**ГОСУДАРСТВЕННОЕ ОБРАЗОВАТЕЛЬНОЕ УЧРЕЖДЕНИЕ
ВЫСШЕГО ПРОФЕССИОНАЛЬНОГО ОБРАЗОВАНИЯ
РОССИЙСКО-АРМЯНСКИЙ УНИВЕРСИТЕТ**

# PROCEEDING OF INTERNATIONAL CONFERENCE "ON NEW TRENDS IN QUANTUM AND MESOSCOPIC PHYSICS"

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The collection includes materials from an international conference that took place on 27 June -3 July 2018 in Yerevan, Armenia with the support of the Russian-Armenian University, Yerevan, Armenia, Russian Quantum Center, Moscow, Russia, the government of Artsakh Republic. The collection contains 27 articles by more than 114 authors on the topics: optics and spin phenomena, nanotechnologies and metamaterials, quantum information and quantum technologies, solid state physics and new trends in physics.

It is of interest for specialists in the field of photonics, laser technologyquantum and mesoscopic physics.



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Российско-Армянский университет был создан на основании «Соглашения между Правительством Российской Федерации и Правительством Республики Армения об условиях учреждения и деятельности в Ереване Российско-Армянского университета», которое было подписано 29 августа 1997 года в Москве. Университет является самостоятельным субъектом с правами юридического лица, со своим наименованием и пр. Университет задумывался и уже состоялся как центр российского образования, науки и культуры в Республике Армении и в Закавказском регионе в целом. К работе в РАУ привлечены лучшие преподавательские силы Армении. В университете открыты кафедры, созданные на базе научно-исследовательских институтов Национальной академии наук Армении.

Приоритетной задачей РАУ является подготовка высококвалифицированных специалистов, патриотов своей Родины, осознающих значимость для Армении её неразрывных связей с Россией и способных применить полученные знания в любой точке Земного шара.

## INTRODUCTION

# HEAT-ASSISTED SELF-LOCALIZATION OF EXCITON POLARITONS

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Bosonic condensation of microcavity polaritons is accompanied by their relaxation from the ensemble of excited states into a single quantum state. The excess of energy is transferred to the crystal lattice [1] that eventually involves heating of the structure (Fig. 1a). Creation of the condensate results in the local increase of the temperature which leads to the red shift of the exciton energy providing the mechanism for polariton self-trapping.

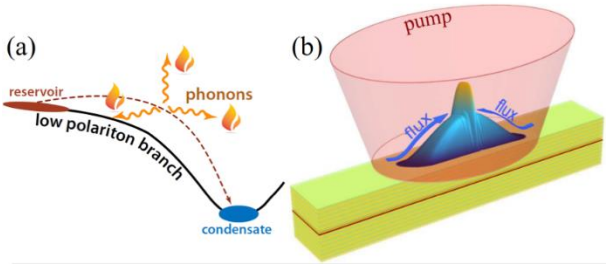


Fig. 1. (a) The schematic showing the dispersion of the low polariton branch and the phonon-assisted scattering processes leading to heating of the crystal lattice. (b) Sketch of a microcavity stripe excited by a non-resonant pump. The polaron solution s formed as the result of interference of the incoming polariton fluxes.

By employing the driven-dissipative Gross-Pitaevskii model we predict a new type of a stable localized solution supported by the thermally-induced self-

trapping in a one-dimensional microcavity structure. We demonstrate that if the heating efficiency exceeds the critical level, the effective nonlinear trapping potential is formed. Because of its driving-dissipative nature the polariton condensates supports the persistent currents flowing towards the center of the trap where the condensate acquires the sink-type structure i.e. it is characterized by the presence of converging density currents, Fig. 1b. We examine the spontaneous formation of these states from the white noise under spatially localized pumping and analyze the criteria for their stability. This finding sheds light on the paradoxical self-trapping effect that seems to contradict the superfluid nature of polariton condensates documented previously [2].

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# QUANTUM MODELS SOLVED IN TERMS OF THE HEUN EQUATIONS

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In conventional quantum mechanics several models are formulated and solved in terms of equations belonging to the hypergeometric class. The hydrogen atom, harmonic oscillator, and $O_4$ symmetry equation are well-known examples. A useful feature of corresponding solutions is that the energy spectrum in each case is calculated explicitly. However, the models are rather stiff in the sense that there is no dependence on an additional parameter.

The quantum problems in which such a dependence on a parameter appears (this dependence is usually referred to as "adiabatic dependence") turn to be considerably more complicated. Several such problems lead to equations belonging to the Heun class [1]. Here is what we presently know about such problems.

- There are no explicit results in simple terms in the general case.
- Modern versions of ACS Maple present computational tools for solutions of the Heun equations. These tools are based on three-terms recurrence relations
- Energy curves appear instead of the point spectrum. It is possible to obtain asymptotic behavior of these curves at small and large values of a parameter. These curves have a specific behavior.
- There exist integral relations for solutions.
- Linear first-order systems are linked with second-order equations. These systems simplify derivation of integral relations.
- Recently, integrable nonlinear equations of the Painlevé class had been derived from the Heun equations via an antiquantization procedure [2].

In this talk we give several examples of quantum models solved in terms of the Heun equations.

- Two Coulomb centers problem
- Hydrogen atom in electrical field
- Periodic potential

- Generalized isotonic potential
- Quartic and sextic oscillators
- The third five-parametric hypergeometric potential

Particular attention is paid to the cases for which the general solution can be simplified and to the Painlevé equations generated by a given quantum problem.

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# SPIN-DEPENDENT RECOMBINATION AND HYPERFINE INTERACTION AT DEEP PARAMAGNETIC DEFECTS

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This contribution is a brief review of the recent experimental and theoretical studies of the effects of hyperfine interaction at deep paramagnetic centers on spin-dependent Shockley-Read-Hall recombination and optical spin orientation in semiconductors and semiconductor nanostructures. Beginning from the pioneer works [1,2], such investigations attract a great interest since the spin-dependent recombination (SDR) can provide an abnormally high (up to 100%) room-temperature spin polarization of free conduction-band electrons, electrons bound at paramagnetic centers and nuclei of the centers in zero and weak magnetic fields [3–14].

The discussed phenomena are illustrated by experiments performed at room temperature on Ga(In)AsN nitride alloys ([N] ~ 1%) and their quantum wells. Paramagnetic centers, responsible for the SDR in these alloys, are the gallium interstitial defects $Ga^{2+}$ [5]. Optical pumping and polarized photoluminescence (PL) are used for creating and measuring spin polarization of free electrons. Spin-dependent capture of spin-polarized conduction-band electrons on deep paramagnetic centers leads to a dynamic spin polarization of the latter. The polarized centers act as a spin-filter amplifying free-electron spin-polarization. At strong pumping, spin polarization of both free and bound electrons can be close to 100% [6].

Hyperfine interaction of spin-polarized bound electron with the intrinsic nucleus of the center exerts considerable influence on the electron polarization

since it is an origin for a strong electron spin relaxation and leads to the dynamic nuclear polarization [15]. The longitudinal magnetic field (Faraday geometry) breaks up the hyperfine interaction and suppresses the bound electron spin relaxation leading to the substantial (up to two times) rise of the circular polarization degree and intensity of the edge PL at weak or moderate pumping [7–11,13]. In its turn, the dynamically polarized nuclei create an effective magnetic field (Overhauser-like field) on the bound electrons, $B_N$ ~200 G, which shifts the magnetic field dependences of the PL polarization and intensity by a value of $B_N$ [7-9,13]. The asymmetry of the dependences increases sharply with a tilt of the magnetic field and disappears at approaching the transverse (Voigt) geometry [12].

A novel effect – electron-nuclear spin beats induced by hyperfine interaction of bound electron with the defect nucleus in zero external magnetic field – has been predicted [13] and observed [14]. Using an original pump-probe technique of detecting polarized PL, the period ~100 ps of modulated beats is measured in $GaAs_{0.98}N_{0.02}$ alloy, from which the hyperfine constants of both gallium isotopes in $Ga^{2+}$ center have been found [14].

The kinetic theory of both continuous-wave and pulsed optical spin orientation and of spin-dependent recombination in a semiconductor in the arbitrarily directed magnetic field is developed. The proposed model describes qualitatively the main experimental findings [11–14].

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# FERMIONIC CHARGE AND CURRENT DENSITIES IN P- AND T- SYMMETRIC 2D MODELS WITH APPLICATIONS TO GRAPHENE RINGS

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Among the most interesting topics in quantum field theory is the investigation of the effects induced by gauge field fluxes on the properties of the quantum vacuum. We discuss the combined effects from the magnetic flux and boundaries on the vacuum expectation values (VEVs) of the fermionic charge and current densities in a two-dimensional circular ring. The examples of graphene nanoribbons and rings have already shown that the edge effects have important consequences on the physical properties of planar systems. In the problem at hand, for the field operator on the ring edges we impose the bag boundary conditions. The distribution of the magnetic flux inside the inner edge can be arbitrary. The boundary separating the ring from the region of the location for the gauge field strength is impenetrable for the fermionic field and the effect of the gauge field is purely topological. It depends on the total flux alone. The latter gives rise the Aharonov-Bohm effect for physical characteristics of the ground state. The consideration is done for both irreducible representations of the Clifford algebra in (2+1)-dimensions. In these representations the mass term in the Dirac equation breaks the parity (P-) and time (T)-reversal invariance.

The VEVs for both the charge and current densities are decomposed into boundary-free, single boundary-induced and the second boundary-induced contributions. All them are odd periodic functions of the magnetic flux with the period equal to the flux quantum. Unlike the case of the boundary-free geometry the charge and current densities in the ring are continuous at half-odd integer values for the ratio of the magnetic flux to the flux quantum, and both of them vanish at these points. An important feature that distinguishes the VEVs of the charge and current densities from those for the energy-momentum tensor is their finiteness on the boundaries. On the outer edge the current density is equal to the charge density whereas on the inner edge they have opposite signs. For fixed values of the other parameters, both the charge and current densities decrease by the

modulus with decreasing outer radius. The boundary condition we consider contains no additional parameters and is a special case in a general class of boundary conditions for the Dirac equation confining the fermionic field in a finite volume. It is the most popular boundary condition in the investigations of the fermionic Casimir effect for various types of the bulk and boundary geometries.

# GRAPHENE BASED METASURFACE FOR THZ APPLICATIONS

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Growing interest in THz science is due to its many important applications, including THz imaging, microscopy, non-destructive testing, tomography, medical diagnosis, health monitoring, environmental control, chemical and biological identification, and in future communication networks. These applications require efficient, durable and robust components capable of generating, manipulating and detecting of THz radiation [1]. According to just published "The 2017 terahertz science and technology roadmap" [2] among the most important challenges are passive quasi-optical components, i.e. shields, filters, polarizers and collimators.

The main drawback of existing THz components is their restricted tunability, which is the must for future THz devices. We propose to resolve the problem by combining unique properties of graphene [3], including its ability to tune the Fermi level with external doping or biasing, with the outstanding opportunities that gives the metasurface paradigm [4], i.e. 'designer' materials technology (see [5] for negative refractive index metamaterials and electromagnetic (EM) cloaking).

The concept of EM components relying on plane graphene structures has been proposed in our recent works [6, 7]. As a next step, in this communication we propose graphene-based metasurface composed of array of hemispheres in order to design tunable passive components THz applications.

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# IMPLICATIONS OF F.R.E.T. IN INVISIBLE INKS FOR ORGANIC PHOTOVOLTAIC/SECURITY APPLICATIONS. PRELIMINARY INVESTIGATIONS WITH ORGANIC DYES

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## ET-INKS INDEX

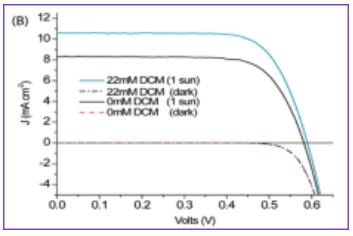
### 1. Induced Energy Transfer

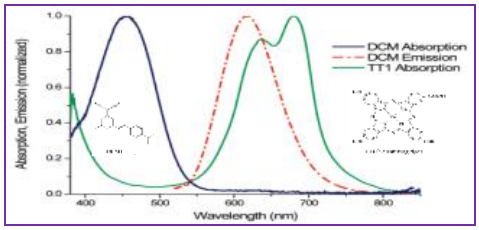
→ Focus on kinetic treatment of Energy Transfer Coulombic Mechanism

$$\eta_{ET} = 1 - \frac{\Phi_{DA}}{\Phi_D} = 1 - \frac{k_r^D + k_{nr}^D + k_q[A]}{k_r^D + k_{nr}^D} = \frac{k_q \cdot \tau_D^0 \cdot [A]}{1 + k_q \cdot \tau_D^0 \cdot [A]}$$

### 2. F.R.E.T. Effect Increase Device Efficiency

→ Focus on Dye Solar Cells Sensitized with Organic Dyes: Chemi/Physi – Sorbed Dyes

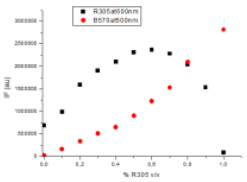



→$\Delta\eta_{PC} \approx 20 \div 80$ % Dye concentration and Thickness/Morphology film dependent

### 3. Preliminary F.R.E.T. Work

→ Focus on Formulated Inks: Actions and Spectro-Fluorimetric Analysis



→CIE CoordinatesMeasurements – SomeConsiderations

**4. F.R.E.T. Inks Horizons**

→ Focus on Matrixes Formulated with Environmental Friendly Compounds

→ Focus on Potential Layered Interconnections: Incorporation of Organic Dyes in InorganicNetworks of Infinite Chains/Sheets showed by Hybrid Perovskite Materials.

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# DYNAMIC MANY-BODY EFFECTS IN STRONGLY DISORDERED SEMICONDUCTORS

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Properties of disordered solids are of wide current interest, partly because they are virtually ubiquitous in the nature, partly because many are of technological importance and partly because they provide new interesting theoretical challenges. In the localized regime screening is nearly absent; so long range Coulomb interactions are important. Dynamical effects then require dynamical many-body considerations, whether in the inelastic hopping transport such as conductivity, or in elastic transport such as many-body delocalization. The former has been a controversial subject for decades, in good part about the importance of many-body effects (the current prevailing theory disregards such effects [1]). The latter is yet an unsolved problem. In the presence of short range interaction the electronic system was quite convincingly shown to be localized (in Fock space) [2]. But in the presence of long range interaction different researchers came to different conclusions, depending on the approach they used. This presentation discusses a resolution to the controversial conductivity problem and it proposes a new collective many body approach (in contrast to the often used HartreeFock approach [3]) to the question of many-body localization vs. many-body delocalization.

The experimental transport situation is consistent with the many-body theory [4]. Experiments on 2d systems, which in the absence of interactions are always localized, have not provided a definitive answer whether long range interactions can cause (collective) delocalization.

Another frequently observed effect which requires many-body effects (collective transitions) for an explanation are glassy effects observed in a variety of systems with electron concentrations above a few times $10^{19}$ $cm^{-3}$ [5]. These experiments are mostly (but not exclusively) performed in thin films. Interestingly, the very light electrons in these high concentration materials show non-ergodic behavior, namely relaxation times much longer than the duration of any executable experiment. For the light electrons this would be hard to explain without invoking dynamic many-body effects

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# HIDDEN POLARIZATION OF UNPOLARIZED LIGHT

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We consider polarization properties of totally unpolarized emission of an ensemble of classical emitters with randomly varying polarization. The light is supposed to be unpolarized in the sense that all three components of its Stokes vector, averaged in time, are zero and cannot be affected with any phase plate. This fact, however, does not allow us to assert anything definite about mean values of squares of the Stokes-vector components. We show that such unpolarized emission may contain information about polarization characteristics of individual emitters which is, however, stored in its polarization noise. Experimentally, this is revealed in a conventional balanced polarimetric scheme with an additional quarter-wave plate which, leaving the light unpolarized, introduces anisotropy to its polarization noise. The character of this anisotropy depends on whether the randomly fluctuating light polarization uniformly covers the whole Poincaré sphere, or is preferentially located in the vicinity of its equator, or near its poles. Vitality of the method is illustrated by its application to polarization analysis of the polariton Bose-condensate emission, whose intrinsic polarization properties are usually studied in the regime of pulsed excitation.

# BRIGHTENING OF THE EXCITON GROUND STATE IN CARBON NANOTUBES IN THE STRONG LIGHT-MATTER COUPLING REGIME

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We propose a scheme to maintain a robust radiative ground state in semiconductor single-walled carbon nanotubes (SWCNT). For that purpose, we employ a microcavity operating in the regime of strong coupling between the confined electromagnetic mode of the cavity and the excitonic resonance in an ensemble of carbon nanotubes (see Fig. 1).

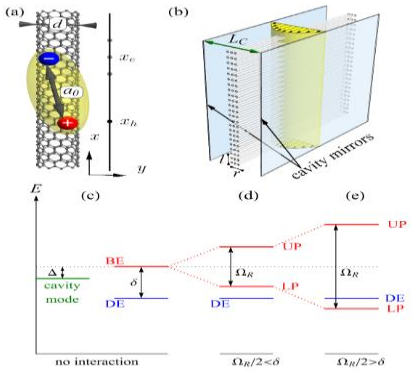


Figure 1. (a) A sketch of a semiconductor carbon nanotube, of diameter d, containing an exciton (bound electron-hole pair) and its 1D mathematical representation. (b) The geometry of the structure considered: a planar microcavity with an array of aligned carbon nanotubes embedded in a position such that the electric field of the confined cavity mode (shown in yellow) reaches its maximum at the centre of the cavity. Strong coupling between bright excitons and confined photons leads to the formation of hybrid polariton modes in the system, which for sufficiently large coupling become radiative ground state of the system (LP), while the bare nanotube has dark exciton (DE) as a ground state (c-e).

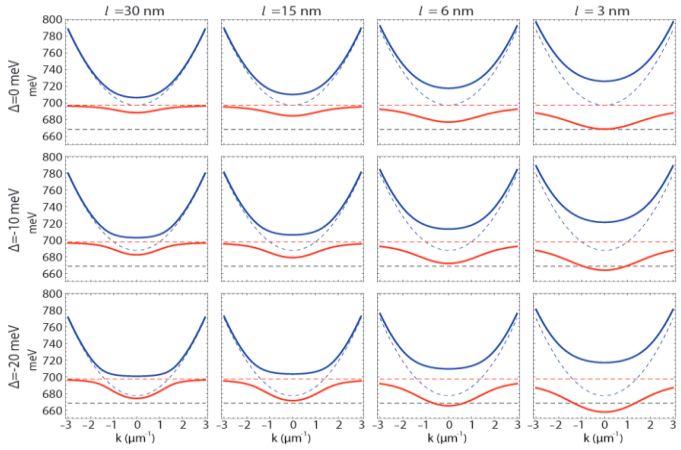


Figure 2. The dispersions of the polariton modes versus those of bare excitons and cavity photons for different detunings (from top to bottom) and nanotube separation distances (from left to right) for the case of a (10,0) SWCNT. The dashed lines correspond to the bare photon (blue), bright exciton (red) and dark exciton (black) modes, solid red and blue lines correspond to the upper and lower polaritons, respectively. One clearly sees that the decrease of the inter-tube separation results in the increase of the Rabi splitting. Consequently, the lower polariton mode moves down in energy and for certain separations can cross the dark exciton. In this situation the brightening of the ground state of the system takes place.

A high value of the interband dipole matrix element in nanotubes makes the light-matter interaction extremely efficient and enables the achievement of the ultra-strong coupling regime. Radiative excitonic states become dressed by cavity photons and form polariton states, which experience a huge vacuum Rabi splitting. The energy of the lower polariton moves downwards and can go beneath the energy of the dark exciton, and thus the ground state of the system becomes radiative (Fig. 2). This leads to the radical enhancement of luminescence and opens new prospectives for potential optoelectronic applications of carbon-nanotube-based structures. The further details of the investigation can be found in **arXiv:1710.02764**.

# FAR-IR OPTICAL RESPONSE OF POSITIVELY CHARGED GE/SI QUANTUM DOTS

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The experimental studies of the optical absorption spectra of structures with Ge/Si quantum dot arrays with different doping level in the far-IR spectral range were carried out. The absorption peak related to the lowest interlevel resonance, i.e. to the optical transition of holes from the ground QD state to the lowest excited state, was experimentally detected both in the doped QD structures and in the undoped structure under conditions of external optical interband excitation of the charge carriers. The optical responses of the QDs with different nominal doping level, including the structures with the average number of holes per dot exceeding unity, as well as the optical response of undoped QDs under interband optical excitation, are found to be identical at low temperatures.

An analytical theory of the size quantization of interacting holes in a lens-shaped Ge/Si QDs was developed taking into account the Coulomb repulsion of the holes in QD. We show that the interaction has no effect on the energy gap between the ground and the lowest excited states as a consequence of the applicability of the generalized Kohn's theorem due to the specific geometry of the QD. The effective parabolic confinement potential arises for the in-plane motion of holes in this case due to the possibility of the adiabatic separation of the in-plane motion and the motion along the growth axis. The theoretical value of the lowest interlevel resonance energy is in a good agreement with the experimental spectral position of the absorption peak taken from the measured low-temperature spectra.

Some specific features of the lateral distribution of the holes over the QDs are also discussed. The temperature dependence of the broadening of the far-IR

absorption spectra is found to be different for the QDs with different average number of holes per dot.

In conclusion, the theory of the quantum confinement of the interacting holes in the QD with lens-shaped geometry approves the experimentally observed single-particle-like behavior of the intra-dot optical transitions in the system with charged quantum dots with more than one holes inside.

# ANTIQUANTIZATION AS A NEW FIELD IN QUANTUM MECHANICS

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In the papers of E. Schrodinger the quantum mechanics appeared as a result of: 1) Hamiltonian formalism and 2) linearization. Early efforts to invert this process undertaken, for instance by H. Weil were not satisfactory because of absence of commutability between quantum operators – momentum and coordinate. The theory of integrable nonlinear Painlevé equations gave rise to new links from linear equations to classical dynamics. Once again the crucial role plays the hamiltonian structure of Painlevé equations discovered by Malmqvist. Three decades ago one of the authors (1) proposed a procedure which generates Painlevé equations from Heun class equations (2). This procedure later was called antiquantization. Two modification of this procedure were proposed. In one modification Heun class equations are taken as a starting point (3). In the other approach deformed Heun class equations with one added apparent singularity is chosen (4). The antiquantization means substitution the classical variables instead of quantum operators of coordinate and momentum into the corresponding Hamiltonian. For a long time unsolved was the problem of proper normalization of the Hamiltonian since in principle it could be multiplied by arbitrary function of parameter. Recently solution of this problem was found (5).

The complete list of Heun class equations includes ten equations. It covers six Painlevé equations also with particular values of parameters. Derivation of the results in ever case is a troublesome procedure. Therefore a maplet in the frame of Algebraic Computing System Maple was developed (6) [6]. The advantage of Painlevé equations among other nonlinear ODEs is due to analytical property of their solutions on the Riemann surface of independent variable. It gives the possibility to construct relations between their solutions similar to the scattering matrix in quantum mechanics.

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# INTERFACING DISCRETE- AND CONTINUOUS-VARIABLE ENCODINGS IN QUANTUM OPTICS

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Quantum technologies are realized in systems of different nature [1]. Photons are suited for transmission, weakly interacting spins can serve as quantum memory, while the most promising platforms for quantum information processing are implemented in superconducting circuitry. The quantum technology of the electromagnetic field, to serve as an efficient intermediary among various systems, should permit interconversion between continuous- and discrete variable encodings of quantum information. Such interconversion is achieved through entanglement and teleportation [2].

The most common discrete-variable (DV) approach to encoding quantum information in an optical wave is the dual-rail(horizontal and vertical polarizations of a single photon) or single-rail(vacuum and single-photon optical states) qubit. In the continuous-variable(CV) domain, a light qubit can be encoded as a superposition of coherent states - Schrödinger's cat state(SCS). SCSs are of wide interest both from fundamental and practical points of view [3,4].

The first important step towards interconverting between DV and CV has been reported in 2014 by two groups [5,6]. They constructed an entangled state between the CV qubit and a single-rail DV qubit. Subsequently, this state has been employed as a resource for rudimentary quantum teleportation between these qubits [7].

However, there are circumstances that make application of single-rail qubits problematic in quantum information processing. First, the single-rail encoding of the qubit complicates single-qubit operations [8] and also enhances the qubit measurement errors associated with optical losses and inefficient detection. Second, for most of applications, it is necessary to have SCSs of high amplitude. But existing methods of optical SCS preparation[9] allow generating cats only with relatively small amplitudes.

Here we present two experiments aimed to overcome these obstacles:

1. The use of a dual-rail qubit instead of a single-rail one in the hybrid resource state could solve the first group of problems. We prepare the hybrid state in which a CV optical qubit is entangled with a qubit encoded in the polarization of the photon (which is typically used for discrete-variable encoding in quantum optics)[10]. In order to confirm the entanglement, the tomography of the continuous-variable part of the entangled state is performed after projecting the DV mode onto diagonal, canonical and circular polarization basis states. This tomography results in the observation of coherent states and their equal-weight superpositions. Also, we applied this scheme for the teleportation of a dual-rail qubit, encoded by means of H/V polarized single photon, onto a continuous variable qubit which is a superposition of positive and negative SCSs.

2. We implement a method of amplifying optical SCSs. In the experiment, we convert a pair of negative SCS of amplitude 1.15 to a single positive SCS of amplitude 1.85 [11]. This method can be applied itteratilvely what in principle allows to create SCSs. of arbitrary high amplitudes.

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# EXCITON-PLASMON INTERACTION IN THE RANGE OF RESONANT SYSTEMS COUPLED TO SILVER NANOPARTICLES OBTAINED VIA PHYSICAL VAPOR DEPOSITION

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Interaction between different resonant systems leads to the promising photonic and electronic applications. Localized surface plasmons in coinage metal nanoparticles provide for electromagnetic field enhancement and localization that may be harvested by semiconductor quantum dots, organic dye molecules and even free atoms in a vapor phase. Despite numerous laboratory demonstrations coupled exciton-plasmon systems have not been included in the real world devices. The main reason for that is the cost of production and fragility of the obtained nanostructures. In this contribution I am going to present several experimental realization of exciton-plasmon coupling based on the localized plasmon resonances in the coinage metal nanoparticles obtained via physical vapor deposition. This well developed inexpensive technique leads to the production of robust solid state thin films with pronounced tunable plasmon bands. At the next step spin coating provide for the formation of a spacer layer and finally for coupling to the resonant system at ones choice.

In the simplest realizations we observed the largely enhanced absorption of different organic dyes, in particular, cyanine dyes spread over the surface of granular silver films supporting localized plasmon excitation. In addition to the influence of the plasmon near field on the dye molecules, the action of the dye on the plasmon resonance was observed as well. In particular, a dip in the plasmon absorption band was observed just in the neighborhood of the J-aggregates absorption band as a consequence of the strongly modified dielectric environment in the range of dye anomalous dispersion.

The fluorescence enhancement was observed as well provided the appropriate thickness of the spacer layer is chosen. Of course, there is no enhancement if the spacer layer is too thick, while at too narrow or absent spacer the fluorescence is quenched. Same observation was made with colloidal quantum dots spread over the granular silver film.

An interesting effect of stimulated emission of dye molecules was observed under pulsed laser excitation. The excitation wavelength was carefully chosen to be out of the plasmon band, while the emission of the dye overlaps with the plasmon band considerably. Several fingerprints of the stimulated emission like the emission band narrowing, generation threshold as well as the peculiar angular and polarization characteristics were observed. Contrary to the numerous previous observations of spaser action in different systems, stimulated emission from the thin film was observed predominantly at the right angle to the film, thus excluding the competing mechanisms based on the propagation of light from one plasmon nanoparticle to another.

We have also realized a reversed system where an ensemble of plasmon nanoparticles was produced via physical vapor deposition over the surface of a semiconductor nanostructure already containing the buried semiconductor quantum dots. In particular, InAs epitaxial QDs were obtained using Stranski-Krastanow mechanism and buried in GaAs. Then, a thin silver layer was added via physical vapor deposition in a vacuum chamber. Scanning electron microscopy reveals a dense labyrinth structure of silver deposits. After annealing at 200°C for two hours, isolated silver NPs with broad size distribution in the range of 20 to 100 nm were formed above the layer of buried InAs QDs. The InAs QDs showed a strong photoluminescence (PL) near 1.1 eV with the width of 0.07 eV. After the formation of Ag NPs, the PL intensity increased by the factor of 2.4. As compared to the ordinary case of colloidal quantum dots spread over the surface of granular metal film provide an advantage of quantum dots inclusion in the high quality semiconductor wafer, thus enabling advanced photoelectric application.

Finally I am going to discuss the possibility to couple localized surface plasmons with the resonances in free atoms approaching the surface. In this case a new and unusual circumstance is that the atoms are moving and their polarization is in the transient regime rather than in the steady state.

This work was supported by RFBR (16-02-00932) and the Ministry of Education and Science of Russian Federation (3.4903.2017/6.7).

# NON-LINEAR HALL EFFECT IN CYLINDRICAL NANOSHELLS WITH TWO-DIMENSIONAL ELECTRON GAS

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With the method of strain-driven nanostructuring [1], we fabricated 192 nm thick cylindrical shells consisting of GaAs/AlAs heterostructures with two-dimensional electron gas (2DEG) in a quantum well of 13 nm width. In a uniform external magnetic field, electrons are governed by the Lorentz force, which is determined by normal to the surface component of the magnetic field: $Bn = B_0 \cdot \cos\varphi$, where $B_0$ is the applied magnetic field, $\varphi$ is the angle between the surface normal at this point, and $B_0$ direction (Fig. 1). Spatial distribution of the Bn on the sample surface is precisely controlled by the angle a given by the Hall bar width, and the rotation angle j, that was set and changed during magnetotransport measurements. So, we were able to set the value of Bn gradient, and also to produce sign-changing Bn on the sample width.

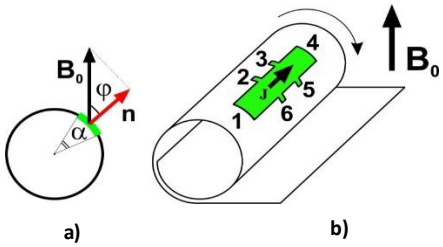


**Fig.1** Schematic view of the contacted cylindrical nanoshell with 2DEG: **a)** cross-section and **b)** 3D view of the cylindrical shell with the Hall bar. **φ** is the angle between the surface normal and the external magnetic field $B_0$; α is the angle between the sides of the Hall bar. 1 and 4 are current probes, Hall voltage is measured with probes 2–6. and 1–5.

The details of contacted shell fabrication are published in [2,3]. In this work, Hall bars were oriented along the cylinder's axis, in order to set current direction perpendicularly to the Bn gradient. We performed magnetotransport measurements at 4.2 K in the magnetic fields up to 3T. Several Hall bars of different width were investigated. The narrowest Hall bar (a=14°) having the least Bn drop on its width, demonstrated Rxx(B) and Rxy(B) dependencies very similar to the 2DEG in tilted

magnetic fields. On wider Hall bars, a non-linearity in their Hall dependencies appears and increases with sample width growth. The Rxy(B) of the widest shell (a=180°) demonstrates sign change in weak fields (curves 3-7, Fig.2) We suggest an explanation of the observed effects in Rxy(B) taking into account contributions of differents types of electron trajectories that form on the presence of the Bn gradient: skipping, cycloid and snake-like [4]. The corresponding simplified calculations qualitatively describe experimental results.

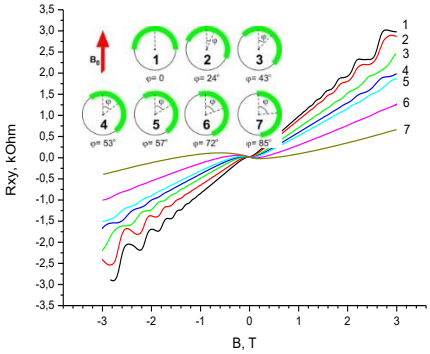


**Fig.2** Rxy(B) of the widest Hall bar ($\alpha = 180°$) at different rotation angles. Its corresponding orientations with respect to $B_0$ are shown on the inset. Ccurves 3–7 demonstrate Hall constant sign change in weak fields.

Cylindrical nanoshells with 2DEG give the unique opportunity to control the shapes of electron trajectories and their distribution. With the electron mobility growth or nanoshell radius decrease, we expect the observed effects to gain even more. In addition, ballistic effects will come into play, opening perspectives of local control of electron transport and magnetic focusing [5]. In quantizing magnetic fields, Bn gradient leads to formation of magnetic-induced 1D channels which are topologically protected similar to the edge states in flat 2DEG. As opposed to them, magnetically-induces edge states are located far from the edge. Their formation and position in space are determined by both the value of Bn and its gradient, so their spacing can be set in the experiment and controllably varied in a wide range, giving new possibilities for the investigations of interchannel scattering [6].

Acknowledgements

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# NEW TRENDS IN SPIN NOISE SPECTROSCOPY

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Spin noise spectroscopy (SNS) is known as a technique primarily intended for nonperturbative detection of magnetic resonance and, therefore, for getting information about energy and relaxation (dynamic) characteristics of a spin system. During the last years, however, SNS has revealed a number of specific properties that considerably widened potential of this technique as a tool of research. In particular, optical spectra of spin noise power proved to be sensitive to the nature of broadening of the resonant optical transitions, making it possible to distinguish between homogeneously and inhomogeneously broadening transitions. A curious effect of homogenization of the Doppler-broadened line, that prevents the spin resonance line from time-of-flight broadening, has been observed in the spin noise spectrum of an alkali-metal vapor. A great efforts were made, in the last years, to detect and to examine the spin-flip Raman field controlling formation of the spin-noise signal. At present, it became clear that spatial characteristics of the scattered field may provide valuable information about spatial correlation of gyrotropy in the medium under study. SNS may serve as a unique sensor of local magnetic fields inside the paramagnet. These abilities of the SNS have been used in recent publications for studying nuclear dynamics in semiconductor nanostructures. In the report, we will consider different aspects of spin noise beyond the bounds of magnetic resonance spectroscopy.

# IONIC COULOMB BLOCKADE AND FRACTIONAL WIEN EFFECT IN ION TRANSPORT ACROSS NANOPORES

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The transport of fluids in nanochannels is exquisitely sensitive to the properties of the confining surfaces[1]. The ability to actively control these properties would open new avenues for tuningfluid flow at the molecular scale, with potential applications in ultrafiltration and desalination processes [2]. I will present the theoretical study of a model system where active tuning of the surface properties unveils contributions of single ions to the electrical conductance.

Our system consists of a long nanochannel filled with a salt solution, which is coupled to a gating electrode. The gating electrode creates an effective tuneable surface charge in the middle ofthe channel (fig. 1a). We probe the properties of the system using brownian dynamics simulations.At equilibrium, the simulations reveal a striking non-linear behaviour of the ion density, whichevades mean field description, and is only accounted for by the exact solution of a 1D Coulombgas type model (fig. 1b). When driven out of equilibrium by an electric field, our system exhibitsoscillations of ionic conductance as a function of surface charge, which are a signature of the discretenature of ions. This effect is qualitatively similar to Coulomb blockade in electron transport. Weshow that here, however, the underlying mechanism is completely different, and is reminiscent ofOnsager's Wien effect [3]. We develop an analytical theory accounting for this mechanism, which is in good agreement with simulation results (fig. 1c).

Our findings reveal a new way of controlling fluid transport at the nanoscale, with the ultimate perspective of manipulating single ions in fluids at room temperature.

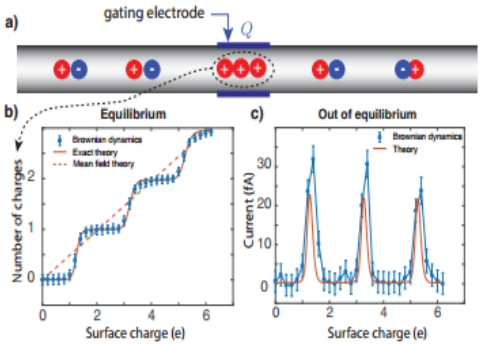


Figure 1: (a) Schematic of the system. (b) Number of neutralising charges in the surfacecharged region. (c) Ionic current as a function of the variable surface charge from Brownian dynamics simulations and theory.

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# POLARITON LASING IN TRANSITION METAL DICHALCOGENIDES

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## 1. Background and motivation

Polariton lasing is generation of coherent and monochromatic light by bosonic condensates of superposition light-matter quasiparticles: exciton-polaritons. In contrast to the conventional lasing, polariton lasing relies on the spontaneous rather than on stimulated emission of light, which is why it is characterised by a very low threshold, typically. In 2007, we have demonstrated the room temperature polariton lasing in GaN based microcavities [1]. Nowadays, polariton lasing is achieved in GaAs, CdTe, ZnO based semiconductor microcavities and microwires as well as in organic structures. So far, polariton lasers remain low power sources of the coherent light. The power limitation is set by the excitonic Mott transition that converts an exciton gas to the electron-hole plasma. In order to realise high power polariton lasers one should look for solid state systems where the Mott transition takes place at high injection densities.

## 2. Transition metal dichalcogenides

After the graphene boom, the scientific community has focused on synthesizing other two-dimensional monoatomically thin crystals and studying their electronic and optical properties. This is how the dichalcogenides of transition metals Mo and W have come into play. Soon, it has been found that transition metal dichalcogenides (TMDC) are semiconductors characterized by a band-gap in the optical frequency range and by excitons possessing a large binding energy (of the order of hundreds of meV) and relatively small Bohr radius (of the order of 1 nm). For this reason, the Mott transition in TMDCs is expected to happen at the exciton densities that exceed those corresponding to the Mott transition in GaAs based quantum wells by three orders of magnitude.

### 3. Our work

I will review a series of works aimed at the realization of polariton lasers based on TMDC (see e.g. [2,3]). It turned out that the most promising design of a microcavity containing a TMDC monolayer is the so-called Tamm microcavity, where an optical mode is confined between a dielectric Bragg mirror and a layer of metal. Tamm cavities with embedded TMDC monolayers exhibit a significant vacuum field Rabi splitting, and also show the stimulated relaxation threshold needed for polariton lasing. Interestingly, the spin-valley locking in TMDC results in the spontaneously circularly polarized emission of such structures. A special emphasize will be put on hybrid GaAs-TMDC microcavities, where all characteristic features of the polariton lasing have been observed.

### 4. Acknowledgement.

I am happy to acknowledge a long-standing fruitful collaboration with the Wurzburg group of Sven Hoefling, Christian Schneider, Nils Lundt. All experimental studies reviewed in this talk are realized at the Wurzburg university, Germany. This work was carried out in the framework of the joint Russian-Greek project supported by Ministry of Education and Science of The Russian Federation (project RFMEFI61617X0085)

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# LASER-INDUCED SEMICONDUCTOR FRACTAL STRUCTURES WITH TOPOLOGICAL QUANTUM EFFECTS

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In experimental aspect, the laser synthesis technique to produce the nanoparticles (NPs) of different composition in both semiconductor samples (PbTe): direct laser modification of thin films and laser evaporation of substance from target in liquid to produce the colloidal systems and subsequent deposition of particles from colloidal system on solid substrate (glass). Under a cw-laser radiation a bimodal distribution on PbTe particle size takes place. For such laser-induced nanostructures we demonstrated the superconductivity tendency to increase the electrical conductivity by several times for our case at room temperature in comparison with a homogenous monolithic sample. By drop deposition technique it has been obtained the cluster structures with various topology, and the nanoparticles become quantum dots under some conditions. Such structures with controlled electro-physical properties are very principal to construct the elements and devices of optoelectronics and photonics in hybrid circuits on new physical principles.

We present the topology controlled laser synthesis of nanoparticles/the semiconductor PbTe nanoparticles by direct laser modification of thin films and by deposition of clusters and so, macroscopic quantum effects for a spatially inhomogeneous/modulated/periodic micro/nano structures occur. In such systems we studied, in particular, the electrical transport properties (electroresistance behavior vs the cluster parameters variation, and also the current Volt-Amper characteristics vs conditions of the experiment), and quantum tunneling effect (for a spatially periodic nanocluster structure) and/or jump conductivity (in frames of shell-model cluster presentations) have been obtained (cf. [2]).

Fig. 1 shows the direct laser modification of a PbTe-target surface due to the termolization equilibrium process only by the laser ablation technique (cw-laser radiation: $\lambda$=1.06 μm, the intensity – up to 106 W/cm$^2$). Real time scale observation of laser-induced processes has been carried out. The observed effect

of the surface self-organization structuring in particle size, is achievable only in a fixed laser intensity range and for a certain scan-velocity of the laser beam on the sample surface.

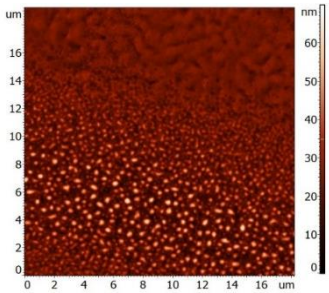


Fig.1. The picture of the target surface structure under laser irradiation: it looks as a bimodal distribution.

Fig. 2 show the results obtained by measuring current Amper-Voltage characteristics for different experimental conditions using a preliminary prepared sample with a bimodal distribution of nanoparticles on the surface discussed above. We give present the results on the detection of the jump-conductivity for different surface density of NPs on the films (shown by figures at the dependences). Moreover, its occurrence is universal – there have been shown two types measurements of the electrical resistance in both longitudinal and transverse one directions; the fact depending only on the topology of the conducting layer (constant for a given sample). So, the implementation of transition of the electrons from the bound state to a free state can be taken into account in the frames of shell model clusters.

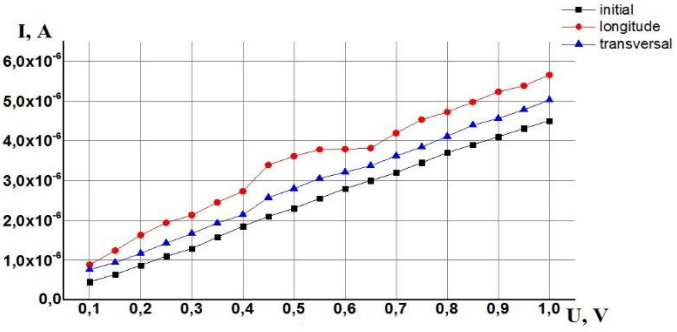


Fig. 2. Jump-conductivity dependences for different surface density of NPs on the PbTe films. All measurements have been carried out by averaging the results of 10 experiments.

In progress, it is expected to carry out a more detailed study of the correlation between the topology of a nanostructure of different composition and its functional and dynamic properties, and also of optical properties for fabricated nanocluster structures under the conditions when macroscopic quantum effects occur, including e.g. the tendency of high-temperature superconductivity, and multiple quantum transitions resulting in modification of the optical spectra in layer structures.

When solving the existing problems we should address modern challenges for the creation of new and also, on new physical principles, the hybrid (optics/photonics + electronics) elements and devices with given properties (both functional and design). The main stream of the problem includes in particular the units for quantum information processing, based on advantages of modern femto-nanophotonic technologies by laser synthesis of nano- and microstructures with variable topology and size/form parameters on the surface of various solid state materials.

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# LASER-INDUCED SYNTHESIS OF NANOSTRUCTURED METAL-CARBON CLUSTERS AND COMPLEXES FOR OPTICAL APPLICATION

***Kucherik A.***[1]***, Arakelian S.***[1]***, Kutrovskaya S.***[1]***, Osipov A.***[1]***, Vartanyan T.***[2]***, Povolotckaia A.***[3]***, Povolotskiy A.***[3]***, Manshina A.***[3]

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Metal-carbon complexes consisting of noble metal nanoparticles and carbon matrix is a prospective material for photonics applications. One application of these objects is to provide materials for the implementation of Surface Enhanced Raman Scattering (SERS) [1,2]. Carbon stabilizes the metal particles and increases SERS. The control of size and morphology of formed metal-complexes allows to vary its properties. The application of laser ablation materials in a liquid allows to create nanoparticles and clusters with various optical properties [3-5]. A very perspective carbon material with structural sensitive optical properties is carbyne [6].

In this work we present the investigation of metal-carbyne clusters formation under the laser radiation of colloidal systems. Colloidal solutions were consisted of carbon and noble metals nanoparticles As a result, there was shown that clusters are forming during the irradiation process. The Raman spectra of those systems depends on the concentration of the particles in the solution and on the laser radiation conditions.

The gold and silver particles were obtained during the cw-irradiation of the targets placed in liquid media. [3]. The power of radiation was 35–50 W, laser beam diameter equaled 30 μm. A target was scanned by the laser beam with the speed of 10–30 μm/s. The irradiation time was 30 min. The average particle size after laser irradiation was 10–30 nm. The size of particles in colloidal system was measured by the Horiba LB-550 (dynamical light scattering particle size analyzer).

Carbon nanoparticles were obtained using the pulse-periodical laser radiation (pulse 2 ms), energy in pulse was from 1 J up to 20 J, pulse frequency – 20 Hz, on the shungite targets placed in water. [7]. This kind of method allows to obtain carbon particles with diameters about 100 nm – 2 μm.

The carbon, gold and silver particle colloidal solution was prepared by the intense mixing with concentratrationC:Au:Ag 10:1:1 in water (5cl), then the ultrasonic bath was used for about 10 minutes for particle decoagulation. The fiber Yb-laser setup (pulse - 100 ns, repetition rate - 20 kHz, the pulse energy up to 1mJ) was used for the metal-carbyne clusters obtaining [5]. This kind of laser system can realize the particle absorption on the wavelength of 1.06 μm, with short pulse. The colloidal system irradiation was carried out by the scanning of the cuvette volume by focused beam (spot diameter - 50 μm, irradiation time – 15 minutes).

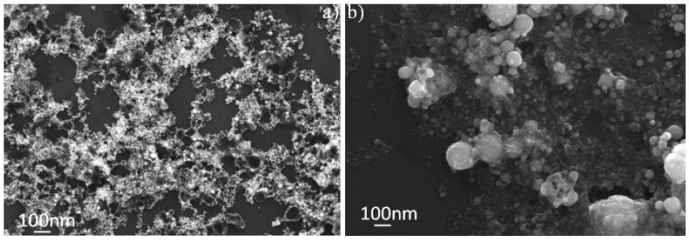


Fig 1. SEM-images of synthesis metal-carbyne clusters for the different laser pulse energy 1mJ (a) and 0.5mJ (b).

The morphological properties of deposited nano-clusters were investigated using atomic force microscopy (AFM) and scanning electron microscopy (SEM). It was found that the transmission spectra of the resulting structures depend on the concentration of gold and silver nanoparticles in the colloidal solution.

The SERS research by deposited films was performed using Senterra spectrometer (Bruker), with the pump laser wavelength of 532 nm, the power of 0.1 mW and the focal spot diameter of 2 microns (Center for laser and optical materials research, SPbSU).

The standard dye Rhodamine 6G was used as a test molecule (Raman spectrum of the solution is shown in Fig. 2a). The dye solution in ethanol ($10^{-6}$ M) was placed on a metal-carbon structures using a micropipette. The metal-carbon surfaces are formed on an oxide glass substrates with different composition of

metal nanoparticle. The Raman spectra of molecules of Rhodamine 6G on various substrates are shown on Figure 2b.

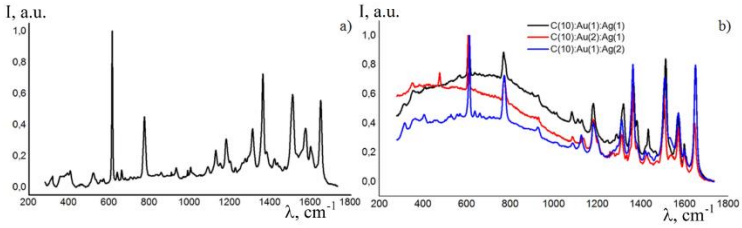


Fig. 2. Raman spectra: initial due (a) and test by deposited metal-carbon films (b).

If the oxide glass or carbon film are used as a substrates – the bands corresponding to Rhodamine 6G with a concentration of $10^{-6}$M are not detected. At the same time, the use of films as a substrate of metal-carbon nanostructures under the same measurement conditions allow to detect and identify the dye on the Raman spectra with sureness in Figure 5b. The changing of the gold and silver nanoparticles ratio results in varying of the amplification degree of different bands in the spectrum of the dye. The peaks of plasmon resonances for silver and gold are in the range of 410 and 540 nm, thus, various vibration modes are amplified at gold and silver particles with different gain.

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# HOMODYNE PHOTODETECTION: FROM QUANTUM TOMOGRAPHY TO APPLICATIONS

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Homodyne photodetector, originally designed for light field measurements, has become a powerful tool for quantum state reconstruction of light field (= quantum state tomography). Advantages and limitations of light homodyne detection for quantum application are reviewed. Single-photon sensitivity of homodyne detection gets on with limited bandwidth of used photodiodes and limited dynamic range of allowed light power.

High sensitivity of homo- and heterodyne photodetection provides variety of technological applications:

- random number generation (RNG);
- quantum key distribution (QKD);
- free-space communication;
- remote sensing (coherent LIDAR).

1. Random number generation is based on quantum uncertainty of beam splitter which is the key element of balanced homodyne detector (BHD) [C.Gabriel et al. Nature Photonics, v. 4, № 10, 711 (2010)]. Advantages: ordinary (not avalanche) photodiodes are used which allows high speed of RNG.

2. Quantum key distribution based on continuous variables, in particular on amplitude and phase of coherent states, was demonstrated to be secure even at loss of communication line < 50% [F.Grosshans et al. P. Phys. Rev. Lett., v. 88, 057902 (2002)]. Advantages: simplicity of light generation and manipulation techniques. BHD can be an effective tool as a receiver in QKD.

3. Free-space optical communication suffers from loss along communication trace. Homo- and heterodyne photodetection can improve the efficiency of optical receiver due to single-photon sensitivity.

4. Remote sensing is well developed area where *coherent* LIDARS are widely used. The methods of coherent detection (homo- and heterodyne type) provide high sensitivity required for reflected signals. Advantages: the capability to register vibration of targets including low frequency (Hz) range [P.Lutzmann*et*

*al*. Proc. SPIE 8186, Electro-Optical Remote Sensing, Photonic Technologies, and Applications V, 818602 (5 October 2011)].

Possibilities of modern photo-electronic components of homodyne detectors to meet various requirements for research and applications will be discussed.

# MODIFICATION OF OPTICAL PROPERTIES PEROVSKITE THIN FILMS BY GOLD NANOPARTICLES

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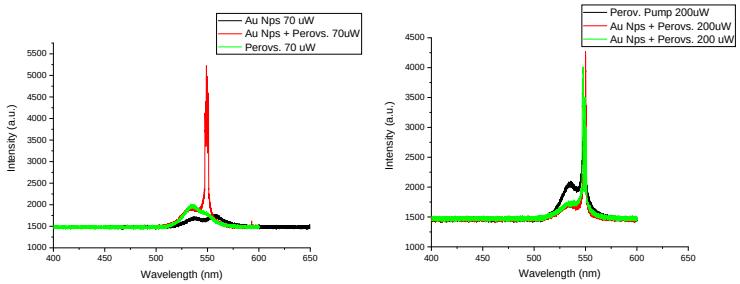
Organic perovskite as a promising material for photonics and optoelectronics applications. In 2009, the first publications appeared on the use of organic perovskites as sensors in solar batteries [1]. It was demonstrated of optical generation in 2012. Since that time organic perovskite has found various technological applications, but one of main problem is stability and intensity of radiation perovskite system.

In this work for stabilize perovskite ($CH_3NH_3PbI_3$) system and increase of it lasing we offer the method of sublayer formation of golden nanoparticles. The Au nanoparticles were obtained by method of laser ablation in liquid [2]. Perovskite thin films were prepared in a two-step sequential deposition process [3]. Nano-particles of noble metals were deposited by spin-coating on a glass substrate and films of organic perovskite were applied to these thin films. The results of research presented in the article suggest that the use of nanoparticles of noble metals enhances perovskite organic laser at low pump level that does not occur in pure perovskite (Fig. 1).




a) b)

Fig.1 Spectra of radiation of perovskite samples, perovskite with a sublayer of nanoastiasts at two different points. a) Pumping 70 uW b) Pumping 200uW

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# DOES THE ELECTRON SPIN IN A SEMICONDUCTOR TRANSPORT ITSELF AS THE CHARGE?

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To meet the growing needs of microelectronics, it has been proposed to use the spin of the electron, this quantum variable whose classic analogue is rotation on itself. Since the spin is carried by the electron, it would be natural to think that the two quantities are transported identically, except for the natural tendency of the spin polarization to disappear by spin relaxation. Yet, several fundamental studies show that the spin can be transported independently of the electron that carries it, and thus "live its life" like an autonomous particle. This presentation is devoted to these highly counter-intuitive results.

# FEMTOSECOND LASER-INDUCED PERIODIC SURFACE STRUCTURES FORMATION ON MOLYBDENUM IN AIR AND LIQUID NITROGEN

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Materials based on transition metals and their chemical compounds occupy a wide range of industrial applications, especially in microelectronics, photonics and optoelectronics. The great interest to nanostructured refractory metals is due to their high catalytic activity [1], the possibility of using in inorganic light-emitting diodes and photovoltaic cells [2] etc.

Surface treatment of molybdenum samples was performed by femtosecond laser system TETA-10 with the following parameters: wavelength 1030 nm, pulse duration 280 fs, pulse energy 15 μJ, pulse repetition rate 10 kHz, radiation polarization-linear. The morphological characteristics and elemental composition of nanostructured layers on the molybdenum surface were investigated by scanning electron microscope Quanta 200 3D. The structural composition of the laser processing results was tested by Raman spectroscopy using an Integra Spectra nanolaboratory.

Laser treatment of molybdenum surface in air leads to the formation of surface periodic structures with very uneven sides (Fig.1,a). The width of ripple is 400 nm with period 800 nm. The formed surface nanostructures have a strongly expressed molten surface, due to the low melting temperature of molybdenum oxide. Nanorods are not registered. The molten nanostructures that are observed in the grooves may be the remains of nanorods or spherical nanoparticles. However, the quasilinear structures of ripple patterns consist of processed items almost cylindrical shape. The formation of such elements is possible when the molten material is collected around the central axis of nanorod. The analysis of chemical composition of the nanostructured layer showed that it is formed from $Mo_2O_5$.

At laser treatment of molybdenum surface in liquid nitrogen, the relief of the modified surface is formed from periodic structures with sharp and almost vertical side surfaces separated by deep grooves. The ripples have a period about 700 nm with width of the lines about 400 nm (Fig. 1,b). Analysis of the chemical

composition of the nanostructured layer showed the content of molybdenum nitride. The relief of the surface of molybdenum nitride also has the same shape over the entire area of laser treatment. Ridges of linear structures are formed as a result of spherical nanoparticles fusion. The average diameter of spherical nanoparticles varies from 50 nm to 100 nm.


Figure 1. SEM-images of nanostructured molybdenum layer (a) and molybdenum nitride layer (b).

In the experiments, liquid nitrogen was used as a medium that helps to reduce the thermal effect of the plasma plume, which is formed over the area of exposure to femtosecond laser radiation above the surface of the material during processing in the air. When using liquid nitrogen, a number of negative features of air treatment are not achievable. Thus, radical changes in the structure of the modified surface layer are not observed. In particular, the formed ripple-structure has more pronounced contours, the characteristic temperature damage as a result of the action of laser-induced plasma has not been revealed [3].

The studies of the treated samples surface using electron microscopy revealed the almost complete absence of surface melting, better fixation of the formed structural surface changes due to the effective heat removal, both in the sample and in the volume of liquid nitrogen. As a result of laser treatment of the sample surface in a liquid nitrogen, the plasma formed experiences resistance caused by higher density of the medium than during processing in air. There is a significant increase in the pressure of the near-surface plasma on the material in the area of influence, which contributes to the change in the period of formed periodic structures.

The reported study was funded by RFBR according to the research project № 16-42-330651.

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# TWISTING MAGNETIZATION BY COHERENT PHONONS

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The exploration of magnetism at the nanoscale continues to be a rapidly developing field. For the most of prototype nanoscale magnetic devices, a microwave magnetic field is an irreplaceable tool for manipulating magnetic states. However, up to now generation of a microwave magnetic field with high amplitude, narrow spectral band and nanoscale localization remains challenging. The precessing magnetization of a ferromagnetic nanostructure may be an effective source of a microwave magnetic field at the nanoscale. Coupling of lattice and magnetization possessed by any ferromagnet allows launching and driving the magnetization precession by coherent phonons [1]. If the frequency of the Eigen phonon (mechanical) mode of a nanostructure coincides with the precession frequency, the phonon driving becomes resonant with the highest efficiency. The present talk gives an overview of the experimental studies, in which this approach has been realized.

We have examined two types of ferromagnetic nanostructures: ferromagnetic phononic nanocavities [2] and lateral ferromagnetic nanogratings [3]. A ferromagnetic phononic nanocavity is a ferromagnetic layer of (Fe,Ga) deposited on GaAs/AlAs superlattice, which plays a role of phonon Bragg mirror. The superlattice from one side of a ferromagnetic layer and the open surface at another side form a phononic Fabry-Perot nanoresonator. The ultrafast optical excitation of a ferromagnetic layer generates a broad coherent acoustic wave packet, which rapidly escapes, while the coherent phonons of the Eigen phonon modes remain localized to drive the magnetization. At resonance, when the precession frequency tuned by external magnetic field coincides with the frequency of the localized phonon mode, we observe drastic changes of the magnetization dynamics with rapid increase of the precession spectral amplitude and decrease of its spectral width.

The same approach has been realized in lateral ferromagnetic nanogratings formed by parallel grooves of ~10 nm width and 10-50 nm depth milled in a 100-

nm (Fe,Ga) film with ~100 nm spatial period. The surface acoustic waves with wavevectors set by the grating period also remain localized in the nanograting due to the elastic anisotropy of (Fe,Ga). They drive the magnetization precession, which generates a microwave magnetic field localized in the grooves. Its ac- induction achieves ~10 mT at the resonant conditions.

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# LUMINESCENCE DETECTION OF TRANSFER OF SPIN-TRIPLET MAGNETOEXCITONS

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It's known that the excitons are unstable in metals, such as 2D-electron gas. However, in quantizing magnetic fields and at temperatures well below the cyclotron quantization energy, a 2D metal turns into a special type of 2D insulator at even integer quantum Hall states. Excitations in quantum Hall insulators are magnetoexcitons. They combine properties of excitons in 2D insulators and plasmons in 2D metals. The simplest realizations are magnetoexcitons formed by an electron promoted from the occupied zeroth Landau level to the empty first Landau level and by the vacancy left in the Fermi sea of electrons. There are two magnetoexcitons: a spin singlet with total spin $\mathbf{S} = 0$; and a spin triplet with total spin $\mathbf{S} = 1$ and spin projections along the magnetic field axis $\mathbf{S}_z = -1, 0, 1$. The singlet magnetoexciton $\mathbf{S} = 0$ is the Kohn magnetoplasmon. Its fast relaxation to the ground state occurs via dipole cyclotron radiation. In contrast to the spin singlet, the spin-triplet magnetoexciton is not radiatively active owing to electron spin conservation. It is a "dark" magnetoexciton. It interacts with all other electrons under the Fermi level. The many-body Coulomb interaction lowers its energy below the cyclotron energy. Thus, the spin-triplet magnetoexciton is the lowest energy excited state in the system [1]. Because of this and the spin conservation, the spin-triplet magnetoexcitons exhibit extremely slow relaxation with the relaxation time reaching hundreds of microseconds [2].

An experimental technique for the creation, manipulation, and detection of macroscopic ensembles of spin-triplet magnetoexcitons has been developed [2, 3]. The ensemble can be created with a resonant optical excitation (the resonances appear due to the orbital and the spin quantization), whereas the usage of extra nonresonantphotopumping adds high-energy electron-hole pairs to the ensemble. Furthermore, we discovered condensation of excitons by time-resolve measurements of exciton lifetime in a temperature range of

0.5–1.5 K [4]. Here we report on spin exciton transfer at distance exceeding 200 μm by pump-probe photoluminescence measurements [5] and photo-resonant reflection (PRR). In this talk we are focusing on a momentum of transferred excitons which is revealed by analyzing intensities of trion luminescence lines. We claim that transferred excitons have specific momentum associated with roton minimum because of increased intensity of Pln line (Fig. 1). This information gives us a clue to understanding the formation of exciton condensate.

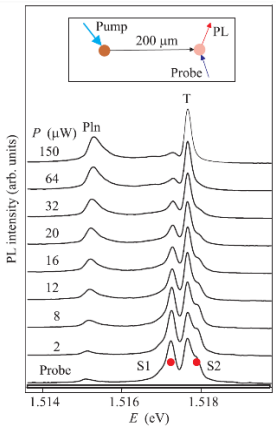


Fig. 1. (Color online) Evolution of the photoluminescence spectra in the probing region with increasing pump power P in the photoexcitation spot. For convenience, the spectra are shifted vertically with respect to each other. The S1 and S2 lines are single-particle transitions of radiative recombination of electrons in the conduction band with heavy holes of the valence band, whereas Pln and T lines are due to radiative recombination of multiparticle complexes. The S1 and Pln lines are seen only $\sigma^-$ in the polarization, whereas S2 and T lines are observed only in the $\sigma^+$ polarization. The temperature was 0,64 K. The inset shows the scheme of the experiment: the probing spot is spaced from the photoexcitation spot by 200 μm.

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# CRITICAL VIEW AT THE E-CAT PROJECTS OF ANDREAS ROSSI ON "COLD NUCLEAR FUSION"

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Andeas Rossi has declared twice "breakthrough" achievements in the controversial area of the "cold nuclear fusion" or LERN-technology. At first, he claimed, mainly through the mass media (though see also [1]) reaching industrial-promising production of thermal energy based on a hypothetical fusion of protons and nickel nuclei with creation of copper isotopes. Details of the process were concealed with reference to commercial secrecy. This statement was criticized by professional community and, in particular, by the Russian Commission for combating pseudoscience and falsification of scientific investigations. Specifically, it was pointed out that this nuclear reaction is essentially endothermal [2]. A few years later, A. Rossi has announced (this time, in a scientific publication, see [3]) a new version of his generator based on another hypothetically possible exothermal reaction of transmutation of lithium-7 to lithium-6 with simultaneous transformation of nickel isotopes. Specific details of the procedure have not been disclosed again. This work was also criticized by our commission [4] – it looked like a banal fake. Still, the pater has drawn a considerable public attention and, in particular, had a continuation in the form of independent attempts to reproduce the experiment (e.g., in Russia, see [5]). Altogether, all confirmations of the sensational results of Rossi look highly doubtful. In this talk, the intriguing and, in many respects, instructive story of cold nuclear fusion will be presented.

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# SUPERFLUIDITY OF SUPERSOLIDS

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I will give an overview of the studies of supersolid states of bosons, which were predicted several tens of years ago and found experimentally only in 2017. These peculiar states are characterized by a simultaneous presence of superfluidity and crystalline order. In the dilute limit for bosons in free space, supersolidity appears as a Bose-Einstein condensate with the wavefunction that has the form of a crystal lattice on top of a uniform background. The supersolidity has been observed in a spin-orbit-coupled two-component Bose-Einsten condensate as a stripe phase, which is featuring density modulations in the direction of spin-orbit coupling. The superfluid behavior of the satripe phase will be characterized by calculating the drag force acting on a moving impurity. Because of the gapless band structure of the excitation spectrum, the Landau critical velocity vanishes if the motion is not stricktly parallel to the stripes, and energy dissipation takes place at any speed. By estimating the time over which the energy dissipation occurs, I will show that for slow impurities the effects of friction can be very small on a time scale up to several seconds, which is comparable with the duration of a typical experiment.

I will eventually rase the question of the effects of the drag force on the moving striped Bose-Einstein condensate. The issue is that in contrast to ordinary uniform superfluids, where it can only reduce the velocity of the flow, in the stripe phase the friction may act in the direction of weakening or eliminating the density modulations.

# PAIR-INTERACTING ELECTRON GAS IN PARABOLIC QUANTUM DOT: THERMODYNAMIC AND MAGNETIC PARAMETERS

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**ABSTRACT**

On the basis of the Moshinksy model of the harmonium atom [1] the thermodynamic and magnetic properties of paired-interacting electron gas in the disk-like quantum dot with parabolic confinement potential has been considered. The spectral problem for such system has been solved by Johnson, where authors suggested replacing the Coulomb paired-interacting potential with the parabolic potential [2]:

$$V\left(r_i, r_j\right) = 2V_0 - \frac{1}{2}\mu\tilde{\Omega}^2\left|\vec{r}_i - \vec{r}_j\right|^2, \qquad (1)$$

where $V_0$ and $\tilde{\Omega}$ are positive parameters of inter-particle interaction potential, $\mu$ is effective mass of the electron.

The multi-particle Hamiltonian of the paired-interacting electron gas, localized in the parabolic quantum dot, can be diagonalized and allows separating the motion of the system's centre of mass and the relative motion. As it is shown in the paper [2], the exact analytical expression for the energy spectrum has the following form:

$$E_{N_A,N_B}^{\alpha_{ij},\beta_{ij}} = E_0 + N_A\hbar\left[\Omega_{rad}\left(B\right) - \frac{\omega_B}{2}\right] + N_B\hbar\left[\Omega_{rad}\left(B\right) + \frac{\omega_B}{2}\right] + \\ + \sum_{i<j}\left[\alpha_{ij}\hbar\left(\Omega_0 - \frac{\omega_B}{2}\right) + \beta_{ij}\hbar\left(\Omega_0 + \frac{\omega_B}{2}\right)\right], \qquad (2)$$

where $\Omega_{rad}\left(B\right) = \sqrt{\omega_\rho^2 + \omega_B^2/4}$, $\omega_B = eB/\mu c$ is cyclotron frequency, $\omega_\rho \sim \frac{\hbar}{\mu R_0^2}$ is radial frequency with $R_0$ – disk-like quantum dot radius,

$\Omega_0(B)=\sqrt{\Omega_{rad}^2(B)-N\tilde{\Omega}^2}$, $E_0=\hbar\Omega_{rad}(B)+(N-1)\hbar\Omega_0+N(N-1)V_0$ is ground-state energy, $N$ is number of particles confined to the quantum dot and $N_A, N_B, \alpha_{ij}, \beta_{ij}$ are positive integers.

The energy spectrum (2) can be used for the calculation of partition function for the system under consideration. Assuming that the electron gas obeys Boltzmann statistics, the partition function can be written as:

$$Z=\frac{e^{\beta\left[N(V_0-\hbar\Omega_0)-N^2V_0+\hbar\left(2\Omega_0+\Omega_{rad}-\frac{\omega_B}{2}\right)\right]}\left(1+e^{\beta\hbar\omega_B}\right)}{\left(e^{\beta\hbar(2\Omega_0-\omega_B)}-1\right)\left(e^{\beta\hbar(2\Omega_0+\omega_B)}-1\right)\left(e^{\beta\hbar\left(\Omega_{rad}-\frac{\omega_B}{2}\right)}-1\right)\left(e^{\beta\hbar\left(\Omega_{rad}+\frac{\omega_B}{2}\right)}-1\right)}, \quad (3)$$

where $\beta=\frac{1}{k_BT}$ is reverse temperature.

The magnetic and thermodynamic parameters of the paired-interacting electron gas can be determined by the help of the expression (3). Fig 1 shows the dependence of magnetization $M$ on the magnetic field strength $B$. For comparison of results, the same dependence in the case of non-interacting electron gas in the parabolic quantum dot is presented (Fig. 2). As can be seen from the figure the presence of the interaction between particles substantially changes the dependence of $M$ on $B$. If this dependence for the case of non-interacting electron gas is almost linearly, the presence of the interaction between particles leads to the significant non-linearity between $M$ and $B$.

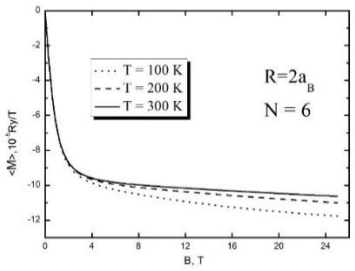


Fig. 1. The dependence of magnetization on the magnetic field strength for different temperature values. (paired-interacting gas)

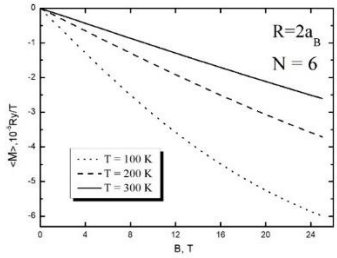


Fig. 2. The dependence of magnetization on the magnetic field strength for different temperature values. (non-interacting gas)

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# SELECTIVE REFLECTION OF LIGHT: AN EFFICIENT SPECTROSCOPIC INSTRUMENT

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**ABSTRACT**

Selective reflection of light from an interface between dielectric window and atomic vapor in the vicinity of atomic resonance frequency is proven to be efficient technique for specific interaction conditions. The presentation gives an overview of recent works of the author, focused at studies of high-density vapor and nanometric-thickness vapor layers, and emerging applications.

**Extended Abstract:**

Fresnel reflection of light from the interface between a dielectric window and atomic medium, affected by the dispersion in the vicinity of atomic resonant lines is termed Selective Reflection (SR). The technique of selective reflection is extensively used as an efficient spectroscopic tool for studies of interatomic collisional mechanisms and determination of the homogeneous linewidth, van der Waals interaction of atoms with a dielectric surface, coherent and magneto-optical processes, formation of sub-Doppler resonances and Doppler-free reflection spectroscopy, locking the laser frequency to atomic resonance lines, spectral filtering, controlling thin film formation, etc. This talk presents the progress in selective reflection studies achieved at the Institute for Physical Research, NAS of Armenia thanks to development of all-sapphire high-temperature optical cells with hot windows, which are immune against chemically aggressive alkali metal vapors.

SR was used as a spectroscopic tool for studies of transition from binary to multi-particle atomic collisions in dense atomic vapor (number density of atoms up to $\sim 10^{19}$ $cm^{-3}$), determination of homogeneous width and collisional cross sections, as well as modification of magneto-optical response in dense vapor [1-3]. Experiments performed covering wide atomic density range (from dilute to super-dense vapor) allowed to develop a versatile self-consistent theory of SR [4], which was employed, in particular, for determination of isotopic abundances in

natural atomic vapors [4,5]. Exploiting temperature-controlled interference effects in cell window, it was possible to realize phase-tunable homodyne detection of the radiated atomic field in SR experiment [6]. The developed high-temperature optical cells were also indispensable for the first observation of selective reflection from molecular vapor, realized for rovibronic components of bound-bound electronic transition of thermally formed $Rb_2$ rubidium dimers [7].

Our recent developments mainly addressed in this presentation relate to selective reflection spectroscopy using unique alkali metal atomic vapor nanocells with thickness $L < \lambda$. Due to strong velocity-selectivity in atomic response, Dicke-type coherent narrowing attained for $L = \lambda/2$ and low-finesse Fabry-Pérot behavior, SR from nanocell exhibits prominent sub-Doppler spectral features, which extend fundamental and applied capabilities of this spectroscopic technique. The first observation of SR from nanocell [8] was followed by its application for tunable stabilization of laser radiation frequency by locking to atomic resonance lines [9].

As it was demonstrated experimentally in [9] and further proved theoretically in [10], the shape of the SR signal changes drastically when passing $L = \lambda/2$ thickness (see Fig.1). Sub-Doppler linewidth of the real-time derivative (D) of SR signal and linear dependence of its amplitude on atomic transition probability allowed to record and study the splitting of hyperfine transitions of cesium and rubidium atoms to tens of individual frequency-resolved Zeeman components and the onset of hyperfine Paschen-Back regime observed with the increase of magnetic field strength [10-13]. Magneto-optical processes in nanometric-thickness alkali vapor cells monitored by selective reflection may underlie development of optical wide-range (0 – 0.5 T) magnetometers with sub-micrometric spatial resolution for measurement and mapping of strongly inhomogeneous magnetic fields. We should note that thanks to low divergence of the SR beam, its relatively high power (~0.5% of the incident radiation), linear response remaining up to ~5 mW laser power, and high signal-to-noise ratio, the proposed technique is appropriate for high-distance remote sensing and monitoring of magnetic field.

Confinement of atoms inside a controllable-thickness sub-wavelength gap between dielectric windows allows studying atom-surface interaction. Recently selective reflection was recorded from the nanocell with 40 nm thickness of atomic vapor column ($L \sim \lambda/20$). A 240 MHz red shift of atomic resonance line due to the van der Waals interaction was observed [12]. This study has proven

that the employed simple technique is appropriate for straightforward retrieval of $C_3$ coefficient.

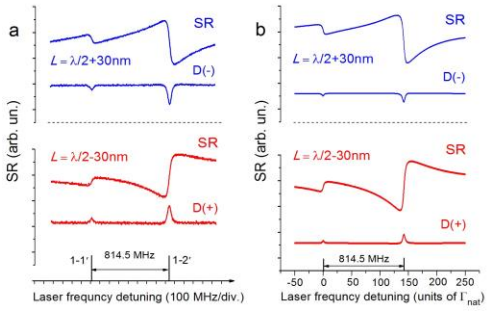


Fig.1. Experimental (a) and theoretical (b) spectra of selective reflection (SR) and its derivatives (D) at $F_g=1 \rightarrow F_e=1,2$ hyperfine transitions of $^{87}$Rb $D_1$ line for $L = \lambda/2+30$ nm $\approx 430$ nm (upper graphs) and $L = \lambda/2-30$ nm $\approx 370$ nm (lower graphs).

Our ongoing research is aimed at further exploitation of capabilities of selective reflection technique for fundamental studies and applications. Particularly, the current SR studies with nanocells are focused at revealing the role of recoil effect, laser radiation intensity and transient interaction time effects, as well as addition of a buffer gas and anti-relaxation coating.

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# SPASER QUENCHING AND MODE MIXING IN PLASMONIC SYSTEMS WITH GAIN

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We study the effect of off-resonance plasmon modes on spaser action in plasmonic systems with gain. We show that mode mixing originates from inhomogeneity of gain distribution near the metal surface and leads to an upward shift of spaser frequency and population inversion threshold. This effect is similar, albeit significantly weaker, to quenching of plasmon-enhanced fluorescence of a single emitter near metal nanostructure due to excitation of nonresonant modes with wide spectral band. We also show that spaser quenching is suppressed for large gain concentrations, and establish a simple criteria for quenching onset, which we support by numerical calculations for spherical geometry.

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