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The results of the 16th all-Russian youth conference on semiconductor and nanostructure physics and semiconductor opto- and nanoelectronics

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Abstract

The paper summarizes the results of the conference and describes the conference organizers and sponsors. The high standards for the materials submitted by undergraduate and graduate students were set by reports from two guest speakers of Ioffe Physical–Technical Institute. The paper includes an analytic review covering reports from all six sections of the conference and lists all reports that have been commended by the Program Committee and awarded certificates and money prizes. A number of reports were recommended for participation in the Member of Youth Science and Innovation Competition program in the 'Scientific results which have significant novelty and the prospect of commercialization' category and shall be further funded by the Foundation for Assistance to Small Innovative Enterprises in Science and Technology.

Keywords: Physics of semiconductors; Nanostructure; Optoelectronics; Nanoelectronics.

The 16th all-Russian youth conference on semiconductor and nanostructure physics and opto- and nanoelectronics took place on November 24–28, 2014 in the conference center of the St. Petersburg Academic University. This traditional event was organized by St. Petersburg Polytechnic University, St. Petersburg Academic University and Nanotechnology Research and Education Centre of the Russian Academy of Sciences, Ioffe Physical–Technical Institute of the Russian Academy of Sciences, and St. Petersburg State University.

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The conference was held with the support of the Russian Foundation of Basic Research (RFBR project 14-32-10042), the non-profit Dynasty Foundation, and the ATC-Semiconductor Devices company.

The organization of the conference owes much to the efforts of the Program Committee, headed by a member of RAS Dr. R.A. Suris of Ioffe Physical–Technical Institute, and the Organizational Committee, headed by Dr. L.E. Vorobiev, of St. Petersburg Polytechnic University.

The conference's published proceedings consisted of ninety-two reports by undergraduate and graduate students from more than twenty universities and research centers of thirteen Russian cities such as Moscow, St. Petersburg, Ekaterinburg, Nizhny Novgorod, Penza, Volgograd, Tula, and Taganrog.

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(Peer review under responsibility of St. Petersburg Polytechnic University).

The conference program included two reports by guest speakers who are among the foremost Russian scientists. These were 'Nitrides: the 4th Nobel Prize on semiconductor heterostructures' by a corresponding member of RAS Dr. P.S. Kopyev, and 'The 21st century is the era of precision cosmology' by Dr. A.V. Ivanchik (both of Ioffe Physical–Technical Institute).

The students gave forty-one spoken reports during the nine plenary sessions. A poster session, during which forty-three reports were given, was held in six sections that were 'Bulk properties of semiconductors'; 'Structure growth, surface and interfaces'; 'Heterostructures, superlattices, quantum wells'; 'Quantum wires, quantum dots and other low-dimensional systems'; 'Optoelectronics and nanoelectronics devices'; 'Novel materials'.

Analytic Review

The conference program covered the main trends of modern semiconductor and nanostructure physics and semiconductor opto- and nanoelectronics in Russia. These are the studies of bulk properties (electrical, magnetic, optical, luminescent and photoelectric) of new and traditional materials and a comprehensive analysis of semiconductor surfaces and interfaces. Heterostructures and low-dimensional structures are also widely studied. The conference participants presented reports on quantum well, quantum wire and quantum dot and nanocluster structures, and nanocomposites and other new materials and structures. There was a pronounced interest in carbon-based structures, e.g. fullerenes, carbon tubes, and graphene. The discussion touched upon the problems of fabricating semiconductor structures and devices. Prominent Russian scientists communicated to the young researchers the problems of modern physics and the state of research in semiconductor and nanostructure physics as well as in opto- and nanoelectronics. These reports set a high standard of discussion for each working day of the conference.

Among the reports that have been presented in the 'Bulk properties of semiconductors' section those meriting particular attention are the results of studies of physical properties and technologies of materials and structures based on group III B-nitrides. These are a theoretical and experimental study of the optical properties of *n*-GaN/sapphire microstructures in infrared and terahertz ranges, which may be useful in manufacturing the sources of terahertz radiation; an analysis of photoconductivity spectra (registered for the first time) and the photoexcitation kinetics of indium nitride for interband transitions at room and helium temperatures. The results of the dislocation structure study of bulk layers of gallium nitride grown on patterned sapphire substrates are of much practical importance. Interesting results were obtained in the study of the electric properties of multicomponent chalcogenides of negative magnetoresistance at high pressures and low temperatures in a Cu–In–As–Se system; of current relaxation in a disordered Pb_3O_4 semiconductor; in a theoretical study of magnetization oscillations and exciton spectrum in irradiated ferromagnetic semiconductors; of energy interchange of phase-modulated beams in gyrotropic photorefractive crystals.

Reports from the 'Structure growth, surface and interfaces' section cover a wide array of studies on surface morphology, relief, and surface potential distribution, nanocluster formation, and atomic level analysis of the initial stages of growth and interface formation in heterostructures. The studies used the most up-to-date technologies, such as molecular-beam and gas-phase epitaxy, ion–plasma sputtering, and electrochemical anodic oxidation, among others.

One of the most promising works in this area had the goal of researching the possibilities of boron chloride plasma treatment for ohmic contact formation in GaN/AlGaN-based structures; others developed a method of analyzing stress–strain material states by diagnosing sample surface roughness using atomic force microscopy. Studies into the interaction of hydrogen with dislocations in silicon have yielded results that may be instrumental in improving the performance parameters of silicon-based solar cells through the enhancement of the hydrogenation process.

Some other problems discussed were the influence of microstructure on the nature of nonequilibrium processes in lead selenide films; the epitaxial growth of a hexagonal modification of silicon on sapphire; a method for estimating layer thickness in a 3C/6H SiC structure; hydrogen absorption and vacancy formation on a 2D boron surface; the growth processes in ultrathin cobalt and cobalt silicide films on a Si(111) surface; the potential of a method of incongruent vaporization for growing type A_3B_5/A_2B_6 multi-component nanoheterostructures.

Noteworthy studies were conducted on the formation of low-dimensional Al_2O_3 films on porous silicon substrates and on the examination of nanometric areas with the use of scanning spreading resistance microscopy.

The Program Committee commended the works on terahertz reflection and emission associated with nonequilibrium surface plasmon polaritons in *n*-GaN, and on the processes of ion implantation in photosensitive structures backside-illuminated using

the method of electrochemical capacitance–voltage profiling.

The greatest amount of reports were presented in the 'Heterostructures, superlattices, quantum wells' section. The focus of the attention was on the formation and examination of silicon-based structures, as well as A_3B_5 and A_2B_6 semiconductor compounds, the solid solutions based on them and the investigation of their energy spectrum. Results of theoretical and experimental studies on graphite, graphene and silicene, were introduced.

Radiation, absorption, reflection and emission, photoelectric properties, electron transport and magneto-optical effects were studied experimentally and theoretically. A number of works were dedicated to the improvement of the parameters of nanostructures for various instrumental applications. Particularly significant experimental works include the studies of photoluminescence and intersubband light absorption by electrons in double quantum wells, of spatial dispersion in the reflection of light from a single symmetric ZnSe/ZnSSeMg quantum well, of the intersubband absorption modulation in GaAs/AlGaAs double tunnel-coupled quantum wells, of resonant photoluminescence in a magnetic field of a thin GaAs/AlGaAs quantum well, of transport properties of heterostructures with ZnCdSe-based quantum wells and ZnSe/ZnSSe superlattices, of relaxation dynamics in polariton lasers using the two-pulse pump method, of gallium arsenide structures with carbon delta-layers using the method of photo reflection. Mid-infrared range photoluminescence in type II InAs/GaSb quantum-well structures and electric resistance and magnetoresistance of graphite and graphene at cold compression.

Another work deserving a specific mention was the experimental study of reflection spectra and Kerr rotation in a parabolic quantum-well microresonator, with observations and analysis of Rabi oscillations of the Kerr rotation signal kinetics carried out. (This report received the E.F. Gross prize.)

The study of the photoluminescence of GaP(As)N-layered heterostructures grown on silicon and gallium phosphide substrates and the study of the influence of growth interruption time on AlGaAs/GaAs superlattice structure are of practical interest. The results of a study of electric and photoelectric properties of *n*-Si/*p*-CdTe anisotype heterojunctions and the design of a production technology might prove promising for solar energy industry.

Noteworthy theoretical works are the studies of the role of polar optical phonons in combined light scattering spectra for strained short-period GaN/AlN superlattices, of electron transport in disordered multi-barrier structures based on graphene with a spatially inhomogeneous Dirac gap, of pure spin currents under Auger recombination in quantum wells with Rashba–Dresselhaus splitting, of temperature control of optical qualities of hyperbolic metamaterials, of constructive and effective silicene Hamiltonian, of exciton states in nanosized EuO–SrO heterosystems, and of 2D electron gas transport in an infinite waveguide with a finite inhomogeneity that is an infinite-length region with a Rashba–Dresselhaus spin-orbit coupling.

A significant number of reports in the 'Quantum wires, quantum dots and other low-dimensional systems' section were dedicated to studying the electric, optical and photoelectric properties of nanostructures of various sizes as well as the method and conditions of their creation. A series of experimental and theoretical works on heteroepitaxial quantum-dot structures comprise studies of the conditions of quantum dot formation and growth in traditional Ge/Si and InAs/GaAs systems, of InSb quantum dots in a InSb/InAs system, of InAs dots in InAs/GaSb and InAs/AlGaAsSb systems; of the processes of charge carrier transfer from a single layer and vertically-aligned InAs quantum-dot arrays into a *n*-GaAs matrix; of local mechanical strains, deformations and the component composition of a single InGaAs/GaAs quantum dot; of photoelectric and optical properties of thin nanostructured indium oxide films with cadmium telluride quantum dots; of the dynamic Burstein–Moss shift in Ge/Si quantum dots; of a theoretical calculation of electron states in a quantum dot formed on the edge of a 2D topological insulator.

Another area of research is the study of colloid quantum dots, or core-shell-type structures. Some of the experimental works that should be mentioned in this regard are the study of luminescence in 'Colloid quantum dots of lead sulfide–porous silicon'-type structures; a theoretical analysis of electron energy spectrum in a type II core-shell quantum dot; the investigation of misfit dislocations in solid and hollow composite type core-shell nanoparticles.

Among particularly attention-worthy works in the area of quantum wire research were ones dedicated to the investigation of the electron energy spectrum in InAs nanowires with an intrinsic conductivity, the experimental verification of the possibility of positioning quasi-one-dimensional quantum objects such as wire-like crystals and carbon nanotubes with the use of a variable electric field, the study of boron–carbon nanotubes modified with atoms of alkali metals. Designs of chemical and biological sensors based on carbon nanotubes modified with carboxyl groups were presented.

There has been an increased interest in porous materials; the results of investigating porous silicon powders using the method of capillary condensation were discussed; the researchers developed methods of obtaining SiO_2–SnO_2-system porous matrices, examined Pb-centers in porous silicon using the EPR method, studied the formation processes of ordered micro- and nanosized capillary membranes based on anodic aluminum oxide (Al_2O_3).

Among the experimental works commended by the Program Committee were studies of exciton states and energy relaxation in quantum-sized ZnCdSe structures with self-organized quantum dots, and among the theoretical works were the studies of the possible applications of metal and dielectric nanoantennas for enhancing the effectiveness of photovoltaic systems.

Reports from the 'Optoelectronics and nanoelectronics devices' section described a wide array of applied areas of modern opto- and nanoelectronics. Holding the most promise in practical application are the investigations of light-emitting structures based on wide-gap group III semiconducting nitrides. Some of the topics discussed were the problems of radiation extraction from nitride–LED structures with textured interfaces, the technology of creating nonalloyed ohmic contacts for AlGaN/GaN structures, finding the optimal conditions ensuring the maximum efficiency of an ultraviolet AlGaN/GaN heterostructure-based LED operation.

There is a persistent interest in problems of solar energy transformation. The conference saw introduced the results of a comprehensive study of the influence of post-growth technology on the photoelectric properties of InGaP/Ga(In)As/Ge multi-junction epitaxial heterostructure-based solar cells; an experimental model of a multi-junction solar cell was devised that allowed to determine the *p*–*n* junction properties for each sub-element.

Notable studies aimed at designing emission sources for integral optoelectronic circuits and quantum cryptography systems. These included the study of lasing in ultrasmall ring and disc microresonators with an InAs/InGaAs quantum dot-based active area, devising a method of undesired mode suppression in emission spectra of microdisc resonators with a quantum-dot-based active area.

Some studies were directed at solving specific applied tasks, such as developing and validating the composition of microlens made of low-melting highly-refractive As–Sb–S–Se–I–system glass and a deposition technology for infrared LEDs, designing ohmic contacts for *m*-HEMT heterostructures on gallium arsenide substrates, obtaining and examining thin $BaTiO_3$ films that may be used in nanoelectronic cooling devices, engineering scintillation detectors based on gallium arsenide *p*–*n* structures grown by molecular beam epitaxy (MBE).

Fascinating designs for manufacturing a field transistor with a non-uniformly doped nanowire channel that demonstrated a high field/charge sensitivity (field and charge sensors) were proposed.

The conference was the first introduction of designs recommended for implementation in a university student laboratory workshop. These are a laboratory device for studying spin phenomena in materials that show promise in nanotechnology, an ODMR (optical detection of magnetic resonance) spectrometer, a working model of a setup for the experimental study of *p*–*n* junction properties in single- and multi-junction solar cells that was adapted for a student laboratory.

The sessions of the 'Optoelectronics and nanoelectronics devices' section yielded high quality reports holding promise in practical applications. Four reports from the section were awarded grants as part of the Member of Youth Science and Innovation Competition ('UMNIK' in Russian) program in the 'Scientific results which have significant novelty and the prospect of commercialization' category.

The reports submitted to the 'Novel materials' section were dedicated to studying the photoluminescence and dynamics of excited electron states in organic and inorganic–organic fullerene-based composite materials that may be used in solar cells, photo emitting structures, memristors, and other organic electronic components; creating an optical method for establishing the chemical and element composition of graphite oxide; studying the electric properties of amorphous Ag-Ge-As-S chalcogenides containing carbon nanotubes; developing a technology for producing magnetic composites based on nanosized ferrite particles integrated into a silicon dioxide matrix, and colloid clusters based on silicon dioxide with a Fe_2O_3 nanoparticle shell.

Intriguing results were obtained in the field of synthesis of nickel, cobalt and manganese oxide nanocrystalline films and their application as supercapacitor electrode materials.

The scope of the conference encompasses the main research trends of semiconductor physics and semiconductor opto- and nanoelectronics. The current focus of attention is the study of quantum-sized structures, heterojunctions, and devices based on them. These problems are considered top-priority in modern semiconductor physics. The greatest advances have been made

in the field of optoelectronics, and in quantum well and quantum dot laser physics in particular. These are, firstly, fabricating and studying new materials, such as organic semiconductors, graphene and its derivatives, and nanoporous materials, and, secondly, designing and manufacturing new devices.

Twenty of the conference reports were supported by twenty-three RFBR (Russian Fund of Basic Research) grants, three reports by the Russian Federation President's grants for young scientists, and eight reports by the Ministry of Education and Science grants. Three other participants received financial support from other funds and government programs. A study by M.Ya. Vinnichenko, a candidate of physical and mathematical sciences and a lecturer of St. Petersburg Polytechnic University, was conducted as part of an international collaboration program.

Reports commended by the Program Committee

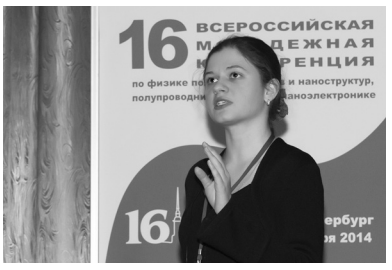
The Program Committee awarded certificates and money prizes to the following participants:

The E.F. Gross prize of 5000 roubles for the best report in semiconductor optics was awarded to:

Maxim Eremenko, a Ioffe Physical–Technical Institute post-graduate student, for 'Exciton states and energy relaxation in quantum-sized ZnCDSe structures with self-organized quantum dots'.

Natalia Kopteva, a St. Petersburg State University undergraduate student, and A.V. Mikhailov, a St. Petersburg State University graduate student, for 'Rabi oscillations in a parabolic quantum well microresonator'.

A first degree certificate and a prize of 4500 roubles were awarded to **Xenia Baryshnikova** (pictured), a post-graduate student of St. Petersburg State University of Information Technologies, Mechanics and Optics, for 'Silicon nanoparticles in thin-film photovoltaic elements'.



X.V. Baryshnikova, a post-graduate student of St. Petersburg State University of Information Technologies, mechanics and optics graduate, presents her report

Second degree certificate and 3500 roubles prize were awarded to:

Yekaterina Azarova, a post-graduate student of N.I. Lobachevsky State University of Nizhny Novgorod, for 'Electron transport in disordered multibarrier structures based on graphene with a spatially inhomogeneous Dirac gap'.

Artur Trifonov, a post-graduate student of St. Petersburg State University, for 'Studying the relaxation dynamics in polariton lasers using the two-pulse pump method'.

Moscow State University students **Ivan Bozhyev** and **A.V. Rzhevsky**, for 'A field transistor with a nonuniformly doped nanowire channel';

Lyubov Kotova, a Baltic State Technical University student for 'The effects of spatial dispersion in the reflection of light from quantum wells';

Kirill Koshelev, a St. Petersburg Polytechnic University student, for 'Temperature control of the optical qualities of hyperbolic metamaterials'.

Third degree certificate and 2500 roubles prizes were awarded to:

Grigory Melentyev, a St. Petersburg Polytechnic University graduate student, and Anatoly Sofronov, a Candidate of physical and mathematical sciences and a St. Petersburg Polytechnic University associate professor, for 'Terahertz reflection and emission associated with nonequilibrium surface plasmon polaritons in *n*-GaN';

Dmitry Pan'kin, a St. Petersburg State University post-graduate student, for 'The role of polar optical phonons in combined light scattering spectra for strained short-period GaNAlN superlattices';

Eduard Moiseev, a St. Petersburg Academic University student, for 'Lasing in ring and disc ultrasmall microresonators with an InAs/InGaAs quantum dot-based active area';

Dmitry Rybalko, a St. Petersburg university undergraduate student, and Roman Balagula, a St. Petersburg Polytechnic University post-graduate student, for 'Intersubband absorption modulation in the GaAs/AlGaAs double tunnel-coupled quantum wells'

Certificates were awarded to the following post-graduate students:

Alexander Abrosimov, of N.I. Lobachevsky State University of Nizhny Novgorod, for 'An EPR study of the temperature dependencies of Pb-centers in porous silicon';

Anton Gert, of Ioffe Physical–Technical Institute, for 'An effective silicene Hamiltonian';

Vladimir Degtyarev, of N.I. Lobachevsky State University of Nizhny Novgorod, for 'The influence of

the cross-section parameters on the energy spectrum of InAs quantum dots';

Ivan Krylov, of Moscow State University, for 'Energy spectrum and optical qualities of thin nanostructured indium oxide (III) films with cadmium telluride quantum dots', co-authored by **E.A. Kostikova**, a Moscow State University student, and **K.A. Drozdov**, a Moscow State University junior research fellow;

Ivan Polukhin, of St. Petersburg Polytechnic University, for 'Obtaining and studying the electric and photoelectric properties of *n*-Si/*p*-CdTe anisotype heterojunctions'.

Certificates were awarded to the following students:

Alexander Afanasiev, of St. Petersburg Polytechnic University, for 'Pure spin current generation under Auger recombination in quantum wells with Rashba–Dresselhaus splitting';

Oleg Kirilenko, an undergraduate student of St. Petersburg Polytechnic University, for 'Dynamic Burstein–Moss effect in Ge/Si quantum dots' (with R.M. Balagula);

Pavel Sokolov, of St. Petersburg State University, for 'The influence of the component composition and mechanical strains on the splitting of nuclear spin states in InGaAs/GaAs quantum dots'.

Undergraduate students of St. Petersburg Polytechnic University **Jiang Jiang** and **I.S. Makhov**, for 'Mid-infrared range photoluminescence in type II InAs/GaSb quantum-well structures';

Vitaly Shkoldin, an undergraduate student of St. Petersburg Polytechnic University, for 'A study of the depth of a 3C/6H-SiC structure through cathodoluminescence';

Ivan Shostak, of St. Petersburg Academic University, for 'Controlling the mode composition of microdisc lasers';

Denis Yaichnikov, a student of St. Petersburg Polytechnic University, and **G.A. Melentyev**, a research fellow of St. Petersburg Polytechnic University, for 'The optical properties of *n*-GaN/sapphire microstructures'.

Twelve reports have been recommended for participating in the Member of Youth Science and Innovation Competition program in the scientific results which have significant novelty and the prospect of commercialization category for the purpose of them being funded by the Foundation for Assistance to Small Innovative Enterprises. These are the following reports:

'An ODMR spectrometer for university physical laboratories' by **Andrei Anisimov**, a post-graduate student of Ioffe Physical–Technical Institute;

'A study of porous silicon powders using the method of capillary condensation'; by **Anton Belorus**, an undergraduate student of St. Petersburg Electrotechnical University;

'Experimental model of multi-junction solar cell: IV curve tailoring and photoresponse artifact simulation' by **Svetlana Kozhukhovskaya** and **E.D. Filimonov**, both undergraduate students of Baltic State Technical University.

Post-growth technology influence on the photoelectric characteristics of InGaP/Ga(In)As/Ge solar cells by **Evgeny Kontrosh**, a Ioffe Physical–Technical Institute graduate student, and **A.V. Malevskaya**, a doctoral candidate of the same institution.

'A study of the dislocation structure of GaN bulk layers grown on patterned sapphire substrates' by **Arina Kremleva**, a St. Petersburg State Electrotechnical University undergraduate student;

'Graphite oxide Auger-electron diagnostics' by **Anton Kryukov**, an Ioffe Physical–Technical Institute graduate student;

'Photoluminescence in GaP(As)N-layered heterostructures grown on GaP and Si substrates' by **Alexandra Lazarenko**, a St. Petersburg Academic University post-graduate student;

'An analysis of semiconductor nanoobjects by scanning tunneling atomic force microscopy' by **Natalia Lashkova**, a St. Petersburg Electrotechnical University undergraduate student;

'A layer-by-layer synthesis of semiconductor nickel, cobalt and manganese oxide nanocrystals and their application as supercapacitor electrode materials' by **Artem Lobinsky**, a St. Petersburg State University post-graduate student;

'Designing the structure and infrared LED-attachment technology of low-melting highly-refractive glass microlens' by **Victor Markov**, a St. Petersburg Polytechnic University post-graduate student;

'Microstructure of narrow-gap InSb quantum dots on an InAs substrate' by **Liliya Sokura**, an Ioffe Physical–Technical Institute post-graduate student;

'The processes of ion implantation in photosensitive backside-illuminated using the method of electrochemical capacitance–voltage profiling' by **Georgiy Yakovlev** and **D.S. Frolov**, both graduate students of Saint Petersburg State Electrotechnical University.

Acknowledgments

The organizers express their gratitude to the staff of the St. Petersburg Research and Education Centre of Physics and Technology for providing the conditions that the conference could be held in.

Previous papers summarizing the results of Youth Conferences were always co-authored by M.A. Vasilieva, who put much time and energy into organizing and holding each conference. However, Maria Alexandrovna took her well-deserved retirement from the university in September, 2014. The administration of the semiconductor physics and nanoelectronics department expresses profound gratitude for M.A. Vasilieva's long-standing effort in arranging the conference and wishes her health and prosperity.

The information about the next conference will be posted in September, 2015 on the following page: http://www.spbstu.ru/rphf/conf2015.html.