Electronic Properties of Materials Final Exam Dec. 15(Mon), 2008

(Prof. Sang-Im Yoo)

1. (20pts) Answer the following questions.

(a) (5pts) Schematically draw the Fermi levels, E_F as a function of temperature for *p*-type semiconductors, and briefly explain the behavior. On the *E-T* diagram, indicate the conduction band, acceptor level, and valence band also.

(b) (10pts) Consider a silicon crystal containing 10^{17} phosphorous atoms per cubic centimeter. Is the conductivity increasing, decreasing or not significantly changed when the temperature is raised from 300 to 350°C? Explain by giving *numerical values* for the mechanisms involved. (Assume $m^*_e/m_0 = 1$)

Use the next equations and the values.

$$N_e = 4.84\times10^{15}\left(\frac{m_e^*}{m_0}\right)^{3/2} T^{3/2}\exp\left[-\left(\frac{E_g}{2k_BT}\right)\right]$$

The band gap energy of Si at 0 K : 1.17eV

$$E_{gT} = E_{g0} - \frac{\xi T^2}{T+\theta_D}$$, $\xi \cong 5 \times 10^{-4}$ eV/K, θ_D (Si) = 650 K

(c) (5pts) Briefly explain the Hall effect in a *n*-type semiconductor.

2. (25pts) Answer the following questions.

(a) (10pts) An *n*-type semiconductor is brought to contact with a metal. If the work function of the metal(ϕ_M) is larger than that of the semiconductor (ϕ_S), the contact shows a rectifying (Schottky barrier) behavior. Explain the reason for it by sketching the band diagram *before* and *after* contact. Please express conduction band of the metal, conduction and valence bands of the semiconductor according to their relative levels. Also express Fermi energy level E_F and the region filled with electrons.

(b) (5pts) Describe the band diagram and function of a *p-n-p* transistor.

(c) (10pts) Schematically draw the depletion-type (or normally-on) MOSFET and the enhancement-type(or normally-off) MOSFET, respectively. Briefly explain their operation principles.

3. (15pts) Answer the following questions.

(a) (5pts) Show the ionic conductivity in ionic conductors is given by

$$\sigma_{ion} = \sigma_0 \exp\left[-\left(\frac{Q}{k_B T}\right)\right] \qquad \sigma_0 = \frac{N_{ion} e^2 D_0}{k_B T}$$

(b) (5pts) Calculate the activation energy for ionic conduction for a metal ion in an ionic crystal at 300K. Take $D_0 = 10^{-3} m^2$ and $D = 10^{-17} m^2/s$

(c) (5pts) Show that $\mathbf{P} = (\varepsilon - 1)\varepsilon_0 \mathbf{E}$ in dielectric materials. What values do $\mathbf{P}$ and $\mathbf{D}$ have for vacuum?

4. (20pts) Answer the following questions.

(a) (5pts) Express the reflectivity R as a function of refractive index n and damping constant k. On the basis of this relationship explain why ceramics and polymers ($n \sim 1.5$, $k \sim 10^{-7}$) exhibit very low R while metals ($n < 1$, $k > 3$) are good reflectors in the infrared region.

(b) (5pts) Derive the Hagen-Rubens relation from the following equation.

$$R = \frac{\sqrt{\varepsilon_1^2 + \varepsilon_2^2} + 1 - \sqrt{2(\sqrt{\varepsilon_1^2 + \varepsilon_2^2} + \varepsilon_1)}}{\sqrt{\varepsilon_1^2 + \varepsilon_2^2} + 1 + \sqrt{2(\sqrt{\varepsilon_1^2 + \varepsilon_2^2} + \varepsilon_1)}}$$

(c) (10pts) Calculate the reflectivity R of sodium in the frequency ranges $\nu > \nu_1$ and $\nu < \nu_1$ using the theory for free electrons without damping. Sketch R vs. frequency. (For Na, plasma frequency, $\nu_1 = 14.3 \times 10^{14} s^{-1}$)

5. (20pts) Answer the following questions.

(a) (10pts) Using a universal relation between magnetic field $\mathbf{H}$, magnetic induction $\mathbf{B}$ and magnetization $\mathbf{M}$, show the relationship between the relative permeability μ_r and the susceptibility χ in SI (Sommerfeld) unit. Explain how this relationship changes in cgs (Gaussian) unit.

(b) (5pts) Calculate the magnetic induction $\mathbf{B}$(in Tesla) and magnetization $\mathbf{M}$(in A/m) of a paramagnetic material with the relative permeability $\mu_r = 1.001$ under an applied field $\mathbf{H}$ of 5.0×10^5 A/m. Where $\mu_0 = 4 \times 10^{-7}$ henry/m and 1 henry · A = 1 Wb.

(c) (5pts) What are the permeability μ_r and the susceptibility χ (in SI unit) of a superconductor? Explain Meissner effect also.