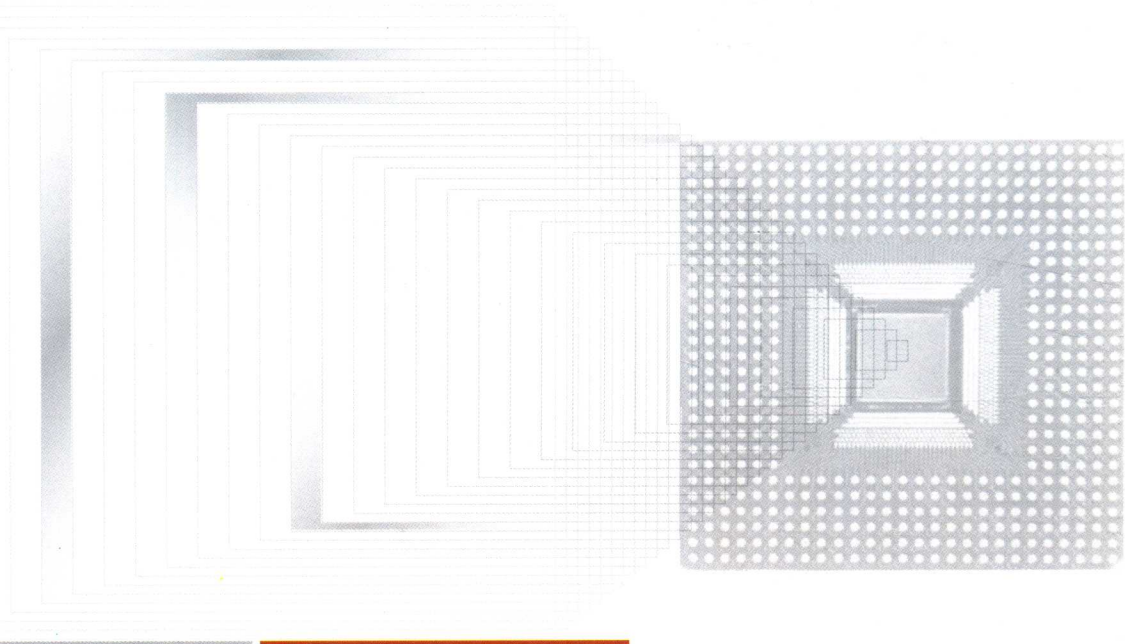




普通高等教育创新型人才培养规划教材



# Professional English for Microelectronics

## 微电子专业英语

Chen Xianping

陈显平

Zhang Ping    Yang Daoguo    Zhou Qiang    Meng Ruishen

张平    杨道国    周强    蒙瑞燊

配有课件



北京航空航天大学出版社  
BEIHANG UNIVERSITY PRESS



普通高等教育创新型人才培养规划教材

# Professional English for Microelectronics

## 微电子专业英语

Chen Xianping

陈显平

Zhang Ping    Yang Daoguo

张平            杨道国

Zhou Qiang    Meng Ruishen

周强            蒙瑞燊

北京航空航天大学出版社

## Summary

This book consists of 9 chapters which can be divided into four parts in content: Chapters 1~2 introduce the basic knowledge of semiconductor physics and semiconductor devices. Chapters 3~6 talk about the manufacturing technologies and processes. In addition, the integration processes for CMOS and MEMS are highlighted. Chapter 7 is to answer "what are the 'MtM' and 'MtM technologies'?" and to derive some indications on "how to develop a roadmap for the 'MtM'". Chapters 8~9 are on professional English writing skills.

This book can serve as the professional English textbook for the undergraduate and postgraduate students committed to the microelectronic or electronic field or other related majors. Moreover, it can be used as a reference for researchers and engineers.

### 图书在版编目(CIP)数据

微电子专业英语 = Professional English for  
Microelectronics / 陈显平主编. — 北京: 北京航空  
航天大学出版社, 2015. 4

ISBN 978-7-5124-1730-4

I. ①微… II. ①陈… III. ①微电子技术—英语  
IV. ①H31

中国版本图书馆 CIP 数据核字(2015)第 052257 号

版权所有, 侵权必究。

### Professional English for Microelectronics

微电子专业英语

Chen Xianping

陈显平

Zhang Ping Yang Daoguo

张平 杨道国

Zhou Qiang Meng Ruishen

周强 蒙瑞森

责任编辑 宋淑娟 周方彦

\*

北京航空航天大学出版社出版发行

北京市海淀区学院路 37 号(邮编 100191) <http://www.buaapress.com.cn>

发行部电话:(010)82317024 传真:(010)82328026

读者信箱: [goodtextbook@126.com](mailto:goodtextbook@126.com) 邮购电话:(010)82316936

北京兴华昌盛印刷有限公司印装 各地书店经销

\*

开本: 787×1 092 1/16 印张: 13.75 字数: 352 千字

2015 年 6 月第 1 版 2015 年 6 月第 1 次印刷 印数: 2 000 册

ISBN 978-7-5124-1730-4 定价: 28.00 元

## Preface

In the past few decades, the discipline of Microelectronic Science and Manufacturing Technology has played a fundamental role in shaping the semiconductor industry. Since the early 70's, Moore's Law has become the important engine to promote the sustainable development of the semiconductor industry. However, the industry is now faced with the increasing importance of a new trend, "More than Moore (MtM)". This great change results in an increased demand for the advanced knowledge of Microelectronic Science and Manufacturing Technology. Therefore, it is of great significance for both of students and researchers in this field to master the professional English. Meanwhile, master of these professional English skills, such as scientific paper or report writing skills, application ability of academic writing tools, searching ability of literatures and presentation skills, may play greatly positive effects on their careers. The purpose of this textbook is to help the people, who are dedicated to this field, to develop their professional English and professional English skills.

This book consists of 9 chapters which can be divided into four parts in content: Chapters 1~2 introduce the basic knowledge of semiconductor physics (semiconductor, charge carrier, band, and doping) and semiconductor devices (PN junction, Schottky and heterojunction diode, bipolar junction and MOS transistor). Chapters 3~6 talk about the manufacturing technologies and processes including photolithography, plasma/reactive ion etch, ion implantation, diffusion, oxidation, evaporation sputter, CVD, vapor phase epitaxial growth, etc. In addition, the integration processes for CMOS and MEMS are highlighted. Chapter 7 is to answer "what are the 'MtM' and 'MtM technologies'?" and to derive some indications on "how to develop a roadmap for the 'MtM'?". Chapters 8~9 are on professional English writing skills, principally introduce the structure of academic research papers, writing skills of each part, academical tool (EndNote), and information searching methods in databases like Web of Science and Google Scholar. Moreover, the content about how to prepare a good professional presentation is discussed.

What makes this book different? Firstly, the "overview", "key words", and "with questions to read" design at the beginning of each chapter can help the readers to quickly grasp the key knowledge points. Secondly, plenty of schematic diagrams makes the abstract and the difficult knowledge points are easier for understanding. Furthermore, the recommended books and the references given in each chapter can assist the readers in advanced study. What is more? The readers can find a comfortable read feeling from the book.



This book can serve as the professional English textbook for the undergraduate and postgraduate students committed to the microelectronic or electronic field or other related majors. Moreover, it can be used as a reference for researchers and engineers.

This book is issued under the general editorship of Dr. Chen Xian ping from Guilin University of Electronic Technology. Due to the limited level of the authors, any comment on this book is very welcome!

Xianping Chen

Sept. 16, 2014

# CONTENTS

---

## **PART I Basic knowledge of semiconductor physics and semiconductor devices**

<b>Chapter 1 Semiconductor</b> .....	2
1.1 Early history of semiconductors .....	3
1.2 Properties and materials of semiconductor .....	4
1.3 Band theory of solids .....	6
1.4 Charge carrier (electrons and holes) .....	7
1.4.1 The carrier concentration .....	7
1.4.2 Carrier generation and recombination .....	7
1.4.3 Drift and diffusion current .....	8
1.5 Electrical conduction .....	9
1.6 Doping of semiconductor .....	10
1.7 Type of semiconductor .....	10
1.7.1 N-type semiconductor .....	10
1.7.2 P-type semiconductor .....	11
1.8 Questions .....	12
1.9 References .....	12
<b>Chapter 2 Semiconductor devices</b> .....	13
2.1 PN junction .....	14
2.1.1 Basic structure of the PN junction .....	14
2.1.2 Unbiased PN junction .....	15
2.1.3 The current-voltage characteristic of PN junction .....	16
2.1.4 The breakdown of PN junction .....	16
2.1.5 Junction capacitance .....	17
2.1.6 The applications of PN junction .....	18
2.2 Schottky diode .....	19
2.2.1 The structure of Schottky diode .....	19
2.2.2 The principle of Schottky diode .....	19



2.2.3	The characteristics of Schottky diode	20
2.2.4	The applications of Schottky diode	20
2.3	Heterojunction diode	21
2.3.1	The concept of heterojunction	21
2.3.2	The characteristics of heterojunction diode	22
2.3.3	The application of heterojunction diode	23
2.4	Bipolar junction transistor(BJT)	24
2.4.1	The basic structure of BJT	24
2.4.2	The current transfer characteristic of transistor	25
2.4.3	Basic configurations and modes of operation	26
2.4.4	The application of transistor	27
2.5	The MOS transistor	28
2.5.1	The basic structure of MOS transistor	28
2.5.2	The form of inversion layer of MOSFET	29
2.5.3	The basic operation and DC characteristic of MOSFET	29
2.5.4	The types of MOSFET	31
2.5.5	The terminal capacitances of MOSFET	32
2.5.6	The advantage and application of MOSFET	33
2.6	Questions	34
2.7	References	35

## **PART II Manufacturing technologies and processes**

<b>Chapter 3</b>	<b>Doping technology and hot processing</b>	<b>38</b>
3.1	Doping	39
3.1.1	Diffusion	40
3.1.2	Ion implantation	41
3.1.3	Idealized ion implantation systems	42
3.1.4	Channeling effects	44
3.1.5	Shadowing effects	45
3.1.6	Ion implantation damage	46
3.2	Thermal oxidation	47
3.3	Rapid thermal processing(RTP)	50
3.3.1	RTP configuration and chamber design	52
3.3.2	Rapid thermal activation of impurities	54
3.3.3	Rapid thermal processing of dielectrics	55
3.4	Questions	57
3.5	References	57



<b>Chapter 4 Pattern transfer</b> .....	58
4.1 Photolithography .....	60
4.2 Photoresist (PR) .....	61
4.2.1 Composition of PR .....	61
4.2.2 The types of PR .....	61
4.2.3 The contrast curve of PR .....	61
4.3 The pre-exposure process .....	62
4.3.1 Priming .....	63
4.3.2 Photoresist coating .....	63
4.3.3 Soft bake .....	65
4.4 Alignment and exposure .....	66
4.4.1 Printer .....	66
4.4.2 Photomask fabrication .....	67
4.4.3 Alignment .....	69
4.4.4 Exposure .....	71
4.5 Postexposure .....	72
4.5.1 Postexposure bake .....	72
4.5.2 Development .....	73
4.5.3 Hard bake .....	75
4.5.4 Pattern inspection .....	76
4.6 Nonoptical lithographic techniques .....	77
4.6.1 X-ray lithography (XRL) .....	77
4.6.2 Projection X-ray lithography .....	78
4.6.3 Electron beam lithography (EBL) .....	79
4.6.4 Projection electron beam lithography (SCALPEL) .....	80
4.6.5 Ion beam lithography .....	81
4.6.6 EBL and XRL resist .....	82
4.7 Etch .....	82
4.7.1 Introduction .....	82
4.7.2 The characteristic of etch .....	83
4.7.3 Wet etch process .....	85
4.7.4 Chemical mechanical polishing (CMP) .....	86
4.7.5 Dry etching .....	87
4.8 High density plasma (HDP) etching .....	92
4.9 Liftoff .....	92
4.10 Questions .....	93
4.11 References .....	94





<b>Chapter 5 Thin film</b> .....	95
5.1 The introduction of thin film .....	96
5.1.1 Metallic thin films .....	98
5.1.2 Polysilicon .....	99
5.1.3 Oxide and nitride thin films .....	99
5.2 Physical vapor deposition .....	100
5.2.1 Evaporation .....	101
5.2.2 Sputter .....	103
5.3 Chemical vapor deposition .....	104
5.3.1 Chemical vapor deposition process description .....	104
5.3.2 Classification of CVD reactors .....	104
5.3.3 Atmospheric pressure CVD .....	106
5.3.4 Low pressure CVD in hot wall systems .....	107
5.3.5 Plasma-enhanced CVD .....	107
5.3.6 Step coverage .....	108
5.4 Epitaxial growth .....	110
5.4.1 Homoepitaxy .....	111
5.4.2 Vapor phase epitaxy .....	111
5.4.3 VPE hardware .....	112
5.4.4 Epitaxy process .....	114
5.4.5 Selective epitaxial growth .....	115
5.4.6 Heteroepitaxy .....	116
5.4.7 MBE .....	117
5.4.8 MOCVD .....	118
5.5 Questions .....	119
5.6 References .....	120
<b>Chapter 6 Process Integration</b> .....	121
6.1 CMOS .....	122
6.1.1 Introduction .....	122
6.1.2 The formation of the CMOS process .....	123
6.2 Microelectromechanical system (MEMS) .....	126
6.2.1 Introduction .....	126
6.2.2 The types and advantages of MEMS .....	128
6.2.3 The processes of MEMS .....	129
6.3 Nanoelectromechanical system (NEMS) .....	136
6.4 Questions .....	136
6.5 References .....	137



### PART III Frontiers of science and technology

<b>Chapter 7 More than Moore: creating high value micro/ nanoelectronics systems</b> .....	140
7.1 Introduction .....	140
7.2 Preconditions for an industry-wide technical roadmap .....	146
7.3 Lessons learned from "More Moore" .....	147
7.3.1 Metallic nanowires .....	147
7.3.2 Combining focus and variety .....	148
7.4 Proposed methodology for "More-than-Moore" .....	148
7.5 Applying the proposed methodology .....	150
7.5.1 Form societal needs to markets .....	150
7.5.2 MtM devices .....	152
7.6 Summary .....	157
7.7 References .....	157

### PART IV Development of professional English ability

<b>Chapter 8 How to write a scientific paper</b> .....	160
8.1 What is a scientific paper? .....	161
8.1.1 The structure of a paper .....	161
8.1.2 Steps for writing a paper .....	161
8.2 Searching information in databases .....	163
8.2.1 Web of Science .....	163
8.2.2 Google Scholar .....	170
8.3 How to prepare the Title .....	172
8.4 How to prepare the abstract .....	173
8.5 How to write the Introduction .....	175
8.6 How to write the Materials and Methods section .....	178
8.7 How to write the Results .....	181
8.8 How to write the Discussion .....	182
8.9 How to state the Acknowledgment .....	183
8.10 How to cite the Reference .....	185
8.11 Questions .....	191
8.12 References .....	191
<b>Chapter 9 How to make a successful presentation</b> .....	192
9.1 Attention curve .....	192
9.2 How to make a great PowerPoint presentation .....	194
9.2.1 Create your narrative .....	194
9.2.2 Utilize the format .....	197



9.3	How to prepare an oral presentation .....	206
9.3.1	Before your presentation .....	206
9.3.2	During your presentation .....	207
9.3.3	Warnings for oral presentation .....	209
9.4	Questions .....	209
9.5	References .....	210

## **PART I**

# **Basic knowledge of semiconductor physics and semiconductor devices**

# Chapter 1 Semiconductor

## OVERVIEW

This chapter provides an introduction to semiconductor. It begins with early history of semiconductors and lists the important events in the development of semiconductor process (section 1. 1). It then introduces the properties, materials of semiconductor and the common semiconductor materials. Meanwhile, the preparation methods of the semiconductor materials are illustrated (section 1. 3). Sections 1. 3~1. 5 aim to introduce the basic knowledge of semiconductor physics, including band theory of solids, charge carrier, electrical conduction, etc. The last two sections are dedicated to introduce the doping of semiconductor (acceptor and donor impurities) and types of semiconductor (N-type and P-type).

## Keywords

English	Chinese	English	Chinese
Impurity	杂质	Doping	掺杂
Rectification	整流	Dopant	掺杂剂
Seed crystal	籽晶	Crystal	晶体
Boule	晶锭	Orientation	晶向
Czochralski pulling technique(CZ)	丘克拉斯基提拉法	Bridgman directional solidification technique	布里奇曼下降法
Holder	固定器	Crucible	坩埚
Solidification	凝固	Wafer	晶圆片
Valence band	价带	Conduction band	导带
Excitation	激发	Fermi level	费米能级
Carrier	载流子	Hole	空穴
Transition	跃迁	Energy gap	能隙
Lattice	晶格	Majority carrier	多数载流子
Minority carrier	少数载流子	Mass action law	质量作用定律
Drift	漂移	Recombination	复合
Donor	施主	Diffusion	扩散
Intrinsic	本征的	Acceptor	受主
Covalent bond	共价键	Ion implantation	离子注入
Extrinsic	非本征的	Degenerate	简并



### With questions to read

1. What's semiconductor?
2. What's the properties of semiconductor?
3. What's charge carrier?
4. What's the doping of semiconductor?



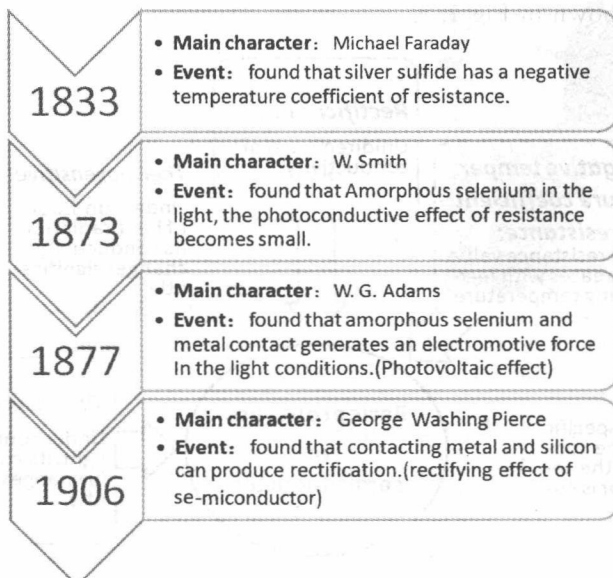
### Recommended Book:

*Electrical Engineering Materials*

Basak TK. Kent, GBR; New Academic Science, 2012.

## 1.1 Early history of semiconductors

Semiconductor research began quite inconspicuously about 180 years ago with some observations on the electrical properties of silver sulfide. The progress was very slow for the next 50 years and then, about 1885, a mild interest developed with the discovery of point contact rectifiers. These devices were used as detectors until being displaced by the vacuum tube around 1915. Development of selenium (Se) and cuprous oxide rectifiers in 1930 revived the interest and the publication of a good theory of semiconductors in 1931 added still more momentum. The next period of active interest came around the World War II when the cat-whisker diode was revived and developed into an excellent radar detector. ***The announcement of the transistor in 1948 gave this field of research such a boost that it has become a real giant in the last few years and semiconductor electronics now rate as a major field of endeavor.*** As shown in Fig 1.1 is early development of semiconductors.



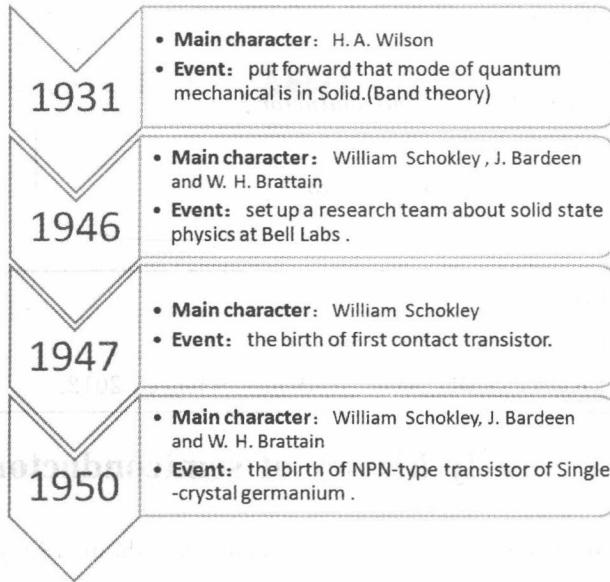


Fig 1.1 Early development of semiconductors

## 1.2 Properties and materials of semiconductor

In general, the main factors that determine basic properties of semiconductors are related to the chemical composition, the (crystallographic) structure, the presence of various defects and impurities (both intentional and unintentional), and the dimensions of the semiconductor or semiconductor structure. **Semiconductor has five basic properties: doping, negative temperature coefficient of resistance, rectification, thermosensitive and photosensitivity**, as shown in Fig 1. 2.

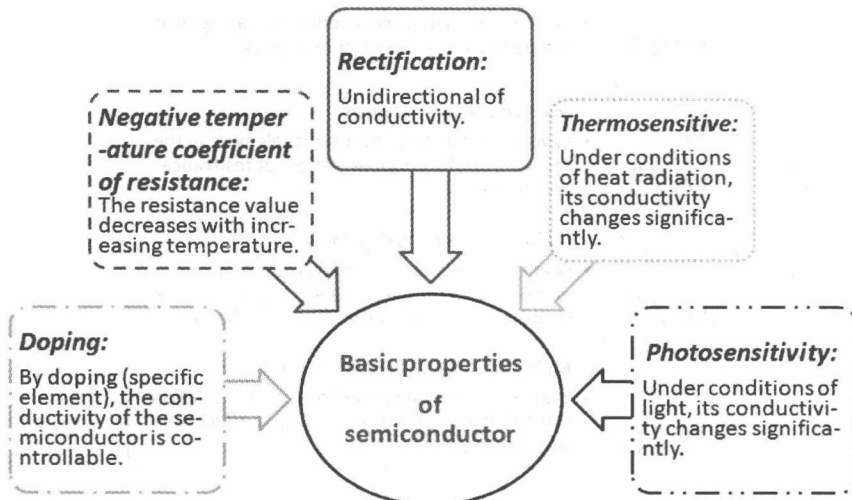


Fig 1.2 The basic properties of semiconductor

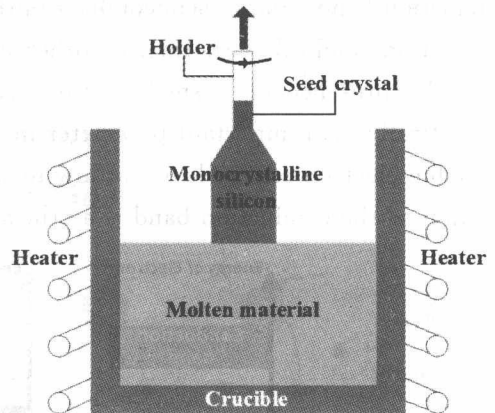


Semiconductor materials are insulators at absolute 0 °C that conduct electricity in a limited way at room temperature. The defining property of semiconductor material is that it can be doped with impurities that alter its electronic properties in a controllable way. Because of their application in devices like transistors (and therefore computers) and lasers, the search for new semiconductor materials and the improvement of existing materials is an important field of study in materials science. The list of common semiconductor materials is shown in Tab 1.1. The most commonly used semiconductor materials are crystalline inorganic solids. These materials can be classified according to the periodic table groups from which their constituent atoms come.

**Tab 1.1 Common semiconductor materials**

Element	Group IV	C, Si, Ge
Compound	Group IV	SiC, SiGe
	Group III~V	AlN, InAs, etc
Alloy	Ternary	AlGaAs, InGaAs, etc
	Quinternary	AlGaInp, InGaAsP, etc
Other	Organic semiconductors	Triphenylamine, Polyacetylene, etc
	Magnetic semiconductors	TiO <sub>2</sub> , CuO, GaN, etc

In general, the majority of semiconductors in various applications are prepared as bulk crystals or thin films. Bulk crystals are typically produced as single crystal (cylindrical) boules by employing, e. g. , the Czochralski pulling technique ( as shown in Fig 1. 3) or the Bridgman directional solidification technique ( as shown in Fig 1. 4). In the Czochralski growth method, a seed crystal (having the required crystal orientation), which is attached to a holder, is inserted into a crucible of the molten material and then is slowly pulled from the melt. This results in crystal growth by solidification of the molten material on the seed crystal surface with the crystal structure and orientation of the growing material being identical to those of the seed crystal. Thus, a cylindrical crystal bar (referred to as a boule) is produced. The crucible is placed inside the graphite, which is heated by employing radio frequency (RF) induction coils. In order to ensure the crystal growth uniformity, the growing crystal and the crucible are rotated at several revolutions per minute. The typical pulling speeds are on the order of several centimeters per hour. And the boule diameter can be controlled by changing the temperature, pulling speed and rotation rate. Then the boules are sliced into wafers (with



**Fig 1.3 The Czochralski growth technique**





thickness in the range between about 0.1 and 1 mm).

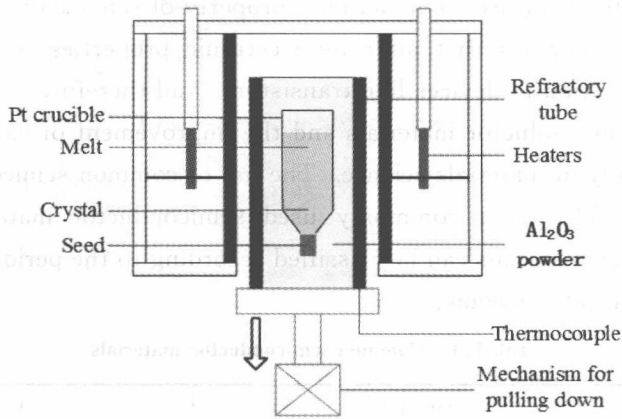
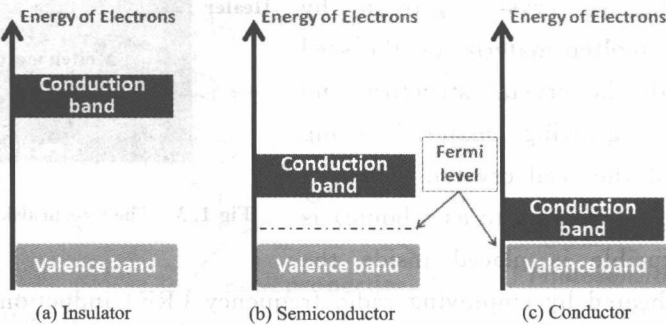


Fig 1.4 The Bridgman directional solidification technique

### 1.3 Band theory of solids

A useful way to visualize the differences between conductors, insulators and semiconductors is to plot the available energies for electrons in the materials, as shown in Fig 1.5. Instead of having discrete energies as in the case of free atoms, the available energy states form bands. *Crucial to the conduction process is whether or not there are electrons in the conduction band.* In insulators the electrons in the valence band are separated by a large gap from the conduction band, in conductors like metals the valence band overlaps the conduction band, and in semiconductors there is a small enough gap between the valence and conduction bands that thermal or other excitations can bridge the gap. With such a small gap, the presence of a small percentage of a doping material can increase conductivity dramatically. An important parameter in the band theory is the Fermi level, the top of the available electron energy levels at low temperatures. The position of the Fermi level with the relation to the conduction band is a crucial factor in determining electrical properties.



(a) The large energy gap between the valence and conduction bands in an insulator says that at ordinary temperatures, no electrons can reach the conduction band; (b) In semiconductors, the band gap is small enough that thermal energy can bridge the gap for a small fraction of the electrons; (c) In conductors, there is no band gap since the valence band overlaps the conduction band.

Fig 1.5 Energy Bands in solids