Наноструктуры и нанотехнологии в электронике

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Generalizations of the research results, published in the monographs "Introduction in Nanoelectroniccs technologies" and "Nanoelectronics materials and devices"

В статье описаны структура и содержание монографий о нанотехнологиях и наноразмерных материалах. Анализируются этапы становления и некоторые перспективные аспекты развития нанотехнологии, в частности, наноэлектроники, получения наноматериалов и микросистемных устройств. В монографиях описаны перспективы и дан обоснованный прогноз развития некоторых нанотехнологий в следующем десятилетии, приведены некоторые основные направления применения нанотехнологии. Это в первую очередь в полупроводниковой наноэлектронике: новые виды памяти (электронные и магнитные), сенсоры на углеродных нанотрубках, комплектующие для атомных микроскопов, новые виды дисплеев (типа OLED - органичные светодиодные дисплеи, дисплеи с полевой эмиссией из квантовых точек, с углеродными трубками и др.). Развитие нанотехнологии и микросистемных применений является важной задачей для развития информационных технологий и современной электроники.

The structure and the contents of the monographies on nanotechnologies and nanoscaled materials is described. Stages of formation and some perspective aspects of nanotechnology development, in particular, nanoelectronics, nanomaterials and microsystem devices are analyzed. Perspectives and grounded forecast of development of some nanotechnologies for the next ten years are described in the monographs. Some key domains of nanotechnologies usage are given. First of all in semiconductor nanoelectronics: new types of memory (electronic and magnetic), sensors based on carbon tubes, parts for atomic microscopes, new types of displays (OLED – organic light-emitting diode, displays with pole emission from quantum points, with carbon tubes etc.). Development of nanotechnology and microsystems application is the important problem for development of information technologies and advanced electronics.

Introduction

The level of nanotechnology utilization in this century will determine the status of every developed nation in the world. The first nanotechnology products have market share in billions of U.S. dollars, and the forecast for the coming years is for much more than now. But segments of the market will take only those that are investing today in the education, relevant scientific research and community knowledge. This understanding is reached at a state level in Ukraine. Thus, in the joint order (Act, document) of Ministry of Education and Science and the National Academy of Sciences from November 26, 2009 № 1066 / 609 "On approval of the main scientific directions and problems the most important fundamental research in 2009-2013 in Ukraine", articles 1.4.5. "Nanophysics and nanotechnology, and 1.6.5. "Nanostructured (nanodisperse, nanocrystalline) materials are written in separate paragraphs.

Nanoelectronics is the leading direction(trend) in the development of nanotechnology and nanomaterials. Progress in microelectronics and the expansion of technologies used in it are the foundation on which to build modern nanotechnology. The synthesis of advanced information technology and nanoelectronics hardware will be the future basis and focus of the development of communication systems, information processing and storage devices, units for control and automation of production processes, intelligent applications in various spheres of human activity.

What do we mean by the term nanotechnology? First of all, this is methods for creation the functional elements, devices and the systems, collected from these elements, as well as fabrication of nanomaterials, with dimensions of individual structural components, comparable with molecular dimensions, namely from parts of one nanometers to few tens or in some cases up to one-two hundred of nanometers.

Nanoscience and Nanotechnology related to research in order to obtain an understanding of the

processes occurring in nanodevices through visualization and measurements, using computer modeling of the processes, utilizing control and directed manipulation of individual atoms or molecules and, as a result, the introduction in the production of nanoscale components , devices and systems.

Due to relevance of involved problems authors wanted the book to compile and review their research results with some of the most promising developments of leading experts in the field of nanoelectronics. In the book are described the state-of-the-arts of the research and application of the most advanced, in our view, materials and technologies in nanoelectronics. Data and analysis given in this monograph will be useful to both specialists and students of universities and doctorants in research institutions, with activity of the areas of studying related to nano- and microelectronics.

Content and some of the features of the described materials

The materials in two monographs[1,2] are organized totally in 5 parts, including introductions and 19 chapters.

The introduction provides information about the phenomenon of the late 80's and 90's of the last century - the nanotechnological revolution. There is described what is meant by the terms nanoscience and nanotechnology. The authors appoint some new properties of nanoscale structures, including mechanical or electrical, that determined the basic, most prospective fields of nanotechnology applications.

Part 1 "Overview of modern micro-and nanoelectronics," contains two chapters.

Chapter 1, "The transition from micro - to nanoelectronics". There is given information about the problems that arise when further microminiaturization in electronics had be done. There are discussed the principle of scaling at reducing the size of the electronic components and integrated circuits (ICs) and the problems of development of new elements of digital silicon nanoelectronics, in particular, silicon transistors and geterotranzistors of nano-dimension region.

Chapter 2 describes **the use of new elements in nanoscale electronics** and is dedicated to the justification and explanation of physical effects in nanostructures. There are given: the physical interpretation of the ballistic motion of electrons, ideas of the creation of such elements and devices, such as one-electron transistor, the new types electronic and magnetic memories, memristors and memristive systems, hybrid nanodimension semiconductor circuits (such as CMOL); use of quantum dots in cellular automata.

Part 2 dedicated to **the fundamental technological methods of analysis of surfaces and nanostructures**, and contains one chapter (**Chapter 3**) describing the methods of analysis of composition and structure of surfaces, thin films and nanostructures. In this section a classification of electron and ion methods for the analysis of materials is done. There are described various electron and ion analytical methods for the study of surfaces, including: X-ray photoelectron (XPS) and Auger electron spectroscopy, secondary ion mass spectroscopy(SIMS), low energy electron diffraction (LEED) and low-energy backscattering ion spectroscopy; spectroscopy utilizing ion-induced optical emission from excited sputtered particles. There are described methods for deep analysis of thin film structures by fast ions and electrons: analysis using the ion microprobe; Rutherford backscattering of ions and the analysis using nuclear reactions, application of diffraction of high energy electrons etc. There are described methods and devices for visualization and characterization of nano-objects, such as transmission electron microscopy, scanning electron microscopy, scanning tunneling and atomic-force microscopy; features of near-field scanning optical microscopy. There shortly are listed also the methods for determining the size of nanoparticles.

Part 3 is an explanation of **the nano-element deposition and structuring.** This is the largest part of the book1 and this part contains 6 chapters.

Chapter 4 begin description of ***the technological methods of thin films*** deposition. Here are explanation of the general characteristics of vacuum-thermal methods of thin film creation. Here are given the physical interpretation and justification of the evaporation of materials; thin film growth by thermal vacuum deposition. In this chapter are discussed the physical processes during ion sputtering and are described triode ion-plasma sputtering system with direct current as well as the magnetron system for thin film deposition . Attention is paid to the details of high-frequency sputtering systems for deposition of dielectric and metallic thin films. Authors describes modern system for molecule-beam epitaxy and atomic layer deposition method as well as the method for the Langmuir – Blodgett thin film fabrication.

Chapter 5 is devoted to ***the ion implantation of fast ions***. Here are explained the basic physical processes of penetration of accelerated ions; the channeling and the generation of radiation-induced defects as well as their annealing. There are given formulae and graphics , permitting evaluation of sheet resistance of the ion implanted layers. Further part of the chapter is devoted to the descrip-

tion of design and operating principles of the equipment for ion implantation and the application and most efficient use of the ion implantation.

In ***chapter 6***, called ***ion etching,*** are described the peculiarities of the methods and systems for reactive ion and plasma etching. Data for processes and equipment are extended with explanation the physical features of the image transfer of the microstructures during ion etching.

Chapter 7 presents ***the physical basis of electron lithography***. In particular, there are described the nature and place of microlithography, together with a summary of the penetration and scattering of fast electrons in thin films and bulk samples. The authors give experimental data for the ranges of the electrons, penetrating in the bulk samples as well as the distribution of absorbed energy in the sample when it is irradiated with electrons.

Chapter 8 contains information about ***equipment and technology of electron and ion lithography***, and namely described various kind of microlithography equipment for electron and ion lithography; there are described the processes in resists for nanolithography. A modern determination of the sensitivity and contrast of electron and ion resists, the dissolution rate dependence on the exposure dose, the resist radiation efficiency are contained in that chapter. Features of mono-component and multi-component resists, actual data for characterization of chemically amplified resists and on non-organic resists used in nanolithography are given. Authors give original description of the processes of resists exposure and development in electron and ion lithography; they estimated the energy absorbed in resists during electron lithography, and energy deposition features in the resist during ion lithography, showed the role of electronic and nuclear energy loss during ion lithography as well as discussed some results of computer simulation of electron and ion lithography.. There are given idea on numerical correction of exposure of micro-images with predetermined shapes and sizes.At end of this chapter is demonstrated an application of regression analysis to improve the quality of the lithographic processes.

Chapter 9, ***"Lithography using a mechanical probe"*** contains actual description of nowadays probe technologies in nanostructure creation. There are given an analysis of STM lithography with utilizing electron sensitive resists, explanation of the lithography by anodization of metal surfaces. There are described the microcontact lithography in polymer layers using mechanical probe of an AFM; the noncontact probe mode of AFM lithography as well as the manipulation of atoms on the basis STM. Data on deep-pen probe lithography and hybrid AFM / STM lithography are discussed too.

The next part of text is issued as **"Nanoelectronics materials and devices"**. There is situated (the number of the parts and the chapters are listed here as consecutive to book1:

Part 4. **Materials of nanoelectronics. The technology of their production, properties, fields of application.**

Chapter 10 is called ***"Self-organized nanoscale structure"*** .There are considered self-organization processes in semiconductors, porous and nanoporous silicon with controllable functional properties, namely: the impact of technological modes of obtaining the porous silicon and the mechanisms of growth of porous and nanoporous silicon. There are described the chemical processes at the formation of nanoporous Si; structure and chemical composition of the layers, gettering and passivation properties, electrophysical and optical properties of porous and nanoporous silicon as well as the methods to control the porosity of porous silicon. The details of photoluminescence and optical properties and the impact of modes of formation on the properties of nanostructured Si together with study the process of gettering are discussed too. Considering the photovoltaic cells based on porous silicon, an advanced determination is given especially the formation of porous silicon on a textured surface of the photovoltaic cells and an analysis of application of nanoporous silicon technology in the important development of high efficient silicon photovoltaic cells. There are given original data on explore and development the technology for production of nanostructured nanocrystalline silicon photovoltaic components as well as propreties of photovoltaich films based on the nanocrystalline silicon. In the end of chapter description of silicon composite materials is given and the influence of rare earth elements (REE) on the properties of nanocristalline Si films is assessed.

Chapter 11 "Carbon nanostructured materials (fullerenes, carbon nanotubes, graphene) contains a description of the methods of preparation and the properties of fullerenes. There are explained the thermal decomposition of graphite catalytic decomposition of hydrocarbons, given the basic idea of the symmetry of fullerenes, collected data on the physical properties and reactivity of fullerenes. There are discussed the prospects chemistry of fullerenes as the concept of intercalation in fullerite. Authors give data on conductivity and structure of the fullerite films; explained the effect of oxygen on its conductivity. It is discussed the polymerization of fullerenes, the prospects of practical use of fullerenes and fullerite. After that

authors described the carbon nanoparticles and nanotubes, in particular, the structure and basic properties of onewall and multiwall carbon nanotubes, capillary effects, electrical resistivity, emission properties, magnetic susceptibility in carbon nanotubes and their practical use. At the chapter end the problems and achievements in the development of grapheme are described.

In ***Chapter 12*** are described ***the diamond-like carbon films*** .The fabrication of these films utilizes high- frequency and microwave plasma chemical deposition of the films. Authors studied the physical properties of created films by Raman scattering, and measures optical properties and the electrical parameters of the diamond-like carbon films.

In ***Chapter 13 "Magnetic nanomaterials"*** and ***Chapter 14"Ferroelectric and piezoelectric Nanostructured Materials"*** are described the physical properties of materials, features of the technology of their production. Authors discuss the structure and orientation of the individual magnetic dipoles. There are considered the technological feasibility of deposited films of studied materials, their etching and features of polarization.

Part 5: "Functional Nanoelectronic Devices" contains 6 chapters.

Chapter 14 "Photonics nanoscale structures" includes information about classification of photonic crystals, the theory of photonic band gaps, ways to make photonic crystals, functional devices based on photonic crystals, photonic crystals and optical fiber based on them; optical fibers with Bragg gratings. The application of photonic crystals in integrated optics are discussed.

Chapter 15 "Magnetoelektronics and spintronics" contain data on nanocomposite materials utilizing magnetic nanoparticles on the basis of ferromagnetic FeCo, embedded in a dielectric matrix and possess unique physical properties: giant magnetoresistance, magnetorefractive effect, good magneto-optic properties, high absorption capacity of electromagnetic radiation in the radio frequency and microwave ranges as well as a wide interval of changes its electrical resistance. The permanent magnet device aiming to create storage medium with an ultra high density of magnetic recording is discussed. This property can be shielded from the effects of microwave radiation irradiation of the samples.

Chapter 16 "Sensory Systems" describes: sensors based on optical waveguide with a photonic-crystal structure, sensors based on carbon nanotubes, including carbon nanotubes using to measure the force; sensors for measuring pH, gas sensors based on carbon nanotubes, flexible hydrogen sensors; sensor for determination the concentration of viruses as well as application of carbon nanotubes as biosensor used for detection in blood cells of breast cancer; biosensor for the detection of hydrogen peroxide-based compound on carbon nanotubes and DNA. Nanobiosensor an; biosensor system using thin films of nanocrystalline silicon magnetic film, sensors based on surface plasma resonance (SPR) and others are discussed. Information on the multisensor electronic systems of type "electronic nose" and "electronic tongue" is given.

In ***chapter 17***, ***"Molecular electronics"*** the basics on molecular microelectronics, molecular conductors, intermolecular charge transfer, molecular superconductors, piezoelectric and pyroelectric properties; organic molecular magnets are given. It is described the technology for production of molecular materials for optoelectronics, organic photochromatic materials, organic light-emitting diodes; functional devices of molecular electronics, polymer transistors.

Chapter 18 "Bioelectronics" describes the information properties of DNA, the wave features of the genome; phantom memory; genetic structures of both the source and destination of the holographic media; wave maps of DNA replication and its immediate environment. A study of DNA nanomechanical robots and computing devices reflects the main trends in the development of devices using the genetic material; nanoinformatics is described.

In ***chapter 19*** "***Nanoelectromechanical systems"*** are considered the technology and examples of practical realization of devices based on the structures of micro-electromechanical systems (MEMS). The device and the technology of their production: nanopillow-block, mechanical relays on carbon nanotubes; nanoaktuator; nanodrive gear; nanomotor; carbon nanotubes for nanorobotics are shortly described. Joining of carbon nanotubes and development of sensors, actuators, frequency selective devices and electric signals filters are described.

Conclusions

1. Materials have new properties and had found new applications in the case of achieving a relevant nanostructure. This is due to the characteristic length corresponding to each of the material properties. For example the electrical resistance of the material is the result of flux of electrons in the conduction band, because of scattering from the vibrating atoms of the material and the impurities. These acts are characterized by the scattering length, thermed as mean free path. When the length of the device becomes comparable to the one or the other characteristic length, most of which are in the nanoscale region, the physics and the chemistry of the phenomenon is changing.

2. The driving force of nanotechnology is nanomaterials as the search for the structure and properties different from those characteristics of bulk materials (as is the case for a large number of materials), and the creation of devices from nanodimension components for which the laws are different from existing laws in the macroworld.

3. Nanoelectronics as natural consecutive of microelectronics is advanced region of development of new nanotechnologies, design and applications of new nanodimension devices and successive utilization of various nanomaterials.

4. Nanotechnology development is of crucial importance for nowadays country robust economy. The products of nanotechnology are not localized in one national economy sector but participated in the quality improvement, functionality and concurrentability of productions in many branches of industry.

5. Complex nature of nanotechnology and nanoelectronics required the research teams with activity in that field to be composed from different professions experts. Due to their impact on a wider branches of human life the education in the nanotechnology and the nanoelectronics must be realized in a wider number of student educational profiles.

6. Problems of development and wide application of nanomaterials and nanodevices will be solved individually for each investigation area and/or for each application. Nanoelectronics and information technology-related equipment, energy efficiency and technology with the energy conversion efficiency, biotechnologies which increase quality of life and ecology compatible technologies, including resource and energy saving nanotechnology will developed faster than other branches.

References

1. *G.Mladenov*, E.Koleva, V.Spivak, A.Bogdan. Introduction in Nanoelectronics technologies. – Kiev: Avers, 2010 - 400 p.
2. *G.Mladenov,* E.Koleva, A.Shmyryeva, V.Spivak, A.Bogdan. Nanoelectronics materials and devices. – Kiev: Avers, 2010 - 410 p.