

Department of  
***MATERIALS SCIENCE AND ENGINEERING***

# **Doctoral Written Exam**

## **Day 1**

**Core Areas:**

**MATERIALS PHYSICS AND CHEMISTRY  
ADVANCED MECHANICAL BEHAVIOR**

**Thursday, May 12, 2005**

*Department of Materials Science and Engineering*

**DOCTORAL WRITTEN EXAM – Day 1  
May 12, 2005**

Your exam packet for day I contains a total of six (6) questions from two (2) core areas, MATERIALS PHYSICS AND CHEMISTRY and ADVANCED MECHANICAL BEHAVIOR, plus 10 answer sheets. Each question is on a separate page. A copy of the Table of Constants is included for your reference. **You must submit 2 questions from each core area for grading.** You will have 4 hours to complete the questions. You can obtain extra answer sheets from the proctor, if needed. Please use the following procedure:

Write a four (4) digit code of your choice, and your name on the 3 X 5 card provided. Use this code in place of your name to identify all answer sheets you submit for both days of the exam. Renee will keep the code information, sealed in an envelope, until after the exams are graded.

**For each answer, use the question sheet as the first page of your answer. If additional pages are required, use the blank answer sheets provided. At the end of the examination, staple each question sheet and corresponding answer sheets for each question separately, put this instruction sheet on top of the questions you are turning in, and place them in one side of your exam folder. Place all other exam pages in the other side of your folder, and return everything to the proctor, or Renee if you finish before 12:30 P.M.**

Please be sure to complete the information required on each page.

**GOOD LUCK!**

**CODE NUMBER \_\_\_\_\_**

**CHECK THE 4 QUESTIONS YOU WISH TO HAVE GRADED.**

**MATERIALS PHYSICS  
AND CHEMISTRY:**

1. \_\_\_\_\_

2. \_\_\_\_\_

3. \_\_\_\_\_

**ADVANCED MECHANICAL  
BEHAVIOR:**

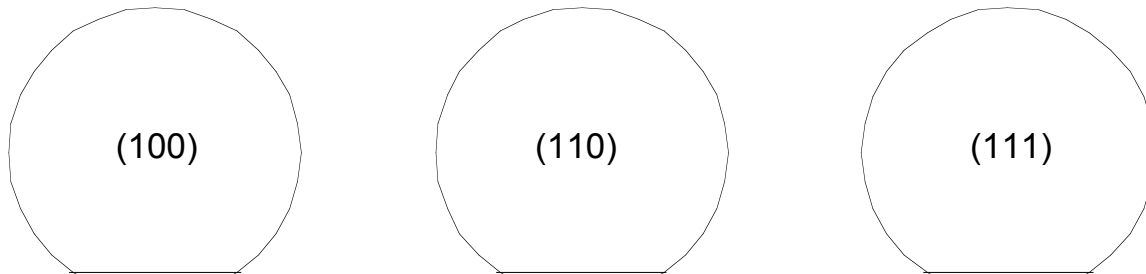
4. \_\_\_\_\_

5. \_\_\_\_\_

6. \_\_\_\_\_

1.

a) A student has 3 silicon wafers, each about 4 inches in diameter, with (100), (110), and (111) surface orientation. If she wants to cleave off a 1-inch wide by 3-inch long rectangular piece from one of the wafers, indicate where she should make the notches:

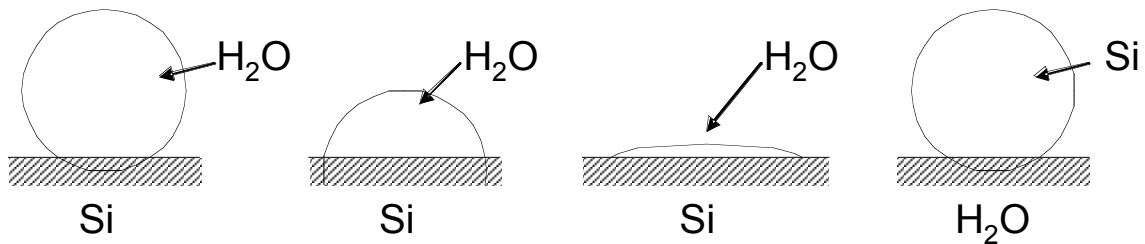


Explain your answer, using additional diagrams if necessary.

b) The piece of silicon then undergoes the following steps:

- i) Rinse in deionized water
- ii) Dip in concentrated HF for 20 seconds
- iii) Rinse in deionized water
- iv) Dip in concentrated HF for 60 more seconds
- v) Rinse in deionized water

Indicate what the piece might look like at the end of Steps (i), (iii), and (v):



c) To what temperature would the silicon wafer have to be heated to drive off the remaining water? Why?

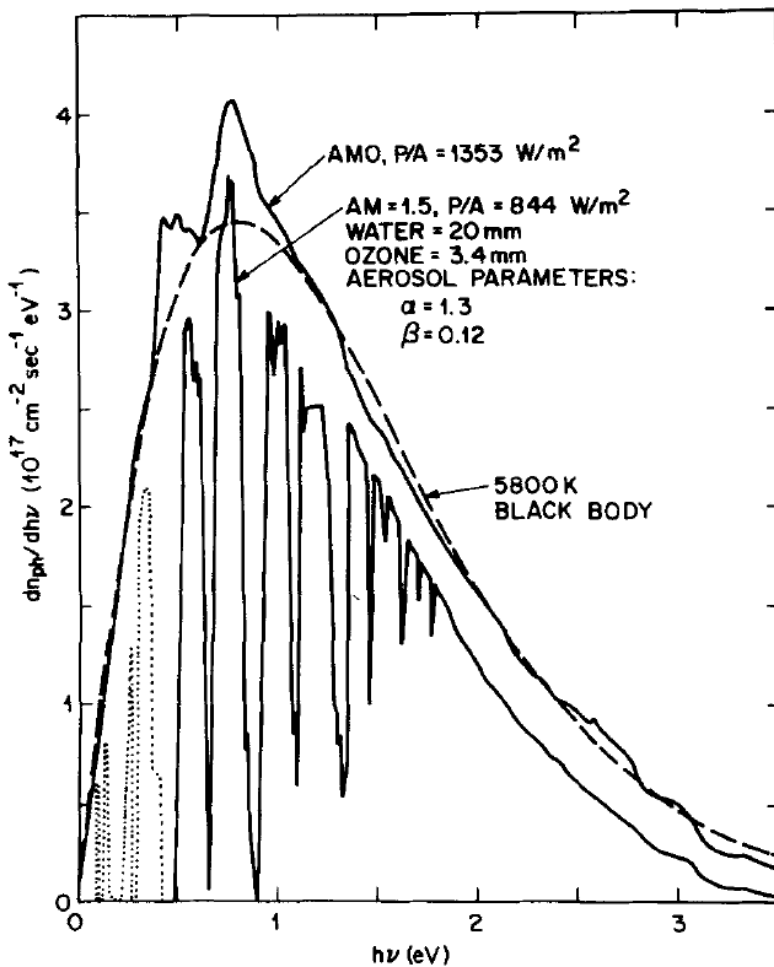
- i) below 100°C
- ii) right at 100°C
- iii) above 100°C
- iv) it depends...

d) At the end of Step (v) in Part (b), is the silicon piece in tension or compression? Why?

2.

An employee of Raytheon is assigned to make a photovoltaic module to power a communications satellite. She has 3 materials available: Si, GaN, Ge.

- A). The solar spectrum in outer space is shown below. It closely resembles a radiation spectrum of a blackbody at about 6000K. At a particular orientation of the solar panel, the solar energy flux will be approximately 1000 Watts / m<sup>2</sup>. What is the maximum power that a 1m x 1m photovoltaic cell could provide?
- B). How much power would a Si cell provide? Explain.
- C). What would be the best combination of the above materials to maximize the power output of the photovoltaic cell? Why?
- D). Please illustrate the solar cell structure you would propose using the combination of materials chosen in (C), and explain why you think it would work the best.



Energy per mode:

$$\langle E \rangle = \frac{h\nu}{e^{h\nu/kT} - 1}$$

Density of modes:

$$\rho(\nu) = \frac{dn_s}{d\nu} = \frac{8\pi}{c^3} \nu^2$$

Energy per unit volume per unit frequency:

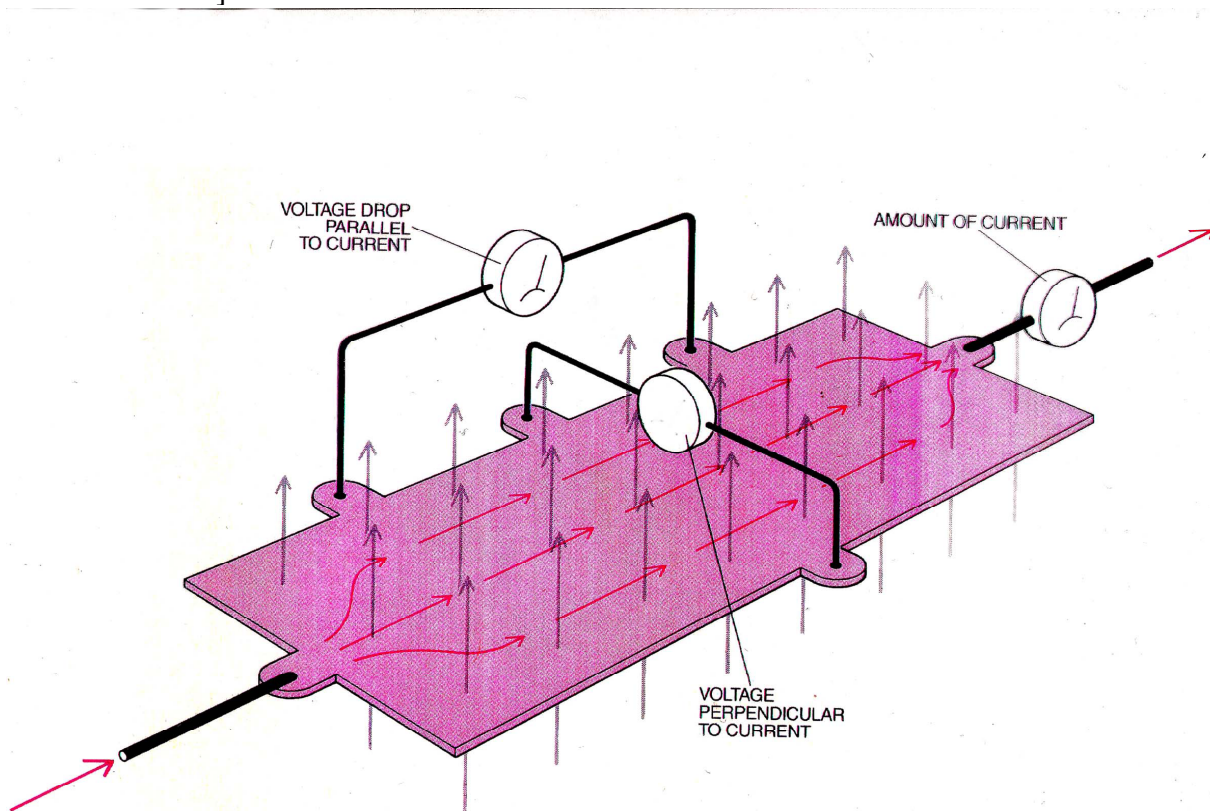
$$S_\nu = \frac{8\pi h}{c^3} \frac{\nu^3}{e^{h\nu/kT} - 1}$$

3.

A strip of indium is 1.5 cm wide and  $125 \mu\text{m}$  thick. When a current of 25A is established in the strip and a uniform field of 0.275T is oriented perpendicular to the plane of the strip, a Hall voltage of  $2.99 \mu\text{V}$  is measured across the width of the strip.

The density of indium is  $7.31 \times 10^3 \text{ kg/m}^3$  and its molar mass is 114.818 g/mole; the majority charge carriers in indium are electrons

- Compute the charge carrier concentration (or “number density of charge carriers”) in indium
- Using your answer in a), compute the Fermi energy of indium, at 293K, in eV
- Compute the average number of charge carriers contributed by each indium atom
- In the diagram below, show the deflection of the charge carriers [Hint: consider the Lorentz force] and indicate the proper sign for the Hall voltage [Hint: use a right-handed coordinate system, and assume that your voltmeter is connected such that voltage increases in the positive y direction]:



## 4.

A cylindrical pressure vessel is made from cast iron. The pressure vessel has an average radius of 250 mm, and a wall thickness of 5.0 mm. Semi-circular cracks of length  $2a$ , and depth  $a$ , may exist in the wall of the cylinder. For these cracks, assume that the mode-I stress-intensity factor is given by  $K_I = \sigma\sqrt{\pi a}$ , where  $\sigma$  is the stress normal to the crack.

The pressure vessel is proof tested at an internal pressure of 5.0 MPa, before service. During service, there is a constant pressure of 1.0 MPa in the cylinder, but the cylinder also supports an oscillating axial load that varies between - 200 kN and + 100kN. Will the pressure vessel fail by brittle fracture, or by leaking when the crack depth equals the wall thickness? What is the minimum number of cycles it will take for the cylinder to fail by this mechanism?

The fracture toughness of the cast iron is  $10 \text{ MPa}\sqrt{\text{m}}$ , and the yield stress is 400 MPa. Under the service conditions described above, it may be assumed that crack growth follows a Paris Law of  $da/dN = 1.50 \times 10^{-9} \Delta K_I^4 \text{ m/cycle}$ , where the stress-intensity factor range,  $\Delta K_I$ , is in  $\text{MPa}\sqrt{\text{m}}$ .

**5.**

A thin layer ( $25\ \mu\text{m}$ ) was removed from a flat thin sheet ( $1.0\ \text{mm}$ ) of a plastic. After the layer was removed, the sheet became dish-shaped with equal radii of curvature,  $\rho = 50\ \text{cm}$ , in both directions. Assume the elastic modulus of plastic is  $4\ \text{GPa}$  and Poisson's ratio,  $\nu = 0.4$ . Calculate the stress that existed in the layer that was removed. Partial credit will be given if the equations are set up correctly.

6.

A two-phase material contains 60 vol % of precipitates that are cube-shaped and coherent with the matrix. The orientation relationship between the precipitates and the matrix is:  $\{100\}_{\text{ppt}} // \{100\}_{\text{matrix}}$  and  $\langle 001 \rangle_{\text{ppt}} // \langle 001 \rangle_{\text{matrix}}$ . Slip occurs on  $\{111\}\langle 110 \rangle$  systems. Assume  $G=50$  GPa and  $b=0.25$ nm.

- a) Assuming that the precipitates are unsharable by dislocations, calculate the yield strength of this material. Assume the dimension of precipitates to be 100 nm cube, and state any other assumptions you may make.
- b) Single crystals of this material are tested. What will be the ratio of the yield strength of a [110]-oriented crystal compared to a [100]-oriented crystal?
- c) Describe three additional mechanisms that might be utilized to strengthen this material.