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S.O.Kasap

电子材料与器件原理 (第3版)

Principles of Electronic Materials
and Devices (Third Edition)

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**Electronic Materials
and Devices**

Third Edition



S. O. Kasap



清华大学出版社

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北京

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清华大学出版社
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英文影印版序

“电子材料与器件”这门课程是美国大学工学院里电机和材料专业高年级本科的必修课或选修课，但对于不同的专业侧重有所不同。在传统的材料导论课程里，整个课程会广泛地介绍现代工业应用的一般材料，包括陶瓷、玻璃、高分子，以及复合材料。对于材料的性质，一般会过于强调材料的机械性质，从而忽略了物理性质，比如电性、光性、磁性和铁电、压电性质等。这种过于偏向力学性质的原因来自几个方面：其一是由于在介绍固体电学性质的时候需要有量子力学基础。比如能带理论、隧道效应和磁矩的量子化。在讨论电子能量分布时还需要统计物理的基础，而一般工学院材料系并不设置任何量子力学的课程。这为教学固体电性增加了关键性的困难；其二是由于美国工学院的资深教授大多来自传统的工程教育背景，那些非电机系出身的老师一般很少开设物理以及固体理论方面的课程。正是由于这两方面的历史原因，工科院系中的传统的材料课程一直有这种重视力学性质而忽视电学性质的倾向。但是在 21 世纪工业飞速发展的环境下，尤其美国工业界在近几十年来，飞速发展了功能材料，尤其是电子材料，包括智能材料、纳米电子器件、传感器、医用感应器，等等。这些器件材料大多是根据许多物理的基本原理和新概念而建立设计的。虽然工科非电机专业的学生并不一定直接涉及这些元器件的设计和制造，但在日常的工程实践中会经常接触到相关材料和器件的应用。比如测温、测压、磁场、光电、通信和医用中的设备和系统。这就要求工学院的材料专业的学生能够对材料的物理性质和概念有一定的掌握。本书就是按照这种需求而出版的。

对材料专业的学生，材料物理性质的教材可以来自两个方面：其一是一般材料导论教材，比如由 Donald Askeland 所著的 *The Science and Engineering of Materials* 中的电学性质的部分，但这部分内容比较浅显。而在此基础上，更程度的材料电学性质就来自本书的主要章节。对于美国工科院校材料专业的学生，课时为三个学分（即一周 3 次课，每课 50 分钟），一般在大学三年级完成该课程。

本书可以分为两个部分，第一部分是基础部分。从第 1~4 章着重讨论与固体电性有关的物理理论。其中包括量子物理中的薛定谔方程、海森堡测不准原理、隧道效应、单粒子势阱等重要概念，并在这些物理理论的基础上建立能带理论，包括态密度、波尔兹曼统计、费米-狄拉克分布、费米能级等。在基础部分中，还给出了基本的导电与导热机制，其中包括趋肤效应和霍尔效应。在这个部分还介绍了一些典型的器件和集成电路的概念，比如霍尔器件。第二部分主要介绍不同种类电子材料，包括半导体与半导体器件、介电材料和绝缘材料、磁性材料和超导材料。在介绍半导体的章节中(第 5, 6 章)，本书讨论了半导体的基本概念，如电子和空穴、本征半导体、N 型和 P 型半导体、载体浓度、载体的温度特性、杂质行为、扩散方程、光吸收，以及缺陷和半导体结等。在第 7 章里着重介绍介电材

料,包括电子和离子在外场下的极化行为、频率特性、介电损耗、介电强度、介电击穿和电容。该章还介绍了铁电和压电的概念以及铁电压电器件,如石英振荡器和滤波器。第8章介绍磁性材料和超导材料。在这一章中,本书首先讨论了磁学的基本概念,比如磁矩、磁化率、磁化强度等,然后给出各种磁性的定义,比如顺磁、铁磁、反磁。该章详细地讨论了磁化饱和、居里点、磁畴与去磁效应。对于磁滞回线以及各种典型的磁性材料,该书也做了详细的介绍。第8章的最后一部分介绍了超导现象和超导材料,包括第一类和第二类超导体、迈斯耐效应、零电阻现象、约瑟芬结和超导电流密度,并介绍了磁性记录材料。第9章介绍光学性质和光学材料。

本书的作者 S.O. Kasap 博士是电子材料领域十分著名的专家。他在本书里不仅对材料的物理电学性质的介绍有独到的见解和非常精彩的阐述,而且对材料的基本结构也作了极为详尽的描述。更为可贵的是本书引入大量现代科技最新发展的成果。比如高温超导体、新一代数字芯片技术、高密度磁记录等。这为开拓学生眼界,熟悉相关领域动态,掌握现代工业发展有着极为积极的意义。

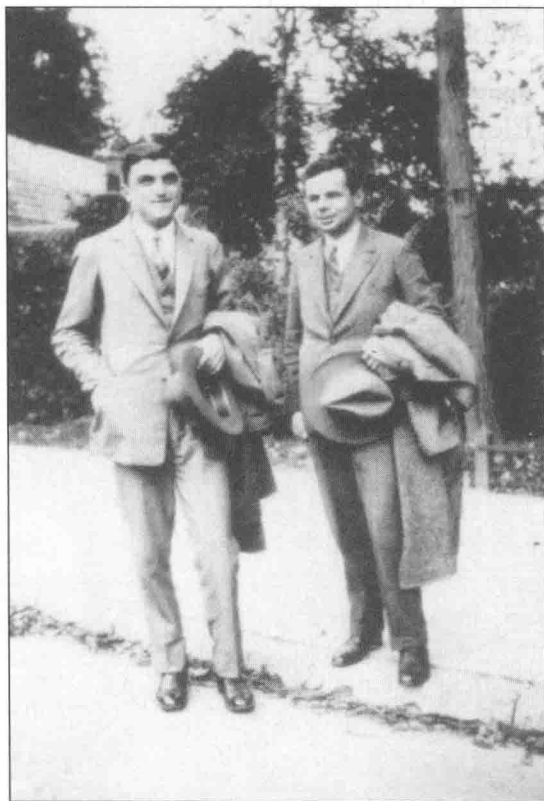
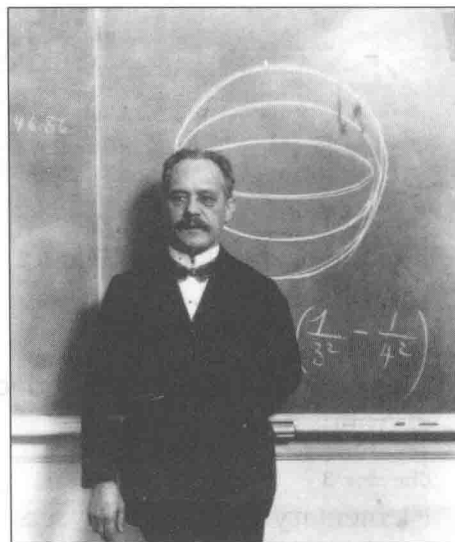
清华大学出版社在中国现代化飞速发展的今天,十分及时地选择 *Principles of Electronic Materials and Devices* 作为中国大学工科专业的主要材料学英文原版教科书并引进该书的版权,是有着非常重要的现实意义。它不仅可以在国内科技英文教学方面作为一个具有国际水准的工程院校的教学标准,也为一般的大专院校和科研单位的研究工作者提供了一本内容丰富、极具科研价值的参考书。我衷心祝愿本书的英文影印版受到国内学生、老师,以及科研同行的欢迎,并在教学和科研中起到重大的作用。

时东陆
美国俄亥俄州立辛辛那提大学工学院
材料科学与工程教授

2006 年

Arnold Johannes Wilhelm Sommerfeld (1868–1951) was responsible for the quantum mechanical free electron theory of metals covered in Chapter 4. Sommerfeld was the Director of Institute of Theoretical Physics, specially established for him, at Munich University.

1 SOURCE: AIP Emilio Segrè Visual Archives, Physics Today Collection.



Felix Bloch (left) and Lothar Wolfgang Nordheim (right). Nordheim (1899–1988) received his PhD from the University of Göttingen.

1 SOURCE: AIP Emilio Segrè Visual Archives, Uhlenbeck Collection.

PREFACE

THIRD EDITION

The textbook represents a first course in electronic materials and devices for undergraduate students. With the additional topics in the accompanying CD, the text can also be used in a graduate introductory course in electronic materials for electrical engineers and material scientists. The third edition is an extensively revised and extended version of the second edition based on reviewer comments, with many new and expanded topics and numerous new worked examples and homework problems. While some of the changes appear to be minor, they have been, nonetheless, quite important in improving the text. For example, the intrinsic concentration n_i in Si is now taken as $1 \times 10^{10} \text{ cm}^{-3}$, instead of the usual value of $1.45 \times 10^{10} \text{ cm}^{-3}$ found in many other textbooks; this change makes a significant difference in device-related calculations. A large number of new homework problems have been added, and more solved problems have been provided that put the concepts into applications. Bragg's diffraction law that is mentioned in several chapters is now explained in Appendix A for those readers who are unfamiliar with it.

The third edition is one of the few books on the market that has a broad coverage of electronic materials that today's scientists and engineers need. I believe that the revisions have improved the rigor without sacrificing the original semi-quantitative approach that both the students and instructors liked. Some of the new and extended topics are as follows:

- Chapter 1 Thermal expansion; atomic diffusion
- Chapter 2 Conduction in thin films; interconnects in microelectronics; electromigration

- Chapter 3 Planck's and Stefan's laws; atomic magnetic moment; Stern–Gerlach experiment
- Chapter 4 Field emission from carbon nanotubes; Grüneisen's thermal expansion
- Chapter 5 Piezoresistivity; amorphous semiconductors
- Chapter 6 LEDs; solar cells; semiconductor lasers
- Chapter 7 Debye relaxation; local field in dielectrics; ionic polarizability; Langevin dipolar polarization; dielectric mixtures
- Chapter 8 Pauli spin paramagnetism; band model of ferromagnetism; giant magnetoresistance (GMR); magnetic storage
- Chapter 9 Sellmeier and Cauchy dispersion relations; Reststrahlen or lattice absorption; luminescence and white LEDs
- Appendices Bragg's diffraction law and X-ray diffraction; luminous flux and brightness of radiation

ORGANIZATION AND FEATURES

In preparing the text, I tried to keep the general treatment and various proofs at a semiquantitative level without going into detailed physics. Many of the problems have been set to satisfy engineering accreditation requirements. Some chapters in the text have additional topics to allow a more detailed treatment, usually including quantum mechanics or more mathematics. Cross referencing has been avoided as much as possible without too much repetition and to allow various sections and

chapters to be skipped as desired by the reader. The text has been written to be easily usable in one-semester courses by allowing such flexibility.

Some important features are

- The principles are developed with the minimum of mathematics and with the emphasis on physical ideas. Quantum mechanics is part of the course but without its difficult mathematical formalism.
- There are more than 170 worked examples or solved problems, most of which have a practical significance. Students learn by way of examples, however simple, and to that end nearly 250 problems have been provided.
- Even simple concepts have examples to aid learning.
- Most students would like to have clear diagrams to help them visualize the explanations and understand concepts. The text includes over 530 illustrations that have been professionally prepared to reflect the concepts and aid the explanations in the text.
- The end-of-chapter questions and problems are graded so that they start with easy concepts and eventually lead to more sophisticated concepts. Difficult problems are identified with an asterisk (*). Many practical applications with diagrams have been included. There is a regularly updated online extended *Solutions Manual* for all instructors; simply locate the McGraw-Hill website for this textbook.
- There is a glossary, *Defining Terms*, at the end of each chapter that defines some of the concepts and terms used, not only within the text but also in the problems.
- The end of each chapter includes a section *Additional Topics* to further develop important concepts, to introduce interesting applications, or to prove a theorem. These topics are intended for the keen student and can be used as part of the text for a two-semester course.
- The end of each chapter also includes a table *CD Selected Topics and Solved Problems* to

enhance not only the subject coverage, but also the range of worked examples and applications. For example, the selected topic *Essential Mechanical Properties* can be used with Chapter 1 to obtain a broader coverage of elementary materials science. The selected topic *Thermoelectric Effects in Semiconductors* can be used with Chapters 5 and 6 to understand the origin of the Seebeck effect in semiconductors, and the reasons behind voltage drift in many semiconductor devices. There are numerous such selected topics and solved problems in the CD.

- The text is supported by McGraw-Hill's textbook website that contains resources, such as solved problems, for both students and instructors. Updates to various articles on the CD will be posted on this website.

CD-ROM ELECTRONIC MATERIALS AND DEVICES: THIRD EDITION

The book has a CD-ROM that contains all the figures as large *color diagrams* in *PowerPoint* for the instructor, and class-ready notes for the students who do not have to draw the diagrams during the lectures. In addition, there are numerous *Selected Topics* and *Solved Problems* to extend the present coverage. These are listed in each chapter, and also at the end of the text. I strongly urge students to print out the CD's *Illustrated Dictionary of Electronic Materials and Devices: Third Student Edition*, to look up new terms and use the dictionary to refresh various concepts. This is probably the best feature of the CD.

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My gratitude goes to my past and present graduate students and postdoctoral research fellows, who have kept me on my toes and read various sections of this book. I have been fortunate to have a colleague and friend like Charbel Tannous

who, as usual, made many sharply critical but helpful comments, especially on Chapter 8. A number of reviewers, at various times, read various portions of the manuscript and provided extensive comments. A number of instructors also wrote to me with their own comments. I incorporated the majority of the suggestions, which I believe made this a better book. No textbook is perfect, and I'm sure that there will be more suggestions for the next edition. I'd like to personally thank them all for their invaluable critiques, some of whom include (alphabetically):

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Safa Kasap

<http://ElectronicMaterials.Usask.Ca>

"The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them."

Sir William Lawrence Bragg

BRIEF CONTENTS

Chapter 1

Elementary Materials Science
Concepts 3

Chapter 2

Electrical and Thermal Conduction
in Solids 113

Chapter 3

Elementary Quantum Physics 191

Chapter 4

Modern Theory of Solids 285

Chapter 5

Semiconductors 373

Chapter 6

Semiconductor Devices 475

Chapter 7

Dielectric Materials and
Insulation 583

Chapter 8

Magnetic Properties and
Superconductivity 685

Chapter 9

Optical Properties of
Materials 773

Appendix A

Bragg's Diffraction Law and X-ray
Diffraction 848

Appendix B

Flux, Luminous Flux, and the
Brightness of Radiation 853

Appendix C

Major Symbols and
Abbreviations 855

Appendix D

Elements to Uranium 861

Appendix E

Constants and Useful
Information 864

Index 866

CONTENTS

Preface xiii

Chapter 1

Elementary Materials Science Concepts 3

- 1.1 Atomic Structure and Atomic Number 3
 - 1.2 Atomic Mass and Mole 8
 - 1.3 Bonding and Types of Solids 9
 - 1.3.1 Molecules and General Bonding Principles 9
 - 1.3.2 Covalently Bonded Solids: Diamond 11
 - 1.3.3 Metallic Bonding: Copper 13
 - 1.3.4 Ionically Bonded Solids: Salt 14
 - 1.3.5 Secondary Bonding 18
 - 1.3.6 Mixed Bonding 22
 - 1.4 Kinetic Molecular Theory 25
 - 1.4.1 Mean Kinetic Energy and Temperature 25
 - 1.4.2 Thermal Expansion 31
 - 1.5 Molecular Velocity and Energy Distribution 36
 - 1.6 Heat, Thermal Fluctuations, and Noise 40
 - 1.7 Thermally Activated Processes 45
 - 1.7.1 Arrhenius Rate Equation 45
 - 1.7.2 Atomic Diffusion and the Diffusion Coefficient 47
 - 1.8 The Crystalline State 49
 - 1.8.1 Types of Crystals 49
 - 1.8.2 Crystal Directions and Planes 56
 - 1.8.3 Allotropy and Carbon 61
 - 1.9 Crystalline Defects and Their Significance 64
 - 1.9.1 Point Defects: Vacancies and Impurities 64
 - 1.9.2 Line Defects: Edge and Screw Dislocations 68
 - 1.9.3 Planar Defects: Grain Boundaries 70
 - 1.9.4 Crystal Surfaces and Surface Properties 73
 - 1.9.5 Stoichiometry, Nonstoichiometry, and Defect Structures 75
 - 1.10 Single-Crystal Czochralski Growth 76
 - 1.11 Glasses and Amorphous Semiconductors 78
 - 1.11.1 Glasses and Amorphous Solids 78
 - 1.11.2 Crystalline and Amorphous Silicon 80
 - 1.12 Solid Solutions and Two-Phase Solids 83
 - 1.12.1 Isomorphous Solid Solutions: Isomorphous Alloys 83
 - 1.12.2 Phase Diagrams: Cu–Ni and Other Isomorphous Alloys 84
 - 1.12.3 Zone Refining and Pure Silicon Crystals 88
 - 1.12.4 Binary Eutectic Phase Diagrams and Pb–Sn Solders 90
- Additional Topics 95
- 1.13 Bravais Lattices 95
- CD Selected Topics and Solved Problems 98
- Defining Terms 98
- Questions and Problems 102

Chapter 2

Electrical and Thermal Conduction in Solids 113

- 2.1 Classical Theory: The Drude Model 114
 - 2.1.1 Metals and Conduction by Electrons 114
- 2.2 Temperature Dependence of Resistivity: Ideal Pure Metals 122
- 2.3 Matthiessen's and Nordheim's Rules 125
 - 2.3.1 Matthiessen's Rule and the Temperature Coefficient of Resistivity (α) 125

- 2.3.2 Solid Solutions and Nordheim's Rule 134
 - 2.4 Resistivity of Mixtures and Porous Materials 139
 - 2.4.1 Heterogeneous Mixtures 139
 - 2.4.2 Two-Phase Alloy (Ag–Ni) Resistivity and Electrical Contacts 143
 - 2.5 The Hall Effect and Hall Devices 145
 - 2.6 Thermal Conduction 149
 - 2.6.1 Thermal Conductivity 149
 - 2.6.2 Thermal Resistance 153
 - 2.7 Electrical Conductivity of Nonmetals 154
 - 2.7.1 Semiconductors 155
 - 2.7.2 Ionic Crystals and Glasses 159
 - Additional Topics 163
 - 2.8 Skin Effect: HF Resistance of a Conductor 163
 - 2.9 Thin Metal Films 166
 - 2.9.1 Conduction in Thin Metal Films 166
 - 2.9.2 Resistivity of Thin Films 167
 - 2.10 Interconnects in Microelectronics 172
 - 2.11 Electromigration and Black's Equation 176
 - CD Selected Topics and Solved Problems 178
 - Defining Terms 178
 - Questions and Problems 180
- Chapter 3**
Elementary Quantum Physics 191
- 3.1 Photons 191
 - 3.1.1 Light as a Wave 191
 - 3.1.2 The Photoelectric Effect 194
 - 3.1.3 Compton Scattering 199
 - 3.1.4 Black Body Radiation 202
 - 3.2 The Electron as a Wave 205
 - 3.2.1 De Broglie Relationship 205
 - 3.2.2 Time-Independent Schrödinger Equation 208
 - 3.3 Infinite Potential Well: A Confined Electron 212
 - 3.4 Heisenberg's Uncertainty Principle 217
 - 3.5 Tunneling Phenomenon: Quantum Leak 221
 - 3.6 Potential Box: Three Quantum Numbers 228
 - 3.7 Hydrogenic Atom 231
 - 3.7.1 Electron Wavefunctions 231
 - 3.7.2 Quantized Electron Energy 236
 - 3.7.3 Orbital Angular Momentum and Space Quantization 241
 - 3.7.4 Electron Spin and Intrinsic Angular Momentum S 245
 - 3.7.5 Magnetic Dipole Moment of the Electron 248
 - 3.7.6 Total Angular Momentum J 252
 - 3.8 The Helium Atom and the Periodic Table 254
 - 3.8.1 He Atom and Pauli Exclusion Principle 254
 - 3.8.2 Hund's Rule 256
 - 3.9 Stimulated Emission and Lasers 258
 - 3.9.1 Stimulated Emission and Photon Amplification 258
 - 3.9.2 Helium–Neon Laser 261
 - 3.9.3 Laser Output Spectrum 265
 - Additional Topics 267
 - 3.10 Optical Fiber Amplifiers 267
 - CD Selected Topics and Solved Problems 268
 - Defining Terms 269
 - Questions and Problems 272
- Chapter 4**
Modern Theory of Solids 285
- 4.1 Hydrogen Molecule: Molecular Orbital Theory of Bonding 285
 - 4.2 Band Theory of Solids 291
 - 4.2.1 Energy Band Formation 291
 - 4.2.2 Properties of Electrons in a Band 296
 - 4.3 Semiconductors 299
 - 4.4 Electron Effective Mass 303
 - 4.5 Density of States in an Energy Band 305
 - 4.6 Statistics: Collections of Particles 312
 - 4.6.1 Boltzmann Classical Statistics 312
 - 4.6.2 Fermi–Dirac Statistics 313
 - 4.7 Quantum Theory of Metals 315
 - 4.7.1 Free Electron Model 315
 - 4.7.2 Conduction in Metals 318

- 4.8 Fermi Energy Significance 320
 - 4.8.1 Metal–Metal Contacts: Contact Potential 320
 - 4.8.2 The Seebeck Effect and the Thermocouple 322
 - 4.9 Thermionic Emission and Vacuum Tube Devices 328
 - 4.9.1 Thermionic Emission: Richardson–Dushman Equation 328
 - 4.9.2 Schottky Effect and Field Emission 332
 - 4.10 Phonons 337
 - 4.10.1 Harmonic Oscillator and Lattice Waves 337
 - 4.10.2 Debye Heat Capacity 342
 - 4.10.3 Thermal Conductivity of Nonmetals 348
 - 4.10.4 Electrical Conductivity 350
 - Additional Topics 352
 - 4.11 Band Theory of Metals: Electron Diffraction in Crystals 352
 - 4.12 Grüneisen’s Model of Thermal Expansion 361
 - CD Selected Topics and Solved Problems 363
 - Defining Terms 363
 - Questions and Problems 365
- Chapter 5**
- Semiconductors 373**
- 5.1 Intrinsic Semiconductors 374
 - 5.1.1 Silicon Crystal and Energy Band Diagram 374
 - 5.1.2 Electrons and Holes 376
 - 5.1.3 Conduction in Semiconductors 378
 - 5.1.4 Electron and Hole Concentrations 380
 - 5.2 Extrinsic Semiconductors 388
 - 5.2.1 *n*-Type Doping 388
 - 5.2.2 *p*-Type Doping 390
 - 5.2.3 Compensation Doping 392
 - 5.3 Temperature Dependence of Conductivity 396
 - 5.3.1 Carrier Concentration Temperature Dependence 396
 - 5.3.2 Drift Mobility: Temperature and Impurity Dependence 401
 - 5.3.3 Conductivity Temperature Dependence 404
 - 5.3.4 Degenerate and Nondegenerate Semiconductors 406
 - 5.4 Recombination and Minority Carrier Injection 407
 - 5.4.1 Direct and Indirect Recombination 407
 - 5.4.2 Minority Carrier Lifetime 410
 - 5.5 Diffusion and Conduction Equations, and Random Motion 416
 - 5.6 Continuity Equation 422
 - 5.6.1 Time-Dependent Continuity Equation 422
 - 5.6.2 Steady-State Continuity Equation 424
 - 5.7 Optical Absorption 427
 - 5.8 Piezoresistivity 431
 - 5.9 Schottky Junction 435
 - 5.9.1 Schottky Diode 435
 - 5.9.2 Schottky Junction Solar Cell 440
 - 5.10 Ohmic Contacts and Thermoelectric Coolers 443
 - Additional Topics 448
 - 5.11 Direct and Indirect Bandgap Semiconductors 448
 - 5.12 Indirect Recombination 457
 - 5.13 Amorphous Semiconductors 458
 - CD Selected Topics and Solved Problems 461
 - Defining Terms 461
 - Questions and Problems 464
- Chapter 6**
- Semiconductor Devices 475**
- 6.1 Ideal *pn* Junction 476
 - 6.1.1 No Applied Bias: Open Circuit 476
 - 6.1.2 Forward Bias: Diffusion Current 481
 - 6.1.3 Forward Bias: Recombination and Total Current 487
 - 6.1.4 Reverse Bias 489
 - 6.2 *pn* Junction Band Diagram 494
 - 6.2.1 Open Circuit 494
 - 6.2.2 Forward and Reverse Bias 495

- 6.3 Depletion Layer Capacitance of the *pn* Junction 498
 - 6.4 Diffusion (Storage) Capacitance and Dynamic Resistance 500
 - 6.5 Reverse Breakdown: Avalanche and Zener Breakdown 502
 - 6.5.1 Avalanche Breakdown 503
 - 6.5.2 Zener Breakdown 504
 - 6.6 Bipolar Transistor (BJT) 506
 - 6.6.1 Common Base (CB) dc Characteristics 506
 - 6.6.2 Common Base Amplifier 515
 - 6.6.3 Common Emitter (CE) dc Characteristics 517
 - 6.6.4 Low-Frequency Small-Signal Model 518
 - 6.7 Junction Field Effect Transistor (JFET) 522
 - 6.7.1 General Principles 522
 - 6.7.2 JFET Amplifier 528
 - 6.8 Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) 532
 - 6.8.1 Field Effect and Inversion 532
 - 6.8.2 Enhancement MOSFET 535
 - 6.8.3 Threshold Voltage 539
 - 6.8.4 Ion Implanted MOS Transistors and Poly-Si Gates 541
 - 6.9 Light Emitting Diodes (LED) 543
 - 6.9.1 LED Principles 543
 - 6.9.2 Heterojunction High-Intensity LEDs 547
 - 6.9.3 LED Characteristics 548
 - 6.10 Solar Cells 551
 - 6.10.1 Photovoltaic Device Principles 551
 - 6.10.2 Series and Shunt Resistance 559
 - 6.10.3 Solar Cell Materials, Devices, and Efficiencies 561
 - Additional Topics 564
 - 6.11 *pin* Diodes, Photodiodes, and Solar Cells 564
 - 6.12 Semiconductor Optical Amplifiers and Lasers 566
 - CD Selected Topics and Solved Problems 570
 - Defining Terms 570
 - Questions and Problems 573
-
- Chapter 7**
 - Dielectric Materials and Insulation 583**
 - 7.1 Matter Polarization and Relative Permittivity 584
 - 7.1.1 Relative Permittivity: Definition 584
 - 7.1.2 Dipole Moment and Electronic Polarization 585
 - 7.1.3 Polarization Vector \mathbf{P} 589
 - 7.1.4 Local Field \mathcal{E}_{loc} and Clausius–Mossotti Equation 593
 - 7.2 Electronic Polarization: Covalent Solids 595
 - 7.3 Polarization Mechanisms 597
 - 7.3.1 Ionic Polarization 597
 - 7.3.2 Orientational (Dipolar) Polarization 598
 - 7.3.3 Interfacial Polarization 600
 - 7.3.4 Total Polarization 601
 - 7.4 Frequency Dependence: Dielectric Constant and Dielectric Loss 603
 - 7.4.1 Dielectric Loss 603
 - 7.4.2 Debye Equations, Cole–Cole Plots, and Equivalent Series Circuit 611
 - 7.5 Gauss’s Law and Boundary Conditions 614
 - 7.6 Dielectric Strength and Insulation Breakdown 620
 - 7.6.1 Dielectric Strength: Definition 620
 - 7.6.2 Dielectric Breakdown and Partial Discharges: Gases 621
 - 7.6.3 Dielectric Breakdown: Liquids 622
 - 7.6.4 Dielectric Breakdown: Solids 623
 - 7.7 Capacitor Dielectric Materials 631
 - 7.7.1 Typical Capacitor Constructions 631
 - 7.7.2 Dielectrics: Comparison 634
 - 7.8 Piezoelectricity, Ferroelectricity, and Pyroelectricity 638
 - 7.8.1 Piezoelectricity 638
 - 7.8.2 Piezoelectricity: Quartz Oscillators and Filters 644
 - 7.8.3 Ferroelectric and Pyroelectric Crystals 647

- Additional Topics 654
- 7.9 Electric Displacement and Depolarization Field 654
- 7.10 Local Field and the Lorentz Equation 658
- 7.11 Dipolar Polarization 660
- 7.12 Ionic Polarization and Dielectric Resonance 662
- 7.13 Dielectric Mixtures and Heterogeneous Media 667
- CD Selected Topics and Solved Problems 669
- Defining Terms 670
- Questions and Problems 673
- Chapter 8**
- Magnetic Properties and Superconductivity 685**
- 8.1 Magnetization of Matter 685
- 8.1.1 Magnetic Dipole Moment 685
- 8.1.2 Atomic Magnetic Moments 687
- 8.1.3 Magnetization Vector \mathbf{M} 688
- 8.1.4 Magnetizing Field or Magnetic Field Intensity \mathbf{H} 691
- 8.1.5 Magnetic Permeability and Magnetic Susceptibility 692
- 8.2 Magnetic Material Classifications 696
- 8.2.1 Diamagnetism 696
- 8.2.2 Paramagnetism 698
- 8.2.3 Ferromagnetism 699
- 8.2.4 Antiferromagnetism 699
- 8.2.5 Ferrimagnetism 700
- 8.3 Ferromagnetism Origin and the Exchange Interaction 700
- 8.4 Saturation Magnetization and Curie Temperature 703
- 8.5 Magnetic Domains: Ferromagnetic Materials 705
- 8.5.1 Magnetic Domains 705
- 8.5.2 Magnetocrystalline Anisotropy 706
- 8.5.3 Domain Walls 708
- 8.5.4 Magnetostriction 711
- 8.5.5 Domain Wall Motion 712
- 8.5.6 Polycrystalline Materials and the M versus H Behavior 713
- 8.5.7 Demagnetization 717
- 8.6 Soft and Hard Magnetic Materials 719
- 8.6.1 Definitions 719
- 8.6.2 Initial and Maximum Permeability 720
- 8.7 Soft Magnetic Materials: Examples and Uses 721
- 8.8 Hard Magnetic Materials: Examples and Uses 724
- 8.9 Superconductivity 729
- 8.9.1 Zero Resistance and the Meissner Effect 729
- 8.9.2 Type I and Type II Superconductors 733
- 8.9.3 Critical Current Density 736
- 8.10 Superconductivity Origin 739
- Additional Topics 740
- 8.11 Energy Band Diagrams and Magnetism 740
- 8.11.1 Pauli Spin Paramagnetism 740
- 8.11.2 Energy Band Model of Ferromagnetism 742
- 8.12 Anisotropic and Giant Magnetoresistance 744
- 8.13 Magnetic Recording Materials 749
- 8.14 Josephson Effect 756
- 8.15 Flux Quantization 758
- CD Selected Topics and Solved Problems 759
- Defining Terms 759
- Questions and Problems 763
- Chapter 9**
- Optical Properties of Materials 773**
- 9.1 Light Waves in a Homogeneous Medium 774
- 9.2 Refractive Index 777
- 9.3 Dispersion: Refractive Index–Wavelength Behavior 779
- 9.4 Group Velocity and Group Index 784
- 9.5 Magnetic Field: Irradiance and Poynting Vector 787
- 9.6 Snell's Law and Total Internal Reflection (TIR) 789
- 9.7 Fresnel's Equations 793
- 9.7.1 Amplitude Reflection and Transmission Coefficients 793

- 9.7.2 Intensity, Reflectance, and Transmittance 799
- 9.8 Complex Refractive Index and Light Absorption 804
- 9.9 Lattice Absorption 811
- 9.10 Band-to-Band Absorption 813
- 9.11 Light Scattering in Materials 816
- 9.12 Attenuation in Optical Fibers 817
- 9.13 Luminescence, Phosphors, and White LEDs 820
- 9.14 Polarization 825
- 9.15 Optical Anisotropy 827
 - 9.15.1 Uniaxial Crystals and Fresnel's Optical Indicatrix 829
 - 9.15.2 Birefringence of Calcite 832
 - 9.15.3 Dichroism 833
- 9.16 Birefringent Retarding Plates 833
- 9.17 Optical Activity and Circular Birefringence 835
- Additional Topics 837
- 9.18 Electro-optic Effects 837
- CD Selected Topics and Solved Problems 841
- Defining Terms 841
- Questions and Problems 844

Appendix A
Bragg's Diffraction Law and X-ray Diffraction 848

Appendix B
Flux, Luminous Flux, and the Brightness of Radiation 853

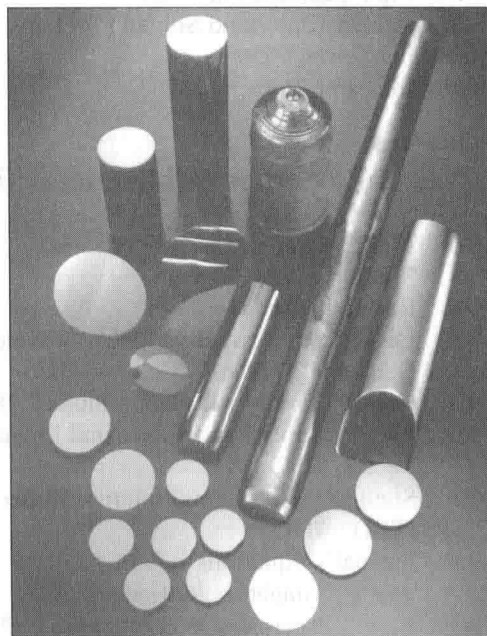
Appendix C
Major Symbols and Abbreviations 855

Appendix D
Elements to Uranium 861

Appendix E
Constants and Useful Information 864

Index 866

附录 875



GaAs ingots and wafers.

1 SOURCE: Courtesy of Sumitomo Electric Industries, Ltd.