowledge of interface physics, as well as heat and electronical transport propertis. And of course the interaction of a complex material with the solar photon spectra.

In this problem we assume that the junction in Fig.1 is uniformly illuminated with solar photons so that an optical carrier generation rate ($g_{op}$) contributes to the generation current. We assume that we know the average diffusion length $L_p$ (and $L_n$) for holes (and electrons). We might then assume that only holes(electrons) generated closer to the interface than the diffusion length contribute to the current. Thus we have contributions from the volumes $A * L_p$ (and $A * L_n$) where $A$ is the cross section of the junction. In addition, holes generated on the n-side of the junction, and electrons generated on the p-side do not need to diffuse but are just swept by the electric field contributing to the current.

-How is the junction equation modified by the illumination? Analyze the equation when the device is short and open circuited. What are meanings of short circuit current ($J_{sc}$) and open circuit voltage ($V_{oc}$)?

The efficiency of a solar cell made of p-n junctions shown schematically in Fig.1 is proportional to the product of $J_{sc}V_{oc}$. Suggest possible scenarios for increasing the solar cell efficiency by modification of semiconductor material/junction properties.

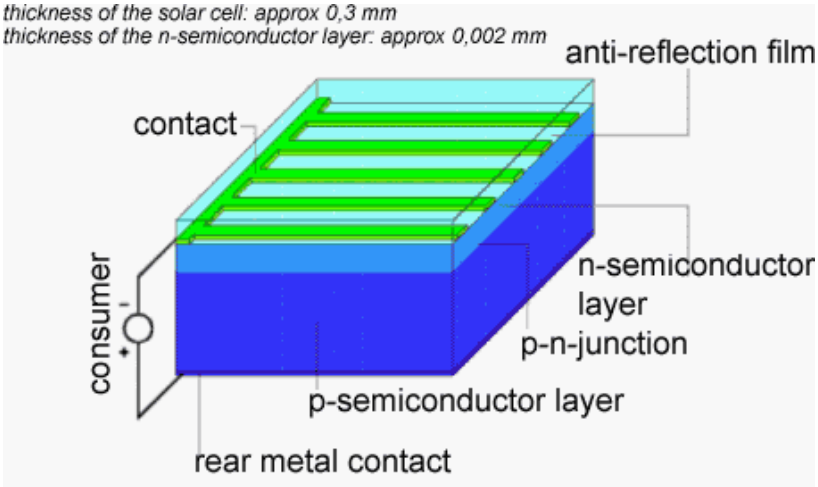


Figure 2: A model of a typical crystalline solar cell

### C. Problem 13.3

Electron diffraction of surface atoms. The physical properties of surfaces can be entirely different from the bulk properties. Always the quantum states of the bulk will be (usually qualitatively) modified near the surface, leading to entirely different properties with respect to transport, but also mechanical properties. To understand the effects and surfaces, one first needs to characterice them. This is often done by electron diffraction. Figure 20 (Kittel p. 514) shows the electron diffraction pattern in the backward direction from the nickel atoms on the (110) surface of a nickel crystal. Explain the orientation of the diffraction pattern in relation to the atomic positions of the surface atoms shown in the model. Assume that only the surface atoms are effective in the reflection of low-energy electrons.