Electronic Properties of Materials **Final Exam** Dec. 15 (Mon), 2014

(Prof. Sang-Im Yoo)

1. (20pts) Answer the following questions.

(a) (10pts) Describe the band diagram and function of a *p-n-p* transistor.

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

2. (15pts) Answer the following questions.

(a) (10pts) Show the ionic conductivity in ionic conductors is given by

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

(b) (5pts) Show that $\boldsymbol{P} = (\varepsilon-1)\varepsilon_0 \boldsymbol{E}$ in dielectric materials, where $\boldsymbol{P}$ and $\boldsymbol{E}$ are the dielectric polarization and electric field, respectively. Also, schematically draw a hysteresis loop for a ferroelectric material on *P-E* diagram. Please express a remanent polarization (P_r) and a coercive field (E_c) on the diagram.

3. (30pts) Answer the following questions.

(a) (5pts) What are the definitions and physical meaning of the refraction index n and the damping constant k, respectively?

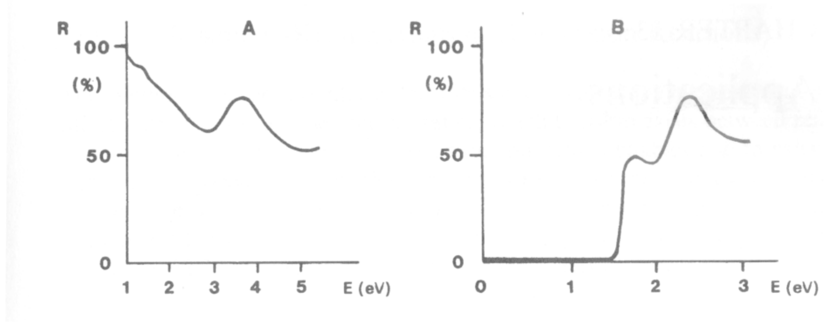
(b) (5pts) Express the reflectivity R as a function of refractive index n and damping constant k. On the basis of this relationship explain why ceramics and polymers (n ~1.5, k ~10^{-7}) exhibit very low R while metals ($n < 1$, $k > 3$) are good reflectors in the infrared region.

(c) (5pts) Derive the Hagen-Rubens relation from the next equation.

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

(d) (5pts) In order to interpret absorption band (absorption of light into materials at high frequency), Lorentz postulated that the electrons are bound to their respective nuclei. Construct the equation of motion for the electron in Lorentz model and explain its physical meaning. Also compare it with free electrons without damping model.

(e) (10pts) Below the reflection spectra for two materials A and B are given. What type of material belongs to reflection spectrum A, what type to B? (Justify). Note the scale difference! Also, for which of the materials would you expect intraband transitions in the infrared region? Explain the reason.



4. (40pts) Answer the following questions.

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

(b) (5pts) What are the relative permeability μ_r and the susceptibility χ (in SI unit) of a superconductor?

(c) (5pts) Using the Langevin electron orbit theory for paramagnetism given below,

$$\boldsymbol{M = n\mu_m \left(coth\xi - \frac{1}{\xi}\right) = n\mu_m \left(\frac{\xi}{3} - \frac{\xi^3}{45} + \frac{2\xi^5}{945} - \cdots\right)}$$

derive the curie law for the paramagnetic materials.

(d) (5pts) Describe the temperature dependency of susceptibility for paramagnetic metals, and explain its behavior quantum mechanically.

(e) (5pts) The basic unit for the magnetic moment is the Bohr magneton, μ_B. Show that 1 μ_B is equal to *eh/(4πm)* by using the Bohr model. Where *e* is the electron charge, *m* is the electron mass and *h* is the Plank constant.

(f) (5pts) Draw and explain the $\chi(T)$ curves for normal diamagnets and non-metallic paramagnets following the Curie-Weiss law.

(g) (5pts) Draw and explain the $M(T)$ curve below Curie temperature T_c and $\chi(T)$ curve above T_c for ferromagnets.

5. (15pts) Answer the following questions.

(a) (10pts) Derive the empirical Dulong-Petit law (molar heat capacity, C_v ~3R, R=gas constant) for the heat capacity of materials using classical theory. If temperature is decreased to a very low temperature, materials exhibit a reduction in their values of heat capacity. Explain this behavior using the Einstein model qualitatively.

(b) (5pts) Explain the limitation of Einstein model for the temperature dependence of C_v and how Debye could overcome this limitation briefly. Also, explain the definition of Debye temperature.