HW 10

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Problem 13.25. What is the power dissipation (I^2R) in the filament of Problem 13.24?.

Problem Ref 13.24. A tungsten lightbulb filament is 9 mm long and 100 μm in diameter. What is the current in the filament when operating at 1,000°C with a line voltage of 110 V?

Using eqn 13.9 in the textbook[1], we first solve for resistivity where T_{th} is room temperature and ρ_{th} is room resistivity. α is a constant we grab from table 13.2 in the book.

$$\rho = \rho_{th}[1 + \alpha(T - T_{th})] = (55.1 \times 10^{-9})(1 + 0.0045(1000 - 20)) = 2.98 \times 10^{-7}\,\Omega m$$

Now we solve for Resistance:

$$R = \frac{\rho l}{A} = \frac{2.98 \times 10^{-7} * 9 \times 10^{-3}}{\pi * (100 \times 10^{-6}/2)^2} = 0.341\Omega$$

Now we solve for Power emission,

$$P = I^2 R = V^2/R = (110V)^2/(0.341) = 35.5 \times 10^3\text{W}$$

Problem 13.35. An alternate definition of polarization (introduced in Examples 13.11 and 13.12) is

$$P = (\kappa–1)\epsilon_0 E, \tag{1}$$

where κ, ϵ_0, and E were defined relative to Equations 13.11 and 13.13. Calculate the polarization for 99.9% Al2O3 under a field strength of 5 kV/mm. (You might note the magnitude of your answer in comparison to the inherent polarization of tetragonal BaTiO3 in Example 13.12).

From table 13.4 [1], $\kappa = 10.1$ and $\epsilon_0 = 8.85 \times 10^{-12} C/Vm$. Also note that 5 kV/mm is the same as $5 * 1000 * 1000V/m$.

$$P = (\kappa–1)\epsilon_0 E = (10.1 - 1) * 8.85 \times 10^{-12} * 5 * 1000 * 1000V/m = 4.03 \times 10^{-4} C/\text{m}^2$$

Problem 13.45. What fraction of the conductivity at room temperature for **(a)** germanium and **(b)** CdS is contributed by (i) electrons and (ii) electron holes?

Using eqn 13.14[1] in the textbook we cal solve this. Note that:

$$\begin{aligned}\sigma_{\text{total}} =& nq(\mu_e + \mu_h) \\ \sigma_e =& nq\mu_e \\ \sigma_h =& nq\mu_h\end{aligned}$$

Now to find the percent conductivity of electrons and holes we simply divide the conductivity due to electrons/holes by the total conductivity.

$$\frac{\sigma_e}{\sigma_{\text{total}}} = \frac{nq\mu_e}{nq(\mu_e + \mu_h)} = \frac{\mu_e}{\mu_e + \mu_h}$$

$$\frac{\sigma_h}{\sigma_{\text{total}}} = \frac{nq\mu_h}{nq(\mu_e + \mu_h)} = \frac{\mu_h}{\mu_e + \mu_h}$$

(a) Using table 13.5[1] we find that for Germanium we have:

$$\frac{\sigma_e}{\sigma_{\text{total}}} = \frac{0.364}{0.364 + 0.190} = 0.66 \approx 66\%$$

$$\frac{\sigma_h}{\sigma_{\text{total}}} = \frac{0.190}{0.364 + 0.190} = 0.34 \approx 34\%$$

(b) For CdS we have:

$$\frac{\sigma_e}{\sigma_{\text{total}}} = \frac{0.034}{0.034 + 0.0018} = 0.95 \approx 95\%$$

$$\frac{\sigma_h}{\sigma_{\text{total}}} = \frac{0.0018}{0.034 + 0.0018} = 0..050 \approx 5.0\%$$

Problem 15.21. The densities for three iron oxides are FeO (5.70 Mg/m^3), Fe_3O_4 (5.18 Mg/m^3), and Fe_2O_3 (5.24 Mg/m^3). Calculate the Pilling-Bedworth ratio for iron relative to each type of oxide, and comment of the implications for the formation of a protective coating.

From the textbook[1] we see that iron has an amu of 55.85 and a density of 7.87 g/cm^3. Also note for eqn 14.13[1] in the textbook that M = amu of the oxide, m = amu of iron, D = density of oxide, d = density of iron, and a = amount of iron in oxide.

(a) For FeO we have a amu of $55.85 + 16.0$ and a density of 5.70 g/cm^3.

$$R = \frac{Md}{amD} = \frac{(55.85 + 16)(7.87)}{1(55.85)(5.70)} = 1.78$$

Since the R value here is between 1 and 2, this means the oxide will allow for a coating layer to form.

(b) For Fe_3O_4 we have a amu of 3(55.85) + 4(16.0) and a density of 5.18 g/cm^3. The formula also contains 3 Fe atoms so a = 3 here.

$$R = \frac{Md}{amD} = \frac{(3(55.85) + 4(16))(7.87)}{3(55.85)(5.18)} = 2.10$$

Since the R value here is greater than 2 it will probably not form a protective coating because of the compressive stresses due to the oxide which will cause it to flake and fall off.

(c) For Fe_2O_3 we have a amu of 2(55.85) + 3(16.0) and a density of 5.24 g/cm^3. The formula also contains 2 Fe atoms so a = 2 here.

$$R = \frac{Md}{amD} = \frac{(2(55.85) + 3(16))(7.87)}{2(55.85)(5.24)} = 2.15$$

Similarly, since the R value here is greater than 2 it will probably not form a protective coating because of the compressive stresses due to the oxide which will cause it to flake and fall off.

Problem 15.39. The maximum corrosion current density in a galvanized steel sheet used in the design of the new engineering laboratories on campus is found to be 5 mA/m^2. What thickness of the zinc layer is necessary to ensure at least (a) 1 year and (b) 5 years of rust resistance?

The solution to this problem is essentially playing with units. We first note the density of zinc is $7.13{\times}10^6$g/m^3. Also the amu of zinc is 65.38g and that zinc has 2 electrons that it gives away when corrosion occurs.

$$\frac{5 \times 10^{-3} A}{m^2} = \frac{5 \times 10^{-3} C}{\mathrm{s} * m^2} \frac{1e}{1.602 \times 10^{-19} C} \frac{1\,\text{zinc atom}}{2e} \frac{65.38g}{6.023 \times 10^{23}\,\text{atoms}} = 1.69 \times 10^{-6} \frac{g}{\mathrm{s} * m^2}$$

Now this is the amount of of zinc leaving the surface of the metal per a second per a meter squared area. Let's set this equal to the density of zinc and solve for units.

$$1.69 \times 10^{-6} \frac{g}{\mathrm{s} * m^2} = (7.13 \times 10^6 \frac{g}{m^3})(x \text{ meters})$$

Now we need to multiply by some number x in order to match our units. This x also happens to be the thickness of zinc leaving the surface per a second.

$$x = \frac{1.69 \times 10^{-6} \frac{g}{\mathrm{s}*m^2}}{7.13 \times 10^6 \frac{g}{m^3}} = 2.37 \times 10^{-13}\, m/s$$

Now the problem asks us for the amount that leaves in a year and 5 years. We simply multiple and convert our units to years.

$$\textbf{(a)} = 2.37 \times 10^{-13}\, m/s * \frac{3600s}{1\text{hr}} \frac{24\text{hr}}{1\text{day}} \frac{365\text{day}}{1\text{year}} = 7.47\mu\text{m/year}$$

$$\textbf{(b)} = 2.37 \times 10^{-13}\, m/s * \frac{3600s}{1\text{hr}} \frac{24\text{hr}}{1\text{day}} \frac{1825\text{day}}{5\text{year}} = 37.4\mu\text{m/5 year}$$

1 References

1. James F. Shackelford, Introduction to Materials Science for Engineers, Seventh Edition, Pearson Higher Education, Inc., Upper Saddle River, New Jersey (2009).