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What do you think of when you think of crystals? You might think of rich jewels or you may think of a hotel chandelier? Well you would be surprised at how many other things in the world are classed as crystals. Certain substances such as salt, sugar and snow are all classed as crystals.Crystals and Crystal Growing For Children: A guide and introduction to the science of crystallography and mineralogy for kids. This guidebook covers basic chemistry and physics that form the fundamentals behind the art and science of growing crystals.
The USSR symposium on crystal growth covered basic theories

and methods for crystal growth, testing and determination. Discussions were made on crystal growth theories, the water-heating crystal growing method, the flame melting crystal growing method, the effects of environmental conditions on crystal growth, methods for semi-conductor crystal growth, methods for metallic single crystal growth, etching and formation of imperfections, crystal growth in molten salts, x-ray diffraction methods for the study of crystal perfection, optical methods for study of crystal perfection, growth of film and fibrous crystals, piezoelectric crystals, crystal growth in solution, and natural single crystals. Kids can learn science and eat it, too! Grow Your Own Crystals, now packaged in a striking gift box, invites kids to learn how crystals are formed, then experiment by growing their own sugar crystals that they can eat just like candy. This great kit includes full--color instruction book, wooden sticks, food-coloring tablets, and a plastic disk. All young scientists need to supply are a glass, water, and sugar.

Experiments and problems to be done by the non-specialist to aid in his understanding of crystals.

With the highly competitive development of pharmaceutical and chemical industries, mastering crystal growth is becoming increasingly important. Modern industrial manufacturers place high importance on the ability to grow novel crystals with a specific habit and improve the performance of existed crystals using tailored operating conditions. Therefore, the ability to synthesise a particular morphology and to predict the crystal morphology of new compounds is becoming even more desirable. The recent development of crystal growth is vital for researchers in crystallography and crystallisation to respond and realise this objective. With this need in mind, this book mainly targeted at introducing crystal growth from three aspects ranging from basic concepts and detailed mechanisms to advanced applications in hot areas of materials science. This book introduces various experimental and theoretical methods to grow different crystals, which includes the techniques to grow single crystals, CaCO3 polymorphs, metal-organic crystals, liquid crystals, fenamate crystals, cocrystals, and the theoretical models to predict the crystal morphologies within a different environment. From these carefully selected contents, readers will not only learn of the basic theory and experimental techniques implemented, but also keep abreast with both state-of-the-art crystal growth and its overlap with other subjects.

Volume IA Handbook of Crystal Growth, 2nd Edition (Fundamentals: Thermodynamics and Kinetics) Volume IA addresses the present status of crystal growth science, and provides scientific tools for the following volumes: Volume II (Bulk Crystal Growth) and III (Thin Film Growth and Epitaxy). Volume IA highlights thermodynamics and kinetics. After historical introduction of the crystal growth, phase equilibria, defect thermodynamics, stoichiometry, and shape of crystal and structure of melt are described. Then, the most fundamental and basic aspects of crystal growth are presented, along with the theories of nucleation and growth kinetics. In addition, the simulations of crystal growth by Monte Carlo, ab initio-based approach and colloidal assembly are thoroughly investigated. Volume IB Handbook of Crystal Growth, 2nd Edition (Fundamentals: Transport and Stability) Volume IB discusses pattern formation, a typical problem in crystal growth. In addition, an introduction to morphological stability is given and the phase-field model is explained with comparison to experiments. The field of nanocrystal growth is rapidly expanding and here the growth from vapor is presented as an example. For the advancement of life science, the crystal growth of protein and other biological molecules is indispensable and biological crystallization in nature gives many hints for their crystal growth. Another subject discussed is pharmaceutical crystal growth. To understand the crystal growth, in situ observation is extremely powerful. The observation techniques are demonstrated. Volume IA Explores phase equilibria, defect thermodynamics of Si, stoichiometry of oxides and atomistic structure of melt and alloys Explains basic ideas to understand crystal growth, equilibrium shape of crystal, rough-smooth transition of step and surface, nucleation and growth mechanisms Focuses on simulation of crystal growth by classical Monte Carlo, ab-initio based quantum mechanical approach, kinetic Monte Carlo and phase field model. Controlled colloidal assembly is presented as an experimental model for crystal growth. Volume IIB Describes morphological stability theory and phase-field model and comparison to experiments of dendritic growth Presents nanocrystal growth in vapor as well as protein crystal growth and biological crystallization Interprets mass production of pharmaceutical crystals to be understood as ordinary crystal growth and explains crystallization of chiral molecules Demonstrates in situ observation of crystal growth in vapor, solution and melt on the ground and in space

The KDP family of single crystals is composed of compounds of alkali metals with light or heavy (hydro, deutero) water and oxides of phosphate or arsenate, including ammonium, potassium, rubidium and caesium dihydro- and dideutero-phosphates, and similar arsenates. While not occurring in nature, their production exceeds that of any other water-soluble crystals and the demand for bigger and more optically pure crystals is ever increasing. KDP-Family Single Crystals is a comprehensive investigation of the crystallization mechanism for these systems. The first part of the book collects the majority of the available data on the physico-chemical analysis of these systems. This is complemented by a review of contemporary concepts related to the crystal growth dislocation mechanism under the influence of impurities, changing supersaturation, and temperature. This is not only relevant to the growth of KDP single crystals but to the majority of crystals grown from low- and high-temperature solutions. Finally, attention is given to the important problem of speeding up the production processes for the growth of these crystals while maintaining the quality of the crystals. The in-depth coverage that KDP-Family Single Crystals provides to the art of crystal growth techniques makes it an essential reference work for all those working in the field of crystal growth and to those using KDP-family crystals in quantum electronics devices.

Hydrothermal crystal growth offers a complementary alternative to many of the classical techniques of crystal growth used to synthesize new materials and grow bulk crystals for specific applications. This specialized technique is often capable of growing crystals at temperatures well below their melting points and thus potentially offers routes to new phases or the growth of bulk crystals with less thermal strain. Borate crystals are widely used as nonlinear optical, laser and luminescent materials due to their diversified structures, and good chemical and physical properties.

The growth of hi.

The goal of the series Physics and Chemistry of Materials with Layered Structures is to give a critical survey of our present knowledge on a large family of materials which can be described as solids containing molecules which in two dimensions extend to infinity and which are loosely stacked on top of each other to form three dimensional crystals. Of course, the physics and chemistry of these crystals are specific chapters in ordinary solid state science, and many a scientist hunting for new phenomena has in the past been disappointed to find that materials with layered structures are not entirely exotic. Their electron and phonon states are not two dimensional, and the high hopes held by some for spectacular dimensionality effects in superconductivity were shattered. Nevertheless, the structural features and their physical and chemical consequences singularize layered structures sufficiently to make them a fascinating subject of research. This is all the more true since they are met in insulators and semiconductors as well as in normal and superconducting metals. Although for the time being the series is intentionally limited to cover inorganic materials only, the many known organic layered structures may well be the subject of future volumes. Among the noteworthy peculiarities of layered structures, we mention specific growth mechanisms and crystal habits. Polytypism is very common and it is fasci nating indeed to find up to 240 different polytypes in the same chemical substance.

Hydrothermal crystal growth offers a complementary alternative to many of the classical techniques of crystal growth used to synthesise new materials and grow bulk crystals for specific applications. This specialised technique is often capable of growing crystals at temperatures well below their melting points and thus potentially offers routes to new phases or the growth of bulk crystals with less thermal strain. Borate crystals are widely used as nonlinear optical, laser and luminescent materials due to their diversified structures, and good chemical and physical properties. The growth of high-quality borate crystals is required for their applications. A fundamental problem for borate crystal growth is the high-temperature melt structures in the crystal growth systems. This book discusses several crystals and the crystal growth processes.

This book introduces the principles and techniques of crystal growth by the flux method, which is arguably the most useful way to obtain millimeter- to centimeter-sized single crystals for physical research. As it is possible to find an appropriate solvent (“flux”) for nearly all inorganic materials, the flux method can be applied to the growth of many crystals ranging from transition metal oxides to intermetallic compounds. Both important principles and experimental procedures are described in a clear and accessible manner. Practical advice on various aspects of the experiment, which is not readily available in the literature, will assist the beginning graduate students in setting up the lab and conducting successful crystal growth. The mechanisms of crystal growth at an elementary level are also provided to better understand the techniques and to help in assessing the quality of the crystals. The book also contains many photographs of beautiful crystals with important physical properties of current interest, such as high-temperature superconductors, strongly correlated electronic systems, topological insulators, relaxor ferroelectrics, low-dimensional quantum magnets, non-linear optical materials, and multiferroics.

New Developments In Crystal Growth

The present volume continues the tradition of the preceding volumes. covering a wide range of crystal growth problems and treating aspects of critical importance for crystalliza tion. Changes in this field of knowledge have. however, changed the criteria for selection of papers for inclusion in this series. The increasing role of crystals in science and technology is even more apparent today. The study and utilization of these highly perfect objects of nature considerably facilitates progress in the physics and chemistry of solids. quantum electronics, optics, microelectron ics, and other sciences. The demand for crystals and crystal devices has grown steadily and has led to the emergence and rapid growth of the single crystal industry (we can safely saythat the state ofthe art in this industry is indicative ofthe overall scientific and technolo- cal potential of a country). At the same time, the introduction of crystallization techniques into other industries is gaining ever-increasing importance. To illustrate this last state ment, we can mention the fabrication of textured structural materials and direct methods of metal reduction in ores by using chemical vapor transport techniques. Crystallization tech ll niques progress both in "width" and in "depth : traditional methods are modernized. and novel techniques appear, some of them at the junction of the already existing technologies (for example, flux growth of crystals, growth from vapor with participation of the liquid phase, etc.).

This tenth volume completes the first series of "Growth of Crystals," which began in 1957. The sources of the volumes are as follows: for Vol. I, the 1st All-Union Conference on Crystal Growth; for Vol. 3, the 2nd; and for Vols. 5 and 6, the 3rd; Vols. 7 and 8 reported the International Symposium on Crystal Growth at the Seventh International Crystallography Con gress, and Vol. 9 the 1969 symposium on crystal growth dedicated to E. S. Fedorov; Vols. 2, 4, and 10 did not originate in conferences. The main problem that largely occupied the conferences and symposia and also the inter mediate volumes was that of real crystal formation, as well as the relation of crystal growth theory to practical crystal production. This tenth volume, which completes this first series, is to a considerable extent a survey. It contains more extensive theoretical and experimental original papers, as well as some shorter papers dealing with particular but important aspects of real crystal formation. The volume opens with a paper by V. V. Voronkov, which deals with the structure of crystal surface in Kossel's model. The model as proposed by Kossel is extremely simple. It deals qualitatively with the basic trends in the growth of an idealized crystal in its own va por at absolute zero, and naturally does not allow one to perform quantitative studies on com plex real processes.

This new textbook provides for the first time a comprehensive treatment of the basics of contemporary crystallography and crystal growth in a single volume. The reader will be familiarized with the concepts for the description of morphological and structural symmetry of crystals. The architecture of crystal structures of selected inorganic and molecular crystals is illustrated. The main crystallographic databases as data sources of crystal structures are described. Nucleation processes, their kinetics and main growth mechanism will be introduced in fundamentals of crystal growth. Some phase diagrams in the solid and liquid phases in correlation with the segregation of dopants are treated on a macro- and microscale. Fluid dynamic aspects with different types of convection in melts and solutions are discussed. Various growth techniques for semiconducting materials in connection with the use of external field (magnetic fields and microgravity) are described. Crystal characterization as the overall assessment of the grown crystal is treated in detail with respect to - crystal defects - crystal quality - field of application Introduction to Crystal Growth and Characterization is an ideal textbook written in a form readily accessible to undergraduate and graduate students of crystallography, physics, chemistry, materials science and engineering. It is also a valuable resource for all scientists concerned with crystal growth and materials engineering.

How do crystals nucleate and grow? Why and how do crystals form such a wide variety of morphologies, from polyhedral to dendritic and spherulitic forms? These are questions that have been posed since the seventeenth century, and are still of vital importance today both for modern technology, and to understand the Earth's interior and the formation of minerals by living organisms. In this book, Ichiro Sunagawa sets out clearly the atomic processes behind crystal growth, and describes case studies of complex systems from diamond, calcite and pyrite, to crystals formed through biomineralization, such as the aragonite of shells, and apatite of teeth. Essential reading for advanced graduates and researchers in mineralogy and materials science.

Springer-Verlag, Berlin Heidelberg, in conjunction with Springer-Verlag New York, is pleased to announce a new series: CRYSTALS Growth, Properties, and Applications The series will present critical reviews of recent developments in the field of crystal growth, properties, and applications. A substantial portion of the new series will be devoted to the theory, mechanisms, and techniques of crystal growth. Occasionally, clear, concise, complete, and tested instructions fqr growing crystals will be published, particularly in the case of methods and procedures that promise to have general applicability. Responding· to the ever-increasing need for crystal substances in research and industry, appropriate space will be devoted to methods of crystal characterization and analysis in the broadest sense, even though reproducible results may be expected only when structures, microstructures, and composition are really known. Relations among procedures, properties, and the morphology of crystals will also be treated with reference to specific aspects of their practical application. In this way, the series will bridge the gaps between the needs of research and industry, the pos sibilities and limitations of crystal growth, and the properties of crystals. Reports on the broad spectrum of new applications - in electronics, laser tech nology, and nonlinear optics, to name only a few - will be of interest not only to industry and technology, but to wider areas of applied physics as well and to solid state physics in particular. In response to the growing interest in and importance of organic crystals and polymers, they will also be treated.

1 The content ofthis article is based on a German book version) which appeared at the end of the year 1986. The author tried to incorporate - as far as possible - new important results published in the last year. But the literature in the field of "convection and inhomogeneities in crystal growth from the melt" has increased

so much in the meantime that the reader and the collegues should make allowance for any incompleteness, also in the case that their important contributions have not been cited. This could for example hold for problems related to the Czochralski growth. But especially for this topic the reader may be refered to the forthcoming volume of this series, which contains special contributions on "Surface Tension Driven Flow in Crystal Growth Melts" by D. Schwabe and on "Convection in Czochralski Melts" by M. Mihelcic, W. Uelhoff, H. Wenzl and K. Wingerath. The preparation of this manuscript has been supported by several women whose help is gratefully acknowledged by the autor: Mrs. Gisela Neuner for the type writing, Mrs. Abigail Sanders, Mrs. Fiona Eels and especially Prof. Nancy Haegel for their help in questions of the English language and Mrs. Christa Weber for reading corrections. Also the good cooperation with the Springer Verlag, especially Mrs. Bohlen and with the managing editor of Crystals, Prof. H. C. Freyhardt, who critically read the manuscript, is acknowledged.

There is no question that the field of solid state electronics, which essentially began with work at Bell laboratories just after World War II, has had a profound impact on today's Society. What is not nearly so widely known is that advances in the art and science of crystal growth underpin this technology. Single crystals, once valued only for their beauty, are now found, in one form or another in most electronic, optoelectronic and numerous optical devices. These devices, in turn, have permeated almost every home and village throughout the world. In fact it is hard to imagine what our electronics industry, much less our entire civilization, would have been like if crystal growth scientists and engineers were unable to produce the large, defect free crystals required by device designers. This book brings together two sets of related articles describing advances made in crystal growth science and technology since World War II. One set is from the proceedings of a Symposium held in August 2002 to celebrate 50 years of progress in the field of crystal growth. The second contains articles previously published in the newsletter of the American Association for Crystal Growth in a series called "Milestones in Crystal Growth". The first section of this book contains several articles which describe some of the early history of crystal growth prior to the electronics revolution, and upon which modern crystal growth science and technology is based. This is followed by a special article by Prof. Sunagawa which provides some insight into how the successful Japanese crystal growth industry developed. The next section deals with crystal growth fundamentals including concepts of solute distribution, interface kinetics, constitutional supercooling, morphological stability and the growth of dendrites. The following section describes the growth of crystals from melts and solutions, while the final part involves thin film growth by MBE and OMVPE. These articles were written by some of the most famous theorists and crystal growers working in the field. They will provide future research workers with valuable insight into how these pioneering discoveries were made, and show how their own research and future devices will be based upon these developments. · Articles written by some of the most famous theorists and crystal growers working in the field · Valuable insight into how pioneering discoveries were made. · Show how their own research and future devices will be based upon these developments
Solution and solubility, solubility and supersolubility; The artificial

preparation of crystals; The curie theory of crystal growth; The so-called velocities of growth; The diffusion theories; Recent theories of crystal growth; Ideal and real crystals; Miscellaneous types of crystallization; Dissolution phenomena; Crystal habit modification by impurities; Relationship of substances during crystallization; Peculiarities of crystal growth.

Provides an understanding of both basic and more advanced principles and concepts of crystal growth using a direct style of exposition succeeded by systematic and comprehensible applications of these in the actual crystallization of Groups 1 and 2 compounds from solution in melts at high temperatures. Explores final crystal numbers and sizes, systematic quantitative experimental studies on solute and solvent interactions, nucleation processes and crystallization kinetics. A mathematical model for calculating diffusion coefficients and, from there, kinetic and thermodynamic parameters for diffusion-controlled crystal growth that can accurately predict the exact distance of separation between a diffusing particle and its hosts in melts are presented.

Growth of Crystals, Volume 21 presents a survey, with detailed analysis, of the scientific and technological approaches, and results obtained, by leading Russian crystal growth specialists from the late 1990's to date. The volume contains 16 reviewed chapters on various aspects of crystal and crystalline film growth from various phases (vapour, solution, liquid and solid). Both fundamental aspects, e.g. growth kinetics and mechanisms, and applied aspects, e.g. preparation of technically important materials in single-crystalline forms, are covered. A large portion of the volume is devoted to film growth, including film growth from eutectic melt, from amorphous solid state, kinetics of lateral epitaxy and film growth on specially structured substrates. An important chapter in this section covers heteroepitaxy of non-isovalent A3B5 semiconductor compounds, which have important applications in the field of photonics. The volume also includes a detailed analysis of the structural aspects of a broad range of laser crystals, information that is invaluable for successfully growing perfect, laser-effective, single crystals.

In this book top experts treat general thermodynamic aspects of crystal fabrication; numerical simulation of industrial growth processes; commercial production of bulk silicon, compound semiconductors, scintillation and oxide crystals; X-ray characterization; and crystal machining. Also, the role of crystal technology for renewable energy and for saving energy is discussed. It will be useful for scientists and engineers involved in crystal and epilayer fabrication as well as for teachers and graduate students in material science, chemical and metallurgical engineering, and micro- and optoelectronics, including nanotechnology.

Crystals are the unacknowledged pillars of modern technology. The modern technological developments depend greatly on the availability of suitable single crystals, whether it is for lasers, semiconductors, magnetic devices, optical devices, superconductors, telecommunication, etc. In spite of great technological advancements in the recent years, we are still in the early stage with respect to the growth of several important crystals such as diamond, silicon carbide, PZT, gallium nitride, and so on. Unless the science of growing these crystals is understood precisely, it is impossible to grow them as large single crystals to be applied in modern industry. This book deals with almost all the modern crystal growth techniques that have been adopted, including appropriate case studies. Since there has been no other book published to cover the subject after the Handbook of Crystal Growth, Eds. DTJ Hurle, published during 1993-1995, this book will fill the existing gap for its readers. The book begins with "Growth Histories of Mineral Crystals" by the most senior expert in this field, Professor Ichiro Sunagawa. The next chapter reviews recent developments in the theory of crystal growth, which is equally important before moving on to actual techniques. After the first two fundamental chapters, the book covers other topics like the recent progress in quartz growth, diamond growth, silicon carbide single crystals, PZT crystals, nonlinear optical crystals, solid state laser crystals, gemstones, high melting oxides like lithium niobates, hydroxyapatite, GaAs by molecular beam epitaxy, superconducting crystals, morphology control, and more. For the first time, the crystal growth modeling has been discussed in detail with reference to PZT and SiC crystals.

The molecular mechanisms underlying the fact that a crystal can take a variety of external forms is something we have come to understand only in the last few decades. This is due to recent developments in theoretical and experimental investigations of crystal growth mechanisms. Morphology of Crystals is divided into three separately available volumes. Part A contains chapters on roughening transition; equilibrium form; step pattern theory; modern PBC; and surface microtopography. This part provides essentially theoretical treatments of the problem, particularly the solid-liquid interface. Part B contains chapters on ultra-fine particles; minerals; transition from polyhedral to dendrite; theory of dendrite; and snow crystals. All chapters are written by world leaders in their respective areas, and some can be seen as representing the essence of a life's work. This is the first English-language work which covers all aspects of the morphology of crystals - a topic which has attracted top scientific minds for centuries. As such, it is indispensable for anyone seeking an answer to a question relating to this fascinating problem: mineralogists, petrologists, crystallographers, materials scientists, workers in solid-state physics and chemistry, etc. In Parts A: Fundamentals and B: Fine Particles, Minerals and Snow equilibrium and kinetic properties of crystals are generally approached from an `atomistic' point of view. In contrast, Part C: The Geometry of Crystal Growth follows the alternative and complementary `geometrical' description, where bulk phases are considered as continuous media and their interfaces as mathematical surfaces with orientation-dependent properties. Equations of motion for a crystal surface are expressed in terms of vector and tensor operators working on surface free energy and growth rate, both expressed as functions of surface orientation and driving force, or `affinity' for growth. This approach emphasizes the interrelation between equilibrium and kinetic behavior. Part 1 establishes the theoretical framework. Part 2 gives a construction toolbox for explicit (analytic) functions. An extra chapter is devoted to experimental techniques for measuring such functions: a new approach to sphere growth experiments. The emphasis throughout is on principles and new concepts. Audience: Advanced readers familiar with traditional aspects of crystal growth theory. Can be used as the basis for an advanced course, provided supplementation is provided in the areas of atomistic models of the advancing surface, diffusion fields, etc.

Introduction to Crystal Growth: Principles and Practice teaches readers about crystals and their origins. It offers a historical perspective of the subject and includes background information whenever possible. The first section of this introductory book takes readers through the historical development and motivation of the field of crystal growth. With more than 40 years of experience in the field, the author covers nucleation, two-dimensional layer growth mechanism, defects in crystals, and screw dislocation theory of crystal growth. He also explains some aspects of the important subject of phase diagrams. The second section focuses on the experimental techniques of crystal growth. For practicing crystal growers, the book provides nuts-and-bolts techniques and tips. It discusses the major techniques categorized by solid–solid, liquid–solid, and vapor–solid equilibria and describes characterization techniques essential to measuring the quality of grown crystals.

Ideal for today's young investigative reader, each A True Book includes lively sidebars, a glossary and index, plus a comprehensive "To Find Out More" section listing books, organizations, and Internet sites. A staple of library collections since the 1950s, the new A True Book series is the definitive nonfiction series for elementary school readers.

Crystallization is an important separation and purification process used in industries ranging from bulk commodity chemicals to specialty chemicals and pharmaceuticals. In recent years, a number of environmental applications have also come to rely on crystallization in waste treatment and recycling processes. The authors provide an introduction to the field of newcomers and a reference to those involved in the various aspects of industrial crystallization. It is a complete volume covering all aspects of industrial crystallization, including material related to both fundamentals and applications. This new edition presents detailed material on crystallization of biomolecules, precipitation, impurity-crystal interactions, solubility, and design. Provides an ideal introduction for industrial crystallization newcomers Serves as a worthwhile reference to anyone involved in the field Covers all aspects of industrial crystallization in a single, complete volume

This is the first-ever textbook on the fundamentals of nucleation, crystal growth and epitaxy. It has been written from a unified point of view and is thus a non-eclectic presentation of this interdisciplinary topic in materials science. The reader is required to possess some basic knowledge of mathematics and physics. All formulae and equations are accompanied by examples that are of technological importance. The book presents not only the fundamentals but also the state of the art in the subject. The second revised edition includes two separate chapters dealing with the effect of the Enrich-Schwoebel barrier for down-step diffusion, as well as the effect of surface active species, on the morphology of the growing surfaces. In addition, many other chapters are updated accordingly. Thus, it serves as a valuable reference book for both graduate students and researchers in materials science.

The present volume of this series, following the tradition of the previous volumes, covers three major lines of research on crystallization: growth from vapor and epitaxy, growth from solution, and growth from melt. As in the previous volumes, preference is given to papers that provide original results and reviews of results obtained by the authors and those from published sources, although some of the papers are either purely original or purely of review character. The first section deals with crystal growth from vapor and epitaxy and contains three papers. One of them, on artificial epitaxy, discusses and reviews published results from the last three years in this rapidly developing area. The results are used in outlining mechanisms for oriented film growth on amorphous substrates. Another paper in this section deals with classical epitaxy, namely oriented growth on single-crystal substrates, where some important conclusions are drawn from the growth of gallium nitride films on sapphire, which concern the orientation relationships in that pair of substances. The last paper in the section deals with film growth under ion bombardment (the corresponding techniques in film crystallization have already advanced from theory to practical applications).