Mc Graw Hill Education

PRINCIPLES OF ELECTRONIC MATERIALS & DEVICES

FORTH EDITION

电子材料与器件

（第四版）

[加] 卡萨普（S. O. Kasap） 著
王进祥 选译

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前　言

本教材可用于大学本科电子材料和器件专业的第一门课程。加上书中的附加主题，本书也可以用于电气工程师和材料研究人员的电子材料研究生入门课程。第四版是第三版的广泛修订和扩展版本，该修订与扩展是基于审稿人的意见以及电子与光电子材料过去 10 年的发展而作出的。第四版有许多新的和扩展的主题，新的例子、图表和思考题；改进了大部分的图表，以使它们更清晰；增加了大量新的思考题，并提供了许多解决问题的方法，将这些概念应用到实际中；修改了超过 50% 的图表以提高清晰度。此外，在术语表中增加了更多的有实用性的术语。对书中多次提到的布拉格衍射定律，不熟悉的读者可以参阅附录 A。

第四版是市场上少数几本涵盖了当今科学家和工程师所需的电子材料的书籍之一，我相信这次修订提高了严谨性，同时也没有牺牲师生们喜欢的半定量方法。系统性内容的主要修订可以归纳如下。

第 1 章：热膨胀；动力学分子理论；原子扩散；分子碰撞与真空沉积；粒子通量密度；线缺陷；面缺陷；晶体表面；Grüneisen 规则。

第 2 章：电阻率的温度依赖性，应变计，霍尔效应；离子导电；漂移迁移率与扩散的爱因斯坦关系式；交流电导率；薄膜电阻率；微电子互连；电迁移。

第 3 章：电子波动性；无限势阱；有限势阱中的受限电子；受激发射与光子放大；氦氖激光器，光纤放大。

第 4 章：功函数；光电效应；二次发射；电子亲和势与光倍增；费米-狄拉克统计；金属导电性；热电与塞贝克系数；热电偶；声子浓度随温度的变化。

第 5 章：简并半导体；直接和间接复合；直接和间接带隙半导体的 e-k 图；肖特基结和耗尽层；塞贝克效应半导体和电压漂移。

第 6 章：pn 结；直接带隙 pn 结；耗尽层电容；线性渐变结；超突变结；发光二极管(LED)；量子阱高强度 LED；发光二极管材料与结构；LED 的特性；LED 光谱；发光二极管的亮度和效率；多结太阳能电池。

第 7 章：原子极化率；界面极化；气体中的碰撞电离和击穿；超级电容器。

第 8 章：各向异性和巨磁电阻；磁记录材料；纵磁记录；磁存储材料；超导电性。

第 9 章：硅的折射率和群指数；介质反射镜；自由载流子吸收；液晶显示器。

内容组织与特点：

如第三版一样，在准备第四版时，我试图把常规论述以及各种证明保持在半定量的水平，而不关注具体的物理现象。为满足工程认证的要求给出了许多问题。正文中的一些章节有一些附加的主题，这些主题给出了更详细的论述，通常包括量子力学和更多的数学知识。书中尽可能避

免交叉引用以免过多的重复，也便于读者根据需要跳过一些章节。本书的这些灵活性使得课程教学更容易。

本书具有以下重要的特点。

- 对一些原理性的介绍，侧重其物理概念，而少做数学推理。量子力学是本课程的内容，但没有列出其深奥的数学形式。
- 书中有大量处理过的实例和解答过的思考题（共227道），其中大部分具有实际意义。学生们可通过实例进行学习。
- 即使简单的概念也有例子，以便学习。
- 大多数学生希望有清晰的图表来帮助他们可视化解释和理解概念。本书包括565幅插图，这些插图都是精心准备的，以反映概念并有助于文中的解释，也有许多实际设备和科学家与工程师的照片，以增强学习体验。
- 每章后面的思考题（共346题）是渐进式的，从容易的概念开始，最终引出更复杂的概念，难点问题用星号（*）标识，许多带图表的实际应用也包含在内。
- 每章后面有一个术语表，定义的概念和术语不仅用于正文中，而且应用于思考题中。
- 每章的结尾包含一节附加的主题以进一步介绍重要的概念，提出有趣的应用或证明一个定理。这些主题是为那些学有余力的学生准备的，可以作为两学期课程的一部分。
- 本书得到了麦格劳-希尔的教科书网站的支持，该网站包含了一些如问题解答之类的师生所需资源。
- 对于使用第四版作为教材的教师，本书还提供一套PowerPoint演示文稿，该演示文稿包含所有的彩色插图和附加的彩色照片。演示文稿中的基本概念和公式高亮显示。
- 针对所有教师提供有定期更新的在线扩展解决方案手册，该手册位于麦格劳-希尔网站本教材的位置，该解决方案手册不仅提供了方案的详细解释，而且有彩色图表，以及参考和有用的笔记（也有文中那些“为什么？”思考题的答案）。

致谢

感谢我过去和现在的研究生和博士后研究员，他们让我保持警觉，并阅读了本书的各个章节。很幸运有Charbel Tannous（布雷斯特大学）这样的同事和朋友，他提出了许多尖锐的批评和有帮助的建议，特别是在第8章。我多年的好友兼同事Robert Johanson（萨斯喀彻温大学），与我共同教授这门课程，也对第四版提供了一些建议。许多审稿人，在不同的时间，阅读手稿的各个部分，并提供广泛的意见。许多教师也把他们的建议写信给我，我采纳了多数有益的建议。没有一本教材是完美的，我相信下一版将会有更多的建议和修正。我个人要感谢他们宝贵的意见。

我想感谢麦格劳-希尔教育的Tina Bower（我现在的产品设计师）和Raghu Srinivasan（我以前的全球品牌经理），在本书的写作和制作过程中，他们不断地提供帮助，总是满怀热情、鼓励、宽容，（每次当我错过最后期限时）总能找到解决办法，这是我自1993年和MHE合作以来的真正

伟大的经历。感谢 Julie De Adder(照片事务),他勤奋地获得了在第四版中没有任何遗漏的第三方照片许可权。本书及其 PowerPoint 中的照片的版权费(大多数情况下很昂贵的)已经支付给版权所有者,没有版权所有者的许可,这些照片不得复制到其他出版物中。如果你是一名教师,喜欢这本书,并且想看第五版(也许是一个彩色版本),最好的意见和建议不是写信给我,而是直接写给麦格劳-希尔教育的电气工程编辑,地址是 501 Bell St., Dubuque, IA 52001, USA。

欢迎教师和学生把你们的意见发电子邮件给我,虽然我不能回复每一封邮件,但我确实读了所有的邮件并做了记录,正是这些意见促成了本版内容的重大修订。

Safa Kasap

Saskatoon, March, 2017

PREFACE

FOURTH EDITION

The textbook represents a first course in electronic materials and devices for undergraduate students. With the additional topics, the text can also be used in a graduate-level introductory course in electronic materials for electrical engineers and material scientists. The fourth edition is an extensively revised and extended version of the third edition based on reviewer comments and the developments in electronic and optoelectronic materials over the last ten years. The fourth edition has many new and expanded topics, new worked examples, new illustrations, and new homework problems. The majority of the illustrations have been greatly improved to make them clearer. A very large number of new homework problems have been added, and many more solved problems have been provided that put the concepts into applications. More than 50% of the illustrations have gone through some kind of revision to improve the clarity. Furthermore, more terms have been added under *Defining Terms,* which the students have found very useful. Bragg's diffraction law that is mentioned in several chapters is kept as Appendix A for those readers who are unfamiliar with it.

The fourth edition is one of the few books on the market that have 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 semiquantitative approach that both the students and instructors liked. The major revisions in scientific content can be summarized as follows:

Chapter 1 Thermal expansion; kinetic molecular theory; atomic diffusion; molecular collisions and vacuum deposition; particle flux density; line defects; planar defects; crystal surfaces; Grüneisen's rule.

Chapter 2 Temperature dependence of resistivity, strain gauges, Hall effect; ionic conduction; Einstein relation for drift mobility and diffusion; ac conductivity; resistivity of thin films; interconnects in microelectronics; electromigration.

Chapter 3 Electron as a wave; infinite potential well; confined electron in a finite potential energy well; stimulated emission and photon amplification; He–Ne laser, optical fiber amplification.

Chapter 4 Work function; electron photoemission; secondary emission; electron affinity and photomultiplication; Fermi–Dirac statistics; conduction in metals; thermoelectricity and Seebeck coefficient; thermocouples; phonon concentration changes with temperature.

Chapter 5 Degenerate semiconductors; direct and indirect recombination; E vs. k diagrams for direct and indirect bandgap semiconductors; Schottky junction and depletion layer; Seebeck effect in semiconductors and voltage drift.

Chapter 6 The *pn* junction; direct bandgap *pn* junction; depletion layer capacitance; linearly graded junction; hyperabrupt junctions; light emitting diodes (LEDs); quantum well high intensity LEDs; LED materials and structures; LED characteristics; LED spectrum; brightness

	and efficiency of LEDs; multijunction solar cells.
Chapter 7	Atomic polarizability; interfacial polarization; impact ionization in gases and breakdown; supercapacitors.
Chapter 8	anisotropic and giant magnetoresistance; magnetic recording materials; longitudinal and vertical magnetic recording; materials for magnetic storage; superconductivity.
Chapter 9	Refractive and group index of Si; dielectric mirrors; free carrier absorption; liquid crystal displays.

ORGANIZATION AND FEATURES

In preparing the fourth edition, as in previous edition, 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 so as 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 numerous worked examples or solved problems, most of which have a practical significance. Students learn by way of examples, however simple, and to that end a large number (227 in total) of solved 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 565 illustrations that have been professionally prepared to reflect the concepts and aid the explanations in the text. There are also numerous photographs of practical devices and scientists and engineers to enhance the learning experience.
- The end-of-chapter questions and problems (346 in total) 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 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 text is supported by McGraw-Hill's textbook website that contains resources, such as solved problems, for both students and instructors.
- The fourth edition is supported by an extensive PowerPoint presentation for instructors who have adopted the book for their course. The PowerPoint has all the illustrations in color, and includes additional color photos. The basic concepts and equations are also highlighted in additional slides.
- There is a regularly updated online extended *Solutions Manual* for all instructors; simply locate the McGraw-Hill website for this textbook. The Solutions Manual provides not only detailed explanations to the solutions, but also has color diagrams as well as

references and helpful notes for instructors. (It also has the answers to those "why?" questions in the text.)

ACKNOWLEDGMENTS

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 (Brest University) who, as usual, made many sharply critical but helpful comments, especially on Chapter 8. My best friend and colleague of many years Robert Johanson (University of Saskatchewan), with whom I share teaching this course, also provided a number of critical comments towards the fourth edition. 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 (and corrections) for the next edition. I'd like to personally thank them all for their invaluable critiques.

I'd like to thank Tina Bower, my present Product Developer, and Raghu Srinivasan, my former Global Brand Manager, at McGraw-Hill Education for their continued help throughout the writing and production of this edition. They were always enthusiastic, encouraging, forgiving (every time I missed a deadline) and always finding solutions. It has been a truly great experience working with MHE since 1993. I'm grateful to Julie De Adder (Photo Affairs) who most diligently obtained the permissions for the third-party photos in the fourth edition without missing any. The copyright fees (exuberant in many cases) have been duly paid and photos from this book or its PowerPoint should not be copied into other publications without contacting the original copyright holder. If you are an instructor and like the book, and would like to see a fifth edition, perhaps a color version, the best way to make your comments and suggestions heard is not to write to me but to write directly to the Electrical Engineering Editor, McGraw-Hill Education, 501 Bell St., Dubuque, IA 52001, USA. Both instructors and students are welcome to email me with their comments. While I cannot reply to each email, I do read all my emails and take note; it was those comments that led to a major content revision in this edition.

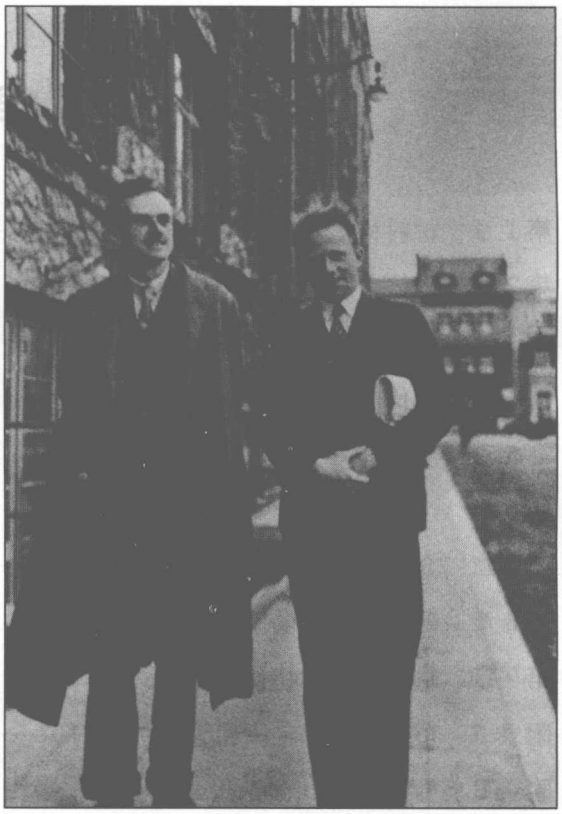
Safa Kasap
Saskatoon, March, 2017

"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

To Nicolette

简要目录



Paul Dirac (1902–1984) and Werner Heisenberg (1901–1976) walking outdoors in Cambridge circa 1930. They received the Nobel Prize in Physics in 1928 and 1932, respectively.

| Courtesy of AIP Emilio Segre Visual Archives, Physics Today Collection

Max Planck (1858–1947), a German theoretical physicist, was one of the originators of quantum theory, and won the Nobel Prize in Physics in 1918. His Nobel citation is *"in recognition of the services he rendered to the advancement of Physics by his discovery of energy quanta"*..

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