纳米科学与技术

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北京

图：01-2014-4054

图书在版编目（CIP）数据

微纳机器人操控系统及其应用：英文/（日）福田敏男主编.—影印本.—北京：科学出版社，2014.7
（纳米科学与技术）
书名原文：Micro-nanorobotic manipulation systems and their applications
ISBN 978-7-03-041434-2
Ⅰ.①微… Ⅱ.①福… Ⅲ.①纳米材料-机器人-操作系统-研究-英文
Ⅳ.①TP242
中国版本图书馆 CIP 数据核字（2014）第 165901 号

丛书策划：杨 震 / 责任编辑：王化冰
责任印制：钱玉芬 / 封面设计：陈 敬

科学出版社出版
北京东黄城根北街 16 号
邮政编码：100717
http://www.sciencep.com
中国科学院印刷厂印制
科学出版社发行 各地新华书店经销
*
2014 年 7 月第 一 版 开本：720×1000 1/16
2014 年 7 月第一次印刷 印张：22
字数：441 000
定价：158.00 元
（如有印装质量问题，我社负责调换）

《纳米科学与技术》丛书序

在新兴前沿领域的快速发展过程中，及时整理、归纳、出版前沿科学的系统性专著，一直是发达国家在国家层面上推动科学与技术发展的重要手段，是一个国家保持科学技术的领先权和引领作用的重要策略之一。

科学技术的发展和应用，离不开知识的传播：我们从事科学研究，得到了“数据”（论文），这只是“信息”。将相关的大量信息进行整理、分析，使之形成体系并付诸实践，才变成“知识”。信息和知识如果不能交流，就没有用处，所以需要“传播”（出版），这样才能被更多的人“应用”，被更有效地应用，被更准确地应用，知识才能产生更大的社会效益，国家才能在越来越高的水平上发展。所以，数据→信息→知识→传播→应用→效益→发展，这是科学技术推动社会发展的基本流程。其中，知识的传播，无疑具有桥梁的作用。

整个 20 世纪，我国在及时地编辑、归纳、出版各个领域的科学技术前沿的系列专著方面，已经大大地落后于科技发达国家，其中的原因有许多，我认为更主要的是缘于科学文化的习惯不同：中国科学家不习惯去花时间整理和梳理自己所从事的研究领域的知识，将其变成具有系统性的知识结构。所以，很多学科领域的第一本原创性“教科书”，大都来自欧美国家。当然，真正优秀的著作不仅需要花费时间和精力，更重要的是要有自己的学术思想以及对这个学科领域充分把握和高度概括的学术能力。

纳米科技已经成为 21 世纪前沿科学技术的代表领域之一，其对经济和社会发展所产生的潜在影响，已经成为全球关注的焦点。国际纯粹与应用化学联合会（IUPAC）会刊在 2006 年 12 月评论：“现在的发达国家如果不发展纳米科技，今后必将沦为第三世界发展中国家。”因此，世界各国，尤其是科技强国，都将发展纳米科技作为国家战略。

兴起于 20 世纪后期的纳米科技，给我国提供了与科技发达国家同步发展的良好机遇。目前，各国政府都在加大力度出版纳米科技领域的教材、专著以及科普读物。在我国，纳米科技领域尚没有一套能够系统、科学地展现纳米科学技术各个方面前沿进展的系统性专著。因此，国家纳米科学中心与科学出版社共同发起并组织出版《纳米科学与技术》，力求体现本领域出版读物的科学性、准确性和系统性，全面科学地阐述纳米科学技术前沿、基础和应用。本套丛书的出版以高质量、科学性、准确性、系统性、实用性为目标，将涵盖纳米科学技术的所有领域，全面介绍国内外纳米科学技术发展的前沿知识；并长期组织专家撰写、编辑出版下去，为我国

表面分子组装》，是对相关工作的归纳总结。

多年来，本人的研究组开展固体表面分子组装研究，不但发展表面组装方法，还一直试图找到分子结构-固体种类-组装结构间的关系，也不放过发现组装结构中重要现象的机会并阐明原因，意欲探索表面分子组装规律，利用分子组装实现表面功能化。书中在介绍固体表面的结构特点和 STM 技术等表面分子组装基础知识之后，顺序介绍了简单烷烃/烷烃衍生物分子的组装结构、复杂配合物分子的组装、主客体组装以及功能化组装等，随后介绍结构转化研究、手性结构研究、电化学环境下的组装和相变化，最后是可能的表面功能化，内容安排尽量承上启下、先易后难且逻辑相关。

借此机会，我要感谢我研究组的研究生们，他们倾心科学，随我多年耕耘于固体表面分子组装研究领域，努力工作，夜以继日，他们终学有所成，也留下了丰富的科研结果。陈婷、严会娟、殷雅侠、陈庆、张旭、崔博、管翠中、郑轻娜等还参与了书稿内容整理、文献核对等工作。感谢科学出版社杨震、张淑晓和刘冉诸位编辑的悉心指导，感谢国家出版基金对本书的出版资助。感谢国家自然科学基金委员会、科技部和中国科学院，多年来，我的研究工作一直得到他们的支持，本书中的研究内容大多是在他们的资助下获得的科研成果。

还要感谢我的妻子姜红，她不厌其烦地整理我写下的零散片段，帮助打字输入我的手写书稿，保存相关资料，愿本书的出版给她带去一份快乐！

分子组装研究历史已久，内容丰富，且时有挑战课题出现，也有轰动性和里程碑性成果问世。限于水平和时间，书中不妥之处在所难免，恳请各位前辈和同行不吝赐教。出版本书意在抛砖引玉，以诱导、鼓励更多的科技工作者，尤其是青年科技工作者加入该研究行列，发展新技术，探索规律，攻坚克难；同时，发现新问题和解决新问题，推动分子组装研究不断发展。

万立骏

Preface

Micro-Nano robotics and automation technologies have rapidly been grown by associated with growth of Micro and Nanotechnologies. This book represents a summary of principals in micro-nano scale engineering and the current state of art of related technologies.

Currently, in our daily life, "Microtechnology" is commonly used and embedded for various devices and systems, such as automobiles, computer peripheries, printers, cameras, amusements, robotics, automation, environmental monitoring, energy resource, and biological-medical treatments to increase their performance, accuracy and to improve energy consumption, cost performance and so on. "Micromechatronics" came up as the one of the important technology by miniaturizing the elemental devices on sensors, actuators, and computers in micro-scale. Recently, "Nanotechnology" comes up to have an important role in the industrial applications as an advanced field of mechatronics named as "Nanomechatronics".

On the other hand, a manipulation technology enables us to control the small objects locally or individually. For industrial applications, automation technology is important to improve efficiency for the creation of large-scale structural devices from small scale based on the micro-nano manipulation techniques.

In this book, we summarize some major techniques which are related with micro-nano robotics and micro-nano manipulation technologies, such especially micro-nano fabrication, micro-nano assembly, micro-nano control techniques, micro-nano materials, micro-nano evaluation techniques and so on. It is Various devices are investigated based on the micro-nano mechatronics technologies to realize high-efficiency, high-integration, high-functionality, low-energy consumption, low-cost, miniature, saving material usage and so on.

One of the application field is the "system cell engineering" which is a new a new academic field aiming at synthetic understanding of cell function using engineering (Fig. 1). The manipulation techniques are one of the key factors to analyze/control to reveal the functions of biological cell system. Recently, the research direction is moving to synthesis from analysis of biological cells based on the system cell engineering.

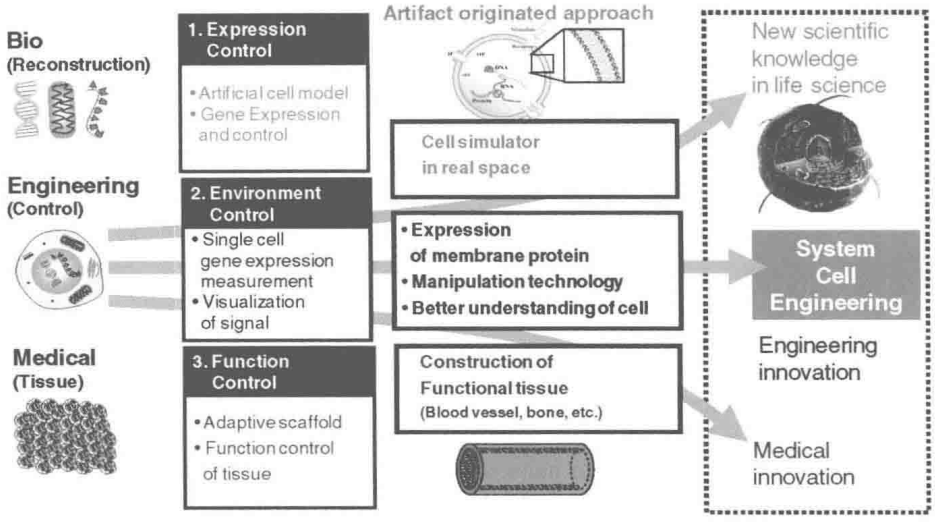

Fig. 1 System Cell Engineering by Micro-Nano Robotics and Automation

Through the micro-nano robotics and automation technologies, various research fields are investigated to achieve the next-generation science and engineering applications as shown in Fig. 2. In robotics field, the soft and wet robotics is key technology to mimic the biological system or combine the biological and artificial systems for example. The importance of micro-nano manipulation is that this technology is placed on the borderline between bottom-up and top-down fabrication and assembly technologies as shown in Fig. 3.

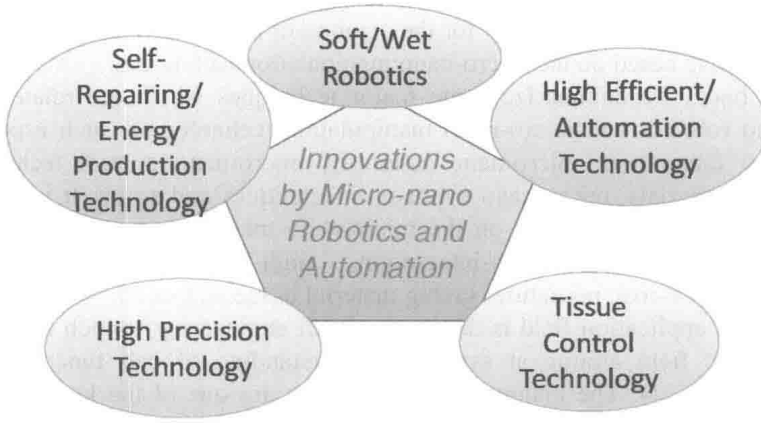

Fig. 2 Innovations by micro-nano robotics and automation

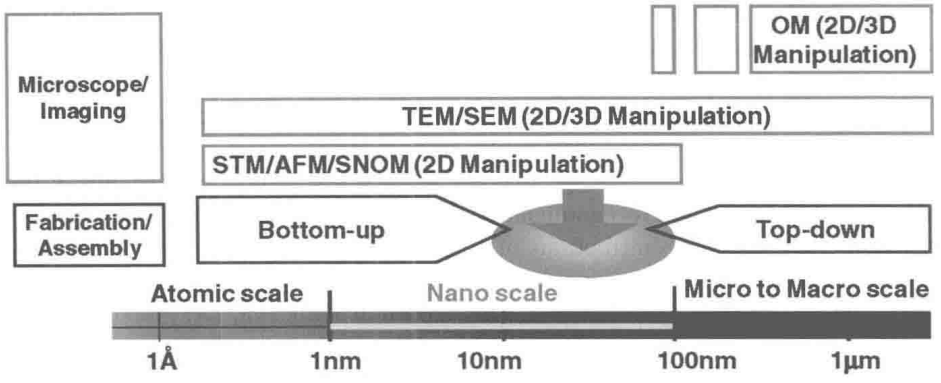

Fig. 3 Micro-Nanomanipulation based on imaging technologies for micro-nano fabrication and micro-nano assembly

In this book, we introduce the advanced technology from the basics and applications aspects of micro-nanorobotic manipulation system with their applications and related technologies. This book is organized as follows:

In Chapter 1, we introduce the overview and introduction of micro-nanorobotics and manipulation technology with some historical background and current achievements with related works.

In Chapter 2, the physics in micro-nano fields is explained in the scaling effects, mechanics, electronics, fluidics, surface interaction, and optical physics.

In Chapter 3, the related technologies in micro-nano scale are explained about the material and science, microscopes, fabrication technology, sensing and actuation, control techniques, and assembly techniques.

In Chapter 4, bio-manipulation system under optical microscope is explained under optical microscope by on-chip micro-fluidics devices, micro-tools, and laser micro-nano manipulations.

In Chapter 5, a rotational speed control of single bacterial flagellar motor is introduces as one of the applications of micromanipulation system under optical microscope.

In Chapter 6, nanomanipulation system is introduced under electron microscopes, with configurations of nano-robotics and manipulation system, hybrid nanorobotic manipulation system inside FE-SEM/TEM, nanorobotic manipulation system inside E-SEM, nano-tool exchanger system under hybrid microscope, automation of nanorobotic manipulation system inside E-SEM.

In Chapter 7, measurement, manipulation, and assembly of carbon nanotubes are explained under FE-SEM and TEM based on the nanomanipulation system. The techniques of picking up, cutting, peeling, bending, fixing of carbon nanotubes are presented as one of the applications of nanomanipulation system under optical microscope.

In Chapter 8, measurement and analysis of biological cells are explained under E-SEM for single cell nano-surgery system, especially mechanical property

characterization, adhesion force measurement, electrical measurement, and cutting of single cell using various nano-tools such as nanoprobe/ nanofork/ nanoputter/ nanopicker/ dual nanoprobe with automation system.

In Chapter 9, we give a description of summary and applications of micro-nanorobotic manipulation and their applications finally.

We would like to acknowledge that the leading researchers extensively in the world to evolve the micro-nanomanipulation and related fields. We especially thanks to the excellent contributions of all students graduated from our laboratory to achieve fabulous results, especially for Dr. Lixin Dong, Dr. Ahmad Ridzuan, Dr. Liu Pou, Dr. Hisataka Maruyama, Dr. Akihiko Ichikawa, Dr. Akiko Kawaji, Dr. Kousuke Nogawa, and Dr. Yajing Shen. We express our sincere appreciation for the publication of this book supported by Nagoya University, the 21st COE program "Micro- and Nano- Mechatronics for Information-Based Society", and the global COE program "COE for Education and Research of Micro-Nano Mechatronics". This book would not have been possible without these generous supports.

Nagoya, January 2012

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Fumihito Arai
Masahiro Nakajima

Contents

Chapter 1
Introduction of Micro-Nanorobotic Manipulation Systems

Technology has been moving toward greater control of the structure of matter for millennia. Progress in science and technology over the past decades suggest the feasibility of achieving thorough control of the molecular structure of matter. The possibility to control the structure of matter atom by atom was first discussed by Richard Feynman in 1959 seriously, which is now labeled "nanotechnology". Feynman wrote in a prophetic article on miniaturization [1]: "I am not afraid to consider the final question as to whether, ultimately—in the great future—we can arrange the atoms the way we want: the very atoms, all the way down!" He asserted that "At the atomic level, we have new kinds of forces and new kinds of possibilities, new kinds of effects. The problems of manufacture and reproduction of materials will be quite different. The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom."

The "great future" of Feynman began to be realized in the 1980s. Some of the capabilities he dreamed of have been demonstrated, while others are being developed. Although we are still far from having a general and reliable nanotechnology, progress in the last two decades or so has been tremendous. As the twenty-first century unfolds, the impact of nanotechnology on the health, wealth, and security of the world's people is expected to be at least as significant as the combined influences in the 20th century of antibiotics, the integrated circuit, and human-made polymers. Neal Lane stated in 1998, "If I were asked for an area of science and engineering that will most likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering."[2] The great scientific and technological opportunities provided by or potentially would be provided by nanotechnology have stimulated extensive exploring of nano world ever since and initiated exciting worldwide competition especially after the publication of "National Nanotechnology Initiative" by U.S.A. government in 2000 [3].

Nanomanipulation is one of the most significant enabling technologies for nanotechnology, and might finally be the core-most part of nanotechnology if Drexler's machine-phase nanosystems based on self- replicative molecular assembler via mechanosynthesis would be realized [4].

Since the discovery, carbon nanotubes (CNTs) [5] have been extensively explored both theoretically and experimentally. The exceptional properties and

broad potential applications of nanotubes make them become the most important and promising materials for nanotechnology discovered by so far.

This dissertation focuses on nanorobotic manipulations of carbon nanotubes. The main purpose is to provide an effective tool for the experimental exploration of this typical mesoscopic material, and for the construction of nanosystems with this exceptional nano building block. The long-term oriented aim is to develop a universal nanosystem builder with the abilities of instrumentation, fabrication, and assembly.

1.1 Background of Micro-Nanorobotic Manipulation Systems

Technological advancement on the top-down fabrication process, or micro machining, provides nanometer structures. On the other hand, the bottom-up fabrication process, or chemical synthesis such as self-assembly or super-molecule techniques, also provides nanometer structures. In fact, both approaches reach nanometer scale with the limitations of physical/chemical aspects at present. The "Nanotechnology" has an important role on the combinations of the top-down and bottom-up approaches. It is considered that the wide scale controlled devices from atomic scale to meter scale will be realized in the near future [6] (Figure 1. 1).

The essence of nanotechnology is the ability to work at these levels to generate larger structures with fundamentally new molecular organization. Such materials and systems can be rationally designed to exhibit novel and significantly improved physical, chemical, and biological properties, phenomena, and processes because of their size. When characteristic structural features are intermediate in extent between isolated atoms and bulk materials, the objects often display physical attributes substantially different from those displayed by either atoms or bulk materials.

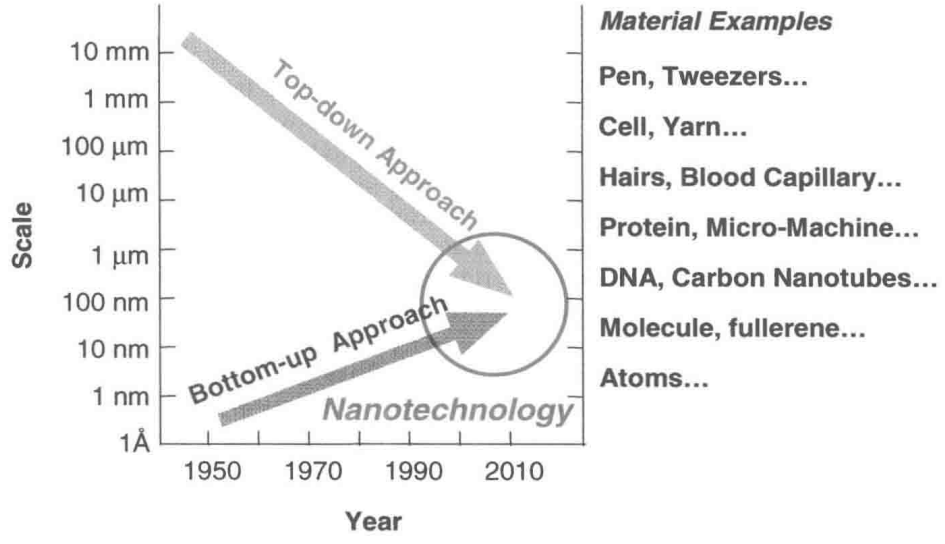

Fig. 1.1 Schematic diagram of "Nanotechnology" ("Top-Down" and "Bottom-Up")