Ch/ChE 140a
Problem Set #2
2007/2008
SHOW ALL OF YOUR WORK!

<u>90 points total</u>

Please read chapter 4 (*pp*. 87-128) of <u>Advanced Semiconductor Fundamentals</u> by Pierret.

(*20 Points*)

1. The effective density of states, N_C, can be calculated from information in the *E vs. k* diagram and by

$$N_C = 2\left(\frac{2\pi m^* kT}{h^2}\right)^{3/2}$$

where m^* is the isotropic effective mass of an electron. Calculate N_C for Si, GaAs, and ZnO at 300K. Use the attached table of physical data to make your calculation. The *E vs. k* diagrams for Si, GaAs, and ZnO are attached as Figures 1, 2, and 3, respectively, and are only intended to help you determine the location of the conduction band minima for the purpose of finding the isotropic effective mass. (Assume the effective mass of an electron in ZnO is $0.27m_o$.)

(*25 Points*)

2. By studying the temperature dependence of the carrier concentration in a semiconductor sample, several things can be learned about its properties. Figure 4 (attached) shows the natural logarithm of the free carrier density (n+p) of a semiconductor sample measured as a function of temperature.

a. Calculate the dopant density, assuming that all dopants are of one type and that they are all fully ionized at room temperature (300 K). (*10 Points*)

b. Calculate the band gap of the semiconductor assuming N_C and N_V are constant with respect to temperature. What semiconductor do you suspect this is? (*10 Points*)

c. Notice the *very* small decrease in $ln(n+p)$ as 1/T increases (T < 200 K). Explain this phenomenon. (*5 Points*)

(*20 Points*)

3. Use the table of physical data and any reference texts that you may want to calculate the following parameters for five semiconducting materials: Ge, Si, GaAs, CdS, and TiO_2.

a. Calculate the intrinsic carrier concentration (n_i) at room temperature (300 K). (*10 Points*)

b. Give an example of an atom substitution which would provide each type of dopant (donor, acceptor) in these semiconductors. (Give the dopant atom choice as well as the atom replaced.) (*10 Points*)

Ch/ChE 140a TA: Josh Spurgeon Office:218 Noyes
Phone: x3964 Email: spurgeon@caltech.edu

(*15 Points*)

4. a. What density of extrinsic dopants would be needed to double the total free carrier (n+p) concentration from its intrinsic value in a sample of Si at 300 K, assuming a complete ionization of the dopants? Repeat this calculation for TiO_2.

Caution: $n+p = n_i+p_i = 2n_i$ and $np = n_i p_i = n_i^2$ for an **intrinsic** sample *only*!

Whereas: $n+p = n_{\text{th}}+N_D+p_{\text{th}}$ and so $np = (n_{\text{th}}+N_D)p_{\text{th}} = n_i^2$ for a **doped** sample.

($n_{\text{th}} = p_{\text{th}}$ = thermalized electron and hole concentrations respectively.)

(*10 Points*)

b. Comment on the feasibility of doping Si and TiO_2 to this level. (*5 Points*)

(*10 Points*)

5. How thick would a wafer of Si have to be to absorb 99% of the 800 nm photons hitting it, assuming no reflection losses at the front surface and <u>complete</u> reflection at the back surface? What thickness of GaAs would be required to accomplish the same feat? *You can find the necessary equations on page 40 and the absorption coefficients in Figure 7 on page 41 of the required article, "Principles and Applications of Semiconductor Photoelectrochemistry."*

Figure 1:

1.2 Silicon (Si) (For tables, see p. 43ff.)

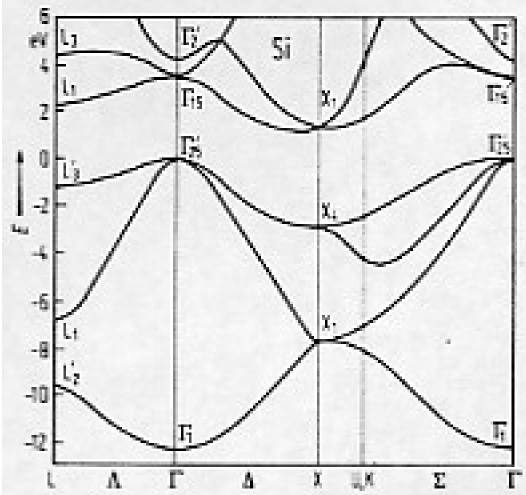


Fig. 1. Si. Band structure obtained by a non-local pseudopotential calculation neglecting spin-orbit interaction [76C2].

Figure 2:

2.10 Gallium arsenide (GaAs) (For tables, see p.

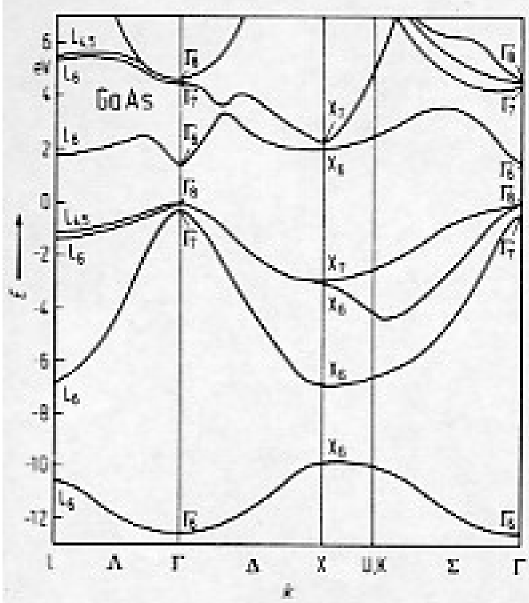


Fig. 1. GaAs. Band structure obtained by a non-local pseudopotential calculation [76C1].

Ch/ChE 140a TA: Josh Spurgeon Office:218 Noyes
Phone: x3964 Email: spurgeon@caltech.edu

Figure 3:

3.5 Zinc oxide (ZnO)

(For tables, see p. 35 ff.)

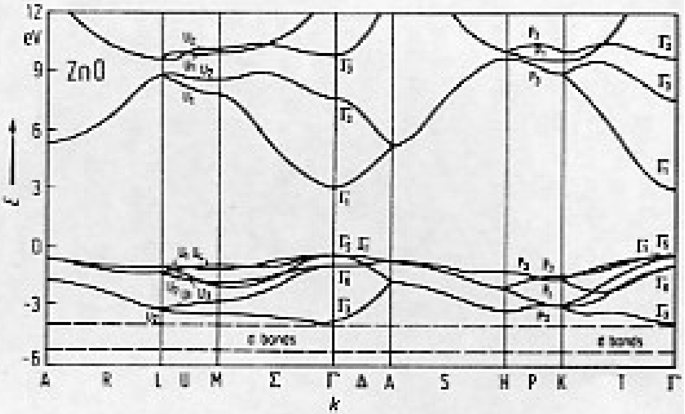


Fig. 1. ZnO. Calculated energy band structure (electron energy vs. reduced wave vector coordinate) according to [69R1]. The irreducible representations of the states at high symmetry points are indicated.

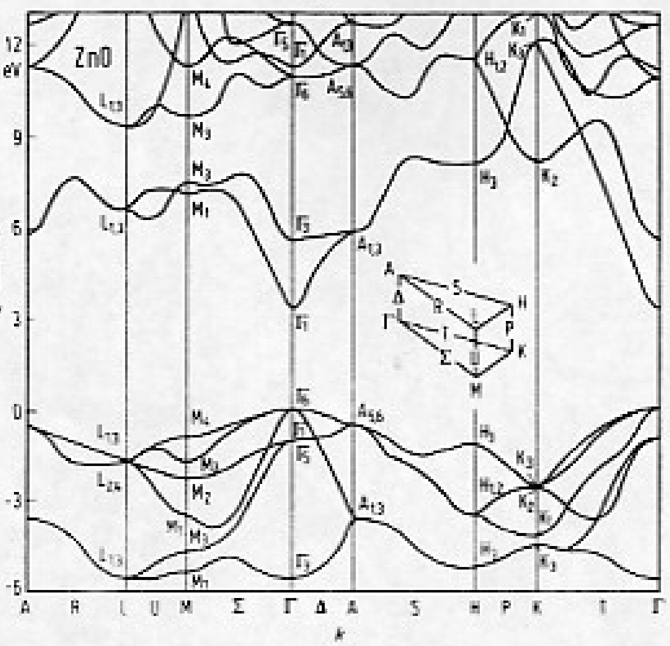
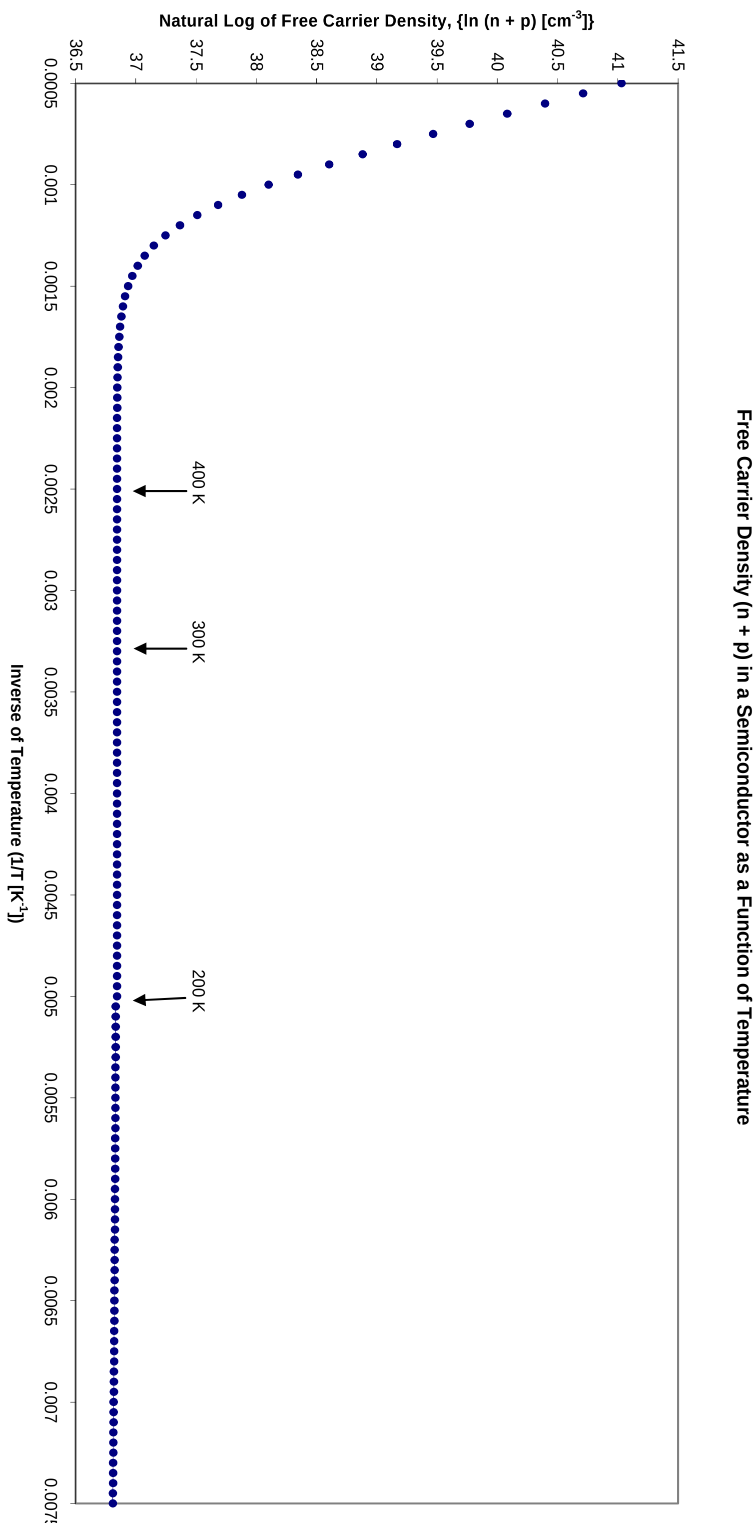


Fig. 2. ZnO. Calculated energy band structure (electron energy vs. reduced wave vector coordinate) according to [73B]. A part of the Brillouin zone is shown in the insert.

Figure 4:



Free Carrier Density (n + p) in a Semiconductor as a Function of Temperature
Natural Log of Free Carrier Density, {ln (n + p) [cm^-3]}
Inverse of Temperature (1/T [K^-1])
400 K
300 K
200 K
36.5
37
37.5
38
38.5
39
39.5
40
40.5
41
41.5
0.0005
0.001
0.0015
0.002
0.0025
0.003
0.0035
0.004
0.0045
0.005
0.0055
0.006
0.0065
0.007
0.0075