# Homework #3

## Due Monday September 12 by 11:59 PM

## Reading

- Chapter 2.5, 2.10

## Problems

1. (2.14 partial) **Hall effect and the Drude model** (Testing the Drude model)

   How good is the simple Drude model? The experimentally measured Hall coefficient and resistivity of sodium metal (Na) at 25 °C has been measured to be $R_H = -2.48 \times 10^{-10}$ m$^3$ C$^{-1}$ and $\rho = 4.88 \times 10^{-8}$ Ω m. Sodium is in Group I of the Periodic Table.

   a. Calculate the Hall mobility for sodium.

   b. Calculate the conduction electron concentration from the experimental value of $R_H$.

   c. Find how many electrons per atom are contributed to the conduction electron gas in the metal per metal atom (hint: calculate the atomic density – see Appendix C and Periodic Table).

   d. What is your conclusion? Does the Drude model work for Na?

   e. For Zn (Group IIB), $R_H = +1.04 \times 10^{-10}$ m$^3$ C$^{-1}$ and $\rho = 6.01 \times 10^{-8}$ Ω m. Does the Drude model work for Zn?

2. (2.42) **Thin films of Cu on Si (100) surface**

   Different thickness polycrystalline Cu films have been deposited on the (100) surface of a Si crystal. Their resistivities have been measured as summarized in Table 2.22 (below). For these films, the average grain size $d$ has been shown to be related to the film thickness $D$ by $d \approx D/2.3$.

   a. Use Matthiessen's rule to combine Fuch-Sondheimer and Mayadas-Shatzkes equations as in

   $$\rho_{film} = \rho_{crystal} + \Delta\rho_{MS} + \Delta\rho_{SF} \qquad \textit{Surface and grain boundary scattering in films}$$

   where $\rho_{crystal}$ is the bulk resistivity of the Cu crystal ($\rho_{crystal}$ = 17.0 nΩ m), and $\Delta\rho_{MS}$ and $\Delta\rho_{SF}$ are the contributions to resistivity arising from the scattering of electrons at the grain boundary and surfaces respectively; that is, the Mayadas-Shatzkes and Fuch-Sondheimer contributions respectively (see textbook or lecture).

   b. Plot the experimental data.

      i. $\rho$ against $1/D$

      ii. $\rho$ against $D$ as a log-log plot (i.e., the x-axis is $\log_{10}(D)$ and y-axis is $\log_{10}(\rho)$

   c. In a new plot, add a plot of the calculated $\rho$ (from part (a)) in the $\rho$ vs. $D$ graph by taking $p = 0$, $\lambda = 40$ nm, and $R = 0.25$. Try a slightly greater and slightly lower $R$ values (*e.g.,* 0.20 and 0.30) to see how the predicted curve changes with respected to the data. What is your conclusion?

d. (Extra credit) Perform a non-linear least-squares fit to the experimental data. If successful, comment on the quality of the fit.

**Table 2.22** The resistivity of thin polycrystalline Cu films on the Si (100) surface.

| ***D* (nm)** | 407 | 222 | 170 | 120 | 101 | 85.4 | 68.5 | 51.2 | 34.1 | 17.2 | 8.59 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **$\rho$ (nΩ m)** | 19.8 | 20.8 | 20.0 | 22.1 | 23.5 | 27.9 | 30.7 | 32.2 | 50.4 | 70.5 | 126 |

NOTE: J.W. Lim and M. Isshiki, *J. Appl. Phys.* **99** 094909, 2006