

27-750

Mid-term number 2

Released Apr. 22nd, 2016

Due Apr. 24th at 11:59 p.m.

$10+15+10+25+15+10+20+20=125$

Q1. [10] One of the tests to verify that a grain growth code is working correctly is to simulate the shrinkage of a single, isolated grain. If the mobility of the boundary of the grain is M and its energy is E , derive the rate of change of its area, dA/dt and show that this is constant.

Q2. [15] Aluminum has an average grain boundary energy of $0.5 \text{ J}\cdot\text{m}^{-2}$, shear modulus 27 GPa, Burgers vector 0.28 nm. For a grain size of $20 \mu\text{m}$, estimate the dislocation density that would balance out the curvature driving force. Only two significant figures are expected.

Q3. [10 points]

You have learned that the number of equivalent descriptions of the misorientation of a grain boundary in cubic materials is 1,152. A) For grain boundaries in tetragonal materials, how many equivalent descriptions are there? B) How many equivalents are there if you describe the orientations as active rotations (i.e. an active rotation of each crystal from the reference position to their orientation)?

Q4. [25]

- a) You have measured the orientations of two adjacent grains in a sample of (bcc) iron which, in Euler angles, turn out to be $\{0, 90, 45\}$ and $\{0, 51.1, 45\}$. What is the misorientation across the boundary? Where does the misorientation axis lie relative to the sample axes? Hint: try plotting a $\{110\}$ pole figure if you would like a quick, intuitive answer.
- b) If the boundary plane normal is parallel to the sample Z axis, what is the tilt/twist character of the boundary?
- c) If the boundary plane normal is parallel to the sample X axis, what is the tilt/twist character of the boundary?
- d) Which CSL type does this boundary correspond to?
- e) You should be able to find information on the variation in grain boundary energy for this misorientation type in bcc metals. Which of the grain boundary normals identified in b) and c) above is high energy, and which is low energy? Hint: you should be able to find such a paper with an MSE professor as a co-author.

Q5. [15]

Assume that slip occurs on $\{111\}$ planes and in $\langle 110 \rangle$ directions.

- (a) For a tensile axis located inside the 001-101-111 standard stereographic triangle, what are the indices of the active slip direction and active slip plane normal?
- b) Compute the coordinates of the point (tensile axis position) that gives a Schmid factor exactly equal to 0.5. Compute this for the point that falls in the 001-101-111

standard stereographic triangle. You may give a numerical answer (to 4 significant figures) or leave it in the form of surds.

Q6. [10]

Explain how abnormal growth in subgrain networks can account for dependence of the (primary) recrystallized grain size in metals as a function of strain, above about 20 %. Include a description of why the grain size is insensitive to the annealing temperature, even though the rate of recrystallization increases with temperature via an Arrhenius expression. Explain which grain boundary property explains the latter point.

Q7. [20]

a) Convert $(3 \ 1 \ 1)[1 \ 0 \ -3]$ to:

Euler angles,

Transformation matrix,

Rodrigues vector, and

Unit quaternion (with cosine term in 4th position).

b) Consider a rotation matrix that describes a 180° rotation about some arbitrary axis, $[u,v,w]$. How can one extract the axis from this matrix? Hint: write out the matrix for this case and consider how you can use one of the rows.

Q8. [20 points]

(i) [5] Starting with the values provided in the notes for C_{11} , C_{12} & C_{44} for sodium chloride (NaCl), show that you can obtain the stated values for E_{100} and E_{111} .

(ii) [5] Write down a formula for the Young's modulus as a function of direction between $[110]$ and $[001]$, where the angle is zero at $[110]$ and 90° at $[001]$. Hint: consider how to write the direction cosines in terms of a single angle.

(iii) [5] Plot the modulus over this same range of directions.

(iv) [5] Repeat for Pb, plot the result on the same graph at the NaCl result and comment on the difference(s) between the two results.