Abstracts: Talks

Contactless photon-photon interactions

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The experimental demonstration of electromagnetically induced transparency (EIT) involving highly-excited Rydberg atoms [1] opened the door to a new field of quantum non-linear optics mediated by dipolar interactions between highly-excited Rydberg atoms [2]. A unique feature of Rydberg quantum optics is the ability of photons to interact without ever being in the same medium. Recently, we demonstrated a van der Waals repulsion between two photons stored in media separated by 15 times their wavelength [3]. Each photon experiences a position dependent refractive index induced by the photon stored in the adjacent medium, as illustrated in the Fig. 1.

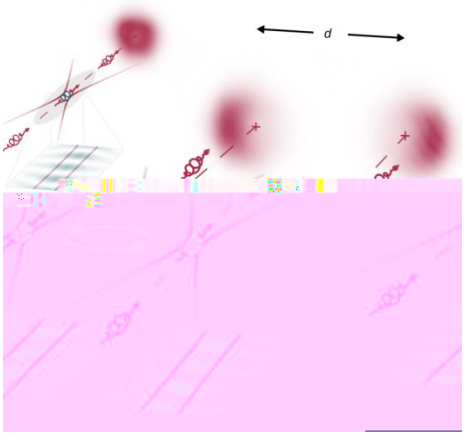

Fig. 1: *Propagation of photons (red) through two independent media (grey). The photons are stored in collective superposition involving highly-excited Rydberg states which interact via long-range van der Waals interactions. The interactions imprint a phase gradient on the superposition state (shown below) leading to a deflection of the outgoing photons. The inset shows the case of a single channel.*

Such long-range interactions between photons provide an interesting platform for scalable multichannel photonic devices, or quantum simulation of strongly correlated many-body dynamics using light.

References

[1] A. Mohapatra et al, Coherent optical detection of highly excited Rydberg states using electromagnetically induced transparency, *Phys Rev Lett*. **9**8, 113003 (2007).
[2] O. Firstenberg, C. S. Adams, and S. Hofferberth, Nonlinear quantum optics mediated by Rydberg interactions *J Phys B* **49**, 152003 (2016).
[3] H Busche et al., Contactless nonlinear optics mediated by long-range Rydberg interactions *Nature Phys.* doi:10.1038/nphys4058 (2017).

Experimental Demonstration of Self-Spectral Compression of

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Self-spectral compression (self-SC) [1-2] has been recently experimentally demonstrated and analyzed in details, as a spectral analogue of soliton-effect compression [3-7]. The self-SC requires strong GVD and weak SPM, while for solitonic pulse compression weak GVD and strong SPM are required. Analogically, an effective adiabatic soliton self-SC in a dispersion increasing fiber for pre-chirped pulses, the spectral analogue of adiabatic soliton compression, has been reported [8].

We report the self-SC of noisy supercontinuum radiation in a standard single-mode fiber. Silica has negative GVD in the wavelength range above 1300 nm. To reach that region we generated supercontinuum and cut the spectrum with a longpass filter at 1300 nm. Then we coupled the radiation into a 600-m long standard single-mode telecom fiber. Additionally, numerical studies of the process were carried out by our group, to understand the peculiarities of self-SC process.

References

[1] L.K. Mouradian, A. Grigoryan, A. Kutuzyuan, *et al*. *Conf. Digest,* FW3F. 3 (2015).

[2] H. Toneyan, M. Sukiasyan, V. Avetisyan *et al*. *Conference Digest,* JW4A. 44 (2016).
[3] L.F. Mollenauer, R.H. Stolen, and J.P. Gordon. *Phys. Rev. Lett.* 45, 1095 (1980).
[4] L.F. Mollenauer, R.H. Stolen, J. P. Gordon, *et al. Opt. Lett.* 8/5, 289 (1983).
[5] M.A. Foster, A.L. Gaeta, Q. Cao, *et al. Opt. Express.* 13, 6848 (2005).
[6] A.B. Salem, R. Cherif, M. Zghal. *Opt. Express* 19, 19955 (2011).
[7] A.A. Amorim, M.V. Tognetti, P. Oliveira, *et al. Opt. Lett.* 34, 3851 (2009).
[8] H. Chuang, and C. Huang. *Opt. Express* 36, 2848 (2011).

Opportunities for designing photonic crystal fibers for efficient femtosecond point-by-point grating inscription

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Fiber Bragg gratings (FBGs) are essential elements in optical fiber technologies. They are being used in a wide range of applications, e.g. in optical communications, fiber lasers and fiber based sensing. Modern methods of writing FBGs use femtosecond laser sources, which allow inducing index change in almost any type of optical material and write gratings that are stable up to 1000 °C [1].

Although successfully demonstrated for conventional step-index fibers, femtosecond grating inscription in photonic crystal fibers (PCFs) proved to be challenging due the detrimental influence of the air holes in the cladding region that are running all along the fiber length [2]. This is especially true for femtosecond point-by-point grating inscription technique, where each period is inscribed by a tightly focused femtosecond laser pulse. Air holes in the cladding make such a tight focusing to the core region very problematic [3].

Our approach to this problem is to exploit design flexibility of the PCF cladding region and to design PCF that will minimally impede femtosecond grating writing at a given wavelength [4]. In particular we studied transmission properties of the hexagonal lattice air holed cladding and identified a wide range of lattice parameters, for which the holey cladding does not hinder tight focusing of the laser beam. Based on this study we fabricated a dedicated PCF and inscribed what we believe to be the first point-by-point FBG inscribed in a hexagonal lattice multi-ring PCF [5].

References

[1] J. Thomas, C. Voigtländer, R.G. Becker, et al., Laser Photon. Rev. **6**, 709, (2012)
[2] F. Berghmans, T. Geernaert, T. Baghdasaryan, et al., Laser Photon. Rev. **8**, 27, (2014)
[3] T. Allsop, K. Kalli, K. Zhou, et al., Opt. Commun. **281**, 5092, (2008)
[4] T. Baghdasaryan, T. Geernaert, F. Berghmans, et al., Optics Express **19**, 7705, (2011)
[5] T. Baghdasaryan, T. Geernaert, K. Chah, et al., OSA Bragg Gratings, Photosensitivity, and Poling in Glass Waveguides (BGPP) 2016, BW4B.3, (2016)

High-Contrast Sub-Doppler Resonance Observed in a Cesium Vapor Cell for Applications in the Compact All-Optical Atomic Clocks

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Coherent population trapping phenomenon (CPT) underlies the high-performance compact and miniature atomic clocks [1,2]. The dark resonance caused by CPT in atomic vapor serves as a reference for stabilization of a microwave oscillator frequency used in these devices. One of the main problems limiting the frequency stability of the oscillator is connected with the light shift of the resonance. Time deviation of this shift can be resulted from the deviations of laser radiation parameters: optical frequency, total power of a beam or relative power of frequency components.

The latest versions of the clocks [3,4] set in use new spectroscopic technique to stabilize the laser optical frequency, leading to unprecedented level of the microwave frequency stability ($\sigma_y \sim 10^{-13}\tau^{-1/2}$). The technique is based on the new nonlinear effect, which has been recently observed in a vacuum cesium vapor cell [5]. The effect consists in creation of a natural-linewidth resonance in the cell during the laser carrier frequency scanning under the two-frequency regime. The

bright feature of the resonance consists in its really high contrast under the certain physical conditions. In spite of the new effect is becoming very useful tool for optical frequency stabilization in CPT clocks, the effect has not been studied. Our current study is aimed to eliminate this lack of knowledge (see also [6]).

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References

[1] Svenja Knappe, *Comprehensive Microsystems* 3, 571 (2008).
[2] Wang Zhong, *Chin. Phys. B* **23**, 030601 (2014).
[3] M. Abdel Hafiz *et al., J. Appl. Phys.* **121**, 104903 (2017).
[4] P. Yun *et al., Phys. Rev. Appl.* **7**, 014018 (2017).
[5] M. Abdel Hafiz *et al., Opt. Lett.* **41**, 2982 (2016).
[6] M. Abdel Hafiz *et al., New J. Phys.*, to be published (2017).

Non-linear localization of the Gaussian beam in Azobenzene Liquid Crystal

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Generation of spatial optical solitons is prospective phenomenon for studies thanks to the wide possibilities of optical signal steering, all-optical switching and readdressing. Nematic liquid crystals (NLC) are very suitable media for these studies owing to high optical transparency, large non-linearity and sensitivity to external factors such as electric field and light. Spatial optical solitons have been induced in NLC by a focused Gaussian beam and termed nematicons. It has been shown that nematicons could be used for optical beam trapping, addressing and all optical logic gating [1].

Optical spatial solitons can be generated using microwatt power laser beams without application of external electric fields in a special category of NLC materials, named Azobenze Liquid Crystals, which undergo trans-cis (nematic-isotropic) isomerization under influence of the light. In a conventional approach for

generating optical solitons in azobenzene NLC-s the planar orientation of NLC director is used [2].

In this work we report the first realization on localization of the Gaussian beam at 632.8 nm in the Azobenzene LC layer with nearly homeotropic orientation of NLC director. It is shown that focused Gaussian beam is localized in case of one linear polarization and diffracts in case of orthogonal polarization of the beam. Extremely long propagation length of 10 mm in soliton regime in NLC cell was observed.

The study of convergence of the Gaussian beam depending on the beam powers sowed that the self-focusing threshold is ~2 mW. The external electrostatic field applied on a NLC layer perpendicular to the initial alignment of the NLC molecules allowed to control the propagation length in soliton regime. The soliton destruction under ultraviolet light illumination, which reduces the number of trans (nematic) molecules and increases the number of cis (isotropic) molecules was observed. The explanation of observed phenomenon is based on a small pre-tilt angle of the NLC molecules which is present in the LC cell due to appropriate anchoring conditions. This provides the strong interaction of certainly polarized light beam with LC molecules which leads to the reorientation of LC director, refractive index change and beam self-focusing regime. The highly stable solitons generated in the absence of external electric field makes them more attractive for construction of photonic and electromagnetic devices.

References

[1] G. Assanto; M. Peccianti; C. Conti, *Opt. Photon. News*. **14** (2): pp. 44–48, 2003

[2] S. V. Serak, N. V. Tabiryan, G. Assanto, *Mol. Cryst. Liq. Cryst.*, **559**: pp. 202–213, 2012.

Generation and diagnostics of laser rubidium plasma: Theory and Experiment

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We present recent results on generation of plasma in rubidium vapors by strong laser pulses in femtosecond duration range from a Ti:Sa laser system. Two schemes of real-time diagnostics are applied for determination of main parameters

of the created plasma including its density and recombination time parameters. One of the schemes of the laser plasma diagnostics is based on resonant absorption spectroscopy and the second one uses Mach-Zehnder interferometry of a probe diode laser signal to measure the main parameters of the created plasma. The presented experimental setup is a table-top analogy of the Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE) at CERN that is a proof of principle experiment that utilizes the proton bunch available at CERN for acceleration of electrons (positrons) to TeV energies in a single acceleration stage. The diagnostics techniques developed in our lab are being used in the AWAKE experiment at CERN.

We also present results of numerical simulations of propagation of strong ionizing ultra-short laser pulses in Rb vapor. The parameters of the laser pulses and those of the Rb vapors are taken similar to the parameters of the plasma source in AWAKE experiment. The results show a rich variety of nonlinear optical effects taking place during the propagation of the ionizing laser pulses in the resonant and highly nonlinear medium of Rb vapors. The back-action of the medium on the propagating laser pulses is taken into account by simultaneous solution of Schrödinger equations for the relevant multilevel system of the Rb model atom and wave equation for the laser pulse electric strength amplitude. The multi-photon and tunneling models of ionization are being used in calculations of the ionization probabilities from different atomic states of Rb atoms.

The results of simulations may be directly applied for optimization of the parameters of the laser pulses for generation of a spatially extended extremely homogeneous plasma necessary in the AWAKE experiment.

Plasmonic Near-Field Effect on Visible and Near-Infrared Emissions from Self-Assembled Gold Nanoparticle Films

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Light interaction with nanoparticles and nanostructured materials gives rise to very interesting optical phenomena occurring at the nanoscale level. The novel optical properties of metal nanostructured materials have attracted great interest because of their potential applications in various fields such as sensing, bio-imaging and cancer therapy, solar cells, and other optoelectronic devices. The properties

associated with the coupled surface plasmon resonance of the noble metal nanostructures play a major role as the fundamental mechanism for these applications.

When gold nanoparticles are assembled to form nanostructured thin films, parameters such as aggregation, surface roughness, distance between particles and coupling of plasmonic near-field of nanoparticles significantly may influence the absorption and emission properties [1-4].

In this work, we have performed a systematic investigation of the plasmon near-field effect on photoluminescence (PL) behavior of the annealed self-assembled gold nanostructured films. For this purpose, PL spectra of the films in different morphologies are compared. This allows us to identify the role of plasmon near-field enhancement and coupling effects in visible and near-infrared emissions as modulating the energy transfer mechanism between excited electrons and emitted photons. Our results indicate that the films' near-infrared emission is generated by allowed intraband transition related to the breakdown of the symmetry and momentum selection rules due to the strongly confined near-field distribution. In addition, it is found that the efficiency of the near-infrared emission is directly proportional to the strength of coupled near-field effect. The observed visible emission of the films is well explained by the interband transition of electrons into the conduction band and subsequent radiation by particle plasmons. The influence of the coupled plasmon resonance of the samples on the characteristics of the visible PL emission is discussed. The observed emission properties of the gold nanostructured films can make them very attractive to design various gold nanostructure-based optoelectronic devices.

References

[1] P. K. Jain and M. A. El-Sayed, *Chemical Physics Letters* 487 153 (2010).
[2] Z. Ebrahimpour and N. Mansour, *Applied Surface Science* 394 240 (2017).
[3] M. Beversluis, A. Bouhelier, and L. Novotny, *Physical Review B* 68 115433 (2003).
[4] L. T. Ngoc, J. Wiedemair, A. van den Berg, and et. al., *Optics express* 23 5547 (2015).

Matter wave interferometers interacting with the external world: decoherence, gravity, complementarity and time irreversibility.

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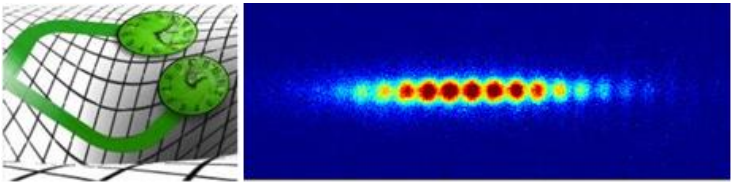
Matter-wave interferometry provides an excellent tool for probing the environment and studying its coupling to isolated atoms. We will present several interferometry experiments done with a BEC on an atom chip [1] and in which different effects of the environment have been investigated. First, we will discuss fluctuations in the nearby environment probed by an interference of atoms trapped in a magnetic lattice very close (5μm) to a room temperature surface [2,3]. Here an order-of-magnitude improvement has been obtained over previous atom-surface distances for which spatial interference has been observed. Next, we will present a new interferometry of self-interfering clocks and show, in a proof-of-principle experiment, how it could probe the interplay of QM and GR [4]. We will also describe a rule for "clock complementarity", which we deduce theoretically and verify experimentally [5]. Finally, we will discuss Stern-Gerlach interferometry [6] and describe it in the context of time irreversibility [7]. To the best of our knowledge, this is the first time spatial Stern-Gerlach interferometry has been realized, and we analyze our data in the context of previous theoretical work relating the difficulties in realizing Stern-Gerlach interferometry to time irreversibility.



Spatial clock interferometry [4]

References

[1] Mark Keil, Omer Amit, Shuyu Zhou, David Groswasser, Yonathan Japha, Ron Folman, "Fifteen years of cold matter on the atom chip: Promise, realizations and prospects", Journal of Modern Optics **63**, 1840 (2016).
[2] Shuyu Zhou, David Groswasser, Mark Keil, Yonathan Japha, Ron Folman, "Robust spatial coherence 5□m from a room temperature atom-chip", Phys. Rev. A **93**, 063615 (2016).

[3] Yonathan Japha, Shuyu Zhou, Mark Keil and Ron Folman, Carsten Henkel, Amichay Vardi, "Suppression and enhancement of decoherence in an atomic Josephson junction", New J. Phys. **18**, 055008 (2016).
[4] Yair Margalit, Zhifan Zhou, Shimon Machluf, Daniel Rohrlich, Yonathan Japha, Ron Folman, "A self-interfering clock as a 'which path' witness", Science **349**, 1205 (2015).
[5] Atom Chip group, "Clock complementarity in the context of general relativity", submitted.
[6] Shimon Machluf, Yonathan Japha and Ron Folman, "Coherent Stern-Gerlach momentum splitting on an atom chip", Nature Communications **4**, 2424 (2013).
[7] Atom Chip group, "Probing the emergence of the arrow of time with a high visibility Stern-Gerlach interferometer", in preparation.

A new time-dependent dissipative level-crossing two-state model solvable in terms of the Hermite functions

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The concept of the level-crossing is a well appreciated paradigm for a long time after the works by Landau, Zener, Majorana, and Stückelberg. Both time-dependent and time-independent models have been widely studied in the context of different physical phenomena including electronic transitions in atomic and molecular collisions, laser cooling, dynamics of Bose-Einstein condensates, cold atom photo- and magneto- association, etc.

However, the number of the known analytic dissipative level-crossing models is very limited. In the present contribution we introduce a new one. To derive this model, we consider the models that are solvable in terms of the bi-confluent Heun functions. These are the solutions of the bi-confluent Heun equation, which is one of the four confluent forms derived by a coalescence procedure from the general Heun equation. We have previously shown that there exist five classes of quantum time-dependent two-state models that are solvable in terms of these functions [1,2]. These classes include all the known confluent-hypergeometric level-crossing models. In addition, the derived classes suggest several other interesting models.

We here present a *dissipative* level-crossing model given as

$$U(t)=U_0e^{3t}\ ,\quad \delta_t(t)=\tilde{\delta}_t(t)-i\Gamma=2\left(\delta_0e^{2t}+\delta_2e^{4t}\right)-i\,,\quad \Gamma=1.$$

To explore the solution for this model we construct an expansion of the involved bi-confluent Heun functions in terms of the Hermite functions. The developed series are terminated thus resulting in three-term solutions. Thus, the linear two-state bi-confluent Heun models allow solutions in terms of linear combinations of a finite number of the Hermite functions of non-integer order.

References

[1] A.M. Ishkhanyan and K.-A. Suominen, "Solutions of the two-level problem in terms of biconfluent Heun functions", *J. Phys. A* ***34****, 6301 (2001).*
[2] M.R. Gevorgyan, "A dissipative conditionally integrable two-state level-crossing model exactly solvable in terms of the biconfluent Heun functions", *Arm. J. Phys.* ***9****, 192 (2016).*

Generation of two entangled photons by scattering of single photon on random grid of optical fiber

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Entanglement of the spatial degrees of freedom of photons is one of the main directions for the development of quantum communications. There are various wayes to create the entangled photons, in which the noise of the environment plays a main role at the processes of decoherence. Optical fibers are often used for transportation of spatially entangled photons. This system supports multiple transverse modes. We study the scenario when, during the propagation of a single photon in an optical fiber, the latter is scattered on a random grid of the impurity atoms, which can absorb and emit two photons. As a result of multiple scattering, there is a probability of formation of multidimensional, (d> 2) entangled photons. The degree of their entanglement and other characteristics of the photons' system are studied in detail. It is shown that the presented method of entangling photons can be interesting and promising, since it allows to effectively manipulating the properties of the entangled photon's system. In the end, we note that, for the solution of this problem we developed a new quantum representation for propagation of photon in disordered media in the terms coordinate representation.

The developed approach allows study all diversity of phenomena occurring photons in disordered media.

Superposition state transfer between single atoms in distant optical cavities

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For the full employment of quantum network, controllable and efficient network nodes are required, which will be able to send, receive and store quantum information reversibly. Cavity QED-based approach has probed its efficiency for the quantum networking as it is a promising platform capable for scalability. We suggest a method offering several advantages to previous quantum network schemes. It is a succession of three steps for the quantum state transfer between two nodes, which are single atoms confined in cavities. First, the quantum information is written in a superposition of atomic Zeeman states in the first cavity. Then, a control laser field is mapping this state into photon-number superposition state, which travels from the first cavity to the next node. As a last step, by properly choosing the control field parameters in the second cavity, the photonic state is transferred to the superposition state of the second atom. The advantages and imperfections in the proposed network are discussed.

Binding energy and photoionization cross-section of hydrogen-like donor impurity in strongly oblate ellipsoidal quantum dot

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Hydrogen-like donor impurity states in strongly oblate ellipsoidal quantum dot have been studied by the variation method. The trial wave function is constructed on the base of wave functions of the system without impurity. The binding energy of the ground and first excited states has been calculated as a function of the geometrical parameters of the ellipsoidal quantum dot and the impurity position. The dependence of the oscillator strength for different angles of light incidence and geometrical parameters has been revealed. The photoionization cross sections of

electron transitions from the impurity ground state to the size-quantized ground and first excited states have been obtained in dependence on the photon energy, impurity position and the geometrical parameters of the ellipsoidal quantum dot.

References

[1] H. Ham, and H.N. Spector. *Journal of applied physics*, **100**(2), 024304 (2006).
[2] D.A. Baghdasaryan, D.B. Hayrapetyan, and E.M. Kazaryan,. *The European Physical Journal B*, **88**(9), 223 (2015).
[3] D.B. Hayrapetyan, K.G. Dvoyan, and E.M. Kazaryan. *Journal of Contemporary Physics*, **42**(4), 151 (2007).
[4] A. Sali, H. Satori, M. Fliyou, and H. Loumrhari. *Physica status solidi (b)*, **232**(2), 209 (2002).

Quantum Optics in the hyperfine Paschen-Back regime

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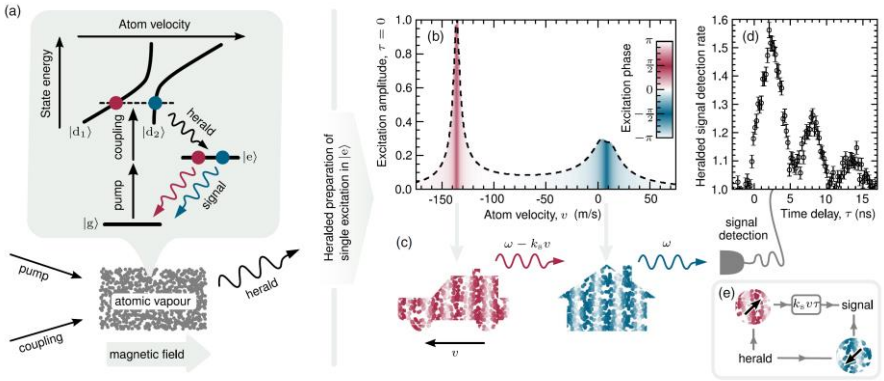
The study of light propagation through thermal atomic vapours subject to external magnetic fields is a flourishing area of research [1]. At Durham we have used our electric susceptibility code *ElecSus* [2] to investigate nondegenerate three-level ladder and four-level diamond schemes. Application of a large magnetic field (where the Zeeman splittings exceed the Doppler width) allows us to gain access to the hyperfine Paschen-Back (HPB) regime [3], [4]. In hot alkali-metal vapors we have demonstrated that it is possible to realise electromagnetically induced transparency (EIT) [5] and absorption (EIA) [6] in nondegenerate three-level systems. Applications range from devices (a compact optical isolator [7], narrow-line filters [8], Faraday laser [9]) to fundamental physics such as single-photon interference due to motion in a collective excitation [10].



References

[1] D. Budker et al., *Reviews of Modern Physics* 74, 1153 (2002)
[2] M. A. Zentile et al., *Computer Physics Communications* 189, 162-174 (2015)
[3] A Sargsyan et al., *Optics Letters* 37, 1379--1381 (2012)
[4] A Sargsyan et al., *Journal of the Optical Society of America B* 31, 1046-1053 (2014)
[5] D. J. Whiting et al., *Physical Review A* 93, 043854 (2016)
[6] D. J. Whiting et al., *Optics Letters* 40, 4289-4292 (2015)
[7] L. Weller et al., *Optics Letters* 37, 3405-3407 (2012)
[8] M. A. Zentile et al., Optics Letters 40, 2000-03 (2015)
[9] J. Keaveney et al., *Review of Scientific Instruments* 87, 095111 (2016)
[10] D. J. Whiting et al. *Physical Review Letters* 118 253601 (2017)

Bi-confluent Heun solutions of the Schrödinger equation

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We present the five six-parametric Lemieux-Bose potentials for which the general solution of the one-dimensional Schrödinger equation is written in terms of the bi-confluent Heun functions [1,2]. To derive the confluent hypergeometric reductions of this family of potentials, we construct an expansion of the solutions of the bi-confluent Heun equation in terms of the Hermite functions. The series is governed by a three-term recurrence relation between successive coefficients of the expansion. We examine the restrictions that are imposed on the involved parameters in order that the series terminates thus resulting in closed-form finite-

sum solutions of the bi-confluent Heun equation. We further identify a particular conditionally integrable potential for which the involved bi-confluent Heun function admits a four-term finite-sum expansion in terms of the Hermite functions [3]. This is an infinite well defined on a half-axis. We present the explicit solution of the one-dimensional Schrödinger equation for this potential and discuss the bound states supported by the potential. We derive the exact equation for the energy spectrum and construct a highly accurate approximation for the bound-state energy levels.

References

[1] A. Lemieux and A.K. Bose, "Construction de potentiels pour lesquels l'équation de Schrödinger est soluble", Ann. Inst. Henri Poincaré A **10**, 259-270 (1969).
[2] A.M. Ishkhanyan and V.P. Krainov, "Discretization of Natanzon potentials", (2016).
[3] T.A. Ishkhanyan and A.M. Ishkhanyan, "Solutions of the bi-confluent Heun equation in terms of the Hermite functions", Ann. Phys. **383**, 79-91 (2017).

A periodic level-crossing two-state model of a general Heun class

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We present a specific constant-amplitude periodic level-crossing model of the semi-classical quantum time-dependent two-state problem that belongs to a general Heun class of field configurations [1]. The exact analytic solution for the probability amplitude, generally written in terms of the general Heun functions, in this specific case admits series expansion in terms of the incomplete Beta functions. Terminating this series results in an infinite hierarchy of finite-sum closed-form solutions each standing for a particular two-state model, which generally is only conditionally integrable in the sense that for these field configurations the amplitude and phase modulation functions are not varied independently. However, there exists at least one exception when the model is unconditionally integrable, that is the Rabi frequency and the detuning of the driving optical field are independent. This is a constant-amplitude periodic level-

crossing model, the detuning for which in a limit becomes a Dirac delta-comb configuration with variable frequency of the level-crossings. We derive the exact solution for this model, determine the Floquet exponents and study the population dynamics in the system for various regions of the input parameters [2].

References

[1] A.M. Ishkhanyan, T.A. Shahverdyan, T.A. Ishkhanyan, *Eur. Phys. J. D. 69, 10 (2015).*
[2] T.A. Ishkhanyan, V.P. Krainov, A.M. Ishkhanyan, *J. Cont. Phys. (Arm. Ac. Sci.), (2017).*

Using atomic vapours to measure fundamental constants

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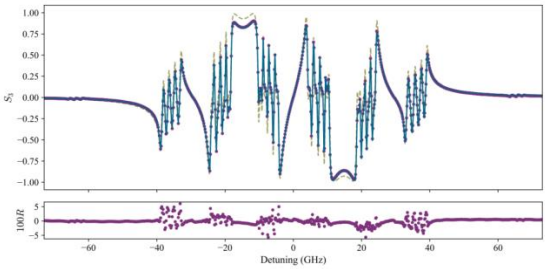
A detailed numerical model [1, 2] of the electric susceptibility, *ElecSus*, has been developed for alkali-metal atomic vapours that accurately calculates transition strengths and frequencies. We have recently added extra functionality to *ElecSus*, which now accounts for light propagation through an atomic medium in the presence of a magnetic field with arbitrary strength and direction [2]. *ElecSus* can be used as a tool to fit experimental data (see figure below) [3] and design applications, e.g. an atomic optical isolator [4], Faraday filters [5] and a frequency-stabilised laser system [6]. Here we present progress towards a precision measurement of Boltzmann's constant using atomic vapours. A large magnetic field splits the $nS_{1/2}$ sub-levels by enough to change the thermal population, which we probe with spectroscopic techniques. By carefully analyzing the spectrum, we aim to extract Boltzmann's constant which is an important step towards redefining the Kelvin based on fundamental constants [7].



References

[1] M. A. Zentile *et al.*, Comp. Phys. Commun. 189, 162-174 (2015).
[2] J. Keaveney *et al.*, ElecSus 2 (in prep)
[3] M. A. Zentile *et al.*, J. Phys. B 47, 075005 (2014).
[4] L. Weller *et al.*, Opt. Lett. 37, 3405 (2012)
[5] M. A. Zentile *et al.*, Opt. Lett. 40, 2000 (2015).
[6] J. Keaveney *et al.*, Rev. Sci. Inst. 87, 095111 (2016).
[7] D. R. White and J. Fischer, Metrologia 52, S213 (2015)

The selective reflection spectra of Rb vapors and retrieval of group refractive index

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We study Reflection and Transition spectra for the hyperfine structure of Rb D2 line buffered by a high-density Cs vapor [1]. In our experiment, we use low-finesse Fabry–Perot cavity, where our interested vapor is filled. It is conventional to think that from low-finesse Fabry–Perot cavity (boundaries of our cavity are not parallel to each other) we will see only reflection from first boundary of our cavity and we will not see interference effect associated with multiply reflected lights from our boundaries. Despite of this from our reflection spectrum we see interferential picture that indicates that we have multiple reflection spectrum. Therefore, we think that here we have radiation channeling effect.

From our Reflection spectrum, we straightforwardly retrieve group refractive index. From this spectrum, we see that near to resonance lines group refractive index becomes bigger, so light in that regions becomes slower (for some frequencies group velocity of light becomes 60 times slower than group velocity of light in vacuum).

All these experimental results were compared with theoretical calculations [2]. In this theory, we consider one dimensional problem with parallel boundaries. With our theoretical model, we calculated spectrum of multiple reflection and single reflection and find that our experimental reflectional spectrum corresponds to multiple reflection. With this model, we also calculated spectrum of group refractive index and showed correspondence with experimental results.

The presented technique can be used for dispersion measurements in dense buffered gases, quantitative studies of transition from dipole-dipole binary to multiparticle collisional regime, as well as for realization of optical effects in coherently driven hot atomic gases [3].

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References

[1] A. Papoyan, S. Shmavonyan, D. Khachatryan, and G. Grigoryan, J. Opt. Soc. Am. B 34, 877 (2017).
[2] A. Badalyan, V. Chaltykyan, G. Grigoryan, et al., Eur. Phys. J. D 37, 157 (2006).
[3] D.J. Whiting, J. Keaveney, C.S. Adams, and I.G. Hughes, Phys. Rev. A 93, 043854 (2016).

Investigation of alkaline vapors properties by derivative of Selective Reflection from a nanometric thickness cell

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In the recent work [1] it was shown that the derivative Selective Reflection (dSR) spectra experience a strong line narrowing when the cell has a thickness $L \approx \lambda/2$ (λ being the resonant wavelength of the laser radiation). Another advantage of the dSR is the proportionality of the recorded signal to the atomic transition probability in opposition to saturated absorption spectroscopy. These benefits make the dSR-method a convenient spectroscopic tool for the frequency reference of atomic transitions [2], or the study of closely-spaced individual atomic transition components in a magnetic field [3].

Using the dSR advantages, we have investigated the properties of alkaline vapors confined in nanometric thickness cells. In particular, we have studied both experimentally and theoretically the Rb D_2 line in a wide range of magnetic field (200 – 1000 G), with a σ^+-polarized cw laser. We demonstrate that the amplitude

of 8 initially "forbidden" transitions (5 for ^{85}Rb, 3 for ^{87}Rb), verifying the selection rule $\Delta F = \pm 2$, become the largest among the 17 transitions of ^{85}Rb $F_g = 2 \rightarrow F_e =$ 1,2,3,4 group, and the 9 transitions of ^{87}Rb $F_g = 1 \rightarrow F_e =$ 0,1,2,3 group, respectively. We have also analyzed the impact of a buffer gas on the dSR spectra, and we show that the line-shape of the dSR is preserved. The theoretical model is well consistent with the experimental results. The possible applications are discussed.

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References

[1] A. Sargsyan, E. Klinger, Y. Pashayan-Leroy, C. Leroy, A. Papoyan and D. Sarkisyan, *JETP Lett.* 104(4), (2016).
[2] A. D. Sargsyan, G. T. Hakhumyan, A. S. Sarkisyan A. O. Amiryan, and D. Sarkisyan, *Journal of Contemporary Physics (Armenian Academy of Sciences)* 51(4), (2016).
[3] A. Sargsyan, E. Klinger, G. Hakhumyan, A. Tonoyan, A. Papoyan, C. Leroy and D. Sarkisyan, *J. Opt. Soc. Am. B* 34(4), (2017).

Ho-doped lithium niobate thin films of stoichiometric composition.

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Stoichiometric composition powders and alkoxide of lithium niobate doped with different (0.01mol%, 0.01mol% and 1mol%) concentrations of Ho^{3+} ions were prepared by solid and wet reactions respectively. Thin films of $LiNbO_3$:Ho^{3+} were grown by Sol-Gel method on a sapphire substrate of (001) orientation. The obtained powders and fired alkoxides were investigated by the use of X-ray diffraction method and corresponding lattice parameters were obtained.

X-ray reciprocal space mapping has been recently established as a powerful method for strain and structural characterization of epilayers and heterostructures. The mentioned method was successfully realized on grown thin films of $LiNbO_3$

doped with different concentration of Ho^{3+} ions having different thickness (130nm, 300nm and 500nm). By comparing the maps obtained from different independent Bragg reflections, the deformation matrix was solved. The lattice parameters of thin films were obtained and compared with those of corresponding powders and bulk crystals.

The structure of thin films were investigated by Raman scattering method.

Semiclassical rates for tunnel ionization from power-law potentials induced by a constant or low-frequency electric field

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The probabilities of tunnel ionization of charged particles confined by one-dimensional power-law and logarithmic potentials are calculates analytically for constant and low-frequency electric fields. In the cases, when the barrier penetrability is expressed through known special functions, the problem becomes easier since the known asymptotic expansions for these functions can be applied as it was done here for the hypergeometric and the Appell functions. Otherwise one may confine himself to the leading term in the penetrability as it was done for the logarithmic potential. The approach we used to calculate the tunnel ionization rate in a constant electric field can also be applied to treat other one-, two- or three-dimensional potentials, for instance, non-singular power-law potentials of positive exponent: $V(x) = V_0 x^s$ with $1 > s > 0$, $V_0 > 0$, the Rosen-Morse potential $V(x) = -V_0 / \cosh^2(x/a)$, $V_0 > 0$, etc. Many advanced potentials, the exact solutions for which are written in terms of the Heun functions [1], can also be treated in the same manner. In particular, of a interest is the short-range singular Lambert-W potential, which behaves like the inverse square root potential in the vicinity of the origin and decreases exponentially at infinity [2]. Although we have considered only the WKB states [3], it is known that the accuracy of the latter wave-functions is rather high even for the ground state if the Maslov index is added to the principal quantum number [4].

References

[1] A. Ishkhanyan, V. Krainov, *Eur. Phys. J. Plus*, 131, 342 (2016).
[2] A.M. Ishkhanyan, *Mod. Phys. Lett. A* 31, 1650177 (2016).
[3] B.M. Karnakov and V.P. Krainov, "WKB Approximation in atomic physics", Springer, Berlin, 2013.
[4] A. Ishkhanyan and V. Krainov, *JETP Lett.* 105, 43 (2017).

Breathing spatial solitons in photorefractive crystals with imprinted Bessel structure

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It is well known that spatial solitons are generated in structured photorefractive crystals at the exact balance between the self-phase nonlinear modulation (SPM) and group velocity dispersion (GVD). However, due to intricate dependence on many parameters the fundamental soliton regime is achieved in a narrow range of parameter values. In this research, we studied the probe light propagation in a photorefractive crystal with imprinted Bessel lattices beyond the exact balance between the SFE and GVD. The numerical calculations show that in most cases the "breathing" solitons are generated, the intensity of which display transverse oscillations. We explored the origin of these oscillations in order to reveal the properties of optical information transfer in the waveguides, generated by the spatial solitons. Of primary importance is the fact that the energy losses of the probe beam, which may carry optically encoded information, are expected to be minimal even in the presence of transverse oscillations.

A theory of one-grating multipath atom interferometer

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Resonant Kapitza-Dirac diffraction of atoms in optical lattices is the shortest path to the multipath atom interferometry. In principle, it may imply a high precision for physical measurements, but one should overcome the "unpleasant" challenge of correct registration and unique interpretation of the multi-spot exit patterns. It is a

hard task and, perhaps, can't be solved if diffraction on the optical gratings is started from a mono-momentum state [1]. Our recent studies show, however, that he situation may be adjusted by using a discrete Gaussian superposition of momentum states and at the same time being somewhat out of the familiar Raman-Nath approximation [2,3]. Here we continue the study in this direction and, first, deduce an analytic formula working well in a deep optical grating and for times longer than the familiar Raman-Nath approximation. Then, proceeding on basis of this formula, we seek promissory momentum distributions in case of simple one-grating atom interferometer and for a reasonable experimental conditions find an output pattern extra-suitable for various measurement applications (see Figure). It almost repeats the initial

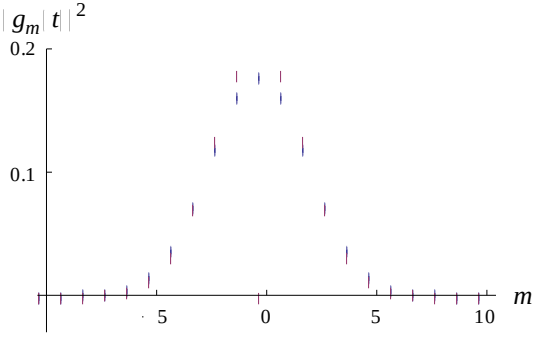

Figure. The output momentum distribution (square dots) in studied one-grating multipath atom interferometer.

discrete Gaussian form (ring dots) except the central, zero-momentum state, which is totally depressed in the output distribution. Note, that atomic excitation is also fully suppressed.

References

[1] A. D. Cronin, J. Schmiedmayer, D. E. Pritchard, *Rev. Mod. Phys.* **81,** 1051 (2009).
[2] G. Muradyan, A.Zh. Muradyan, *Phys. Scr.* **90,** 115401 (2015).

Complex nematic liquid crystal structures initiated by photo-alignment on the substrates

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Two-beam interference gives a possibility to create a variety of polarization and intensity patterns which can be used for photo-alignment at the liquid crystal (LC) cell substrates. When the two interfering beams have a right- and left-handed circular polarization, their interference creates a specific periodic alignment pattern on the substrate coated with the photosensitive material. By inducing the same pattern on both substrates and rotating one of them over 90 degrees, a 3D periodic structure is generated in the bulk of the nematic LC [1,2].

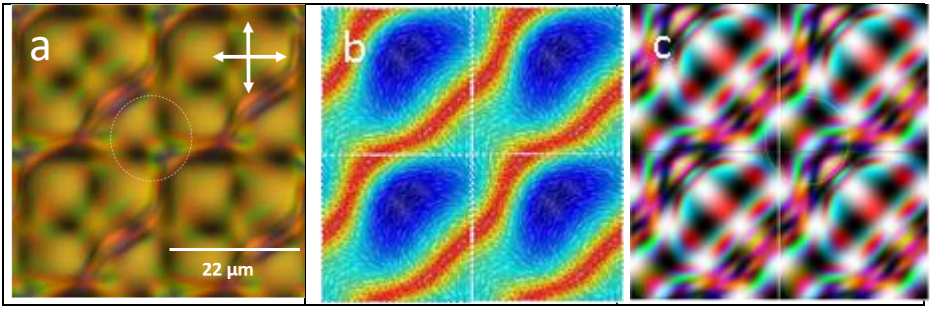

Fig. 1. (a) Transmission image from the microscope with crossed polarizers, (b) simulated mid-plane director distribution, (c) optical transmission simulation using Jones Calculus.

By changing the thickness of the LC layer and the period of the interference pattern different topologies can be induced. In this work we create and investigate structures with the thickness of 11 µm and the periodicity of 11 µm. As a photo-alignment material we used PAAD 22 (BEAM) which is sensitive to UV light. A relatively large thickness and periodicity give freedom for more detailed microscope observations for the unit domain of the structure. All obtained structures are analyzed with the polarizing optical microscope and have the double period of the initial interference pattern (Fig. 1a). This is related to the symmetry breaking that takes place to avoid the formation of the disclinations in the system. In some regions, the alignment of the substrates is not strong enough and the

director doesn't manage to make a full rotation on top and bottom substrates. For relatively thicker cells in these regions the mid-plane director is close to homeotropic.

The formed complex LC structures are verified by numerical simulations (Fig.1b). Optical transmission between crossed polarizers was simulated using Jones Calculus (Fig. 1c).

References

[1] G. Crawforda *et al., Journal of Applied Physics* **98**, 123102 (2005).
[2] Nys *et al., Soft Matter* **11**, 7802 (2015).

Entanglement characteristics of bound and resonant few-body states

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Studying the physics of quantum correlations has gained increasing attention since the first experimental fabrication of artificial few-body systems on the nanoscale, such as semiconductor quantum dots [1] or small ensembles of ultracold atoms in optical traps [2]. Those structures may be considered as composed of a small number of interacting elements with controllable and highly tunable parameters, effectively described by Schrödinger equation. This offers possibility of comparing theoretical and experimental results for a broad range of system's parameters enabling a deeper understanding of correlation effects in few-body states.

The bipartite correlations are well characterised by their entanglement content [3]. In order to quantify entanglement, the reduction of the density matrix of a state has to be performed by tracing over a chosen subsystem. The entanglement spectrum, i.e. the eigenvalues of the reduced density matrix, encodes all the information on the entanglement between the subsystems. I will discuss various entropies of the spectrum which are used as entanglement measures. The results for simple models of natural and artificial few-body systems with different confinement potentials and various inter-particle interactions will be presented in dependence on the interaction strength [4,5]. The entanglement properties of few-body systems which may exhibit resonances will be discussed in relation to their stability [6]. The relationship of entanglement and quantum chemical correlation measures will be discussed on the example of He-like ions in dependence on their nuclear charge. I will also investigate the dimensional crossover from two to one dimensions,

studying how confining a transverse spatial dimension influences entanglement in few-body systems with different interactions.

References

[1] L. Jacak, P. Hawrylak, A. Wójs, "Quantum Dots*"*, Springer, Berlin, 1997.
[2] F. Serwane, *et al*., *Science* **330** , 6027 (2011).
[3] M.A. Nielsen and I. L. Chuang, "Quantum Computation and Quantum Information", Cambridge University Press, Cambridge, 2000.
[4] P.Kościk, A. Okopińska, *Few-Body Sys.* **54**,1637 (2013), *Few Body Sys.* **55**,1151 (2014).
[5] O.Osenda, *et al.*, J.Phys.A **48**, 485301 (2015).
[6] A.Kuroś, A.Okopińska, Int.J.Th.Phys. **54**, 4164 (2015), Few-Body Sys. **56,** 853 (2015).

Microfluidic devices for Raman spectroscopy and optical trapping

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Chemical analyses of components and substances in fluids are of importance in application fields such as medicine, life science, agriculture and the pharmaceutical industry. However one needs sensitive techniques to detect and quantify the limited amount of molecules that are present in the sample. One of the optical detection techniques that is used in these application domains is Raman spectroscopy, a non-invasive, label-free technology. The traditional Raman spectroscopy analyses are done in a specialized lab, with considerable requirements in terms of equipment, time and manual sampling of the substances of interest. More and more there is a trend to use labs-on-chip (LOC) and reduce the cost and complexity of the bulky laboratory analyses by miniaturizing and integrating multiple laboratory processes on a single device.

During the conference we will first discuss a polymer-based lab-on-chip device embedded with a free-form reflector for confocal Raman measurements [1]. With this novel approach we aim at enhancing the detection of Raman signals from the substance of interest due to the suppression of the parasitic Raman signals from the Polymethyl Methacrylate (PMMA) material of the chip. We ensure a robust design for the reflector chip and make use of fabrication technologies compatible with mass manufacturability, paving the way to a low-cost and disposable lab-on-chip. Next we will present the miniaturization and integration of optical trapping on-chip

[2]. We will discuss an optical trapping simulation model based on wave-optics and ray-tracing and used this model as a tool to design a microfluidic chip for dual fiber optical trapping. We will present the design, simulation, fabrication process and proof-of-concept demonstration of this chip. The third optofluidic device includes a combined integration of Raman spectroscopy and optical trapping [3].

References

[1] D. De Coster, D. Loterie, H. Ottevaere, M. Vervaeke, J. Van Erps, J. Missinne, and H. Thienpont, "Free-form optics enhanced confocal Raman spectroscopy for optofluidic lab-on-chips," IEEE J. Sel. Topics Quantum Electron. 21, 4, 2701108 (2015)
[2] D. De Coster, H. Ottevaere, M. Vervaeke, J. Van Erps, M. Callewaert, P. Wuytens, S. Simpson, S. Hanna, W. De Malsche, and H. Thienpont, "Mass-manufacturable polymer microfluidic device for dual fiber optical trapping," Opt. Express 23, 30991–31009 (2015)
[3] D. De Coster, H. Ottevaere, M. Vervaeke, J. Van Erps, and H. Thienpont, "Optofluidic chip for single-beam optical trapping enabling confocal Raman measurements," IEEE J. Sel. Top. Quantum Electron. 23, 2, 5500109 (2017)

Optical Three-Axis Vector Magnetometry Based on Nonlinear Hanle Effect in Rubidium Vapor

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A concept of optical two-axis magnetometer based on compensation of measured *B*-field to the zero value, monitored by a nonlinear Hanle effect in an unshielded Rb atomic vapor cell was recently proposed in [1]. We report on further elaboration of this technique, enhancement and optimization of its performance characteristics. The following issues were addressed in particular: i) upgrading the optical scheme of vector magnetometer to three-axis operation; ii) significant reduction of measurement time by implementing appropriate scanning algorithms; iii) developing automated computer-controlled operation of the device, with friendly readout of the measured *B*-field.

This was achieved by exciting Rb vapor with two mutually perpendicular resonant radiation beams, branched from the same laser source, and recording fluorescence in an orthogonal direction. Furthermore, alternative *B*-field scanning algorithms were employed, allowing much faster steering towards compensation value. Proof-

of-the-concept measurements have been performed using experimental configuration appropriate for elaboration of a non-expensive prototype device. Although the preliminarily obtained characteristics (≈ 1 mT *B*-field resolution for ≈ 1 s measurement time) are far from those attained for the state-of-the-art optical magnetometers, there are specific application areas where the proposed scheme can be appropriate. These areas include, but not limited to, geophysical monitoring of ambient magnetic field, laboratory *B*-field cancellation (alternative to mu-metal shielding), positioning systems.

Among the advantages of developed magnetometry approach are: i) wide measurement range (up to ±4 mT region where fluorescence signal monotonously increases towards $B = 0$); ii) sign-symmetric shape of the fluorescence dependence on *B*-field, helpful for precise determination of resonance position; iii) wide $B = 0$ magnetic resonance allowing implementation of feedback-based maximum steering algorithms; iv) uniformity of sensitivity across the whole measurement range. Moreover, the technique is immune against background biasing illumination and slow variations of laser radiation intensity. Further elaboration of the proposed scheme leading to a 10-fold gain in sensitivity and prospective of developing a compact magnetometer device will be discussed.

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References

[1] A. Papoyan, S. Shmavonyan, A. Khanbekyan, K. Khanbekyan, C. Marinelli, E. Mariotti, Appl. Opt. **55**, 892 (2016).

Adiabatic passage in dissipative Rydberg superatoms

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Strong, long-range interactions between atoms in high-lying Rydberg states can suppress resonant Rydberg excitations of closely spaced atoms. Collection of atoms within a certain blockade volume then forms a “superatom” which can accommodate at most one Rydberg excitation [1]. A superatom composed of two-level atoms behaves as an effective two-level atom with the collective ground and symmetric single Rydberg excitation states coupled by collectively enhanced Rabi

frequency of the near-resonant laser [2]. With a slightly-more involved level structure of three-level atoms, quantum interference phenomena associated with coherent population trapping states come into play. In a Rydberg superatom composed of three-level atoms in a ladder configuration with short-lived intermediate state, the STIRAP sequence of pulses [3] produces exactly one Rydberg excitation incoherently shared among all the atoms [4]. From the perspective of quantum Zeno effect, the Rydberg blocked atoms repetitively scattering photons effectively monitor a randomly excited atom, which therefore remains in the Rydberg state. Using an auxiliary microwave field to carefully engineer the decay of Rydberg-blockaded atoms to untrapped states, the adiabatic passage can be used to filter out single atoms from trapped ensembles with unknown number of atoms.

References

[1] M.D. Lukin *et al*., Phys. Rev. Lett. **87**, 037901 (2001).
[2] M. Ebert, M. Kwon, T. G. Walker, M. Saffman, Phys. Rev. Lett. **115**, 093601 (2015); Zeiher *et al.*, Phys. Rev. X **5**, 031015 (2015); Weber *et al*., Nature Phys. **11**, 157 (2015).
[3] K. Bergmann, H. Theuer, and B. W. Shore, Rev. Mod. Phys. **70**, 1003 (1998).
[4] D. Petrosyan and K. Mølmer, Phys. Rev. A **87**, 033416 (2013); D. Petrosyan, D.D. Bhaktavatsala Rao, and K. Mølmer, Phys. Rev. A **91**, 043402 (2015).

Fano Resonance in a 3D System Of Metallic Nanoparticles

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Calculations are presented for Fano resonance in a 3D system of identical prolate metallic nanospheroids located at the vertices of a regular tetrahedron. The long axis of one of the spheroids is oriented along the symmetry axis of the third order of the tetrahedron (Z axis), and the long axes of the remaining three lie in the orthogonal plane, forming angles $2\pi/3$ between themselves. The polarization vector of the incident light wave oscillates along the Z axis, directly exciting plasmon oscillations in only one spheroid. The results of calculations are presented showing the strong nonuniformity of energy distribution between spheroids for various orientations of spheroids perpendicular to the Z axis.

To the best of our knowledge, Fano resonance in the three-dimensional system of nanoparticles is considered for the first time.

Photoionization of alkali molecules

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It is surprising that the photoionization of the alkali diatomic molecules is not well known in contrast to the atomic photoionization phenomenon. Alkali dimers have two optical electrons which could be simultaneously excited above the ionization limit. Those states are naturally subjected to autoionization process. However, some of these autoionization states can be observed especially in the case of the heaviest cases like Cs_2 [1] and Rb_2 [2] as distinct molecular bands. We believe that those states are represented by doubly excited molecular states, which can be reached from the ground Cs_2 and Rb_2 states by single photon excitation subjected by usual dipole allowed molecular selection rules.

We shall review photoionization of the homonuclear alkali molecules K_2, Rb_2 and Cs_2 and will present the most recent results for heteronuclear alkali molecules KRb and RbCs. The case of KCs will be experimentally investigated in the nearest future using the well-known sapphire cell technology developed by D. Sarkisyan and his coworkers**.** The published literature indicates no photoionization bands for lighter alkali molecules, so only the heavier alkali molecules involved in the far ultraviolet excitation process are presently of interest.

There are two possible applications based on the present findings. The first one relates to experiments at ultra-cold conditions, where the observed photoionization bands can be observed in the molecular ion channels. The second one relates to energy conversion experiments based on thermionic process in which far ultraviolet part of the solar spectrum can be used in heavier alkali mixtures with elevated percentage of the alkali molecules. That means high temperatures beyond 500 ^{o}C, where sapphire cell technology or some kind of the heat-pipe oven technology can be very useful in the future experiments.

References

[1] G. Pichler, Y. Makdisi, J. Kokaj, N. Thomas, J. Mathew, *J. Phys. B: At. Mol. Opt. Phys.* **48**, 165002 (2015).
[2] M. Rakić, G. Pichler, to be published (2017).

Selective reflection from a Rb layer with a thickness as small as

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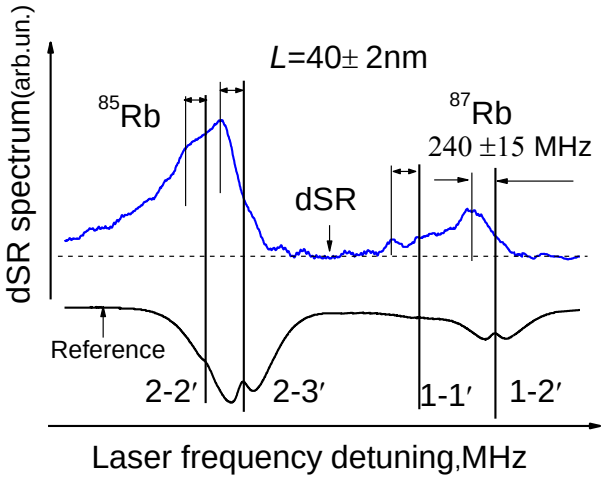
We have studied the peculiarities of selective reflection (SR) from an Rb vapor cell with a thickness $L < 70$ nm, which is smaller than the length scale of evanescent fields $\lambda/2\pi$ and more than an order of magnitude smaller than the optical wavelength. A 240 MHz red-shift due to the atom-surface interaction is observed for a cell thickness of $L \sim 40$ nm and is shown in Figure. The upper line is the spectrum of derivative of the SR signal (dSR), showing ~240 MHz red shift with respect to ^{87}Rb, D_1 line Fg =1 → Fe = 1, 2 and ^{85}Rb, D_1 line $F_g = 2 \rightarrow F_e = 2; 3$ reference frequencies.



Complete frequency-resolved splitting of Rb atomic transitions is recorded in a strong magnetic field (B > 2 kG).The SR signal exhibits a low divergence, relatively high power, and a high signal-to-noise ratio. Consequently, the SR technique can be used for high distance remote monitoring and mapping of both homogeneous and highly inhomogeneous *B*-fields in a wide range with ~40 nm spatial resolution,

References

[1] A. Sargsyan, A.Papoyan, I. G. Hughes, Ch. S. Adams, and D.Sarkisyan, Optics Letters V. 42, 1476 (2017).

Symmetry breaking exhibition by magnetic field induced explicit circular dichroism

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We demonstrate universal symmetry breaking by means of magnetically induced circular dichroism. Magnetic field induces forbidden at zero field atomic transitions between $\Delta F = \pm 2$ hyperfine levels. In a particular range of magnetic fields, intensities of these transitions undergo significant enhancement.

We have deduced a general rule applicable for the D_2 lines of all bosonic alkali atoms, that is transition intensity enhancement is larger for the case of σ^+ than for σ^- excitation for $\Delta F = +2$, whereas it is larger (e.g. up to 10^{11} times for Rb atoms) in the case of σ^- than for σ^+ polarization for $\Delta F = -2$. This asymmetry behavior results in an explicit circular dichroism. In contrast to this asymmetry we also show the complete mirror symmetry in Hyperfine Paschen - Back regime ($B \gg B_0$). For experimental verification we employed half-wavelength-thick atomic vapor nanocells using a derivative of selective reflection technique, which provides sub-Doppler spectroscopic linewidth ($\sim$ 50 MHz). The presented theoretical curves well describe the experimental results.

Adsorption of Rubidium Atoms on Sapphire Studied via Laser Induced Desorption

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Adsorption on and desorption from solid surfaces play a crucial role in nature as well as in many technological processes. Despite their importance and many efforts devoted to their studies adsorption-desorption processes are still rather poorly documented. In particular there are few examples of experimentally obtained energies of absorption of atoms on solid surfaces. The difficulties of such measurements are obvious: when the surface number density of adsorbed species is small they are difficult to register, when the surface number density rises the adsorbed species tend to condensate. The way around this problem is to study adsorption on the overheated surface in the dynamic equilibrium with the saturated vapors. Up to now this program was realized only for sodium [1]. In this contribution we repot on the adsorption of rubidium on sapphire.

In the experiment the surface number density of rubidium atoms adsorbed on sapphire was monitored via laser induced desorption in the time-of-flight measurements setup. We employ the evacuated cell filled with the natural mixture of rubidium isotopes. The construction of the furnace allowed for the independent heating of the sapphire window used as a substrate and the rest of the cell. The surface number density of rubidium atoms was obtained in the range on the substrate temperatures from 20 to 75 °C and fitted to the Boltzmann distribution. This procedure leaded to the energy of adsorption of rubidium atoms on sapphire surface of 0.7 eV.

In addition to the surface number density time-of-flight measurement gave also the velocity distribution of the desorbed atoms. These results were used to establish the dependence of the mean kinetic energy of the desorbed atoms on the fluence and the energy of the photons of the desorbing radiation. In the low fluence regime the kinetic energy distribution of the desorbed atoms is independent of the fluence while at higher fluences the mean kinetic energy of the desorbed atoms stats to grow. Contrary to the expectation in the low fluence regime the mean kinetic energy of the desorbed atoms decreases with the increase of the photon energy in the range of 1.3 to 3.0 eV. This counterintuitive behavior may be explained by the opening of new channels of energy relaxation when the photon energy rises.

References

[1] A.M. Bonch-Bruevich, *et al*., *Proc. SPIE 3404, 187, (1998).*

Relaxation delay of quantum dipole emitter at the phase-shifted response of metallic nanostructure

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Coupling between quantum dipole emitters (QDEs), such as molecules, color centers in diamond or quantum dots, and surface plasmon polaritons at optical frequencies allows control over the flow of electromagnetic energy [1, 2]. Recent advances in nano-optics, especially experiments with single molecules interacting with well-defined metal nanoparticles [3, 4], often referred to as nanoantennas, greatly expanded the possibility of detecting new properties of light-matter interaction.

One of the very fundamental effects occurring as a result of these interactions is the modification of QDEs relaxation dynamics due to the presence of metal nanostructures (MNS), strongly perturbing local electromagnetic fields.

We are investigating relaxation dynamics of a QDE coupled to MNS and our work is focused on the issue of finding out the role of the phase response of the metal nanostructure on that process.

Thus, in the connected QDE-MNS system, when the MNS decay rate greatly exceeds the decay rate of QDE, the nature of the relaxation is largely determined by the phase-shifted response of MNS, which acts as a feedback on QDE. Depending on the value of the phase shift of the MNS response (less or greater than π), the decay rate of the system increases or slows down. This allows one to give a unified explonation to the processes of enhancement or quenching of fluorescence, found in various experiments with phenomenon of phase shifted response of MNS. With a substantial delay in the excited state of QDE, the possibility of QDE to lose energy through channels rather than transition to the ground state rises, which can promote the enhancement of the effect of Raman scattering and luminescence upconversion.

References

[1] D. E. Chang, A. S. Sorensen, P. R. Hemmer, *et al.*, *Phys. Rev. Lett.*, **97**, 053002, (2006).
[2] A.V. Akimov, A. Mukherjee, C. L. Yu, *et al.*, *Nature*, **450**, 402, (2007).
[3] J. N. Farahani, D. W. Pohl, H. J. Eisler, *et al.*, *Phys. Rev. Lett.*, **95**, 017402 (2005).
[4] Wen-Xing Yang, Ai-Xi Chen, Ziwen Huang, *et al.*, *Optics Express*, **23**, 13032, (2015).

Abstracts: Posters

IMPLEMENTATION PROGRAMMABLE LOGICAL ATOMIC GATE

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Classical computation theory began when Turing[1] and Church[2] independently published their inquiries into the nature of computability in 1936 [1,2] and then the first concerns about the reversibility of computation were raised in the 1970s.

Logical reversibility refers to the ability to reconstruct the input from the output of a computation, or gate function. For instance, the NAND gate is explicitly irreversible, while the Toffoli[3], Fredkin and other gates are reversible (it is its own inverse).

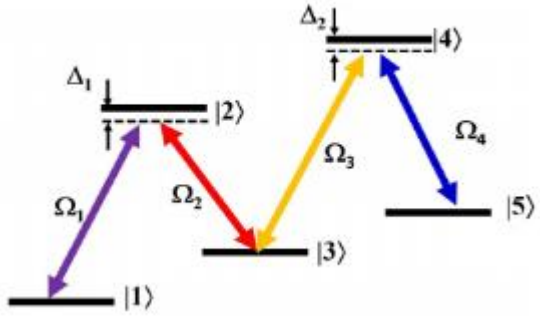

Fig. 1 M-type system

In this paper we demonstrate a simple realization of a programmable atomic gate in five-level atoms. The proposed scheme is based on the cyclic adiabatic population transfer resembling the technique of STIRAP and b-STIRAP in M-type system [4,5] (see fig. 1). In the present work we examine in detail the generalization of these population-transfer methods for five level diagrams in order to construct a tree-bit programmable atomic gate.

We are very grateful to Prof. Gayane Grigoryan for fruitful discussion.

This work was supported by the SCS MES of Armenia (15T-1C066 theme) and IRMAS project.

References

[1] A. Turing, "On computable number with an application to the Entcheidungs-problems", Proc. Lond. Math.Soc. Ser. 2, **42,** pp 230-265 (1936).
[2] A. Church, "An unsolvable problem of elementary number theory", American J. of Math., **58**, pp 345-363 (1936)
[3] T. Toffoli, "Reversible Computing", Tech. Memo MIT/LCS/TM-151, MIT Lab. For Com.Sci. (1980)
[4] E. Gazazyan, G. G. Grigoryan, V. O. Chaltykyan, D. Schraft,"Implementation of all-optical Toffoli gate in Λ-system", J. of Cont. Phys. (Armenia Academy of Sciences),**47**(5) (2012)
[5] G. Grigoryan, E. Gazazyan, V. Chaltykyan, and O. Tikhova,Laser Physics, **24**, 035301 (2014)

Faraday Rotation for Rb atomic transitions using a nanocell: modification of Faraday Rotation method

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Magneto-optical processes occur once the light interacts with a medium placed in a magnetic field. These effects are observed in usual cm length cells and are widely used in metrology, atomic spectroscopy, quantum information, etc. [1]. Among these processes in the study [2], the rotation of plane of polarization of the light, also known as Faraday Rotation (FR) was studied with use of a Rb atomic vapor contained in a nano-cell placed in a longitudinal magnetic field. The cell is placed in a special vacuum chamber and the thickness L = 140 - 1700 nm is controlled by varying the internal pressure inside the chamber. This new technique allows one to measure cell thickness with better accuracy than it was done up to now.

Recently, our group has developed a new technique which we call modification of Faraday Rotation method (MFR). The geometry of the polarizers is similar to Faraday Rotation geometry, *i.e.* they are crossed, except that the second polarizer (analyzer) is placed on a special holder. The latter allows one to rotate and measure

the rotation angle of the analyzer. For the angle of rotation ~ 5 degrees, the recorded spectrum has a dispersion shape. The derivative of the recorded spectrum gives narrow resonances (MFR – resonances). The width of these resonances is about 3 times narrower than in the case of the usual Faraday rotation.

The research was conducted in the scope of the International Associated Laboratory IRMAS (CNRS France - SCS Armenia) and SCS MES of Armenia N 15T-1C040.

References

[1] D. Budker, W. Gawlik, D. F. Kimball, *et al.*, *Reviews of modern physics*. **74**(4), 1153 (2002).
[2] A. Sargsyan, A. Amiryan, S. Cartaleva and D. Sarkisyan, Journal of Experimental and Theoretical Physics. 152 (7) (2017).

Investigation of ruby R lines luminescence under $^2T_1$ level frequency scanned excitation

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The luminescent properties of the ruby crystal ($Al_2O_3:Cr^{3+}$) have been thoroughly studied due to its wide applications as an active laser element. Laser generation of this crystal was obtained at 693.4 nm on the R_1 line corresponding to the transition $^2E \rightarrow {}^4A_2$ of Cr^{3+} ions [1-6]. In the process of studying the luminescent properties of a ruby crystal, the main attention was paid to the excitation of broadband states $^4T_1$ and $^4T_2$. The excitation of these bands upon pumping by pulsed lamps led to the generation of monochromatic radiation after the nonradiative transfer of the excitation energy to the ^2E state. However, many questions related to energy transfer between the levels of $^2T_1$ and ^2E states of Cr^{3+} ions under coherent excitation of $^2T_1$ levels are still unexplored. The purpose of this report is to study the filling of the ^2E levels under coherent excitation of two higher levels of the triplet $^2T_1$ with frequency scanning of the corresponding absorption bands of the $^4A_2 \rightarrow$ Ēa, 2Ā transitions. We are thoroughly studied the luminescence of the R lines of ruby upon excitation of the $^2T_1$ levels by a tunable semiconductor laser. The laser radiation wavelength scanning is realized by changing the current and (or) temperature of the laser diode. All measurements are carried out at room temperature. The matching of the absorption spectra of the $^4A_2 \rightarrow {}^2T_1$ ($\bar{E}_a$ and 2À

sublevel) transitions of Cr^{3+} ions with the behaviors of luminescence intensities of the R_1 and R_2 lines as a function of excitation wavenumber is investigated. The dependence of the intensity of R_1 and R_2 luminescence peaks on the pump wavenumber practically coincides with the shape of these absorption bands. The luminescence intensity is normalized to the radiation power of a semiconductor laser. As far as we know, for the first time we observed under certain excitation wavenumber the shifts of luminescence peaks which are multiple to the value 0.52 cm^{-1} (multiplication factor – 1, 2, 3).

References

[1] B.V.Thosar, Phys.Rev, 60, 616, (1941).
[2] T.H.Maiman, Nature, 187,493,(1960).
[3] J. A. Calviello, E. W. Fisher, and Z. H. Heller, J. Appl. Phys, 37, 3156, (1966).
[4] Takashi Kushida, Minoru Kikuchi, J.Phys.Soc. of Japan, 23, 1333, (1967).
[5] J.l. Dijkhuis, A. van der Pol and H.W. de Wijn, Phys. Rev. Lett. 37, 1554, (1976).
[6] B.Champagnon, E.Duval, A.Montell, and R.Englman, Phys. Lett., 93A, 241(1983).

Tunable excitonic absorption in gapped graphene systems

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Theoretical and experimental investigations of optical properties of graphene systems so far have been mainly focused in monolayer graphene. Meanwhile, in the physics of graphene there is growing interest in bilayer and trilayer graphene systems, where the electronic band structures are richer than in monolayer graphene and can be easily manipulated by external field [1].

Theoretical and experimental investigations have shown that a perpendicular electric field applied to bilayer of graphene modifies its band structure near the K point and may open an energy gap in the electronic spectrum, which is tunable by the gate voltage [2]. Experimental investigations showed that the induced gap between the conduction and valence bands could be tuned between zero and midinfrared energies. Also, the magnitude of the gap strongly depends on the number of graphene layers and its stacking order [3]. Multilayer graphene systems

with tunable band structure can be useful for different goals of nano- and optoelectronics.

In order to understand the influence of Coulomb interaction and impact of many body physics in graphene systems it is essential to study electronic and optical properties of graphene systems with opened energy gap. In gapless monolayer graphene, the Coulomb problem has no true bound states, but resonances [4]. The optical response of graphene with an opened energy gap between the conduction and valence bands is dominated by bound excitons.

In this work excitonic absorption in graphene systems (monolayer and bilayer) with opened energy gap in the field of laser radiation is investigated for different values of the gap and the parameters describing the band structure.

The obtained value of excitonic binding energy in monolayer is in good agreement with the exact analytical solution.

It is shown that the account of all tight binding parameters in bilayer graphene leads to strong increase of exciton binding energy.

References

[1] Bao, W. et al. Nature Physics **7**, 948 (2011)

[2] Eduardo V. Castro, K. S. Novoselov, et al., Phys. Rev. Lett. **99**, 216802 (2007).

[3] A. Avetisyan, B. Partoens, and F. M. Peeters, Phys. Rev. B **81**, 115432, (2010).

[4] N. M. R. Peres, R. M. Ribeiro, and A. H. Castro Neto, Phys. Rev. Lett. 105, 055501 (2010).

Microstructure and chemical composition of the YSZ and La, Mg - hexaaluminate double-ceramic-layer TBC systems

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The Ni(Co)CrAlY bond coat (BC) and ceramic thermo-insulating layer (TC) are the parts of complex thermal barrier coatings (TBCs) used to protect the metal components of gas turbine engines. The increase in their efficiency is associated with an increase in the temperature of the turbine gas (> 1200°C), which requires a reduction in the thermal conductivity of the TC, high heat resistance and long-term stability at high temperatures. A new concept for multilayer BC preparation in order to have a better conformity between the BC and TC and, thus, an improved thermal characteristics and mechanical performance of the TBC is developed [1]. One of the promising materials for the TC, as well as for laser applications, is $LaMgAl_{11}O_{19}$ hexaaluminate. In this study, the microstructure and chemical composition of TBCs were studied (SEM, EDX) after a short time thermal cycling

on polished and carbon coated cross-sections. The TC was a double ceramic layer (DCL) in which one layer, consisting of $LaMgAl_{11}O_{19}$, were prepared by electron beam physical vapour deposition technique on NiCrAlY BC or on another ceramic layer. It was required a precise experimental selection of the target composition and the deposition temperature. Another ceramic layer of each DCL system was yttria stabilized zirconia (YSZ) or $LaMgAl_{11}O_{19}$ prepared by atmospheric plasma spraying or solution plasma spraying technique. Understanding the dynamics of microstructure changes and formation of new chemical compounds in the process of thermal cycling is an important link in the development of thermal insulating coatings.

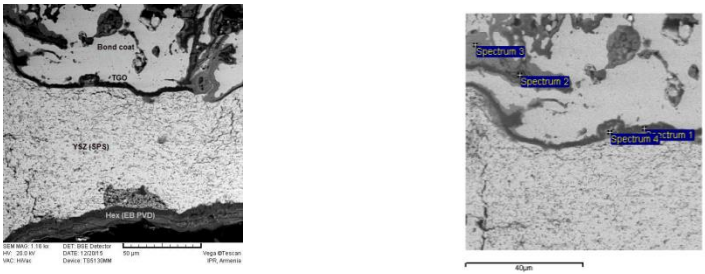

Figure 1. SEM image of TC/BC border region and areas of the EDX microanalysis

References

[1] A.S.Kuzanyan, A.Petrosyan, A.A.Kuzanyan, S.Petrosyan, V.Stathopoulos. Patent of Armenia № 2897, 25.12.2014.

On the mechanism of formation of nuclear processes under the influence of acoustic oscillations on a liquid

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The paper presents the results of the realization of ionizing radiation under mechanical action on water with an acoustic frequency. The ionizing radiation was registered by the DKS-04 dosimeter and the RUP-1 radiometer. It is shown that this phenomenon is not associated with the process of cavitation in water under the action of ultrasound. A strong dependence of the occurrence of ionizing radiation

on the shape of the signal applied to the piezoceramics for the generation of sound was detected. The presence of γ-radiation may indicate the presence of nuclear processes. It is accepted that for the realization of thermonuclear reactions conditions of high temperature T≈108 ^{0}K, high pressure P≈106 atm are necessary. Moreover, the corresponding Lawson criterion (nτ> 1014 s / cm^3, where n is the density of the high-temperature plasma, and τ is the retention time in the system) must be taken into account. In our experiments, there are no first two conditions for the realization of thermonuclear processes and, accordingly, justification for the presence of γ-radiation. The search for mechanisms of possible formation of thermal neutrons is being carried out. Through the presence of a double electric layer, which arises upon the contact of media, a mechanism of neutrons' formation is presented. It is natural to assume that with a sharp mechanical action of piezoceramic radiators metal concentrator in the form of titanium rod on the liquid in a direction perpendicular to the double electric layer it is possible to disrupt the integrity of the layer and collide hydrogen ions with electrons on the surface layer of the titanium concentrator. And, by analogy with the K-capture, a quasineutron formation ($p+ + e- \longrightarrow n + \upsilon$) is possible which will have mass defect by an energy value of 1.46 MeV. Therefore, to compensate the missing mass Δm = 1.46 MeV / c^2, the neutron must enter into energy bond with the nearest nucleus transforming it into an unstable isotope in the (n, γ) nuclear reaction. It is suggested that the γ-activity is possibly connected with the transformation of the nucleus of oxygen $^8O_{18}$ stable isotope, present in water, to the fluorine nucleus O (n, γ) F. To confirm the validity of judgments about possible nuclear processes and the formation of fluorine element (F), measurements were made for the presence of fluoride ions of samples subjected to acoustic action and initial distilled water. The presence of fluoride ions in water was measured by ion chromatograph DIONEX IC 1000 (USA). As a result, there was a significant formation of fluoride ions in samples exposed to sound. The electrical conductivity and the hydrogen index of the water samples under study were also measured. There is some correlation between the amount of fluoride ions produced and the pH value of the water samples which, probably, can be related to the formation of hydrofluoric acid HF in water.

Non-linear control of lasing wavelength in dye-doped chiral photonic structures by means of light

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Chiral Nematic Liquid Crystals (CLC) are spontaneously forming a helical structure with large modulation of refractive index. These structures lead to a Photonic Band Gap (PBG), which is the wavelength range where light with a particular circular polarization is totally reflected. Thus CLC-s often are regarded as 1D Photonic structures. Fluorescent dye-doped CLC (DDCLC) structures enable tunable mirror-less lasing from the short and long wavelength edges of the PBG, where the density of photonic states is strongly increased. This lasing is obtained usually by optical pumping (usually by pulsed UV or 532 nm) and it is possible to obtain lasing lines within a 70 nm wide wavelength range in the visible part of the spectrum. Also, the lasing wavelength can be tuned by external factors [1]. The lasing wavelength tuning can be obtained by means of temperature, pressure, flow, electric fields and light.

In this work we investigate the influence of the pumping beam on the structural characteristics of the DDCLC and its consequences on the emission wavelength. It is demonstrated that under the influence of the electric field of the pumping beam, the CLC can change the number of windings, causing a jump in the CLC pitch. This enables the possibility of lasing with a different wavelength, defined by the thickness and the pitch of the DDCLC. It was demonstrated that under the influence of a pumping beam with high repetition rate, besides of the influence of the beam electric field, local heating causes hydrodynamic flow which creates the possibility of obtaining up to 8 new equidistant lasing wavelengths within the 560-600 nm band.

References

[1] H. Coles, S. Morris, *Nature Photonics*. **4**, pp.676–685 (2010).
[2] T. Dadalyan, R. Alaverdyan, Zh. Ninoyan., et.al., Liquid Crystals, 44(2), pp. 372-378 (2017).

Sructural and physical properties of iron doped various composition lithium niobate crystals

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Lithium niobate crystal is attractive material for electro-optic signal modulation and frequency conversion thanks to its excellent EO properties controlling by crystal composition and the introduction of impurity ions. Characterization of crystal composition have been realized by analysis of lattice parameters for iron doped lithium niobate crystals doped with fixed iron content with the help of powder X-ray diffraction illustrating the increase of constants with the decrease of crystal stoichiometry and the presence of dopant ions (figure 1).

The third column of EO tensor was investigated by experimental interferometric setup, whereas the measurements of r_{22} and combined EO coefficients have been performed by one-beam Senarmont-type ellipsometric technique with two methods "Frequency doubling electro-optic modulation" (FDEOM) and the "Modulation Depth Method" (MDM) following to the results with the difference in the small range. Correspondingly, the values of dielectric permittivity have been determined confirming the behavior of variation of EO coefficients depending on the crystal composition.

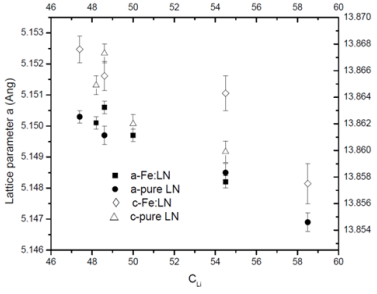

Figure 1: Lattice parameters of Fe:LN compared to the pure LN crystals [1].

Reference

[1] G. Malovichko, O. Cerclier, J Estienne, V. Grachev, E. Kokanyan and C. Boulesteix, J. Phys. Chem. Solids Vol. 56, No. 9, pp. 1285-1289 (1995).

Interaction of Re3+ impurity ions with inhomogeneous field of radiation

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A scheme for calculating the probability of a dipole–forbidden f–f transition during interaction of an impurity RE3+ ion with an inhomogeneous exciting radiation field is proposed. It is shown that in the case under consideration the prohibition of electric–dipole transitions can be removed without invoking the Judd–Ofelt theory of induced electric–dipole transitions. The quantitative estimation of absorption cross–section YAG: Er^{3+} crystal at 1530 nm wavelength (${}^4I_{15/2} \rightarrow {}^4I_{13/2}$) was carried out for the simplest model of inhomogeneous exciting radiation.

References

[1] B. R. Judd, Phys. Rev. 1962, V.127. P. 750.
[2] G. S. Ofelt, J. Chem. Phys. 1962. V.37. P 511.
[3] H. Dai, O.M. Stafsudd, J. Phys. Chem. Solid. 1991. V. 52. № 2. P 367.
[4] G.G. Demirkhanyan, Laser Physics, v. 16, № 7, pp. 1054–1057 (2006)
[5] G.G. Demirkhanyan, R.B. Kostanyan, Inter. Conf. on Laser Phys. 2010, ed. by A. Papoyan, Proc. of SPIE, v. 7998, 799805
[6] D.S. Bethum, Opt. Lett. 6(6), p. 287 (1981)
[7] A.M. Kern and J.F. Martin, Phys. Rev. A 85, 022501, (2012)
[8] Q. Zhan, Adv. Opt. Photon. 1, 157 (2009)
[9] А.П. Юцис, А.Ю. Саиукинас, Математические основы теории атома, Вильнюс, 1973
[10] А. Абрагам, Б. Блини, Электронный парамагнитный резонанс переходных ионов, т. 2, Москва, Мир, 1973
[11] D.C. Brown, Laser Phys., 24, pp. 085003 – 085012 (2014)

YAG:Yb^{3+} Crystal As A Potential Material For Optical Temperature Sensors

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Optical sensors are sensitive devices based on monitoring of intensity changes of one or several light beams (or their phase changes), due to their interaction with physical systems. Intensive searching of possibilities of creation new optical sensors conditioned by their clear advantage connected to high sensitivity, protection from electromagnetic noises, wide range of application areas (chemical and biochemical changes, measurement of deformations, temperature, pressure etc.).

A special place among optical sensors is occupied by optical temperature sensors (OTS), which can be successfully used for measuring and controlling the temperature, where conventional techniques cannot be used and/or run to problems representing drawbacks for successful applications. Among the possible applications one should note temperature monitoring in highly corrosive media, electrical power stations, oil refineries, coal mines and building fire detection.

Idea of the use of rare earth (RE^{3+}) ions doped materials as optical sensors, including temperature ones is based on temperature dependences of spectroscopic characteristics (fluorescence intensities, fluorescence lifetimes, absorption coefficients etc.) of systems in the infrared and visible range. But as a rule, it is limited by consideration of the OTSs based on fluorescence intensity ratio (FIR) assuming, that temperature dependence of FIR is conditioned by Boltzmann factor of population of neighboring energy levels [1-6]. In [7-9], as a temperature dependent measure value, an average time of fluorescence (FL) from two near-lying levels is considered. Wherein, it is assumed, that the speed of thermalization between two excited i and j levels is higher compared to their spontaneous lifetimes $\tau_i = A_{i0}^{-1}$ and $\tau_j = A_{j0}^{-1}$. Note, that during the searching of new materials and mechanisms for temperature sensing, it is necessary to take into account, that thermal connected working energy levels of OTS must satisfy the following conditions:

Energy gap between initial levels:

- must be less than ~ 200 cm^{-1}, that will guarantee the necessary solvability of the corresponding spectral lines,
- must be no more than 2000 cm^{-1}, that will guarantee the necessary population of initial levels in given temperature range.

Energy remoteness of lower initial level from the right next lower level must be quite large (more than 6 times higher than Debye's phonon energy of considered material), which will guarantee domination of radiative transitions over non-radiative.

Until now a large number of distributed and point OTSs on the base of different RE^{3+} ions (Er^{3+}, Sm^{3+}, Eu^{3+}, Pr^{3+}) doped glasses, ceramics and fibers have been presented [1-3]. The OTSs on above mentioned materials have the ability to cover a wide temperature range (300 to 1623 K) with reasonable measurement resolution [3-6]. At the same time, despite to their attractive properties, such as high temperature mechanical strength, chemical stability and excellent optical property, RE^{3+} - doped bulk single crystals on this day practically were not investigated with an object to design optical temperature sensors on their basis.

In this work the possibilities of YAG-Yb^{3+} crystal as material for OTS based on two others schemes: a) the absorption coefficient ratio (ACR) and b) zero-phonon line intensity (ZPLI) of fluorescence are discussed. Thus, in cryogenic temperature range, the YAG:Yb^{3+} crystal reveals excellent sensing capabilities based on the ZPLI method. These is noteworthy, because already known OTSs, which are based on the RE^{3+} - doped materials, are operating on FIR method, are effective in room temperature and above temperature range. At the same time, the average sensitivity of YAG:Yb^{3+} crystal based OTS, operating on the ZPLI method, is 3.4%×K^{-1} in 40 – 130 K temperature range, which is an order of magnitude larger than sensitivity of resistive temperature sensor (0.3 %×K^{-1}) [10].

References

[1] V.K. Rai. *Appl. Phys. B* **88**, 297 (2007).
[2] V.K. Rai. *Appl. Phys. B* 87, 323 (2007).
[3] V.K. Rai, D.K. Rai, S.B. Rai. *Sensor Actuator A* **128,** 14 (2006).
[4] A.S. Camargo, J.F. Possatto, L.A. Nunes, et al. *Solid State Commun.* **137**, 1 (2006).
[5] L. Feng, B. Lai, J. Wang, G.Dua, Q.Su. *J. Lumin.* **130**, 2418 (2010).
[6] C. Li, B. Dong, Sh. Li, Ch. Song. *Chem. Phys. Lett.* **443**, 426 (2007).
[7] Z.Y.Zhang, T.Sun, K.T.V.Grattan, A.W.Palmer. *Sensor Actuator A*, **71**, 183 (1998).

[8] T. Sun, Z.Y. Zhang, K.T.V. Grattam, A.W. Paimer. *Rev. Sci. Instrum.*, **69**, 4179 (1998).
[9] N. Rai, V.K. Rai. *Sensors & Transducers Journal* **77**, 1040 (2007).
[10] G. Tripathi, V.K. Rai, S.B. Rai, *Optical Materials* **30**, 201 (2007).

Optical properties, radioluminescence and scintillation decay of YAG:Ce.Li(Na)

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YAG:Ce is a well-known efficient X-ray scintillator applied in very different fields of science and technology [1]. A positive effect of co-doping of some Ce-doped garnets with divalent or monovalent impurities has been recently reported [2]. In the present work the major properties of YAG:Ce,Li and YAG:Ce,Na single crystals grown by the vertical Bridgman method were studied. The amount of impurities in the crystals was in the following ranges: Ce(0.1÷0.35 at%), Li(35÷400 ppm), Na(70÷250 ppm). Radioluminescence spectra were recorded at RT under X-ray irradiation; scintillation decay measurements were performed at RT under X-ray excitation using a picosecond pulsed laser. The function of additional non-isovalent impurities (Li,Na) in modifying the optical absorption in the 190-400 nm range, radioluminescence and scintillation decay kinetics is discussed.

Optical absorption spectra were compared in as-grown crystals and after applied heat treatments (air 1500^{o} C) and gamma-ray irradiation (^{60}Co; 1 KGy, 10 KGy) to trace variation of absorption at 340 nm due to $Ce^{3+} \rightarrow Ce^{4+}$ and UV absorption. As observed, an essential input to absorption in the UV range (along with Ce^{3+} band at 224 nm and Ce^{4+} centers in the range around 260 nm) is due to oxygen-related defects (F-type centers). The radioluminescence emission intensity in samples containing Li^{+} is lower, as compared to YAG:Ce with the same Ce concentration. An acceleration of the decay components is registered in YAG:Ce,Li for light (35-70 ppm) amounts of introduced Li^{+} which can be attributed to decrease of oxygen vacancies acting as traps, but not to presence of Ce^{4+}. Reduction of traps in Li^{+}-codoped crystals is evidenced also by lower induced absorption in the UV in γ-ray irradiated crystals, as compared to YAG:Ce. Absorption induced in the range of emission is also lower showing that the radiation hardness of Li^{+}-codoped crystals

is higher. Radiation hardness of YAG:Ce,Na, in comparison to YAG:Ce,Li, is lower.

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References

[1] M. Nikl, *Meas. Sci. Technol. 17(4)*, R37 (2006).
[2] K. Kamada, Y. Shoji, V. Kochurikhin, et al., *Optical Materials* ***65,*** 52 (2017).

RF spiral scanning streak camera

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A Radio frequency (RF) spiral scanning streak camera will be presented. The spiral scanning deflector represents two RF circular scanning systems, operating at slightly different RF frequencies in 500-1000 MHz range. The spiral scanning periods are by 1-2 orders of magnitude longer than the circular scanning periods. The time resolution of this device is a few picoseconds for the whole spiral scanning period. The principles of operation of the technique are described, results of current theoretical and experimental studies are presented and possible applications are outlined.

Stimulated photodissociation of Feshbach resonances with emission of photon at the collision of two atoms in a laser radiation field

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In the present work we consider collision of atoms with formation of the Feshbach resonances [1] and the subsequent stimulated transition to the lower unbound molecular electronic states with emission of photon of the laser radiation [2].

Such a situation may be realized, in particular for the molecules Rb_2 at the resonance scattering of two atoms Rb in states 5s and 5p for the Rb molecules on the excited electronic molecular state $^3\Pi_u$ with subsequent induced transition to the lower unbound molecular electronic state with emission of photon (Fig.1). This process is a basis for the creation of excimer lasers. The typical atomic gas density is 10^{14}-10^{17} cm^{-3}. If the density of excited atoms is 0.001%, then the intensity of emitted photons during the stimulated transition is 10^9-10^{12} times larger. As a result, we have source of high radiation, which serves as an example of an excimer laser.

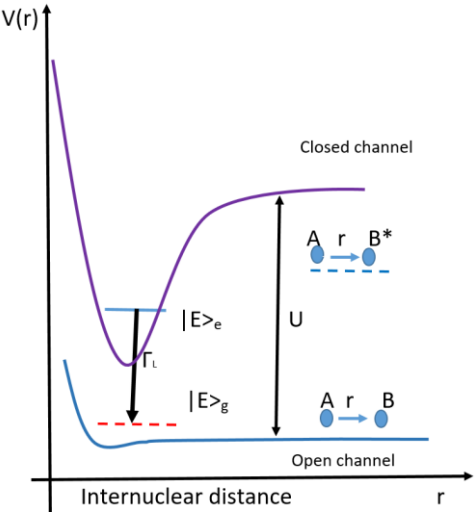

Fig. 1: Diagram of formation of Feshbach resonances at the collision of two atoms.

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References

[1] H. Feshbach, Ann.Phys. 19,287 (1962)
[2] W. Heithler,"The Quantume Theory of Radiation", 3rd edn (London: Oxford University Press) (1954)

Fourth Photon Doppler Free Rydberg State Excitation

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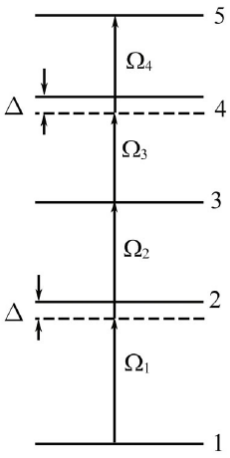
The excitation of atoms from ground state to the Rydberg states [1,2] attracts attention of researchers in recent years in the field of quantum and nonlinear optics. The effective method of excitation of target state is the well-known method of Stimulated Raman Adiabatic Passage (STIRAP). The generalization of STIRAP on the multi-level systems, the theoretical and experimental investigations of peculiarities of this method, its advantages over the other methods of the population transfer and the numerous applications are studied in details (see for example [3-5]).

In this work, we investigated the five-level system of ladder-type Interacting with three laser pulses (see. Fig.). The pulses can have different intensity and sequence of switching on and off. At the same time, it is assumed that the pulse durations are much longer or shorter than the all relaxation times within the system [1]. We consider the adiabatic interaction of this system and show that the different combination of sequences of pulses provide the effective adiabatic excitation of such a system. The main requirement of this excitation is zero four-photon detuning. This method can be successfully applied to obtain the Rydberg atoms and to study its spectroscopic properties study.



Acknowledgments: This work was supported by the SCS MES of Armenia (15T-1C066 theme) and IRMAS project.

References

[1] Jorge M. Kondo, Nikola Šibalić, Alexander Guttridge, Christopher G. Wade, Natalia R. De Melo, Charles S. Adams, and Kevin J. Weatherill, Opt. Lett.,V.40,N23,pp5570-5573 (2015)
[2] N. Šibalić, J. M. Kondo, C. S. Adams, and K. J. Weatherill,Phys. Rev. A 94, Vol. 94, Iss. 3, 033840, (2016)
[3]E. A. Gazazyan , G. G. Grigoryan, and, V. O. Chaltykyan, Journal of Contemporary Physics (Armenian Academy of Sciences), Vol. 50, No. 3, pp. 233–239 (2015)
[4] Møller, D., Sørensen, J.L., Thomsen, J.B., and Drewsen, M., Phys. Rev. A, vol. 76, p. 062321 (2007)
[5]. Shore, B.W., Bergmann, K., Oreg, J., and Rosenwaks, S., Phys. Rev A, vol. 44, p. 7442. (1991)

Quantum Coherence and Squeezed Vacuum in Third Subharmonic Generation Process

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The quantum dynamics of the mean number of photons and quantum entropy of interacting modes, as well as the Wigner function of the stationary state of the fundamental mode and the third subharmonic mode has been investigated for the intracavity third-subharmonic generation [1]. It is shown that the quantum dynamics of the system depends strongly on the nonlinear coupling coefficient between the modes. It is also demonstrated that, in the steady-state limit, depending on the intermodal coupling coefficient, the fundamental mode can be either in a pure coherent state, or in a squeezed state, or in a pure vacuum state. The third subharmonic mode in the subthreshold regime of generation of this mode is in the vacuum state. The Wigner function is squeezed over three sides of an equilateral triangle (squeezed vacuum). The quantum entropy of this state is nonzero. It is also shown that the third subharmonic mode, depending on the nonlinear coupling coefficient in the steady-state limit, can be localized in the three-component state with the same probability of detecting a field in each coherent component of the state and with the presence of quantum-mechanical interference between the state components. The mean number of photons in this state is smaller than unity. Depending on the nonlinear coupling coefficient, the third subharmonic mode can also be localized in the three-component state, which is a statistical mixture of three squeezed states.

References

[1] S.T.Gevorgyan, M.S.Gevorgyan, Optics and Spectroscopy, 2017, Vol. 122, No. 5, pp. 784–790.

LIDAR Return And Depolarization Ratio Profile Measurements In The Atmosphere

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LIDAR system sensitive to the polarization of the elastic backscattered signal is being developed in Yerevan Physics Institute. At present, the system is being tuned for measuring vertical atmospheric backscatter profiles of aerosols and hydrometeors, analyze the depolarization ratio of elastic backscattered laser beams and investigate the influence of external factors on the beam polarization. In this paper, we describe the first measurements of polarization separated lidar return profiles and depolarization ratio profile in the atmosphere and clouds by means of our LIDAR system.

References

[1] K. Sassen. Bull. Am. Meteorol. Soc. 12, p. 1848 (1991).

Nonreciprocal Transmission in Electro-Tunable Cholesterics

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Here, we experimentally demonstrate an optical nonreciprocity phenomenon in the system of non-absorbing CLCs of different pitches which exhibits pitch gradient during the diffusion process [1]. Importantly this CLC structure can work as optical diode in some spectral regions. Besides, we show that the nonreciprocal properties of the cell can be vanished or recovered back by using external electric or thermal influences. Namely, it was demonstrated by unpolarised normal incident light that nonreciprocal effects can be strengthened or almost disappeared by changing the temperature or applying external electric field in the above mentioned structure. Besides, it was shown that the nonreciprocal properties of the system recover back as soon as the external influences are removed. Theoretical verification of nonreciprocal phenomenon due to the spatial pitch gradient was shown based on Ambartsumian's layer addition modified method [2].

The obtained results introduce a novel class of nonreciprocal chiral elements which are applicable in modern optoelectronic logical elements.

References

[1] A. H. Gevorgyan, R. B. Alaverdyan, H. Gharagulyan, M. S. Rafayelyan, H. Grigoryan, J Nanophotonics, 9, 093591, (2015).
[2] A. H. Gevorgyan and M. Z. Harutyunyan, Phys. Rev. E 76, 031701, (2007).

Femtosecond Pulse Shaping with Spatial-Light Modulator Based on Cholesteric with Homeotropic Boundary Conditions

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In the last two decades, much attention has been paid to the development of a technique for the shaping and compression of femtosecond optical pulses using a grating-lens apparatus with a liquid-crystal spatial-light modulator (SLM) [1, 2]. Such SLMs can independently control the amplitude and the phase of the transmitted light giving possibility to programmable generation of pulses with practically arbitrary (within physical limits) shaping and are now commercially available. The commercial SLMs most often have a twisted-nematic structure, and the amplitude and the phase of the transmitted light are coupled in a specific manner. That is why in [3] they focused on pulse shaping with such SLMs in the time domain, and investigated the potential of the technique. In [4] we have considered the distribution of the director of a cholesteric liquid crystal (CLC) in planar cells on whose walls the director orientation is maintained rigidly along the normal to the boundary. Near the critical cell thickness this system becomes sensitive to the external fields and at a very low electrical voltage a transition of the Fréedericksz type takes place from a stable twisted distribution to a stable homogeneous homeotropic distribution.

In this study, we have theoretically characterized the properties of a CLC SLM with homeotropic boundary conditions. The SLM consists of a CLC layer which is embedded between two glass slides. The CLC mask is subdivided into a linear array of pixels which can be controlled individually using a driving voltage. It is applied via two transparent indium tin oxide (ITO) electrodes which are deposited on the inner surface of the glass slides. The pixels are defined by patterning of one ITO layer into stripe-shaped electrodes, with neighboring pixels being separated by thin gaps (typically a few μm) in the ITO layer. We developed the relevant mode extraction method for the calculation of mask patterns which can generate multiple pulse sequences with arbitrary relative amplitudes and phases. By the choosing relevant distribution of the electric field voltages (lower than 1V) across the mask with CLC SLM we get very different pulse shaping: double pulses (symmetric or asymmetric), triple pulses, multiple pulses, optical square pulse and others. Let us note, that this approach allows the control of the relative amplitudes of different pulse within pulse train. By varying the modulation depth (by altering the

amplitude of the electric field voltages distribution), we generate different number of pulses and their intensity ratios.

References

[1]. A.M. Weiner, Review of Scientific Instruments, 71 (5), 1929-1960 (2000).
[2]. B. Sun, P. S. Salter, M. J. Booth, Optics Express, 23 (15), 19348-19357 (2015).
[3]. T. Hattori, K. Kabuki, Y. Kawashima, M. Daikoku, H. Nakatsuka, Jpn. J. Appl. Phys., 38, 5898–5904 (1999).
[4]. R.S.Akopyan, R.B.Alaverdyan, V.V.Saakyan, Yu.S.Chilingaryan. Kristallografiya, 30 (4), 746-749 (1985).

Influence of different oscillator strength on coherent process in five-level media

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The coherent interactions of resonant laser radiation with single atom and atomic media was a prominent strand of research in nonlinear optics and laser physics from the very beginning. However, in recent years the number of publications in this field of physics has increased significantly due to the rapid development of experimental techniques. Construction of needed coherent superposition states of atoms in a macroscopic volume, the storage and subsequent retrieval of optical and quantum information, excitation of atoms from the ground to the Rydberg state are bright examples of the application of the coherent process in the field of quantum information.

These phenomena have been comprehensively studied, both theoretically and experimentally, for various three-level systems and their media. The multilevel systems may have a number of advantages compared with three-level. In our previous works we demonstrated the possibility of a double storage of optical information in the five-level M-type system and effective Rydberg state excitation in five-level ladder system. We considered in this works adiabatic interaction of five-level atomic systems and their media with four short laser pulses under the condition of all two-photon detunings being zero. We show that, under certain conditions the five-level system completely imitates a three-level system not only for a single atom but also in the medium, since the propagation equations are sp lit into those for three- and two-level media separately.

However, in this study we considered only the medium with equal oscillator strength. In the present work, we generalize the results obtained earlier for media with different oscillator strength. We will conduct numerical and analytical calculations using the density matrix formalism and Maxwell's equations. Our research has shown that the all the coherent effects observed in three-level media, such as population transfer, slow and fast light, light storage, and so on, may efficiently be realized in five-level media in the case when materials with very different strengths of adjacent transitions are used. This result can be useful in the implementation of the above processes in solid materials

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Spatial soliton formation in azobenzene without external electric field

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The spatial solitons in nematic liquid-crystals are generated assisted by an external electric field usually. We have theoretically explored unusual properties of azobenzene. The remarkable feature of the latter is that spatial solitons are observed without applying any external electric field on the liquid crystal (LC) cell. This makes azobenzene LCs more attractive to employ to devise less complicated photonic and electromagnetic devices.

The effect is explained by strong nonlinear interaction of the azobenzene molecules with the laser field and supposing that they are not strongly anchored to the boundary. The last assumption implies that the molecule alignment can be readily varied by a low-power laser field even for small pre-orientation angles θ_0 with respect to laser propagation axis z. The theoretical model of 3D spatial soliton generation described by the Schrödinger-type equation reproduces the observed dynamics of solitons very well. We have shown that for laser power of P = 2mW the produced soliton remains stable at small range of distances, while at the larger laser field power P = 8mW the distances of stable propagation of solitons strongly exceed the diffraction length.

On nano-characterization of threading dislocations via electron holographic interference microscopy

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Off-axis electron holography (EH) in a field emission transmission electron microscope is a coherent interferometric technique that can be used for phase imaging of electrically active crystallographic defects with nanometer-scale resolution. Several experimental groups have employed EH interference microscopy for nano-characterization of electronic charge distribution at individual threading dislocations (TDs) in wide bandgap semiconductors, such as n-type GaN [1,2], ZnO [2], and 4H-SiC [3]. In the latter work a numerical-simulation scheme has also been proposed for reconstructing by means of the EH phase image the profile of the conduction band bending in the vicinity of a highly negatively charged TD core. Motivated by aforementioned studies, here we examine the inverse scattering problem for the EH wave interacting in cross-section imaging mode [2, 3] with the space charge region associated with a TD line in n-conducting material. We proceed within the framework of the Read screening scenario [2, 3] and use in calculations the methods of geometrical optics for electron ray-trajectories. Our analytical expressions show explicitly how the variations in screened electric field and inner potential across a TD can be retrieved with the help of detected features of EH phase distributions. By invoking the experimental transmission phase shift data [2, 3], we obtain quantitative information on the magnitudes of transport and recombination barriers originating around mixed-type [2] and screw-type [3] TDs. A sum rule is formulated for TD-related phase shifts.

References

[1] D. Cherns, C. Jiao, Phys. Rev. Lett. 87, 205504 (2001).
[2] E. Müller, D. Gerthsen, P. Brückner et al., Phys. Rev. B 73, 245316 (2006).
[3] S. Chung, R. A. Berechman, M. R. McCartney et al., J. Appl. Phys. 109, 034906 (2011).

Spatial evolution of light polarization in wedge-shaped cholesteric liquid crystal cell

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In modern optoelectronics, many inhomogeneous media (both natural and induced) are considered as potential targets for various applications in control elements: periodic and non-periodic media with metallic, semiconductor, dielectric, gyrotropic, liquid-crystalline and bianisotropic layers, etc. [1.2]. Parameters of such media can be controlled by static and variable electric, magnetic or acoustic fields. In particular, biaxial and cholesteric liquid crystals, as well as nematic liquid crystals with twist orientation, have many applications in LCD displays, in controlled phase elements, polarization filters, etc. It is theoretically proved in [3,4] that during propagation in such medium the state of polarization undergoes oscillations, spatial frequency of which depends on thickness of sample.

The purpose of this paper is to experimentally and theoretically study the process of spatial energy exchange between ordinary and extraordinary waves in a twisted anisotropic medium, particularly, in a CLC cell with variable thickness.

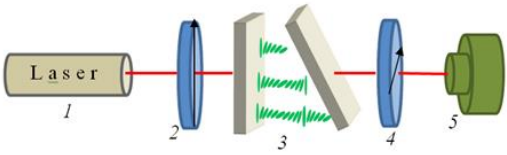

Fig.1. Experimental setup: 1 - He-Ne laser, 2 - polarizer, 3 – wedge-shaped cell (thickness 0-100 μm), 4 - analyzer, 5 - power meter.

An experimental setup, shown in Fig.1 was used to study the change of polarization of an initially linearly polarized laser beam when it passes through the CLC cell with a variable thickness. A laser beam of He-Ne laser (1) with a wavelength of 0.63 μm passes through the polarizer (2) and acquires a linear polarization. The linearly polarized beam then perpendicularly falls on the wedge-shaped CLC cell (3). The state of polarization of the transmitted light is investigated using an analyzer (4) and a power meter (5). The polarization of the transmitted beam is determined by rotating the analyzer and measuring the power of the laser beam. In the course of the experiment normal incidence of the beam

onto the cell was ensured, and the scanning across the sample was performed mechanically. The experiment was carried out at room temperature.

The results of the investigation show that the polarization of a linearly polarized beam actually undergoes oscillations when it passes through the CLC cell during transverse scanning along the vertical axis of the wedge.

Thus, the experimental results approve the theoretical results [3,4].

References

[1] E. Collett, B. Schaefer. Lincroft, New Jersey USA, Polawave Group, 2012.
[2] G. R. Luckhurst, T.J. Sluckin. Biaxial NLC. Southampton, Wiley&Sons. 2015.
[3] L. Aslanyan. National Academy of Science of Armenia. Journal of Contemporary Physics, 52, *No* 3, p. 279 -288, 2017
[4] A. Aslanyan, L. Aslanyan, Yu. Chilingaryan Optics And Spectroscopy, 116, 516 (2014).
[5] R. Alaverdyan, A. Aslanyan, L. Aslanyan, G. Gevorgyan , S. Nersisyan. National Academy of Science of Armenia, Journal of Contemporary Physics , 50, 185 (2015).

Structural and optical properties of YAG:Ce and LuAG:Ce with additional Li and Na

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Conversion of a part of Ce^{3+} ions to Ce^{4+} by either divalent or monovalent co-doping is presently considered as one of the most efficient ways to improve the performance of Ce-doped garnet scintillators [1-3]. While cations with unit charge difference and nearly the same size (Ca^{2+}, Mg^{2+}) in respect to the three valence host cations they substitute, are easily tolerated in garnet hosts, the case of monovalent cations (Li^{+}, Na^{+}) is less evident and no information is available on their site occupation and charge compensation mechanisms.

The goal of this study is to investigate substitution preferences of Li^{+} and Na^{+} codopant impurities in YAG:Ce and LuAG:Ce garnets. For this purpose,

polycrystalline samples with Li^+ and Na^+ (0-1600 ppm) and Ce (0 and 1 at%) were prepared by solid phase reactions and studied for phase composition and unit cell dimension (a_0). Selected compositions were grown by the vertical Bridgman technique and studied for typical defects and optical absorption.

The results on variation of a_0 with impurity concentration are discussed taking into account the size and electronegativity of impurity ions, in respect to those of host cations they may replace in the garnet structure. The involved charge compensation mechanisms are considered taking in addition, as a criterion, that formation of Ce^{4+} states should lead to an essential increase of absorption in the 250-300 nm range [1]. Variation of a_0 in series with Na^+ is within the measurement error and does not give clear evidence for substitution preferences. It is found that Li^+ in LuAG:Ce,Li goes to Lu^{3+} sites with charge compensation maintained in part by $Ce^{3+} \rightarrow Ce^{4+}$ transitions. Li^+ in YAG:Ce,Li more evidently goes to interstitial positions and eliminating near-by oxygen vacancies, for charge compensation.

This work was performed in the scope of the International Associated Laboratory (CNRS–France & SCS–Armenia) IRMAS, Crystal Clear collaboration and European Union Horizon 2020 Program under grant agreement no. 644260 (INTELUM).

References

[1] M. Nikl, K. Kamada,V. Babin, et al., Crystal Growth Design 14, 4827 (2014).
[2] K. Kamada, Y. Shoji, V. Kochurikhin, et al.,Optical Materials 65, 52 (2017).
[3] A.G. Petrosyan, K.L. Ovanesyan, M.V. Derdzyan, et al, J. Crystal Growth 430, 46 (2015).

Theory of selective reflection spectroscopy in a cell with parallel windows

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The selective reflection (SR) is an essential spectroscopic tool differing in a number of aspects from the absorption spectroscopy because of relatively narrow width of spectral lines. The small widths of spectral lines in SR, resolving the resonances inside the Doppler profile, is associated with non-locality of the atomic medium polarization and with peculiarity of interaction of atoms having different velocity directions with the cell walls. Indeed, the atoms lose their polarization in collisions with the cell wall. Such a selectivity of the polarization with respect to

the sign of the velocity projection gives, as a result, the experimentally observed spectra.

Despite of large amount of theoretical and experimental papers concerning studies of SR [1], there is, to the best of our knowledge, no analytical model describing adequately the selective reflection phenomenon. Theoretical models deal as a rule with the approximation of dilute media (the given pumping approximation). Absorption of laser radiation is in this approach completely neglected. The self-consistent problem was studied only numerically.

The present work is aimed at theoretical study of the selective reflection in atomic media with arbitrary optical density and multiple component lines in a cell with parallel windows. The theoretical model is based on the self-consistent solution of Maxwell equations together with the density matrix equation for a multilevel system. We obtain relatively simple expressions well describing the experimental results and passing, in limiting cases, to the well-known expressions [2]. A number of selective reflection spectra from the atomic cesium and rubidium vapor were recorded under various experimental conditions.

The work was supported by the Ministry of Education and Science MES RA in frame of research projects No.15T-1C066.

References

[1] J.P. Woerdman, M.F.H. Schuurmans, Opt. Com. 14, 248 (1975); A. Weis, V.A. Sautenkov, T.W. Hansch, PRA 45, 7991 (1992); T.A. Vartanyan, D. Lin, PRA 51, 1959 (1995); P.Wang, A Galager,J.Cooper PRA 56,1598,1997; D.J. Whiting,J. Keaveney, C.S. Adams, I.G. Hughes Physical Review A 93(4) 043854(2016).

[2] Badalyan, V. Chaltykyan, G. Grigoryan, et al. Eur. Phys. J. D 37, 157-162 (2006); A. Papoyan, S. Shmavonyan, D. Khachatryan, and G. Grigoryan J. Opt. Soc. Am. B 34, 877-883 (2017).

References

[1] T. Momose and T. Shida, "Matrix-isolation spectroscopy using solid parahydrogen as the matrix: application to high-resolution spectroscopy, photochemistry, and cryochemistry," Bulletin of the Chemical Society of Japan, Vol. 71, no. 1, pp. 1–15, (1998).
[2] S. Upadhyay et al. "Longitudinal spin relaxation of optically pumped rubidium atoms in solid parahydrogen,", Physical Review Letters, Vol. 117, no. 17, p. 175301, (2016).

Superconductor/Thermoelectric/Superconductor Heterostructure for Single-Photon Detection

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Single-photon detectors are demanded in quantum electronics, astrophysics, high energy physics, quantum informatics, telecommunication systems, quantum metrology, measuring systems for applications in medicine, homeland security and other fields [1]. Among the developments of this century, superconducting nanowire single-photon detectors are considered as the most promising [2]. The thermoelectric single-photon detector (TSPD) possesses similar characteristics. Earlier we showed that by decreasing the thickness of thermoelectric sensor of multilayer detection pixel of TSPD is possible to obtain transducers for registration of photons with count rates higher than tens gigahertz [3]. However, the thinner is the thermoelectric layer, the lower is it's electrical resistance, that may be an obstacle for the registration of the voltage on the sensor. The latter barrier can be overcome if the resistance of the measuring circuit is lower than the resistance of the thermoelectric sensor. The problem can be solved by using a superconducting material. We propose a new type of TSPD with a sensor consisting of two superconducting layers and a thermoelectric layer between them [4]. In the present work the results of computer simulation of heat distribution processes taking place after the absorption of single photons of 1-1000 eV energy in the multi-layer detection pixel of the thermoelectric detector are presented. We considered different geometries of the detection pixel in which CeB6 and La1-xCexB6 hexaborides are used as a thermoelectric sensor and absorber and heat sink are of Nb, Pb and YB2C3O7-δ superconductors. The calculations are based on the heat conduction equation and are carried out by the matrix method for differential equations. It is shown, that by changing materials and sizes of the detection pixel's

elements, as well as the working temperature of the detector, it is possible to obtain transducers for the registration of photons within the given spectral range with the required energy resolution and count rate. It is demonstrated that such detector has a number of advantages which give ground to consider the thermoelectric detector as a real alternative to the most promising single photon detectors.

References

[1] R.H. Hadfield, Nature Photonics, 3, 12, 696 (2009).
[2] T. Yamashita, S. Miki, H. Terai, IEICE Transact. on Electronics, E100-C, 3, 274 (2017),
[3] A.A. Kuzanyan, V.R. Nikoghosyan, A.S. Kuzanyan, Sensors & Transducers, 207, 12, 21 (2015).
[4] A.S. Kuzanyan, A.A. Kuzanyan, V.R. Nikoghosyan, Patent of Armenia № A3043 (2016).

Thermoelectric Sensor for Energy-Resolving Ultrafast Detection of Single Photon from Infrared to Ultraviolet

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Single-photon detectors are required in different areas of modern science and technology. The thermoelectric single-photon detector (TSPD) can compete with detectors having record characteristics. The single layer TSPD sensor contains two absorbers made of a heavy metal which are deposited on a dielectric substrate and coupled to each other by a thermoelectric bridge (Figure a). When a photon enters the absorber its temperature rises, in comparison to that of the second absorber, leading to appearance of a potential difference; by measuring this potential the fact of absorption can be registered and the energy of the photon determined. Recently, the idea of a three-layer TSPD sensor was proposed (Figure b).

In this work the results of computer simulation of heat distribution processes taking place after absorption of single photons of 1 - 100 eV energy in the sensor of the thermoelectric detector are being analyzed. The computer simulation was based on the heat propagation equation from the limited volume with the use of three-dimensional matrix method. Different geometries of the detection pixel with tungsten absorber, thermoelectric sensor made of rare earth hexaborides are considered.

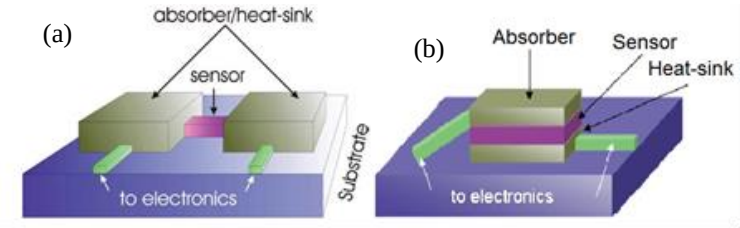

Figure. Single layer (a) and three-layer (b) sensors design.

The obtained results allow the following conclusions to be done.

- The three-layer thermoelectric detection pixel may register individual photons in a wide range of the electromagnetic spectrum from 1 eV to 100 eV, providing energy resolution of better than 1% and count rates from tens gigahertz to terahertz.
- For the solution of a wide range of different tasks the ratio (energy resolution)/(count rate) can be varied by changing the geometric sizes of the sensor.
- Thermoelectric single photon detector with a three-layer detection pixel can present a real concurrence to superconducting detectors and avalanche photodiodes.

Reflectance ratio behavior of apricot green leaves and soil in the 400-900 nm spectral region.

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Satellites and aerial drones are widely used for remote sensing of structured substances on the earth's surface. The substance can be identified from its spectral reflectance signature if the sensing system of the satellite has sufficient spectral resolution to distinguish its spectrum from those of other substances [1]. In this work we present the results of measurements of spectral reflectance signature of apricot (widely distributed tree in Armenia) leaves in comparison with the dry and wet soil.

The white light source is used for illumination of samples. Diffuse reflection from samples surface is registered via ASEQ Instruments LR1 fiber-coupled spectrometer with spectral resolution of 1 nm. In the experiments, the spectrometer

fiber input was perpendicular to the samples surface, and the registration area was large enough allowing us to register averaged (by samples surface) light intensity. The spectrometer is connected via USB cable to the computer, and processing of registered spectra is carried out by OriginLab software package. A soil in both 20% wet and dry conditions as well as apricot green leaves are used during studies as samples.

Experimental results show that spectral reflectance of the apricot green leaves has maxima at 520-560 nm and 740-800 nm ranges and minimum at 640-700 nm, that is in accordance with the results for other green species [1]. In the 760-900 nm spectral range the results concerning soil reflectance are reduced which differ from those in literature [1]. We have obtained that the wet soil reflectance is reduced by twice with respect to the dry soil reflectance. Relative reflectance spectra of the samples indicate that leaves/soil contrast is maximal in green (the center at 540 nm) and near IR (the center at 820 nm) spectral regions. The (leaves)/(wet soil) reflectance ratio reaches to 4 in green and 15 in near IR regions. Thus the investigations show that the near IR is the most appropriate spectral region to carry out experiments for exact separation of apricot leaves distribution from the soil.

The work has been performed within the framework of ISTC grant project #A-2244.

References

[1] A.E. Altynov, V.A. Malinnikov, S.M. Popov, A.F. Stetsenko, “Landscape Spectrometry”, Reprografia, Moscow, 2010.

The structure of Ho-doped lithium niobate thin films.

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Lithium niobate is one of the most well-known and widely used ferroelectric material due to its unique non-linear optical, piezo- and pyroelectric, electro-optical and photorefractive properties.

A series of LiNbO3 thin films doped with different concentrations of Ho3+ ions were grown with the Sol-Gel technique on the c plane sapphire substrate.

Z-cut LiNbO3:Ho3+ thin films structural modifications were measured by high-resolution x-ray reciprocal space mapping diffraction. Experiments were done with Philips X'Pert diffractometer. Obtained results were analyzed by X'Pert Epitaxy program, which give a possibility to determine lattice parameters and orientation of films.

For calculating the lattice parameters one need to solve deformation matrix ξ:

$$\hat{\xi} = \begin{pmatrix} \xi_{xx} & \xi_{xy} & \xi_{xz} \\ \xi_{yx} & \xi_{yy} & \xi_{yz} \\ \xi_{zx} & \xi_{zy} & \xi_{zz} \end{pmatrix} \qquad (1)$$

The component $\xi_{\parallel\perp}$ is considered as zero, therefore the matrix will be modified as the one given bellow:

$$\xi = \begin{pmatrix} \xi_{\parallel\parallel} & \xi_{\parallel\perp} \\ \xi_{\perp\parallel} & \xi_{\perp\perp} \end{pmatrix} \qquad (2)$$

Lattice parameters were calculated by the use of the followed equations:

$$a_L = a = b = a_s(\xi_{\parallel} + 1) \qquad (3)$$

$$c_L = c_s(\xi_{\perp} + 1) \qquad (4)$$

where, a_L and a_S are lattice parameters a of film and substrate, while c_L and c_S are lattice parameters c of film and substrate correspondingly.

Influence of Multiwavelength Radiation Trapping on the IR Luminescence of YAG:Er,Ce Crystal

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YAG:Er^{3+} crystals codoped with Ce^{3+} sensitizer ions are promising source of highly effective radiation near 1.5 μm. Presence of radiation trapping (RT) leads to spatial and temporal redistribution of excitation energy in the impurity subsystem. This essentially affects different characteristics of materials such as the kinetics of excitation decay, dynamics of population and depopulation of electronic levels of

impurity ions, etc. Influence of RT on spectroscopic characteristics of YAG:Er^{3+} crystals is studied experimentally in [1].

The RT effect in YAG:Er^{3+},Ce^{3+} crystals exhibits more complex behavior. Ce^{3+} sensitizer ions along with excitation transfer to Er^{3+} ions show broad emission in the visible spectral range. This indicates that the RT process may take place not only between Er^{3+} ions but also between Ce^{3+} and Er^{3+} ions.

In the present study we discuss the obtained experimental data and suggest a model that allows us to simulate the possible processes of RT in $^4S_{3/2} - {}^4I_{15/2}$, $^4F_{9/2} - {}^4I_{15/2}$ and $^4I_{13/2} - {}^4I_{15/2}$ emission/absorption bands of Er^{3+} ions. Studies are carried out on two bulk YAG:Er^{3+},Ce^{3+} crystals with 5at.% and 1at.% of Er^{3+} while the Ce^{3+} concentration is kept the same (0.3at.%). Time resolved measurements of Er^{3+} luminescence decay at 1.5 μm are carried out at several positions of the crystal surface perpendicular to the excitation. Simulation of possible RT processes in crystals under study is performed using system of modified rate equations. Numerical calculation of rate equations and subsequent comparison with experimental data showed good agreement confirming the substantial presence of mentioned RT processes.

References

[1] V.G. Babajanyan, R.B. Kostanyan, P.H. Muzhikyan, Optical Materials 45, 215, (2015).

Tuning the lasing wavelength in dye-doped chiral photonic structure with pitch gradient by means of hydrodynamic flow

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Cholesteric liquid crystals (CLC) are mostly organic materials which form periodic structure with modulation of refractive index. The period of these structures is the same order as wavelength of light, thus these structures could be used to control the characteristics of light beams. CLC structures have photonic band gap (PBG) which is a wavelength range which is totally reflected from a CLC layer. In dye-doped CLC (DDCLC) structures from the edges of the PBG it is possible to obtain lasing in the visible wavelength range and control the wavelength by means of hydrodynamic flow. In [1] it is shown that the lasing wavelength could be finely tuned by means of controlling hydrodynamic flow velocity. Hydrodynamic flow

also causes emergence of equidistant lasing beaks.

In this work we investigate the possibility of controlling the lasing wavelength in a DDCLC layer with a pitch gradient. In a DDCLC structure with a pitch gradient it is possible to have multiple PBG-s. By means of precise positioning of the optical pumping beam it is possible first to select the desired lasing wavelength and then control it by means of controlling it with hydrodynamic flow.

References

[1] T. Dadalyan, R. Alaverdyan, Zh. Ninoyan., et.al., *Liquid Crystals*, 44(2), pp. 372-378 (2017)

Optical properties of copper oxides nanostructures prepared by thermal and laser sputtering techniques

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Nanostructured copper oxide-based semiconductors are of great interest due to their low cost and abundance, photoconductive, photochemical and antiferromagnetic properties suitable for a variety of applications. In the present study, properties of copper oxides nanostructures prepared by thermal and laser sputtering techniques are discussed. The thermal sputtering technique was realized by vacuum evaporation of copper wire on different substrates with post-deposition annealing of the formed thin films in air in muffle furnace (at 400°C). Laser sputtering experiments were carried out by focusing the radiation of the Nd:YAG laser (LOTIS TII, LS2134D), operating in a double-pulse mode at 1064 nm (energy 80 mJ/pulse, repetition rate 10 Hz, pulse duration 8 ns), on a surface of metallic copper and CuO targets placed in the cell filled with a liquid (water or isopropyl alcohol). The CuO target was formed from the pressed CuO powder. Quasi spherical nanoparticles (NPs) with similar morphology were obtained by laser ablation (LA) of the CuO target in both solutions. The morphology and structure of the prepared samples were analysed by the UV-Vis and Raman spectroscopy (RS), XRD, TEM, EDX and SEM techniques. Raman spectra were obtained with a spectral resolution of 3 cm^{-1} using a confocal Raman spectrometer Nanofinder HE (LOTIS TII). For excitation of Raman radiation, a solid-state laser

with a wavelength of 532 nm was used. The X-ray microanalysis was performed by INCA Energy–300 microanalysis system. The surface microstructure of the samples was investigated by the "VEGA TS5130MM" SEM. As an example, Fig.1 demonstrates TEM and SEM images as well as UV-Vis optical absorption spectra of the prepared NPs.

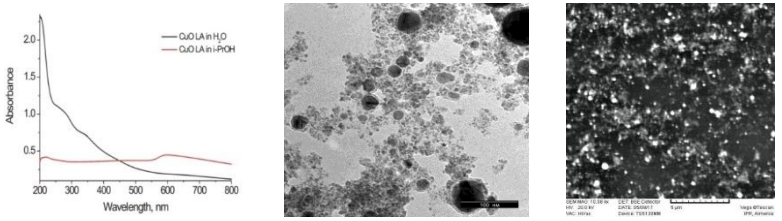

Figure 1. Absorption spectra, TEM and SEM images of the prepared NPs.

As can be seen from the absorption spectra, the presence of copper plasmon resonance peak at 600 nm indicates that after laser ablation of CuO target in i-PrOH metallic copper NPs are formed opposite to the LA in water where the particles composition most probably corresponds to the CuO target composition. This result was also confirmed by X-ray microanalysis. So, the control of stoichiometry, as well as stability, size and crystallinity of the formed particles has been achieved by a proper selection of the experimental parameters such as a sort of liquid used, laser fluence, interpulse delay and ablation exposition.

The authors are grateful to S. I. Petrosyan and G. R. Badalyan, M.S. Tivanov and O.V. Korolik for their help in the experiment.

Investigation of the influence of direct volume expansion on optical properties of Nematic Liquid Crystal layer

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Nematic Liquid Crystals (NLC) are liquids with large optical anisotropy. They enable creation of thin layered controllable optical components such as wave retarders, filters, shutters etc. The optical properties of NLC layers are defined by the alignment of NLC molecules which is sensitive to such external influences such as electromagnetic fields and hydrodynamic flow. Under the influence of the hydrodynamic flow alignment of the NLC molecules varies and the optical properties of the NLC layers become different. One of the methods of inducing a hydrodynamic flow in NLC layer is based on the mechanism of direct volume

expansion. One of the ends of microfluidic cell consisting of two supportive volumes filled with NLC and connected with rectangular capillary channel is heated using a laser beam. This induces volume expansion of the NLC and as a consequence a hydrodynamic flow.

Based on this method in [2] it was studied the influence of the hydrodynamic flow induced by low power laser irradiation on the optical properties of NLC layer with homeotropic alignment and revealed a large prospective for sensing applications. In this work we investigate the influence of the hydrodynamic flow on the optical properties of hybrid aligned Nematic Liquid Crystal layer. We measure the transmission coefficient dependence on the flow velocity and structural changes occurring in the NLC layer.

References

[1] I. C. Khoo, B. A. Saleh (Series Editor), "Liquid Crystals: Physical Properties and Nonlinear Optical Phenomena, 2nd Edition", Wiley Publishing, ISBN: 978-0-471-75153-3, (2007).
[2] R. S. Akopyan, R. B. Alaverdyan, A. S. Vardanyan , Yu. S. Chilingaryan, Quantum Electronics, 30 (8), pp.745-746, (2000).

Electron-Beam Deposition of W/CeB_6/W Heterostructures

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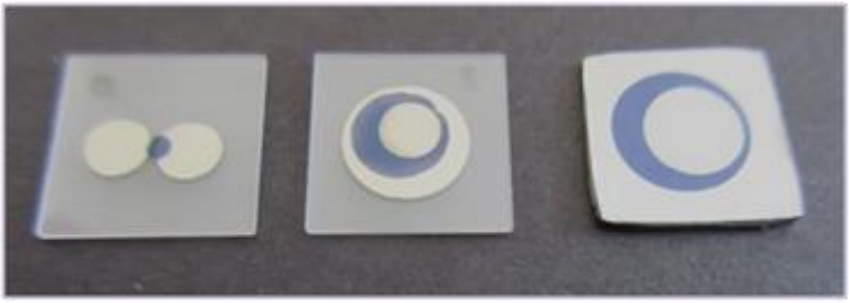
Metal/rare-earth hexaboride/metal heterostructures can be widely used in low-temperature thermoelectric devices. In particular, tungsten/cerium hexaboride/tungsten heterostructure (W/CeB6/W) can serve as a detection pixel of single-photon thermoelectric detectors. There are a few papers in literature on W thin films deposition [1, 2]. The development conditions for electron-beam deposition of tungsten thin films on dielectric substrates, cerium hexaboride on tungsten substrates, and creation of heterostructures W/CeB6/W of various configurations and sizes are presented. Difficulties are faced while the deposition of thin films of tungsten - heavy metal with a very high evaporation temperature. We prevented these difficulties by using composite target of tungsten. The data on thin film deposition conditions, measurement of the thickness, elemental and phase composition and microstructure are presented. The comparative reflection spectra for tungsten films of different thicknesses on various substrates are also investigated. The obtained results serve as a base for the creation of the

thermoelectric detector's detection pixel prototype. The figure bellow shows the manufactured detection pixel's three types. All layers are deposited by using the electron gun of VU-1A vacuum device.



a) b) c)

Figure. Three types of the thermoelectric detector detection pixels: single-layer (a), three-layer on sapphire substrates (b), two-layer on tungsten substrate (c).

References

[1] A.K. Sinha, T.E. Smith, T.T. Sheng, and N.N. Axelrod. Journal of Vacuum Science & Technology 10, 436 (1973).
[2] V. Stelmakh, V. Rinnerbauer, J.D. Joannopoulos, M. Soljacˇic´,I. Celanovic, J.J. Senkevich, C. Tucker, T. Ives, R. Shrader, J. Vac. Sci. Technol. A 31, 061505 (2013).

Magnetic field assisted nondestructive optical probing of Bessel photonic structures in photorefractive crystal

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Photonic lattice structures optically induced by holographic technique are very promising for many applications in optical device engineering and controlled optical information transfer. Nondiffracting beams [1] are of particular interest for optical induction of high-contrast μm-scale refractive lattice structures in photorefractive [2,3] and liquid [4] crystals providing unchanged lattice structure over the length of medium. One of the problems for practical applications is

erasure of holograms by homogeneous light during readout process. We report a novel method for non-destructive optical probing of photonic structures in photorefractive crystals in an external magnetic field.

Experiments were performed for Bessel-like lattices. CW single mode laser beam at 532 nm and 17 mW power was used for formation of Bessel beam with concentric ring profile having 10 μm periodicity by an axicon. The Bessel-like lattices were recorded in Fe doped lithium niobate crystal with optical C-axis along crystal surface. The probing of recorded lattices was performed by diffraction of Gaussian beam at the same wavelength on the lattices, which provides quantitative measurements of lattice diffraction efficiency. Directions of magnetic field, C-axis of the crystal and probe beam were mutually perpendicular. The stability of recorded lattices against erasure during readout was studied by measuring the time evolution of hologram diffraction efficiency for readout beam power of 17 mW without and with external magnetic field of B = 0.85 Tesla.
Investigations showed an essential decrease of stored lattices erasure during readout in external magnetic field. Nearly exponential decrease of diffraction efficiencies η depending on erasure time for B=0 is modified when erasure was measured in the external magnetic field of 0.85 Tesla and shows slower decrease. Erasure constant for magnetic field assisted readout of stored hologram by 17mW beam shows 2.4 times increase from 1180 to 2870 sec at ηmaxe-1 level for B=0 and B=0.85 T, respectively, due to magneto-photorefractive effect. The elaboration of physical model describing the obtained results is under way.

References

[1] J. Durnin, J.J. Mikely Jr, J.H. Eberly, Phys.Rev.Lett. 58, 1499, (1987).
[2] F. Diebel, M. Boguslawski, T. Dadalyan, R. Drampyan, C. Denz, Opt. Express, 24, 2933- 12940, (2016).
[3] A. Badalyan, R. Hovsepyan, V. Mekhitaryan, P. Mantashyan, R. Drampyan, Eur. Phys. J. D, 68, 82- 1-8 (2014).
[4] P. Mantashyan, R. Drampyan, J. Beeckman et al. Opt. Comm.. 338, 467-472 (2015).

Dielectric mismatch and polaron effects on optical-absorption spectra and refractive index changes associated with impurities in quantum dots

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The optical properties of a quantum dot (QD) can significantly depend on the presence of impurities in QDs. The electronic states in nanostructures can be significantly changed because of image charges which arise due to the mismatch of

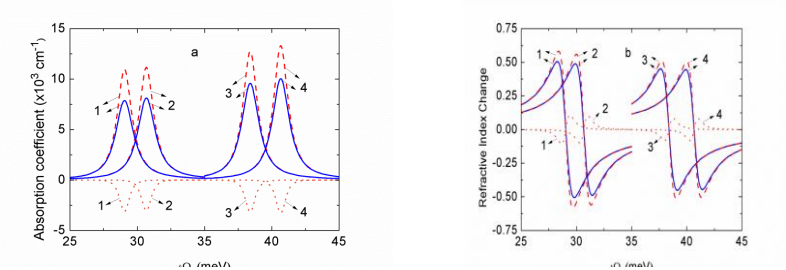

Fig.1. The linear (dashed lines), nonlinear (dotted lines), and total (solid lines) a) ACs b) RICs for transition $1s \rightarrow 2p_x$ *as functions of photon energy in a GaAs QD: 1) without MDC and without EPI, 2) without MDC and with EPI, 3) with MDC and without EPI, 4) with MDC and with EPI.*

the dielectric constant (MDC) at the surface. Also, since QD's are usually manufactured from polar materials, the electron-LO phonon interaction (EPI) must be taken into account for reliable description of the optical properties. We have investigated the joint effect of MDC and EPI on the oscillator strengths as well as the absorption coefficients (ACs) and the refractive index changes (RICs) for transition $1s \rightarrow 2p_x$. We consider a polar spherical parabolic QD, embedded into nonpolar medium in a uniform electric field. Fig.1 shows the ACs and the RICs as functions of photon energy at electric field $F = 5$kV/cm and at the value of parabolic confinement energy $\hbar\omega_0 = 20meV$. The obtained results show that the absorption peak positions and the curves of RICs shift to the higher photon energies when the EPI and MDC are taken into account either separately or jointly. The blue sifts of optical characteristics due to MDC are more significant than ones due to EPI. Also, the MDC leads to the increase (decrease) of peak values of ACs (RICs).

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