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Contents

Oral **Presenters,** "Presentations"

Poster **Presenters,** "Presentations"

Oral presentations

Radiation of a charged particle moving near curved metals/mixture materials

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The wide applications of the synchrotron radiation motivate the importance of investigations for various mechanisms of control of the radiation parameters. From this point of view, it is of interest to investigate the influence of a medium and boundaries on the spectral and angular distributions of the synchrotron emission. The radiation from a charge rotating around a dielectric cylinder enclosed by a homogeneous medium has been investigated [1-4]. In resent investigation we study the features, the special aspects of the radiation from a charged particle rotating around a dielectric cylinder with a negative real part of dielectric permittivity. The metals provide an example of this kind of material. Due to relatively large densities of free carriers they exhibit a negative permittivity from the visible to microwave frequencies. Another example of material with negative real part of the dielectric permittivity is provided by doped semiconductors (GaAs, InSb, InP) or mixed materials. Compared to the metals, the latter can exhibit very small losses at infrared and longer wavelengths and the corresponding plasma frequency can be controlled by tuning the free carrier densities.

The importance of the investigation of electrodynamical effects for materials which real part of the dielectric permittivity is negative is partially motivated by potential applications in plasmonics. In the problem under consideration two types of radiations are present. The first type of radiation corresponds to the waves propagating at large distances from the cylinder. The second one corresponds to the surface-type modes (surface polaritons) which are localized near the cylinder surface.

For the general case of frequency dispersion in dielectric permittivity, expressions are derived for the electric and magnetic fields and for the angular density of the radiation intensity on a given harmonic. Compared with the case of a cylinder with positive real part of the permittivity, new interesting features arise in the nonrelativistic limit and for the radiation at small angles with respect to the cylinder axis. We analytically estimate the height, width and the location of arising peaks. The influence of the imaginary part of dielectric permittivity on the characteristics of the peaks is discussed. The analytical results are illustrated by numerical examples. We show that the radiation intensity on a given harmonic, integrated over the angles, can be essentially amplified by the presence of the cylinder.

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On the Possibility to Couple Plasmons and Excitons in the Gold-Atomic Vapor and Zn-ZnO Systems

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Exciton-plasmon coupling leads to major modifications of the combined system optical properties. In most cases the plasmon absorption band is broader than the exciton band. Gold nanoparticles surrounded by atomic vapors may be regarded as an extreme example. Indeed, the atomic transition widths are defined by the Doppler broadening or collisions with other atoms. Either mechanisms lead to the widths well below 0.05 nm at the highest accessible temperatures and densities. On the other hand, the plasmon band width is of the order of 50 nm. Calculations show that the combined system absorption spectrum is not a sum of the absorption spectra of the atomic vapors and the gold nanoparticles but rather demonstrates a complicated behavior depending on the spectral position of plasmon band relative to that of the atomic transition. Even without gold nanoparticles interaction of atomic transitions with the cavity modes of an ultra narrow spectroscopic cell leads to unusual modifications of spectral line shapes and density depended shifts.

Another interesting example of exciton-plasmon coupling demonstrates Zn-ZnO system. Zinc oxide is a very promising sensing material that changes optical and electrical properties under the action of external stimuli. Being a wide-band semiconductor with the direct band gap of 3.37 eV, zinc oxide supports also an exciton. The binding energy of the exciton is as large as 60 meV. For this reason, excitons in zinc oxide are readily observable in absorption and fluorescence at about 360 nm even at room temperature. On the other hand, based on the literature data about optical properties of metallic zinc, one can expect that the localized surface plasmons in zinc nanoparticles may be tuned to become in resonance with the exciton in the zinc oxide. With this goal in mind we developed several approaches for getting mixed Zn-ZnO nanostructures on the transparent dielectric supports. The best results were achieved with the vacuum laser deposition of zinc oxide. In the course of laser ablation, the ZnO tablet is heated and partially dissociate. Mixed vapors condense on the substrate and form a deposit, the composition of which depends on the laser fluence and repetition rate. At low laser repetition rate the deposit consists of a mixture of metal and oxide. As the repetition rate grows, laser light (that goes through the substrate before it strikes the target) starts to desorb loosely bound zinc atoms. At the same time, stronger bound zinc oxide remains on the substrate surface. In the unilluminated part of the substrate one obtains the mixed metal-oxide system even at high repetition rates.

Efficiency comparison of mid-IR nonlinear crystals for broadband frequency conversion

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Frequency conversion of laser radiation in nonlinear crystals is the part and parcel of the modern laser and optic technology [1]. Currently, one of the intensively studding applications is broadband frequency conversion/generation in the mid-IR range. That required for different applications as spectroscopy, atmosphere sensing and attosecond pulse generation through high harmonic generation [2]. An efficiency and spectral parameters of frequency conversion is determined both pump radiation and crystal properties. A selecting of the most efficient crystal for a particular laser system is complicated problem. The purpose of our study was an examination of a simple integral figure of merit (FOM) from [3] to apply it for mid-IR nonlinear crystals.

The FOM was studied with broadband sum frequency generation of multiline CO laser radiation performed in the same experimental conditions. CO laser emitted about 100 spectral lines within 5-6 μm range in a single sub-microsecond pulse. We considered both wide-spread ($ZnGeP_2$, $AgGaSe_2$, GaSe) and new ($PbIn_6Te_{10}$ and $BaGa_2GeSe_6$) nonlinear crystals. The FOM taking into account effective nonlinearity, refractive index, spectral and angular phase-matching bandwidths provided the best agreement with the experiment. Its correlation with experiment in simple linear regression model was following: coefficient of determination r^2=0.973, residual standard deviation s^2=0.004. It means that this simple FOM can be applied for qualitative and even quantitative comparison of the nonlinear crystals.

Further, the verified FOM was applied for efficiency studding of other mid-IR nonlinear crystals, as $AgGaS_2$, $HgGa_2S_4$, CdSe, $CdSiP_2$. The calculations show that the most efficient nonlinear crystal for broadband frequency conversion is still $ZnGeP_2$. Also, the new $BaGa_2GeSe_6$ crystal should be noted due to its high efficiency, wide transparency range and great optical damage threshold.

The research was supported by the RFBR (Project No 18-32-00209).

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Dark Matter Search at Atomic Energies and New Detector Design

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Nowadays, one of the most fascinating challenges in the physical research is the possibility of a direct detection of dark matter components. Laser spectroscopy can be a fundamental tool for studying effects in energy ranges where, for example, the axions are predicted to interact with "normal" matter. The DEMIURGOS R&D project intends to design and realize an experimental setup based on single particle detection in solid matrices at cryogenic temperature: in this sense, the system makes part of a larger category of detectors, able to "see" the passage of different kind of objects releasing very small energy in the volume. The apparatus will be described and the preliminary measurements of undoped and doped crystals will be shown.

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Symmetry forbidden Raman lines activated by photorefractivity

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Lithium niobate (LN) has various advantageous properties such as large nonlinear optical coefficients, high transparency in the visible and near infrared range, technology for the manufacturing of waveguides and domain structures. It is widely used in various applications such as light modulation, frequency conversion, SAW sensors, photonic devices. LN, especially when doped with iron (Fe) shows another very remarkable property which is photorefractivity [1]. The effect is observed in the illuminated region of the crystal, and relies on the spatial transfer of photo-excited carriers, which are then re-captured in dark regions by deep traps. The result of this light-induced charge redistribution is the creation of an internal space charge field that locally modulates the refractive index of the crystal via the electro-optic effect.

Raman spectroscopy is a nondestructive method for characterizing the molecular vibrational and chemical bond structure of materials. This technique was widely used to characterize LN crystals of different composition [2]. The assignment of all frequencies of TO and LO components of E and A_1 phonons is now clearly established.

Transmission Raman spectra were recorded in photorefractive iron-doped LN crystal within a priori equivalent configurations, Y(XZ)Y and Y(ZX)Y showed completely different behaviors as function of time. In Y(ZX)Y only E[TO] modes are present in accordance with selection rules, while in Y(XZ)Y configuration spectra showed a strong dependence on time with a rise of A_1[TO] Raman modes. The intensity of the forbidden activated lines reveals a time evolution of the conversion from the o- polarization to the e- polarization after crossing the sample. The intensity ratio of activated A_1[TO]* and E[TO_8] reflects the conversion efficiency as a function of time. This time dependence is fairly well reproduced by simulations based upon the model earlier proposed by Wilson et al.

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Exact solutions of the reduced sextic oscillator from the bi-confluent Heun equation

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The sextic oscillator is discussed as a potential obtained from the biconfluent Heun equation after a suitable variable transformation [1]. Following earlier results, the solutions of this differential equation are expressed as a series expansion of Hermite functions with shifted and scaled arguments [2]. The expansion coefficients are obtained from a three-term recurrence relation. It is shown that this construction leads to the known quasi-exactly solvable (QES) form of the sextic oscillator when some parameters are chosen in a specific way. By forcing the termination of the recurrence relation, the Hermite functions turn into Hermite polynomials with shifted arguments, and, at the same time, a polynomial expression is obtained for one of the parameters, the roots of which supply the energy eigenvalues. With the $\delta = 0$ choice the quartic potential term is canceled, leading to the *reduced* sextic oscillator. It was found that the expressions for the energy eigenvalues and the corresponding wave functions of this potential agree with those obtained from the QES formalism [3,4]. Possible generalizations of the method are also presented.

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Current progress on direct observation of backward degenerate mirrorless lasing in rubidium vapor

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In [1] we have reported an experimental observation of degenerate mirrorless lasing in forward direction under excitation of a dilute atomic Rb vapor with a single linearly polarized cw laser light resonant with cycling $F_e > F_g$ atomic D_2 transitions. Light polarized orthogonally to the laser light was generated for the input intensity exceeding a threshold value of ~ 3 mW/cm^2. Application of a transverse magnetic field directed along the input light polarization revealed a ~ 20 mG wide magnetic resonance centered at $B = 0$. Increase of the incident light intensity from 3 to 300 mW/cm^2 resulted in rapid amplitude increase of the generated light followed by a decline and magnetic resonance broadening. Such nonlinear behavior was attributed to the population inversion on optical transitions between magnetic sublevels established under linearly polarized excitation. The observations obtained in [1] indicate that a combination of nonlinear-optical effects occurs in this system, including degenerate mirrorless lasing and four-wave mixing.

In this talk we report on the ongoing experiment aimed at direct experimental observation of a degenerate *backward lasing radiation* in a single-pass configuration when exciting dilute rubidium vapor with linearly-polarized cw laser radiation tuned to hyperfine transition groups ^{85}Rb $F_g=3 \rightarrow F_e=4$ or ^{87}Rb $F_g=2 \rightarrow F_e=3$ of Rb D_2 line. The preliminary measurements have evidenced a low-divergence orthogonally-polarized backward lasing beam, which appears over mW-range threshold power in the vicinity of zero-magnetic field, with conversion efficiency of up to 7.5×10^{-4}, exhibiting sharp sub-Doppler peak structure superimposed on a broad spectral profile. Dependences of the backward lasing signal on input radiation frequency and power, as well as B-field applied along the linear polarization of input light have been measured. Nevertheless, the obtained results are not yet surely reproducible. In this presentation we will discuss the distinctions of degenerate mirrorless lasing in forward and backward directions, as well as the impacts from possible experimental parameters and conditions affecting reproducibility of the lasing in backward direction.

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Selective reflection from Potassium ultrathin atomic layers

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It is demonstrated that a method using derivative of the selective reflection signal (DSR) from the nanocell containing atomic vapor of the potassium, D_2 line is a convenient and robust tool for atomic laser spectroscopy realizing nearly Doppler-free spectral resolution. The linewidth of DSR using nanocell with the thickness of L in the range of 350 nm-500 nm is 18 times smaller than the Doppler line-width. The demonstrated DSR method is a convenient tool for atom- surface van der Waals interaction study for the nanocell thicknesses L in the range of 60-120 nm. The interaction coefficient C_3 = 1.9±0.3 kHz for the K atom $4S_{1/2}$ -$4P_{3/2}$ transition and the nanocell sapphire windows has been measured [1]. The experimentally recorded on hyperfine transitions Fg =1,2 ® Fe=0,1,2,3 of the K D_2 line spectra for three different processes for the nanocell thickness L=300 nm are shown in Fig. 1.

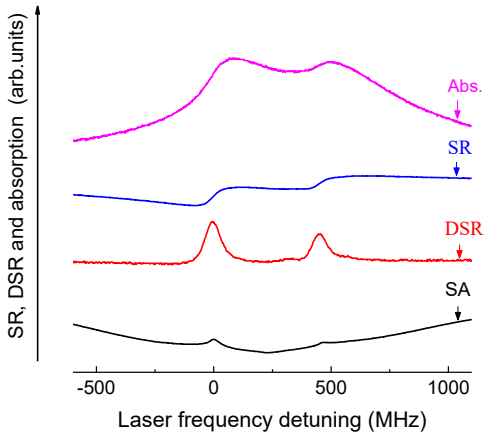

Fig.1.^{39}K, D_2 line, nanocell thickness L=300 nm, upper curve Abs.- absorption spectrum, SR – selective reflection spectrum (has a dispersive shape), DSR- derivative of SR curve which present the selective reflection spectrum. The linewidth of DSR is of ~ 60 MHz (FWHM). The lower line shows the reference Saturated absorption (SA) spectrum.

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Optical properties of excitonic complexes in ellipsoidal quantum dots

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The biexciton, negative and positive trion states in strongly oblate ellipsoidal quantum dot are investigated in the framework of variational method and Heisenberg's uncertainty principle. Because of the oblate geometry of the quantum dot, the exciton complexes are considered as quasi-two-dimensional. The trial wave function for the biexciton and trions are constructed on the base of one -particle wave functions, which are obtained within the framework of adiabatic approximation. The dependencies of the energies and binding energies for the biexciton, negative and positive trions on the geometrical parameters of ellipsoidal quantum dot and ratio of the effective masses of the electron and hole are obtained. The recombination energies for the biexciton, negative and positive trions are considered as a function of the strongly oblate ellipsoidal quantum dot's small semiaxis. For the crossover states, it is shown that for the decreasing small semiaxis the photoluminescence emission peaks of exciton and biexciton shift to the higher energies, but the intensities remain constant. Finally, with the increase of temperature, the photoluminescence emission peaks and intensities become lower. The radiative lifetime of biexciton in ellipsoid is estimated.

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Few-cycle optical-terahertz bullet in a nonlinear waveguide

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Generation of terahertz pulses with the effect of optical rectification is of great interest and both theoretical and experimental studies of this process are undertaken [1 - 3]. Interaction of input optical signal and generated terahertz pulse may result in the formation of optical terahertz bullets as it was demonstrated in a medium with resonant impurities [4]. Optical technique for generating broadband terahertz radiation in a gradient waveguide was investigated in [5]. In quasi-monochromatic case the diffraction length of an optical pulse is significantly higher than the diffraction length of a terahertz signal. It is natural to expect that with a broadband optical pulse one can get a stable optical-terahertz bullet.

In this work we present results of our numerical simulation of the generation of a terahertz signal from a few-cycle optical pulse. To this aim we use the generalization of the Yajima–Oikawa system [6, 7]. Contributions of diffraction for optical and terahertz components are comparable with each other in the few-cycle case. Thus, the role of optical waveguide increases with the reduction of oscillations' number under the envelope of optical pulse. We perform our simulation in the range of normal group velocity dispersion which makes it necessary to use a waveguide geometry. We demonstrate that a possibility of the formation of an optical-terahertz spatiotemporal soliton in a focusing gradient waveguide is more promising in the case of few-cycle optical pulses than in the quasi-monochromatic case.

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A Lambert-W Exactly Solvable Level-Crossing Confluent Hypergeometric Two-State Model

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We introduce a new exactly integrable level-crossing model of quantum semiclassical two-state problem for which the analytic solution is written in terms of the Kummer confluent hypergeometric functions.

$$U(t) = U_0 = const, \qquad \Delta(t) = \Delta_R + \frac{\Delta_L - \Delta_R}{1 + W(e^{(t-t_0)/\sigma})} \tag{1}$$

This is a constant-amplitude field-configuration describing an asymmetric-in-time level-crossing process for which the laser field frequency detuning is given in terms of the Lambert-W function (fig. 1):

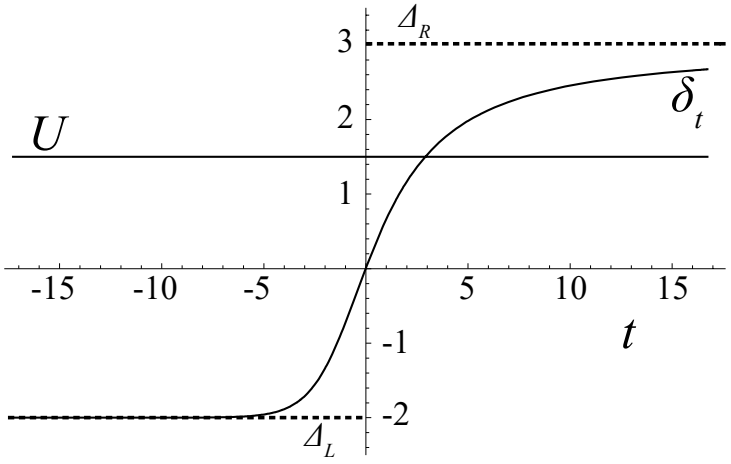

Fig. 1. The Lambert-W exactly solvable level-crossing confluent hypergeometric two-state model (1) for U_0=1.5, Δ_L= - 2, Δ_R= 3, σ=1.

The general solution of the problem for this model is written as a linear combination, with arbitrary constant coefficients, of two fundamental solutions each of which presents an irreducible linear combination of two confluent hypergeometric functions. We present the fundamental solutions and analyze the behavior of the system in the external field defined by the specific field configuration.

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A proof of concept for a wide range optical magnetometer based on nanocells

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In the past decade, optical nanocells (NC) of about 40 nm to 1 mm thickness in light propagation direction have proven to be efficient spectroscopic tools, allowing to perform linear Doppler-free spectroscopy with a simple one-beam experimental setup. We have recently shown that the derivative of selective reflection (dSR) from NC allows one to record atomic spectra with a about 50 MHz linewidth [1]. The sub-Doppler nature of recorded signals and the linearity with respect to the atomic transitions strength make the NC-based dSR technique an extremely convenient tool for studying the splitting of hyperfine atomic transitions in a longitudinal magnetic field and modification of their transition probabilities [2]. Our theoretical model, based on the articles [3,4], has shown a very good agreement with the recorded experimental spectra in a wide range of magnetic field variation covering evolution from Zeeman to hyperfine Paschen-Back regime.

Based on these studies, we have explored the feasibility of designing a nanocell-based optical magnetometer having a measurement range of 0.1 – 5.0 kG with a precision of about 1 G. To do so, a Raspberry Pi computer coupled to an Arduino Due board records the Rb D_2 line from a NC exposed to the magnetic field to be measured. After fitting the experimental spectrum by minimizing the residuals between experiment and theory, our Mathematica program returns the measured magnetic field value. To demonstrate its efficiency, the magnetometer was used to measure the inhomogeneous magnetic field produced by a permanent neodymium-iron-boron alloy ring magnet at different distances from the cell. The coefficient of variation of the measurements remains under 5% in the magnetic field range of 2 – 0.4 kG. Possible optimization and outlook are addressed.

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A novel approach to quantitative spectroscopy of atoms based on 50-400 nm thick column of atomic vapor: the second derivative method

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We present a method for recovery narrow homogeneous spectral features out of broad inhomogeneous overlapped profile based on second-derivative processing of the absorption spectra of alkali metal atomic vapor nanocells. The method is shown to preserve the frequency positions and amplitudes of spectral transitions, thus being applicable for quantitative spectroscopy. The proposed technique was successfully applied and tested for: measurements of hyperfine splitting and atomic transition probabilities; development of an atomic frequency reference; determination of isotopic abundance; study of atom–surface interaction; and determination of magnetic field-induced modification of atomic transitions frequency and probability. The obtained experimental results are fully consistent with theoretical modeling.

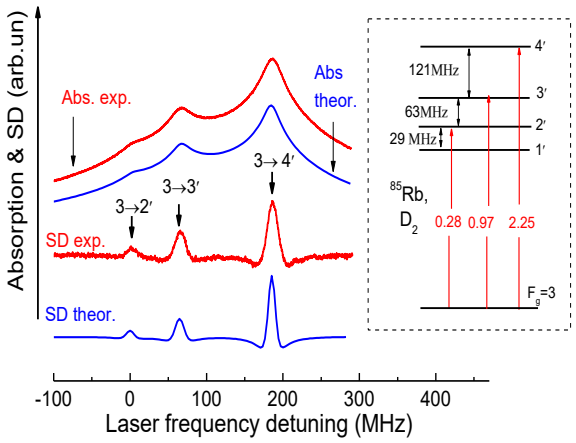

Fig.1 Absorption spectrum of a rubidium nanocell with the thickness L = 390 nm, for 3→ 2′, 3′, 4′ hyperfine transitions of ^{85}Rb D_2 line. Red lines: experiment; blue lines: theory. The curves labeled SD are the second derivative of the absorption spectrum. Red lines SD: experiment; blue lines: theory. Right panel: energy levels diagram, showing the transitions, their frequency separations and relative probabilities.

Reference

A. Sargsyan, A. Amiryan, Y. Pashayan-Leroy, C. Leroy, A. Papoyan, and D. Sarkisyan

"Resolution-enhanced quantitative spectroscopy of atomic vapor in optical

nanocells based on second-derivative processing of spectra"

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Features of Faraday rotation and its modification from a nano-cell

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When linearly-polarized light passes through a medium in a direction parallel to the applied magnetic field, the plane of polarization rotates. The effect is discovered by Michael Faraday in 1845 and found many applications in optical isolators, telecommunications, optical current sensors, spectroscopy *etc*.

Recently, we have demonstrated both experimentally and theoretically that the Faraday rotation (FR) of optical radiation using a nano-cell (NC) placed up to 1000 G longitudinal magnetic fields [1]. Having a spectral width of about 50 MHz, FR resonances are frequency-resolved and despite the large number of transition components this allows one to investigate the behavior of an individual transition in strong magnetic fields. Moreover, we propose a new method based on FR from a NC, so called MFR [2]. The essence of the modified FR method is the following: the output Glan polarizer is placed on a mechanical holder, which enables its smooth rotation around the axis in both clockwise and counterclockwise directions. In this case, the spectrum recorded at the analyser output has a dispersive shape. The MFR method allows to form atomic resonances atomic transitions that are characterized by a spectral width a factor of 1.5 - 2 smaller than those obtained by a common FR method in NCs. To demonstrate its efficiency, we have used the MFR to study to study the atomic transitions of the D_2 line of the Cs atom enables a spectral separation and successful analysis of the behavior of individual atomic transitions in a wide range of magnetic fields up to 7000 G. The method of MFR works particularly well in the case of a nano-cell filled with vapors of potassium atoms [3], because transitions of K atoms are split into several atomic transitions characterized by a small frequency separation of 100 MHz in magnetic field, while Doppler broadening of atomic lines reaches 900 MHz.

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Singlet Exciton Fission: What is it?

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Singlet exciton fission (SF) is a spin-allowed process when two triplet states can be produced from excited singlet state after absorption of one photon, potentially increasing the efficiency of photovoltaic devices. [1] This specific process was observed mostly in organic crystals, solid films and dimeric molecular systems.

Here, SF was studied in α-perylene single crystal and cofacial perylene dimer solution by use of time-resolved fluorescence and femtosecond transient absorption techniques under different excitation conditions. [2-3] In α-perylene crystal, SF competes efficiently with other excited-states decay channels: excimer formation and dimer cation generation. Similar to crystal, in perylene dimers SF was detected directly from upper excited vibrational and electronic states within 100 fs bypassing the relaxed state S_1, i.e. violating Kasha-Vavilov rule.

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Ultrafast Laser Spectroscopy: Graphene, SURMOF, Organic Crystals

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Some applications of femtosecond laser spectroscopy i.e. single-photon dianion formation in molecular crystals, ultrafast relaxation dynamics in tetraphenylporphyrin/SURMOF (Surface Mounted Metal Organic Framework), hot exciton cooling in perovskites, one- and two-quantum induced singlet exciton fission in organic single crystals and dimeric molecules, and quasiparticle ultrafast dynamics in graphene will be presented and discussed. [1-6] Briefly will also be introduced the methods of ultrafast laser spectroscopy.

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Singlet Fission for Solar Cells

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Here, the most general choice for solar cells is briefly interpreted, given the following types are silicon-based solar cells, dye-sensitized solar cells and perovskite based solar cells. We explore possibilities to increase efficiency of solar cells by using the singlet fission (SF). SF is a process when a photogenerated singlet exciton splits into two dark triplet states, i.e. with one single absorbed photon is possible to generate two excitons.

SF was studied in six-thiophene single crystals and thin films by use of time-resolved fluorescence and femtosecond transient absorption techniques under different excitation conditions. The SF has threshold for six-thiophene thin films: E = 3.02 eV. SF was observed directly from upper excited singlet states within 240 fs, which competes well with internal conversion, charge transfer and intersystem crossing processes.

Quadratic Heun potentials for a Stationary Relativistic Wave Equation for a Spinless Particle

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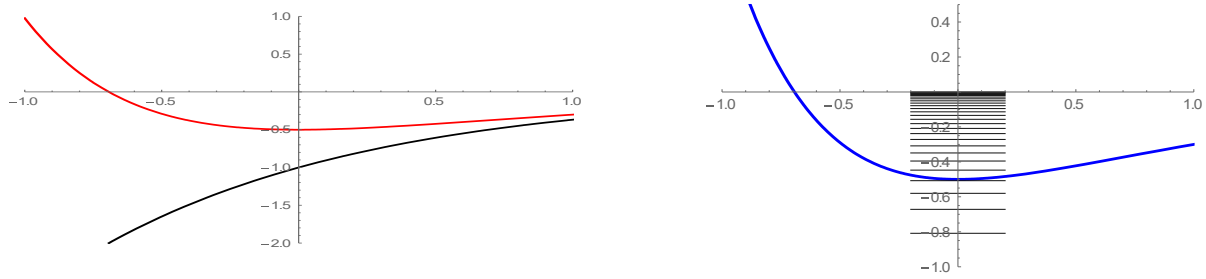
Distinct quadratic Heun potentials are presented for the stationary relativistic wave equation for a spinless particle [1,2]. The physical potentials and energy spectrum of this wave equation are related to those for the Schrödinger equation in the sense that all potentials obtained for the latter equation prove to be suitable also in the case of the wave equation under consideration. It is shown that the Heun potentials of the quadratic form $-\varphi(x)+\varphi^2(x)/2$ correspond to the attractive potentials $-\varphi(x)$ for the relativistic wave equation. This justifies the known approach for selection of the effective potential in the form of the sum of an attracting potential and the half of its square as a repulsive part of the potential. As an example, the solution of the relativistic wave equation for the attracting exponential potential that corresponds to the Morse potential energy in the Heun equation is investigated. The figure below shows exponential field potential $\varphi(x)$ and potential energy of Morse interaction $V(x)$. Figure b) shows V energy levels of a particle.



a) b)

It is shown that contrary to the Schrödinger equation, the characteristic spatial size of the potential imposes a restriction on the energy spectrum. The interaction constant is not limited in magnitude and it is not present in the expression for energy levels. The highest bounding energy of the ground state of the stationary particle for a potential energy $V(x)$ with the depth $mc^2/2$ is mc^2. The quadratic form of the potential energy and the restrictions on the energy spectrum are direct representations of Heisenberg uncertainty principle.

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Fluorescence of ^{85}Rb and ^{87}Rb vapor in a transient interaction regime

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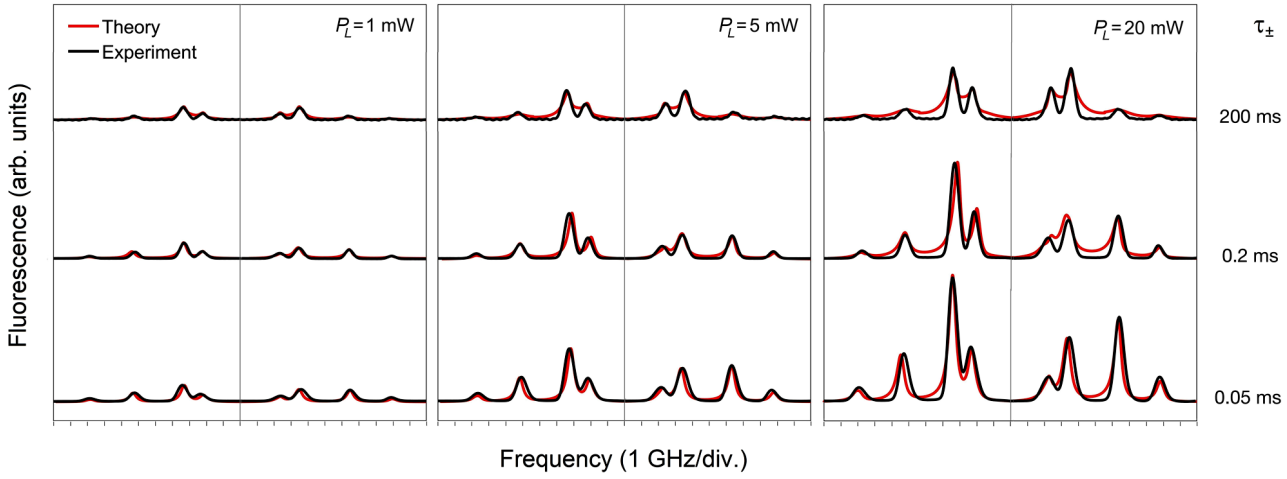
Resonant interaction of narrow-linewidth cw laser radiation with atomic vapors of alkali metals is intensely studied in the past decades, driven by fundamental interest and emerging important applications. Most of these studies deal with a steady-state regime of interaction of atomic ensemble with resonant light required for establishment of the relevant processes.

To the best of our knowledge, there are just a few works where transient resonant interaction processes were studied. Particularly, theoretical and experimental investigations of processes under dynamic excitation of atomic media with modulated cw laser radiation were done for nonlinear magneto-optical processes, saturation spectroscopy, four-wave mixing, coherent population trapping.

We have studied modification of the fluorescence spectra of a room-temperature atomic rubidium vapor in the region of ^{85}Rb and ^{87}Rb D_2 line while changing the temporal rate of linear (triangular) scanning of laser radiation frequency. Increase of the ramping speed over certain value ($\approx 10^6$ MHz/s) results in essential modification of magnitudes of individual atomic transitions, different on rising and falling slopes, which characterize transition from a steady-state interaction regime to a transient one. Our experimental results are well consistent with the developed theoretical model (see figure below). The obtained results can be used for determination of atomic system parameters such as relaxation rates. Possible follow-up actions on addressed control of atomic levels population will be discussed.



This work was supported by the State Committee of Science MES RA, in frame of the research project No.18T-1C234. We acknowledge the Institute for Informatics and Automation Problems, NAS of Armenia for technical support.

Polaron effects on the impurity-related linear and nonlinear optical properties in nanowire with magnetic field

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The optical properties of a nanowire (NW) can significantly depend on the presence of impurities in NWs. Since NWs are usually made of polar materials, the interaction between electrons and confined optical (CO) as well as interface optical (IO) phonon modes must be taken into account for a reliable description of the optical properties.

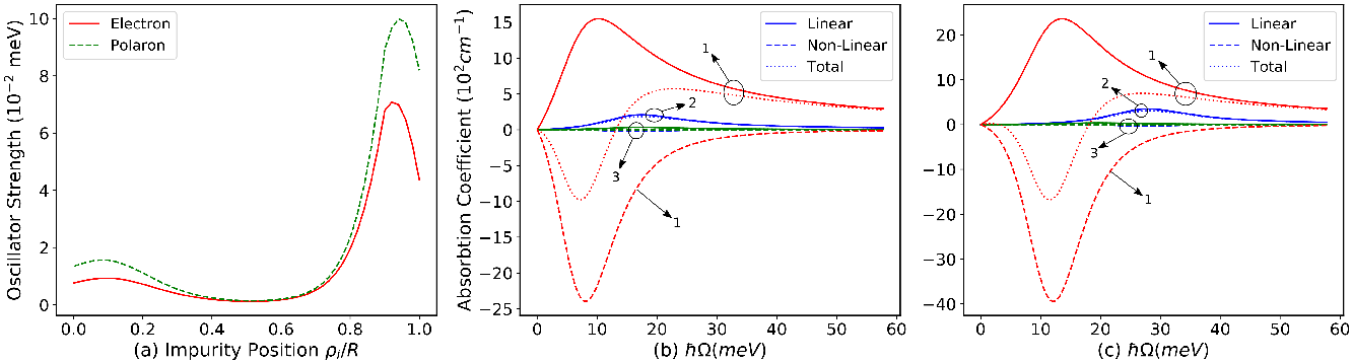

Fig. 1: Oscillator strengths (a) as functions of impurity position and absorption coefficients for (b) electron and (c) polaron as functions of photon energy at H=3T $1s \rightarrow 2p_x$ *for transitions.*

We considered a polar cylindrical parabolic NW, embedded into non-polar medium in a uniform magnetic field along the wire axis. the influence of impurity position, magnetic field strength and confining potential frequency on the electron and polaron binding energy as well as oscillator strength and linear and non-linear absorption coefficients (AC) and refractive index changes (RIC) for transitions from the ground state to a few excited states, have been investigated. Fig 1. shows the oscillator strength, AC and RIC for $1s \rightarrow 2p_x$ transitions for electrons and polarons. The obtained results show, that the polaron effect on the optical characteristics is noticeably manifested when the electron interacts mainly with either CO or IO phonons. We have shown that the electron -phonon interaction leads to blue shifts of all the absorption coefficients extrema. Also, the extrema of polaron transitions have larger values than electronic ones.

Superfluorescence in Erbium-doped YLF crystals

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We present a novel scheme for detection of low energy release in solid crystals made of inert gases solidified at cryogenic temperature named matrices.

Reactive species have been studied since the 50's by embedding them into crystals made of inert gases solidified at cryogenic temperature that provide a low interacting environment [1]. This technique called matrix isolation spectroscopy as the guest particles are isolated within the crystal that is made of un-reactive material. In the last year this kind of crystals were applied also for applications magnetic sensors [2], and for research in fundamental physics. We use these materials, in order to develop a new generation of hybrid detectors aimed to the study of low energy deposition rare events that are typical of dark matter studies. Based on the actual observations, different theoretical models are possible and so there are many possible candidates for the solution of the Dark Matter (DM) problem. In particular, we focus our research on the Axion like particles that have a mass constrained in eV and sub-eV range; in addition, their coupling with normal matter and radiation is very weak. To grow solid crystals with a large volume, both doped and undoped, according to the MIS technique, we have assembled a cryogenic facility at the INFN National Laboratories of Legnaro. The devised scheme is based on electrons ionization and emission in vacuum through the surface of these matrices that are characterized by a band-gap energy of about tens of eV, in particular, we initially test a crystal of high purity Neon. With un-doped crystals a few hundreds of electrons, that carry an information of few eV per each, can be detected reaching a low threshold scheme. Furthermore, alkali doping of the crystals, joined with single electrons detection, should lead in a lower energy threshold under the eV. High purity solid crystals with a cm^3 volume of neon were used in our tests aimed to verify electrons emission through the solid–vacuum interface.

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Control of Optical Pulse using A-Si:H and GaAlAs/GaAs Waveguides

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Controlling the velocity of light pulses through a nonlinear microring system is attractive research challenge for high speed optical and quantum computer, optical communication networks and secured communication. In this paper generation of fast light through Hydrogenated-amorphous silicon (a-Si:H) and GaAlAs/GaAs waveguides with fabricated Micro Ring Resonator (MRR) is reported. Using multistage system, the attosecond pulse can be generated. Simulation results obtained have shown that the generation of a very narrow full-width at half maximum (FWHM) and sharp tip are achieved.

Attosecond pulse from the output of micro ring resonators can be achieved by fabrication of Hydrogenated-amorphous silicon (a-Si:H) and GaAlAs/GaAs materials. Various authors have also reported external electro-optic modulators based on GaA1As/GaAs. Level integrable with semiconductor lasers using current technology, and most of the research on GaAlAs/GaAs waveguide modulators has been at 1.33 μm. Hydrogenated amorphous silicon is an alternative material which can be used for integration of silicon photonics.

In this study, discuss the results obtained to date on the performance of attosecond pulse generation using two martial in form of microring resonators. Figure (1) shows the proposed system which is consisting of multistage microring resonators with same radii.

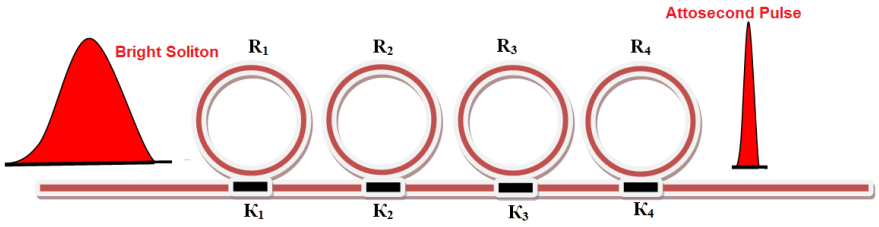

Figure 1. Schematic of multistage micro ring resonators.

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Optical monitoring of arbitrary distributed substances via radially-quadratic apodizing filter

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In the last decades, remote sensing of the Earth's surface is widely used to monitor the environment from the atmosphere and space. To this purpose, various methods of remote sensing by satellites [1] and unmanned aerial vehicles [2] are used. Although imaging technologies are widely used in optical monitoring systems, they have certain limitations [3].

In this work we describe a novel technique to monitor the changes in landscape using the unique properties of specially designed radially-quadratic transmission apodizing filter which can directly determine the integral characteristics of objects or distributed substances.

The developed remote sensing method deals with non-matrix detectors, and requires only one-step conversion of light energy into electrical signal to investigate the substance under study. Theoretical studies have been performed to derive the formulas characterizing substance parameters: distribution center, drift and drift speed of the center, radial standard deviation and its changing rate, diffusion. The technique is applied to remotely monitor the process of reduction of artificial snow area on the mock-up surface covered with a soil.

The proposed technique has the following advantages compared to imaging technologies:

- only one-step conversion of light energy into electrical signal is required to investigate the substance under study;

- the nonlinear uncertainty of measurements is minimal because of the usage of non-matrix detectors operating in the linear sensitivity range;

- the substance characteristics are calculated (not processed) with simple formulas by using data from non-matrix detectors.

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Poster presentations

Influence of air-annealing on optical absorption in Pr-doped garnet single crystals

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Annealing and non-isovalent co-doping of oxide scintillators with Ce^{3+} and Pr^{3+} luminescent ions are widely applied to promote changes in the valence state of activator ions and in the concentration of defects. In the present work, single crystals of yttrium and lutetium garnets with Pr^{3+} ions and co-doped with additional impurities (Ca^{2+} and Hf^{4+} substituting for trivalent lattice sites) were grown by the vertical Bridgman method and further subjected to air-annealing at high temperatures. Comparative studies of color centers in as-grown and air-annealed crystals (both un-doped and doped with Pr) were performed to find out the nature of related defects, as well as conditions leading to possible oxidation of Pr to its tetravalent state. The analysis of optical spectra has revealed the major reasons for observed differences in induced absorption profiles following air-annealing depending on the crystal composition.

Radiative Decays of Many Close Lying Feshbach Resonances at the Collision of Two Atoms in Laser Radiation Field

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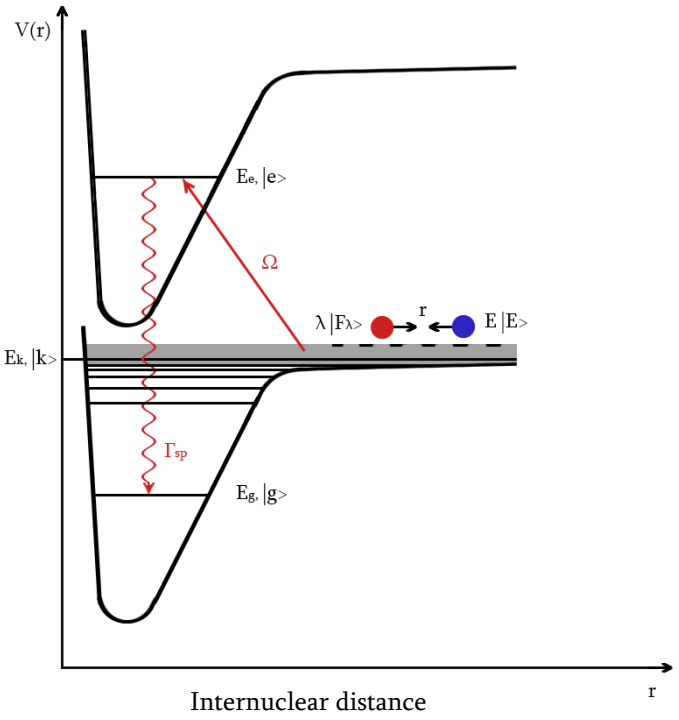
The formation of metastable molecules (Feshbach resonances $|F_\lambda\rangle$ [1]) at the collisions of two atoms and the subsequent spontaneous emission to lower electronic molecular state are investigated. In previous paper [2], stimulated transition to a lower unbound electronic molecular state with emission of a photon of the laser radiation filed has been investigated. When examining the phenomena in the Bose-Einstein condensate quantum system at the collision of cold atoms, it is necessary to take into account the formation of Feshbach's resonances through the highly excited molecular levels (Rydberg state) close to the decay threshold, in which case it is necessary to take into account the phenomenon overlapping resonances.



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Lasing in three-layer cholesteric-dye-doped polymer-cholesteric sandwich cell

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Cholesteric liquid crystals (CLC) are characterized with photonic band gap (PBG) due to spatial modulation of refractive index. It was known that the CLC layer can be used in different systems and serves as a media for the lasing generation [1]. They provide low threshold, mirrorless lasing. As liquid crystal's PBG can be controlled via external influences it was possible to control the lasing wavelength as well. They are promising microlasers which can be used in different photonic devices [2].

In our work, we prepare a sandwich cell consisting of two cholesteric layers and dye-doped polymer layer between them. Cholesterics provide light feedback with specific visible spectrum range. Dye-doped polymer layer is the active medium for the cholesteric-dye-doped polymer-cholesteric system. It was shown that due to the presence of polymeric layer defect modes have been appeared inside the PBG. The count of defect modes depends on polymer layer thickness. The defect modes existence has been also verified theoretically. Besides, we experimentally show the lasing possibility on the several defect modes' wavelengths simultaneously.

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Direct laser writing of buried phase structures in BK7 glass

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Materials processing by ultrashort-pulse lasers has found a widespread use as an efficient and versatile microfabrication tool [1-3]. The high level of tunability of laser parameters offered with modern laser systems allows one to choose among the variety of modes of laser-matter interactions and provides a wider choice of materials and design approaches for fabrication of specific devices and components. In this view, processing of glasses, crystals, and other transparent media is of specific interest due to a huge potential of applications in photonics and integrated optics.

In this presentation, direct laser writing technique is used for fabrication of buried structures in the volume of BK7 glass samples. Sub-picosecond laser pulses with sufficiently high energy induce permanent modifications resulting in the refractive index change (RIC) in the laser processed area. It is shown that by accurate choice of fabrication regimes (energy dose, scanning speed, etc.) enables 3D structuring with smooth RIC. Using the optimal regimes 3D patterns of buried structures are fabricated in layer-by-layer mode. As a particular application, binary phase element is fabricated and used for conversion of the laser beam profile from Gaussian to flat-top. Moreover, the capability of fabrication of nearly homogeneous large structures allows to suggest an "express" method for qualitative estimate of the sign and the value of the RIC in a particular fabrication regime.

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Studies on Nano-Sized Copper Oxide Thin Films Prepared by Pulsed Laser Deposition Technique

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Pulsed laser deposition (PLD) is an effective method for the low-temperature synthesis of thin films and/or multilayer-structured samples. The production of copper oxides-based nanoscale structures by the PLD is of both fundamental and practical interest for their use in the production of solar cells, sensors, photodetectors, and other optoelectronic devices [1-3]. In the present work vacuum pulsed laser deposition from CuO target was used to grow thin films of nanoscale thickness on glass and sapphire substrates at different grown temperatures. A compressed sputtering target was formed from pure CuO powder (99.9%) followed by annealing in muffle furnace (T=900 ° C). PLD experiments were carried out by Nd:YAG laser operating at 1064 nm. The obtained films of a thickness about 70 nm were annealed in the temperatures range of 500–700 ° C. To determine the characteristics of the films obtained SEM, EDX, surface roughness measurements, UV–Visible absorption spectroscopy used. It is shown that films as deposited in the temperature range of the substrate up to 400 °C have a surface roughness of no more than 6 nm and increases after annealing to 17 nm. Before annealing, all films demonstrate the same character of the spectral dependence of absorption, regardless of the growth temperature, both at room temperature and at 400 ° C. (Fig. 1. 1, 2 – on glass, 3 – on sapphire substrate).

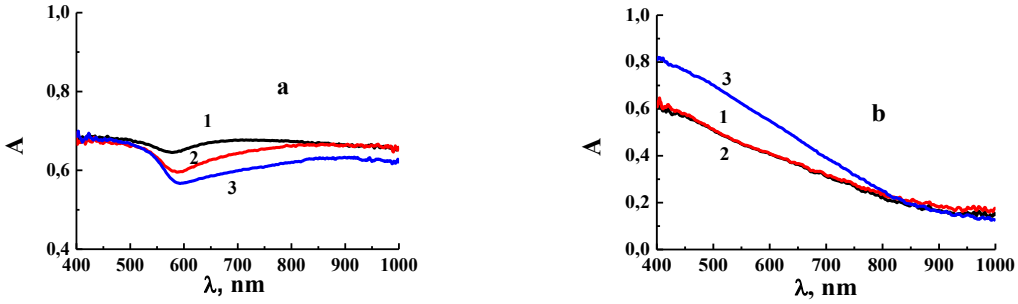

FIGURE 1. Absorption spectra of deposited films: before (a) and after annealing (b).

At the same time, annealing of the films leads to a decrease in the absorption in the long-wavelength range (at λ>750 nm) (Fig.1b). The results obtained, can be used to develop optoelectronic devices and solar cells.

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On optoelectronic properties of twin lamellae in homoepitaxial b - Ga_2O_3 layers

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Ga_2O_3 is an ultra-wide band gap material attracting considerable technological attention in the field of transparent semiconducting oxide optoelectronics [1]. Transmission electron microscopy observations [2] reveal that β–Ga_2O_3 layers grown homoepitaxially by metal-organic vapor phase epitaxy on (100) substrates contain a high density (10^{11}–10^{12} cm^{-2}) of thin twin lamellae (TL). The study of electrical transport properties of these layers has shown [2] that the mobility of transported electrons experiences a collapse below a threshold electron concentration of about $1x10^{18}$ cm^{-3}. It has been suggested [2] that the observed collapse phenomenon originates due to electrical activity of the TL-related acceptor-like traps. The aim of the present contribution is to show how the experimental collapse data [2] can be utilized for determining the statistical filling factor f of the TL-related traps in β–Ga_2O_3 layers. For this purpose we invoke the strong-coupling theory of electron-defect interactions in wide band gap compounds [3]. We use the deduced value of f for estimating the characteristic magnitude and the spatial extent of the band bending in the vicinity of an individual TL. We also discuss the influence of TL density on the band edge luminescence of β–Ga_2O_3.

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Development of compact alkali-metal vapour cells with buffer gas for coherent-population-trapping atomic clocks

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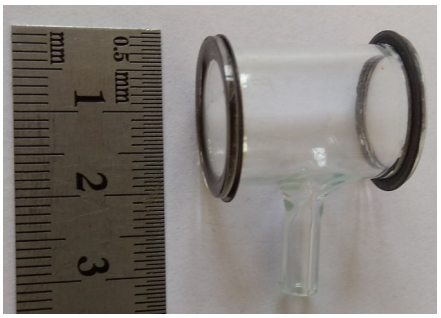
Atomic clocks based on buffer-gas filled vapour cells is of great interest for many fields of modern science. Many research groups are nowadays focused on creation of small-size vapor cells [1, 2], because it is a crucial issue for miniaturization of atomic clocks based on coherent population trapping phenomenon.

The present work is devoted to development of compact glass cells with flat windows, containing alkali -metal vapor such as rubidium and cesium, and mixture of buffer gases. The work is aimed at achieving good optical quality of the cell windows. Our cell is composed of two plain windows bonded through a metal ring with the glass cylinder. Bonding happens by utilizing induction welding. Induction welding is a very fast process, so it leads to the optically undistorted cell windows. As a result of the work, compact cells with good quality of optical surfaces have been created. Some of them are filled with alkali-metal vapour and buffer gas mixture (neon and argon).



Compat A compact cylindrical glass vapour cell with flat windows

The light field absorption profiles and coherent populations trapping resonances have been observed with the help of the cells developed. The results will be presented and discussed during the Conference.

The work was supported by RFBR and Government of Novosibirsk region in the frame of the research project № 19-42-543001.

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Influence of $ZnGeP_2$ crystal absorption on CO laser down-conversion to THz range

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The terahertz (THz) spectral range 0.1-10 THz (wavelength 30-3000 μm) has received increased attention of scientists due to a lot of important applications. A promising wave to get THz laser radiation is down-conversion (difference frequency generation) of mid-IR laser radiation in nonlinear crystal. Down-conversion of mid-IR lasers should be more efficient as compared to near-IR lasers due to the higher Manley–Rowe relation. For example, MW peak power of THz radiation was obtained with CO_2 laser pulses of subnanosecond duration [1].

A disadvantage of CO_2 laser for THz generation is a small set of spectral lines which limited its THz spectroscopy applications. Meanwhile carbon monoxide (CO) laser has significantly richer spectrum numbering hundreds spectral lines from 4.7 to 8.7 μm range. Such rich spectrum allows one to densely cover full THz range. For the first time CO laser down conversion in $ZnGeP_2$ crystal was numerically studied in [2]. However the calculations [2] were performed rightly and most importantly did not consider the crystal absorption. In current work we improved upon the numerical simulation of CO laser down conversion in $ZnGeP_2$ crystal, took into account the crystal absorption in THz range. The down conversion efficiencies integrated over spectrum without (1) and with (2) taking into account the crystal absorption are presented in FIGURE. The plot (2) was multiplied in 10 times.

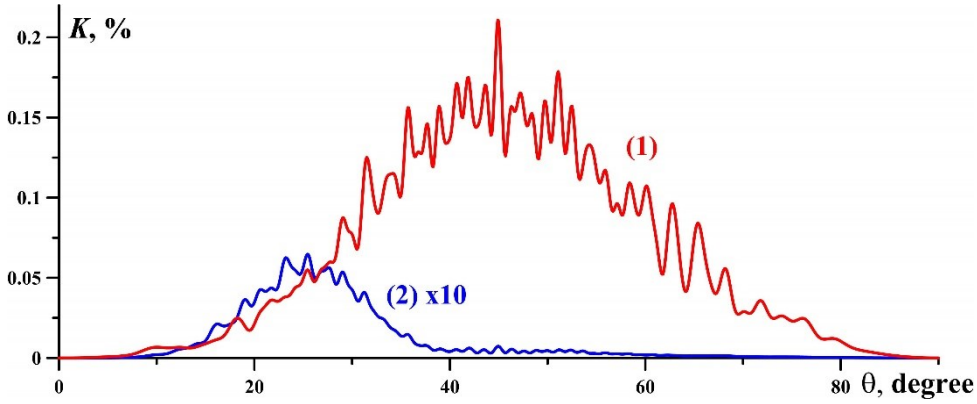

FIGURE CO laser down conversion efficiencies without (1) and with (2) $ZnGeP_2$ absorption

The FIGURE demonstrates that the influence of $ZnGeP_2$ absorption on CO laser down conversion is significant. The crystal length and cut angle of $ZnGeP_2$ were corrected by the improved numerical simulation. The research was supported by the RFBR (Project No 18-52-16019).

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Characteristics of LaB_6 and CeB_6 Thin Films and Detection Pixel Based on Them

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The characteristics of a single and three-layer detection pixel of a thermoelectric single-photon detector with the LaB_6 absorber and the sensor (La, Ce)B_6 and CeB_6 are investigated by computer modeling in [1,2]. Results show that such the detector is able to register the single photons in the wavelength range from the UV to near IR. At the same time, the gigahertz count rate is ensured, the energy resolution is not worse than 1% and the system detection efficiency exceeds 90%. High detection efficiency is obtained due the fact that the use of the LaB_6 absorber can provide the 95% of optical coupling efficiency of the photons and the detection pixel, 99.9% of photon absorption efficiency, and close to 100% the internal detection efficiency. In close proximity to the unit cell and the coefficient of volume expansion of hexaborides used in the construction of the three-layer detection pixel opens up the possibility to obtain high-quality heterostructures and to use them as a detection pixel of the thermoelectric detector at helium temperatures. Such structures are stable to the thermocycling and have the mechanical characteristics that ensure their long-term use at operating temperatures of detection pixel.

LaB_6 and CeB_6 thin films were fabricated by electron-beam deposition. Thin films' depositions were carried out from ceramic targets on the insulator, semiconductor, and metal substrates at different temperatures. The microstructure, elemental and phase compositions, thickness and roughness of films, as well as some physical properties are studied. The conditions for the preparation of highquality films are determined. Reflection spectra of LaB6 films of various thicknesses on different substrates and CeB_6 thin films are investigated.

The results obtained can be used for creation of a prototype of the sensitive element for thermoelectric detectors. One can assert in consideration of the advantages of thermoelectric detectors that thermoelectric detectors with multilayer $LaB_6/CeB_6/LaB_6$ detection pixel may be real competitors of superconductive single-photon detectors.

This work was supported by the RA MES State Committee of Science in the frames of the research projects 18T 2F134.

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Ultrafast and High-Efficient Single Photon Detector on the Bases of CeB_6 Thermoelectric Sensor: 0.8-4 eV Photon Detection

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The design of four-layer detection pixel SiO_2/W/CeB_6/W of thermoelectric single-photon detector (TSPD) is proposed. It is justified that the detector with such detection pixel can provide system efficiency above 90% for photons with 0.8-4 eV energies. The method of computer simulation is used to study the heat propagation processes in the four-layer detection pixel of the thermoelectric single-photon detector after photon absorption. The temporal dependence of the amplitude of the signal appearing on the detection pixel is calculated for different thicknesses of detection pixel layers. The signal delay time, the maximum signal value, the maximum signal reaching time, the signal decay time to the background, and the detector's count rate are determined. It is shown that the maximum of the signal is many times higher than the background level, does not depend on the area of photon thermalization in the absorber and has a linear dependence on the photon energy. The dependence of maximal voltage arising at the detection pixel and count rate of TSPD on the photon energy at different thickness of absorber are shown in Figure 1.

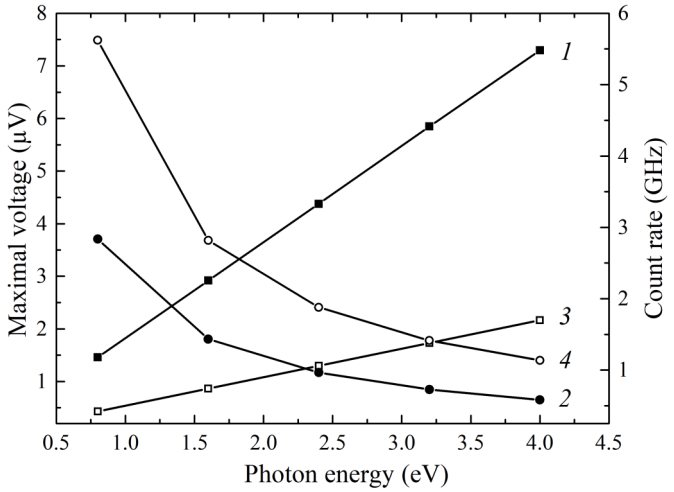

Figure 1. Dependence of V_m (1, 3) and R (2, 4) parameters on the photon energy at thickness of absorber equal to 0.1 μm (1, 2) and 0.2 μm (3, 4).

The construction of the detection pixel also provides terahertz count rates. The signal delay time is less than a femtosecond. Detectors with such characteristics are in demand in various fields of science and may have wide range of practical applications in future technologies.

This work was supported by the RA MES State Committee of Science in the frames of the research projects 18T 2F134.

Effects of non-isovalent impurities on optical and radiative properties of Ce-doped garnet single crystals

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Recent studies have shown that the scintillation performance of Ce-doped garnets strongly depends on the Ce^{3+}/Ce^{4+} ratio and the amount of anion vacancies present in the lattice. Divalent co-dopant ions (Ca^{2+}, Mg^{2+}) favor Ce^{4+} states but can also increase the amount of anion vacancies [1]. Our recent studies have shown that monovalent Li^{+} ions in YAG, when taken in low concentrations, are localized at interstitials and decrease the amount of anion vacancies, for charge compensation [2]. In the present work two types of garnet crystals were grown and investigated: (1) YAG:Ce,Ca,Li in which the combined positive effect of co-dopants was expected, and (2) YScAG:Ce,Li in which Li^{+} was expected to substitute Sc^{3+} in octahedral sites due to their very close ionic radii. The studies included X-ray measurements of lattice parameters, optical absorption and X-ray induced luminescence rise time and decay which confirmed the functional role of co-dopants. The results on YAG:Ce,Ca,Li have shown that, as compared to YAG:Ce, the slow decay components are further suppressed which can be due to decrease of anion vacancies acting as traps. A small effect of Li on the decay in YScAG:Ce was registered showing that despite Li^{+} goes to Sc^{3+} sites its efficiency in promoting Ce^{4+} states is not high and that the charge compensation mainly proceeds in other ways.

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Thermophysical and Optical Properties of Semitransparent Obsidian from Arteni Deposit (Armenia)

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Armenia has significant reserves of obsidian, volcanic glass, produced when volcanic lava rapidly cools through to the glass transition temperature and does not give enough sufficient time for crystallization. Obsidians are natural alumosilicate glasses composed of M_2O–Al_2O_3–SiO_2, (M = Na, K, Ca), and contain different elements present in major (>1 wt%), minor (0.1–1.0 wt%) and trace (<0.1 wt%) amounts incorporated into the silicate network during glass formation. They can contain also significant amounts of water both in the form of OH groups and as molecular water, which affect strongly their physical and chemical properties, and as well as the crystalline inclusions (so-called microlites, up to 1–5 wt%) in the glassy matrix. The color of the glass depends upon the presence of various metals together with the circumstances of its formation, but obsidian is typically black or grey and is sometimes banded. Translucent obsidian samples from the Arteni deposit were investigated.

Analysis of obsidian samples were carried out by different methods (scanning electron microscopy –energy dispersive spectroscopy (SEM–EDS), XRD analysis, the absorption, reflection and Raman spectroscopy in the UV, visible and IR ranges, as well as differential thermal DTA and thermogravimetric analysis (TGA) for characterization of semitransparent obsidian of gray color from the Arteni deposit.

Theoretical Investigation of Impurity States and Light Absorption in Quantum Well with Modified Pöschl-Teller Potential

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During the growth of real structures, the most often the symmetric confinement potential due to diffusion arises, which in most cases is approximated with great accuracy by the parabolic potential. Moreover, it should be noted that the ideal parabolic approximation is well used at relatively low levels of size quantization [1]. The problem of impurity absorption in a parabolic quantum well (QW) was considered in detail in [2]. However, on the other hand, for low levels of energy of charge carriers, the modified Pöschl-Teller potential is well approximated by the parabolic potential, which makes it possible to bring the model we are considering as close as possible to the real [3]. One of the advantages of this potential over the parabolic one is that in a model with a modified Pöschl-Teller confining potential, it is possible to consider electron ejection from the well, which is impossible in the case of the parabolic potential, since the walls of the latter are impenetrable (see Figure).

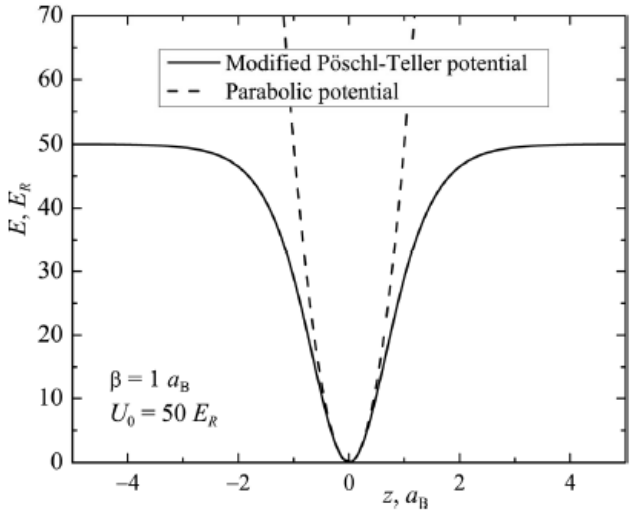

FIGURE. The comparison of parabolic and modified Pöschl-Teller potentials. The parameters of the parabolic potential are obtained by the decomposition of the modified Pöschl-Teller potential into series.

In connection with the above, the study of hydrogen-like donor impurity states and optical absorption in the QW with the modified Pöschl-Teller potential is an urgent and interesting problem. This work is devoted to the study of hydrogen-like donor impurity states and impurity absorption in a quantum well with the modified Pöschl-Teller potential. In particular, the intersubband transition from the ground level of the donor impurity to the first level of the conduction band is considered.

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$LiNbO_3:Tm^{3+}$ crystal: Material for optical cooling

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Lithium niobate (LN) crystal doped by the three-valence rare-earth impurity ions (RE3+) is a promising multifunctional material for compact self-doubling lasers in the infrared and visible regions of the spectrum [1, 2]. They can be considered also as a material for optical cooling on the base of the anti-Stokes (ASL) radiation of impurity ions as well as for so called balanced lasers.

In the current work results on experimental study of absorption and luminescence of congruent composition LN crystals doped with different concentration of Tm^{3+} impurity ions. On the base of analyses of the energy scheme of the Stark levels of the multiplets $^3F_4$ and $^3H_6$ and the results of theoretical studies of the spectroscopic properties of the LN-Tm^{3+} crystal it is considered possibilities of the mentioned crystal for optical cooling based on ASL in the wavelength range of 1650 -2000 nm.

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Interband light absorption in cylindrical quantum dot with modified Pöschl - Teller potential in the presence of electrical field

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Consider the motion of electron (hole) in a cylindrical QD, with modified Pöschl - Teller potential (MPPT) in z-axis, and in a radial direction by the infinitely deep potential [1,2].

$$V(z) = \tilde{U}_0 - \frac{\tilde{U}_0}{ch^2\left(\tilde{z}/\tilde{\beta}\right)}$$

Where $\tilde{U}_0$ and $\tilde{\beta}$ are respectively the depth and half-width of the MPPT. In the regime of strong size quantization, the energy of Coulomb interaction between an electron and a hole is much smaller than the energy caused by the walls of the QD and can be neglected.

Put system in an external electric field (FIGURE) [2]. For dimensionless Hamiltonian we have

$$H = -\frac{\partial^2}{\partial r^2} - \frac{1}{r}\frac{\partial}{\partial r} - \frac{1}{r^2}\frac{\partial^2}{\partial \varphi^2} - \frac{\partial^2}{\partial z^2} + U_0 - \frac{U_0}{ch^2\left(\frac{z}{\beta}\right)} - eEz$$

where e is electron charge, E is electric field straight.

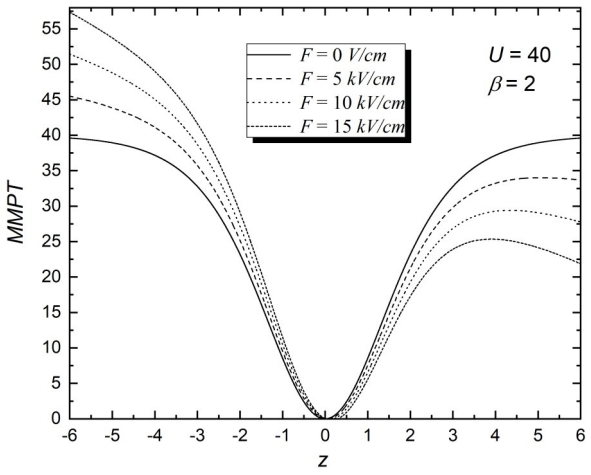

FIGURE. MPPT in an external electric field.

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The band gap variation of Boron Nitride nanotube

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Abstract. The structure, stability of the zigzag (6,0) and armchair (6,6) Boron Nitride nanotubes with embedded carbon atoms have been investigated in the framework of both generalized-gradient approximation (GGA) and local-density approximation (LDA) density functional theory. Carbon atoms have significant impact on both structures. The results show that embedded carbon atoms reduce band gap.

Investigation method and tool

Simulation and calculation of BN-NT physical properties have been done with Synopsys QuantumATK software tool. In order to estimate the carbon atoms' influence on BN-NT at first it has been created clear zigzag (6,0) structure consisted of 120 atoms with 1.42 lattice constant which is schematically shown in Fig 1 a) and armchair (6,6) boron nitride nanotube consisted of 240 atoms with 1.42 lattice constant Fig 1 b).

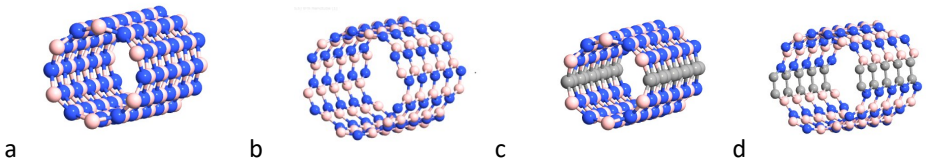

Figure 1. The schematic view of BN-NT structure for **a)** zigzag (6,0) **b)** armchair (6,6) **c)** BN-NT (6,0) structure with embedded carbon atoms **d)** BN-NT (6,6) structure with embedded carbon atoms

Results and discussions

DFT in local-density approximation or in the generalized-gradient approximation overestimates the additional electrons' screening. The results with both approximations are given in Table 1. The band structures are shown in Figure 2. Results show that bandgap on BN-NT with embedded carbon atoms is smaller than clear BN-NT. But bandgap increases with BN-NT diameter.

Table1.

BAND GAP		
	GGA	LDA
(6,0) BN	2.82eV	2.61eV
(6,0) BNC	0.97eV	0.84eV
(6,6) BN	4.64eV	4.48eV
(6,6)BNC	3.05eV	2.97eV

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Effect of Hydrostatic Pressure and Temperature on the Impurity States and Diamagnetic Susceptibility in Strongly Oblate Ellipsoidal Quantum Dot

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In this work, the hydrogen-like impurity states in a strongly oblate ellipsoidal quantum dot have been investigated in the presence of the external hydrostatic pressure and temperature. Numerical computations were performed within the framework of the variational method. The dependences of the binding energy on the location of the donor impurity were obtained for various values of external pressure and temperature. At various values of external pressure, the dependence of the diamagnetic susceptibility on the impurity coordinate has been revealed. The dependence of the oscillator strength for the first two transitions from the impurity ground state to the conduction band has been computed. The three-dimensional dependence of the photoionization cross section on the frequency of the incident light and hydrostatic pressure is given. In dimensionless quantities and cylindrical coordinates, the Hamiltonian of the system has the following form:

$$\hat{H} = -\frac{m_e^*}{m_e^*(P,T)}\left(\frac{\partial^2}{\partial\rho^2}+\frac{1}{\rho}\frac{\partial}{\partial\rho}+\frac{1}{\rho^2}\frac{\partial^2}{\partial\varphi^2}+\frac{\partial^2}{\partial z^2}\right)-\frac{k}{k(P,T)}\frac{2}{\sqrt{\rho^2+\rho_0^{\,2}+(z-z_0)^2-2\rho\rho_0\cos(\varphi)}}$$

Where are the coordinates of the donor impurity. Note that all lengths in the problem will be measured in effective electron $\{\rho_0, z_0\}$ Bohr radii, and energies in electron effective Rydberg energy. Since this problem does not have analytical solution, the variational method for the calculation will be used. The trial wave function will be constructed on the base of wave function of non-impurity problem obtained within the geometrical adiabatic method [1].

The optical and electronic properties of the system have been studied [2]. It was found that the dependence of the binding energy on the impurity displacement along the semi-major axes is non-monotonic. The dependence on temperature in these systems is ill-defined. In case of transition from the impurity ground state to the ground state of the conduction band, the oscillator strength monotonically increases with impurity position, while in the case of the transition from the impurity ground state to the first excited level of the conduction band, the dependence is bell-shaped.

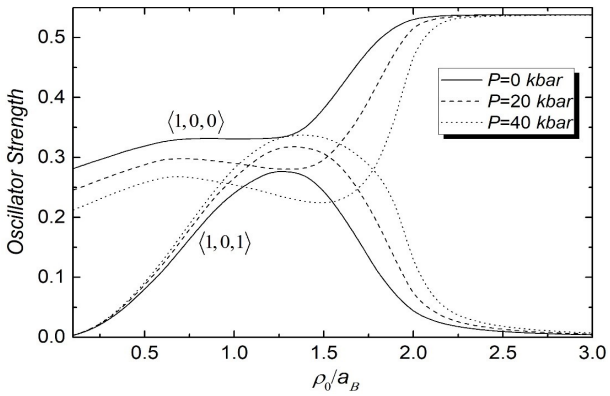

Fig. Dependence of oscillator strength on impurity displacement for various pressure values

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Frequency Conversion in Nanocomposite Materials

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Ultrashort laser pulse propagation through a nanocomposite consisted of semiconductor quantum dots (QD) incorporated into nonlinear dielectric matrix is studied. Value, angular distribution and spatial dispersion of permanent dipole moments (PDM) are taken into account. The three-level system resonant to pump pulse at the lowest transition between QD exciton states is analyzed. The Hamiltonian describing the light-matter interaction includes fast oscillating diagonal elements due to PDM that impedes to apply traditional approach to calculate photoinduced macroscopic polarization. Transformed Hamiltonian describes QD interaction with fields at multiple frequencies. After some transformations we get generalized two-level system in rotating reference frame without fast oscillating terms, suitable for one- and two-quantum transitions, and Bloch equations for the QD with PDM in slowly varying amplitude approximation (SVEA). The macroscopic polarization contains multiple harmonics, which can be a source of harmonics at corresponding frequencies for the nanocomposite.

THz generation is shown to increase under phase-matching conditions (PMC) due to Zakharov-Benney resonance between THz and pump waves. When PDM is weak and one-photon transitions predominate, the THz field dependence on the pump pulse field is quadratic, in this case THz efficiency does not exceed 0.1%. With increasing PDM magnitude the underlying two-photon transitions (2PT) result in stronger dependence of THz harmonic on the pump pulse providing more efficient frequency conversion. For prevailing 2PT, THz efficiency reaches 16-17%. At the same time the nanocomposite can provide the second harmonic (SH) generation efficiency such as 70 % and more. Speaking about high harmonic generation we should note that intensity of n-th order harmonics is proportional to the PDM magnitude in 2(n-1) degree and pump pulse intensity in 2n degree. Impact of the pump pulse phase modulation and local field and also matrix nonlinearity effect on harmonic generation process are analyzed.

Having optimized the parameters of the pump pulse and nanocomposite materials, highly efficient frequency conversion to THz and SH has been established.

Investigation of binding and recombination energies of heavy hole- and light hole- trion states in ellipsoidal quantum dot

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The negative trion, which consists of two electrons bound by a hole, is the semiconductor analogue of the hydrogen ion H^-. As the exciton is neutral, its attraction is very weak the trion can only be observed at very low temperatures. Hence, the existence of trions was proposed more than 50 years, but it was only, in the 1990's, identified in semiconductor quantum wells [1, 2]. The variational function for the negative trion will be constructed on the single-particle wave functions, which has been used in [3]:

Hamiltonian of the system $\hat{H}$ has the following form:

$$X^-,\ \hat{H} = \sum_j \frac{\hat{P}_j^2}{2m_j^*} + V_{\text{int}}\left(\vec{\rho}_1, \vec{\rho}_2, \vec{\rho}_a\right) + \sum_j U_{conf}\left(\vec{\rho}_j, z_j\right),\ j = \{1, 2, a\} \tag{3}$$

By the help of the variational method one can calculate the energy of negative trions for the ground level. For two types of negative trions, expressions for the binding energy are defined below:

$$\begin{aligned} E_{bind}\left(X_\ell^-\right) &= \left(2E_e + E_{\ell h}\right) - E\left(X_\ell^-\right), \\ E_{bind}\left(X_h^-\right) &= \left(2E_e + E_{hh}\right) - E\left(X_h^-\right). \end{aligned} \tag{4}$$

where E_e, $E_{\ell h}$ and E_{hh} are the energies of the electron, light hole and heavy hole respectively, in the SPEQD. As the next step let us calculate the recombination energies of negative trions, calculated according to the following formulas:

$$\begin{aligned} \omega_{if}\left(X_\ell^-\right) &= E^{(i)}\left(X_\ell^-\right) - E_e^{(f)}, \\ \omega_{if}\left(X_h^-\right) &= E^{(i)}\left(X_h^-\right) - E_e^{(f)}, \end{aligned} \tag{5}$$

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Full Population Transfer in Five Level System Using Stark-Chirp Method by Two Laser Fields

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Many works [1,2] show the population transfer between two quantum states, using the technique of Stark-chirped rapid adiabatic passage SCRAP which also allows a simple and robust method for a complete population transfer among three states in atoms and molecules. Extension to three-level systems, e.g. double-SCRAP (D-SCRAP) or three-state-SCRAP (T-SCRAP) were theoretically proposed [1,3,4] and experimentally demonstrated [3,4]. However, these powerful extensions of SCRAP have been so far mainly investigated numerically. In particular, the sensitivity of the technique with respect to pulse propagation effects, dynamic detuning, and parametric spectral broadening requires a detailed analytical treatment.

In this work, we present a simple implementation population transfer in a five-level atom based on the numerical analysis, a generalization of the Stark-chirp method on a five-level system, considering all the relaxation processes. The proposed models of optical reversible Fredkin gate can serve as a basis for the design of a reversible optical processor operating on the cyclic transfer of atomic populations.

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Nuclear processes in a high voltage discharge with a water surface

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The results of the study of high-voltage discharge between the external electrode and the surface of the water, when the interelectrode space is partially filled with water and the discharge, in fact, occurs between one of the electrodes and the surface of the water, are presented. When water is in direct contact with the anode, and the cathode is a copper wire with a diameter of 0.4-0.5 mm, due to an electrical discharge, the tip of the copper wire melts to form a round ball at its end. The magnitude of the discharge current depends on the length of the discharge gap and in our experiment ~ 20mA. After melting the tip with the formation of a ball and a 15-minute exposure to an electric discharge, the composition of the surface layer of the formed copper ball was studied. The measurements were carried out on a VEGA TS 5130MM scanning electron microscope with an INCA Energy 300 microanalytical system. The results of the study showed the emergence of new chemical elements after a high-voltage discharge with the surface of the water. Of interest is, in particular, the formation of nickel on the surface of a copper ball (~ 1.4% by weight). When changing the polarity of the electrodes, this phenomenon is absent. It is impossible to explain the formation of the Ni element from Cu by chemical methods, therefore, we can assume the presence of the process of nuclear conversion of copper to nickel according to the scheme:

$$_{29}Cu^{63} + n^{*} \rightarrow {}_{29}(Cu^{64})^{*} + \gamma \rightarrow {}_{28}Ni^{64} + \beta^{+} + \gamma \qquad (1)$$

To implement the scheme (1), a neutron source is needed, which can be formed as follows. At the beginning of the electric discharge, water evaporates, and the copper cathode in the form of a ball is enveloped by water molecules. Naturally, H + ions will be directed to the negative electrode, which will lead to the formation of a double electric layer based on H + ions and electrons present in the metal cathode. In the process of discharge, by analogy with [1,2], quasineutrons are formed according to the scheme:

$$H^{+} + e^{-} \rightarrow n^{*} + \nu \qquad (2)$$

Thus, the cause of the nuclear transformation is the quasineutron (n *), which, having a mass defect, easily enters into communication with the nearest nuclei, including the copper nucleus. Neutrons can be formed under the influence of cosmic rays, radioactive isotopes and during a thunderstorm [3]. It can be assumed that the mechanism of neutron generation during thunderstorm activity also occurs in accordance with scheme (2).

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Observation of angular-momentum alignment-to-orientation conversion in the ground-state of rubidium

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The results of this work show that the angular momentum spatial symmetry can be transformed by combined action of linearly polarized exciting laser radiation and an external magnetic field. The linearly polarized light first creates an aligned state and the external magnetic field can transform the angular momentum spatial distribution into a partially oriented state. It means that the aligned state, which had a determined axis, now has also preferred spatial direction. This angular momentum spatial symmetry transformation is also known as alignment-to-orientation conversion (AOC). In the present work we show the obtained experimental signals of two mutually oppositely circularly polarized laser-induced fluorescence (LIF) components and their difference. The results show that there is a non-zero difference between the two circularly polarized LIF components, which is direct evidence of partial orientation of total angular-momentum. The excitation and observation geometry for creating and observing AOC stands as follows: the magnetic field **B** defines the quantization axis and the exciting linearly polarized laser radiation **E** forms an angle of $\pi/4$ with respect to the magnetic field **B**, observation direction is in the direction perpendicular to both **E** and **B**. In the previous work [1], where the same excitation and observation geometry was used, the AOC phenomenon was studied in the excited state where due to the nonlinear Zeeman effect of the excited state magnetic sublevel crossings occurred thus allowing for linearly polarized light to create coherence among sublevels that differ in value by 1 ($\Delta m_F = 1$). In contrast, there is no magnetic sublevel crossings in the D1 line of rubidium and one would not expect to observe AOC. But due to the nonlinear dependencies of the energies of ground-state magnetic sublevels, the angular momentum alignment, created by linearly polarized light, can be partially converted to orientation. The energies of the excited-state magnetic sublevels also depend nonlinearly on the external magnetic field, but after around 1000 gauss this dependence becomes linear, but the energies of ground-state magnetic sublevels still exert nonlinear behavior. For this reason, the ground-state AOC can be observed at relatively high magnetic field values – more than 1000 gauss.

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Spectroscopic Properties of Yb^{3+} in $Y_3(Sc_{0.3}Al_{0.7})_5O_{12}$ (YSAG) and in $Y_3Al_5O_{12}$ (YAG) Laser Ceramics

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Abstact

The absorption and emission spectra of laser grade Yb^{3+} ion doped $Y_3Al_5O_{12}$ (YAG) and $Y_3(Sc_{0.3}Al_{0.7})_5O_{12}$ (YSAG) ceramics have been measured at room temperature [1]. With the aim of analyzing the relationship between the spectroscopic properties of optically active Yb^{3+} ions and the lattice structure in the above mentioned ceramics hosts the line strengths of indirect electric dipole and magnetic dipole transitions between Stark sublevels of the Yb^{3+} have been calculated [2]. Starting from the experimental data the Judd-Ofelt intensity parameters and the spectroscopic characteristics of inter-Stark transitions of YAG and YSAG ceramics, i.e. the probabilities of spontaneous transitions and radiative lifetimes of Stark sublevels of excited manifold and fluorescence branching ratios have been computed. Due to the modified crystal field, the sublevels of the upper ($^2F_{5/2}$) and of the lower ($^2F_{7/2}$) manifolds of Yb^{3+} are more broadly split in YSAG compared to YAG. Furthermore, the main Yb^{3+} emission peaks undergo red shift.

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