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*Editors*

# 微系统和纳米技术

# Microsystems and Nanotechnology

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With 586 figures, 148 of them in color

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## 内 容 简 介

微系统和纳米技术是微米纳米技术的两个重要组成部分，既有区别又有联系。微系统和纳米技术是一个新兴的、多学科交叉的科技领域。本书由40多位国内外著名专家、学者分章撰写，分为微系统和纳米科学技术基础、微系统技术、纳米技术、应用问题、发展和展望等五个部分，共23章。全书统一规划、各章独立、由浅入深、图文并茂。本书内容的一个重要特点是反映了美、德、英、日和我国权威专家在微系统和纳米技术领域的研究成果，同时也阐述了他们数十年来的研究经验和对该领域的展望，从科技发展的规律说明微米纳米科技发展的阶段性和成熟周期。

本书可以作为相关领域本科生、研究生和教师的教学参考书，并可供相关的科技人员参考。



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# From the Editors

It's a great honor for me to cooperate with Prof. Zhonglin Wang, Regents' Professor at the Georgia Institute of Technology and member of the European Academy of Sciences, and Prof. Liwei Lin, Co-Director of the Berkeley Sensor and Actuator Center, University of California at Berkeley, in the compilation and publication of this book. In this multi-disciplinary field characterized by rapid development it is extremely hard, if not impossible, for an individual to complete a comprehensive and accurate monograph, given that hundreds or even thousands of relevant papers might be submitted at some international conference. Hence, our decision to collaboration on this book.

Early in 2003, after much discussion, we decided on an outline of chapters divided into four sections: Fundamentals of MEMS and Nanotechnology, MEMS, Nanotechnology, and Applications of MEMS and Nanotechnology. Subsequently, more than forty experts and scholars were invited to cooperate in developing the book with us, among whom are Prof. Li Zhijian, Tsinghua University, Academician of the Chinese Academy of Sciences (CAS); Prof. Hou Jianguo, the University of Science & Technology of China, Academician of CAS; Prof. Chih-Ming Ho, University of California, Los Angeles, Member of the National Academy of Engineering; Prof. Yu-Chong Tai, California Institute of Technology; and Prof. Roland Zengerle from Germany, etc. Some authorities and experts of world-renown in this field, such as Academician Richard S. Muller from the US, Prof. Wolfgang Menz from Germany, Prof. Masayoshi Esashi from Japan as well as Dr. Geoff Beardmore from the UK, described their own experience of decades of research as well as their perspectives for the future of MEMS. Their views together with the achievements from the scientific and technological frontier constitute the substance of this book.

We are indebted to these more than 40 experts for their contributions to the book, and sincerely hope that this work will stimulate discussions and communications well into the future. We are also grateful to those experts and scholars who intended to contribute but failed to meet the deadline of publication of this book, and hope that their writing will enrich this book when reprinted afterwards.

MEMS and nanotechnology, or micro-nanotechnology, is a rising field of science and technology. Many scientific workers have been inspired by the prophecy of several Nobel Prize winners, such as Richard Feynman's famous speech at the California Institute of Technology (CIT) in 1959: "There's Plenty of Room at the Bottom." Many scientists and scientific and technological research contributors have incisively explained the problem using the inductive method. For instance, some people regard Biological Engineering, Information Technology and Micro-Nano technology as the three most important fields of the scientific frontier in the 21st century, whose combination and development will cause a new technological revolution. Some others think that science and technology develops towards two opposite extremes, with space technology at the large scale and micro-nanotechnology at the small scale. Because of its growing importance-nanotechnology has received strong support, but also sometimes too urgent demands, from governments as well as corporations. Confident in their knowledge of this field, the authors of this book have explained the stages of micro-nanotechnology development according to the developmental laws of science and technology, and thus responsibly promoting its development.

Many people have made contributions to the development of micro-nanotechnology, which is, according to the developmental laws of science, a long-term development. With the strong support of governments, micro-nanotechnology has been promoted, relevant mechanisms innovated, strong research teams formed, and a high level development platform for micro-nanotechnology is under construction. Surely, micro-nanotechnology has bright prospects. Therefore, the knowledge, experience and achievements of the authors of this book are well worth studying. My gratitude also goes to Miss Lijuan Wang and Miss Xiaoli Liu, who have helped sort through the contents, chapters, and pictures of the book.

During publication, we express our thanks to the support of National Science and Technology Publication Fund and the State Key Laboratory.

**Zhaoying Zhou, Tsinghua University, Beijing, China**

Over the past few decades, microelectronics has been developing following Moore's Law, which predicts that the number of electronic components that can be integrated onto a silicon chip doubles every 18 months. One of the important characteristics of microelectronic technology is the size of components, such as the 90-nanometer technology and the 60-nanometer technology. However, when its size shrinks to under 50 nanometers, the performance of the component may depend strongly on the device size due to surface and interface effects, thus electronics inevitably enters into the Nano Era.

Nanotechnology is the integration and application of functional systems at the atomic or molecular scale; the integration and application of nanometer-scale functional structures involves at least the one spacial dimension. It is one of the

two technologies characterized by length scale, and its future development and application are mainly in the following three fields: the integration with micro-systems, life sciences and medical technology based on nano-processing technologies, and the application of nanomaterials in energy and environmental technologies. This book is about the integration of nanotechnology with micro-systems.

The dominant material of the first Industrial Revolution is steel. Silicon is the material for the second industrial revolution. When nanotechnology was first introduced, it was believed that it might replace micron technology and that silicon might be replaced by other materials. However, no matter on how small a scale the technology is based, even pico-scale technology, it has to be connected with the real world. In other words, a technology with practical importance should be the one based on multi-scales from nanometer to micrometer, and then to the millimeter, etc. Therefore, the application of nanotechnology in microsystems involves the integration of new nanomaterials, components and nanotechnology. This book is to present this subject as well as its prospects to the reader.

It's my honor to have collaborated with Prof. Zhou Zhaoying and Prof. Liwei Lin in editing this book. First I would extend my thanks to all the authors of this book, and I am indebted to Prof. Zhou for his leading role and elaborate planning of the editing. I hope that this book will be instrumental in promoting the integration of micro-nanotechnology world-wide.

**Zhonglin Wang, Georgia Institute of Technology, Atlanta, USA**

Over the past few decades, microelectronic technology has been applied in the manufacturing of micro-components of movable mechanical parts, which in turn has prompted research into micro/nanometer sensors and actuators. Multi-functionality of semiconductor materials and microminiaturization of VLSI technology provide the new system with higher performance and more reasonable performance/price ratio compared with traditional components. Key components and general components of such a system mainly depend on the following two factors. Firstly, various micro-manufacturing processes, such as surface processing, volume processing and hot embossing plastic mold and injection mold design, and manufacture of innovative concepts will be updated. As devices get better, multifunctional systems become cheaper. Secondly, new and existing basic sciences and technical basis prompt new discoveries. Earlier research results, such as micro-pressure sensors, acceleration sensors and gyroscopes, have become mature products.

With the research on MEMS and nanotechnology, significant capital and vast resources have been invested in many fields. Traditionally, the United States, Japan and Europe have been the three typical powerhouses, predominating in the research activities around the world. Research on MEMS and nanotechnology fields are no exception. However recent research in many fields in Asia have

made rapid progress, which has brought remarkable progress on MEMS and nanotechnology. Korea, for instance, hosted the 13th International Conference of Solid-State Sensors, Actuators and Microsystems in 2005, which is the largest in the field of MEMS, held on a two-year rotational schedule in the United States, Europe and Asia. China is the host of this conference in 2011, which clearly demonstrates that the research carried out in China are well accepted worldwide. Now in China more than 100 universities and over 500 academic researchers are engaged in research on MEMS, and it is estimated that China will invest more than 150 million dollars in this field in the next five years. All these facts indicate that China will become one of the powerhouses for micro-nanotechnology activity in the near future.

With its emphasis on MEMS and nanotechnology, this book has integrated knowledge of mechanics, material science, manufacturing and products. I owe my gratitude to these senior researchers in MEMS and nanotechnology who have contributed different chapters to the book. Here I would like to extend my special thanks to Prof. Chih-Ming Ho from UCLA, who contributed Mechanics in MEMS, and Prof. Yu-Chong Tai from Caltech, author of the Introduction to MEMS; Prof. Ming Wu from UC Berkeley, who wrote Optical MEMS, and Prof. Yu-Chuan Su from Hsinchu Tsing Hua University, who provided MEMS Design; Prof. Mu Chiao from British Columbia University and Prof. Yu-Ting Cheng from Tainan Chiao-Tung University, co-authors of MEMS Packaging; Dr. Weijie Ynn, author of Microaccelerometer, and Dr. Scott Chang, who contributed MEMS in Automobiles. Obviously, this book could not have been produced without their contributions. And it might be important to know that these experts and other researchers look forward to improvements in quality and increases in quantity of research in the near future, just as progress has been made in recent years. We hope that this book will be among the works in the field of MEMS and nanotechnology that will fuel the research on MEMS and nanotechnology.

**Liwei Lin, University of California, Berkeley, USA**

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## Nanotechnology