

Massachusetts Institute of Technology  
*Department of Materials Science and Engineering*  
77 Massachusetts Avenue, Cambridge MA 02139-4307

3.21 Kinetics Processes in Materials—Spring 2006

Examination #3

May 17, 2006

9:30–10:55 A.M.

This is a *closed book* examination. Calculators may be used when necessary.

Please answer the questions directly on the exam pages. If you require more room, use the backs of the facing pages.

There are three questions on this examination. Apportion your time accordingly.

Keep your answers short and to the point. When appropriate, include sufficient information to indicate your reasoning. This will enable us to award appropriate credit even if you do not answer the question completely.

Good luck!

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Please write your name here

1. Figure 1 is a transmission electron micrograph of the transformation morphology observed when an ordered FeAl crystal with the CsCl structure is cooled into a miscibility gap and transformed there. The micrograph is a dark-field image using a superlattice reflection, so that bright regions are ordered and higher in Al content, and dark regions are disordered and lower in Al content. The long curved dark line is an antiphase boundary, and can be ignored in this problem.

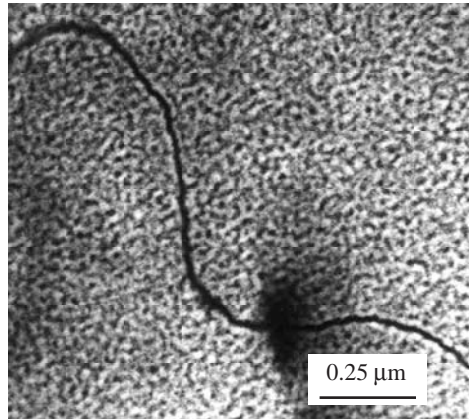


Figure 1: Microstructure in phase separated Fe–24 at.% Al alloy.

- (a) Considering the morphology and characteristic length scale of the microstructure, the likely mechanism of phase separation is spinodal decomposition. Why is it somewhat surprising that this alloy transforms by spinodal decomposition?

Problem 1, continued:

(b) Measurements of elastic constants in Fe-Al alloy single crystals show them to be highly elastically anisotropic. Considering the observed microstructure and your knowledge of spinodal decomposition, why is this surprising?

(c) Measurements of the lattice constants of Fe-Al alloys over a range of compositions and temperatures show that the lattice constant increases with Al content in disordered alloys and that increasing long-range order actually decreases the lattice constant. Explain how this might explain the observed phase separated morphology in the micrograph.

2. An orthorhombic crystal has three orthogonal low-energy surface orientations with values of excess free energy per unit area of  $\gamma^{100} = 500 \text{ mJ/m}^2$ ,  $\gamma^{010} = 300 \text{ mJ/m}^2$ , and  $\gamma^{001} = 100 \text{ mJ/m}^2$ . Assume that a fully-faceted critical nucleus forms with these interface orientations.

(a) Demonstrate that the shape of the critical nucleus will obey the relation

$$\frac{\gamma^{100}}{X} = \frac{\gamma^{010}}{Y} = \frac{\gamma^{001}}{Z} \quad (1)$$

where  $X$ ,  $Y$ , and  $Z$  are the distances of the (100), (010), and (001) faces from the center of the critical nucleus, respectively.

- (b) The shape of this critical nucleus is very different from a sphere which has the minimum surface area per unit volume enclosed. Rationalize the faceted shape of the critical nucleus in this case in terms of the surface energy anisotropy.

3. Please identify which of the following statements is true or false. Give a brief justification for each answer. *Full credit requires concise, correct reasoning.*

(a) “Barrierless nucleation” of the  $\beta$  phase on  $\alpha/\alpha$  grain boundaries can occur when the interfacial energies are such that  $\gamma^{\alpha/\alpha} \geq 2\gamma^{\alpha/\beta}$ .

(b) A molten binary alloy may become constitutionally supercooled if the thermal gradient in the liquid ahead of the solid/liquid interface is sufficiently steep.

(c) Antiphase boundaries are the most conspicuous microstructural feature in a material that has undergone a continuous ordering transformation.

(d) The time-cone method of describing transformation kinetics can be used to predict the grain size in a devitrified glass, knowing the grain nucleation rate  $J$  and the growth rate  $\dot{R}$ .