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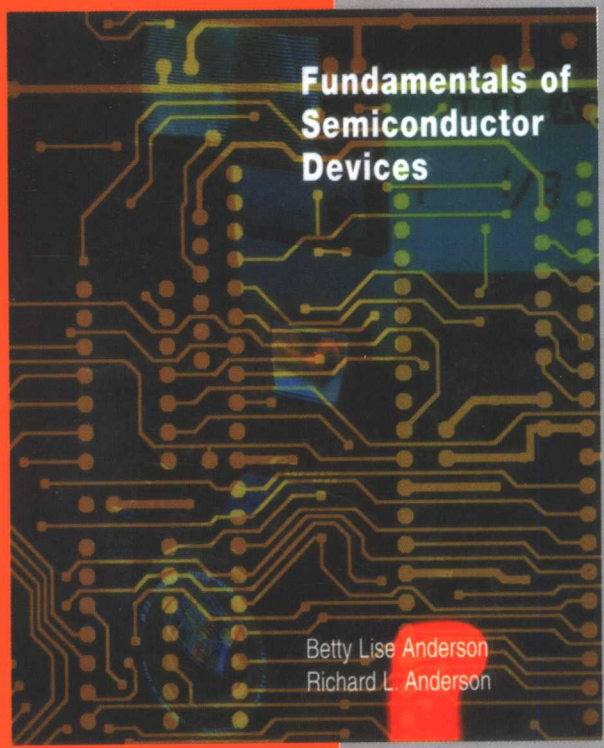
Betty Lise Anderson　Richard L. Anderson

半导体器件基础



Mc Graw Hill 清华大学出版社

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半导体器件基础

Fundamentals of Semiconductor Devices

Betty Lise Anderson
Richard L. Anderson

清华大学出版社
北京

Betty Lise Anderson, Richard L. Anderson
Fundamentals of Semiconductor Devices
EISBN: 0-07-236977-9

北京市版权局著作权合同登记号　图字：01-2006-0563

图书在版编目(CIP)数据

半导体器件基础 = Fundamentals of Semiconductor Devices /（美）安德森（Anderson, B. L.），（美）安德森（Anderson, R. L.）著. —影印本. —北京：清华大学出版社，2006.3
（国外大学优秀教材——微电子类系列）
ISBN 7-302-12450-7

Ⅰ. 半…　Ⅱ. ①安…　②安…　Ⅲ. 半导体器件－高等学校－教材－英文　Ⅳ. TN303

中国版本图书馆 CIP 数据核字（2006）第 006149 号

出 版 者：清华大学出版社　　地　　址：北京清华大学学研大厦
http://www.tup.com.cn　　邮　　编：100084
社总机：010-62770175　　客户服务：010-62776969
责任编辑：田志明
印 装 者：清华大学印刷厂
发 行 者：新华书店总店北京发行所
开　　本：185×230　印张：49.5
版　　次：2006 年 3 月第 1 版　2006 年 3 月第 1 次印刷
书　　号：ISBN 7-302-12450-7/TN • 305
印　　数：1~3000
定　　价：78.00 元

出 版 前 言

微电子技术是信息科学技术的核心技术之一，微电子产业是当代高新技术产业群的核心和维护国家主权、保障国家安全的战略性产业。我国在《信息产业“十五”计划纲要》中明确提出：坚持自主发展，增强创新能力和核心竞争力，掌握以集成电路和软件技术为重点的信息产业的核心技术，提高具有自主知识产权产品的比重。发展集成电路技术的关键之一是培养具有国际竞争力的专业人才。

微电子技术发展迅速，内容更新快，而我国微电子专业图书数量少，且内容和体系不能反映科技发展的水平，不能满足培养人才的需求，为此，我们系统挑选了一批国外经典教材和前沿著作，组织分批出版。图书选择的几个基本原则是：在本领域内广泛采用，有很大影响力；内容反映科技的最新发展，所述内容是本领域的研究热点；编写和体系与国内现有图书差别较大，能对我国微电子教育改革有所启示。本套丛书还侧重于微电子技术的实用性，选取了一批集成电路设计方面的工程技术用书，使读者能方便地应用于实践。本套丛书不仅能作为相关课程的教科书和教学参考书，也可作为工程技术人员的自学读物。

我们真诚地希望，这套丛书能对国内高校师生、工程技术人员以及科研人员的学习和工作有所帮助，对推动我国集成电路的发展有所促进。也衷心期望着广大读者对我们一如既往的关怀和支持，鼓励我们出版更多、更好的图书。

清华大学出版社

2003.9

Fundamentals of Semiconductor Devices

影 印 版 序

Anderson 的这本《半导体器件基础》(Fundamentals of Semiconductor Devices)是一本适合微电子专业、电气和电子工程专业本科高年级学生和研究生使用的教材。与国内外关于半导体器件的其他教科书相比，这本书和半导体物理衔接更紧密，介绍了最新的半导体器件方面的进展，从器件物理和工程应用的角度对现代半导体器件进行了全面而注重实际的讲述。本书特别强调对决定半导体材料和器件电学性质的物理过程的理解，以及器件的实际应用。读者阅读此书，不仅可以知道公式的推导过程，更能够理解公式的物理意义，了解公式的应用范围。此外，作者清晰和有条理的写作风格、核心内容的全面覆盖以及对当前研究热点问题的关注也是这本书的特点。

全书分为 5 部分共 11 章，全面介绍了半导体材料的基本性质和半导体器件的基本工作原理。在内容的选取方面，本书不仅包括了量子力学、半导体物理和半导体器件（包括二极管、场效应晶体管、双极晶体管和光电器件）的基本工作原理等内容，还写进了现代半导体器件的最新进展以及器件的实际应用。例如：对于显著影响现代小尺寸器件电学特性的二级效应进行了分析和公式推导，给出了描述小尺寸器件特性的最新的数学表达式；考虑到异质结在场效应器件、双极器件和光电器件中的应用日益增加，书中对半导体异质结作了着重介绍；由于半导体制造设备和工艺技术的提高，“能带工程”得以实现，随之带来了器件性能的提高，所以本书在重点介绍硅材料和硅器件的基础上，还介绍了化合物半导体器件、合金器件（如 SiGe，AlGaAs）和异质结器件；本书还利用电路分析程序 SPICE 对器件的 I-V 特性进行了模拟，对简单电路进行了稳态和瞬态分析。书中列出的参考文献大多选自最近几年业内最具影响力的刊物（如 IEEE Transaction on Electron Devices, Journal of Applied Physics）和会议（如 IEDM）。

在内容的组织方面，除了正文，书中每一章的后面都有总结、复习提纲和习题，还有参考书和参考文献。为了使全书的结构更加紧凑，作者把那些对于理解器件的基本工作原理不是必需的，但有助于加强这门课程的内容放在各部分后面的补充材料（Supplement）里，供读者根据需要选择阅读。书的最后还有若干附录，以方便读者查阅。

本书采用了有特色的插图、例题、习题等多种形式帮助读者加深对问题的理解。例如：用含有载流子浓度分布的能带图来定性解释器件的工作原理，通过大量的例题告诉读者如何解决一个实际问题。这些例题的结果也使读者对所

求的参数有了定量的概念。

本教材内容可以按照 2 学期 96 学时或 1 学期 64 学时的进度教授。附录中的内容可以结合教学情况安排学生课后阅读。

作者 Betty Lise Anderson 博士是美国俄亥俄州立大学工学院的电机工程教授，讲授多门本科生和研究生的课程。曾经在工业界（Tektrinix, Inc., Draper Labs, GTE Laboratories 等）工作过九年，有丰富的研究经验，是 IEEE、Optical Society of America 和 Society for Photo-Instrumentation Engineers 的会员，目前正在从事用于通信、雷达和信息处理的光子学器件研究。因此和实际器件应用结合紧密是本书的一大特色。

本书不仅是一本很好的教科书，同时也适合用作微电子和相关领域的工程技术人员的参考书。

田立林，邓宁

2005 年 12 月于清华园

PREFACE

This is a textbook on the operating principles of semiconductor devices. It is appropriate for undergraduate (junior or senior) or beginning graduate students in electrical engineering as well as students of computer engineering, physics, and materials science. It is also useful as a reference for practicing engineers and scientists who are involved with modern semiconductor devices.

Prerequisites are courses in chemistry and physics and in basic electric circuits, which are normally taken in the freshman and sophomore years.

This text is appropriate for a two-semester course on semiconductor devices. However, it can be used for a one-semester course by eliminating some of the more advanced material and assigning some of the sections as "read only." The authors have attempted to organize the material so that some of the detailed derivation sections can be skipped without affecting the comprehension of other sections. Some of these sections are marked with an asterisk.

This book is divided into five parts:

1. Materials
2. Diodes
3. Field-Effect Transistors
4. Bipolar Transistors
5. Optoelectronic Devices

The first four parts are followed by "Supplements" that, while not required for an understanding of the basic principles of device operation, contain related material that may be assigned at the discretion of the instructor. For example, the use of SPICE for device and circuit analysis is briefly discussed for diodes, field-effect transistors, and bipolar transistors. While SPICE is normally taught in courses on electric circuits, it is useful to know the origin of the various parameters used to characterize devices. This material on SPICE is relegated to supplements, since not all schools cover SPICE in courses on electron circuit analysis and such courses may be taught before, concurrently with, or after the course on semiconductor devices.

Part 1, "Materials," contains four chapters and two supplements. The first two chapters contain considerable review material from the prerequisite courses. This material is included since it is used extensively in later chapters to explain the principles of device operations. Depending on the detailed content of the prerequisite courses, much of these chapters can be relegated to reading assignments.

The level of quantum mechanics to be covered in a course like this varies widely. In this book some basic concepts are included in the main chapters of Part 1; those wishing to cover quantum mechanics in more detail will find more extensive material in Supplement A to Part 1.

The basic operating principles of large and small devices of a particular type (e.g., diodes, field-effect transistors, bipolar junction transistors, photodetectors) are the same. However, the relative importance of many of the parameters involved in device operation depends on the device dimensions. In this book the general behavior of devices of large dimensions is treated first. We treat, in each case, "prototype" devices (such as step junctions and long-channel field-effect transistors), from which the fundamental physics can be learned, and then develop more realistic models considering "second-order effects." These second-order effects can have significant influence on the electrical characteristics of modern, small-geometry devices. The instructor can go into as much depth as desired or as time permits.

Topics treated that are typically omitted in undergraduate texts are:

- The differences between the electron and hole effective masses as used in density-of-state calculations and conductivity calculations.
- The differences in electron and hole mobilities (and thus diffusion coefficients) if they are majority carriers or minority carriers.
- The effects of doping gradients in the base of bipolar junction transistors (and/or the composition in heterojunction BJTs) on the current gain and switching speed.
- Band-gap reduction in degenerate semiconductors. While this has little effect on the electrical characteristics of diodes or field-effect transistors, its effect in the emitter of bipolar junction transistors reduces the current gain by an order of magnitude.
- The velocity saturation effects due to the longitudinal field in the channel of modern field-effect transistors with submicrometer channel lengths reduces the current by an order of magnitude compared with that calculated if this effect is neglected.

While the major emphasis is on silicon and silicon devices, the operation of compound semiconductor devices, alloyed devices (e.g., SiGe, AlGaAs) and heterojunction devices (junctions between semiconductors of different composition) are also considered because of the increased performance that is possible with such *band-gap engineering*.

Many of the seminal publications on semiconductor devices cited in the references at the end of each chapter through 1990 are reprinted in *Semiconductor Devices: Pioneering Papers*, edited by S. M. Sze, World Scientific Publishing Co., Singapore, 1991.

Fabrication, while an important part of semiconductor engineering, is often skipped in the interest of time. This material is introduced in Appendix C, and can be assigned as read-only material if desired.

ACKNOWLEDGEMENTS

We would like to thank, first and foremost, our spouses Bill and Claire for their love, support, patience, and help. We are also grateful to the anonymous manuscript reviewers for their comments and suggestions, as well as the staff at McGraw-Hill for all their help. We thank our students for valuable feedback on the manuscript. Finally, we would like to thank all the companies and individuals that provided photographs and data for this book.

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