The Production and Processing of Inorganic Materials

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With a CD of thermodynamic data and
spreadsheet examples prepared by

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ISBN 978-3-319-48566-9

ISBN 978-3-319-48163-0 (eBook)

DOI 10.1007/978-3-319-48163-0

Library of Congress Control Number: 2002109114

Chemistry and Materials Science: Professional

© 2016 by The Minerals, Metals, & Materials Society

Published by Springer International Publishers, Switzerland, 2016

Reprint of the original edition published by TMS (The Minerals, Metals & Materials Society), 2002, 978-0-87339-541-0

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Printed on acid-free paper

This Springer imprint is published by Springer Nature

The registered company is Springer International Publishing AG

The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

To our families:

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Hugh

Claire

Lynn

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Preface

The past few decades have seen the emergence of materials science (and engineering) as a discipline. The roots of that growth lay initially in the long established fields of metallurgy and ceramics and the discipline is nowadays seen as embracing these traditional fields plus electronic, optical, composite and polymeric materials, as well as biomaterials. Materials science and engineering examines materials over a large range of scales, from the nanometers of quantum dots to the meters of the steel girders used for building construction. The discipline is currently growing in popularity and likely to remain so. New materials for aerospace applications, optical fibers and new applications of materials in bioengineering stir the imaginations of students and stimulate a flow of research funds.

The character of materials science is evolving as the growth continues and as scientists and engineers from other disciplines (notably physics, chemistry, chemical engineering and electrical engineering) enter the field. Nevertheless most would agree that materials science is a field at the interface between more traditional sciences and engineering fields (those listed already plus civil and mechanical engineering). It is both a scientific discipline concerned with fundamentals (in the same way as the adjacent topic of solid state physics) and an engineering subject concerned with the application of knowledge to the production and use of materials.

Another view of the field is that it has the structure of a tetrahedron with vertices labeled “Structure”, “Properties”, “Performance” and “Processing” and the edges representing the important interactions between these four topics. While alternative geometries have been suggested, an opinion held by many is that, until recently, the processing vertex has been neglected, at least in the USA, in favor of the other vertices. Certainly, if processing is taken to include everything from synthesis in laboratory “test tube” experiments to industrial manufacturing, then this opinion is supported by even the most casual inspection of trade figures or the business pages.

This neglect of processing has been reflected in the materials curricula at many of our universities. Courses on processing have frequently been regarded as optional or secondary and have failed to embrace the unity of materials that is recognized, for example, in other courses on fracture or characterization of microstructure. Our hope is that the production of all types of (inorganic) materials can be taught as one. Naturally there are differences between the production of a silicon nitride engine component and that of a copper wirebar but they appear to us no larger than that between producing the

wirebar and producing a titanium ingot. In any event we claim that these differences are insignificant compared to the commonality of thermodynamics, kinetics, transport phenomena, phase equilibria and transformation, process engineering and surface chemistry on which all three rely. Naturally, those who find such integration implausible can use the book selectively, by skipping chapters on “other” materials.

This book, then, places its emphasis on fundamentals and on how those fundamentals can be applied to understand how the major inorganic materials are produced and the initial stages of their processing. These should equip the student for engineering future processes for producing materials or for studying the processing of the many less common materials not examined in this text.

This emphasis on fundamentals has posed a question. Can other texts and previous courses be relied upon to provide the necessary fundamentals for this text and a course based on it? The answer will of course depend on the students and the instructor will always have the option of skipping parts or the whole of the first few chapters. However, we argue that, because so many of the practitioners of materials science enter from different disciplines, it is wise to establish a common ground. For example, those entering from a mechanical engineering background would probably have a knowledge of chemical thermodynamics not as complete as that expected of chemists, but a considerable knowledge of process engineering. Even those from a materials science background frequently have not come across some fundamental topics important in materials processing. For example, undergraduate materials courses on diffusion seldom treat the convective mass transport that is important in the many materials processing operations where gases or liquids play a part.

Previous courses and texts encountered by the student may well have probed deeper and ranged wider into the topics of the first seven chapters but those chapters serve to emphasize what is important from those courses in terms of materials production. Selective reading of these chapters is encouraged but few will be the students who have an understanding of all the subject matter contained therein. The student who reads and grasps these chapters will be well equipped for the remaining chapters and work in the field of materials processing.

A second question we have faced is the extent to which references should be included in the text. Usually we have not included references although each chapter concludes with a list of suggested additional reading. Much of the material in this, and many other undergraduate texts, is “well known” in the sense of being scattered throughout other texts, or widely known to scientists or engineers in the field. Examples would be Fick’s laws of diffusion or the statement that the electrolytic cells used to produce aluminum typically operate at 950–960°C. Little is gained by including original references to substantiate these facts. The exception is in some of the later chapters which on occasion touch on developments that are too recent to be regarded as well known. At those points we have inserted a limited number of references, sufficient to serve as the origin for a literature survey.

We have used SI units in most cases. However, if present progress is any indication, it will be well into this century before the older units disappear, particularly in the United States. Consequently a few of the problems at the ends of the chapters have used older units.

Our intention has been to write a book suitable for a one semester (or two quarter)

course at the Junior or Senior level. Furthermore it is hoped that graduate students, or practicing scientists or engineers, entering the field will find the book a useful introductory and reference work. This selection of the level of presentation has not been allowed to constrain our writing. Some subjects are best described using mathematics that may tax some less accomplished juniors. Indeed some of the problems have been written so as to challenge the better seniors. Conversely, other topics, for example some of the process descriptions, are so easily grasped that we have striven to avoid dwelling on them.

We emphasize the scope of the text as implied by the title. The production and primary processing of inorganic materials (ceramics, metals, silicon and some composite materials) is the subject. Although much in the first few chapters applies equally to the production of polymeric materials, their production entails topics (organic chemistry and rheology, for example) that are peculiar to them. We have therefore thought it wise to stay within the bounds of inorganic materials.

At a late stage in the production of this second edition, Arthur Morris, Professor Emeritus of Metallurgical Engineering, University of Missouri, Rolla, suggested the inclusion of a CD, to include thermodynamic data and a few Excel® based examples of how to use them. This excellent suggestion led to the CD included with this text. That CD contains files that are the thermodynamic data for approximately one hundred elements and compounds (all those encountered in the problems and more). This is a subset of the large data set FREED that is mostly the thermodynamic database of the US Bureau of Mines and is available from <http://home.att.net/~thermart/> at nominal cost to students. Prof. Morris has also included on the CD some sample solutions to problems in the book, plus other problems. Some of these solutions were obtained using the software THERBAL (also available from <http://home.att.net/~thermart/>). Solutions obtained by such computational techniques are much more powerful instructional tools than the usual printed solutions. The student can easily change the parameters of the problem and the consequences are immediately and graphically apparent. We are greatly indebted to Art Morris

We also wish to thank Eve Edelson, who was very helpful in the preparation of the book. The late David Johnstone, editor at MacMillan, patiently steered us toward the finished manuscript that became the first edition published by that company. Stephen J. Kendall of TMS has been our aid in producing this second edition. Claire M. Evans is thanked for help in preparing the index. We would also express our appreciation to our students, who have contributed to our research and thereby to some of the body of knowledge that we have incorporated in the book. Thanks are also due to our reviewers, particularly Professors Dave Gaskell, Dennis Readey, George St. Pierre, and Nickolas Themelis for constructive criticism. We express special gratitude to our families for enduring our preoccupation with this book for a lengthy period.

JWE

LCDJ

Berkeley, March, 2002

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