MN-2
August 2011 QE

1) The following five questions are qualitative and examine your basic knowledge of Semiconductors, they all have short answers. If needed, you can draw a schematic to explain your answers.

a- The vast majority of semiconductor devices are made from silicon; however, compound semiconductors (e.g., GaN, GaAs, InGaAs, etc.) retain some niche applications. Name two main ones. (***4 points***)

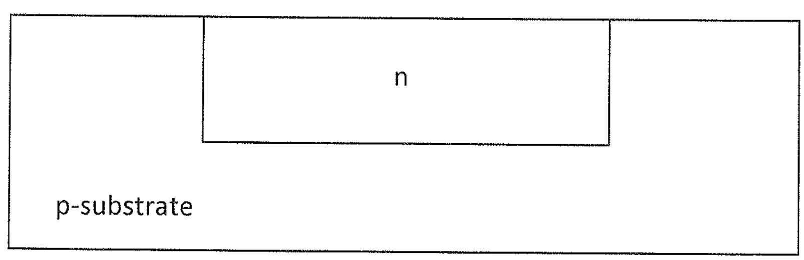
b- The original semiconductor devices were made from germanium, but soon thereafter silicon became the main element from which transistors and other active components are manufactured. Name two reasons for this switch. (***4 points***).

c- What is the band gap of high quality silicon dioxide (SiO_2)? (***4 points***)

d- Miller indices are used to identify crystallographic planes and directions; Miller indices for a plane is (210). Draw the plane in xyz coordinate system. (***4 points***)

e- What is the temperature range at which thermal silicon dioxide (SiO_2) is typically grown using oxidation process? (***4 points***)

2) A p-type silicon wafer with a doping of 10^{15} cm^{-3} is used to make a pn junction diode by diffusing phosphorous at a concentration of 10^{18} cm^{-3} through the substrate. Assume an abrupt junction with constant doping concentrations on each side. Calculate the electron and hole density in neutral p and n regions at thermal equilibrium? (***6 points***), assume $n_i=10^{10}$ cm^{-3}



3) If the width of depletion region under zero bias in the n side is $x_{no}=0.001$ µm, what is its width in the p type region? (***4 points***)

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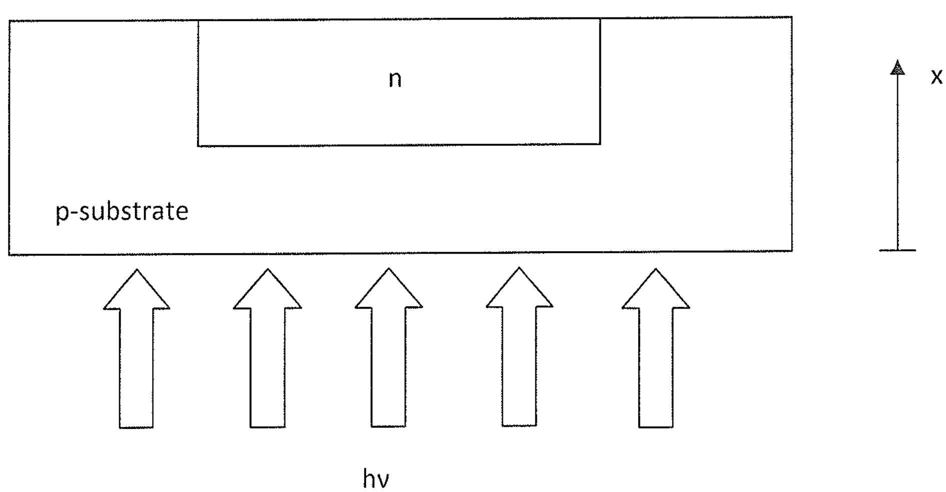
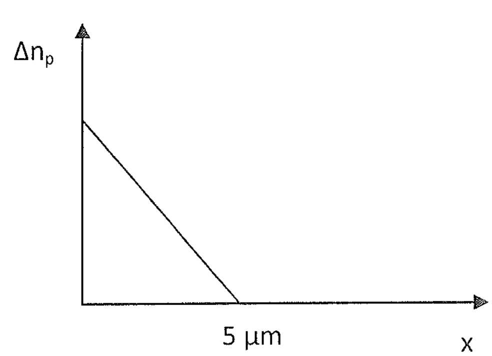
4) Suppose a reverse bias voltage of V is applied to the above junction. Write the expression relating the depletion width in the n region (x_n) to the bias voltage. Use approximation if necessary. (***5 points***)

5) The same n region is used to make a diffused resistor. Assuming a junction depth of 5 μm and an electron mobility of 500 $cm^2/V.s$ in the n region, what is the sheet resistance (Rs) of the resistor in Ω/□? (***10 points***) (assume electronic charge is $2x10^{-19}$ C)

6) If an electric field of 1 kV/cm is applied to the above resistor, what is the drift current density in the resistor $J_{n\text{-}drift}$? (***5 points***)

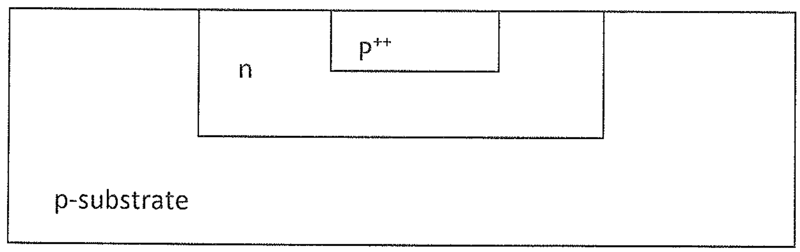
7) The bottom side of the above diode is illuminated such that $\Delta n_p=10^{10}$ cm^{-3} excess electrons are created at the surface (x=0). The following profile describes the carrier vs. depth. Assuming the p-substrate region is much thicker than the diffusion length of excess carriers, what is the minority carrier diffusion current density in the substrate as the result of the illumination ($J_{n\text{-}diff}$)? (assume electron charge is $2x10^{-19}$ C, thermal voltage of 25 mV, and electron mobility of 500 $cm^2/V.s$) (***10 points***)





8) Suppose the above diode is illuminated from top. Plot the iv curve under such condition and label the solar cell and photodetector regions on your iv curve. Explain your answer in terms of energy/power consideration. Show the iv curve of the non-illuminated diode on the same plot for comparison (***10 points***).

9) The above diode is further processed by implanting a high dose of boron (10^{20} cm^{-3}) into the n-type region to make a pnp transistor (below). Draw the thermal equilibrium band diagram of the transistor labeling E_C, E_V, E_i, and E_F throughout the emitter, base, and collector regions. (***5 points***)



10) Plot minority carrier densities in the emitter (p^{++}), base (n) and collector (p-substrate) regions (***5 points***) and write the equations for the minority carrier concentrations at the edges of EB depletion region. (***5 points***).

11) Plot $\ln(I_B)$ and $\ln(I_C)$ vs V_{EB} showing the effects of current crowding and generation-recombination in the depletion region on the base and collector currents. What is the influence of these two phenomena on β of the transistor. (***5 points***)

12) Heterojunction bipolar transistors (HBT) use an emitter with a wider band gap than that of the base in order to improve the high frequency performance. Assume the emitter of the transistor in problem 9 is made of an exotic semiconductor with a band gap of 2 eV while the base and collector regions are silicon (Eg=1.1 eV). Assume both conduction and valence band discontinuities (ΔE_c and ΔE_v). Draw the equilibrium band diagram of the transistor labeling E_C, E_V, E_i, E_F, and E_0 (vacuum level) throughout the emitter, base, and collector regions. Label ΔE_c and ΔE_v. (***10 points***)

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