ENGR 145 **Chemistry of Materials** **Fall 2023**

Exam #3
November 30-December 1, 2023

Duration: 24 hours; 11:30am Nov. 30 – 11:30 am Dec. 1
Submit your answers via Canvas by 11:30 am EST on Dec. 1

Any resources (book, notes, web, etc.) are allowed, but you are not allowed to talk with anyone during the exam. With submission of your answers, you implicitly affirm that all work is your own, without consultation of peers or others.

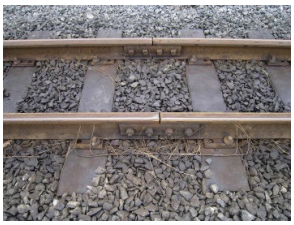
1a. Germanium pre-dates silicon as the material used to construct the first transistor (Bell Labs, 1947). Ge has a bandgap of 0.67 eV. Calculate the frequency of light that is necessary to promote an electron from the valence to the conduction band. (10)

b. One reason that germanium is not used for semiconductor devices is its lower bandgap vs. silicon, which can lead to more thermal generation of e-h pairs. Why might this be a problem? (5)

c. Suppose a single crystal of Ge contains $10^{-24}/m^3$ boron atoms, and all B atoms in the Ge are ionized. Is this material p-type or n-type? Explain your answer through a description of the differences between n-type and p-type doping. (10)

2a. A steel railroad track has a thermal expansion coefficient of 11.5 x 10^{-6} mm/mm°-C. Calculate the elongation of a section of track that is 10m long if the ambient temperature changes from 60°F to 85°F. (10)

b. Continuously-welded rail (CWR) was laid for the first time in the U.S. in 1933, and gradually replaced short, jointed rails shown below. The length of these rails was usually standardized at 39 feet.



In your own words:

What considerations drove the transition to CWR? (5)

How do materials engineers deal with thermal expansion of CWR in an attempt to prevent buckling when the ambient temperature is hot?

3a. You are asked to build a capacitor using two plates of metal, for example aluminum. For the dielectric, you have several materials to choose from: (i) Nylon 11, $\varepsilon = 6$; (ii) poly(vinylidene fluoride) or PVDF, $\varepsilon = 10$; and (iii), biaxially-oriented polypropylene, $\varepsilon = 2.2$. Assume a constant thickness for each material. To obtain the largest capacitance at a fixed voltage, which of the three material sheets should you use? Back up your answer with basic equations. (10)

b. Now consider that you have access to different thicknesses of Nylon 11. How will the capacitance change as the polymer film thickness decreases? (10)

c. Why might there be a practical lower limit to the thickness of the polymer dielectric? (5)

4a. Using an energy band model, explain why metals have both high electrical and thermal conductivity. (10)

b. Diamond is a rather odd material, in that it is an excellent electrical insulator and an excellent thermal conductor. In your own words, offer explanations for both. (10)

c. Suggest an application where high thermal conductivity along with high electrical resistance would be desirable. (5)

Extra Credit (10)

Write a short essay, no more than about 300 words, on a commercial process for doping of highly-pure silicon with, for example, boron or arsenic.