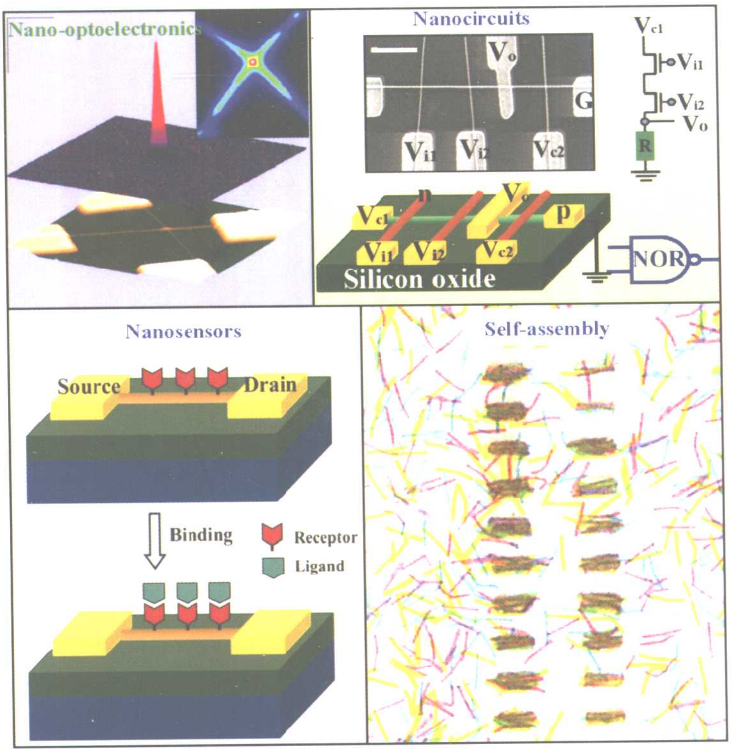
Nanowires and Nanobelts
—— Materials,Properties and Devices
Vol I: Metal and Semiconductor Nanowires

纳米线和纳米带——材料、性能和器件
卷Ⅰ：金属和半导体纳米线

Editor in Chief **Zhonglin Wang**



清华大学出版社

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清华大学出版社
北京

图书在版编目(CIP)数据

纳米线和纳米带——材料、性能和器件. 卷Ⅰ: 金属和半导体纳米线 = Nanowires and Nanobelts—Materials, Properties and Devices Vol Ⅰ: Metal and Semiconductor Nanowires/王中林主编. —北京:清华大学出版社,2004.3

ISBN 7-302-08214-6

Ⅰ. 纳… Ⅱ. 王… Ⅲ. ①金属材料: 纳米材料—英文②半导体材料: 纳米材料—英文 Ⅳ. TB383

中国版本图书馆 CIP 数据核字(2004)第 015433 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: 张兆琪
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: 153×235　印张: 29.75
版　次: 2004 年 3 月第 1 版　2004 年 3 月第 1 次印刷
书　号: ISBN 7-302-08214-6/TB · 70
印　数: 1～1000
定　价: 85.00 元(平)
100.00 元(精)

中国版序言

纳米线和纳米带是目前纳米科学和技术研究和发展中最为前沿的材料。这些一维纳米结构容纳了大量的材料,从金属、陶瓷、半导体到高分子，几乎所有的材料都可以合成出一维纳米结构。半导体一维纳米结构的发展是从1998年开始的，而功能性氧化物一维纳米结构的研究是从2001年发现纳米带状结构开始的，到目前，该方面的研究成果与日俱增，发展速度惊人。作为介绍纳米线和纳米带研究的首套专著，我于2003年编辑的英文版上下册《Nanowires and Nanotubes》汇集了目前世界范围内在该领域最前沿的成果。值得我们骄傲的是在该领域的许多优秀学者都是我们炎黄子孙。我起初开始编辑该书的动机就是让世人对华人学者在该领域的学术成就和创造性得到充分的承认和肯定。我感谢清华大学出版社在出版该书中的大力协助。并希望本书能对从事一维纳米结构研究方面的科技工作者和学生有所帮助。

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Preface

Nanowires, nanobelts, nanoribbons, nanorods ..., are a new class of quasi-one-dimensional materials that have been attracting a great research interest in the last few years. These non-carbon based materials have been demonstrated to exhibit superior electrical, optical, mechanical and thermal properties, and can be used as fundamental building blocks for nano-scale science and technology, ranging from chemical and biological sensors, field effect transistors to logic circuits. Nanocircuits built using semiconductor nanowires demonstrated were declared a "breakthrough in science" by *Science* magazine in 2001. *Nature* magazine recently published a report claiming that "Nanowires, nanorods, nanowhiskers, it does not matter what you call them, they are the hottest property in nanotechnology" (*Nature* **419** (2002) 553). There is no doubt that nanowire based quasi-one-dimensional materials will be the new focal point of research in the next decades.

Volume 1: Metal and Semiconductor Nanowires covers a wide range of materials systems, from noble metals (such as Au, Ag, Cu), single element semiconductors (such as Si and Ge), compound semiconductors (such as InP, CdS and GaAs as well as heterostructures), nitrides (such as GaN and Si_3N_4) to carbides (such as SiC). The objective of this volume is to cover the synthesis, properties and device applications of nanowires based on metal and semiconductor materials. The volume starts with a review on novel electronic and optical nanodevices, nanosensors and logic circuits that have been built using individual nanowires as building blocks. Then, the theoretical background for electrical properties and mechanical properties of nanowires is given. The molecular nanowires, their quantized conductance, and metallic nanowires synthesized by chemical technique will be introduced next. Finally, the volume covers the synthesis and properties of semiconductor and nitrides nanowires.

Volume 2: Nanowires and Nanobelts of Functional Materials covers a wide range of materials systems, from functional oxides (such as ZnO, SnO_2 and In_2O_3), structural ceramics (such as MgO, SiO_2 and Al_2O_3), composite materials (such as Si-Ge, SiC–SiO_2), to polymers. This volume focuses on the synthesis, properties and applications of nanowires and nanobelts based on functional materials. Novel devices and applications made from functional oxide nanowires and nanobelts will be presented first, showing their unique properties and applications. The majority of the text will be devoted to the synthesis and properties of nanowires and nanobelts of functional oxides. Finally, sulphide nanowires, composite nanowires and polymer nanowires will be covered.

The materials covered in both volumes are very diverse and rich in properties. Most of the nanowire and nanobelt structures are structurally controlled with respect to growth directions and side surfaces, resulting in controlled and tunable electrical and optical properties, which offer huge advantages for applications in nanotechnology.

The chapters were written by leading scientists worldwide whose groups have been the pioneers in the field and have done substantial work in their specific disciplines. Both volumes review the most up-to-date progress in nanowires and nanobelts. The books are intended as research books for advanced students and researchers with background in physics, chemistry, electrical engineering, mechanical engineering, chemical engineering, biology and bioengineering.

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Contents

III. Molecular Nanowires and Metallic Nanowires

Part I

Nanodevices and Nanocircuits Based on Nanowires

Chapter 1

Nanowires as Building Blocks for Nanoscale Science and Technology

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1. Introduction

1.1. Bottom-up paradigm for nanoscale science and technology

The field of nanotechnology represents an exciting and rapidly expanding research area that crosses the borders between the physical, life and engineering sciences [1, 2]. Much of the excitement in this area of research has arisen from recognition that new phenomena and unprecedented integration density are possible with nanometer scale structures. Correspondingly, these ideas have driven scientists to develop methods for making nanostructures. In general, there are two philosophically distinct approaches for creating small objects, which can be characterized as top-down and bottom-up. In the top-down approach, small features are patterned in bulk materials by a combination of lithography, etching and deposition to form functional devices. The top-down approach has been exceedingly successful in many venues with microelectronics being perhaps the best example today. While developments continue to push the resolution limits of the top-down approach, these improvements in resolution are associated with a near exponential increase in cost associated with each new level manufacturing facility. This economic limitation and other scientific issues with the top-down approach have motivated efforts worldwide to search for new strategies to meet the demand for nanoscale structures today and in the future [3–5].

The bottom-up approach, in which functional electronic structures are assembled from chemically synthesized, well-defined nanoscale building blocks, much like the way nature uses proteins and other macromolecules to construct complex biological systems, represents a powerful alternative approach to conventional top-down methods [4, 6, 7]. The bottom-up approach has the potential to go far beyond of the limits

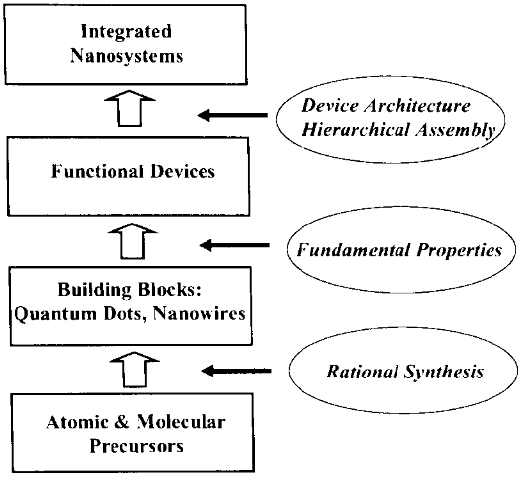

Fig. 1. Schematic outlining key challenges (open rectangular) and specific research areas (ellipses) required to enable the bottom-up approach to functional nanosystems.

of top-down technology by defining key nanometer scale metrics through synthesis and subsequent assembly—not by lithography.

To enable this bottom-up approach for nanotechnology requires a focus on three key areas, which are at the heart of devices and integration (Fig. 1). First, the bottom-up approach necessitates nanoscale building blocks with precisely controlled and tunable chemical composition, structure, size, and morphology since these characteristics determine their corresponding physical properties. To meet this goal requires developing methods that enable rational design and predictable synthesis of building blocks. Second, it is critical to develop and explore the limits of functional devices based on these building blocks. Nanoscale structures may behave in ways similar to current electronic and optoelectronic devices, although it is also expected that new and potentially revolutionary concepts will emerge from these building blocks, for example, due to quantum properties. Third and central to the bottom-up concept, will be the development of architectures that enable high-density integration with predictable function, and the development of hierarchical assembly methods that can organize building blocks into these architectures.

Addressing and overcoming the hurdles in these three major areas of the bottom-up approach could revolutionize a wide range of technologies of today. Moreover, it is very likely that the bottom-up approach will enable entirely new device concepts and functional systems, and thereby create technologies that we have not yet imagined. For example, it is possible to combine seamlessly chemically distinct nanoscale building blocks, which could not be integrated together in top-down processing, and thus obtain unique function and/or combinations of function in an integrated nanosystem. Small and highly perfect building blocks may also lead to quantum electronic devices that enable quantum computing in architectures that have common features to digital systems.