

Preface

Since the invention of the first transistor in 1949, there has been a continuous avalanche of growth and development in the science and technology of semiconductor materials and device applications. The thrust of the advances has involved the steady lowering of the dimensions in which confined charge carriers can move, ultimately reaching the nano-world. The term *nano*, a prefix derived from the Greek word for dwarf (νᾶνος), is used to indicate sizes in the range of about one to a hundred nanometers, or 10^{-9} to 10^{-7} m. By 1970, systems thin enough to be regarded as two dimensional (for example, semiconductor inversion layers, etc.) were being analyzed, and these were rapidly followed by one-dimensional quantum wires and zero-dimensional quantum dots. In conjunction with technology, “nano” was used for the first time by Norio Taniguchi in 1974. As he predicted, nanoscience and nanotechnology emerged strongly as research fields in the 1980s: the scanning tunneling microscope was invented by Gerd Binnig and Heinrich Rohrer in 1981 and the first carbon nanomaterial, C60 buckyballs, was discovered by Richard Smalley, Robert Curl, Harold Kroto, James Heath, and Sean O'Brien in 1985, followed by carbon nanotubes in 1991 found by Sumio Iijima. With the discovery of graphene in 2004 by Andre Geim and Kostya Novoselov, the world was presented with a two-dimensional device-friendly carbon material just a single atom thick, and this was followed by similar materials including silicene, germanene, stanene, metal dichalcogenides, and topological insulators.

The requisite support basis of nanotechnology, laden with promising developments tantamount to a new industrial revolution, has been a qualitatively reliable understanding of the underlying physics of semiconducting materials accompanied by quantitatively precise predictions of device performance. This has led to new concepts and techniques of semiconductor growth that have facilitated the emergence of a generation of advanced devices with more complex functionality and much higher densities for electronic, computational, and optical applications. Advances in the growth of semiconductor thin films of differing structural, electronic, and optical properties, and the diminution of layer thickness approaching atomic dimensions, have provided new opportunities for fundamental scientific

studies and technological applications of semiconductors in new devices. Moreover, contemporary fabrication technologies have made it possible to reduce device dimensions to the point where size effects must be properly described quantum mechanically in order to reliably predict the potential and performance of low-dimensional semiconductor systems for electronic and optical applications.

Advances in single and multilayer thin film growth technologies (e.g., molecular beam epitaxy (MBE), and metal organic chemical vapor deposition (MOCVD)), have made it possible to produce semiconductor heterostructure thin films based on group IV–IV, III–V and II–VI semiconductors in binary/binary and alloy/binary forms, having engineered electronic and optical properties that are not available in nature. One can now control the alloy composition and doping in ternary, quaternary and pentanary IV–IV, III–V and II–VI semiconductors over atomic distances. These growth techniques, taken jointly with advanced characterization and fabrication techniques have facilitated the development of a number of high performance devices for fast signal processing, as well as some novel structures that are of fundamental interest to solid state scientists and device engineers. The epitaxial layers are so thin that quantum mechanical effects govern the operation of such heterostructure devices. These materials, coupled with device design, have enabled the emergence of novel devices in which signals propagate faster, promising to replace silicon with compound semiconductors having much higher electron mobility and velocity. Low-dimensional bipolar and unipolar compound semiconductor devices (e.g., GaAs based heterojunction bipolar transistors (HBTs), modulation doped field effect transistors (MODFETs), light-emitting diodes, lasers, etc.) operate much faster than conventional homostructure silicon devices (e.g., bipolar junction transistors (BJTs), metal oxide field effect transistors (MOSFETs), etc.), leading to a many-thousand-fold increase in speed, which is of crucial importance to the electronic and optical communication and computer industries.

This book describes recent scientific and technological developments of low-dimensional nanomaterials in over 20 review and research articles. It begins with metrology and methodology, with simple carbon nanomaterials (nanotubes and graphene), and with metal oxide thin films, nanowires, and quantum dots. More complex issues associated with the environment and with energy production and storage follow. Furthermore, important achievements in materials pertinent to the fields of biology and medicine are also reviewed, exhibiting an outstanding confluence of basic physical science and vital human endeavor. Finally, after a brief excursion into device physics, new and interesting developments relating to quantum computing are addressed.

In recognition of the vastly important role that low-dimensional semiconductor systems are now playing in all fields of science and technology and the even greater role that they are poised to play in high-functionality devices for electronic, computational, optical, biological, and medical systems that will support much greater economic development and human well-being, much of this book has been prepared in a way that permits access to the various subjects by readers who are not

experts at the outset. This is to say that this book will be helpful to graduate students and young scientists who want to develop an understanding of the subject; and it will also be informative to seasoned scientists and engineers who are knowledgeable in some areas and wish to broaden their perspective in others in this multidisciplinary field.

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