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3.21 Kinetics of Materials—Spring 2006

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Lecture 19: Grain Growth.

References

1. Balluffi, Allen, and Carter, *Kinetics of Materials*, Sections 15.2 and 13.3.5.

Key Concepts

- Grain growth in a polycrystal is a capillarity-driven process with the driving force equal to $\gamma(K_1 + K_2) = \gamma\kappa$ (this is the reduction in excess interfacial free energy per unit volume swept out by the grain boundary as it moves). Grain boundaries (and other single-phase interfaces) migrate toward their center of curvature.

- Three-dimensional polycrystals have *grains* that occupy volumes, *grain boundaries* that are two-dimensional imperfections at which two grains abut, *grain edges* which are one-dimensional imperfections along which three grain boundaries meet, and *grain corners* which are point imperfections at which four grain edges meet.

- Models for two-dimensional grain growth such as would occur in a thin polycrystalline film can be developed starting with the assumption that the local interfacial velocity is linearly proportional to driving force. For a grain entirely embedded within a second grain (no grain-boundary junctions), this leads to the law $dA/dt =$ constant, where A is the instantaneous area of the shrinking grain. A circular grain will disappear with a parabolic "growth" law. A multiply-connected network of polygonal grains in two dimensions follows the law $dA/dt =$ constant $(N - 6)$, where N the number of sides of a particular grain. This famous finding of von Neumann's is known as the "$N - 6$ rule."

- There is no simple analog to the $N - 6$ rule for grain growth in three dimensions. A vast number of experimental studies and computer simulations shows that grain growth kinetics in pure polycrystalline materials follows a parabolic growth law in which the square of the average grain size varies linearly with time.

- In impure materials, grain-boundary migration can be strongly influenced by impurities. *Impurity drag* and *solute drag* effects may arise if the impurity or solute species segregates to grain boundaries. This leads to nonlinear velocity–driving force relations for boundary motion. At low driving forces, boundaries move slowly and the segregant has time to diffuse along with the boundary as it moves (this is called extrinsic motion). At sufficiently high driving forces, the boundary can break free of the solute and enable the boundary to move with a higher mobility (called intrinsic motion).

- In polycrystals containing a dispersion of second-phase particles, grain boundaries can act to "pin" grain boundaries because particles that reside *on* grain boundaries eliminate an amount of grain boundary area equal to the grain boundary particle's cross section. An energy barrier must be overcome for the boundary to break free of the particle. Fine-particle dispersions are sometimes used in polycrystals in order to stabilize very fine-grain structures against grain growth.

Related Exercises in *Kinetics of Materials*

Review Exercises 15.3–15.4, pp. 384–386.