21-24 September, 2021
Ashtarak, Armenia

International Conference

Laser Physics 2021

&

4th MaNaCa Training Workshop

Magnetic Nanohybrids for Cancer Therapy

Book of Abstracts

Ministry of Education, Science, Culture and Sports RA
Science Committee

OSA STUDENT CHAPTER
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Welcome words

Owing to this uncertainty related to the ongoing COVID-19 pandemic situation, the Laser Physics (LP) conference format has changed from a face-to-face meeting to a hybrid format including in person and virtual participation. As usual, LP 2021 program cover all aspects of laser physics with focus on new and exciting developments and results in physics of coherent light sources, nonlinear and quantum optics, matter waves, laser spectroscopy of atoms and condensed matter, laser instrumentation, crystal growth and thin film preparation of inorganic materials for quantum electronics and integral optics, photonics, optical properties of nanostructures and luminescent materials, as well as related fields. The 1st day of the LP 2021 will be the joint "MaNaCa meets to Laser Physics" session with the 4th H2020 MaNaCa Training Workshop on Magnetic Nanohybrids for BioMedical Applications.

TOPICS

- Lasers, Laser Optics, Materials and Applications
- Nonlinear Optics and Novel Phenomena
- Laser Spectroscopy and Mathematical Modelling
- Atomic Physics
- Optical Magnetometry
- Quantum Optics and Matter Waves
- Quantum Information
- Photonics and Optical Properties of Structured Media
- Scintillating Materials, hybrid materials and its applications

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OSA STUDENT CHAPTER
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MaNaCa

joint “MaNaCa meets to Laser Physics” session

with the 4th H2020 MaNaCa Training Workshop on

Magnetic Nanohybrids for BioMedical Applications

Synthesis, Structure and Magnetic Properties of Carbon Encapsulated Fe/Fe_3C Nanoparticles as Magnetic Heating Mediators

H. Gyulasaryan[1], E. Papadopoulou[2], N. Tetos[2], G. Chilingaryan[1], N. Sisakyan[1], E. Myrovali[3], A. Makridis[3], M. Angelakeris[3], M. Farle[2], M. Spasova[2], A. Manukyan[1]

[1] *Institute for Physical Research of National Academy of Sciences, Armenia*

[2] *Faculty of Physics and Center of Nanointegration (CENIDE), University of Duisburg-Essen, Germany*

[3] *Physics Department, Aristotle University of Thessaloniki, Greece*

Email: sisakyan@gmail.com

Carbon coated iron-cementite (Fe-Fe_3C) nanoparticles were synthesized by a solid-phase pyrolysis of iron phthalocyanine ($FeC_{32}H_{16}N_8$). The morphology and size investigations of the fabricated nanocomposites has been studied using high resolution transmission and scanning transmission electron microscopes (HRTEM, STEM). The average diameter of Fe/Fe_3C nanoparticles embedded in carbon matrix is around 10 nm. The structure, composition and magnetic properties of the sample were analyzed by XRD, XPS, Mössbauer spectroscopies and magnetometry. The magnetization values of Fe-Fe_3C nanoparticles are correlated with bulk Fe and Fe_3C contributions. Magnetic hysteresis loops of the sample at 10 K and 300 K temperatures exhibit a demagnetization jump at low applied fields, which could be attributed to a core-shell architecture of Fe-Fe_3C nanoparticles. Magnetic particle hyperthermia efficiency was investigated in aqueous solutions under tunable AC magnetic fields (f: 375, 765 kHz, 30-60 mT). In excellent agreement with magnetic features, the SLP (Specific Loss Power) index which quantifies heating efficiency in W/g strongly depends on the Fe content in Fe-Fe_3C nanoparticles. Optimization of synthesis conditions will support a significant ΔT increase (10-35 K) together with enhanced SLP values (50-200 W/g) rendering such nanoparticles potential magnetic hyperthermia mediators.

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Determination of weak and strong magnetic fields using atomic spectroscopy

A. Papoyan and D. Sarkisyan

Institute for Physical Research, National Academy of Sciences of Armenia, Ashtarak, 0203 Armenia

e-mail: sarkdav@gmail.com

The measurement of magnitude of a weak magnetic field (B-field) in three orthogonal directions is developed based on of a B-field scanning to compensate the measured field to zero value, which is monitored by a resonant magneto-optical process in an unshielded atomic vapor cell. Implementation of the technique via the maximum detection of the resonant fluorescence detection on the D2 line of rubidium and cesium atomic vapor are demonstrated [1,2].

It is experimentally demonstrated that using the Selective Reflection (SR) spectrum of laser radiation from a spectroscopic nanocell filled with rubidium atomic vapor (vapor column thickness is of L=300 nm), it is possible to determine the value of the strong magnetic induction B applied to the nanocell with a high spatial resolution. The range of B- values is in the interval of 0.1 kG - 10 kG , and there is no need for a reference spectrum in a zero field [3,4].

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Development of nanoparticles for the combined localized therapy of cancer adjacent to proton therapy, and evaluation of their acute toxicity to mammals

A. Chirakadze[1], N. N. Dvali[2], G. Petriashvili[1], M. Ambokadze[1]

[1]Georgian Technical University, 77 Kostava Str., Tbilisi, 0160, Georgia
[2]National High Technology Center of Georgia, 21 Petre Kavtaradze Str., Tbilisi, Georgia
email achirakadze@gtu.ge

Proton therapy is the most advanced form of cancer therapy that is widely used in more than 110 medical centers around the world. In addition to biomedical applications, the impact of high energy charged particles on the living organisms has a growing importance in astrobiology, as about 90% of galactic radiation is represented by protons. (ii) The localized combined therapy using radiotherapy, mild hyperthermia, chemotherapy and photodynamic therapy is one of the most prospective tools to increase the biological effectiveness and safety of cancer therapy (e. g. [1,2]), while the most advanced kind of the currently applied hyperthermia is the Curie temperature controlled localized hyperthermia (CTCLH) (e. g.[1]). A principally new approach is to use the boron-neutron and boron-proton capture nuclear reaction products (e. g. [3, 4]). (iii) Novel microwave enhanced methods of synthesis and testing of magnetic nanoparticles (Cu-Ni, $Ag_xLa_{1-x}MnO_3$), isotopic enriched ^{10}B, ^{11}B nanoparticles and boron nitride nanoparticles for the CTCLH and the localized boron-neutron and boron-proton capture therapy were developed and tested. Several new solutions of the above problem have been proposed and considered, and acute toxicity of the synthesized materials to mammals was evaluated in the frame of the reported research. Preliminary testing of the effect of developed materials on the DNM of radiomimetic (bleomycin) treated cell cultures was performed.

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New therapeutic approaches of combinations of plant-derived and chemotherapeutic compounds in anti-cancer therapy

Nikolay Avtandilyan[1,2*], Hayarpi Javrushyan[1], Anna Grigoryan[3], Hasmik Karapetyan[2], Goharik Sevoyan[4], Andranik Keryan[4], Mikayel Ginovyan[1], Zaruhi Karabekian[4]

[1]*Research Institute of Biology, Yerevan State University, Yerevan, Armenia*

[2]*Department of Biochemistry, Microbiology and Biotechnology, Yerevan State University, Armenia.*

[3]*Department of Human and Animal Physiology, Yerevan State University, Yerevan, Armenia.*

[4]*L.A. Orbeli Institute of Physiology NAS RA, Yerevan, Armenia*

Email nv.avtandilyan@ysu.am

Armenia has one of the highest rates of death caused by cancer. Despite the current advances and achievements in systems biology and translational research, the current strategies for cancer therapy, such as radiotherapy, targeted therapy, immunotherapy, and chemotherapy remain unsatisfactory. It was the result of tumor metastasis or recurrence after surgery/therapy, drug resistance, and adverse side effects. The search for new therapeutic approaches is very important. More profound knowledge of herbal medicine may uncover new leads for anti-cancer drugs. Modulation of biochemical and immune functions using medicinal plants and their products in combination with chemotherapeutic agents has recently become an accepted therapeutic approach. Thanks to unique geography, Armenian plants traditionally have high biological, including anti-cancer activity.

We hypothesized that phytoextracts in anti-cancer treatment, either single or in combination with chemotherapy compounds, may effectively modulate the immune system, can lead to inhibition of tumor proliferation and growth, cause tumor apoptosis and increase the production of antioxidant proteins.

Upon completion of our recent studies, we have detected the induction of immunostimulatory effect by up-regulation of IL-2, induce of tumor apoptosis (caspase-3↑) and antioxidant properties (SOD↑, MDA↓), inhibition of cancer cell proliferation after treatment by several Armenian herbal extracts separately and in combination with anti-cancer chemoprevention agents in cancerous cell lines *in vitro* and *in vivo* rat mammary cancer model. Our results showed that the effect of some tested herbal extracts either single or in combination with chemotherapy compounds can affect the regulation of cancer cell metabolism, which have been reflected in changes in tumor size, weight, numbers, histopathological alterations, and mortality rate during *in vivo* rat mammary cancer model. It is noteworthy that the combination of some tested herbal extracts and chemotherapeutic agents has a synergistic effect.

Application and combination of experimental models with anticancer effect will provide new practical material for clinical oncology, phytotherapy, advanced anticancer, harmless and targeted treatment model. As a result, we expect to carefully select a promising combination of plant and drug that will exhibit a significant anti-cancer activity, which may potentially have a practical use in cancer treatment.

Comparative analysis of chemical and biogenic Fe_3O_4 NPs biocompatibility and toxicity

L. Farsyan, Sh. Kazaryan, A. Hovhannisyan

Russian-Armenian University, Laboratory of Analytical Biochemistry and Biotechnology

Email ashkhen.hovhannisyan@rau.am

The development of nanotechnology has opened up a wide range of prospective for the synthesis of structures with qualitatively new properties. The use of these nanostructures promisingly expands the capabilities of material production in different fields; however, their most promising applications are in the field of biomedicine: diagnostics, MRI imaging, therapy, drug delivery, etc [1]. But Fe_3O_4 NPs used in biomedicine must meet the criteria of biocompatibility and have minimal toxicity to the human body. It is proven, that the manifestation of toxic properties of any NPs, including Fe_3O_4 NPs, depends on their size, shape, stabilizing agents, dose, and duration of exposure [2].

In this regard, the main goal of this research was the synthesis of Fe_3O_4 NPs by chemical and biological methods, as well as the comparative analysis of their biocompatibility and toxicity.

Fe_3O_4 NPs were synthesized by chemical and biogenic methods [3,4]. The size and shape of NPs were investigated using TEM (LEO 912 AB omega, Carl Zeiss, Germany) and SEM (Carl Ziess EVO10) analysis. The cyto-toxicity of NPs was tested on human erythrocytes, wild-type E. coli strain DSM 1116 and the non-pathogenic S. aureus MDC5233 [3, 4, 5].

During the process of iron NPs chemical synthesis, a black precipitate was formed. The average size of the Fe_3O_4 NPs synthesized with chemical method was found to be 10.64 ± 4.73 nm, they have a rounded shape with a diameter from 4 to 24 nm and a single-crystalline structure. The average size of the Fe_3O_4 NPs core structure synthesized with biogenic method was found to be 15-20 nm, they have single-crystalline structure, and organic shell. All NPs, regardless from synthesis method showed paramagnetic properties.

Extract stabilized biogenic and chemical Fe_3O_4 NPs in the concentrations of 150 μM didn't show cytotoxic effect on E. coli DSM 1116 strain. It was also revealed that all Fe_3O_4 NPs, regardless of the synthesis method at a maximum concentration of 150 μM, didn't show antibacterial effects against S. aureus MDC5233, while positive control (O. basilicum 50 % ethanolic extract) showed cytotoxic properties.

The toxicity of extracts and obtained biogenic and chemical NPs was also studied on erythrocytes, as a result of which it was determined that the NPs of iron oxides, as well as the studied extracts, did not have hemolytic properties. After 24 hours in dark incubation conditions, the extracts of O.basilicum showed no hemolytic activity. In the conditions of dark incubation biogenic iron oxide NPs on the basis of O.basilicum aqueous extracts, after 24 hours of incubation didn't lead to hemolysis and erythrocyte resistance was 100%.

From the given experimental results, it can be concluded that consequently, O. basilicum extracts as well as iron oxides NPs based on them and chemical NPs don't practically cause hemolysis of erythrocyte, and hence can be used for further in vivo studies.

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Possible Role of Water in Carcinogenesis and Influence of Non-Ionizing and Non-Thermal Electromagnetic Radiation (Millimeter Waves)

V.Kalantaryan[1], R. Martirosyan[1], Y. Babayan[2], V. Petrosyan[3]

[1] *Yerevan State University, dept. Radiophysics and Electronics, Yerevan, Armenia*
[2] *Yerevan State Medical University, dept. Medical Physics, Yerevan, Armenia*
[3] *Saratov State Medical University, Saratov, Russia*
Corresponding author: vkalantaryan@ysu.am

Proven, that the non-thermal millimeter and centimeter waves of selective frequencies have a specific therapeutic effect and are therefore widely used in medicine and, in particular, in oncology. In [1] it was shown that irradiation of Sarcoma-37 tumor cells with low-intensity non-ionizing and non-thermal millimeter waves at a frequency of 42 GHz suppresses cell growth by 33% and lowers the level of methylation to almost normal. In [2], on the basis of experimental and theoretical studies, it is concluded that irradiation of tumor tissue at the resonant frequencies of natural vibrations of the molecular structures of water (triads and hexagons) can significantly increase the degree of binding of anticancer drugs to tumor DNA. This will make it possible for traditional treatment to significantly reduce the dose of drugs and the cost of the overall course of therapy. In addition, some patients develop intolerance due to side toxic effects and the course of treatment is forced to be interrupted. With a reduction in the dose of drugs, the course of therapy can be successfully completed. This paper discusses the hypothesis about the possible transformation of healthy cells into cancer cells as a result of modification in them of the normal hexagonal molecular structure of water to abnormal cubic structure due to various external and internal damaging factors (radiation, chemical, viral, mechanical, microbiological). Obviously, with a local change from a hexagonal water matrix to a cubic one, a "program failure" occurs, and as a result, the cells begin to reproduce "abnormal" water, which leads to a change in the biochemical mechanisms of their vital activity. This possibility is indicated by experimental results, namely, the complete coincidence of the radio spectra from the cubic phase of water and from tissues affected by cancer.

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Photoelectron and X-ray spectroscopy at the Kurchatov synchrotron radiation source

R.G. Chumakov, A.M. Lebedev, V.G. Stankevich

National Research Centre "Kurchatov institute", Moscow, Russia

Email ratibor.chumakov@gmail.com

Photoelectron and soft X-ray spectroscopy have established themselves as a simple and reliable way to study the physicochemical properties of surfaces for solving problems of materials science, solid state physics and surface science, nanosystems, organic, inorganic and catalytic chemistry, hybrid and layered systems, spintronics and nature-like technologies. X-ray photoelectron spectroscopy is extremely sensitive to the chemical and valence composition of thin surface layers up to 5 nm thick, which makes it indispensable for the analysis of new functional nanosystems, surfaces and microelectronic elements. X-ray absorption spectroscopy (XAS, NEXAFS) investigates not only the chemical composition of samples and the valence state of elements, but also due to the polarization properties of light also the orientation of chemical bonds in the sample, the filled electronic states and the local environment of atoms, which gives unique information as about ordered objects, such as self-organized monolayers (SAM), and weakly ordered objects, such as solid solutions, melts and bimetallic nanoparticles.

An experimental synchrotron station NanoPES [1] [2], specializing in spectroscopic studies of samples, operates at the Kurchatov complex for synchrotron-neutron research. The station operates in the photon energy range from 25 to 1500 eV and is designed to solve fundamental problems in the field of solid state physics, surface science and nanosystems, as well as to develop technological processes in micro- and nanoelectronics. The station implements methods of photoelectron spectroscopy (PES, UPS), including those with angular resolution (ARPES), X-ray absorption spectroscopy (NEXAFS) and scanning probe microscopy. The station is equipped with a wide range of additional equipment for sample preparation, cleaning and modification of the sample surface.

The report presents the optical schemes of the stations, technical characteristics, experimental capabilities, as well as examples of the most interesting experimental results.

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Photoactive Complexes for Photodynamic Therapy of Tumors

L.V. Mkrtchyan, A.A. Zakoyan, A.G. Gyulkhandanyan, T. Ye. Seferyan,

G.V. Gyulkhandanyan

Institute of Biochemistry of the NAS of Armenia, 5/1 P. Sevak str., Yerevan, 0014, Armenia

gvg536898@gmail.com

In photodynamic therapy (PDT) of tumors photosensitizers (PS) (mainly cationic porphyrins) are used as anticancer drugs, which selectively accumulate in tumors [1]. Under the influence of light, they cause the formation of singlet oxygen and free cytotoxic radicals, leading to cell death [2]. Folic acid in large quantities binds to the receptors of cancer cells: the expression of folic acid receptor is 100–300 times higher than on healthy cells and there are in the order of 1–10 million receptor copies per cell [3]. To destroy cancer cells, we propose a technology for obtaining folic acid complexes with cationic porphyrins. The aim of this study was to develop a new technology for the purification and production of stable complexes of folic acid and porphyrins using bovine serum albumin (BSA) as a stabilizing component. To achieve this goal, we used complexes [folic acid+BSA+porphyrin]. Unbound components (porphyrin and folic acid) in the complex were purified on a Sephadex G-10 column equilibrated with phosphate buffer (0.1 M, pH 7.4). In the complex, folic acid and porphyrin stabilizes the albumin: the increase in the intensity of its fluorescence in 24 hours was only 4%. According to fluorescent data, porphyrin also retains its stability, decreasing in intensity by only 1.4%. Folic acid in the complex is less stable, there is an increase in its peak by 14.8%, which indicates the dynamic binding of folic acid in the complex. Thus, we have obtained stable complexes of folic acid with cationic porphyrins (using serum albumin), which may have good prospects for PDT of tumors.

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International Conference

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Talks from 22-24 September, 2021

Signature of Optical Rabi Oscillations in Transmission Signal of Atomic Vapor under Continuous-Wave Laser Excitation

A. Papoyan, S. Shmavonyan

[1] *Institute for Physical Research, NAS of Armenia, Ashtarak-2, 0203, Armenia*

aram.papoyan@gmail.com

We have studied the temporal behavior of the atomic absorption signal under resonant excitation with a continuous-wave laser radiation. Measurements done for D_2 line of ^{85}Rb with ≈ 1 ns temporal resolution have shown irregular oscillatory behavior of the transmission signal, which becomes well pronounced for high laser power, and disappears when the laser is tuned off-resonance. Application of the fast Fourier transform analysis of the transmission signal reveals power-dependent frequency peaks, which are shown to be associated with Rabi frequency. Possible linkage of the observed results with the phase-to-amplitude noise conversion caused by the phase fluctuations of laser field is discussed [1].

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Features of the non-stationary response of the medium of two-level atoms

G.G. Grigoryan

Institute for Physical Research, 0203, Ashtarak-2, Armenia

gaygrig@gmail.com

The self-consistent problem of laser radiation propagation in a medium of two-level atoms has been well studied in the stationary limit (when the interaction time is so long that the atoms forget about the initial conditions) and in the limit of ultrashort pulses (when the interaction time is so short that all possible relaxation processes can be neglected).

However, when the interaction time is comparable to the characteristic relaxation times in the medium, a number of problems arise that will be analysed in detail in this report.

The problem of amplification of spontaneous emission in a medium is also discussed in detail, as well as the spectral and temporal characteristics of the nonstationary response of the medium after the sufficiently intense pumping is turned off.

Quantum tunneling of $V(x)=V_0/|x|^{\alpha}$ singular potential

A. Zh. Muradyan

Laboratory for research and modelling of quantum phenomena, Yerevan State University, 0025, 1 Alex Manoogian, Yerevan, Republic of Armenia

E-mail: muradyan@ysu.am

Singularity of the potential energy function makes quantum tunneling problem, the case $V(x)=V_0/|x|^{\alpha}$ of which is the subject of this report, mathematically not uniquely defined. To circumvent the difficulties that this introduces into physics, a potential singularity cutoff is often used, followed by a reverse limit transition, or is a suitable self-adjoint extension of the Hamiltonian along the entire coordinate axis made. However, both of them somehow affect the singular nature of the problem, and so I discuss here how quantum tunneling will behave if the original singular essencee of the Schrodinger equation left untouched. To do this, I use the probability density current, since in it the singularities are mutually destroyed. It is found that the mildly singular potential with $0<\alpha<1$ has a finite, but unusual tunnelling transparency, in particular, a non-zero value at zero energy of the incident particle. The tunneling of 1D Coulomb potential ($\alpha=1$) exhibits infinitely fast and complete oscillation at the zero energy boundary and a suppression to zero in the high-energy limit.

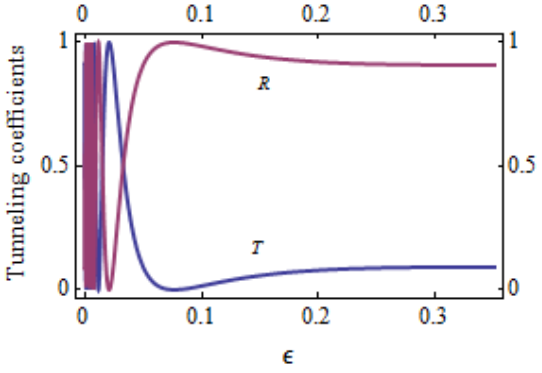

FIGURE. Quantum tunneling coefficients T and R for the 1D Coulomb potential as a function of the energy of the incident particle (the same for both repulsive and attractive cases).

In the more singular region with $\alpha>1$, the tunneling becomes forbidden, thereby repeating the well-known result of the regularized counterparts.

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Radiation of surface polaritons in cylindrical waveguides

A. A. Saharian, L.Sh. Grigoryan, H.F. Khachatryan, A.S. Kotanjyan, V.Kh. Kotanjyan

Institute of Applied Problems of Physics NAS RA, 25 Nersessian Street, 0014 Yerevan, Armenia

Email saharian@ysu.am

The presence of medium can essentially change the characteristics of the high energy electromagnetic processes and gives rise to new types of phenomena. Well-known examples are Cherenkov, transition, and diffraction radiations. In a series of papers (see references given in [1]) we have considered the synchrotron radiation from a charge rotating around a dielectric cylinder enclosed by a homogeneous medium. It has been shown that the superposition between the synchrotron and Cherenkov radiations leads to interesting effects: under the Cherenkov condition for the material of the ball/cylinder and the particle velocity, strong narrow peaks appear in the radiation intensity. At these peaks the radiated energy exceeds the corresponding quantity in the case of a homogeneous medium by several orders of magnitude.

Here we present the results of investigations for radiation of surface polaritons by charged particles in the geometry of cylindrical dielectric waveguide immersed in a homogeneous medium. The corresponding radiation is present in the spectral range where the dielectric permittivities of the cylinder and surrounding medium have opposite signs. Two cases of the charge motion are considered [2,3]: (i) charge rotating around a waveguide and (ii) charged particle moving outside a dielectric cylinder parallel to its axis. For the evaluation of the corresponding electromagnetic fields the electromagnetic Green tensor is used. Formulae are derived for the spectral distribution of the radiation intensity on the surface-type modes. It is shown that the corresponding waves are radiated on the eigenmodes of the dielectric cylinder. We demonstrate that the number of radiated quanta for surface polaritons of a given harmonic can be essentially larger than that for guiding modes of the cylinder. The Cherenkov and synchrotron radiations in the exterior medium are discussed as well.

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Nanostructured zinc oxide photoluminescence under laser pulse excitation

M.D. Komissarov, N.B. Leonov, T.A. Vartanyan

ITMO University, Kronverksky pr. 49, 197101 St. Petersburg, Russia

tavartanyan@itmo.ru

Zink oxide is a semiconductor material with a direct wide band gap of about 3.3 eV [1]. An attractive feature of this material is large exciton binding energy of 60 meV making it possible to observe excitonic effects at room temperature. Among a manifold of ways of zinc oxide production [2], we choose laser pulse deposition of pure Zn under high vacuum conditions followed by thermal oxidation in air. This procedure leads to the formation of thin granular film of zinc oxide on the quartz substrate.

Photoluminescence of zinc oxide under ultraviolet excitation consists of two bands. The most intense and well understood band is due to the exciton recombination. The central wavelength of this band varies between 370 nm and 390 nm depending on the film thickness and excitation wavelength. Another band span from 450 nm to 550 nm. Although this band is weaker it is of great importance for sensor applications. Being connected with the oxygen vacancies the photoluminescence intensity in this band depends on the composition of the ambient atmosphere. We studied be behavior of this 'green' band under intense laser pulse excitation at 355 nm and found that it saturates at the fluence of 0.3 MW cm^{-2}, while the exciton recombination band continues to grow linearly with the excitation intensity for at least another order of magnitude.

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A measurement of the vacuum magnetic birefringence: the project VMB@CERN

G. Zavattini[1], G. Messineo[1], M. Andreotti[1], G. Crapulli[1], L. Formaggio[1], A. Soflau[1], G. Ruoso[2], A.Ejilli[3], S. Kunc[4], C. Marinelli[5], E. Mariotti[5], F. Della Valle[5]

[1]*INFN, Sez. di Ferrara and Dip. di Fisica e Scienze della Terra, Universit`a di Ferrara, via G. Saragat 1, Edificio C, 44122 Ferrara, Italy*

[2]*INFN, Laboratori Nazionali di Legnaro, viale dell' Università 2, 35020 Legnaro (PD), Italy*

[3]*School of Physics and Astronomy, Cardiff University, Queen's Building, The Parade, Cardiff CF24 3AA, United Kingdom*

[4]*Technical University of Liberec, Studentsk´a 1402/2, 46117 Liberec, Czech Republic*

[5]*Dip. di Scienze Fisiche, della Terra e dell'Ambiente, Università di Siena, via Roma 56, 53100 Siena, Italy and INFN, Sez. di Pisa, largo B. Pontecorvo 3, 56127 Pisa, Italy*

emilio.mariotti@unisi.it

The collaboration has prepared an experimental feasibility study of a polarimetric method for measuring the Vacuum Magnetic Birefringence [1,2]. We have characterised the systematic, discussed its origin and proposed a strategy to overcome the noise sources. The project will be completed at CERN, where a superconducting magnet can generate the intensity field that approaches the final goal of a real attempt of this tiny QED effect [3].

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Towards a Miniature Optical Frequency Standard: Current Status and New Approaches in Sub-Doppler Spectroscopy of Cs Vapors

I.S. Mesenzova[1], S.M. Ignatovich[1], A.M. Mikhailov[1,2], R. Boudot[3], D.V. Brazhnikov[1,2]

[1] *Institute of Laser Physics SB RAS, 15B Lavrentyev Avenue, Novosibirsk 630090, Russia*

[2] *Novosibirsk State University, 1 Pirogov Street, Novosibirsk 630090, Russia*
[3] *FEMTO-ST, CNRS, UBFC, 26 rue de l'épitaphe, Besançon 25030, France*

Email brazhnikov@laser.nsc.ru

Miniature quantum frequency standards (QFSs) are nowadays highly demanded for developing various modern technologies, such as satellite navigation and optical communication systems, radar electronics, monitoring the Earth's ionosphere, etc. Miniature QFSs have been successfully developed since the early 2000s. The advanced up-to-date samples of such QFSs have a volume of less than 100 cm^3 and demonstrate fractional frequency stability (Allan deviation) of the order of 10^{-11} at 1 s. However, until quite recently, these standards have operated only in a microwave frequency domain.

In the past four years, miniature QFSs got their second wind after a series of publications. In particular, a two-photon spectroscopy of rubidium vapors was proposed and successfully implemented in a microcell-based miniature optical frequency standard (OFS) [1,2]. Here we examine an alternative approach based on a dual-frequency sub-Doppler spectroscopy of cesium atoms [3]. Indeed, a high optical frequency stability ($\sigma_y \approx 2 \cdot 10^{-12}$ at 1 s) has been demonstrated in the earliest experiments with a vapor microcell [4]. Therefore, we believe this approach has good prospects for creation of a miniature OFS.

During the conference, we will present the current status of our investigations, including experiments with different Cs vapor cells, different light-field configurations and resonance registration techniques. For instance, we propose to apply a direct GHz-frequency modulation to diode laser current to obtain the required multi-frequency regime of excitation for observing the sub-Doppler resonance. To increase a signal-to-noise ratio, we have also studied a possibility of using a differential (polarimetric) detection technique.

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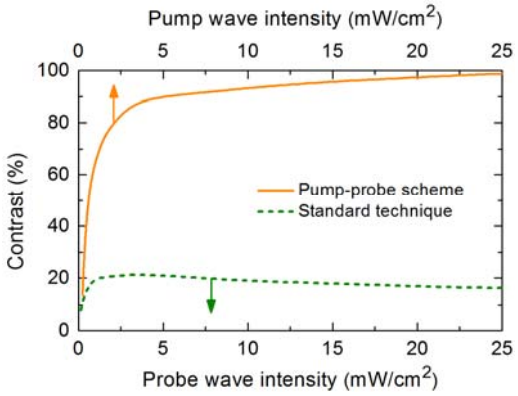
High-Quality Level-Crossing Resonances in a Cesium Vapor Cell for Applications in Atomic Magnetometry and Magneto-Optical Switching

D.V. Brazhnikov[1,2], V.I. Vishnyakov[1], A.N. Goncharov[1,2,3]

[1] *Institute of Laser Physics SB RAS, 15B Lavrentyev Avenue, Novosibirsk 630090, Russia*
[2] *Novosibirsk State University, 1 Pirogov Street, Novosibirsk 630090, Russia*
[3] *Novosibirsk State Technical University, 20 Karl Marks Avenue, Novosibirsk 630073, Russia*
split7fire@yandex.ru

One of the simplest and simultaneously most robust techniques in quantum magnetometry is based on zero-field level-crossing resonances (LCRs) in alkali-metal vapors (see review [1]). A standard scheme involves a single circularly polarized wave, while a transverse magnetic field is scanned to observe the LCR in the vapor cell transmission. This scheme has already been implemented in various miniature magnetic-field sensors for performing various biomedical measurements (e.g., see [2]).

The standard scheme can be significantly improved just by adding the second (pump) light wave [3]. Here we examine a scheme where the second light wave is added, having the opposite circular polarization with respect to the first wave. We show that such a pump-probe configuration can lead to significant improvement in LCR parameters (see figure below). A small cubic glass cell is used, having spectroscopy volume of about 0.12 cm^3. It is filled with cesium atoms and 130 Torr of neon as a buffer gas. We focus on a low temperature regime (T_{cell} < 60°C) that can be important for applications. During the conference, we will also discuss how the magnetic-field sensor can be miniaturized.



Contrast of level-crossing resonances in the standard single-beam scheme (dashed) and in the proposed pump-probe scheme (solid)

The proposed scheme has good prospects for atomic magnetometry and magneto-optical switching. We thank Russian Science Foundation (17-72-20089) for support.

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Spiking and Intensity-Correlated Polychromatic Emission from Alkali Vapors

A.M. Akulshin[1,2], N. Rahaman[1], F. Pedreros Bustos[2], R.J. McLean[1], and D. Budker[2]
[1] Optical Sciences Centre, Swinburne University of Technology, PO Box 218, Melbourne 3122, Australia
[2] Helmholtz-Institut, GSI Helmholtzzentrum für Schwerionenforschung, Johannes Gutenberg University, 55128 Mainz, Germany
Email aakoulchine@swin.edu.au

Polychromatic laser-like emission produced in alkali vapors has received a lot of attention due to promising applications ranging from quantum memory and medical imaging to remote magnetometry. To meet the requirements of such a variety of applications, a detailed study of the most important processes involved is needed. Here we report on an experimental investigation of the spectral, temporal and correlation characteristics of directional radiation generated in Rb and Na vapors.

Despite the cw excitation, the temporal profiles of the generated fields consist of chaotic, partially overlapping spikes. The spike appearance time, as well as their shape and amplitude, vary considerably from sample to sample; however, their duration is shorter than the natural lifetime of the corresponding energy levels [1, 2]. We associate this behavior with cooperative effects (CE) in population-inverted media [3], as the generated fields possess many of the characteristic properties of collective emission. CE leading to superfluorescence or superradiance have been thoroughly studied in various systems with pulsed excitation. Our experiments show that short-pulse excitation is not a necessary condition for observing cooperative radiation, revealing a new important aspect of CE.

Intensity profiles of the generated polychromatic radiation are remarkably similar. A high level of intensity correlation is demonstrated not only for the fields coupled by the FWM process, but also between the cascade-generated fields.

We also found that intensity noise of new fields is completely uncorrelated if they are obtained simultaneously using the same pump lasers in two spatially separated regions in the same cell. This observation demonstrates the stochasticity of the intensity spikes associated with the quantum-mechanical nature of the cooperative effects. It is interesting to note that if the applied pump beams are crossed at a small angle (˜50 mrad), the intensity correlation becomes significant. Correlation controlled by the geometry of the applied fields opens new possibilities for generating entangled fields from different spectral regions.

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Calculations of magic and zero-magic wavelengths for Ca and Hg atoms and applications in quantum optics

A. Gogyan[1,2], G. Kazakov[3], P. Tecmer[1], M. Bober[1], M. Zawada[1]

[1] *Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, 5 Grudziądzka, 87-100, Toruń, Poland*

[2]*Institute for Physical Research, National Academy of Sciences of Armenia, 0203-Ashtarak, Armenia*

[3]*Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria*

agogyan@gmail.com

A magic wavelength, at which two atomic states experience the same ac Stark shift in a laser field, was first proposed in Refs [1,2]. It is being actively used not only in high-precision optical atomic clocks, but also for trapping and controlling atoms in high-Q cavities, for the implementation of Rydberg-based quantum computing protocols with neutral atoms, for demonstration of light-atom entanglement in Rydberg atoms, etc. The wavelength, at which the AC Stark shift is zero for a particular state is called zero-magic wavelength. The spectroscopy of zero-magic wavelengths provides information on atomic transition matrix elements, especially those that cannot be determined otherwise, serving as a benchmark of the spectroscopic accuracy that is required for the development of high-precision theoretical models.

We have identified magic wavelengths for $^1S_0 \rightarrow {}^3P_1$ ($m_J = 0$) transition and the zero-magic wavelengths for the $^3P_1$, ($m_J = 0$) state in ^{40}Ca [3] and magic wavelengths for the $^1S_0 \rightarrow {}^3P_{1,2}$ ($m_J = 0$) transitions and zero-magic wavelengths for the $^3P_{1,2}$ ($m_J = 0$) states of ^{200}Hg atoms [4], as well as analysed the robustness of the magic conditions with respect to wavelength and polarization imperfections. We have predicted the experimentally most feasible magic wavelengths.

For ^{200}Hg atoms, relevant transition wavelengths and transition strengths are calculated using the state-of-the-art Complete Active Space Self-Consistent-Field (CASSCF) method with a perturbative inclusion of spin-orbit coupling. The transition wavelengths are *a posteriori* corrected for the dynamical energy using the second-order perturbation theory.

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Sr optical atomic clock in a blue-detuned lattice

A. Tonoyan[1,2], M. Witkowski[1], S. Bilicki[1], M. Bober[1], D. Kovačić[1,3], V. Singh[1], and M. Zawada[1]

[1] *Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Grudziądzka 5, PL-87-100 Toruń, Poland*

[2] *Institute for Physical Research, National Academy of Sciences of the Republic of Armenia, Ashtarak-2, 0203, Armenia*

[3] *Institute of Physics, Bijenička cesta 46, 10000 Zagreb, Croatia*

Email aratonoyan@gmail.com

We are building a setup for new generation active optical atomic clocks operating with ^{88}Sr atoms that are confined in blue-detuned lattice. At the first stage the setup allows superradiant pulse generation on the clock transition, and in the following step continuous or quasi-continuous operating is planned.

To examine the potential feasibility of the blue-detuned 390 nm magic wavelength strontium optical lattice trap, we have measured and estimated photoionisation-induced atomic losses in a three-dimensional optical lattice trap operating at minimal intensity required to prevent the power broadening and recoil shifts of the clock transition. Measured photoionization cross-sections of $^1P_1$ and $^3S_1$ states of ^{88}Sr atoms are 2.2×10^{-20} m^2 and 4.5×10^{-23} m^2, respectively. The loss rates of $^1P_1$ and $^3S_1$ states are 2.4×10^5 and 8.1×10^3 atoms/sec.

Formation of Surface Metal Microstructures by Bessel Beam Controlled Atomic Deposition

L. Tsarukyan[1], A. Badalyan[1], E. Gazazyan[1], O. Fedotova[2], C. Marinelli[3], E. Mariotti[3], N. Leonov[4], T. Vartanyan[4], R. Drampyan[1]

[1]*Institute for Physical Research, National Academy of Sciences of Armenia, Ashtarak-2, 0203, Armenia*
[2]*Scientific-Practical Materials Research Center, National Academy of Sciences of Belarus, Minsk, 220072 Belarus*
[3]*Department of Physical Sciences, Earth and Environment, University of Siena, via Roma 56, 53100 Siena, Italy*
[4]*Center of Information Optical Technologies, ITMO University, St.Petersburg, 197101, Russian Federation*

email rafael.drampyan@gmail.com

We report the experimental realization of a non-diffracting Bessel beam technique for micro-structuring of thin metallic films on the surface of dielectric materials. The technique of optical microstructuring of metal films is based on processes of metal atoms adsorption on the surface of dielectric substrate and simultaneous photo-stimulated desorption of atoms by *nonuniform* laser beam illumination.

Experiments were performed for Na and Rb atoms deposition on the surface of sapphire [1, 2], as well as Rb atomic deposition on the nano-porous glass sample [3]. The evacuated alkali metal cells were used in the experiments with possibility of heating and controlling the atomic density. The atomic depositions on the sapphire windows of the cell and on the porous glass plate inserted into the cell were studied.

The cw 532 nm wavelength laser beam with a few W/cm^2 intensity and femtosecond laser pulses at 1560 nm with intensity of 10^3 W/cm^2 and its second harmonic at 780 nm are used for laser control of atomic deposition. For the formation of nonuniform laser beam a non-diffracting Bessel beam with concentric ring structure is used. Strong enough *nonuniform* illumination leads to the formation of areas with low and high surface density of adsorbed atoms, thus reproducing the spatial distribution of the illumination intensity over the surface. The use of femtosecond laser pulses speeds up the microstructuring process.

The absorption spectra of thin metal films were studied, which revealed the presence of plasmonic resonances attributed to the presence of nanoparticles in the micro-sized metallic rings. Simulations are in good coincidence with the experimental results.

The advantages of the suggested technique with the use of non-diffracting beams are the high contrast of the obtained metal microstructures, possibility of simultaneous processing of thin metal films on many substrates inserted in the evacuated cell and reduced requirements to the laser source wavelength, spectral width and power.

The developed technique can be extended to the deposition of Zn, Ag, Au atoms in air environment and other types of non-diffracting beams. The suggested technique opens new ways

for the laser structuring of metal films with micro- and sub-micrometric scale resolution promising for numerous applications in all-optical and photonic devices.

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Magnetically induced transitions with highest probabilities of alkali metal atoms

A. Sargsyan[1], A. Tonoyan, A. Amiryan and D. Sarkisyan

Institute for Physical Research, National Academy of Sciences of Armenia, Ashtarak, 0203 Armenia

email sargsyanarmen85@gmail.com

Atomic transitions of alkali metals that have zero probability in the absence of a magnetic field but have large probabilities in the presence of a magnetic field are called magnetically induced (MI). They are of interest because of their large probabilities, which exceed the probabilities of usual transitions in a wide magnetic field range. Magnetically induced transitions are classified as type-1 (MI1) and type-2 (MI2) and their total number is about 100 [1]. MI2 transitions are examined between ground F_g and excited levels F_e of the hyperfine structure satisfying the rule $F_e - F_g = \Delta F = \pm 2$. The MI transitions are forbidden in zero magnetic field, but have large probabilities in the presence of a magnetic field. The probabilities of the MI2 transitions with $\Delta F = +2$ and the MI transitions with $\Delta F = -2$ are maximal in the case of optical radiation with the σ^+ and σ^- polarizations, respectively. This difference is called type-1 magnetically induced circular dichroism (MICD1). It has been shown that the probability of the strongest MI2 transition in the ^{85}Rb atom corresponding to the D_2 line in magnetic fields >100 G in the case of σ^+ radiation is larger than the probability of the strongest MI2 transition in the case of $\sigma-$ radiation by a factor of 2.5 [2]. It is shown that the same statement is also true for Cs atom (for the range of magnetic fields of 0.2-6 kGs) [3]. This difference is called type-2 magnetically induced circular dichroism (MICD2). Theoretical curves reproduce well experimental results. Possible applications of MI transitions are presented.

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Applications of Magnetically Induced Transitions in the Electromagnetically Induced Transparency phenomena

A. Sargsyan, A. Tonoyan, and D. Sarkisyan,
Institute for Physical Research, National Academy of Sciences of Armenia, Ashtarak, 0203 Armenia
e-mail: sarkdav@gmail.com

Magnetically induced (MI) transitions $F_g = 2 \rightarrow Fe = 4$ of the ^{85}Rb D_2 line and $F_g = 4 \rightarrow F_e = 2$ of the Cs atoms D2 line using the σ^+ and σ^- circularly polarized radiation and have been implemented for the first time to form optical EIT -resonances in strong magnetic fields up to a few kG under electromagnetically induced transparency (EIT) conditions. A 1.5-μm-thick cell filled with Rb and Cs atomic vapor has been used [1-3].

For the EIT–resonance successful formation the following new rule has been established for the first time: if one of the transitions of the Λ- system is formed by a magnetically induced atomic transition for which the condition F_e-F_g=ΔF = + 2 is satisfied, then both the probe and the coupling radiation must have σ+ polarization. Meanwhile, if one of the transitions of the Λ-system is formed by a magnetically induced atomic transition for which the condition F_e-F_g=ΔF = - 2 is satisfied, and then both the probe and the coupling radiation must have σ^- polarization.

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Large-Scale Optical Simulator for Spin Glasses

M. Rafayelyan[1], D. Pierangeli[2,3], C. Conti[2,3], and S. Gigan[4]

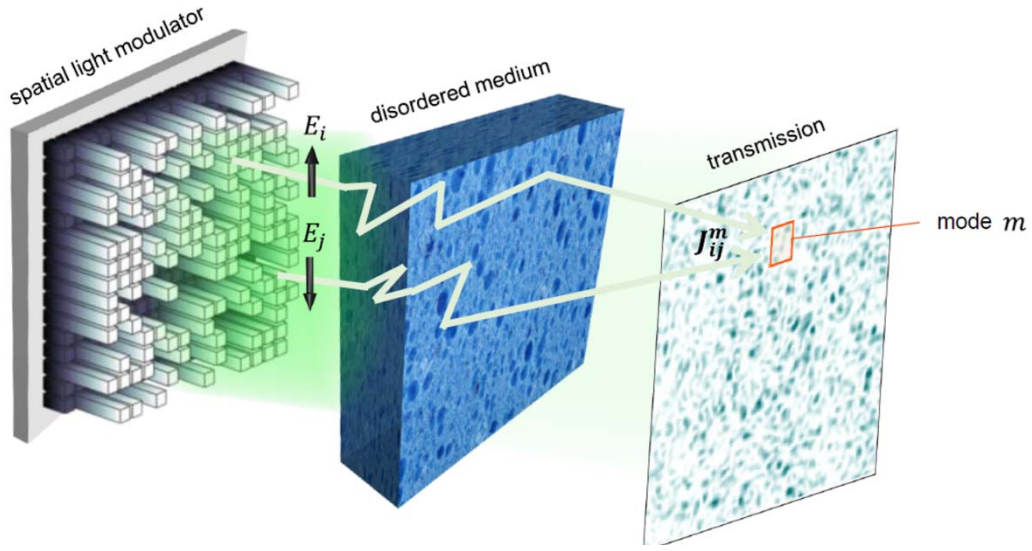
[1] *Department of Physics, Yerevan State University, 0025, 1 Alex Manoogian, Yerevan, Armenia*
[2] *Dipartimento di Fisica, Università di Roma "La Sapienza", 00185 Rome, Italy*
[3] *Institute for Complex System, National Research Council (ISC-CNR), 00185 Rome, Italy*
[4] *Laboratoire Kastler Brossel, Ecole Normale Superiéeure-Université PSL, CNRS, Sorbonne Université, College de France, 75005 Paris, France*

mushegh.rafayelyan@ysu.am

Many developments in science and engineering depend on tackling complex optimizations on large scales. The challenge motivates an intense search for specific computing hardware that takes advantage from quantum features, nonlinear dynamics, or photonics. A paradigmatic optimization problem is finding low-energy states of a spin-glass (SG) composed of N unitary Ising spins $\sigma \in \{+1, -1\}$ with fully random interaction $J_{i,j}$ between the i-th and j-th spins [1]. The quadratic SG Hamiltonian has the form

$$\mathrm{H}(\sigma) = -\frac{1}{2}\sum_{i,j=1}^{N} J_{i,j}\sigma_i\sigma_j.$$

To date, no alternative computing platform can address such spin-glass problems on a large scale. Here we propose and realize an optical scalable spin-glass simulator based on spatial light modulation and multiple light scattering [2]. By tailoring optical transmission through a disordered medium, we optically accelerate the computation of the ground state of large spin networks with all-to-all random couplings. Our setup may potentially speed-up a wide range of optimization algorithms.



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Superconductivity and Superconductor-Insulator Transition in Single Crystal Sb_2Te_3 Nanoplates

A.A. Kuzanyan[1], S.R. Harutyunyan[1,2]

[1] *Institute for Physical Research, Ashtarak-2, 0203, Republic of Armenia*
[2] *Russian-Armenian University, Hovsep Emin 123, Yerevan, 0051, Republic of Armenia*
Email sergeyhar56@gmail.com

Sb_2Te_3 is one of the well-known robust topological insulators (TIs). TIs are a new class of quantum matters. After the discovery of TIs, it was realized that there is strong correlation between superconductivity and topology nature.

Transport characteristics of ultrathin Sb_2Te_3 single crystal nanoflakes were studied as a function of nanoplate thickness. The angular dependences of the resistance R(Θ) on the magnetic field of 11 nm thick sample were measured at 1.8 K in various constant magnetic fields and demonstrate the absence of any response to a parallel magnetic field and thereby confirming the 2D nature of the nanoplate.

Here we show that the steep drop of the resistance which appear near 4 K as the nanoplate thickness decreases from 50 nm to 7 nm, manifesting a superconducting transition. The results show that the existence of certain optimum degree of disorder is a necessary condition for emergence of the superconductivity. The magnetic-field-induced superconductor-insulator transition characteristic of the disordered 2D superconductor is observed in these nanoplates. Temperature dependence of magnetoresistance shows a consecutive transformation of the weak antilocalization into the superconducting transition at low magnetic fields.

Artificial periodic structures in crystals

V.S. Arakelyan

Institute for Physical Research, NAS of Armenia

Email vladimirarakelyan05@gmail.com

Crystals with spatially modulated parameters have a large number of applications in nonlinear optics, opto- and microelectronics, hyper sound generation, etc. The static and dynamic properties of such regular structures are also of great interest. Numerous attempts to obtain such structures were based on a time-periodic effect on the growth process. The spatial modulation period A is determined in this case by the time interval between exposure pulses. However, the rate of crystallization fluctuates significantly during the growth process and it is difficult to achieve high regularity with such an effect. High regularity can be achieved due to a spatially distributed effect during crystal growth, namely, through the use of a standing ultrasonic wave. The results of research on the creation of periodic structures from the melt, solution [1-3], and solid phases [4] are presented in this report. An explanation of the influence of an ultrasonic standing wave on the formation of periodic structures from a melt and a solution is given. An explanation of the mechanism of formation of periodic structures in the solid phase is also given.

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Magnetoresistance properties of Ag-doped ZnO films

A. Kuzanyan, S. Harutyunyan, N. Aghamalyan, R. Hovsepyan, S. Petrosyan, A. Poghosyan, A. Sarkisyan, M. Nersisyan, Y. Kafadaryan*

[1]Institute for Physical Research, National Academy of Sciences, Ashtarak-2, 378410, Armenia
[2]Russian–Armenian University, Yerevan, 0051 Armenia

Silver (0.27 at.%)-doped zinc oxide (Ag:ZnO) films were deposited on sapphire substrates by *e*-beam evaporation technique at 290 °C and post-annealed at 350°C for 1 h under ambient air. The structural, magnetic, and transport properties of Ag-doped ZnO films are studied.

The structural analyses show that the films were in the [0002] preferred direction and that Ag atoms are bound to the oxygen atoms by replacing the Zn host atoms. From the UV–Vis absorption spectra, the annealed film involves a slight decrease in the optical band gap as compared to that of the as-deposited Ag:ZnO film. Infrared reflection spectra of the annealed Ag:ZnO films indicate hole polaron states placed in the range of 0.136–0.439 eV above the valence band maximum. According to the calculated electron–phonon coupling strength (1.04) and binding energy (– 76 meV), the polaron of large radius is defined. The polaron optical conductivity and carrier relaxation time are determined from the experimental spectra using Kramers–Kronig relations.

The electrical resistance and magnetoresistance (MR) of the samples was measured as a function of temperature at magnetic field of 0.1 and 0.25 T perpendicular to the current direction. The resistivity of the as-deposited sample exhibits a semiconducting behavior without any anomaly in the temperature range of 4-390 K, whereas the annealed sample demonstrates a semiconductor-insulator transition containing 3 sharp peaks at 160, 130.6 and 101 K under zero magnetic field. Under magnetic field the number of peaks (R_{max}) *decreases,* and the *peak at 101 K broadens* and increases in intensity. Positive MR ratio [(R(H)-R(0))·100%/R(0)] of 55 % has been defined at 0.25 T for annealed film at temperature close to those where they undergo a semiconductor-insulator transition. The MR ratio displays a maxima at a temperatures lower than those for R_{max}, and T_{max} is independent on the applied magnetic fields. In addition the minimum at T_{min}= 60 K under zero magnetic field shifts to 39.6 and 19.6 K with increase in magnetic field from 0.1 to 0.25 T. This phenomenon is similar to the Kondo effect observed in magnetic materials [1], though in AgZnO it comes from nonmagnetic ions and attributes to the exchange interaction between itinerant conduction electrons and localized spin impurities [2]. The annealed Ag:ZnO film shows many phenomenon including polarons, magnetoresistance, Kondo effect, which have potential applications in magnetic sensors, spintronic, biomedical field and magnetic refrigeration technology.

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Influence of dislocations on electron transport in Sn-doped α-Ga_2O_3 layers

L. B. Hovakimian

Institute of Radiophysics and Electronics of NAS RA, 0203 Ashtarak, Armenia

Email levon@irphe.am

Corundum structured α-Ga_2O_3 is an ultra-wide bandgap III-oxide semiconductor ($E_g \approx 5.3\,\mathrm{eV}$) with superior material properties for applications in high-power, high-frequency electronics and short-wavelength optoelectronics [1]. In experimental studies [2, 3] the mist chemical vapor deposition (mist-CVD) method was used as a cost-effective growth technology for successful fabrication of electrically conductive Sn-doped *n*-type α-Ga_2O_3 layers on c-plane sapphire substrates. Transmission electron microscopy observations have revealed that the crystal structure of epitaxially stabilized layers is infected by high edge dislocation densities with a typical value of $N_{dis} \cong 7\times10^{10}\,\mathrm{cm}^{-2}$. Despite the efforts to reduce the line defect density with the aid of annealed buffer layers, the measured maximum mobility of electrons was as low as $\mu_M \cong 24\ \mathrm{cm}^2\mathrm{V}^{-1}\mathrm{s}^{-1}$ at the carrier concentration of $n_M \cong 2\times10^{18}\,\mathrm{cm}^{-3}$ [3]. The aim of our exploratory theoretical investigation is to elucidate the specific effect of N_{dis} on the low-field electron transport characteristics of α-Ga_2O_3:Sn epilayers. An approach is presented that is capable of extracting from the experimental data sets [2, 3] the necessary information about the charged states of dislocation-related deep levels. The obtained information enables one to describe the salient features of the potential landscape controlling the current flow through the defect-rich host matrix. Further analysis leads to a physical picture where an electrically active dislocation forest manages to suppress the carrier mobility without affecting essentially the mean free path of transported electrons. Our main conclusions drawn from this picture are reflected in the following analytical relations, $(\partial\mu_M / \partial N_{dis}) < 0$, $(\partial n_M / \partial N_{dis}) > 0$, which are in precise agreement with the reported experimental evidence (Ref. 3, Fig. 8). In addition, a basic interrelation between the experimentally observed values of μ_M and n_M is unraveled and discussed. We also show how the results of this study may become useful for improving the conductivity control [3] of mist-CVD grown epilayers for actual device applications [1].

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“Dancing” optical bullet forming in a crystal with quadratic nonlinearity

Bryantsev B.S., Sazonov S.V., Kalinovich A.A., Zakharova I.G.

Lomonosov Moscow State University, Moscow 119992, Russia

email brisbryantsev@mail.ru

The possibility of forming “dancing” light bullets was analytically shown in waveguides with a gradient profile of the refractive index for two types of nonlinear media: Kerr and quadratic [1] Trajectories of such bullets can be represented in the form of spatial Lissajous figures with anisotropic spatial distribution of the refractive index. In the present work, using numerical simulation, we study the formation of “dancing” light bullets at second harmonic generation (SHG).

Equations describing SHG in a waveguide at phase and group matching are as follows [1]:

$$i\frac{\partial\psi_1}{\partial z} = -\omega f_1\psi_1 - \frac{\beta_1}{2}\frac{\partial^2\psi_1}{\partial\tau^2} + \alpha_1\psi_1^*\psi_2 + \frac{c}{2\omega n}\Delta_\perp\psi_1 \quad (1)$$

$$i\frac{\partial\psi_2}{\partial z} = -2\omega f_2\psi_2 - \frac{\beta_2}{2}\frac{\partial^2\psi_2}{\partial\tau^2} + \alpha_2\psi_1^2 + \frac{c}{4\omega n}\Delta_\perp\psi_2 \quad . \quad (2)$$

In (1)-(2) $\psi_{1,2}$ are the slowly varying envelopes of the first and second harmonics, $\tau = t - z/v_g$, $\beta_{1,2}$ are dispersion coefficients of harmonics, $\alpha_1 = \frac{2\pi\omega}{cn}\chi^{(2)}(2\omega, -\omega)$, $\alpha_2 = \frac{4\pi\omega}{cn}\chi^{(2)}(\omega, \omega)$, $\chi^{(2)}$ is second-order nonlinear susceptibility, $\Delta_\perp = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$, $f_{1,2} = \frac{n^2 - n_{1,2}^2(x,y)}{2cn}$ describe waveguide, $n_{1,2}(x,y)$ – refractive indices.

The expression for the initial radiation when simulating the propagation of “dancing” light bullets was chosen in accordance with the results of the article [1].

We demonstrate that in a quadratically nonlinear medium, two-color “dancing” bullets can form at both normal and anomalous dispersions at the first harmonic. We also analyze a certain relationship between the calculation parameters and specific Lissajous figures obtained in our computations.

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Exciton Related Raman Scattering, Interband Absorption and Photoluminescence in Colloidal Cdse/Cds Core/Shell Quantum Dots Ensemble

G.A. Mantashian[1], P.A. Mantashyan[1,2], H.A. Sarkisyan[1], E.M. Kazaryan[1], G. Bester[3], S. Baskoutas[3,4] and D.B. Hayrapetyan[1*]

[1]*Institute of Engineering and Physics, Russian-Armenian University, Yerevan 0051, Armenia;*

[2]*Institute for Physical Research of NAS RA, Ashtarak, 0203, Armenia*

[3]*Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, 20146 Hamburg, Germany*

[4]*Department of Materials Science, University of Patras, GR-26504 Patras, Greece*

Email: grigor.mantashyan@rau.am

In recent years, interest in quantum dots (QDs) has increased, because of their wide range of uses in various devices, from photovoltaic cells to QD batteries. Colloidal semiconductor QDs' low□cost manufacturing provides an opportunity for industrial use. Some applications of colloidal QDs include, but are not limited to, photodiodes and photovoltaics, photoconductors, electroluminescent devices, advanced batteries, etc. One of the powerful methods for the investigation of QDs is Raman spectroscopy, which has been used in a considerable range of research activity. The investigation of Raman and PL spectra for CdSe/CdS core/shell colloidal QDs is a problem of the current interest problem.

By using the numerical discretization method within the effective-mass approximation, we have theoretically investigated the exciton related Raman scattering, interband absorption and photoluminescence in colloidal CdSe/CdS core/shell quantum dots ensemble. The interband optical absorption and photoluminescence spectra have been revealed for CdSe/CdS quantum dots taking into account the size dispersion of the ensemble. Numerical calculation of the differential cross section has been presented for the exciton related Stokes Raman scattering in CdSe/CdS quantum dots ensemble with different mean sizes.

Presented results will be useful for identifying the exciton□related Raman scattering in semiconductor quantum nanosystems.

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Alkali atom transition cancellations under the magnetic field

A. Aleksanyan[1,2], R. Momier[1,2], E. Gazazyan[1,3], A. Papoyan[1], C. Leroy[2]

[1] *Institute for Physical Research, NAS of Armenia, 0203 Ashtarak, Armenia*

[2] *Laboratoire Interdisciplinaire Carnot de Bourgogne, UMR CNRS 6303, UBFC, 21000 Dijon, France*

[3] *Yerevan State University, 0025 Yerevan, Armenia*

Email arthuraleksan@gmail.com

In presence of magnetic field, for D_1 line structure we built Hamiltonian matrices for the ground and excited states in order to describe all the transitions (σ^+, π and σ^-). The "modified" transfer coefficients are function of the nuclear spin I, the magnetic quantum number m and the magnetic field magnitude B. In the case of D_1 line structure, there are no any σ^+ or σ^- polarized transitions, cancelling for any value of magnetic field. In addition, cancellation appear only for those π transitions, where the total atomic angular momenta of ground and excited states are equal to each other ($F_g = F_e$). A unique formula is obtained, which express the magnetic field value cancelling transitions:

$$B = -\frac{1}{\mu_B} \cdot \frac{2m}{1+2I} \cdot \frac{2\xi\varepsilon}{(g_I - g_S)\varepsilon + \frac{3g_I - 4g_L + g_S}{3}\xi},$$

We also depicted ^{23}Na, ^{39}K, ^{40}K, ^{41}K, ^{85}Rb, ^{87}Rb and ^{133}Cs isotopes transitions for wide range of magnetic field (from zero up to 10000 G) that have cancellations.

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Theoretical study of sodium D lines in a wide range of magnetic field with sub-Doppler resolution

R. Momier[1,2], A. Papoyan[2], C. Leroy[1]

[1] *Laboratoire Interdisciplinaire Carnot de Bourgogne, UMR CNRS 6303 – Université de Bourgogne, 21000 Dijon, France*

[2] *Institute for Physical Research, NAS of Armenia, Ashtarak, 0203 Armenia*

momier.rodolphe@gmail.com

Alkali metal atoms are commonly used in various aspects of atomic physics, notably due to the presence of strong optical transitions in the visible or near-IR domain (*D* lines) and due to their high vapor density at relatively low temperatures. From the theoretical point of view, they are attractive due to the simplicity of their electronic structure.

Complete understanding of the various magneto-optical effects occurring in alkali vapors [1] is a key point for example in the domains of electromagnetically induced transparency [2], Faraday filters [3] or optical magnetometry [4]. These phenomena often rely on the peculiarities of the behavior of Zeeman transitions, which have been extensively studied in the case of rubidium, cesium, potassium, both theoretically and experimentally.

Here, we compute theoretically the interaction of a sodium vapor with a static magnetic field up to the hyperfine Paschen-Back regime, and we describe all possible Zeeman transitions of the *D* lines of sodium for any incident polarization (π , $\sigma^{\pm}$). These results are combined with a Fabry-Pérot microcavity model [5] to describe the transmitted and reflected signals of a sodium vapor confined in a nanometric-thin cell. For the first time, we present sub-Doppler transmission and reflection spectra of sodium, and we demonstrate the appearance of important peculiarities such as guiding transitions and magnetically-induced circular dichroism in sodium vapors [6]. The results, still purely theoretical, can be used in upcoming experiments with sodium vapor nanocells.

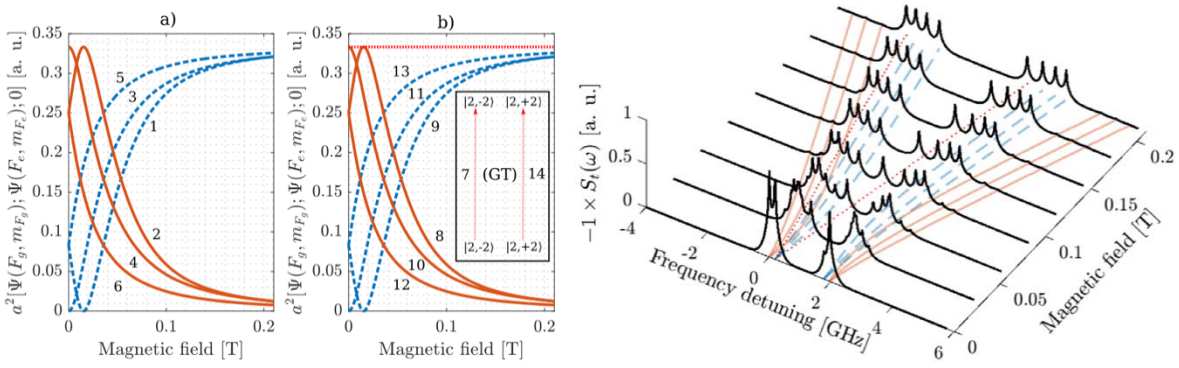

Fig. 1. Left panel: Sodium D_1 line hyperfine transition intensities for π-polarized incident laser radiation. a) transitions from $F_g = 1$. b) Transitions from $F_g = 2$. Right panel: absorption spectra of the D_1 line of Sodium for π-polarized incident laser radiation. Magnetic field varies from 0 to 0.21 T with a step of 30 mT.

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Acoustogalvanic Phenomena in Ordinary Water

R.N. Balasanyan, I.G. Grigoryan, R.B. Kostanyan

Institute for Physical Research by M. Ter-Mikaelyan, NAS, Armenia.

E-mail: irina.g.grigoryan@gmail.com

It is known that the propagation of acoustic waves in metals and semiconductors generates an electric current [1]. This phenomenon, called the acoustoelectric phenomenon, was theoretically predicted and presented by R.P. Parmenter in 1952 [2], and then N.G. Gurevich in 1957 [3]. The acoustoelectric phenomenon was experimentally discovered for the first time also in 1957 in germanium (Ge) crystals by Wayne Gray, White [4], and also by the Japanese researchers W. Sasaki and E. Yoshida [5]. Acoustoelectric currents are rather weak in semiconductor crystals with a center of symmetry, such as germanium (Ge) and silicon (Si), as well as in metals, However, this phenomenon increases by 5–6 orders of magnitude in crystals CdS, CdSe, ZnO, GaAs, InSb, and in other piezoelectric media. According to the accepted concept of the physical mechanism of this phenomenon, the generation of an electric current is caused by the transfer of part of the energy of sound impulses to conduction electrons. We were unable to obtain an answer to many questions related to physicochemical processes when exposed to acoustic radiation with liquids and, in particular, with water and aqueous solutions. We present the results of an attempt to experimentally detect and study the acoustoelectric phenomenon in ordinary water. It is known that the electrical conductivity of water is carried out with the help of H+ and OH– ions dissociated in water and, under the influence of acoustic waves, the charges are displaced in a certain direction. In addition, it is known that the acoustoelectric current is inversely proportional to the mass of the charges and the masses of the H^+ and OH^- ions significantly exceed the mass of the electrons. Possibly, the large difference in the masses of conductive water ions and electrons can explain the invariability of the electrical resistance of water under the influence of acoustic waves. Based on this model of an electric double layer, a study was made of the change in the capacitance value of the system of two electric double layers depending on the value of the potential difference induced by acoustic exposure. Under conditions of acoustic vibrations with a large amplitude, the electrochemical potential can vanish, then the magnitude of the measured potential difference will correspond to the electrochemical potential of another metal electrode introduced into the water.

Thus, it was revealed that the acoustoelectric phenomenon in water is very small due to the large massiveness of the carriers of electrical conductivity of water in comparison with electrons. Under the influence of acoustic vibrations on the water under conditions of acoustic resonance, an acoustic-galvanic phenomenon.

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Optical scalable matrix-vector multiplication

A. Tigranyan[1], N. Badalyan[1], A. Sargsyan[2,3], M. Rafayelyan[1]

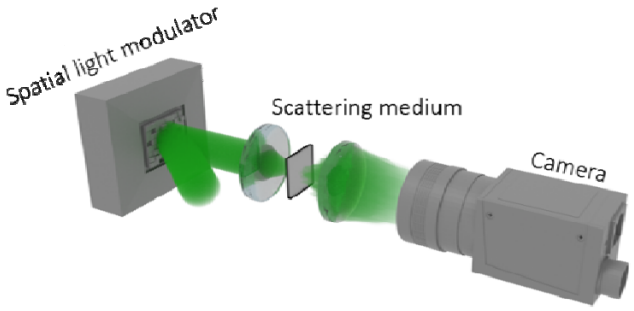
[1] *Department of Physics, Yerevan State University, 0025, 1 Alex Manoogian, Yerevan, Armenia*
[2] *American University of Armenia, 0019, 40 Marshal Baghramyan Ave, Yerevan*
[3] *Institute of Informatics and Automation Problems NAS RA, 0014, Paruyr Sevaki St., 1 Building, Yerevan*
tigranyan997@gmail.com

The rapid development of high-performance computing, machine learning, and powerful data processing extremely increases energy consumption leading to the research of novel computational units. Optics is one of the most promising fields to realize large and efficient computations due to its intrinsic properties of parallelism and its ability to process the data at the speed of light with low energy consumption [1]. In our research, we have created a model of an optical computing unit that performs linear algebra operations.

Light propagation through a highly scattering medium at a given frequency is fully described by its transmission matrix T, which is a random matrix consisting of independent and identically distributed random complex variables [2]

$$E_{out} = E_{in}T,$$

where E_{in} and E_{out} are the input and output vectors of electromagnetic field, respectively, and T is the transmission matrix of scattering medium. Our model of the optical setup consists of a spatial light modulator (SLM) to encode any input vector E_{in}, a camera to detect the intensity of the output light $I_{out} = |E_{out}|$, and a scattering medium. Furthermore, we introduce new parameters that induce an additional phase and amplitude modulation of the input field on the SLM, and allow having an effective control on the transmission matrix of the scattering medium. The latter in its turn allows accomplishing arbitrary vector-matrix multiplications on such an optical setup.



As a validation to our concept, we have studied three basics. Namely, we trained the reconfigurable parameters to get a vector-matrix multiplication with an arbitrary random matrix T_0 different from the initial T, a discrete Fourier transform matrix, and an identity matrix. The latter two correspond to the cases when the scattering medium turns to a focusing lens or becomes completely transparent, respectively.

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New Material for Optical Cooling: Tm-doped Lithium Niobate

Ninel Kokanyan [1,2], Nune Mkhitaryan [3], Gagik Demirkhanyan [3,4], Ajith Kumar [5], Michel Aillerie [2], Dhiraj Sardar [5] and Edvard Kokanyan [3,4].

[1] *Chaire Photonique, LMOPS, CentraleSupélec, 2 rue Edouard Belin, 57220 Metz, France*
[2] *Université de Lorraine, LMOPS, 2 rue Edouard Belin, 57070 Metz, France; michel.aillerie@univ-lorraine.fr*
[3] *Armenian State Pedagogical University after Kh. Abovyan, TigranMetsi Ave., 17, Yerevan 0010, Armenia;*
nune.leo.nm@gmail.com (N.M.); gdemirkhanyan@gmail.com (G.D.);
edvardkokanyan@gmail.com (E.K.)
[4] *Institute for Physical Research, National Academy of Sciences of Armenia, Ashtarak-2 0203, Armenia*
[5] *Department of Physics and Astronomy, The University of Texas at San Antonio, San Antonio, TX 78249, USA;*
akgsh2005@gmail.com (A.K.); Dsardar@utsa.edu (D.S.)

Lithium niobate crystals, $LiNbO_3$ (LN), doped with trivalent rare earth ions, are promising materials for compact multifunctional lasers in the infrared and visible spectral regions [1-2]. These crystals can be considered as new material for optical cooling based on anti-Stokes radiation of impurity ions, as well as for creating of balanced (self-cooling) lasers [3]. It should be noted, that possibility of LN crystals for optical cooling processes has been investigated in Ho-doped LN crystals [4].

To assess the possibilities of using LN:Tm crystals for optical cooling based on anti-Stokes luminescence spectroscopic studies were carried out in the wavelength range of 1818–2200 nm. The concentration dependences of the final temperature of the crystal have been determined under continuous (CW) excitation at wavelengths of 1822–1977 nm with a pump intensity $F_p = 5 \times 10^{21} cm^{-2} s^{-1}$. The research results give the basis for the indicated crystal can be successfully used in devices for optical cooling. In particular, it was shown that significant cooling with ΔT = 22 K, 19 K, and 16.4 K can be achieved, respectively, with excitation at wavelengths 1977, 1967, and 1948 nm.

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Sensing of Near-infrared Weak Radiation Using Thermoelectric Single-photon Detector

A.A. Kuzanyan, V.R. Nikoghosyan, and A.S. Kuzanyan

Institute for Physical Research, Ashtarak-2, 0203, Republic of Armenia

Email akuzanyan@yahoo.com

Single-photon detectors have many applications when working in the single photon registration mode [1]. Some existing detectors can also sense several photons [2]. The question arises whether single-photon detector can sense weak radiation. The IR range of electromagnetic spectrum is one of the most important, in view of numerous applications. For example, radiation at 1550 nm is used in telecommunication systems and quantum information [3]. Thermoelectric single-photon detector based on four-layer detection pixel has a high detection efficiency and count rate for 1550 nm wavelength photons [4].

In this work we present the results of modeling and simulation of heat propagation processes taking place in SiO_2/W/CeB_6/W, SiO_2/W/$FeSb_2$/W, and SiO_2/Bi2223/CeB_6/Bi2223 detection pixels of a thermoelectric single-photon detector after simultaneous or with optical delay absorption of many photons with a wavelength of 1550 nm. Calculations were carried out by the finite difference method (FDM) for differential equations on the basis of the equation of heat propagation from a limited volume using a three-dimensional matrix. The cases of photon absorption in the center of the detection pixel are considered for different fixed distances from each other and for distances the values of which are given by the generator of random numbers. We have shown that in all cases considered a thermoelectric single-photon detector is able to sense and to count many photons.

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Preparation of Heterostructures Containing Anti-reflective Layer Used as a Detection Pixel of Single-Photon Thermoelectric Detector

A.A. Kuzanyan[1], S.I. Petrosyan[1], G.R. Badalyan[1], V.N. Gurin[2], A.S. Kuzanyan[1]

[1] *Institute for Physical Research, Ashtarak-2, 0203, Republic of Armenia*

[2] *Ioffe Physical-Technical Institute of the Russian Academy of Sciences, 26 Politekhnicheskaya, St. Petersburg, 194021, Russian Federation*

Email astghik.kuzanyan@gmail.com

Computer simulation of heat distribution processes in the detection pixel of thermoelectric single-photon detector (TSPD) has shown that the four-layer architecture of the detection pixel can provide high detection efficiency in a wide area of the electromagnetic spectrum [1, 2]. In this work, we studied the possibility of obtaining heterostructures containing layers: antireflection (SiO_2), absorber (W or LaB_6), thermoelectric sensor (CeB_6), and heat sink (W). Thin films and heterostructures were prepared on Al_2O_3, AlN, Si, and W substrates by electron beam deposition. Surface and elemental composition of samples were examined by VEGA TS5130MM scanning electron microscope equipped with INCA Energy 300 energy dispersive X-ray microanalysis system. The relationship between surface roughness and reflection spectra of the obtained samples is investigated. The surface roughness was measured with the Ambios Technology XP-1 profiler. The vertical resolution of profiler for drops in measured heights of up to 10 μm was 0.1 nm. Optical reflection spectra of heterostructures were recorded using SF-8 spectrophotometer with a mirror reflection attachment in the wavelength range from 400 nm to 2000 nm.

It is shown that thermoelectric single-photon detector with detection pixel prepared from investigated heterostructures can achieve efficiency 98% for wavelength 400 nm and 97% for wavelength 1550 nm.

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Amplified spontaneous emission-assisted remote magnetometry from sodium vapor cells

R. Zhang[1,2,3,4], E. Klinger[1,2], F. Pedreros Bustos[1,2,5], A. Akulshin[1,2,6], H. Guo[3], A. Wickenbrock[1,2] and D. Budker[1,2,7]

[1]*Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany*
[2]*Helmholtz-Institut Mainz, GSI Helmholtzzentrum für Schwerionenforschung, 55128 Mainz, Germany*
[3]*State Key Laboratory of Advanced Optical Communication Systems and Networks, Department of Electronics, and Center for Quantum Information Technology, Peking University, 100871 Beijing, China*
[4]*Beijing Academy of Quantum Information Sciences, 100193 Beijing, China*
[5]*Aix-Marseille Université, CNRS, CNES, LAM, 13388 Marseille, France*
[6]*Optical Sciences Centre, Swinburne University of Technology, 3122 Melbourne, Australia*
[7]*Department of Physics, University of California, Berkeley, 94720 California, USA*

eklinger@uni-mainz.de

The measurement of Earth magnetic field is an extremely important topic in geophysical research; measurements in the range 10-300 km can only be achieved with stand-off magnetometry. Current techniques, based on resonant scattering from atoms or molecules, are often limited by low collection efficiency [1]. In the mean time, the generation of a directional laser-like emission, amplified spontaneous emission (ASE), from a sodium vapor cell was recently reported [2].

Here we demonstrate, on a table-top experiment, the detection of the sodium ground-state free-precession under the influence of an external magnetic field by recording the intensity of the backward-directed ASE, see Fig. 1. This method enables scalar magnetometry in the Earth field range without the need of calibration which is extremely promising for remote sensing using the sodium layer in the mesosphere.

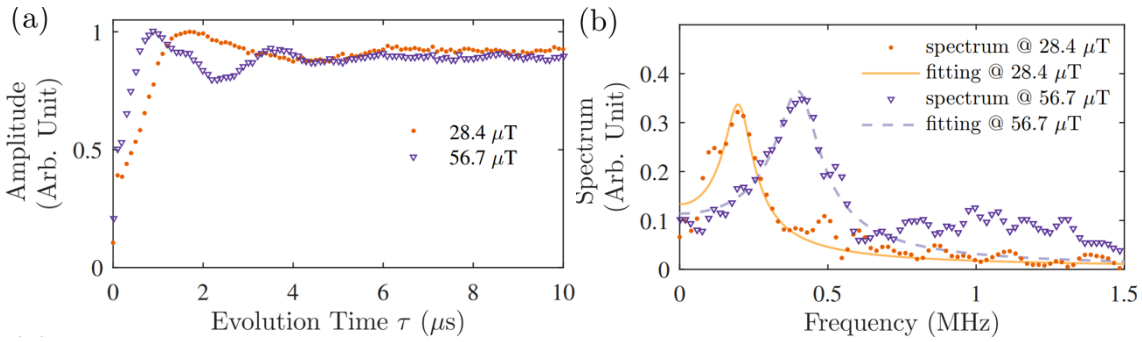

FIGURE 1: Sodium ground-state free-precession detected with ASE. (a) ASE intensity as a function of the evolution time. (b) Fourier transform of the ground-state free-precession.

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The role of the geometric phase in cholesteric with a defect layer toward multimodal robust lasing

T.M. Sarukhanyan[1], H. Gharagulyan[2,1], M.S. Rafayelyan[1], S.S. Golik[3,4], A.H. Gevorgyan[3], R.B. Alaverdyan[1]

[1] *Department of Physics, Yerevan State University, 1 Alex Manukyan Str., 0025 Yerevan, Armenia*

[2] *Institute of Chemical Physics NAS RA, 5/2 P. Sevak Str., 0014 Yerevan, Armenia*

[3] *School of Natural Sciences, Far Eastern Federal University, 10 Ajax Bay, Russky Island, 690922 Vladivostok, Russia*

[4] *Institute of Automation and Control Processes, Far Eastern Branch, Russian Academy of Sciences, 690041 Vladivostok, Russia*

Email: sarukhanyan.tm@gmail.com

Cholesteric liquid crystals (CLCs) with induced defects are one of the most prominent materials to realize compact, low-threshold and tunable coherent light sources. In this context, the investigation of optical properties of induced defect modes in such CLCs is of great interest. In particular, many studies have been devoted to the spectral control of the defect modes depending on their thickness, optical properties, distribution along the CLC, etc [1].

The geometric phase, induced by the photonic spin-orbit interaction, has attracted intensive attention due to its beam shaping capability. It can be generated via the inhomogeneous anisotropic materials such as liquid crystals [2,3]. To our knowledge there is no investigations dedicated to the role of the geometric phase toward multimodal lasing. In the frame of this work, we investigate the lasing possibilities of a dye-doped polymer layer embedded in a wedge-shaped CLC. We show that multimode laser generation is possible due to the observed multiple defect modes in the PBG that enlarges the application range of the system. Furthermore, our simulations based on a Berreman 4×4 matrix approach for a wide range of CLC thickness show both periodic and continuous generation of defect modes along particular spectral lines inside the PBG. Such a robust spectral behaviour of induced defect modes is unique, and, to our knowledge, is not observed in similar CLC-based structures.

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Theoretical signals of a dual-axis optically pumped Cs atomic vapor magnetometer

D. Osīte, M. Auzinsh, L. Bušaite, A. Mozers

Laser Centre, University of Latvia, Rainis Boulevard 19, LV-1586 Riga, Latvia
dace.osite@gmail.com

Due to the excellent magnetic field resolution of optically pumped magnetometers they have found application in a wide range of scientific areas such as biology, geology, etc. [1]. Nevertheless, the necessity of measuring all three orthogonal magnetic field components still pose a challenge. By applying a pump / probe excitation geometry used in recent research [2], it is possible to access this signal from a single optical port, which makes the setup more compact. In the present study we propose a setup for measuring two orthogonal magnetic field components by using only one probe beam in one direction.

The linearly polarized pump beam (E_p in FIG. 1 (a)) pumps the atoms in an aligned state. When a magnetic field is applied along x axis, this aligned state starts to precess in a plane perpendicular to the external magnetic field (the z-y plane in FIG. 1 (a)). This rotation can be detected by a linearly polarized probe beam (E_x in FIG. 1 (a)). Results of such signals from simulations are shown in FIG. 1 (b).

If a magnetic field is applied along the y axis, the precession occurs in the z-x plane and can be probed with a linearly polarized beam, shifted by an angle of $\frac{\pi}{2}$ with respect to the previous case. By exploiting the polarization shifting properties of an electro-optical modulator, it is possible to rapidly switch between the two polarization states of the probe beam and thus detect both of these magnetic field components using a single probe beam.

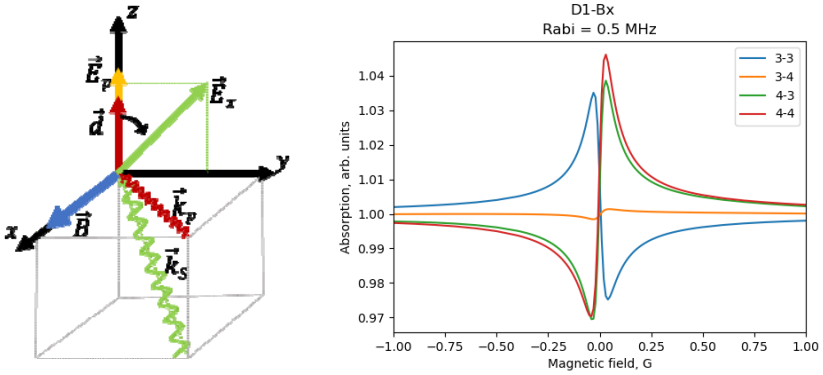

FIGURE 1: Schematic representation of the dual-axis alignment OPM. Subfigure (a) shows the polarization direction of the probe beam, (b) shows the dispersive magnetic field dependence

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