Homework #9

Reading

- Kasap 5.3

Problems

1. **Temperature Dependence of Conductivity (Kasap 5.12)**

An n-type Si sample has been doped with 10^{15} phosphorus atoms cm^{-3}. The donor energy level for P in Si is 0.045 eV below the conduction band edge energy.

a. Calculate the room temperature conductivity of the sample.
b. Estimate the temperature above which the sample behaves as if intrinsic.
c. Using a few iterations, estimate to within 20 percent the lowest temperature above which all the donors are ionized. (hint: start with N_c from Table 5.1 (below), then find T_S (saturation temp for donor ionization), then use this temp to calculate N_c, and repeat…)
d. Sketch schematically the dependence of the electron concentration in the conduction band on the temperature as $\log(n)$ versus $1/T$, and mark the various important regions and critical temperatures. For each region draw an energy band diagram that clearly shows from where the electrons are excited into the conduction band.
e. Sketch schematically the dependence of the conductivity on the temperature as $\log(\sigma)$ versus $1/T$ and mark the various critical temperatures and other relevant information..

Table 5.1 Selected typical properties of Ge, Si, InP, and GaAs at 300 K

	E_g (eV)	χ (eV)	N_c (cm^{-3})	N_v (cm^{-3})	n_i (cm^{-3})	μ_e (cm^2 V^{-1} s^{-1})	μ_h (cm^2 V^{-1} s^{-1})	m_e^*/m_e	m_h^*/m_e	ε_r
Ge	0.66	4.13	1.04×10^{19}	6.0×10^{18}	2.3×10^{13}	3900	1900	0.12*a* 0.56*b*	0.23*a* 0.40*b*	16
Si	1.10	4.01	2.8×10^{19}	1.2×10^{19}	1.0×10^{10}	1400	450	0.26*a* 1.08*b*	0.38*a* 0.60*b*	11.9
InP	1.34	4.50	5.2×10^{17}	1.1×10^{19}	1.3×10^{7}	4600	190	0.079*a,b*	0.46*a* 0.58*b*	12.6
GaAs	1.42	4.07	4.4×10^{17}	7.7×10^{18}	2.1×10^{6}	8800	400	0.067*a,b*	0.40*a* 0.50*b*	13.0

NOTE: Ge and Si are indirect whereas InP and GaAs are direct bandgap semiconductors. Effective mass related to conductivity (labeled a) is different than that for density of states (labeled b). In numerous textbooks, n_i is taken as 1.45×10^{10} cm^{-3} and is therefore the most widely used value of n_i for Si, though the correct value is actually 1.0×10^{10} cm^{-3}. (Green, M.A., Journal of Applied Physics, 67, 2944, 1990.) (Data combined from various sources.)

2. **Degenerate Semiconductor (Kasap 5.21) – more conceptual rather than quantitative**

Consider the general exponential expression for the concentration of electrons in the CB,

$$n = N_c \exp\left[-\frac{(E_c - E_F)}{kT}\right]$$

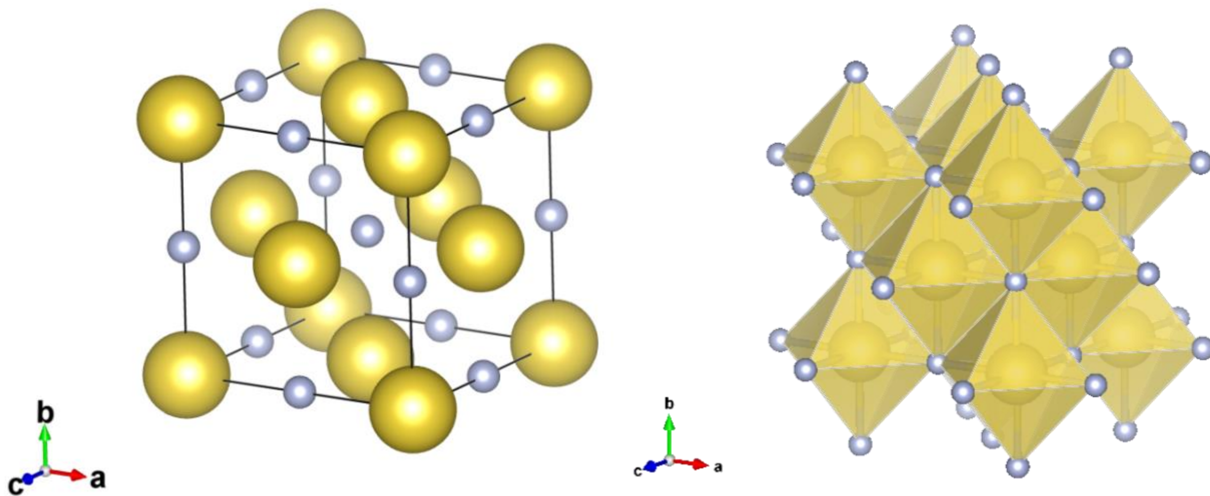
and the mass action law, $np = n_i^2$. What happens when the doping level is such that n approaches N_c and exceeds it? Can you still use the above expressions for n and p?

Consider an n-type Si that has been heavily doped and the electron concentration in the CB is 10^{20} cm^{-3}. Where is the Fermi level? Can you use $np = n_i^2$ to find the hole concentration? What is its resistivity? How does this compare with a typical metal? What use is such a semiconductor?

3. **Project Atomic Model**

Using CrystalMaker, VESTA, or similar, generate a model of your material's structure. Knowing the space group and lattice parameters will make this more straightforward. Usually, a model will show a unit cell, but you may need to be creative (e.g., for amorphous materials). Non-atomic representations (e.g., polyhedral) are fine. Be creative.

***** You can submit an image (PNG/JPG/PDF) of your model with your homework 9 solutions, but also submit your image and the native file in Canvas by replying to the Electronic Materials Project topics thread *****.



Example unit cells for sodium fluoride (NaF) created in VESTA.