UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING
FINAL EXAMINATION (TYPE C), DECEMBER 18, 2001
MMS 320
Examiner: Prof. Z.H. Lu

1. Describe the statistical function you should use to determine the probability of having an energy E at a temperature T for the following particles: (a) electrons, (b) phonons, and (c) free moving gaseous molecules.

2. Describe in your words the wave nature of electrons. Calculate the wavelength of an electron which has a kinetic energy of 4 eV.

3. Sketch the E vs k relationship for a free electron in the 1st B.Z.

4. Consider an incandescent light bulb with a tungsten filament that is 0.382 m long and has a diameter of 33 μm. Its resistivity at room temperature is 5.51×10^{-8} Ω m. Given that the resistivity of the tungsten filament varies according to $\rho(T)=\rho_o(T/T_o)^{1.2}$, and the temperature of the W is 2746K at 120 V operating voltage. Estimate the power consumption (or the wattage) of the bulb at 120 V.

5. Sketch band diagrams across the following interfaces: (a) between Au and n-type Si, (b) between Ca and n-type Si. Label relevant parameters on the diagrams. (Hint: see the attached appendix for important parameters)

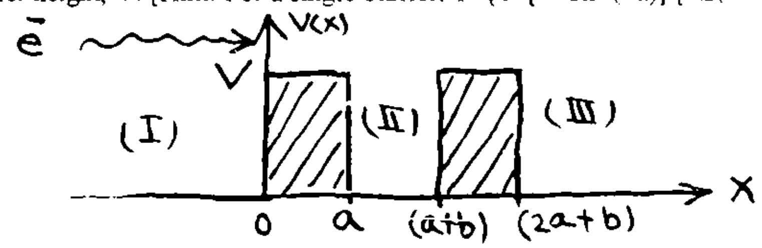
6. Sketch an energy band diagram across an interface between p-type Si and n-type GaAs. Label relevant parameters on the diagram.

7. Part A. Briefly describe the conduction mechanism for: (a) a conducting polymer, (b) an ionic materials, and (c) an amorphous silicon. Part B. Sketch P (polarization) vs E (external electric field) characteristics (known as hysteresis loop at room temperature) of a ferroelectric material: at (a) T=0K, (b) a temperature just below Currie temperature, and (c) above Currie temperature.

8. Describe all possible thermal energy carriers.

9. For a classical free particle with degree of motion is restricted to two dimensions. Derive (a) velocity distribution function and (b) a formula to calculate the average energy of the particle. [Hint: see appendix for definite integrals].

10. Estimate the transmission probability for an electron traveling from region I through region II to region III in the following cases; (a) the separation distance between two potential barrier b is very large. (b) b is much smaller than that of the electron wavelength. Discuss only the case where electron energy E is larger than the potential barrier height, V. [Hint: For a single barrier, $T=\{1+[V^2\mathrm{Sin}^2(ka)]/[4E(E-V)]\}^{-1}$]



MMS320 Final Exam Appendix

Electronic Properties of Some Metals

Material	Effective mass $\left(\frac{m^*}{m_0}\right)_{el}$	Effective mass $\left(\frac{m^*}{m_0}\right)_{opt}$	Fermi energy, E_F [eV]	Number of free electrons, N_{eff} $\left[\frac{\text{electrons}}{\text{m}^3}\right]$	Work function (photoelectric), ϕ [eV]	Resistivity, ρ [$\mu\Omega$ cm] at 20°C
Ag		0.95	5.5	6.1×10^{28}	4.3	1.59
Al	0.97	1.08	11.8	16.7×10^{28}	4.1	2.65
Au		1.04	5.5	5.65×10^{28}	4.8	2.35
Be	1.6		12.0		3.9	4.0
Ca	1.4		3.0		2.7	3.91
Cs			1.6		1.9	20.0
Cu	1.0	1.42	7.0	6.3×10^{28}	4.5	1.67
Fe	1.2				4.7	9.71

Properties	Si	GaAs
Atoms/cm^3	5.02×10^{22}	4.42×10^{22}
Atomic weight	28.09	144.63
Breakdown field (V/cm)	$\sim 3 \times 10^5$	$\sim 4 \times 10^5$
Crystal structure	Diamond	Zincblende
Density (g/cm^3)	2.329	5.317
Dielectric constant	11.9	12.4
Effective density of states in conduction band, N_c (cm^{-3})	2.8×10^{19}	4.7×10^{17}
Effective density of states in valence band, N_v (cm^{-3})	1.04×10^{19}	7.0×10^{18}
Effective mass, m^*/m_0		
Electrons	$m_l^* = 0.92$ $m_t^* = 0.19$	0.063
Holes	$m_{lh}^* = 0.15$ $m_{hh}^* = 0.54$	$m_{lh}^* = 0.076$ $m^*_{hh} = 0.50$
Electron affinity, χ(V)	4.05	4.07
Energy gap (eV) at 300 K	1.124	1.424
Index of refraction	3.42	3.3
Intrinsic carrier concentration (cm^{-3})	1.02×10^{10}	2.1×10^6
Intrinsic Debye length (μm)	41	2900
Intrinsic resistivity (Ω-cm)	3.16×10^5	3.1×10^8
Lattice constant (A)	5.43102	5.65325
Linear coefficient of thermal expansion, $\Delta L/L\Delta T$ (°C^{-1})	2.59×10^{-6}	5.75×10^{-6}

Some Definite Integrals

$$\int_0^\infty x \cdot e^{-ax} dx \cong 1/a^2$$

$$\int_0^\infty e^{-ax^2} dx \equiv (\pi/4a)^{1/2}$$

$$\int_0^\infty x \cdot e^{-ax^2} dx \equiv 1/(2a)$$

$$\int_0^\infty x^2 \cdot e^{-ax^2} dx \equiv \left(\pi/16a^3\right)^{1/2}$$

$$\int_0^\infty x^3 \cdot e^{-ax^2} dx \equiv 1/(2a^2)$$

$$\int_0^\infty x^4 \cdot e^{-ax^2} dx \equiv (3/8a^2)(\pi/a)^{1/2}$$