Homework 1

ECE 4339 Spring 2014
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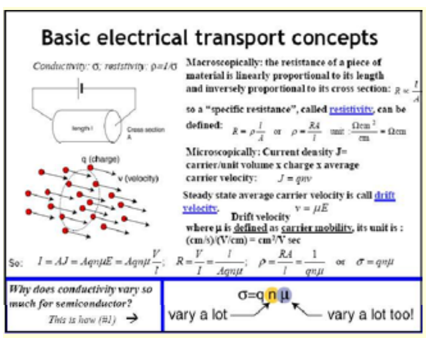
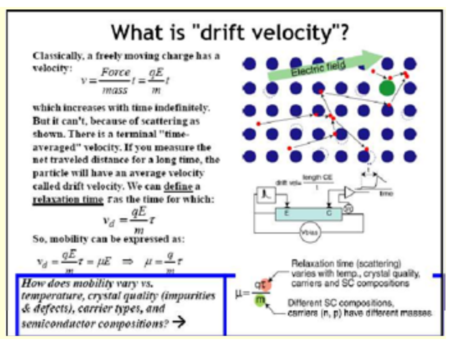
1. (20 pts) Review of classical conductivity: Drude model

1.1 (10 pts) Partial answer to question 1 is given as an example.

Look up the number of outer shell electrons (conduction electrons) per atom of Au, Cu, Al, Ni. Look up their specific density in gram/cm^3. Calculate the conduction electron density (# electrons per unit volume, use unit cm^3) of these metals. Put in a table.
Then, from the looked up values of their conductivities, calculate the electron drift velocity in these metals as a function of E field from E from 0 to 10 V/cm (plot them)





Partial answer (you should finish the rest - answer the missing part)

1. From periodic table (example: http://www.ptable.com/)

Element	Conducting electrons	Atomic W	Density (g / cm3)	Conductivity (/ Ohm cm)	Cond elec density	μ
Au	1	196.966569	19.30	4.51671×10^5	□	□
Cu	1	63.546	8.94	5.959×10^5	□	□
Al	3	26.9815386	2.70	3.546×10^5	□	□
Ni	1	58.6934	8.908	1.443×10^5	□	□

Conduction electron density n_C can be calculated as follow:

$$n_C = \text{Conducting electrons per atom} * \text{ atoms per unit volume}$$

For atoms per unit volume, called it N:

$$N = \text{AvogadroConstant} * \frac{\text{Density}}{\text{Atomic weight}}$$

AvogadroConstant= $6.02214179 \times 10^{23}$

Hence: $n_C = p\, \text{AvogadroConstant} * \frac{\text{Density}}{\text{Atomic weight}}$

where p is the number of conducting electrons on the outer shell.
You can use Excel for example to calculate.
Below is a *Mathematica* calculation (you can use any other mean to calculate)

```
Density = {19.30, 8.94, 2.7, 8.908}; AW = {196.966569, 63.546, 26.9815386, 58.6934};
Cond = {4.51671×10^5, 5.959×10^5, 3.546×10^5, 1.443×10^5};
CondE = {1, 1, 3, 1};
```

```
AvogadroConstant = 6.02214179×10^23;
ElecDensity = AvogadroConstant * CondE * Density / AW
```

$\{5.9009 \times 10^{22}, 8.4723 \times 10^{22}, 1.8079 \times 10^{23}, 9.1399 \times 10^{22}\}$

Mobility is given (by the Drude model) as: $\mu = \frac{\sigma}{e\, n_C}$

where e is the electron charge: $e = 1.602176487 * 10^{-19}$ Coulomb.
Below is another style of *Mathematica* calculation (you can use any other mean to calculate)

```
σ = {4.51671×10^5, 5.959×10^5, 3.546×10^5, 1.443×10^5};
e = 1.602176487 * 10^-19;
nC =
    {5.900866179326096`*^22, 8.472279545935226`*^22, 1.80787868409402`*^23, 9.139909949895559`*^22};
σ / (e nC)
```

{47.774, 43.9, 12.242, 9.854}

Thus, the mobility is:
{47.774,43.9,12.242,9.854} $\text{cm}^2 / \text{Volt Sec}$

Should do similarly to calculate the drift velocity.

1.2 Question 2 (5 pts):

Let’s say we have a copper wire 2 meter long (about 6 ft), and we plug it in the outlet. Starting from 120 Volt and assume the other end is at zero volt (treat the whole thing as DC for a very brief moment in time), how long does it take for electrons to flow from one end to the other?

1.3 Question 3:(5 pts)

The electron mass in these metals is practically the same as the free electron mass. Calculate their relaxation time.

Hint about unit

We write the relaxation time as: $\tau = \mu \frac{m}{q}$. Here, pay attention to the unit.

The unit of μ is $\text{cm}^2 / \text{Volt}\, s$, the unit of q is Coulomb.

We note that Volt=Joule/Coulomb= kg m^2 / s^2

Hence, make sure the conversion between m^2 and cm^2 is done.

2. (45 pts) Mobility review.

Mobility is one of the most important properties affecting the conductivity of semiconductor. Below are study questions reviewing mobility. You are encouraged to think and discuss, not just looking for “the right answer”

2.1 Question 1 (5 pts)

Look up the electron and hole mobility at room temperature (300 K) in high purity samples of the following semiconductors: Si, Ge, GaAs, InAs, and InP - along with its effective mass (make a table similarly with the one above). For hole, use the heavy hole mass. You can use data from this web site: http://www.ioffe.ru/SVA/NSM/Semicond/

(Note: the quoted basic parameters are for 300 K and high purity sample). Make a table (see problem 1).

2.2 Question 2 (10 pts)

Plot the carrier effective mass vs. their mobility on a log log plot for n-type and p-type. Use the heavy hole mass for p-type. Write what you observe. (This is to encourage you to do thinking for yourself. Think like a scientist, if you see this data, what would you think?)

2.3 Question 3 (10 pts)

As an electron (or hole) moves, collision with other particles affects its speed, and hence mobility. The more frequent the collision is, the slower the carrier moves, and hence the lower is its mobility. The collision is called “scattering”, which includes carrier-carrier scattering, carrier-phonon scattering, and carrier-impurity (including dopant) scattering. Based on the result in 2.1 and 2.2, make a table of the ratio m_e^* / m_h^* for each semiconductor, and compare with μ_e / μ_h. What would you say about the electron and hole scattering in each semiconductors? (Do you think they have the same relaxation time?)

2.4 Question 4 (5 pts)

As temperature is increased, the lattice vibrates stronger, or, another way to say this quantum mechanically, is that there are more phonons. Do you think the mobility (of both carriers) increases or decreases vs temperature? why?

2.5 Question 5 (10 pts)

Below are empirical temperature dependence of mobilities. (There are theories, but in practice, people just use empirical relations). Plot the mobilities of electron and hole for high-purity Si and GaAs from 250 K to 450 K according to the model below.

© Bart Van Zeghbroeck 2007	Germanium	Silicon	Gallium Arsenide
Electron mobility	$\propto T^{-1.7}$	$\propto T^{-2.4}$	$\propto T^{-1.0}$
Hole mobility	$\propto T^{-2.3}$	$\propto T^{-2.2}$	$\propto T^{-2.1}$

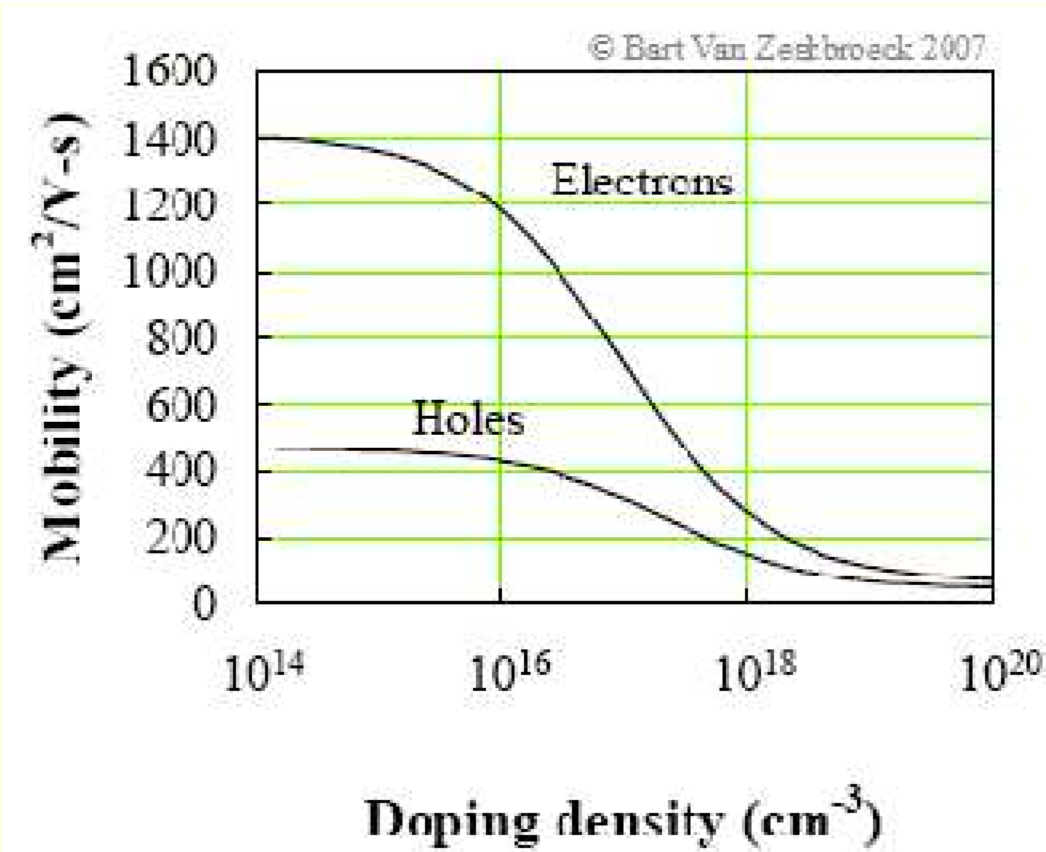
Source: http://ecee.colorado.edu/~bart/book/book/chapter2/ch2_7.htm

2.6 Question 6 (5 pts)

As you dope a semiconductor with more impurities (donors or acceptors), do you think the mobility increases or decreases vs doping concentration? why?

For reference

You may want to read the following information for the question above:
Below are empirical mobilities in Si vs. doping densities (In reality, different types of dopants affect the mobility differently, but for this chart, we just ignore their difference). Download the excel file from the given website: http://ecee.colorado.edu/~bart/book/book/chapter2/xls/fig2_7_3.xls for your own use.



source: http://ecee.colorado.edu/~bart/book/book/chapter2/ch2_7.htm
http://ecee.colorado.edu/~bart/book/book/chapter2/xls/fig2_7_3.xls

3. (35 pts) The problem of an unknown wafer *(problem solving skill and integrated knowledge)*

You just bought an intrinsic GaAs wafer from a manufacturer who claimed that the impurity level is definitely below a few times 10^{15} cm^{-3}, but they did not do any characterization and could not tell what types of impurities in there, n-type or p-type; nor do they know its mobility and resistivity. Your boss wants to know: majority carrier type (n or p), resistivity, and mobility. But you are about to go on vacation and want to ask your co-workers to do you a big favor.

3.1 Question 1 (10 pts)

Write out the entire instruction plan in details what you want your co-workers do for you. You have to specify what experiments to do, how to do it, what to measure, what to look for, etc. (Hint: remember that you are asking for a favor, the burden of clarity is on you to explain to your co-worker)

3.2 Question 2 (5 pts)

Your nice co-worker called you while you are on the beach and the conversation went like this:

YOUR CO-WORKER: "I looked on the bench and there were two wafers, which one ya want?"

YOU: "Well, only one is what we want to measure, I don't know what the other one is"

YOUR CO-WORKER: "Oh I remember, I think the other is Sam's. He was working on his InP wafer, but he's gone for the day! "

YOU: "Mine should be about 2-inch in diameter"

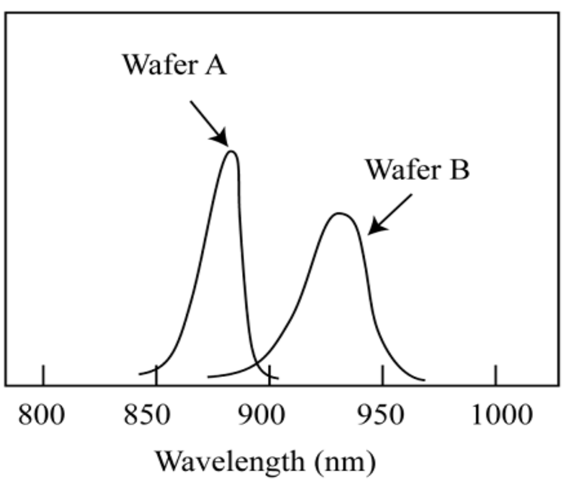
YOUR CO-WORKER: "Let's see... They both are 2-inch, both look black, in the same kind of fluorware container, let me measure their thickness… Well, both are 10 mil (1 mil is 1/1000 of an inch)

What will you tell your co-worker to do next?

3.3 Question 3 (5 pts)

When you got back to the hotel, you were told that you had an urgent fax from your company, as shown below. What is shown in this fax? What is your response? And explain.

Tell us ASAP: Do you want wafer A or B?



3.4 Question 4 (15 pts)

Your co-worker called again and told you that the resistivity he got was ~ 2.6 Ω-cm, and he had a postive Hall effect. Here is how the conversation went:

YOUR CO-WORKER: "I got a Hall voltage reading of 42 mV "

YOU: "How high did you crank up the magnet?"

YOUR CO-WORKER: "It says 5 kG here"

YOU: “How much current did you use on the sample?”

YOUR CO-WORKER: “1 mA “

YOU: “And you said the voltage was positive?”

YOUR CO-WORKER: “Well, that’s what the tags say, this tag says plus and this one says minus”

YOU: “Those scotch-taped tags fell off all the time. You’re sure they were put on right?”

YOUR CO-WORKER: “I dunno, but they didn’t fall off the whole time I was doing! Oh! One more thing, a guy from Wafer Warehouse called. He said you left a message for him asking about this wafer you bought? here is his extension… “

YOU: “Great! Thanks a bunch! That’s what I have been waiting! I’ll call him right now”.

You called the Wafer Warehouse and here is how it went:

YOU: “Hey, I want to know what impurity, concentration, mobility etc. for that wafer I bought on sale from you?”

WAFER WAREHOUSE: “Sorry, we didn’t really know those things. We forgot to do it before shipping out to you. One thing though, for that batch, I think most of the impurity is tellurium “

YOU: “You are sure?”

WAFER WAREHOUSE: “Our analysis of other samples, all indicate tellurium, may be with very little carbon, that’s all we know about it! “

What are you going to report to your boss? must explain your reasoning and show your work to get credit.