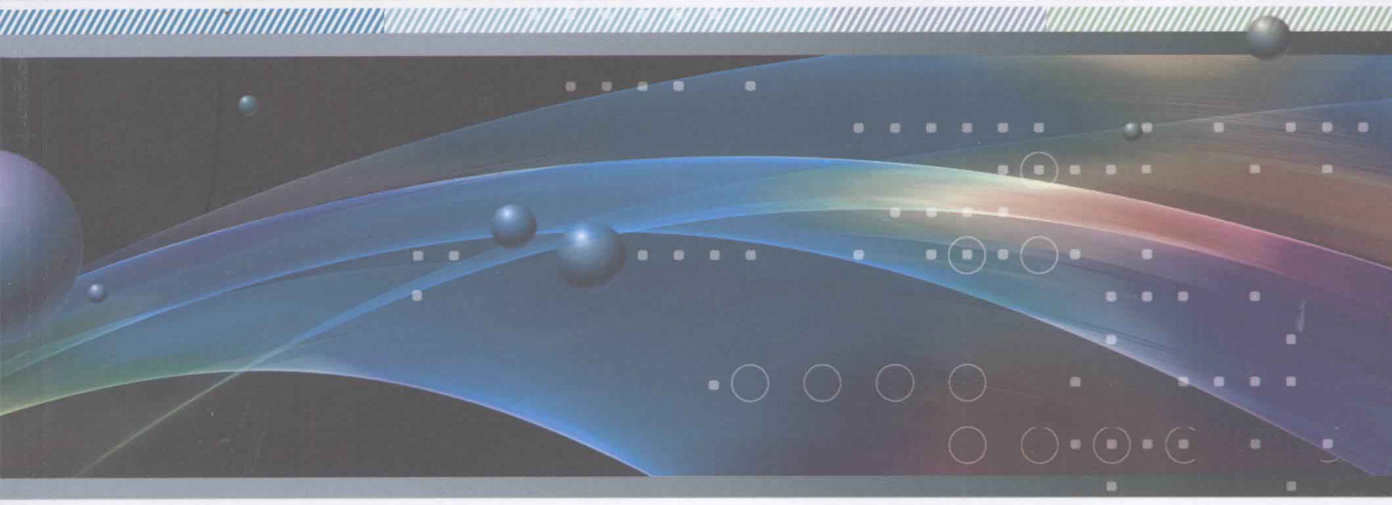
高等学校专业英语教材

微电子专业英语

English for Microelectronics

▶ 吕红亮　李　聪　等编著
▶ 贾新章　主审



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内 容 简 介

本书以英文的形式介绍了微电子学和集成电路设计的相关技术。全书共分四部分:第一部分为半导体物理基础知识,包括晶格结构、能带结构、载流子浓度和输运等;第二部分介绍半导体器件物理基础理论,包括pn结、肖特基二极管、异质结二极管、双极型晶体管和场效应晶体管;第三部分简要阐述半导体集成电路的设计过程和设计方法;第四部分介绍半导体集成电路的制造工艺。

本书可作为高等学校微电子学、集成电路设计及相关专业的“专业英语”课程的教材,也可作为从事微电子和集成电路相关科研和工程技术人员的参考书。

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前　　言

编写本书的目的是为高等学校学生提供一本学习和掌握微电子技术与集成电路设计专业英语方面的教材。本书是在为西安电子科技大学微电子学院讲授“专业英语”课程而编写的讲义多年试用的基础上，由多年从事教学和科研的一线教师编写而成的。

本书可作为高等学校微电子学、集成电路设计及其相关专业本科高年级学生和研究生的“专业英语”课程的教材，也可作为从事半导体技术科研和工程技术人员的参考书。对于目前从事研究、集成电路设计与制造工作，而大学阶段不是学习微电子专业的技术人员，掌握基本的微电子技术名称术语、阅读微电子方向的英文资料，也有很好的参考作用。

全书共25讲，主要内容包括半导体物理基础、半导体器件物理、集成电路设计和半导体工艺。课文选自国外微电子方面的经典教材，在安排上紧扣微电子专业中文主干教学课程，并适当有所扩展，重点突出、深入浅出、简明扼要，具有以下特点。

（1）在半导体物理基础内容部分（1～6讲），与学生先期掌握的相关半导体物理基础知识紧密联系，一脉相承，介绍了半导体材料与物理的基本概念、基本理论和分析方法；

（2）在半导体器件物理部分（7～15讲），包括pn结、肖特基接触、双极型晶体管、MOSFET场效应晶体管等器件物理内容，覆盖了半导体器件的范畴，与微电子专业的器件相关主干课程内容相呼应，也对半导体器件发展的前沿与未来有所展望。

（3）在集成电路与系统设计部分（16～20讲），介绍了模拟、数字及射频集成电路设计的基本理论和方法，并给出了验证方法。这些内容与集成电路设计的中文主干课程内容保持一致，对集成电路与系统的设计知识起到互补的作用。

（4）在半导体器件与电路工艺部分（21～25讲），介绍了典型的双极型和MOSFET器件与电路的工艺，并给出了测试表征方法及可靠性基本概念。这与微电子学专业本科教学中的工艺课程内容也是不谋而合的。

本书除了在内容安排上比较科学、合理外，在编写体例上也独具匠心。结合专业英语的学习，每讲单独配有生词、专业词汇（加黑斜体）；为了加深学生对语法的理解和应用，在每一讲正文之后配有重、难点语句的注释（Notes）；根据各讲内容，配有思考题，供读者练习。此外，为方便使用，本书的最后还给出了相应的中文译文供参考。为了拓展学生的专业阅读能力、提高翻译能力，每一讲的正文之后还提供了相关的英文阅读材料（Reading Material），教师还可凭学校开具的教学证明，向电子工业出版社（www.hxedu.com.cn）索取阅读材料的中文翻译。

本书由吕红亮、李聪等编著，贾新章主审。其中吕红亮教授负责第1～6讲、第9、10讲和第21～23讲，李聪副教授负责第13～20讲，贾新章教授负责第7、8、11、12、24、25讲。在本书的编写和试用过程中，西安电子科技大学微电子学院的张岩龙、白之东、陈楠、王禛、任小娇、翟羽佳、孙立锐、孙巍、杨雪、杨振、常安和宋东东等同学参与了部分内容的翻译工作，并对教材初稿提出了宝贵的意见和建议，在此一并表示深切的谢意。

由于作者水平有限，书中难免存在一些缺点和错漏，殷切希望广大读者批评指正。

编者

2012年6月

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参考译文

Session 1 Introduction to Semiconductor

It would not be an exaggeration to say that semiconductors have transformed human life over last 60 years. From computers to communications to internet and video games, semiconductor technology has expanded human experience in a way that is unique in history.[1]

In the late 1940s the invention of the transistor was the start of a rapid development towards ever faster and smaller electronic components. Complex systems are built with these components. Products founded on the basis of semiconductor devices such as computers (CPUs, memories), optical-storage media (CD, DVD), communication infrastructure (optical-fiber technology, mobile communication) and lighting (LEDs) are commonplace.[2] Now every human is left with about 100 million transistors (on average). Thus, fundamental research on semiconductors and semiconductor physics and its offspring in the form of devices has contributed largely to the development of modern civilization and culture.[3] For students, semiconductors offer a rich, diverse and exciting field with a great tradition and a bright future.[4]

1.1 What is Semiconductor

"The English physicist Cavendish has proved experimentally that water conducts electricity 400 million times worse than metals; nevertheless it is not a very bad conductor of electricity. Bodies which take the intermediate position between conductors and nonconductors are usually called SEMICONDUCTORS."[5]

Ivan Dvigubsky
"Fundamentals of Experimental Physics",
1826

There are several ways of defining a semiconductor. Historically, the term semiconductor has been used to denote materials having conductivities between those of metals and insulators. Today, there are two more types of conductors: superconductors and semimetals. Typical conductivities of superconductors, metals, semimetals, semiconductors and insulators are listed in Tab. 1. 1.

Tab. 1. 1 Typical conductivities of superconductors, metals, semimetals, semiconductors, and insulators at room temperature

Type of solid	$\sigma(\mathrm{S \cdot cm^{-1}})$	Example
Superconductor(low temperature)	$>10^{10}$	Pb, $YBa_2Cu_3O_7$
Metal	$10^5 \sim 10^{10}$	Au, Cu, Pb, Ag
Semimetal	$10^2 \sim 10^5$	graphite(C), HgTe
Semiconductor	$10^{-9} \sim 10^2$	Si, Ge, GaAs, InSb, ZnSe
Insulator	$<10^{-9}$	quartz(SiO_2), CaF_2

This definition is not complete. What really distinguishes metals from semiconductors is the temperature dependence of the conductivity. While metals (except for superconductors) and semimetals retain their metallic conductivity even at low temperatures, semiconductors are transformed into insulators at very low temperatures. In this sense semiconductors and insulators are actually one class of materials, which differs from metals and semimetals. This classification is directly connected to the existence of a gap between ***occupied*** and ***empty states*** , i. e. , an ***energy gap*** , in semiconductors and insulators.[6] In Tab. 1. 2 the classification according to the energy gap is summarized.

Tab. 1. 2 Classification of solids according to their energy gap and carrier density at room temperature

Type of solid	E_g(eV)	n(cm^{-3})
Metal	no energy gap	10^{22}
Semimetal	$E_g \leqslant 0$	$10^{17} \sim 10^{21}$
Semiconductor	$0 < E_g < 4$	$< 10^{17}$
Insulator	$E_g \geqslant 4$	$\ll 1$

The border line between semiconductors and insulators is rather arbitrary.[7] In particular, the value of the energy gap separating the semiconducting materials from insulating one is not well-defined. For example, diamond (C) was considered for a long time an insulator, but today it is possible to prepare it in such a way that it has semiconducting properties even at room temperature.[8] The important distinction between these two systems originates historically from their different conductivities at room temperature. However, an insulator at room temperature can become a semiconductor at higher temperatures.[9] Therefore, wide energy gap materials are currently under investigation for high temperature electronics.

Another possibility of defining a semiconductor, which is related to the energy gap, is through the free *carrier concentration* at room temperature. While metals and semimetals have a rather large carrier density, semiconductors exhibit a moderate carrier density at room temperature, while insulators have a negligible carrier density. Typical carrier densities for these different types of solids are compiled in Tab. 1. 2. The listed densities are ***intrinsic*** values, i. e. for pure materials. However, real semiconductors always contain some ***impurities*** , which can act as ***dopants*** leading to larger values for the carrier densities than the intrinsic ones.

In ***solid state electronic device*** and ***integrated circuit*** applications, a semiconductor is required which must be crystalline and must contain a carefully controlled concentration (or volume density) of specific impurities[10]. Semiconductor containing at least two specific impurities is needed for the following two fundamental device reasons:

(1) to provide a wide range of conductivity in one semiconductor by controlling its impurity concentration profile (density versus distance or space location) since each group-V impurity atom (P, As, Sb and Bi in Si) gives one negatively charged conduction electron, and each group- III impurity atom (B Al, Ga, In in Si) gives one positively charged conduction hole, and

(2) to provide two types of charge carriers (electrons and holes) to carry the electrical current or to provide two conductivity types, the *n-type* (conduction by electrons) and *p-type* (conduction by holes).[11]

The wide range of electrical conductivity makes it possible to control and modulate the magnitude of the conductivity by applying a time-dependent voltage, current, light, temperature, or mechanical force. In contrast, metal has so many conduction electrons that it is difficult to change its conductivity by modulating its electron concentration. In the other extreme, insulator has so few electrons that its conductivity cannot be modulated significantly at all.[12]

To summarize, a semiconductor is a solid with a finite energy gap below 4 eV, which results in a moderate conductivity and carrier density at room temperature. By doping the semiconductor in a controlled fashion, the conductivity and carrier density can be varied over several orders of magnitude. Due to the existence of the energy gap, semiconductors are transparent for energies below the gap, i. e., in the far- to near-infrared region depending on the value of the energy gap. [13] However, they strongly absorb light for energies above the energy gap, typically in the near-infrared to visible regime. In the absorptive region, the conductivity of semiconductors increases, when they are irradiated.

1.2 Classification of Semiconductor

There is a large variety of semiconductors available today, although for applications Si completely dominates the market. Nevertheless, other semiconductors can have quite different properties. For example, Si cannot be used for light emitting diodes or lasers, while semiconductors such as GaAs can.

Two general classifications of semiconductors are the ***elemental semiconductor*** materials, found in group Ⅳ of the periodic table, and the ***compound semiconductor*** materials, most of which are formed from special combinations of group Ⅲ and group Ⅴ elements. Tab. 1.3 shows a portion of the periodic table in which the more common semiconductors are found and Tab. 1.4 lists a few of the semiconductor materials.

The elemental materials, those that are composed of single species of atoms, are silicon and germanium. Silicon is by far the most common semiconductor used in integrated circuits and will be emphasized to a great extent.

Tab. 1.3 A portion of the periodic table

Ⅲ	Ⅳ	Ⅴ
B	C	
Al	Si	P
Ga	Ge	As
In		Sb

Tab. 1.4 A list of some semiconductor materials

Elemental semiconductors	
Si	Silicon
Ge	Germanium
Compound semiconductors	
AlP	Aluminum phosphide
AlAs	Aluminum arsenide
GaP	Gallium phosphide
GaAs	Gallium arsenide
InP	Indium phosphide

The two-element, or ***binary***, compounds such as gallium arsenide or gallium phosphide are formed by combining one group III and one group V element. Gallium arsenide is one of the more common of the compound semiconductors. Its good optical properties make it useful in optical devices. GaAs is also used in specialized applications in which, for example, high speed is required.

We can also form a three-element, of ***ternary***, compound semiconductor. An example is $Al_xGa_{1-x}As$, in which the subscript x indicates the fraction of the lower atomic number element component. More complex semiconductors can also be formed that provide flexibility when choosing material properties.

Reading Materials

Timetable

In this section early important milestones in semiconductor physics and technology are listed.

1821: T. J. Seebeck-discovery of semiconductor properties of PbS.

1833: M. Faraday-discovery of the temperature dependence of the conductivity of AgS (negative dR/dT).

1873: W. Smith-discovery of photoconductivity in selenium.

1874: F. Braun-discovery of rectification in metal sulfide semiconductor contacts, e. g. for PbS.[14] The current through a metal semiconductor contact is nonlinear (as compared to that through a metal, Fig. 1. 1), i. e. a deviation from ***Ohm's law***. Braun's structure is similar to a ***MSM diode***.

1876: W. G. Adams and R. E. Day-discovery of the ***photovoltaic effect*** in selenium.

1883: Ch. Fritts-first solar cell, based on an Au/selenium ***rectifier***. The efficiency was below 1%.

1907: H. J. Round-discovery of electroluminescence investigating blue light emission from SiC.

1911: The term 'Halbleiter' (semiconductor) is introduced for the first time by J. Königsberger and J. Weiss.

1925: J. E. Lilienfeld-proposal of the ***field-effect transistor*** (Fig. 1. 2) (Method and Apparatus for Controlling Electric Currents, US patent 1,745,175, 1930, filed 1926). J. E. Lilienfeld was also awarded patents for a ***depletion mode MOSFET*** (US patent 1,900,018, 1933) and ***current amplification*** with nppn and pnnp-transistors (US patent 1,877,140, 1932).

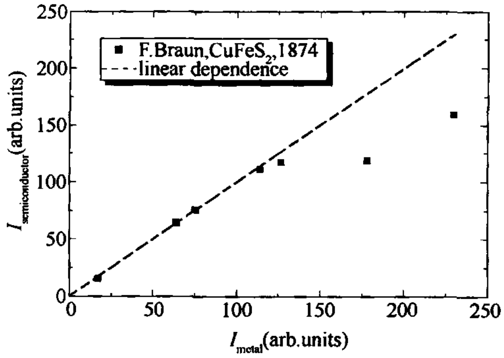


Fig. 1. 1 Current through a silver-CuFeS$_2$-silver structure as a function of the current through the metal only, 1874. Data points are for different applied voltages.

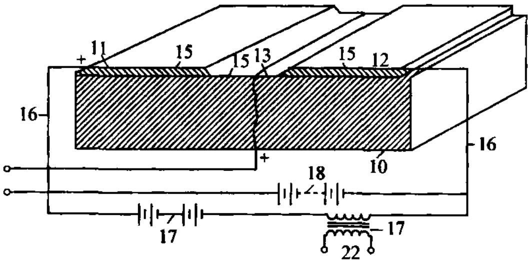


Fig. 1. 2 Sketch of a field-effect transistor, 1926.

1927: A. Schleede and Baggisch-impurities are of decisive importance for conductivity.

1931: R. de L. Kronig and W. G. Penney-properties of ***periodic potentials*** in solids.

A. H. Wilson-development of ***band-structure*** theory.

C. Zener-***Zener tunneling***.

1936: J. Frenkel-description of excitons.

1938: B. Davydov-theoretical prediction of rectification in Cu_2O.

W. Schottky-theory of the boundary layer in ***metal-semiconductor contacts***, being the basis for ***Schottky contacts*** and field-effect transistors (FETs).

N. F. Mott-***metal-semiconductor rectifier theory***.

R. Hilsch and R. W. Pohl-proposal of a three-electrode crystal (from NaCl).

1941: R. S. Ohl-Si rectifier with point contact (Fig. 1. 3) (US patent 2,402,661).

1942: K. Clusius, E. Holz and H. Welker-rectification in germanium (German patent DBP 966 387, 21g, 11/02).

1945: H. Welker-patents for JFET and MESFET (German patent DBP 980 084, 21g, 11/02).

1947: W. Shockley, J. Bardeen and W. Brattain fabricate the first transistor in the AT&T Bell Laboratories. Strictly speaking the structure was a point-contact transistor. A $50\mu m$ wide slit was cut with a razor blade into gold foil over a plastic (insulating) triangle and pressed with a spring on n-type germanium (Fig. 1.4). The one gold contact controls via the field effect (depletion of a surface layer) the current from Ge to the other gold contact. For the first time, amplification was observed.

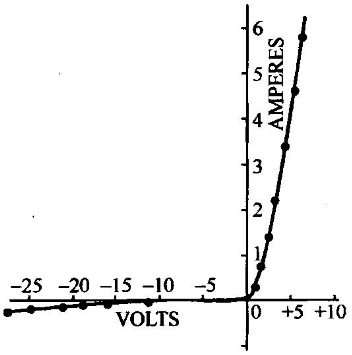


Fig. 1.3 Characteristics of a silicon rectifier, 1941.

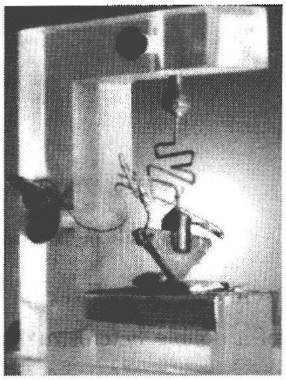


Fig. 1.4 The first transistor, 1947 (length of side of wedge: 32mm).

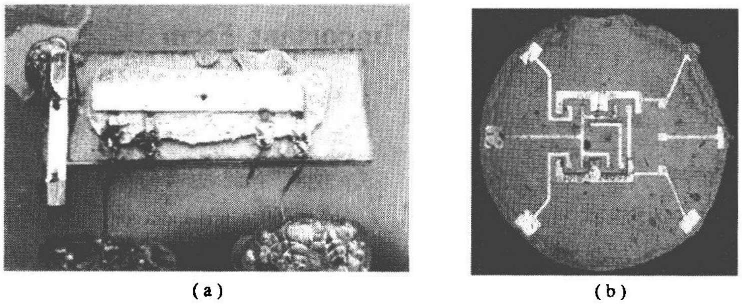
1952: H. Welker - fabrication of compound semiconductors (German patent DBP 976 791, 12c, 2)

W. Shockley-today's version of the (J)FET.

1953: G. C. Dacey and I. M. Ross-first realization of a JFET.

D. M. Chapin, C. S. Fuller and G. L. Pearson-invention of the silicon ***solar cell*** at Bell Laboratories. A single 2 cm^2 ***photovoltaic cell*** from Si, with about 6% efficiency generated 5mW of electrical power.[15] Previously existing solar cells based on selenium had very low efficiency (<0.5%).

1958: J. Kilby made the first integrated circuit at Texas Instruments. The simple oscillator consisted of one transistor, three resistors and a capacitor on an $11 \times 1.7mm^2$ Ge platelet [Fig. 1.5(a)]. J. Kilby filed in 1959 for US patent 3,138,743 for miniaturized electronic circuits. At practically the same time R. Noyce from Fairchild Semiconductors, the predecessor of INTEL, invented the integrated circuit on silicon using planar technology (US patent 2,981,877, 1959, for a silicon-based integrated circuit). Fig. 1.5(b) shows a ***flip-flop*** with four ***bipolar transistors*** and five resistors. Initially, the invention of the integrated circuit met scepticism because of concerns regarding yield and the achievable quality of the transistors and the other components (such as resistors and capacitors).



(a) (b)

Fig. 1.5 (a) The first integrated circuit, 1958 (germanium, $11 \times 1.7mm^2$); (b) The first planar integrated circuit, 1959 (silicon, diameter: 1.5mm).

1959: J. Hoerni and R. Noyce-first realization of a planar transistor (Fig. 1.6).

1960: D. Kahng and M. M. Atalla-first realization of a MOSFET.

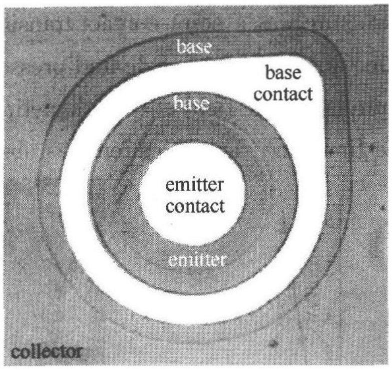


Fig. 1.6 Planar pnp silicon transistor, 1959. The contacts are Al surfaces (not bonded)

1962: The first semiconductor laser on GaAs basis at 77K at GE and at IBM.

1963: Proposal of a double heterostructure laser (DH laser) by Zh. I. Alferov and H. Kroemer.

1966: Zh. I. Alferov-report of the first DH laser on the basis of GaInP at 77K.

C. A. Mead-proposal of the MESFET ('Schottky Barrier Gate FET').

1967: W. W. Hooper and W. I. Lehrer-first realization of a MESFET.

1968: DH laser on the basis of GaAs/AlGaAs at room temperature by Zh. I. Alferov and I. Hayashi.

Words and Expressions

exaggeration	*n.* 夸张，夸大之词
infrastructure	*n.* 下部构造，基础下部组织，基础设施
diverse	*adj.* 不同的，变化多的
Si (silicon)	*n.* 硅，硅元素
GaAs (gallium arsenide)	*n.* 砷化镓
periodic table	元素周期表
Ge (germanium)	*n.* 锗，锗元素
binary	*adj.* 二进制的，二元的
GaP (gallium phosphide)	*n.* 磷化镓
ternary	*adj.* 三重的
subscript	*adj.* 写在下方的
selenium	*n.* 硒，硒元素
sulfide	*n.* 硫化物
electroluminescence	*n.* 场致发光，电致发光
apparatus	*n.* 设备、仪器
slit	*vt.* 切开，撕裂
razor	*n.* 剃刀
blade	*n.* 刀刃
foil	*n.* 箔，金属薄片
oscillator	*n.* 振荡器
scepticism	*n.* 怀疑主义

Glossary of Important Term

occupied states	被占据的状态
empty states	空态
energy gap	禁带、能隙、带隙
carrier concentration	载流子浓度
intrinsic carrier concentration	本征载流子浓度
impurity	杂质
dopant	掺杂剂
solid state electronic device	固态电子器件
integrated circuit	集成电路
n-type	n 型的（半导体）
p-type	p 型的（半导体）
elemental semiconductor	元素半导体
compound semiconductor	化合物半导体
binary compound	二元化合物半导体
ternary compound	三元化合物半导体
Ohm's law	欧姆定律