Department of Materials Science and Engineering
Massachusetts Institute of Technology
3.14 Physical Metallurgy – Fall 2009

Exam I

Monday, October 26, 2009

The Rules:

1) No calculators allowed

2) One hand written 3x5 index card may be prepared as a crutch

3) Complete 5 out of the 6 problems. If you do more than 5 problems, I will grade the first 5 that are not crossed out.

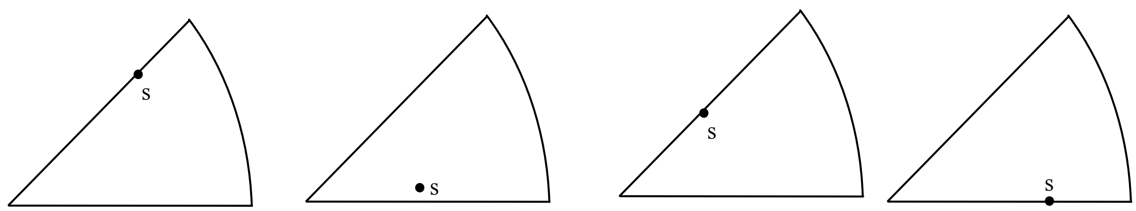
4) Make sure that you READ THE QUESTIONS CAREFULLY

5) Supplementary materials are attached to the end of the test (eqns., etc.)

6) WRITE YOUR NAME HERE:

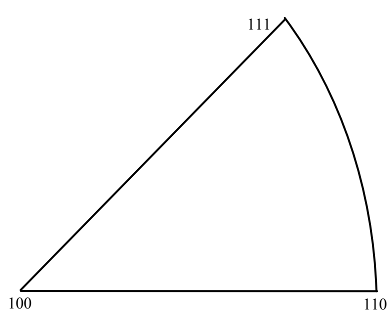
Problem #1: The Orientation of a Crystal is Inferred from Four Samples Processed Differently

A single crystal of an FCC metal is cut into four pieces and deformed uniaxially. The resulting four orientations are shown below, where the location of the stress axis is shown at the end of the test.



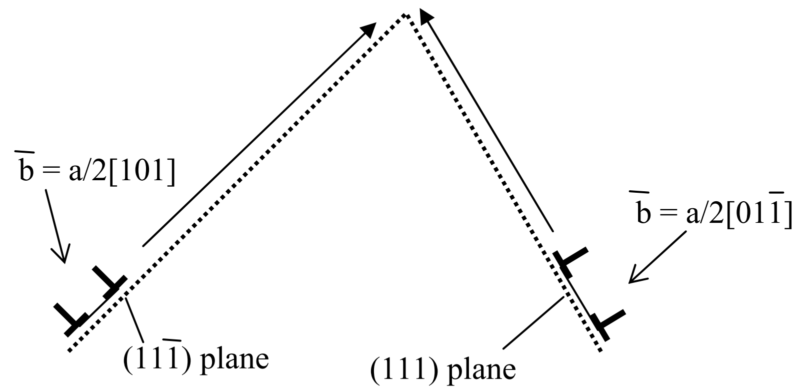
To complete this problem you need to do two things:

1. Identify the most likely original orientation of the testing (the original position of the stress axis—mark it in the blank stereographic triangle below)
2. Identify the four different deformations that must have been applied to these crystals in order to achieve the configurations shown at the end of the test.



Problem #2: Lock, Stock, and a Barrel Full of Partials

Consider two dislocations moving on different {111} planes in an FCC crystal, which are coming together at the same position as shown.



The two initial dislocations have Burgers vectors of a/2<110> type as shown; however, as the picture implies, these dislocations are actually separated into partials of a/6<211> type.

Part A:

Write out the correct Burgers vectors for the four partials in this problem (not just families—make sure all the signs and order of the digits hkl are correct, and make sure that they lie in the slip plane).

Part B:

Draw a picture showing the dislocation reaction that will occur when these dislocations meet. Will the reaction lead to a sessile or a glissile configuration?

Problem 3: Twinning

In class we analyzed twinning in HCP metals quite thoroughly. We mentioned that twinning can happen in FCC metals, although it is not as common. In fact, we discussed the fact that in FCC crystals, the twinning plane is (111), and the twinning direction is $\langle 11\bar{2} \rangle$.

Part A:

Twinning involves two undistorted planes. The second undistorted plane is $(11\bar{1})$. What is the first undistorted plane?

Part B:

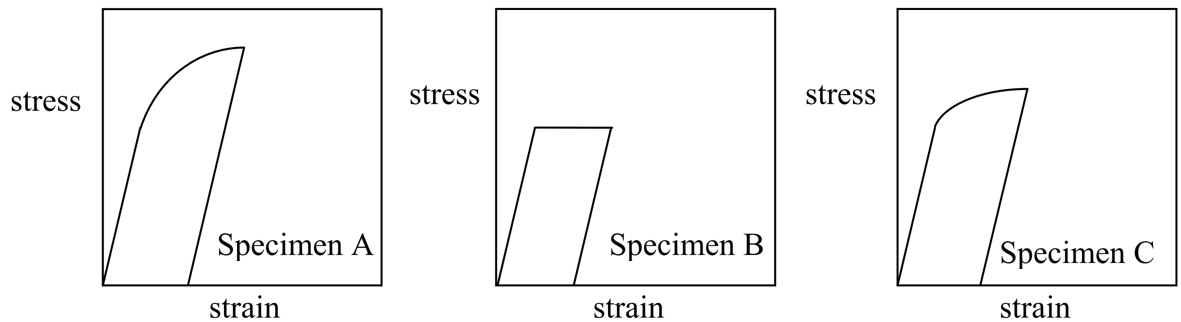
Knowing the twinning planes and twinning direction, do a simple calculation to determine the amount of shear strain that would be produced by a twin. (Hint: you may want to draw some pictures of the unit cell in order to get a feeling for the orientation of these planes and directions with respect to one another)

Part C:

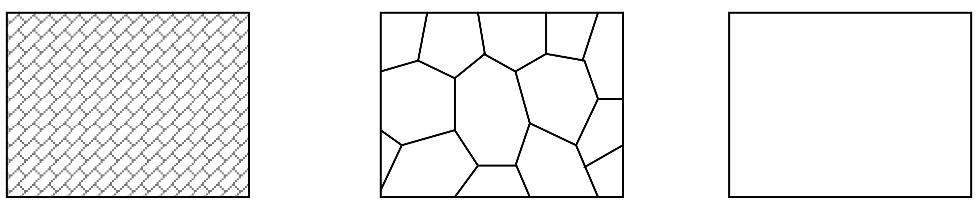
Do you think that twinning would have a sign dependence to it in an FCC crystal? In other words, will a positive stress cause twinning, but a negative stress not cause it (or vice versa)? Explain your thinking.

Problem #4: Post-UROP Forensics

Working in an MIT lab, you are studying deformation and annealing of **single crystals**. You have three identical specimens of the same metal, but which are cut with different crystal orientations. You carefully perform tensile tests to a fixed level of strain, and then unload them. You find:



Now you take the three specimens and give them to your UROP, with the request that they all be annealed at the same temperature for the same amount of time. Your UROP dutifully follows your orders, but manages to forget which sample is which! Looking for clues to sort out this mess, you perform metallography to look at the microstructure. Here is what you see:

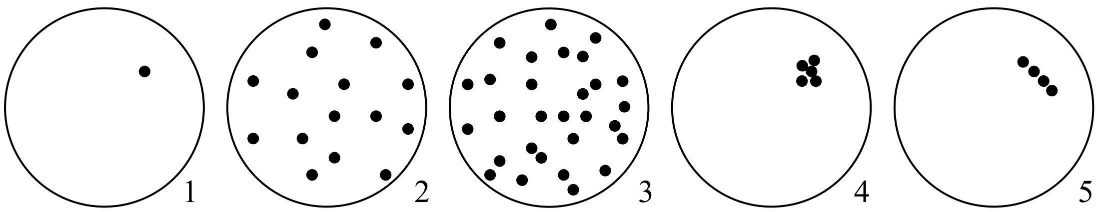


Structure I Structure II Structure III

Sort out which post-annealing microstructure belongs to which sample, and write a short explanation for your choices.

Problem 5: Annealing in Stereo

Below are five stereographic projections presented in the external reference frame. These projections show the distribution of crystal orientations in different samples of an HCP metal. The points represent the orientations of the c-axis (0001) of the crystals.



Which of these projections corresponds to each of the following situations? Provide one sentence of explanation for each answer, please.

a. A single crystal is bent and then annealed lightly

b. A single crystal is deformed slightly in compression and annealed lightly

c. A single crystal is deformed slightly in compression and annealed thoroughly

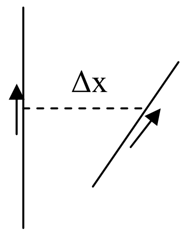
d. A single crystal is deformed heavily in compression and annealed

e. The sample from ‘d’ above is again deformed heavily and annealed

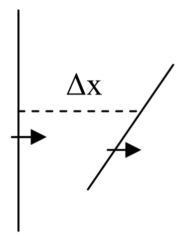
Problem 6: In Which We Consider the Interaction Among Non-Parallel Dislocations, Including Those That are Crossed and Those That Form Intriguing Loop Configurations

In class we dealt with the stress-field interactions between parallel dislocations only; we did not talk about whether dislocations feel each other in other configurations. Based on your understanding of dislocation stress fields, indicate whether the interaction in the following cases would be attractive, repulsive, or non-existent. In each picture below, the Burgers vectors are shown as arrows

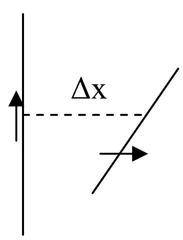
Case A: Two screw dislocations separated by a distance Δx, at 90º from one another. (The picture is drawn in perspective; the dislocations are parallel to the y and z axes)



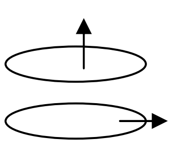
Case B: Two edge dislocations separated by a distance Δx, at 90º from one another. (The picture is drawn in perspective; the dislocations are parallel to the y and z axes)



Case C: An edge and a screw dislocation separated by a distance Δx, at 90º from one another. (The picture is drawn in perspective; the dislocations are parallel to the y and z axes)



Case D: Two loops atop one another, one with the Burger's vector in the plane of the loop, and one with it normal to the loop.



Helpful (?) Bonus Information

Stress field around an edge dislocation:

$$\sigma_{xx} \propto \frac{y(3x^2 + y^2)}{(x^2 + y^2)^2}$$

$$\sigma_{yy} \propto \frac{y(x^2 - y^2)}{(x^2 + y^2)^2}$$

$$\sigma_{xy} \propto \frac{x(x^2 - y^2)}{(x^2 + y^2)^2}$$

all other σ components are = 0.

Stress field around a screw dislocation:

$$\sigma_{rz} \propto \frac{1}{r}$$

all other σ components are = 0, and note that $r^2 = x^2+y^2$

Forces between dislocations:
Parallel edge:

$$F_y = \frac{\mu b^2}{2\pi(1-\nu)} \frac{y(3x^2 + y^2)}{(x^2 + y^2)^2}$$

$$F_x = \frac{\mu b^2}{2\pi(1-\nu)} \frac{x(x^2 - y^2)}{(x^2 + y^2)^2}$$

Parallel screw:

$$F_r = \frac{\mu b^2}{2\pi r}$$

JMAK Equation:

$f = 1\text{-}\exp(-kv^d t^{d+1})$

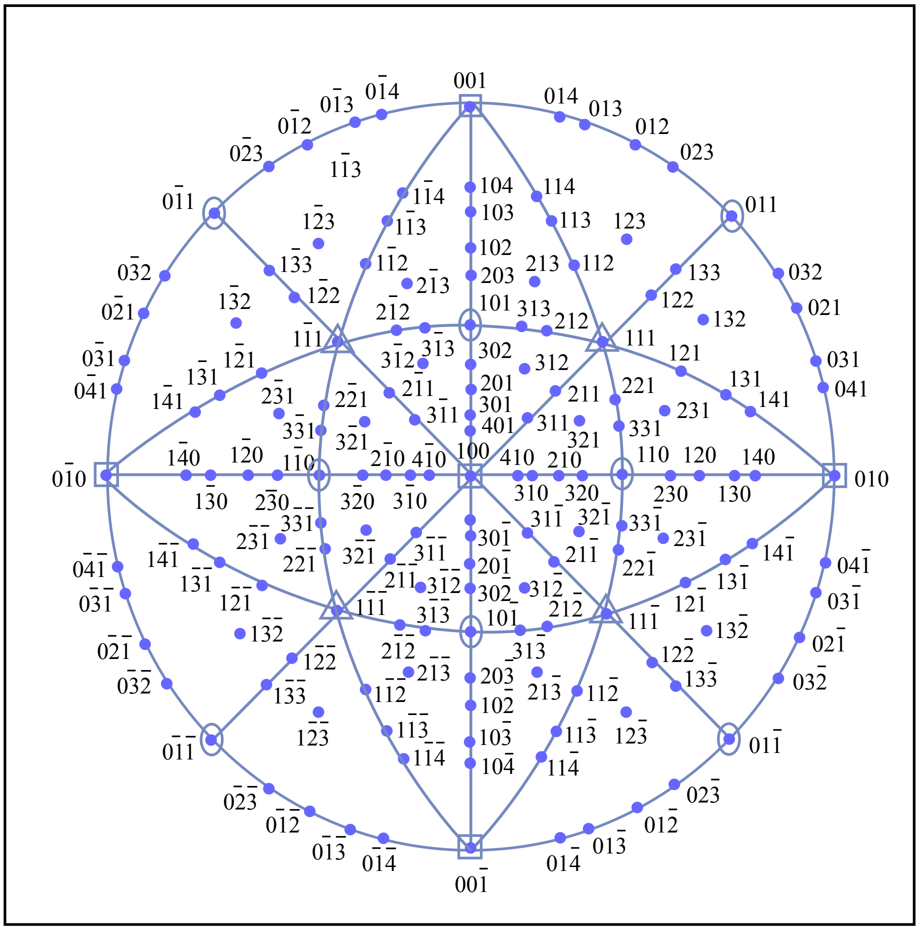


Figure by MIT OpenCourseWare.

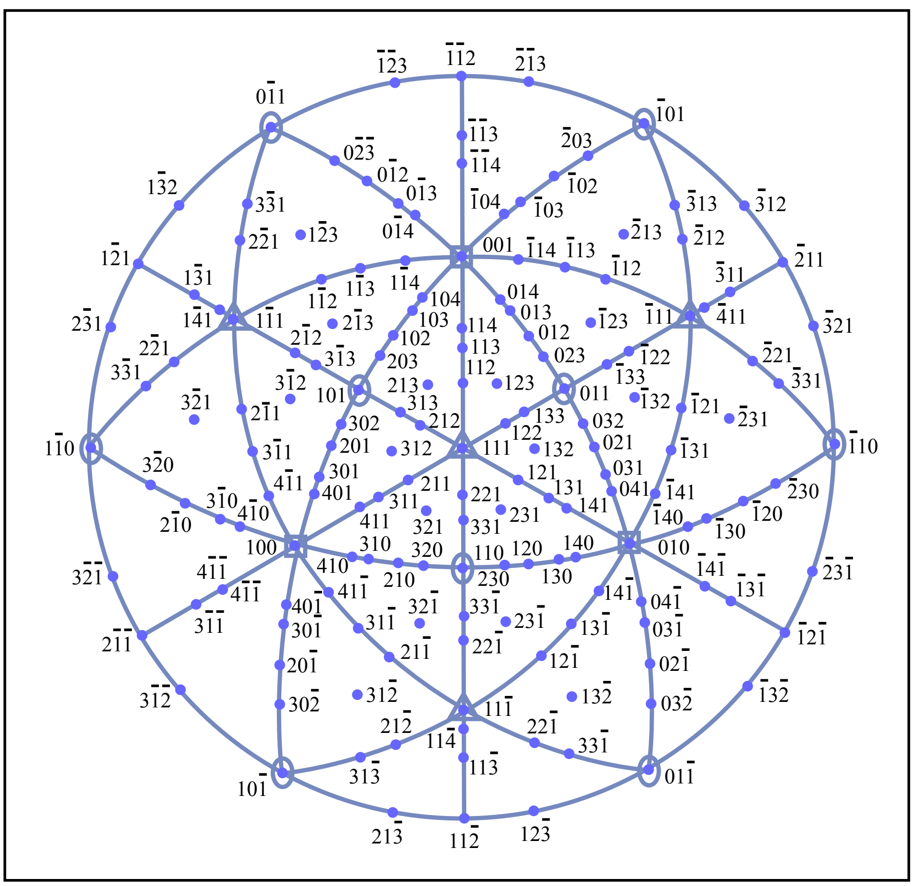


Figure by MIT OpenCourseWare.