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MSE 104, Quiz 2 ver 1 (1 hr)
Winter 2017

8 March 2017
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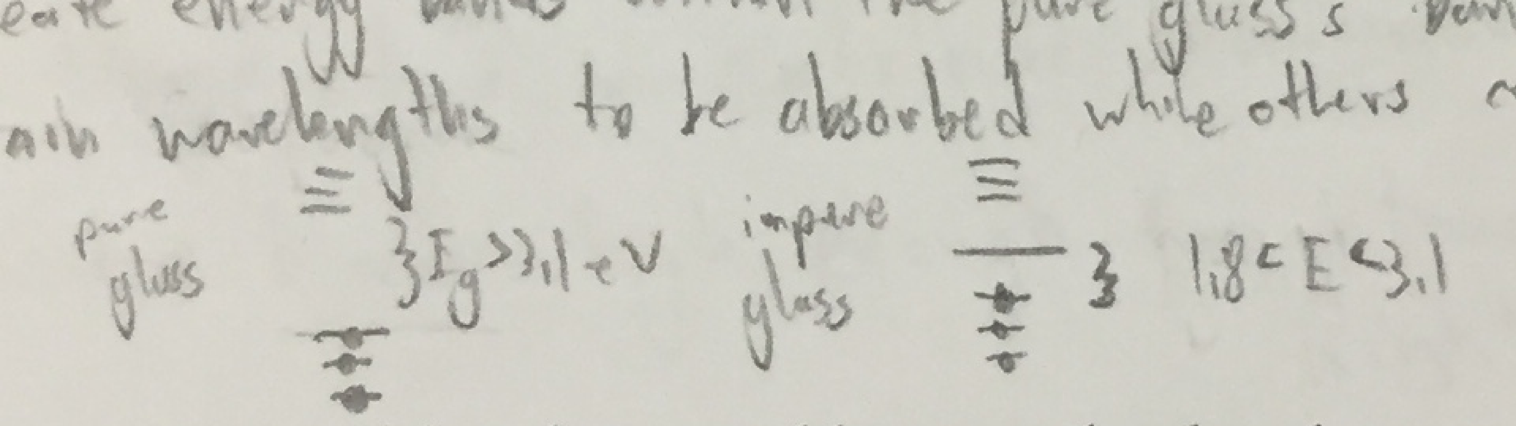
Show all work and include units for full credit

1 (25 pts)	21
2 (25 pts)	25
3 (20 pts)	20
4 (30 pts)	30
TOTAL (100)	96

1. You escaped from working on ammunition and armor and took a job as a ceramist at a glass manufacturing company. The current processing methods yield a colorless, transparent glass. The company wants to diversify its product line, and you have been given the following tasks:

(a) With at most minor changes in composition, how would you make the glass colored, but still transparent? Explain / justify your answer by referencing relevant equations, numeric values, *and/or* a sketch. **[6]** You could color the glass by introducing impurity atoms that create energy bands within the pure glass's band gap. This allows for visible light of certain wavelengths to be absorbed while others continue to be transmitted, producing color. E must be between 1.8 and 3.1 eV for coloring to occur.



(b) Using the same composition, how could you make the glass opaque? What property would you introduce or what processing method would you use? **[4]**
The glass could be made opaque by increasing porosity. This could be done by melting the glass and cooling it unevenly, thus preferentially creating multiple separate grains within the macrostructure that act to scatter light at boundaries, causing opacity.

(c) Identify one method of improving the strength of a glass fiber. Explain how/why the strength is improved. Transformation toughening is not possible with the glass composition you are using, and you can not change the composition. **[5]**

Strength of a glass fiber could be improved by heating it to melting and then quenching it. This would induce compressive stresses within the fiber, thus increasing strength by allowing greater loads to be applied without breaking.

(d) Glass is cut by scribing (scratching) a line on the glass and then bending the glass along this line. The glass generally breaks cleanly and fairly easily. What mechanical property is most relevant in this process, and why can't most metals be cut by the same process? **[4]**

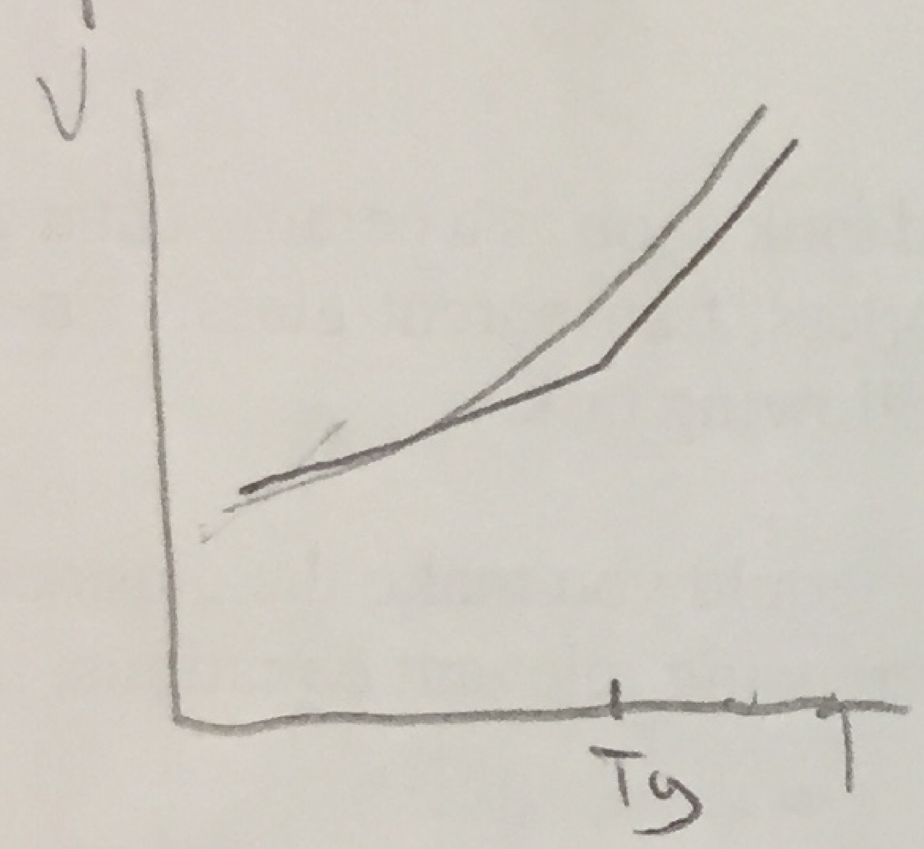
Brittle fracture as a result of low ductility allows glass to be cut by scribing and bending. The glass does not plastically deform, instead cracking along the scratch. Metals cannot be cut this way due to their high ductility causing plastic deformation before fracture. ✓

(e) Describe the glass transition temperature. Sketch the volume as a function of temperature for an amorphous material and for a crystalline material. **[6]**

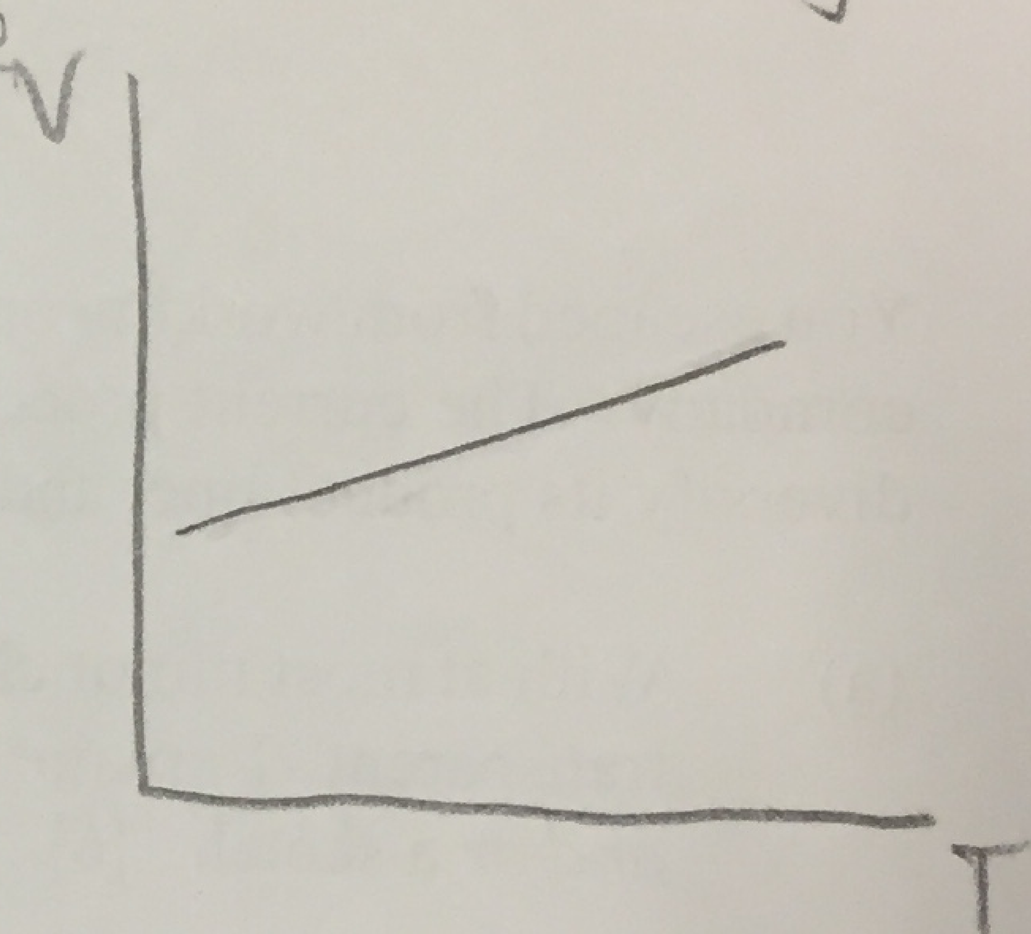
The glass transition temperature is the temperature at which the constituent materials have their crystal structures broken down, becoming amorphous.

-4

amorphous



crystalline



2. (a) What is the effect of doping intrinsic Si with In? [4]

Since In has only 3 valence electrons, doping Si with it creates holes that turn the mixture into a p-type extrinsic semiconductor.

(b) Is In an acceptor or a donor for Si? Briefly explain why. [5]

In is an acceptor since its empty fourth valence site can receive electrons from Si.

(c) How could you use a variable wavelength light source (energy variable from 0.5 eV to 4.0 eV) to determine the band gap of your new semiconductor? [5]

Starting at .5 eV, the light should be shone upon the semiconductor while a photodetector reads the intensity of light transmitted through the semiconductor. Then decrease the wavelength (increasing energy) until the no light is transmitted. This value will correspond to the band gap, since this is the lowest energy light which can be absorbed.

(d) If you heat your new, doped semiconductor, will its conductivity increase, decrease, or stay the same? *Explain*! [6]

The conductivity will decrease, since hole mobility decreases with temperature in extrinsic semiconductors. This will be true until the temperature becomes high enough for intrinsic semiconduction to take over.

Right!

(e) The resistance of a solar cell decreases when sunlight falls on it. Name and explain the operating principle/process. [5]

A decrease in resistance corresponds to an increase in conductivity. This will be seen for photoelectric materials, which have electrons jump the band gap during the absorption process. The incident photon from the sun transfers sufficient energy to an electron of the photoreactive material to send it into the conduction band, increasing the number of free electrons and thus conductivity (decreasing resistance).

3. (a) Calculate the Fermi energy E_F of monovalent copper.

$$E_F = 3.65 \times 10^{-19} n^{2/3} \text{ eV}$$

where n is the number of conduction electrons per m³ [6]

$$n = \frac{1 \text{ conduction } e^-}{\text{atom Cu}} \cdot \frac{6.022 \times 10^{23} \text{ atoms}}{\text{mol}} \cdot \frac{1 \text{ mol}}{63.55 \text{ g}} \cdot \frac{8.94 \text{ g}}{\text{cm}^3} \cdot \frac{10^6 \text{ cm}^3}{\text{m}^3}$$

$$n = 8.47 \times 10^{28} \, e^-/\text{m}^3$$

$$E_F = 3.25 \times 10^{-19} (8.47 \times 10^{28} \, e^-/\text{m}^3)^{2/3}$$

$$= \boxed{7.04 \text{ eV}}$$

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(b) Using the information given/calculated above, calculate the *conductivity* of Cu, given that the mobility of the free electrons is 3.5×10^{-3} m²/(V•s). If you were unable to complete part (a) and feel you need a calculated value, leave that value as a variable and note it in your solution. [6]

$$\sigma = n|e|\mu_s$$

$$\sigma = (8.47 \times 10^{28} \, e^-/\text{m}^3) \cdot 1.602 \times 10^{-19} \, C \cdot 3.5 \times 10^{-3} \, \frac{\text{m}^2}{V \cdot s}$$

$$= \boxed{4.75 \times 10^7 \, (\Omega \cdot \text{m})^{-1}}$$

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(c) What is the Fermi energy? What is its significance? [4]

The Fermi energy is the energy level that divides the nonconducting and conducting bands for electrons

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(d) If the copper is heated to 200°C, will its *resistivity* increase, decrease, or have no change? [4]

Its resistivity will increase, since $\rho = \frac{1}{\sigma}$ and σ decreases with T

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4. A pure elemental semiconductor has a room temperature electrical conductivity of 4 x 10^{-4} (Ω-m)-1, band gap of 1.11 eV, electron mobility of 0.145 m^2/V-s and hole mobility of 0.05 m^2/V-s. If the number of free electrons per valence electron is 6.4 x 10^{-14}, answer the following questions. For dopants, assume that dopant atoms substitute for host atoms, saturation/exhaustion is reached, and intrinsic conduction is negligible.

(a) What is the number ~~of~~ density of elemental *atoms* (m^{-3}) in this pure semiconductor? **[10]**

$\sigma = ne(\mu_e + \mu_h)$ $n = \frac{\sigma}{e(\mu_e+\mu_h)} = \frac{4\times10^{-4}\ (\Omega\cdot m)^{-1}}{1.602\times10^{-19}\,C\,(.145\ m^2/V\cdot s + .05\ m^2/V\cdot s)}$

$= 1.28\times10^{16}\ m^{-3}$

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$N = \frac{1.28\times10^{16}\ \text{free } e^-}{m^3} \cdot \frac{1\ \text{valence } e^-}{6.4\times10^{-14}\ \text{free } e^-} \cdot \frac{1\ \text{atom}}{4\ \text{valence } e^-} = \boxed{5.00\times10^{28}\ m^{-3}}$

(b) What atomic % of n-type dopant must be used to increase the electrical conductivity by factor of 100? **[8]**

$4\times10^{-2} = ne\mu_e$

$n = \frac{4\times10^{-2}\ (\Omega\cdot m)^{-1}}{1.602\times10^{-19}\,C \cdot .145\ m^2/V\cdot s}$

$n = 1.72\times10^{18}\ m^{-3}$

atom % dopant $= \frac{n}{n+N}\times100$

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$= \boxed{3.44\times10^{-9}\ \%\ \text{dopant}}$

(c) What atomic % of p-type dopant must be used to increase the electrical conductivity by factor of 100? **[8]**

$4\times10^{-2} = ne\mu_h$

$n = \frac{4\times10^{-2}\ (\Omega\cdot m)^{-1}}{1.602\times10^{-19}\,C \cdot .05\ m^2/V\cdot s}$

$n = 4.99\times10^{18}\ m^{-3}$

atom % dopant $= \frac{n}{n+N}\times100$

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$= \boxed{9.98\times10^{-9}\ \%\ \text{dopant}}$

(d) If this semiconductor were heated to 100°C, would the electrical conductivity increase, decrease or have no change? **[4]**

~~Since impurity concentration is relatively low ($<10^{21}\ m^{-3}$), hole mobility will strictly decrease with temperature. Since the impurity concentration remains the same, this means the conductivity will decrease.~~

The conductivity will increase, as intrinsic semiconductors have conductivities that increase with T as more electrons gain sufficient thermal energy to jump the band gap.

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