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Nano Devices and Microsystem Technologies: Brief Overview

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Abstract*—The article provides brief overview of composition and principle of Nano devices and microsystem technology operation, which allows focusing on important micro processing technologies, which are proposed to be divided into 4 classes; analyzes principles of surface treatment technology – prospect of development and promotion of new range of intelligent materials, innovative architectures and technologies for their production.*

Keywords—Feature; IDE; Visual Studio; Eclipse; NetBeans.

1. INTRODUCTION

The development of new devices, materials, technologies for their production and processing is now generally recognized as so-called "key".

Over period from beginning of XXI century to present time, one of most intensively and dynamically developing areas of world industry has become microsystem technology (MST) and nanotechnology (NT) [1]-[5].

The rapid development of MST is mainly based on development and production of various miniature sensors for inertial and external information, micromotors and converters. Elements of microsystem technology are devices with electrical, optical and micromechanical structures integrated in volume or on surface of solid.

NTs include technologies that provide ability to create and modify nanomaterials in controlled manner, as well as integrate them into fully functioning systems of large scale.

2. RELATED WORK

The constant improvement of microdevices, their components and manufacturing technologies have significant impact over past decades on NT and MST, therefore, which accordingly affected number of works in this area.

Complex microsystems consisting of sensors and actuators integrated with sensor, etc. are actively developing.

Nanoscience, together with NT, encompasses study and application of very miniature devices and can be used in many fields of science such as physics, chemistry, biology, materials science and engineering.

Various sectors such as healthcare, materials, textiles, information and communication technology, and energy can reap huge benefits from nanotechnology.

Application of NT in light industry [6]-[8]. The authors focus on current state of NT use in order to improve various properties of textiles.

Among many scientific advances, NT has been identified as potential technology for revival of agriculture and food industry [9], [10]. The authors considered their role in crop production, food processing and packaging, food security and water purification, environmental restoration, crop improvement and plant protection.

The use of NT in medicine to develop faster and more effective solutions to medical problems or treatment of diseases [11], [12].

Any technology requires information support. In [13] general characteristics of processes of collection, transmission, processing and storage of information are presented; organization of information processes; information technology when choosing solutions in field of nano- and microsystem technology, organization, planning and production management, as well as automated research systems, CAD, MEMS and NEMS, technology for computer modeling of nano- and microsystem technology.

The development of microsystem technology based on microprocessing technology and integrated circuit technology for purpose of miniaturization is discussed in [14].

The basics of microtechnology and nanotechnology are given in [15].

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In [16], authors provided wealth of theoretical and practical information on nanotechnology and NEMS, and also offer basic and comprehensive information about materials, processes and manufacturing options. Provides complete overview of manufacturing technologies for micro- and nano-processing and manufacturing technologies and applications of Bio-MEMS and Bio-NEMS.

3. Features of Modern Technology of Nano Devices and Microsystem Technology

Nanotechnology is field of basic and applied science and technology that deals with set of theoretical substantiation, practical methods of research, analysis and synthesis, as well as methods of production and application of products with given atomic structure by controlled manipulation of individual atoms and molecules.

Objects of nanotechnology, on one hand, can have characteristic sizes of specified range (from 1 to 100 nm), and on other hand, object of nanotechnologies can be macroscopic objects which atomic structure is created in controlled way with resolution at level of separate atoms.

The development of nano- and microsystems is relatively new direction in science and technology, born at intersection of mechanics and microelectronics, determining future of automated systems, "smart cities" of "unmanned production" technologies.

MCT and NT play an essential role in development of nuclear weapons based on microsynthesis reactions.

Already, use of MST makes it possible to create very small space satellites (microsatellites).

Specialists in field of NT and MST are also involved in development, research and application of electronic devices with element sizes from micrometer to nanometer.

Examples of such systems are airbag sensors in cars, microscopic controllable mirrors, which have found application in well-known DLP projectors, including those for home theaters.

Also, these are all kinds of various physical quantities sensors:

- acceleration;
- changes in angle of rotation (gyroscopes);
- temperature;
- microphones.

Technologies of nano- and microsystem technology are designed to create an elemental base of modern microelectronic systems; they allow developing separate mechanical structures and complex integrated electronic-mechanical devices.

Examples of such devices are micro- and nanoelectromechanical systems that combine information and energy-converting components, created on basis of use of micro- and optoelectronics technology, fiber-optic technology, acoustoelectronics and micromechanics.

Consider few examples of Nano devices.

Molecular gears (fig. 1, a) [17], [18] and pumps (fig. 1, b) [19].

a) b)

Figure 1: Examples of Nano devices:

a) molecular size gears based on nanotubes; b) molecular pump

Consider design feature of molecular gear.

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A pair of DNA nanocircles was constructed to simulate gears. Nanoparticles can move against each other continuously. Each gear consists of duplex circle of DNA and three single twisted teeth. The teeth on two gears are connected by connecting threads that complement gear teeth. The teeth are separated from each other by removal of linker chains using chain displacement mechanism [17].

Consider design feature of molecular pump. The gear shafts in gearbox are carbon nanotubes, and teeth are benzene molecules. Characteristic speeds of gears make some tens GHz.

The devices "work" either in deep vacuum or in inert environment at room temperature. Inert gases are used to "cool" device.

Such pumps have found practical application as stages of high pressure when working with pumps having mutually perpendicular movement of gas and working surfaces, as well as when pumping gases with high molecular weight.

Advantages: pumps take little time to get started. As stipulated speed is reached, they are already operating at full capacity; pump is insensitive to air breakthrough; fast evacuation of heavy gases, which in some cases is of great importance.

Disadvantages:

- pump operation is associated with significant noise;

- sensitivity to dirt and from ingress of metal or glass particles quickly renders motor unusable;

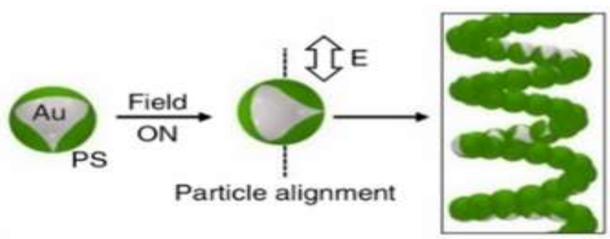
- presence of moving parts leads to wear of pumps;

- in most designs, clearances in these pumps should not exceed few hundredths of millimeter. This accuracy significantly increases cost of pump.

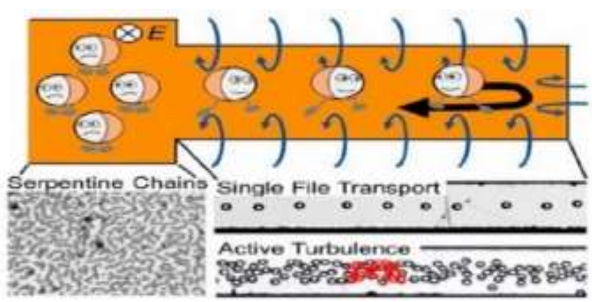
In addition to molecular gears, pumps, etc., let us single out nanomotors.

Many of nanomotors require electrical or chemical propulsion for their mechanical mobility. But moving towards renewable energy sources such as solar, wind and light / sound energy has become trend lately.

A typical example can be nanoelectric motors can be driven by an external electric field (fig. 2) [20], [21].



a)



b)

Figure 2: An example of nanoelectric motor:
a) schematic diagram of initial alignment of particle when external alternating electric field is switched on;
b) schematic diagram of interdigital microelectrode system, in which, when alternating current electric field is applied, metal-dielectric particles

Nanomotors for various applications such as drug delivery, environmental restoration, biosensor and precision micro / nanometer surgery, robotics, etc.

Application examples include pumping liquids or even synthesizing materials.

The key feature of nanomotors is their ability to functionalize, that is, to change surface of device with acquisition of ability to perform some tasks. For example, receptors or short DNA fragment can be attached to nanobot to detect molecules, or nanobot can be linked to drug [22].

Nanomotors can be made using synthetic materials and chemical methods.

Advantages:

- sizes;

- nanomotor works very quickly and complete cycle takes less than thousandth of second;

- ability to work without chemical fuel (for example, nanomotor can take energy directly from sunlight, does not require fuel delivery and does not produce waste).

The disadvantages of nanomotors include: sometimes small amount of forces developed by them; high temperature gradient, can have very detrimental effect on service life of nanomotors; low accuracy (for example, electrostatic nanomotor containing power source, at least two plates located relative to each other with gap and with possibility of changing due to electrostatic effect of their spatial orientation relative to each other).

On basis of synergistic transfer of microelectronic technology, mechanical, electrochemical technologies and other methods of material processing, it became possible to create commercially effective microsystem samples for computer technology, medical technology, biochemical technology, etc.

Microsystem technology is closer to instrumentation (mechanical engineering), electrical engineering, i.e. to creation of structures than to any particular technology.

If design of microsystem is designed, then best technology is already sought to create required number of structural details. The easiest way to design is to assemble product from modules.

A triad in design of classical microsystem:

- sensitive element (receiver of external information, sensor, sensor);

- signal processing systems of sensitive element (amplifier, converter, processor);

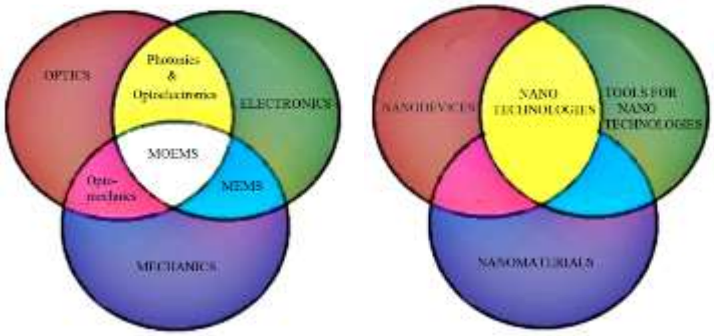
- feedback device (actuator, communication channel, etc.) contributes to perception of microsystem as possible combination of three microsystem blocks of modules.

The technologies of Nano devices and microsystem technology include technologies listed in table 1.

Table 1: Technology of Nano devices and microsystem technology

<table>
<tr><th>№</th><th colspan="2">Name</th></tr>
<tr><td>1</td><td colspan="2">Basic technologies for creating high-frequency microelectromechanical and nanoelectromechanical systems</td></tr>
<tr><td>2</td><td colspan="2">Development of nano- and microsystems, devices and their components</td></tr>
<tr><td rowspan="4">3</td><td rowspan="4">Development of production technologies</td><td>materials based on nanocrystalline silicon and thin-film silicon</td></tr>
<tr><td>ultrafast heterojunction integrated circuits</td></tr>
<tr><td>nanostructured photovoltaic converters for solar energy</td></tr>
<tr><td>energy storage devices</td></tr>
<tr><td>4</td><td colspan="2">Development of intelligent materials based on use of nanostructures</td></tr>
<tr><td>5</td><td colspan="2">Development of methods and tools for diagnostics and quality control of materials and products of microsystem technology</td></tr>
</table>

Generalized classifications of microsystems technology (fig. 3, a) and NT (fig. 3, b).



a) b)

Figure 3: Generalized classifications: a) microsystems technology; b) nanotechnology

There is no single technology of microsystem technology that allows creating various designs by acting on material with same type of operations.

Microsystem technology products are focused on specific application, that is, they are custom-made. The optimum technology modules must be selected for each product.

The basis for development of microsystem technology is creation of fairly wide range of technological modules.

Consider technology using example of

microelectromechanical systems (MEMS). Today, with expansion of MEMS applications in Europe, MST for microsystem technologies has become more popular [15], [23].

At present, number of standard technologies for manufacture of MEMS have already been determined, which use achievements of various branches of technology.

There are about 20 technologies for MEMS manufacture – products' using semiconductor technologies and their number is constantly increasing. The most famous technologies are shown in table 2.

Table 2: Technologies for MEMS manufacture

Technology name		
Abformung, Oberflachen mikromechanik, Membanu bertragung		
AMANDA	Micromachining, casting and moving diaphragm. Feature – technology combines LIGA technology (or precision machining and silicon micromachining).	Volumetric technology
Electrical Discharge Machining		
EDM	Electrical discharge machining – under influence of electrical discharges arising between work piece and electrode-tool. That is, heat energy is used to remove material from work piece. This treatment does not require mechanical effort during removal process. Feature – in EDM, electrode is not in direct contact with material, so it will not be damaged. Increased surface smoothness. Can create complex shapes that can be difficult to create.	Other processing technologies
High Aspect Ratio Machining		

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HARM	Processing with high aspect ratio (depth to lateral dimensions). The peculiarity is that components with high aspect can lead to significant increase in profitability of both accelerometers and gyroscopes. It is one of common technologies for reproducing microstructures with high performance to cost ratio. Deep dry etching of bulk silicon membrane is used, which is determined by wet etching.	Volumetric technology
High aspect-ratio combined poly and single-crystal silicon		
HARPSS	Processing of polysilicon – silicon structures with high aspect ratio. High aspect ratio polysilicon structures are created by filling grooves hundreds of micrometers deep with polysilicon deposited on sacrificial oxide layer.	Hybrid technology
HARPSS	The all-silicon cell of this technology improves long-term stability and temperature sensitivity, and fabrication of large-area vertical measuring electrodes with submicron gap spacing will increase sensitivity of MEMS devices by orders of magnitude.	Hybrid technology
integrated MEMS		
iMEMS	This technology combines micromechanical structures with integrated circuits. Components are fabricated in trenches on silicon substrate, and then standard electronics are machined on same substrate. The peculiarity of this in technology is smaller size, speed, lower cost, lower power and higher sensitivity of integrated systems. To handle differences in surface topography, MEMS components are fabricated in shallow trench below wafer surface prior to integrated circuit processing.	Surface technology
Lithographic, Galvanoformung, Abformung		
LIGA	Lithography, electroplating, molding (casting). Important tooling and replication technology for high-aspect-ratio microstructures. The technique employs X-ray synchrotron radiation to expose thick acrylic resist of PMMA under lithographic mask. LIGA is limited by need to have access to an X-ray synchrotron facility. Feature – possibility of multiple replications due to integral principles of processing allows production of volumetric structures up to 1 mm in height in quantities of up to 1000 pieces. On one plate.	Volumetric technology
Low Pressure Chemical Vapor Deposition		
LPCVD	Chemical vapor deposition (chemical vapor deposition). The technology uses thermal energy to initiate precursor gas reaction on surface of substrate. This reaction on surface forms solid-phase material. It is widely used for deposition of silicon-germanium films. Feature – reduced pressure reduces likelihood of undesirable reactions in gas phase and leads to more uniform deposition of film on substrate.	Volumetric technology

Multi User MEMS Process Silicon		
MUMPS	Three-layer polysilicon process of standard surface micromachining technology. Most of planar MEMS elements are manufactured using this technology. The use of polysilicon as structural material for sensor and actuator elements of microsystem technology in MUMPs technology is justified by fact that this material has good mechanical properties. Feature – ability to create large number of different functional MEMS elements in one manufacturing process with minor changes, as well as possibility of integral creation of sensor and actuator elements on same substrate with elements of processing, transmission and storage of information.	Surface technology
Sacrificial LIGA		
SLIGA	LIGA with sacrificial layer. A sacrificial layer (titanium) is applied to substrate, which is structured to shape into desired shape prior to starting actual LIGA process. The technology combines some of features of LIGA with micro-surface treatment that eliminates need for X-ray exposure. Feature – enable production of MEMS components with much lower manufacturing infrastructures in terms of investment, facilities and access to advanced materials and technology.	Volumetric technology
Reactive Ion Etching		
RIE	Reactive ion etching. Dry etching type. RIE uses chemically reactive plasma to remove material deposited on plates. RIE is widely used etch technology in integrated circuits (IC) manufacturing. Dominant technology for high aspect ratio semiconductor micromachining. Feature – etching conditions in RIE system are highly dependent on many process parameters such as pressure, gas flows and HF power.	Other processing technologies
Single Crystal Reactive Etching and Metallization		
SCREAM	Vertical bulk etching of silicon with metallization, which is combination of anisotropic and isotropic plasma etching. SCREAM is used for production of accelerometers, micromirrors, etc.	Hybrid technology
Single Crystal Reactive Etching and Metallization		
SCREAM	Feature – using monocrystalline materials for mechanical structures is advantageous, since these materials have fewer defects, have no grain boundaries and, therefore, must scale to submicron sizes and retain their structural and mechanical properties.	Hybrid technology
Sandia Ultra – Planar Multi-layer MEMS Technology		
SUMMIT	Four-layer polysilicon process of standard surface micromachining technology developed by Sandia National Laboratories (USA). Feature – possibility of integral creation of large number of MST elements of different functional purpose in same manufacturing process with IC elements, which will reduce cost of devices. Flaw SUMMIT – impossibility of manufacturing MST elements from material other than polysilicon.	Surface technology

Thus, 4 classes of technologies are distinguished:

1. Volumetric technology – processing to obtain high aspect ratio of depth to lateral dimensions. Volumetric micromachining consists in process of removing substrate material in order to form required structure, which includes flexible arms or cantilevers, holes, grooves and membrane elements.

2. Surface technology – consists in sequential deposition of structural silicon layers and "sacrificial" layers, which are made of silicon dioxide, silicon nitride or polymer, onto substrate.

3. Hybrid technology with assembly of mechanical and electronic parts, including at level of atomic-molecular splicing.

4. Other processing technologies (technologies that are not included in first three classes) – vacuum-plasma; fiber, micromechanical processing, bulk polymer, multilayer film structures, etc.

After analyzing, it was determined that surface micromachining makes it possible to produce MEMS sensor and actuator elements of smaller thickness than similar structures created using volumetric micromachining.

The advantage of surface micromachining is possibility of multiple removal of auxiliary layers without damaging interconnection of basic structural layers.

Surface MEMS technologies use high-volume IC manufacturing processes that involve deposition or removal of 2D layers on substrates by lithography and chemical etching techniques. As a result, 3D structure of MST is obtained from templates of 2D layers.

Bulk MEMS technologies make it possible to obtain structures up to 2 mm with lateral dimensions of elements of order of several microns.

4. CONCLUSION

The combination of small size and ability to acquire new properties makes NT and MST devices promising tool for solving many problems.

The creation of nanostructures is based on latest technological advances in design at atomic level of solid surface and multilayer structures with given electronic spectrum and necessary electrical, optical, magnetic and other properties.

The brief review of composition and principle of nanodevices and microsystem technology operation allows focusing on important microprocessing technologies, which are proposed to be divided into 4 classes; analyzes principles of surface treatment technology – prospect of development and promotion of new range of intelligent materials, innovative architectures and technologies for their production.

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