ECE 350F – Physical Electronics

Final Examination

Dec.12, 9:30am, 1997

(1-page Aid Sheet and non-programmable calculators are allowed)

Name____________________ **Student #**____________________

(1, 20 points) (a) Sketch the changes of the minority carrier distributions caused by shortening a standard pn junction diode on both sides such that the electrodes are placed well within one diffusion length (measured from the boundary of the transition region on either side);

(b) explain how the diode current changes as a result and why; comment on how consistent (or inconsistent) it is with the charge-control model;

(c) how would the storage capacitance change as a result ? and

(d) the aforementioned electrodes are obviously ohmic contacts, please sketch qualitatively correct band diagrams for both ohmic contacts.

a)

(2, 25 points) For an ideal silicon MOSFET with a P substrate doping $N_A = 10^{15}/cm^3$ and at the onset of strong inversion, calculate:

(a) The width of the depletion layer,
(b) The space charge in the depletion region (layer)
(c) The electron density n_s at the surface (i.e, the interface between oxide and silicon)
(d) The threshold voltage
(e) If we now replace the gate metal with one that has a smaller work function, i.e., ϕ_m(new) < ϕ_m (old), how would the threshold voltage change, by how much? illustrate your reason by drawing the zero bias MOS band diagrams before and after.

(Given for silicon: $\varepsilon = 11.8 \times 8.854 \times 10^{-14}$ F/cm, $n_i = 1 \times 10^{10}/cm^3$)

(Given for the oxide: $\varepsilon_{ox} = 3.9 \times 8.854 \times 10^{-14}$ F/cm, oxide thickness = 9 nm)

(3, 25 points) For an n^+pn bipolar transistor,

(a) Sketch the qualitatively correct band diagrams at equilibrium and in normal mode of operation, respectively;

(b) Corresponding to the Early effect and for the same $V_{be} > 0$, draw the minority profiles in the base at a small reverse bias V_{bc1} (< 0) and a large reverse bias V_{bc2} ($<< 0$), respectively; assuming the base width W is much smaller than the diffusion length at V_{bc1};

(c) Derive the expression for the change in Ic as function of ΔV_{bc}

(d) In order to minimize the Early effect and not to sacrifice the emitter injection efficiency, one can change both the base doping level and the emitter bandgap. How? and why? (Draw a band diagram when necessary).

(4, 15 points) (a) For laser operation, what are the necessary conditions for the type of bandgap? and for the relation between the electron concentrations n_2 and n_1 in the upper and lower bands? Why? (Use E-K band structure and the Einstein relation).

(b) In an arbitrary semiconductor with non-uniform doping, there are normally both diffusion and drift currents for electrons and holes; show that the total electron (or hole) current(s) can be expressed in terms of spatial gradient(s) of the quasi-Fermi level(s).

(c) If one end of the semiconductor is placed under constant illumination ($\hbar\omega > Eg$), and the semiconductor is in electrical isolation, how would the quasi-Fermi levels and their derivatives change and/or not change?

(5, 15 points) (a) A Ge sample is doped with 5×10^{13} Sb atoms/cm^3. Assuming local charge neutrality, calculate the hole concentration Po at 300K. (See attached tables for info).

(b) The tunneling probability of an electron through the barrier below is: $T \propto e^{-KL}$; if (Vo-E) is doubled, how would T change? (Hint: first find K-E relation from Schrodinger eq., then show T(new)/T(old) = ?).

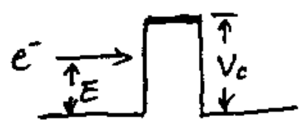

TABLE 3.3 Properties of Silicon, Germanium and Gallium Arsenide at $T = 300$K

Property	Unit	Si	Ge	GaAs
Density of atoms	cm^{-3}	5×10^{22}	4.4×10^{22}	2.2×10^{22}
Energy gap	eV	1.12	0.66	1.42
Effective mass m^*/m_0				
electron		1.182	0.553	0.0655
hole		0.81	0.357	0.524

$K = 1.38 \times 10^{-23}$ J/K $= 8.62 \times 10^{-5}$ eV/K ; $KT = 0.0259$ eV

(a) II	III	IV	V	VI
	B	C		
	Al	Si	P	S
Zn	Ga	Ge	As	Se
Cd	In		Sb	Te