Journal of
Applied Crystallography
ISSN 0021-8898

book reviews

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Crystal growth for beginners. 2nd edition. Edited by Ivan V Markov. World Scientific Press, pp. 564. USD 68, GBP 46. ISBN 981-238-245-3.

Crystal growth today is an applied science that underpins a number of the world's major industries, most notably those that utilize electronic or opto-electronic technologies. To a large degree, theory and practice are well connected. A book on crystal growth for beginners might therefore be expected to provide a description of the basic technologies for the growth of bulk single crystals, of epitaxial layers and of industrial mass crystallization, together with the fundamentals of the science that describes those processes. Despite its title, this is not that book. Firstly, it does not describe any of the technological processes of crystal growth, except, oddly, for a one-paragraph description of hydrothermal growth on p. 187.

Secondly, it addresses only a fraction of the underlying science, namely that based on the 'classical' theories of nucleation and of the atomic kinetics of growth with which the names of Stranski, Volmer, Becker and Doring, and Burton, Cabrera and Frank, amongst others, are associated. Transport processes, which usually dominate the dynamics of melt and high-temperature solution growth processes, are entirely ignored. Thirdly, most commercial crystal growth is concerned with the controlled incorporation of dopants, yet this book considers only the growth of pure materials, with the exception of the inclusion of a consideration of the effects of surfactants on epitaxial growth in the final chapter.

The effect of dislocations on the atomic growth mechanism is considered, but how the imposed growth parameters affect defect generation in the growing crystal (*e.g.* dopant and structural inhomogeneities induced by melt flow and by morphological instability, the effects of thermal stress in a cooling crystal, non-equilibrium doping at interfacial facets, native point defect incorporation, *etc.*) are not even mentioned. In fact, virtually the whole of the modern theory of crystal growth from the melt and from high-temperature solution is entirely absent.

The lack of any coverage of the practical aspects of crystal growth is hinted at in the subtitle: 'Fundamentals of Nucleation, Crystal Growth and Epitaxy'. But again, the absence of any modern theory of melt growth makes even this description of the book too extensive. A more accurate and informative title might be 'Thermodynamic and Atomic–Kinetic Descriptions of Nucleation, Crystal Growth and Epitaxy of Pure Materials'. The book perpetuates the old German distinction between *Kristallwachstum* (the academic study of mechanisms and kinetics of growth) and *Kristallzüchtung* (the production of technically useful crystals), the former having been held in higher regard than the latter! This is an excellent text on *Kristallwachstum*. It contains only four chapters in its over 500 pages. These are entitled: '1. Crystal–Ambient Phase Equilibrium', '2. Nucleation', '3. Crystal Growth' and '4. Epitaxial Growth'. Almost all the theory is developed analytically, from which much significant insight into basic mechanisms is elucidated.

In the first chapter, the basic thermodynamic concepts of phase equilibria in bulk and interfacial phases, based on the classic work of Gibbs, are presented, but only for one-component systems. In the second chapter, the energetics of two-dimensional and three-dimensional nucleation, both homogeneous and heterogeneous, are presented, together with a description of nucleation rate based on the classic Becker–Doring theory. Finally, the Oswald step rule, which predicts the sequence of transition through metastable phases to an equilibrium phase, is discussed. These two chapters contain the core theory utilized in the remaining two chapters.

The chapter 'Crystal Growth' deals principally with layer growth mechanisms and this second edition contains a new section on the Ehrlich–Schwoebel effect (the different effects produced by surface diffusion of the growth units to a step edge from its upper and lower terraces, respectively). Macrostep formation is considered, but the important role of segregation effects in LPE growth and the beautiful experiments of Elizabeth Bauser demonstrating this are not mentioned. The kinematic theory of step bunching expounded by Frank is presented and the chapter concludes with a 20 page description and analysis of the beautiful and classic experiments of Kaischew and his group at the University of Sofia (the author was a member of this group). These experiments visually demonstrated basic nucleation and step flow behaviour on a silver crystal surface growing electrolytically.

The final chapter considers both homo- and hetero-epitaxial processes, the former being carefully defined as the case where the difference in chemical potentials of substrate and layer is due mainly to the lattice misfit rather than to chemical differences. The widely recognized three basic models of epitaxial growth, namely Volmer–Weber (island growth), Stranski–Krastanov (initial layer-by-layer growth followed by formation of isolated three-dimensional islands) and Frank–van der Merwe (continued layer-by-layer growth), are explored. The final section, new to this second edition, is on the effect of surfactants on nucleation and growth. It is this last chapter that is likely to be of most value to the epitaxial-crystal grower. The bulk-crystal grower will find little of interest to him. About half of the nearly 700 references in the book predate 1980. Most of the more recent references are to strain-related effects in epitaxial layers. This appears to be the author's current field of research.

As to the rest of the book, it is a rather comprehensive review of the 'classical' theory of crystal growth and it strongly reflects the interests and ethos of the Sofia school. In my judgement it is far too narrow in its field and too advanced in its treatment to be suitable for beginners. For example, nearly 100 pages on the theory of nucleation is surely too much for a beginner to assimilate.

In his preface to this second edition, the author is concerned to address criticism which he received as to the readability of the first edition. I commend him on the clarity of his presentation in this second edition. It is logical and pedagogical in its development and provides deep insights into mechanisms. The felicity of the English varies a little from

chapter to chapter but nowhere does it drop to a point where comprehension is compromised. For all its omissions, I enjoyed reading this book and learned from it. I felt a special affinity with the author in his affirmation of the value of a thermodynamic understanding of growth phenomena, even when that growth takes place far from equilibrium. As he writes, 'Thermodynamics tells us what is possible and what is not'. Given the merits of this book, it is a pity that its title will cause some who would benefit from it to ignore it and to cause others new to the field of crystal growth to be daunted by it.

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