Devices – Ph.D. Qualifying Exam Spring 2009

(i). (5 points)

a) Suppose you have a sample of silicon at room temperature doped with a density of 4×10^{17} arsenic atoms (donors) per cubic centimeter, (i.e. n = 4×10^{17} electrons/cm^3). What is the approximate density of holes in the silicon and how do you determine it?

b) What is the resistivity of the silicon in the case a) ? (To receive full credit, you must give a correct expression and substitute the appropriate numbers from the table below.)

c) Now suppose you have a sample of silicon doped with 8×10^{17} arsenic atoms (donors) per cubic centimeter, and with 4×10^{17} boron atoms (acceptors) per cm^3. What is the density of holes in the silicon?

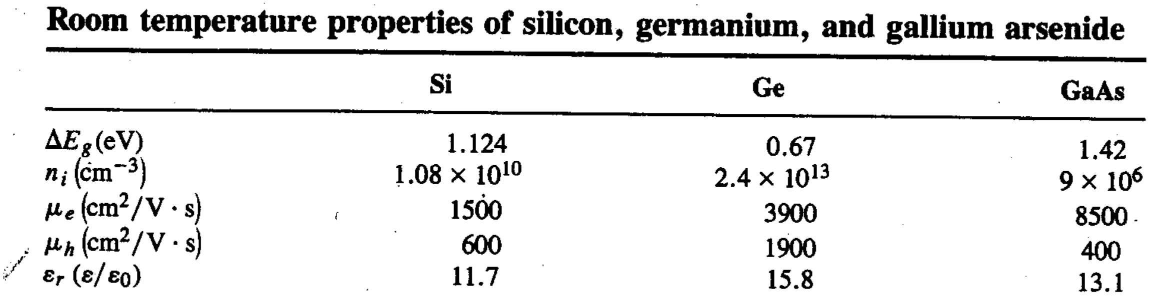


Table A.1.

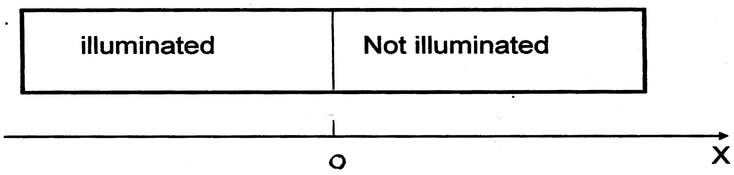
Room temperature properties of silicon, germanium, and gallium arsenide

	Si	Ge	GaAs
ΔE_g (eV)	1.124	0.67	1.42
n_i (cm^{-3})	1.08×10^{10}	2.4×10^{13}	9×10^{6}
μ_e (cm^2/V · s)	1500	3900	8500
μ_h (cm^2/V · s)	600	1900	400
ε_r ($\varepsilon/\varepsilon_0$)	11.7	15.8	13.1

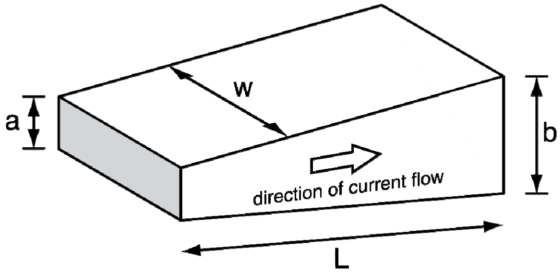
(ii). (5 points) a) Suppose you have an n-type Si sample with n_o electrons/cm^3 . Suppose it is uniformly illuminated to create electron-hole pairs at a constant density throughout the sample, such that the electron density becomes $n_o + n'$ and the hole density becomes $p_o + p'$ where $n' = p'$. Assume $n' << n_o$. Suppose at time $t = 0$ the illumination is turned off. Write an expression for the hole concentration, p', as a function of time.

b) Now suppose the illumination is more intense and the assumption $n' << n_o$ is no longer true, i.e. $n' \sim n_o$. When the illumination is turned off, how is the situation different? In particular is the initial decay rate of p', (dp'/dt) faster or slower than in part a)? Explain.

c) Suppose you are continuously and uniformly illuminating only half of the sample, i.e. for $x < 0$ in the drawing. Otherwise the conditions are the same as in part a). Sketch the dependence of p' on x throughout the sample. Assume the sample is long, i.e. don't consider end effects.



(iii) (5 points) Derive an expression for the resistance (from the end with thickness, a, to the end with thickness, b) of a slab of material of resistivity ρ if the slab is in the shape of a linearly tapered wedge as shown.



(iv) (5 points) MOSFETs are usually fabricated using the so-called self aligned process in which the gate electrode is used as a shadow mask for the implantation of the source and drain. For example, for an n-MOS transistor the silicon under the gate electrode remains p-type. The areas not covered by the gate electrode, or the field oxide are implanted and become n+ and serve as the source and drain. Suppose during the fabrication process a break occurs in the gate electrode. Assume the break is large enough so that the action of the gate does not “bridge” the break. Consider the four different cases with horizontal (H) and vertical (V) breaks and describe how the transistor operation would be affected. Assume an enhancement mode transistor, i.e. no source-drain current flows unless a positive gate-source voltage is applied. Assume the two halves of the gate electrodes in the case (H) are electrically connected.(As they are in case (V)).

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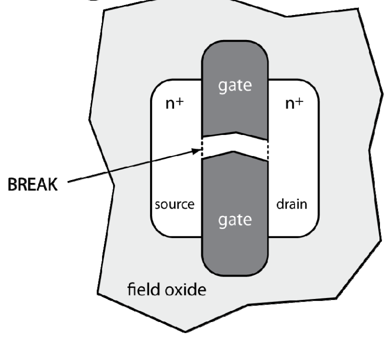

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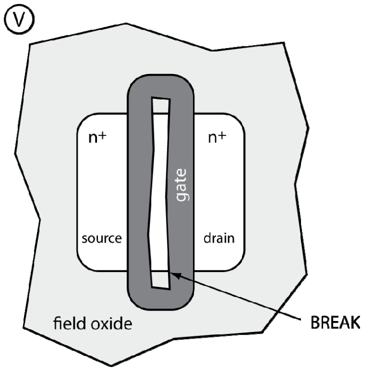

a) geometry H, the break occurred **before** implantation

b) geometry H, the break occurred **after** implantation.

c) geometry V, the break occurred **before** implantation.

d) geometry V, the break occurred **after** implantation.