Electronic Properties of Materials

Fourth Edition

Rolf E. Hummel

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Springer

Rolf E. Hummel
College of Engineering
University of Florida
Rhines Hall 216
Gainesville, FL 32611, USA
rhumm@mse.ufl.edu

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Preface to the Fourth Edition

The present textbook, which introduces my readers to elements of solid state physics and then moves on to the presentation of electrical, optical, magnetic, and thermal properties of materials, has been in print for 25 years, i.e. since 1985 when the first edition appeared. It has received quite favorable acceptance by students, professors, and scientists who particularly appreciated that the text is easy to understand and that it emphasizes concepts rather than overburdening the reader with mathematical formalism. I am grateful for all the kind comments which reached me either by personal letters or in reviews found in scientific journals and on the internet.

The third edition was published in 2001, and was followed by a revised printing in 2005. My publisher therefore felt that a new edition would be in order at this time to give me the opportunity to update the material in a field which undergoes explosive development. I do this update with some reluctance because each new edition increases the size (and unfortunately also the price) of a book. It is not my goal to present an encyclopedia on the electronic properties of materials. I still feel that the book should contain just the right amount of material that can be conveniently covered in a 15-week/3-credit hour course. Thus, the added material was restricted to the newest developments in the field. This implies that the fundamentals, particularly in Part I and at the beginning of Parts II to V, remained essentially untouched. However, new topics have been added in the "applied sections", such as energy-saving light sources, particularly compact fluorescence light fixtures, organic light-emitting diodes (OLEDs), organic photovoltaics (OPV cells), optical fibers, pyroelectricity, phase-change memories, blue-ray disks, holographic versatile disks, galvanoelectric phenomena (emphasizing the entire spectrum of primary and rechargeable batteries), graphene, quantum Hall effect, iron-based semiconductors (pnictides), etc., to mention just a few subjects. The reader should find them interesting and educational.

As usual, a book of this wide variety of topics needs the advice of a number of colleagues. I am grateful for the help of Drs. Paul Holloway, Wolfgang Sigmund, Jiangeng Xue, Franky So, Jacob Jones, Thierry Dubroca, all of the University of Florida, Dr. Markus Rettenmayr (Friedrich-Schiller-Universität Jena, Germany), and to Grif Wise.

Gainesville, Florida Rolf E. Hummel
September 2010

Preface to the Third Edition

Books are seldom finished. At best, they are abandoned. The second edition of "Electronic Properties of Materials" has been in use now for about seven years. During this time my publisher gave me ample opportunities to update and improve the text whenever the book was reprinted. There were about six of these reprinting cycles. Eventually, however, it became clear that substantially more new material had to be added to account for the stormy developments which occurred in the field of electrical, optical, and magnetic materials. In particular, expanded sections on flat-panel displays (liquid crystals, electroluminescence devices, field emission displays, and plasma displays) were added. Further, the recent developments in blue- and green-emitting LED's and in photonics are included. Magnetic storage devices also underwent rapid development. Thus, magneto-optical memories, magneto-resistance devices, and new magnetic materials needed to be covered. The sections on dielectric properties, ferroelectricity, piezoelectricity, electrostriction, and thermoelectric properties have been expanded. Of course, the entire text was critically reviewed, updated, and improved. However, the most extensive change I undertook was the conversion of all equations to SI-units throughout. In most of the world and in virtually all of the international scientific journals use of this system of units is required. If today's students do not learn to utilize it, another generation is "lost" on this matter. In other words, it is important that students become comfortable with SI units.

If plagiarism is the highest form of flattery, then I have indeed been flattered. Substantial portions of the first edition have made up verbatim most of another text by a professor in Madras without giving credit to where it first appeared. In addition, pirated copies of the first and second editions have surfaced in Asian countries. Further, a translation into Korean appeared. Of course, I feel that one should respect the rights of the owner of intellectual property.

I am grateful for the many favorable comments and suggestions promulgated by professors and students from the University of Florida and other schools who helped to improve the text. Dr. H. Rüfer from Wacker Siltronic AG has again appraised me of many recent developments in wafer fabrication. Professor John Reynolds (University of Florida) educated me on the current trends in conducting polymers. Drs. Regina and Gerd Müller (Agilent Corporation) enlightened me on recent LED developments. Professor Paul Holloway (University of Florida) shared with me some insights in phosphors and flat-panel displays. Professor Volkmar Gerold (MPI Stuttgart) was always available when help was needed. My thanks go to all of them.

Gainesville, Florida Rolf E. Hummel
October 2000

Preface to the Second Edition

It is quite satisfying for an author to learn that his brainchild has been favorably accepted by students as well as by professors and thus seems to serve some useful purpose. This horizontally integrated text on the electronic properties of metals, alloys, semiconductors, insulators, ceramics, and polymeric materials has been adopted by many universities in the United States as well as abroad, probably because of the relative ease with which the material can be understood. The book has now gone through several reprinting cycles (among them a few pirate prints in Asian countries). I am grateful to all readers for their acceptance and for the many encouraging comments which have been received.

I have thought very carefully about possible changes for the second edition. There is, of course, always room for improvement. Thus, some rewording, deletions, and additions have been made here and there. I withstood, however, the temptation to expand considerably the book by adding completely new subjects. Nevertheless, a few pages on recent developments needed to be inserted. Among them are, naturally, the discussion of ceramic (high-temperature) superconductors, and certain elements of the rapidly expanding field of optoelectronics. Further, I felt that the readers might be interested in learning some more practical applications which result from the physical concepts which have been treated here. Thus, the second edition describes common types of field-effect transistors (such as JFET, MOSFET, and MESFET), quantum semiconductor devices, electrical memories (such as D-RAM, S-RAM, and electrically erasable-programmable read-only memories), and logic circuits for computers. The reader will also find an expansion of the chapter on semiconductor device fabrication. The principal mechanisms behind some consumer devices, such as xerography, compact disc players, and optical computers, are also discussed.

Part III (Magnetic Properties of Materials) has been expanded to include more details on magnetic domains, as well as magnetostriction, amorphous ferromagnetics, the newest developments in permanent magnets, new magnetic recording materials, and magneto-optical memories.

Whenever appropriate, some economic facts pertaining to the manufacturing processes or sales figures have been given. Responding to occasional requests, the solutions for the numerical problems are now contained in the Appendix.

I am grateful for valuable expert advice from a number of colleagues, such as Professor Volkmar Gerold, Dr. Dieter Hagmann, Dr. H. Rüfer, Mr. David Malone, Professor Chris Batich, Professor Rolf Haase, Professor Robert Park, Professor Rajiv Singh, and Professor Ken Watson. Mrs. Angelika Hagmann and, to a lesser extent, my daughter, Sirka Hummel, have drawn the new figures. I thank them for their patience.

Gainesville, Florida — Rolf E. Hummel
1993

Preface to the First Edition

Die meisten Grundideen der Wissenschaft sind an sich einfach und lassen sich in der Regel in einer für jedermann verständlichen Sprache wiedergeben.

—ALBERT EINSTEIN

The present book on electrical, optical, magnetic, and thermal properties of materials is, in many aspects, different from other introductory texts in solid state physics. First of all, this book is written for engineers, particularly materials and electrical engineers who want to gain a fundamental understanding of semiconductor devices, magnetic materials, lasers, alloys, etc. Second, it stresses concepts rather than mathematical formalism, which should make the presentation relatively easy to understand. Thus, this book provides a thorough preparation for advanced texts, monographs, or specialized journal articles. Third, this book is not an encyclopedia. The selection of topics is restricted to material which is considered to be essential and which can be covered in a 15-week semester course. For those professors who want to teach a two-semester course, supplemental topics can be found which deepen the understanding. (These sections are marked by an asterisk [*].) Fourth, the present text leaves the teaching of crystallography, X-ray diffraction, diffusion, lattice defects, etc., to those courses which specialize in these subjects. As a rule, engineering students learn this material at the beginning of their upper division curriculum. The reader is, however, reminded of some of these topics whenever the need arises. Fifth, this book is distinctly divided into five self-contained parts which may be read independently. All are based on the first part, entitled "Fundamentals of Electron Theory", because the electron theory of materials is a basic tool with which most material properties can be understood. The modern electron theory of solids is relatively involved. It is, however, not my intent to train a student to become proficient in the entire field of quantum theory. This should be left to more specialized texts. Instead, the essential quantum mechanical concepts are introduced only to the extent to which they are needed for the understanding of materials science. Sixth, plenty of practical applications are presented in the text, as well as in the problem sections, so that the students may gain an understanding of many devices that are used every day. In other words, I tried to bridge the gap between physics and engineering. Finally, I gave the treatment of the optical properties of materials about equal coverage to that of the electrical properties. This is partly due to my personal inclinations and partly because it is felt that a more detailed description of the optical properties is needed since most other texts on solid state physics devote relatively little space to this topic. It should be kept in mind that the optical properties have gained an increasing amount of attention in recent years, because of their potential application in communication devices as well as their contributions to the understanding of the electronic structure of materials.

The philosophy and substance of the present text emerged from lecture notes which I accumulated during more than twenty years of teaching. A preliminary version of Parts I and II appeared several years ago in *Journal of Educational Modules for Materials Science and Engineering* **4**, 1 (1982) and **4**, 781 (1982).

I sincerely hope that students who read and work with this book will enjoy, as much as I, the journey through the fascinating field of the physical properties of materials.

Each work benefits greatly from the interaction between author and colleagues or students. I am grateful in particular to Professor R.T. DeHoff, who read the entire manuscript and who helped with his inquisitive mind to clarify many points in the presentation. Professor Ken Watson read the part dealing with magnetism and made many helpful suggestions. Other colleagues to whom I am indebted are Professor Fred Lindholm, Professor Terry Orlando, and Dr. Siegfried Hofmann. My daughter, Sirka Hummel, contributed with her skills as an artist. Last, but not least, I am obliged to my family, to faculty, and to the chairman of the Department of Materials Science and Engineering at the University of Florida for providing the harmonious atmosphere which is of the utmost necessity for being creative.

Gainesville, Florida
1985

Rolf E. Hummel

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PART III
Optical Properties of Materials

Note: Sections marked with an asterisk (*) are topics which are beyond a 15-week semester course or may be treated in a graduate course.