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Growth and Coarsening

Ostwald Ripening in Material Processing

With 99 Figures

Springer

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To Sylvia and Maria

Preface

Whenever a single phase system is quenched into a metastable state nucleation of a second phase lowers the free energy of the system. Following this nucleation event, in solid state transformations, the second phase typically grows by the diffusion of mass either into or from the matrix. When the composition of the matrix is nearly at its equilibrium value coarsening occurs. In this process the matrix is no longer a source or sink of solute, but the majority of the mass transport is from small to large particles. This process is driven by the decrease in interfacial energy per unit volume and results in an increase in the size scale of the two-phase mixture. The first to observe this coarsening process was Ostwald in 1900 who reported that the solubility of small HgO-particles is a function of the radius of the particle. The phenomenon has come to bear his name: Ostwald ripening. Ostwald ripening can occur in virtually any two-phase mixture in which there is significant diffusion. It is thus observed in two-phase mixtures ranging from liquid-vapor mixtures, such as droplets in clouds, to solid-liquid mixtures both during and following solidification. Understanding the dynamics of this ripening process and its surprising self-organizational nature has been at the center of the field since the seminal papers of Lifshitz and Slyozov, and Wagner appeared in the early 60's. From a more applied view, the Ostwald ripening process has a significant impact on manner in which materials are processed, e.g. age hardening of metallic alloys, grain refining, grain growth during recrystallisation, liquid and solid state sintering, and the deoxidation of steel melts. Given the ubiquitous nature of the ripening process and its clear technological importance, we feel that this subject deserves a unified development that is only possible in a monograph.

The main idea behind this monograph is to present students and researchers all the bits and pieces of coarsening theories such that they can understand the main issues and the underlying mathematics of self-similar coarsening of dispersed systems. Growth and coarsening are usually side notes in standard textbooks on physical metallurgy or materials science and as such they are treated in a very simplified fashion. Therefore, the monograph contains all of the background material necessary to understand growth and coarsening of spherical particles or droplets in a liquid or solid matrix. We do not refer the reader to any of the publications given in the bibliography for a derivation of a central result used in the monograph, but try to be self-consistent and comprehensive. Some basic knowledge of heat and mass transfer, thermodynamics, and differential equations would be helpful, but is not necessary as all the concepts required are presented, at least briefly. The monograph is suitable for advanced undergraduate students, graduate students, and researchers. The monograph is not a comprehensive review of coarsening and growth nor is it intended to give a complete survey of both topics. For example, we do not discuss the many mathematical approaches to the theory or the vast experimental literature. Rather, the monograph is intended to present a careful derivation of existing results and to place these results in some prespective.

Cologne and Evanston, July 2001

Lorenz Ratke and Peter W. Voorhees

Table of Contents