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Nanotechnologies for the fabrication and self-organization of electronic components, circuits and products

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Abstract—Nanotechnology from one direction is considered, namely the production of electronic circuits or mechanical elements from several atoms, which is subject to the fields of micro and nanoelectronics. Multi-element nanostructures include complex heterostructures, superlattices, quantum holes and barriers (fibers, dots, layers, nanotubes and spheres, "giant atoms", superlattices, photonic crystals and etc.), one- two- and three-dimensional arrays of quantum dots, shown in the article.

Key words- *Nanotechnology for fabrication; self-organization of electronic components, circuits and products*

I. INTRODUCTION

Here, nanotechnology will be considered from one direction, namely the production of electronic circuits or mechanical elements from a few atoms, which is subject to some of the indicated areas of micro and nanoelectronics. Modern microelectronics is built on the basis of semiconductor crystals and integral methods with repeated cycles for processing their surface layer. According to [1], according to their purpose and place occupied in the general process of production of elements and microcircuits, the operations are united in independent TP (operations), which are subdivided into 3 groups: preparatory, processing and assembly-control. In this case, the processing operations for the formation of the structure are of interest, which include epitaxy, oxidation, diffusion, vacuum evaporation, ion implantation, litographie and thermochemical treatments. It is believed that reaching component sizes of 7-13 (10 to 15) nm will completely exhaust the capabilities of these technologies. For example, natural statistical fluctuations in doping, defects in crystals, inaccuracies in processing processes, will lead to such large deviations in the parameters of individual elements that they cannot be used. MOS-transistors and circuits have reached their physical limits of 20-30 nm, which concern the wave nature of electrons or they exhibit the quantum-tunneling effect and pass insulating layers with material thickness greater than 20 nm. For a possible way out of the situation, electronics are created on a completely new, quantum basis. The parametric and structural features of the nano BRIDGE are specified in [2]. Some of the requirements are contradictory, etc. the subject goes a little beyond the focus of the present book, I will only say that they are analyzed in detail by the same author.

The specificity of the properties of substances at the nanometer scale and the related new physical phenomena are determined by the fact that the characteristic sizes of the elements in the structures of nanobeaks are in the range 10^{-8} – 10^{-9} mm, corresponding to the average sizes of atoms and molecules in the usual materials. From this point of view, we should consider nanostructures as a special phase state of substances. Multi-element nanostructures should include complex heterostructures, superlattices, quantum holes and barriers (fibers, dots, layers, nanotubes and spheres, "giant atoms", superlattices, photonic crystals, etc.), one-two- and three-dimensional arrays of quantum points. All these nano-objects are the basis of electronic elements and circuits, which are defined by a trinity between process physics, production technology and field of application. On the basis of quantum wells and barriers, quantum transistors can be created - devices for switching signals of a new type, portable quantum particles. For this purpose, methods were developed for the formation of quantum structures with different configurations and sizes. The width of the pit or barrier can be adjusted by changing the size of the cluster, and the height or depth by changing its chemical composition. The parameters of quantum wells can also be controlled using the applied electric, magnetic or light field. In addition, clusters of different shapes and sizes can be produced in the three layers. Quantum structures can also be created by deliberately creating a defect in the crystal lattice, forming a vacancy, or introducing dopant atoms or ions.

Non-isovalent alloying atoms are introduced into semiconductors intentionally in order to change their electronic and optical characteristics. The concentration of these impurities is generally very small, and therefore their amount in semiconductor elements with dimensions of about 10 nm can literally be counted on the fingers, even one or two in number. The spin and/or charge states of the donors are supposed to be used to organize the operation in solid-state quantum computers, which requires the development of methods to determine the electronic and magnetic properties of individual dopant atoms. In addition, on the basis of mesoscopic structures, new elements such as heterojunction transistors, heterostructure tunnel-resonance transistors and diodes, injection semiconductor lasers of trimeric quantum dot arrays, molecular quantum wire transistors of carbon nanotubes, spin injection transistors based on the Aaron effect have been created and are being created. Bohm and others. In the field of molecular electronics, quantum electronic elements, circuits and devices are created from details/elements synthesized as a result of periodic chemical processes. These details are then assembled into circuits through self-assembly and self-organized arrangement. The task of the nanosystem technique is the development of a new generation of transistors, diodes, memories and other elements using the top-down approach. Fig. 1. illustrates how some active electronic elements or logic circuits can be created according to the different conductivities of the molecules. By going down to the level of a molecule or an atom, the sizes of the elements are automatically reduced, the issues with the lithography and the processing necessary to obtain the corresponding element are eliminated. However, this does not mean that every new proposed solution is so easy and hassle-free.

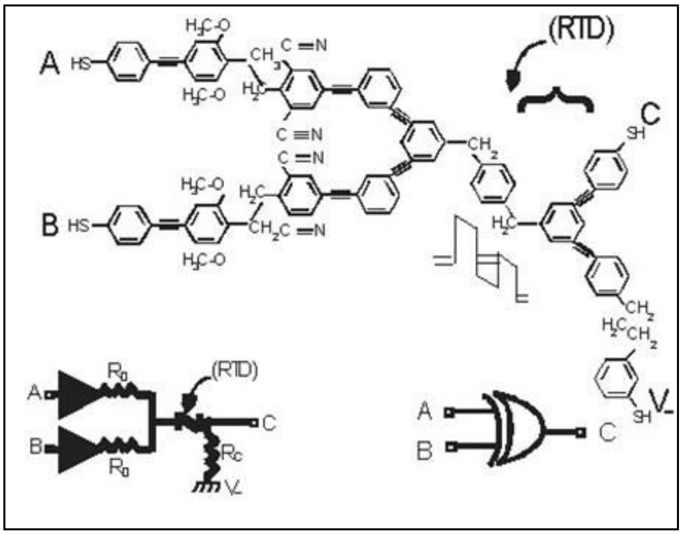

Figure 1. Active electronic elements at the molecular level

II. EXPOSURE

A change in the order of arrangement of atoms in nanotubes occurs when the diameter of the tube changes, when two or more tubes are joined, when the tube is deformed during its growth. In the area where the atoms are non-standardly arranged, unusual electronic properties are observed, which can also be used to create electronic elements - for example, transistors and diodes. A single or single electron transistor operating at room temperature was realized with a bent nanotube more in 1999 [4]. Carbon nanotubes are sandwiched between two gold contacts. Using an atomic force microscope probe, the tube is bent in 2 places to form 2 tunnel contacts. In doing so, the resistance in this area increases and the current conduction is modulated by the step-like voltage of the base (gate-electrode) under the island structure (see Fig. 2). As the temperature changes and cools down to 4K, the conditions change dramatically and the field-effect transistor operates as a single- or single-electron transistor [4]. It is the modification of the properties of a nanotube with a diameter of 1.5 nm and a length of 50 nm by deformation that has allowed scientists from the University of Delft in the Netherlands to make the smallest transistor. It can work with even just one electron and is thousands of times smaller than the smallest known so far. Nanotransistors can also be made by doping/crossing nanotubes with suitable electronic properties in a network or by analogy with field-effect transistors. The latest tunnel barrier technology shown in Fig. 2, consists in the local oxidation of a metal conductive layer of aluminum (anode) using a scanning tunneling or atomic force microscope, in which a barrier with a thickness of less than 5 nm is obtained for the transport of electrons or so. by E. Snow in 1996 "Elektronen Confinements".

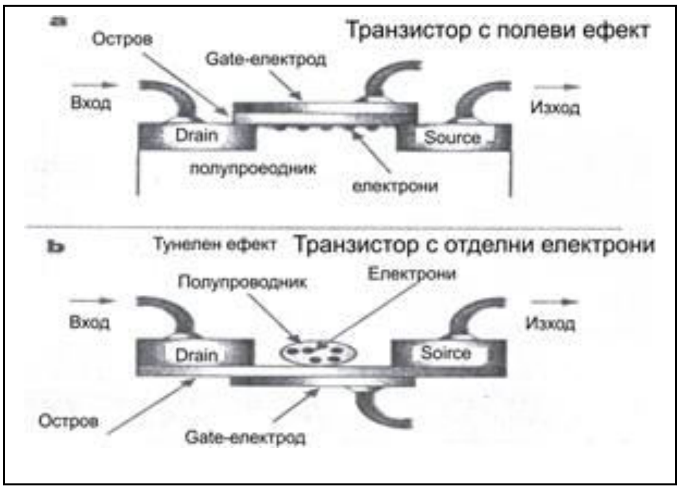

Figure 2. Schematic of a field-effect transistor
Legend: input, island, semiconductor, electrons, output

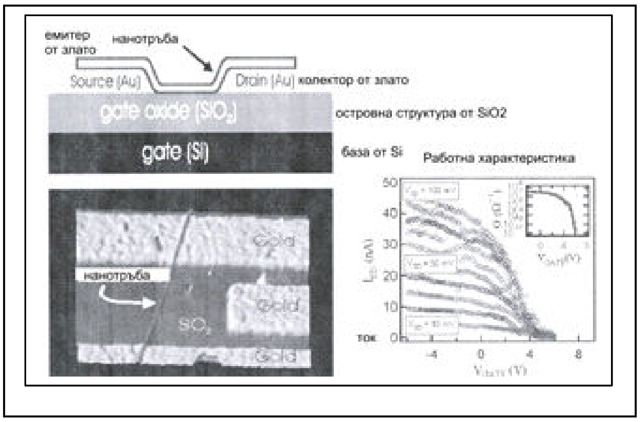

Figure 3. Single-electron nanotransistor
Legend: gold emitter, nanotube, collector, SiO_2 structure, performance characteristic (on the right)

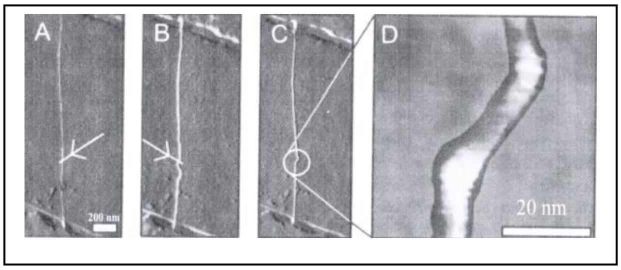

Figure 4. Transistor control characteristic

Figure 5. Tunnel barrier bending

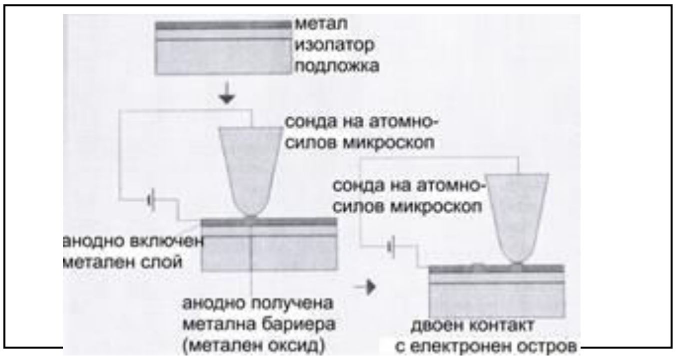

Figure 6. Nanostructuring of tunnel barriers. **Legend:** anode metal layer, substrate, atomic microscope probe, double contact

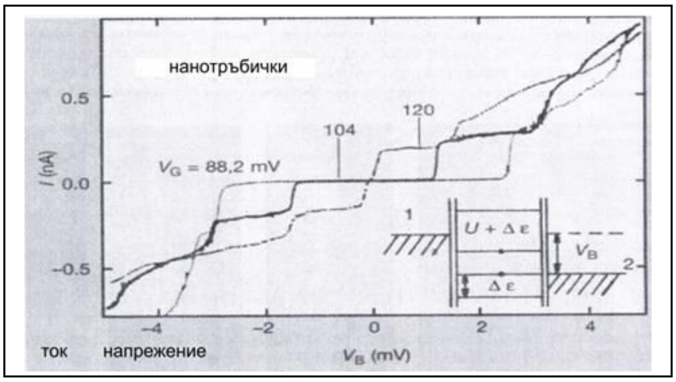

Figure 7. HTWT Mitvajda study materials for nanotubes, by Philips Research

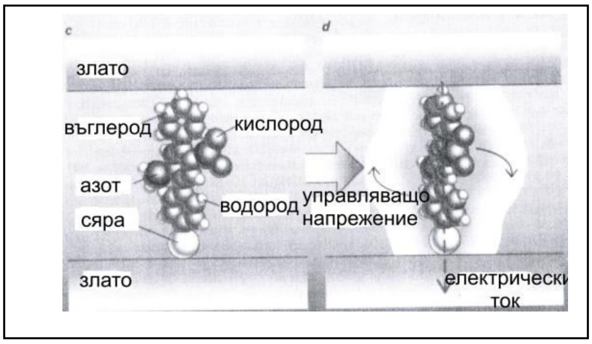

Figure 8. Transistor switch created using nanotechnology

Legend: gold, carbon, nitrogen, sulfur, oxygen, hydrogen, control voltage

A nanofluid transistor is another type of electronic device [5]. The created transistors are based on nanochannels or nanotubes. The very term "nanofluidic" means that the element controls the exchange of liquid and certain ions through channels with a submicrometer diameter (Fig. 9). It could serve as the basis of miniature chemical monolithic chip devices, such as disease-diagnosing reactors, operating without a single moving part. The field of application is the identification of proteins in cancer cells in the initial stages of the disease and similar functions.

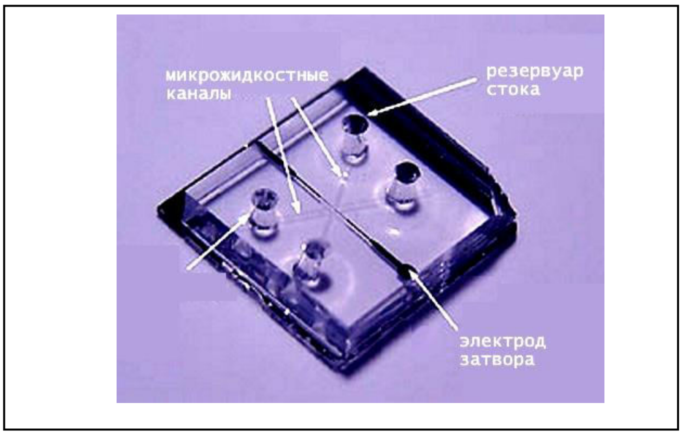

Figure 9. Structure of a «nanofluidic transistor»
Legend: microfluidic channels, reservoir, electrode

An analogue of a nanofluidic transistor was also proposed, which was developed on the basis of nanotubes in the role of conducting channels (Fig. 10.). After research, a similarity in characteristics was found between the usual MOSFET (Metal-Oxide Semiconductor Field Effect transistor) metal oxide, semiconductor, field effect transistors and nanofluid ones. The advantage of the latter is that the technology for mass production of the chip does not differ from that for the production of integrated computer chips. Furthermore, nanofluidic channels can be easily integrated into semiconductor devices and circuits. They are controlled by opening or closing the nanofluidic channel. For this purpose, the electronic components are placed on the board according to the usual methods in micro-electronics, micro-channels and tanks - separately.

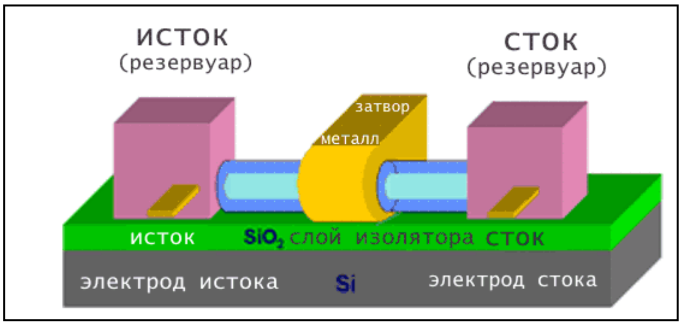

Figure 10. "Non-liquid transistor" with nanotube channels

Legend: source, drain, SiO_2 insulator, electrodes

The main detail of the device, capable of controlling the flow of liquid, is a microchannel with a diameter of 35 nm located between two layers of silicon dioxide. It is full of water with dissolved salts to form water ions. When a voltage is applied to the gate, analogous to that of the MOSFET field-effect transistor, the flow of liquid is stopped. The principle of operation is analogous to that of electronic transistors. A voltage on the order of 75 V applied to the ends of the channel causes the ions to move from one reservoir to the other. Such control with ions in the narrow channel is otherwise impossible because the ions in the liquid move rapidly and can lose their charge on contact with the channel walls. Therefore, in channels with a diameter of up to 100 nm, shielding is applied.

Nanotransistor types also include the light-emitting transistor (LET, light-emitting transistor) or light-triggered transistor. Scientists from the research center of the company Hitachi have developed such a transistor. It is a semiconductor element with a size of the order of 1 nm that allows it to be transmitted, detected and controlled with electrical signals. A schematic diagram of the transistor is shown in Fig. 11.

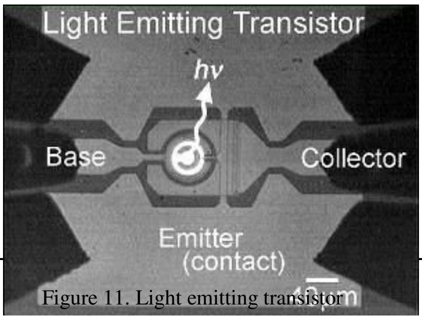

Figure 11. Light emitting transistor

Another group of nanoelements are memory nanointegrated circuits. These are functional elements or memory cells that are designed to record and store a unit of information. A number of models of nanointegrated memories are under development, which can be conventionally divided into classical and new ones. Of the first kind are two structures: silicon on insulator (SOI, discussed in the previous chapter) and floating gate (FMOS). In Fig. 12. a. schematic diagram of a memory cell is shown. The charging and discharging of the capacitor C_U by means of the resistor R_T determines the two basic logic states. As such, tunneling oxide can be used in the BRIDGE construction or electron injection via tunneling in recording (see Fig. 3 of the front chapter). In memory cells of the new, "single-electron" type, one electron is enough to record 1 bit of information. Figure 12. b. shows the operation of such a memory as with each write the floating gate is charged with one electron. A silicon nanomemory or "quantum dot memory" is shown in Fig. 12. c., on the right. In it, the nanoparticles perform the functions of floating gates with single electrons, which screen them and cause a change in the threshold voltage. Advantages are the small size and the technological possibility of implementation as a CMOS IC. Other types of memory cells for integrated nanomemories are classical, dynamic memories of the DRAM type, the new single-electron driver memories PLEDM, and multi-tunnel junction nanomemories MTJ. The advantages of nano-MOS memories are extremely low power consumption, increased speed and use at room temperature.

Photonic crystals are materials whose optical properties change according to a certain regularity: the amplitude of the oscillations is several hundred nanometers. An ideal photonic crystal will transmit light of only one wavelength and block the others from passing through.

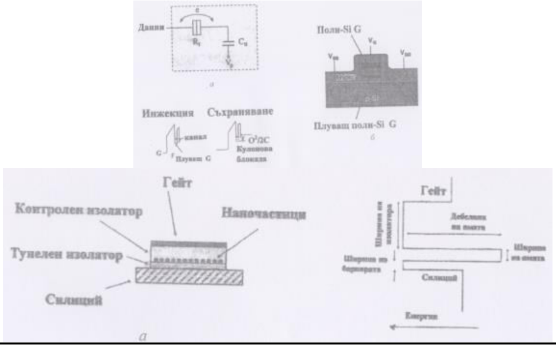

Figure 12. Classic and new memory cells [2]

Legend: injection, storage, control and tunnel insulator, nanoparticles, gate, barrier width, silicon, energy

The simplest type of this type of material is layered, and a natural type in nature is opal. The operation of such photonic crystals is based on the phenomenon of interference of light waves scattered by the elements of the internal structure. A photon, the energy of which corresponds to a logical zero, "flying" at point 1 (Fig. 13), has equal chances to pass into a deeper layer or to be reflected. However, it is reflected because the crystal structure is chosen to provide interference attenuation of any wave except the reflected one.

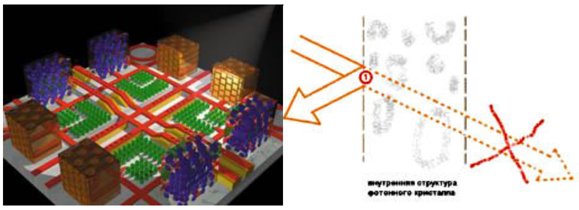

Figure 13. Photonic crystal circuit, internal structure

It is known from quantum mechanics that the speed of light in a vacuum is the limit, the greatest speed for the transmission of signals (and communication in general) in our World. In other words, no phenomenon can proceed from the cause of another phenomenon earlier than the interval of time required by light to overcome the distance between certain points in the vacuum in which these phenomena take place. Photonic crystals, in principle new crystals, in which the speed of light can vary within very wide limits, offer unprecedented opportunities for the organization of phenomena based on local violations of cause-and-effect relationships. From here, programming on such a basis is a search for such a suitable structure of the crystal, through which to realize the necessary type of wave function of the photon, determining its interaction. In photonic crystals, often appearing as a nonlinear optical medium, it is possible for self-organizing phenomena of structural inhomogeneities, known as dissipative structures or dynamical chaos, to occur. It is they who find application for logical elements. Figure 14 shows the connection of multiprocessor chips with integrated silicon photonic chips.

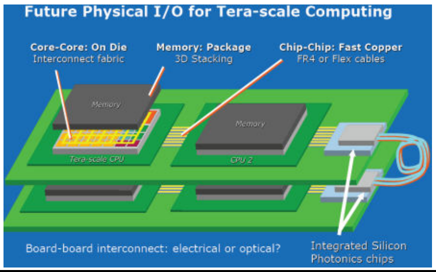

Figure 14. Combining microprocessors with integrated silicon photonic chips

About the equipment the largest equipment manufacturing company is ASML (Netherlands), founded in 1984 (Figure15). Competitors are Japanese Canon and Nikon (they have not developed EUV technology), Samsung from South Korea, Global Foundries and TSMC (Taiwan Semiconductor Manufacturing Co.) Taiwan, AMD from mid-2020 are using 7nm EUV technology, and Intel - by 2020 it was based on 14nm and by the end of 2021 – on 7 nm. As the wavelengths of the beam decrease inside EUV-machines, nearly 50,000 droplets of molten tin fall through a chamber at its base every second. A pair of lasers seal off each droplet, creating a plasma that in turn releases light of the desired wavelength. The mirrors directing this light, made of layers of silicon and molybdenum, are focused precisely. With the complex optical system, the sample is reduced, focused and printed on a thin layer of silicon coated with a light-sensitive resist. This is repeated dozens of times, layer by layer, leaving a grid of hundreds of chips on a single silicon substrate. Since EUV light is absorbed by almost everything, including air, the process takes place in a vacuum. If ICs and especially microprocessors drive the world of technology, ASML comes closest to the key position in this multi-trillion dollar industry.

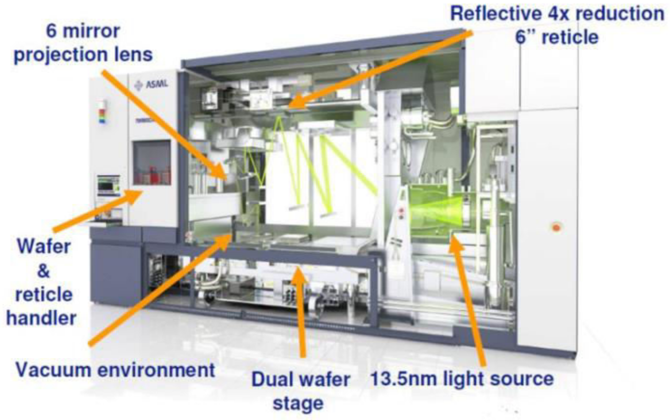

Figure 15. ASML company installation
(https://bg.compkkart.com/asml-making-euv-components-connecticut)

III. CONCLUSION

Modern microelectronics is built on the basis of semiconductor crystals and integral methods with repeated cycles for processing their surface layer. It is believed that reaching component sizes of 7-13 (10 to 15) nm will completely exhaust the capabilities of these technologies [6]. Nanoobjects are the basis of electronic elements and circuits, which are defined by a trinity between process physics, production technology and field of application [7, 8, 9]. The advantages and disadvantages are analyzed and the main conclusion is made that the wavelength of the beam determines and is commensurate with the resolution and size of the components in micro- and nanotechnics.

Acknowledgement

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