NANOTECHNOLOGY: FLOURISHING DIVERSITY

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An overview is presented of research and development activity in the field of nanotechnology and nanolectronics in MIET which is carried out in the following directions: semiconductor heterostructure molecular-beam epitaxy, arc plasma coating, electro-chemical nanostructure formation, porous alumina growth, formation of Ge nanocluster arrays in Si matrix using ion implantation; scanning probe technologies: local oxidation based nanolithography, material placing, nanolithography cantilever creation. Based on the given technologies, the following nanomaterials and nanostructures for electronic applications have been obtained and investigated: semiconductor heterostructures based on A3B5compounds including resonant-tunneling structures for ultra-high speed electronic devices and circuits; solid nanocoatings for various applications including coatings for nanolithography, conducting and magnetic coatings for scanning probe microscope cantilevers; carbon nanotubes for studying quantum transport, developing and manufacturing electronic devices based on quantum conductors; it was for the first time that germanium quantum dots in silicon matrix were obtained using ion implantation technique, under certain conditions these quantum dots produce ordered self-organized arrays; nanoporous alumina for optoelectronic applications as well as for creating terabit semiconductor memory elements, filling pores with different materials forms the basis for various applications in optoelectronics, nanoelectronics and spintronics; sample nanovaristors displaying quantum properties at room temperature were obtained by local anodic and current induced oxidation of various metals

A special emphasis is given to the nanotechnologies based on semiconductor heterostructures. The following topics are discussed: heterostructures for high-speed IC applications; nanoelectronic elements for ultra-high-speed ICs; heterostructures for fundamental researches (microscopic structure of heterojunctions).

The technological facilities include clean room for manufacturing of compound semiconductor devices and integrated circuits with 0.35 mkm Karl Suss mask aligner and a set of vacuum and chemical equipment. Measuring equipment provides the possibility to study fast electrophysical processes up to 18 GHz. Program packages for heterostructure based device modeling and design includes options for the description of diffusive-drift, hot-carrier and interference quantum mechanical electron transport.

The application oriented activity in design and manufacturing of high-speed ICs is based on the well-known ability of heterostructures to improve considerably transisitor characteristics. Depending on the specific iCs requirements different transistor heterostructures are used: heterostructures with wide-gap buffer, HEMTs, inverted HEMTS etc. A number of integrated circuits operating within the gigahertz range were developed based on the heterostructure gallium arsenide technology in MIET. With reference to these circuits, high-frequency sample-and-hold devices (samplers) were developed to convert fast signals into slow ones, with all the characteristic features of the shape (signal expansion) preserved. Such samplers are the main element of microwave tomographs, which can be used as subsurface locators, in particular. Widening the frequency range up to 10 GHz makes it possible to detect objects smaller than 1 cm in concrete reinforcement, for example, with the metal mesh pitch of 5 cm. Future developments are connected with the implementation of GaAs based nanotransistors.

A special attention is paid in the report to the new possibilities in creating planar integrated circuits based on semiconductor heterostructures. The use of resonant-tunneling diodes is one of perspective designer solutions permitting to reduce number of devices in circuits, to raise their operating speed and to reduce power consumption. According to the latest edition of "Technology Roadmap for Nanoelectronics" the main obstacle on the way of introducing RTDs into IC mass production is the lack of a planar technology, so far, to produce RTD-based devices. The scientists from MIET suggested a new approach to solve this problem, based on the know-how in using complex multilayer heterostructures providing planar integration of conventional field-effect transistors and RTDs due to the special design of the heterostructure. Test models (prototypes) of basic ICs have been manufactured.

An ultimate reduction of lithography dimensions make it promising to electronic devices based on electronic waveguides. A new approach is presented in the report to the modeling and design of electronic wave-guides based on the analogy between ballistic transport in electronic WG with variable cross-section and vertical transport in semiconductor heterostructures. The role of quantum barriers and wells in heterostructures is played respectively by constrictions and dilatations of waveguides. Hence analogs of basic elements of semiconductor nanolectronics can be simply "drawn" by lithograph's beam on a two-dimensional conducting layer. This technique permits straightforward realization of splitters as well as of multiple-connected waveguides with complex topology, which opens the way to the creation of complex devices and integrated circuits. It is shown that like the traditional IC which can be represented as an equivalent circuit consisting of basic electric elements: resistors, capacitors, inductances and current sources, waveguides device operation can be described as a result of combination of four basic electronic resonances. The described approach is used to explain the performance of recently proposed logical gates for quantum computers.

Fundamental researches based on heterostructure investigations are presented in the report as well. One of the most problems of contemporary physics is a problem of a dark matter in the Universe. Up to now all the fundamental phenomena in particle physics were shown to have their counterparts in condensed matter physics. In the report recent results were presented which describe the analog of dark matter in condensed matter. The existence of a new type of electron transmission resonance is demonstrated. It is shown that extended microscopic objects can exist in a one-dimensional lattice model which possess anomalous transparency in the case of electron scattering - they are invisible in the low-energy case. These objects are pairs of defects (hidden defect pairs) with antisymmetric defect potentials located at unequivalent sites at certain distances and in a special pattern. The transparency coefficient of an hidden defect pairs equals unity without any phase factors and bound states are absent. This fact sets the described objects apart from the well-known reflectionless potentials. In the continuous case described by effective mass method the effective size of an object can essentially differ from its real microscopic size. Anomalous transparency of an hidden defect pairs corresponds to the collapse of effective defect pair size in the continuous case. The continuous representation of a separate defect is known to be a delta-function potential. However an hidden defect pairs in this case may appear as a structureless homogeneous medium - as if the two defects cancel each other. Without the use of effective mass approximation microscopic objects also can be characterized by an effective size which in this case becomes energy dependent. At a certain energy this size becomes zero and a resonance of a new type takes place manifesting itself through the absence of electron reflection. Anomalous macroscopic behavior of scattering data results from the underlying spatial asymmetry. This scenario seems to be quite universal and proposes a variety of "invisible" objects to exist in condensed matter. Another objects of this type are a quantum well in the lattice model without center of inversion with foreign atoms at the heterojunctions and a defect pair in the generalized asymmteric Kronig-Penney model, which will be described in a forthcoming publication.