12-15 September, 2023

Ashtarak, Armenia

International Conference

# Laser Physics 2023

# Book of Abstracts

The Conference is dedicated to the **100th anniversary** of the **founder** of the Institute for Physical Research, **Professor Mikael Ter-Mikaelyan**, a Member of National Academy of Sciences of Armenia

&

**the 80th anniversary** of the **foundation** of the **National Academy of Sciences of Armenia**

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# Laser Physics 2023

## TOPICS

- Lasers, New Laser Technologies and Applications
- Optical and Scintillating Materials, Characterization Methods and Techniques
- Light-Matter Interaction, Including Resonant Interaction with Atoms
- Laser-Assisted Surface Effects
- Nonlinear Optics and Novel Phenomena
- Spectroscopy for Characterization of Materials
- Laser Spectroscopy and Mathematical Modelling
- Physical Optics, Atomic Physics
- Optical Magnetometry
- Quantum Optics and Matter Waves
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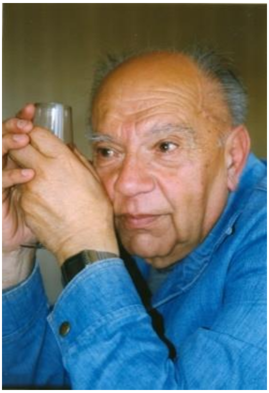

**Mikael Ter-Mikaelyan** was born in Tbilisi in 1923. After the death of his father, the family moved to Yerevan, where he graduated from the Yerevan State University in 1948. The supervisor of his thesis was academician V.A. Hambartsumyan. After graduating from university, Ter-Mikaelyan went to Moscow, where he completed his PhD thesis at the Lebedev Physical Institute of Russian Academy of Sciences in 1953 under the supervision of Academician E.L. Feinberg.

The thesis was devoted to coherent bremsstrahlung in crystals. In this remarkable work, he discovered a paradoxical effect, which became the basis for a new understanding of the interaction of high-energy particles with matter. Ter-Mikaelyan showed that the radiation process is formed in an elongated region of space, the longitudinal length (the coherence length) of which increases with increasing of the particle's energy and all the atoms of the medium that are contained in this zone coherently participate in this process. The obtained result was intriguing and at first, even some of the most prominent scientists considered this work not realistic for experimental realization. However, Ter-Mikaelyan's important discovery received direct experimental confirmation 40 years later in 1994 at the Stanford University Accelerator Center (SLAC). The concept of coherence-length and its growth with particle's energy has found wide application not only for electrodynamic processes in a medium, but also in high-energy physics, in the interaction of hadrons with a nucleus, and in chromodynamics.

After defending his Ph.D. thesis, Ter-Mikaelyan returned to Armenia, where he began working at the Yerevan Physics Institute (YerPhI). For a short period 1954-1963 he had advancement from a junior researcher to the head of the theoretical department and deputy director of the institute. In 1954, he predicted that, the Bethe–Heitler bremsstrahlung spectrum would be suppressed at certain photon energies. This phenomenon, called as the Ter-Mikaelian or longitudinal density effect, resembles the Fermi density effect. During 1960–61, Ter-Mikaelian developed the theory of x-ray transition radiation (XTR) produced in a stack of plates. He and his colleagues showed that XTR could be used to identify and measure the energy of single particles with energies much higher than it is possible with Cherenkov detectors. XTR detectors first developed at YerPhI are now used in high-energy physics experiments all over the world. In 1962, Ter-Mikaelyan received his doctorate in physics and mathematics from the Lebedev Institute.

The works of M.L. Ter-Mikaelyan in the field of high-energy physics were summarized by him in classic monograph *High-Energy Electromagnetic Processes in Condensed Media*, published in 1969 in Russian and in 1972 in English (New-York, Wiley-Interscience). This book has served as a handbook on radiation processes since its publication.

In 1963, Ter-Mikaelyan became the dean of the Faculty of Physics of Yerevan State University and in a short time carried out its complete reorganization. Eight new departments were opened in promising areas of the science. Young talented scientists were involved in the leadership of these departments. During these years, M.L. Ter-Mikaelyan began to develop a new direction of science in Armenia - laser physics. To start the experimental works, it was necessary to organize a laboratory with modern equipment, to engage specialists, and to train personnel. He organized the Joint Radiation Laboratory of the Academy of Sciences of Armenia and the Yerevan State University (ORLANEGU). The first experimental works were related to the studies of ruby lasers. These investigations led to the development and industrial production of a series of quantum optical generators “Arzni”, the first models of which were demonstrated at the Leipzig Fair in 1965. The results of these works were included in the monograph by A.L. Mikaelyan, M.L. Ter-Mikaelyan, Yu. S. Turkov, entitled *Solid-State Optical Generators* (Moscow, Soviet Radio, 1967) the first book on laser physics in the Soviet Union. The theoretical studies were summarized in review A. L. Mikaelyan, M. L. Ter-Mikaelyan “*Quasi-Classical Theory of Laser Radiation, Progress in Optics, 1969.*

In 1968, on the basis of ORLANEGU, the Institute for Physical Research (IPR) of the Academy of Sciences of Armenia was founded and M.L Ter-Mikaelyan became its director for many years. In the same year, 1968, the head of department of Optics of IPR Melist Movsesyan with his team carried out the first direct experimental confirmation of the nonlinear interaction of laser radiation with gaseous media at the Institute for Physical Research. Under Ter-Milaelyan’s leadership, in the theoretical department of the Institute a new direction in nonlinear optics-resonant interactions of laser radiation with atomic media was intensively developed. Ter-Mikayelyan and his team intensively investigated the theory of “dressed” states of atoms and adiabatic interaction of light with atoms. The adiabatic states formed the basis of many new effects that continue to be extensively studied even today and find new applications in modern technologies and quantum computers. Unfortunately, his monograph on resonant optics, summarizing all these results, remained unpublished.

In the spring of 1987, the discovery of high-temperature (HT) superconductivity was a sensation in the scientific world. Gathering young employees of the institute, Ter-Mikaelyan raised a new task, impossible at the first glance - to reproduce the results on HT superconductors synthesis, reported in some publications, in two weeks. In a short time, the new laboratory, created at the institute, began to work and realized the synthesis of HT superconductors. The staff of this laboratory synthesized hundreds of superconducting samples with characterization of their physical properties. Obtained results were included in the Proceedings of the first 50 reports from the Soviet researchers published in a special issue of Journal of Experimental and Theoretical Physics Letters. In 1988, the Institute received additional funding on high-temperature superconductivity under two State programs of the USSR.

When the President of the Academy of Sciences, Academician of USSR Gury Marchuk visited the Institute for Physical Research in 1989, he was amazed by the variety of superconductor samples exhibited for him. In the guest book, he wrote: "I hope to see your institute among the world leaders in the superconductivity”.

Another example of Ter-Mikaelyan’s amazing scientific intuition is the scientific report he made in 1997 at the Academy of Sciences of Armenia. With this report, he tried to draw the attention of the scientific community to a new field of science - rapidly developing quantum informatics.

From 1988 to 1993 Ter-Mikaelyan combined the leadership of the institute with the position of academician - secretary of the Department of Physical and Mathematical Sciences of the Armenian National Academy of Sciences. However, in 1994 he retired keeping the position of honorary director of the institute and the head of the theoretical department. Until the last days of his life, he continued to work intensively. Among his last publications are: Ter-Mikhaelyan, M. L. Simple atomic systems in resonant laser fields. *Physics-Uspekhi*, *40*(12), 1195,1997; Ter-Mikaelyan, M. L. Diffracted X Rays and Resonance (Coherent) Transition Radiation Generated by High-Energy Charged Particles *Physics-Uspekhi*, *44*(3), 321, 2001. Ter-Mikhaelyan, M. L. (2003). High energy electromagnetic processes in amorphous and inhomogeneous media. *Physics-Uspekhi*, *46*(12), 1231. 2003.

Because of his high intelligence, significant scientific achievements, administrative leadership, personal charm, M. L. Ter-Mikaelyan is highly revered by his fellows and followers, and by the international scientific community at large.

International Conference

# Laser Physics 2023

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**Book of Abstracts**

# *Abstracts of plenary reports*

***Plenary report***

# Atomic limit in optical microscopy & photon confinement: tip-enhanced Raman scattering in the atomistic near-field

**V. A. Apkarian[1], J. Lee[1,2]**

[1]*Department of Chemistry, University of California at Irvine, Irvine CA 92697, USA*
[2]*Department of Physics, University of Nevada, Reno NV 89557, USA*

aapkaria@uci.edu

To the extent that we see objects by the light they scatter, it is now possible to see atoms, albeit using a plasmonic lens to focus light down to the size of an atom. We have illustrated this through the first ever atom-resolved optical images of surfaces [1], electric currents and mechanical vibrations (phonons) inside a single molecule [2]. This natural limit in resolution, which is ultimately determined by the atomic granularity of matter, is attained through tip-enhanced Raman spectro-microscopy (TERSM) in the atomistic near-field (ANF). We use an atomically sharp silver needle to couple light into the subatomic junction gap of an ultra-high vacuum cryogenic scanning tunneling microscope (STM) [3]. The implemented superfocusing of light was predicted by the seminal works of Nerkararyan and coworkers, who pointed out that unlike diffractive optics, classically, there is no limit to confinement of light guided by a tapered plasmonic nanowire [4,5]. The classical singularity is eliminated by the quantization of matter. The Helmholtz wave equation, or optical Schrodinger equation, can be exactly solved to show that the photon is atomically confined on an atomically terminated plasmonic needle. In effect, the waveguided photon on a cone adiabatically converts to matter by acquiring mass and charge. This is most directly demonstrated experimentally by showing that the mass and momentum of the tunneling plasmon is identical to that of an electron. In the tunneling limit of plasmons, optics and electronics merge, photons can be directly wired into molecular electronic circuits, and entangled light-matter states generalize as quantized dielectrics. Atomically confined photons gives simultaneous access to pico-photonics and pico-electronics, it opens up the post-nano era of picoscience, as we illustrate through accomplished examples.

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***Plenary report***

# Magnetometry with nuclear spin polarized 14N in nitrogen-vacancy centers in diamond

**M. Auzinsh**

*Laser Centre of the University of Latvia, Raina boulevard 19, Riga, LV1586, Latvia*

marcis.auzins@lu.lv

Recently the nitrogen-vacancy (NV) centres in diamond attracted noticeable attention as a robust magnetic field sensors for different quantum technology applications. The

development of practical devices requires a good understanding of the properties of NV centres at different magnetic field strength. In this presentation the experimental and theoretical studies of dynamic nuclear spin polarization of nitrogen in negatively charged nitrogen-vacancy centers in diamond over a wide range of magnetic fields from 0 - 1100 G covering both the excited-state level anticrossing and the ground-state level anticrossing magnetic field regions, will be reported [1] Special attention will be paid to the less studied ground-state level anticrossing region.

In this study the nuclear spin polarization was inferred from measurements of the optically detected magnetic resonance (ODMR) signal. These measurements show that a very large (up to 96 %) nuclear spin polarization of nitrogen can be achieved over a very broad range of magnetic field starting from around 400 G up to magnetic field values substantially exceeding the ground-state level anticrossing at 102 G. In this study we measured the influence of angular deviations of the magnetic field from the NV axis on the nuclear spin polarization efficiency and found that, in the vicinity of the ground-state level anticrossing, the nuclear spin polarization is more sensitive to this angle than in the vicinity of the excited-state level anticrossing. Indeed, an angle as small as a tenth of a degree of arc can destroy almost completely the spin polarization of a nitrogen nucleus. In addition, we investigated theoretically the influence of strain and optical excitation power on the nuclear spin polarization.

Alongside with nuclear spin polarization at certain magnetic field values the cross relaxation between nitrogen-vacancy centers and substitutional nitrogen in a diamond crystal takes place [2]. It was demonstrated that ODMR measurements can be used also to probe cross relaxation. ODMR was detected at axial magnetic field values around 51.2 mT in a diamond sample with a relatively high (200 ppm) nitrogen concentration. We observe transitions that involve magnetic sublevels that are split by the hyperfine interaction. Microwaves in the frequency ranges from 1.3 GHz to 1.6 GHz ($m_S$ = 0 -> $m_S$ = -1 NV transitions) and from 4.1 to 4.6 GHz ($m_S$ = 0 $m_S$ = +1 NV transitions) were used. To understand the cross-relaxation process in more detail and, as a result, reproduce measured signals more accurately, a model was developed that describes the microwave-initiated transitions between hyperfine levels of the NV center at anticrossing that are strongly mixed. Additionally, we simulated the extent to which the microwave radiation driving ODMR in the NV center also induces transitions in the substitutional nitrogen via cross relaxation. The improved understanding of the NV processes in the presence of magnetic field will be useful for designing NV-diamond-based devices for a wide range of applications from implementation of *q*-bits to hyperpolarization of large molecules to various quantum technological applications such as field sensors.

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***Plenary report***

# Microring and microdisk resonators for nonlinear and quantum optics

**A. E. Shitikov[1], S. N. Balybin[1,2], N. Yu. Dmitriev[1], D. A. Chermoshentsev[1], V. E. Lobanov[1], F. Ya. Khalili[1], I. A. Bilenko[1,2]**

[1]*Russian Quantum Center, Skolkovo, Moscow 143025, Russia*
[2]*Faculty of Physics, Lomonosov Moscow State University, 119991 Moscow, Russia*

igorbilenko@gmail.com

Whispering gallery mode (WGM) microresonators with a quality factor Q > 108 were proposed and demonstrated more than 3 decades ago [1]. At present microring and microdisk optical resonators are widely used in physical measurements and technical applications. The possibility to reach very high Q (value as high as $10^{11}$ was demonstrated for crystalline CaF2 mm size disks [2]) makes them extremely attractive for creating unique instruments, like high resolution spectrometers, laser distance and speed meters, frequency standards. The long lifetime of photons in the resonator material determines the low threshold for the manifestation of nonlinear effects and the possibility to resolve quantum evolution [3]. Nowadays the technology has become mature enough for mass production of chips with microring resonators, the quality factor of which exceeds $10^7$ at given dispersion and coupling parameters [4]. Hybrid integration of such resonators with semiconductor lasers using the self-injection locking (SIL) effect appears to be efficient way for creating ultracompact narrow line lasers and frequency comb sources [5].
In our recent researches we study the rich dynamic of the four-wave mixing and SIL in the microring resonators. Experiments were made on the Si3N4 platform, with single and dual semiconductor laser pump in the self-injection locking regime. It was shown that in the case of the dual pump the lasers became mutually coupled, even when locked to different modes of the microresonator. The important role of thermal effects was also revealed. The auto and cross phase modulations arising in the microresonators with Kerr non-linearity make it possible to implement purely quantum effects: the generation of a nonclassical states of light and quantum-non-demolishing measurements. However, their experimental demonstration turns out to be extremely difficult due to losses in the outcoupling and detection scheme.

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***Plenary report***

# Nanoscintillators: a curiosity or real applications?

**C. Dujardin[1,2]**

[1] *Institut Lumière Matière, Université Claude Bernard Lyon1 CNRS UMR 5306, France*
[2] *Institut Universitaire de France (IUF)*

christophe.dujardin@univ-lyon1.fr

Scintillators are materials capable to emit light when excited by ionizing radiations (a, b, g particles, neutrons…). They are widely used in many fields of applications including environment survey, medical imaging, security, high energy physics. They have been developed for more than 100 years from now in many forms (powder, crystals, fibers, thin films, needles) to satisfy more and more demanding needs. In nanometric forms, they are called nanoscintillators and have been introduced in the last 20 years [1]. In this presentation, an overview of some of the specific features and how they differ from bulky materials will be given about several steps of the process such as escapes of the electrons, exciton confinement, traps, dielectric confinement… As a second part, to illustrate the potential of nanoscintillator either for their intrinsic properties or for their shaping capabilities, some applications where scintillators as nanoparticle are serious candidates will be described. Examples include:

- Time-of-flight positron emission tomography where hybrid materials involving quantum dots or nanoplatelets are candidates [2]
- X-ray induced photodynamic therapy, where the optimization deals with a tremendous number of aspects since it involves a complex sequence of phenomena [3]
- Radioactive gas detection which aims to impact the radioactivity metrology field as well as the survey of the nuclear activities [4].

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***Plenary report***

# Local charge carrier dynamics of photocatalytic materials using the pattern-illumination time-resolved phase microscopy

**K. Katayama**

*Department of Applied Chemistry, Chuo University, 1-13-27 Kasuga Bunkyo Tokyo, Japan*

kkata@kc.chuo-u.ac.jp

The pattern-illumination time-resolved phase microscopy (PI-PM) is a new type of ht time-resolved microscopy combining the microscopy, time-resolved measurement and informatics calculation. In this measurement, a sample is illuminated with an arbitrary pattern of the excited light, and the photo-induced change of the sample is imaged via the phase-contrast imaging. Since the change is minor, the scarce change is recovered by the latest image recovery calculations. Obviously this method is helpful for understanding the inhomogeneous response on a sample surface, and it has been applied for the charge carrier dynamics of photocatalytic reactions, [1-3] photovoltaic processes [4] and phase transition of liquid crystals. [5]

Here, we will show the application of the PI-PM method for the photocatalytic water splitting, where the sunlight energy is used for the water decomposition into hydrogen and oxygen on a photo-responsive semiconductor surface. This technology is promising for the renewable energy source of hydrogen. We have studied a-hematite, strontium titanium oxide ($SrTiO_3$) and bismuth vanadate ($BiVO_4$) and their combination. They are inhomogeneously deposited on a substrate and also needs cocatalysts to exhibit the best performance. To understand the mechanism fully, the inhomegenous reaction processes involving the phto-excited charge carriers need to be monitored. The PI-PM method was appropriate for understanding the charge carrier dynamics especially for the photocatalytic materials, where the reaction activity depends on the local position on a surface. In this talk, we will introduce several applications of the PI-PM method for studying the local charge carrier dynamics to understand the inhomogeneous surface reactions.

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***Plenary report***

## Biophotonics at Brussels photonics and its applications in life sciences and medicine

**H. Ottevaere**

*Vrije Universiteit Brussel and Flanders Make, Department of Applied Physics and Photonics, Brussels Photonics, Pleinlaan 2, 1050 Brussels, Belgium*

Heidi.Ottevaere@vub.be

Biophotonics aims at exploring innovative optical and photonics concepts for biological and chemical sensing, addressing key societal challenges such as sanitary, environmental, and food analysis, as well as fast, reliable, sensitive, compact, and cost-effective diagnostics.

We will touch upon various integrated miniaturized photonics-enhanced polymer optofluidic chips. We will first present the technology platform that encompasses the entire food-chain of micro-photonics: from optical design, to measurement, prototyping, replication, all the way to proof-of-concept demonstration and pre-production level fabrication. During the past years we have investigated versatile units which can easily be reconfigured for sensing various molecules at different wavelengths paving the way towards multifunctional, low-cost, portable, robust, and, ultimately, disposable lab-on-a-chip systems that can be used in the field and for point-of-care diagnostic applications in life sciences and medicine.

As illustration we will discuss different types of optofluidic chips for which we made use of this high-tech prototyping platform. First we will present the micro-optical detection units we developed for absorbance and fluorescence measurements in various types of microfluidic channels. Next we will highlight optofluidic lab-on-chips for confocal Raman spectroscopy and Surface Enhanced Raman Scattering used in various biomedical applications. The obtained spectroscopic data in combination with chemometrics and machine learning paves the way to supersensitive detection of complex media in compact lab-on-chip systems.

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# *Abstracts of invited reports*

***Invited report***

# Single-layer atom chip

**A. E. Afanasiev[1], P. I. Skakunenko[1,2], D. V. Bykova[1,3], A. S. Kalmykov[1], R. V. Kirtaev[2], D. V. Negrov[2], V. I. Balykin[1]**

[1] *Institute of Spectroscopy Russian Academy of Sciences, Fizicheskaya Str., 5, Moscow, Troitsk, 108840, Russia*

[2] *Moscow Institute of Physics and Technology, 9 Institutskiy per., Dolgoprudny, Moscow Reg., 141700, Russia*

[3] *National Research University Higher School of Economics, Myasnitskaya str., 20, Moscow, 101000, Russia*

afanasiev@isan.troitsk.ru

Atom interferometry is considered as a new platform for high precision fundamental experiments and for solving numerous applied problems [1]. To reach high precision of quantum sensors based on atom interferometry the effective source of cold atoms is necessary. There are three types of atoms sources can be used for atom interferometry: (1) atomic beam; (2) cold atoms in magneto-optical trap (MOT); (3) ultracold atoms trapped by atom chip. The first source is too large for building compact sensors.

Cold atoms from MOT are actively used for quantum sensors, for instance, in atomic gravimeter [2,3]. The drawback of MOT as an atomic source is the temperature of atomic ensemble. In case of sub-Doppler cooling the temperature is not lower than several microkelvins. Lower temperatures require evaporative cooling. Unfortunately, MOT is not suitable for evaporative cooling, which is usually done in a magnetic trap. Such efficient evaporative cooling requires a large magnetic field gradient.

The basic principle of atom chip operation is based on a cold atom trapping near the microwire. In this case a high gradient of magnetic field can be reached relatively easy. Approach for ultracold atom source based on atom chip has been demonstrated with high bandwidth [4]. So far, most of the atomic chips that have been demonstrated have been technically sophisticated and have multiple layers of microwires to cool and trap atoms. Previously, we demonstrated single-layer atom chip which can be used as atom source for atom interferometry and quantum sensors [5]. Now the new type of single-layer atom chip developed, which makes it possible to increase the number of atoms up to $5\times10^7$. The magnetic trapping of atoms gives the possibility to use evaporative cooling to reach the temperatures below 1 μK.

The study was supported by the Russian Science Foundation, grant No. 23-22-00255.

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*Invited report*

# Direct laser writing of optical waveguide components and ring resonators in polymer

**T. Baghdasaryan, K. Vanmol, F. Berghmans, H. Thienpont, and J. Van Erps**

*Vrije Universiteit Brussel, Department of Applied Physics and Photonics, Brussels Photonics (B-PHOT) and Flanders Make, Pleinlaan 2, 1050 Brussels, Belgium*

tigran.baghdasaryan@vub.be

3D-printing technology has developed to the level that high accuracy and rapid prototyping of optical components with sub-micrometer resolution is now feasible. Direct laser writing with 2-photon polymerization (2PP-DLW) is the primary driving force in the field [1]. The technology uses tightly focused femtosecond duration laser pulses to induce a highly confined polymerization process. The printing is usually done in a liquid photoresist that turns into solid cross-linked polymer as a result of a light induced non-linear chemical reaction. By scanning the laser focus in the photoresist, the desired 3D structure can by polymerized, while the non-exposed photoresist can afterwards be washed away.

Significant efforts in the field have been directed towards development of efficient 3D-printed waveguide components and basic photonic circuits as well [2]. Single and few-mode waveguides complemented by passive photonic components target applications in optical communication, short-distance optical interconnects, sensing and quantum information [1]. Nevertheless, further development of the fields requires defining adequate rules for designing and fabricating effective building block components. Here we report on a series of components that have been thoroughly modeled, optimized, and fabricated using 2PP-DLW for operation in telecommunication C- and L-bands (1530 nm – 1630 nm) featuring losses below 3 dB and low polarization dependent performance [3]. We demonstrate waveguides that are mode matched with standard SMF-28 fibers, adiabatic tapers for mode conversion to waveguides with dimensions down to 1 μm, and S-bends with aspect ratio lower than 1 that offset the waveguide axis. We also show our early results on ring resonators, where we demonstrate 22 μm rings with 10.8 nm free spectral range and resonance quality factor (Q-factor) above 5000.

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*Invited report*

# Submillimeter wave spectrum of methylene chloride, $^{12}CH_2{}^{35}Cl_2$, up to 1 THz

**E. S. Bekhtereva[1], O. N. Ulenikov[1], O. V. Gromova[1], H. S. P. Müller[2], and L. Margulès[3]**

[1]*Research School of High-Energy Physics, National Research Tomsk Polytechnic University, 634050 Tomsk, Russia*
[2]*Physikalische Institut, Universität zu Köln, 50937 Köln, Germany*
[3]*UMR8523-PhLAM, Université de Lille, 59000 Lille, France*

bextereva@tpu.ru

High resolution spectra of methylene chlorine are recorded in the wide spectral region from microwave up to 1 THz. About 5200 multiplet centrum transitions (more than 7000 transitions, if to take into account transitions caused by the quadrupole splittings) with the value of quantum number $J^{max}$ =108 and $K_a^{max}$=20 were assigned to the $^{12}CH_2{}^{35}Cl_2$ species. The weighed fit of the experimental data allowed us to obtain a set of 20 rotational and centrifugal distortion parameters which reproduce the initial experimental data with the $d_{rms}$ = 22.05 KHz in the whole region. Results can be interesting to the use in astrophysics and for a control of the processes of industrial transportation and processing of petroleum products.

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***Invited report***

## New approaches to the development of compact high-stability microwave and optical frequency standards

**D.V. Brazhnikov[1,2], S.M. Ignatovich[1], I.S. Mesenzova[1], A.M. Mikhailov[1,2], M.N. Skvortsov[1]**

[1] *Institute of Laser Physics SB RAS, 15B Lavrentyev Avenue, Novosibirsk 630090, Russia*
[2] *Novosibirsk State University, 1 Pirogov Street, Novosibirsk 630090, Russia*

x-kvant@mail.ru

Microwave frequency standards (atomic clocks) based on coherent population trapping in alkali-metal vapor cells are a rapidly developing quantum technology. High frequency stability of these clocks goes hand in hand with low power consumption and small size. Many efforts are nowadays put into increasing a long-term stability of these clocks by suppressing the light shift of the reference resonance. We develop a new approach based on the use of two counter-propagating light beams to observe the resonance in a miniature cesium vapor cell. The results have revealed that the light shift effect can be suppressed by adjusting a mutual phase between the beams: a curve with circles in Fig. 1 demonstrates low frequency sensitivity to the power fluctuations in vicinity of 200 μW.

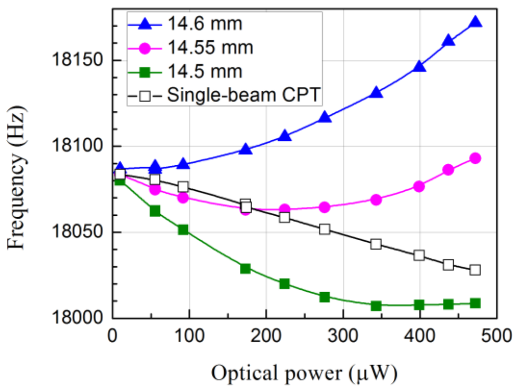


**Fig. 1.** Light shift of error signal at different positions of a mirror, which produces a backward light beam in our scheme. Linear law is for a common single-beam technique.

The second part of our work is associated with a miniaturized frequency standard in optical frequency range. This new direction in quantum metrology promises a tenfold increase in frequency stability with respect to stability of microwave miniature standards. Here we consider an approach based on a dual-frequency sub-Doppler spectroscopy [1]. In this case, an experimental setup is usually involves a diode laser and an electro-optical modulator (EOM). The latter does not support miniaturization of the device. Instead, we use a directly modulated distributed-Bragg-reflector laser in combination with a polarimetric detection technique.

The work was supported by Russian Science Foundation (Grant no. 22-12-00279).

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***Invited report***

# Nanodiamond Facilitated Drug Delivery and Drug Efficacy Evaluations in 3D cellular models

**Ch.-Y. Huang[1], Y.-J. Su[1], E. V. Perevedentseva[1,2], A. V. Karmenyan[1], Ch.-L. Cheng[1]**

*[1] Department of Physics, National Dong Hwa University, Hualien, Taiwan*
*[2] P. N. Lebedev Physics Institute of Russian Academy of Sciences, Moscow, Russia*

clcheng@gms.ndhu.edu.tw

Nanodiamond (ND) has generally been accepted as the most biocompatible nanoparticle in the carbon family. The fluorescence properties of ND are originated from defects and admixtures in the crystal lattice or on the surfaces. This provides a stable and non-photobleaching fluorescence for imaging. The defect-induced fluorescence lifetime can be used in fluorescence lifetime imaging microscopy (FLIM). The unique carbon $sp^3$-natured Raman signal (1332 $cm^{-1}$) that does not overlap with almost any bio signal provides another marker in Raman mapping. All these natural signals allow label-free imaging or mapping in the bio/medical applications using nanodiamond.

ND's surface can be functionalized to form complexes with bio-molecules of interest, either covalently or using electrostatic attraction. This renders ND the possibilities of drug conjugation and delivery. Nanodiamond and drug complexes (ND-X) produced from different methods are realized for drug delivery. The number of works raised rapidly during past years [1-3].

In this work we will show examples of bio imaging and drug delivery that has been realized in the cellular models. Various cases in the cellular models are realized for several different cancer cell lines. However conventional 2D cell culture model does not represent 3D structural of tissues and tumors, the 2D cellular models offer poor access to the efficiency of drug delivery. To address this, we developed a 3D multicellular tumor spheroid (MCTS) of Human alveolar basal epithelial cell (A549) cellular model to demonstrate the possibility of using ND for drug delivery and to evaluate the efficacy of the drug conjugate of ND-Drug in cancer therapy.

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***Invited report***

# 2D Trapping of DNA Molecules on a Lithium Niobate Crystal by Nonuniform Laser Beam-Induced Photovoltaic Effect

**L. Tsarukyan[1], A. Badalyan[1], L. Aloyan[2], Y. Dalyan[2], R. Drampyan[1]**

[1] *Institute for Physical Research, National Academy of Sciences of Armenia, 0204, Ashtarak-2, Armenia;*
[2] *Yerevan State University, 1 Alek Manukyan st., 0025, Yerevan, Armenia*

rafael.drampyan@gmail.com

The principle of optical holography is based on the spatially nonuniform illumination of photorefractive crystals that generates strong space-charge electric fields ($E_{SC}$ ~$10^7$ V/m) by the photovoltaic effect. The light-induced photovoltaic field modulates the refractive index in the crystal volume via the electro-optic effect thus creating a refractive lattice. $E_{SC}$ -field is also a source of periodically distributed electric fields near the crystal surface that can act on micro-/nano-objects located close to the crystal surface (photovoltaic tweezers). We report for the first time on the application of the concept of photovoltaic tweezers for the trapping of DNA molecules on the photorefractive crystal surface.

The nonuniform 2D photovoltaic fields are generated near the surface of a Fe-doped lithium niobate (LN:Fe) crystal by a nondiffracting optical Bessel beam with concentric ring structures and 532 nm wavelength [1]. The DNA molecules from the calf thymus with a mean diameter of the DNA random coil of 0.8 μm in $10^{-3}$ M NaCl buffer with a concentration of 0.58 mg/ml are used for the trapping on the crystal surface. The simultaneous observation of the long-living Bessel-like refractive lattice with 40 μm periodicity recorded in the LN:Fe crystal and the trapped DNA molecules on the crystalline surface was performed by an optical phase microscope operating in the transmission mode. With this approach, the DNA molecules are registered as refractive index nonuniformities on the Bessel refractive lattice pattern.

Investigations revealed the formation of neutral molecular clusters of DNA due to screening of the negative-charged phosphate groups along DNA by $Na^+$ counterions. The DNA clusters have a nearly globular shape with an average size of ~4 μm and an estimated value of ~$10^2$ DNA molecules in the cluster. Observations showed that DNA molecular clusters are trapped at the borderlines of the concentric rings of the Bessel lattice (Fig.1) by photovoltaic-induced dielectrophoretic force. The photovoltaic tweezers are promising as lab-on-a-chip devices for photonics, micro-/nano-electronics and biotechnology.

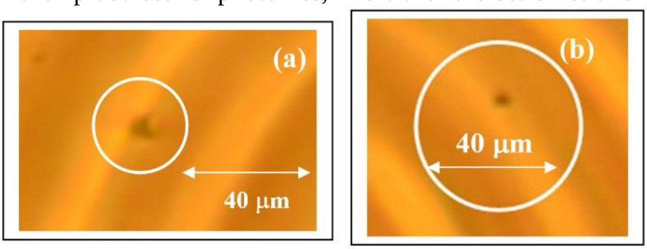


**Fig.1.**

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***Invited report***

# Liquid crystal adaptive optical components for light manipulation and sensing

**T. Galstian**

*Center for optics, photonics and lasers, Department of physics, engineering physics and optics, Faculty of sciences and engineering, Université Laval*
*Quebec, 2375 rue de la Terrasse, G1V0A6, Canada*

galstian@phy.ulaval.ca

Adaptive optical systems are gaining more popularity thanks to their flexibility and the new functionalities they can offer. Traditional mechanical deformation or moving techniques may be rather acceptable for laboratory experiments. However, their use in commercial systems (particularly in mobile or wearable applications) is not obvious for many reasons, including electrical power consumption, size, cost, etc.

Here is where electro optic materials and systems become interesting. Among them, electrically tunable liquid crystal components are very attractive [1]. They can be made very small (thin) with extremely low power consumption [2]. In addition, they can be designed to have multiple optical functionalities [3].

In this talk, I will introduce the concept of dielectric torque induced refractive index modulations. I shall then show a few examples of well-established applications of this electro optic mechanism in optical applications. Then, I will describe our most recent results that allow developing components with multiple optical functionalities. Possible ranges of their applications will be discussed.

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***Invited report***

# High–resolution spectroscopy of spherical top molecules: Ro-vibrational spectra of $SiH_4$ in the 500–8500 $cm^{-1}$ region

**<u>O. V. Gromova</u>[1], O. N. Ulenikov[1], E. S. Bekhtereva[1], C. Sydow[2], S. Bauerecker[2]**

[1] *Research School of High-Energy Physics, National Research Tomsk Polytechnic University, 634050 Tomsk, Russia*
[2] *Institut für Physikalische und Theoretische Chemie, Technische Universität Braunschweig, D-38106 Braunschweig, Germany*

gromova@list.ru

High resolution spectra of $SiH_4$ are recorded with the Zürich prototype ZP2001 (Bruker IFS125 HR) Fourier transform interferometer at a resolution of 0.001 $cm^{-1}$ in the wide spectral region from 500 up to 8500 $cm^{-1}$. More than 80000 ro–vibrational transitions belonging to about 50 absorption bands were assigned and analysed, and spectroscopic parameters of all studied bands were determined which reproduce the initial experimental line positions with the accuracy close to the experimental uncertainties (i.e., around 0.0002 cm$^{-1}$). Absolute strengths of the experimental transitions were obtained from the fit of their shapes both with the Voigt and Hartmann–Tran profiles, and effective dipole moment parameters were determined.

This work was supported by The Ministry of Science and Higher Education of the Russian Federation in part of the Science program (Project № FSWW-2023-0003) and by grant of the Volkswagen Foundation (Germany).

***Invited report***

## Conditionally exactly solvable Dirac potential, including $x^{1/3}$ pseudoscalar interaction

**A.M. Ishkhanyan[1], V.P. Krainov[2]**

[1] *Institute for Physical Research, Ashtarak, 0204 Armenia*
[2] *Moscow Institute of Physics and Technology, Dolgoprudnyi, 141701 Russia*

aishkhanyan@gmail.com

We study the solution of the 1D Dirac equation for a pseudoscalar potential, which includes an interaction term proportional to $x^{1/3}$ and a $\sim 1/x$ term with a fixed strength. This is a conditionally exactly solvable singular potential, symmetric with respect to the origin. A feature of the potential is that the effective potential for the Schrödinger equation, to which the Dirac equation can be reduced, splits into two known potentials: the first Stillinger potential and the second Exton potential for the positive and negative semiaxes, respectively. We present the solution and analyze the energy spectrum and wave functions of the bound states. Our results reveal notable differences between the Schrödinger and Dirac behaviors.

***Invited report***

## Laser Embryology – Precise Laser Methods for Micromanipulation, Monitoring and Investigation of Early Mammalian Embryos

**A.V. Karmenyan[1], A.S. Krivokharchenko[2], E.V. Perevedentseva,[1,3] C.-L. Cheng[1]**

[1]*Department of Physics, National Dong Hwa University, Hualien, Taiwan,*
[2] *N.N. Semenov Institute of Chemical Physics, RAS, Moscow, Russia*
[3] *P.N. Lebedev Physical Institute, RAS, Moscow, Russia*

artashes@gms.ndhu.edu.tw

Along with development of Assisted Reproductive Technology (ART) for medical, agricultural, and other purposes the development of new effective stable methods to observe and manipulate without injure viable cloned embryos becomes an urgent task. In this work we demonstrate and discuss applications of few laser methods in embryology.
The methods using short-pulse lasers with high repetition rate were developed for embryo microsurgery. On the model of murine early embryo the enucleation, nuclear transfer, blastomeres fusion, the transfer of the somatic cell under the zone pellucida and following fusion with embryo were demonstrated. Viability of the treated embryos were estimated.

In additional to morphological estimation of the embryo state, the different laser spectroscopy methods are demonstrated for investigation of the early mammalian embryo (EME):

- Raman spectroscopy made it possible to obtain characteristic "fingerprints" at different stages of EME development and analyze the spectra in context of the embryo state. The optimal parameters of laser exposure during measurements were chosen.
- Fluorescence lifetime imaging with 2-photon excitation (2p-FLIM) was used to analyze autofluorescence from metabolic cofactors reduced nicotinamide adenine dinucleotide (NADH) and flavin adenine dinucleotide (FAD). The lifetimes of embryos and oocytes were measured and distribution of lifetimes (2p-FLIM) in different areas was analyzed to understand a relation between metabolic processes, their dynamics in various stages of development.

The increasing use of nanoparticles (NP) in various fields of human activities leads to their wide distribution around us. With development of ART significantly increases the probability of direct contact of NP with mammalian gametes and embryos under in vitro conditions. Analysis of the possible impact of NPs on the development of EME is becoming increasingly important. The suitability and efficiency of 2p-FLIM for detection and observation of NPs to study their interaction with mammalian embryo is evaluated.

Our results demonstrate that methods of Laser Embryology are precise and low-invasive and can be considered for applications in embryology research and in ART.

***Invited report***

## Ho-doped lithium niobate thin films: structure and luminescence

**E. Kokanyan[1,2]**

[1] *Institute for Physical Researches, National Academy of Sciences of Armenia, Ashtarak, Armenia*
[2] *Armenian State Pedagogical University after Kh. Abovyan, Yerevan, Armenia*

edvardkokanyan@gmail.com

Ho-doped lithium niobate (LN:Ho) thin films were successfully fabricated on sapphire substrates using the Zol-Gel technique. The films were oriented along the crystallographic axis "c" normal to the sapphire substrate surface. X-ray diffraction patterns and X-ray reciprocal space mapping of the LN:Ho thin films revealed the presence of an intense peak corresponding to the (006) reflection, confirming the LN crystal structure.

To further characterize the films, Raman spectroscopy investigations were conducted using a confocal Raman microscope LabRAM HR Evolution with exciting lines of 532 and 785 nm. Notably, when pumped with a 785 nm laser beam, the scattering modes observed in the Raman spectra corresponded to the Raman selection rules. However, in the case of a 532 nm laser, multiple additional forbidden lines were present, reminiscent of the behavior observed in bulk LN:Ho crystals [1,2].

Additional lines were attributed to the material's luminescence under excitation at 532 nm. The analysis was facilitated through calculations utilizing the data obtained from anti-Stokes Raman lines, enabling the separation of the luminescence spectra of the investigated samples. Furthermore, surface scanning of the thin films demonstrated homogeneity in both structure and luminescence.

These findings offer valuable insights into the structural properties of Ho-doped lithium niobate thin films and highlight the promising luminescence behavior for potential applications in optoelectronic devices. The presented results contribute to the understanding of LN:Ho thin films, fostering their potential as essential components in future photonic and electronic applications.

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***Invited report***

## Generation and properties of optical platicons in hot cavities

**V.E. Lobanov[1], A.E. Shitikov[1], O.V. Borovkova[2], I.A. Bilenko[1,2]**

[1]*Russian Quantum Center, 30 Bolshoy Boulevard, building 1, Skolkovo Innovation Center territory, Moscow, 121205, Russia*
[2] *Faculty of Physics, Lomonosov Moscow State University, 119991, Moscow, Russia*

vallobanov@gmail.com

During last decades high-quality-factor optical microresonators have become an effective tool in different areas of optics and photonics [1], providing optimal conditions for implementing, investigation, and application of various nonlinear optical phenomena, including frequency conversion and a generation of frequency combs and dissipative solitons [2]. However, when a high-Q optical microresonator is pumped by an external laser, thermal effects, such as thermo-optic and thermal expansion effects, inevitably appear [3]. They manifest themself as various thermal drifts, fluctuations, and instabilities and have a significant impact on the dynamics of nonlinear processes in such structures. Excitation and properties of bright solitons at anomalous group velocity dispersion (GVD) in such heated microresonators are well studied, and several methods to minimize the effect of thermal processes have been developed. However, for dark solitons or platicons at normal GVD these issues have been studied much less.

We studied numerically the properties of platicons in heated microresonators for different ranges of the “laser-microresonator” system parameters. It was revealed that high-energy wide platicons (or narrow dark solitons) are stable for “positive” thermal effects (i.e., the directions of the nonlinear and thermal resonance shifts are the same), while “negative” effect stabilizes the narrow low-energy platicons. Moreover, in microresonators with "negative" thermal effects, the interplay of Kerr nonlinearity and thermal processes can provide the possibility of generating platicons without the use of special techniques. We showed numerically that at “negative” thermal effects platicon excitation may be realized upon the pump frequency scan without any additional approaches if the ratio of the thermal relaxation time and photon lifetime is small enough. Parameter range providing platicon generation was found, and different generation regimes were identified. Moreover, we revealed the possibility of the turn-key regime of platicon generation.

The obtained results provide a deep insight into complex nonlinear dynamics in microresonator-based photonic platforms at normal GVD and propose novel effective method of platicon generation based on thermal effects.

The work was supported by the Russian Science Foundation (project 22-22-00872).

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***Invited report***

# Atom diffraction by a standing wave: from Raman-Nath to Bragg and multi-beam atom interferometry

**A. Muradyan**

*Institute of Physics, YSU, Armenia, 0025, Alex Manoogian st., 1*

muradyan@ysu.am

Atom diffraction by a standing optical wave (near resonant Kapitza-Dirac effect) exhibits the dual particle-wave nature of matter and light in one of most convenient ways [1-3]. This phenomenon has led to the formation of high-tech scientific areas of atom interferometry and atom optics.

In the periodic potential of two counterpropagating waves of the same frequency $\omega$, the atomic wave function is

$$\Psi(z,t) = \sum_{n=-\infty}^{\infty} c_n(t)\exp[i\,2nkz]\,.$$

In the first approach, the probability amplitude $c_n(t)$ we seek in the form

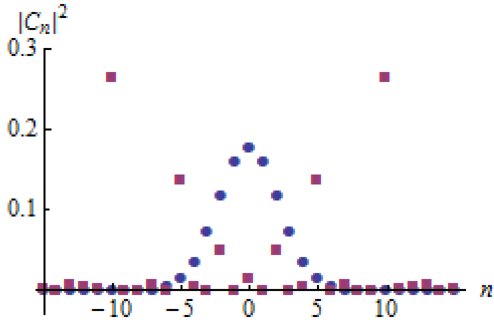
$$c_n(t) = \sum_{m=-\infty}^{\infty} g_n\, J_{n\text{-}m}\left[\frac{U_0}{2\omega_r(n_0+n)}\sin 2\omega_r\ \ n_0+n\ \ t\right]\exp\left[2i\,\omega_r n\ \ n-m\ \ t\right],$$

where $J_{n\text{-}m}\ \cdots$ is the Bessel function, $\omega_r$ is the recoil frequency. In the second approach,

$$c_n(t) = \exp[-\,i\,\omega_r(n_0+n)^2 t]\frac{1}{\pi}\int_0^{\pi}\cos(n\phi)\exp[i\lambda_n(\phi)\,t]\,d\phi\,.$$

The first of them generalizes the familiar Raman-Nath approximation to longer interaction times, and the second also includes the first-order Bragg diffraction.

Calculations show that for longer times, inaccessible in the Raman-Nath approximation, the diffraction on on optical grating can form new kinds of diffraction distribution, desirable in matter wave atom interferometry. One such a case is

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where blue round dots represent the initial Gaussian distribution. One, two and three states, in turn, are suppressed.

In result, the near-resonant Kapitza-Dirac diffraction theory is extended out of familiar Raman–Nath approximation. New solutions, applied to one- and two-optical grating atom interferometer schemes, reveals output patterns, usable for large-area multiple beam atom interferometer.

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***Invited report***

## Vector Atomic Magnetometer via lin||lin EIT resonances

**I. Novikova[1], M. G. Maldonado[1], O. Rollins[1], E. E. Mikhailov[1], J. A. McKelvy[2], A. Matsko[2], I. Fan[3], Y. Li[3], Y.-J Wang[3], J. Kitching[3]**

[1]*Physics Department, College of William & Mary, Willaimsburg, VA 23187, USA*
[2]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA*
[3]*National Institute of Standards and Technology, Boulder, CO 80305, USA*

inovikova@physics.wm.edu

Atomic magnetometers, relying on tracking the magnetic precession of the long-lived spin states, are among the most sensitive and accurate magnetic field sensors. At the same time, they are often intrinsically scalar, being sensitive only to the magnitude of the magnetic field. Here, we describe progress toward realization of a new method for vector magnetic field magnetometer based on all-optical excitation of an atomic ensemble in a vapor cell. The vector measurements are referenced to fundamental properties of optical fields, namely the propagation direction and the linear polarization axis, and can be extracted from the optical transmission data with the help of machine learning techniques.The proposed magnetometer relies on Electromagnetically induced transparency (EIT) to measure the Zeeman shift of the magneto-sensitive spin sublevels of the ground state in Rb atoms. In our experiment we use phase-modulated laser output to excite multiple EIT peaks in non-zero magnetic field. By adjusting the rf modulation frequency to match the energy separation between two magnetic sublevels of electronic ground state, we can produce the number of transmission peaks with frequency separation proportional to the local magnetic field magnitude. After optimization of experimental parameters such as vapor cell temperature, laser power and detuning and the intensity ratio between rf modulation sidebands, we were able to achieve the scalar sensitivity of 3pT/√Hz in a 100 mm$^3$ Rb vapor cell in the range of 10-100Hz detection band.

The dependence of EIT resonance amplitudes on the magnetic field orientation provides a unique opportunity for measuring the direction of the magnetic field without relying on external orientation calibration. For a linearly polarized bichromatic laser field (lin||lin configuration) EIT resonance amplitudes depend on relative orientations of the three key vectors: laser wave-vector, polarization, and the magnetic field. By analyzing possible two-photon transitions and their combinations, we can, in principle, analytically calculate the amplitude of various CPT resonances as functions of the relative angles between these three vectors. Using a combination of active locking of the light polarization to the EIT resonance amplitude extrema and the AI-based EIT resonance lineshape analysis, we are able to determine the magnetic field orientation with sensitivity better than 0.1$^o$/√Hz for large angle between the light propagation and the magnetic field, although the sensitivity drops when these vectors are nearly collinear.

This research was supported by the Defense Advanced Research Projects Agency (DARPA) under the US Army Research Office (ARO) award W911NF-21-2-0094.

***Invited report***

## Toward all-optical intelligent machines: liquid crystal-enhanced optical computing

**T. Sarukhanyan, H. Melkonyan, M. Rafayelyan**

*Institute of Physics, Yerevan State University, 0025, 1 Alex Manoogian, Yerevan, Armenia*

mushegh.rafayelyan@ysu.am

All-optical intelligent machines capable of learning and processing information in the optical domain are one of the main objectives in the field of neuromorphic computing. They promise to perform size-independent, ultrafast, and highly efficient computations on complex problems on a large scale. So far, optical computing has already demonstrated remarkable performance across various domains, from basic mathematical operations to optimizing complex systems and predicting their dynamics. Notably, our recent research has showcased the unique parallel mixing process for information encoding through the scattering of spatially modulated light in a passive disordered medium [1, 2].

Advancing our idea further, we incorporate multiple light scattering with nonlinear light-matter interactions by integrating liquid crystal (LC) technology into the optical computing setup. As a proof of principle, we make pioneering predictions on large spatiotemporal chaotic systems. Our estimations demonstrate the scalability of the new optical scheme, significantly outperforming other optoelectronic neural network implementations in terms of power efficiency and computation speed.

In summary, our study represents a major step towards realizing all-optical intelligent machines. By harnessing the potential of liquid crystals in optical computing, we unlock exciting possibilities for faster and more efficient computation of complex problems, bringing us closer to achieving the goal of ultrafast, size-independent optical computations.

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***Invited report***

# Spin 2 particle with anomalous magnetic moment in presence of the uniform magnetic field, the exact solutions and energy spectra

**A.V. Ivashkevich, A.V. Bury, V.V. Kisel, V.M. Red'kov**

*B.I. Stepanov Institute of Physics, 68-2 Independence ave. 220072 Minsk*

v.redkov@ifanbel.bas-net.by

The known Pauli- Fierz theory for spin 2 field is based on the use of second order equations. Equivalent approach based on the first order equations was developed by Fedorov and Regge, this theory assumes the use of 30-component field function. Later it was proposed more complicated 50-component theory which describes the massive spin 2 particle possessing the anomalous magnetic moment. In both theories, there is known transition to massless case. Initially in 50-component theory it was used the following set of tensors: scalar, two vectors, symmetric second rank tensor, symmetric tensor of the third rank, and 3-rank tensor antisymmetric in two indices. It was demonstrated that there exist possibility to transform the initial system of equations to new variables: symmetric 2-rank tensor and 3-rank tensor which is symmetric in two indices. The symmetry properties of the new variables are similar to symmetry properties of the metric tensor and Kristoffel symbols in General Relativity.
The matrix 50-component theory in Minkowski space-time is elaborated. It is demonstrated that in presence of external electromagnetic fields, after eliminating the 3rd rank tensor we arrive at the system of equations for symmetric tensor which contains the non-minimal interaction term trough electromagnetic tensor due to anomalous magnetic moment of the spin 2 particle. In accordance with the tetrad method by Tetrode - Weyl - Fock -Ivanenko, extension to any curved space-time is performed.
In the present paper we will study this covariant equation in cylindrical coordinates.
By diagonalizing the operators of the energy, the third projection of the total angular momentum and the third projection of the linear momentum, we derive the system of 50 differential equations of the first order in polar coordinate. In accordance with the method based on the use of projective operators, we express all the 50 variables trough 7 functions, equations for them reduce to the hypergeometric functions. With the use of additional differential constraints consistent with the all equations, we obtain a system algebraic equations which should determine the structure of the total 50-component wave function. After eliminating the variables related to the 3-rank tensor, we derive the algebraic system of 10 equations. It provides us with 5 independent solutions. There arise 5 energy spectra as solution of the second and the third order polynomial equations. They are found in analytical form and studied numerically
The massless case is considered as well. We have found 6 independent solutions. Then we have obtained explicit expressions for 4 gauge solutions defined in accordance with the Pauli - Fierz general approach, they relate to states which do not contribute to physically observable quantities like energy-momentum tensor. In the end, we have constructed two classes of solutions which do not contain any gauge components.

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***Invited report***

# The most important magnetically-induced transitions of Cs and Rb atoms for the applications in spectroscopy

**D. Sarkisyan, A. Tonoyan, and A. Sargsyan**

*Institute for Physical Research, National Academy of Sciences of Armenia, Ashtarak, 0204 Armenia*

sarkdav@gmail.com

Magnetically induced (MI) transitions $F_g = 1 \rightarrow F_e = 3$ of $^{87}$Rb atoms excited by circular σ+ polarization are among of the most promising atomic transitions for the applications. They reach their maximum intensity in the range of magnetic fields of 0.2–2 kG and are more intense than many conventional atomic transitions. An important feature of MI transitions is the large frequency shift, which reaches ~12 GHz in magnetic fields of ~ 3 kG, while they are formed on the high-frequency wing of the spectrum and do not overlap with other transitions, which is of practical interest, particularly, for electromagnetically-induced transparency (EIT) effect []. Earlier our studies have been done for $5S_{1/2}$- $nP_{3/2}$ transition for n=5, while it is theoretically shown to be promising also for the transitions with n= 6, 7, 8 and 9, using the corresponding radiation wavelengths in the range of 420 nm - 323 nm.

Magnetically induced transitions $F_g = 3 \rightarrow F_e = 5$ of Cs atoms excited by circular σ+ polarization are among of the most promising atomic transitions for the applications. They reach their maximum intensity in the range of magnetic fields of 0.2–3 kG and are more intense than many conventional atomic transitions. An important feature of MI transitions is the large frequency shift, which reaches ~35 GHz in magnetic fields of ~ 7 kG, while they are formed on the high-frequency wing of the spectrum and do not overlap with other transitions, which is of practical interest, particularly, for the EIT effect.

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***Invited report***

# Versatility of the SIL-based laser stabilization for the different spectral bands and operating regimes

**A.E. Shitikov[1], D.A. Chermoshentsev[1,2,3], N.Yu. Dmitriev[1], V.E. Lobanov[1], I.A. Bilenko[1,4]**

[1]*Russian Quantum Center, 143026 Skolkovo, Russia*
[2] *Moscow Institute of Physics and Technology, 141701, Dolgoprudny, Russia*
[3]*Skolkovo Institute of Science and Technology, Moscow 143025, Russia*
[4]*Faculty of Physics, Lomonosov Moscow State University, 119991 Moscow, Russia*

Artem.E.Shitikov@gmail.com

In the realm of cutting-edge technologies, the demand for narrow-linewidth and highly stable lasers has been steadily rising. Applications in coherent communication systems, ultrafast optical ranging, atomic clocks, astronomy, and various other progressive fields greatly benefit from the implementation of narrow-linewidth lasers. Among the robust and efficient methods of laser stabilization, self-injection locking (SIL) of a diode laser frequency to an eigenfrequency of the high-quality-factor optical microresonator has emerged as a prominent technique [1]. Over the course of several decades, this technique has established itself as a universal and versatile approach for stabilizing lasers across different spectral ranges and operating regimes [2]. In this study, we focus on the development of the effective methods to enhance the performance of SIL lasers operating in different spectral ranges (i.e., visible range and telecommunication bands), different regimes including gain-switch regime and made of different laser diodes (multifrequency and single-frequency).

We constructed microresonator-based laser sources measured instantaneous linewidths of 1 Hz at 1550 nm for 10 μs measurement time. We studied analytically and experimentally the dependence of the stabilization coefficient on tunable parameters such as locking phase and coupling rate and unveiled optimum parameters. We also demonstrated a narrow-linewidth lasing at 638 nm from a Fabry-Pérot laser diode self-injection locked to a high-Q $MgF_2$ microresonator [4]. The instantaneous linewidth of the stabilized laser was less than 10 Hz at 20 μs measurement time. A β-separation line technique characterizing the long-term stability of the laser showed a linewidth of less than 1.4 kHz at 10 ms. Moreover, if the operating diode current is supplied through a bias tee element, and the laser operates in the gain-switch regime, it still can be stabilized by microresonator via SIL. It leads to the reduction of the linewidth of all spectral lines providing high-contrast frequency comb with a tunable linespacing, which was demonstrated both at 1550 and 638 nm [4, 5].

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***Invited report***

# High resolution molecular spectroscopy as a bridge to understanding the basic properties of matter: operator perturbation theory in the $X^2B_1$ electronic ground state

**O. N. Ulenikov**, **E. S. Bekhtereva, O. V. Gromova**

*Research School of High-Energy Physics, National Research Tomsk Polytechnic University, Lenin av., 30, 634050, Tomsk, Russia*

ulenikov@mail.ru

For decades, spectroscopy has been and continues to be the source of the most complete and accurate information on the structure and properties of substances in the Nature. In this case, among the methods used by the theoretical molecular spectroscopy, one of the most efficient and powerful is the "method of effective operators" (or, in other words, "operator perturbation theory"), which is usually realized in the form of one of two approaches: "contact transformations" and/or "matrix formulation operator perturbation theory". In the talk, it is supposed to discuss the second of the two above approaches: advantages, disadvantages, results of its application to the spectroscopic study of different types of polyatomic molecules.

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***Invited report***

## Application of silver nanoparticles with strong localized surface plasmon resonances for chemiluminescence enhancement, endocytosis monitoring and circular dichroism induction in 2D and 3D chiral structures

**T.A. Vartanyan, D.R. Dadadzhanov, I.A. Gladskikh, A.A. Starovoytov, A.V. Palekhova, G. Alexan, N.S. Petrov, A.A. Fandeev, I.Yu. Nikitin, A.V. Afanasjeva**

*ITMO University, 197101, St. Petersburg, Russian Federation*

Tigran.Vartanyan@mail.ru

Silver nanoparticles remain the most attractive agents in studies and applications related to the excitation of localized surface plasmon resonances. They are readily fabricated by a number of physical as well as chemical methods and produce strong electromagnetic field enhancement when excited at the resonance frequencies. Being strong absorbers, they are also sensitive to the environment refractive index. This combination of optical properties makes them excellent reporters of the material conditions at the nanoscale.

In this contribution we concentrate on three relatively unexamined areas of silver nanoparticles applications. First, silver nanoparticles were used to enhance chemiluminescence of luminol. Although luminol chemiluminescence is strong enough in the alkali solutions, it becomes much weaker in the neutral and slightly acidic environment characteristic for biochemical applications. We used silver nanoparticles fabricated via laser ablation and reached a 5-fold enhancement of luminol chemiluminescence at pH=5 via Purcell effect. Second, application of silver nanoparticles for monitoring of endocytosis was exploded via numerical modeling. We showed that the triply degenerate localized surface plasmon of a silver nanosphere splits in two components when the nanoparticle crosses the cell membrane, thus, providing a means to monitor the process in the far field. Third, we used silver nanoparticles to prepare a thin film with strong circular dichroism. To this end, a thin porous glass slab was impregnated with colloidal solution of silver nanoparticles and then illuminated with strong circularly polarized light. Due to the process that resembles the well-known spectral hole burning, the whole ensemble of nanoparticles acquire circular dichroism. Interestingly, 2D and 3D chiral silver nanostructures equally contributes to the observed circular dichroism leading to the unusual dependence of the circular dichroism value on the side from which it is observed.

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# *Abstracts of oral reports*

*Oral report*

# Spectroscopy 2.0

**R. Aramyan[1,2], O. Tretiak[1,2], S. S. Sahoo[1,2], M. Smolis[3], A. Wickenbrock[1,2], D. Budker[1,2,4]**

[1] *Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany*
[2] *Helmholtz-Institut Mainz, GSI Helmholtzzentrum für Schwerionenforschung, 55128 Mainz, Germany*
[3] *Jagiellonian University, 30-348 Kraków, Poland*
[4] *Department of Physics, University of California, Berkeley, California 94720, USA*

aramyanr@uni-mainz.de

A frequency comb is a broad spectrum composed of evenly spaced narrow lines, resembling a precise ruler. The invention of frequency combs was revolutionary for metrology [1], but very soon it also become a game-changer for other fields like astronomy [2], optical communications [3], etc. It has also found its place in spectroscopy, where combs are utilized not only as precise references but also as the primary tool for interrogating the sample [4]. The integration of frequency combs into spectroscopy has sparked a revolutionary transformation. But Dual-Comb Spectroscopy (DCS), with its unique ability to acquire spectra in a rapid and parallel manner, has taken this revolution even further by enabling high-speed, high-resolution, and time-resolved spectroscopic analyses [5].

Atomic data are essential in various fields of physics, including the search for "new physics" beyond the standard model. They provide crucial information for understanding fundamental interactions and designing experiments to explore the unknown frontiers of science. The aim of our project is to develop and use DCS technique to do broad-band spectroscopy of Rare-Earth Elements (REE), under strong magnetic field (up to 100 T). The data will be used to train a neural network to make it capable of providing accurate predictions of information about atoms. We will present the current state of the development of DCS and share preliminary results from our coherent data acquisition and analysis technique. We will additionally show the outcomes of various evaporation methods applied to the REE (in our first test case, samarium). These findings establish reliable techniques for evaporating complex atoms.

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*Oral report*

# Multi-Cycle Terahertz Pulse Generation in Single-Domain Lithium Niobate Crystal Using Phase Mask

**Y. H. Avetisyan, A. H. Makaryan**

*Yerevan State University, Alex Manoogian str. 1, 0025 Yerevan, Armenia*

yuriav@ysu.am

The development of a terahertz (THz) sources is given great attention due to their

importance for fundamental science and application of THz technology.
In this report we theoretically study the generation of narrowband THz radiation by optical rectification in an artificial periodically poled lithium niobate (LN) crystal with a wide aperture. The latter is formed by placing a multi-slit phase mask in front of a conventional (single-domain) LN crystal. It is shown that the bandwidth of THz generation can be varied over a wide range by changing the linear size of the pump beam in the crystal. In addition, it is possible to tune the generation frequency (in the range of 0.4 – 0.8 THz) by building a mask image in the crystal with different magnifications.
According to estimates, the energy of narrowband THz pulses at a frequency of 0.5 THz in a stoichiometric LN crystal at a temperature of 100 K is about 220 μJ for a pump pulse energy of 200 mJ.

***Oral report***

# Theory of mirrorless lasing from the standpoint of classical electromagnetism

**H.V. Baghdasaryan[1]**, **T.M. Knyazyan[1]**, **T.T. Hovhannisyan[1]**, **T. Baghdasaryan[2]**

[1]*Fiber Optics Communication Laboratory, National Polytechnic University of Armenia, 0009 Yerevan, 105 Terian str., Armenia*
[2]*Brussels Photonics (B-PHOT), Department of Applied Physics and Photonics Vrije, Universiteit Brussel (VUB), Brussels, Belgium*
hovik@seua.am

Lasing is a well-established and thoroughly studied phenomenon in science and technology. It is widely accepted that lasers consist of an active light emitting medium with high reflection-based feedback, where mirrors are commonly used. Meanwhile, there were reports in literature about existence of mirrorless lasing phenomenon [1], however it has been not deeply understood, studied and explained. For example, the mechanism of super-narrowing mirrorless lasing requires further elaboration. Our work is devoted to filling this gap in theory of mirrorless lasing via electromagnetic analysis from the point of view of classical electromagnetism.
In existing publications devoted to the theory of lasers the main attention has been directed towards the analysis of quantum phenomena in materials providing coherent light radiation (lasing) [2-4]. Meanwhile, analysis of light emission from a laser's active medium using classical electromagnetics is not well covered. To explain the role of mirrors in light emission in lasers the assumption of hypothetic mirrors or reflection is used [2, 3].
In the current work the conditions of mirrorless lasing from a uniform amplifying medium are analyzed from the standpoint of classical electromagnetism for the first time. In this analysis an amplifying medium is represented by its complex permittivity without detailing the microscopic processes in the active medium. The performed analysis allows observing specific light radiation with super-narrow peak, light intensity localization inside the lasing medium and specific behaviour of the Poynting vector within. We used the method of single expression for that purpose, that is highly suitable numerical simulations tool for electromagnetic analysis and allows monitoring light localization within any materials, such as amplifying ones [5, 6]. The obtained results provide

explanation of the lasing phenomenon from uniformly amplifying media, such as gases, dyes, fibers and ring lasers.

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***Oral report***

# Measurement of light-shift in rubidium vapor microcell

**A.E. Afanasiev[1], D.V. Bykova[1,2], A. Sargsyan[3], D. Sarkisyan[3], V.I. Balykin[1]**

[1] *Institute of Spectroscopy Russian Academy of Sciences, Fizicheskaya Str., 5, Moscow, Troitsk, 108840, Russia*
[2] *National Research University Higher School of Economics, Myasnitskaya str., 20, Moscow, 101000, Russia*
[3] *Institute for Physical Research, National Academy of Sciences of Armenia, Ashtarak, 0204 Armenia*

dvbykova@edu.hse.ru

Stark effect is one among the fundamental interaction of quantum system with the external fields [1]. In case of optical field, the ac Stark effect plays essential role for atomic clocks. For instance, it limits the precision of microwave atomic clocks based on coherent population trapping (CPT) due to dependence of resonance line position on the intensity of laser field. In case of optical clocks such dependence can be significantly but not completely reduced by using of magic wavelength for the trapping laser field. In general, it can be claimed that the study of the optical Stark shift is important for both fundamental and applied physics.

Optical Stark shift appear as changing of resonance line position under the perturbation of atomic system by the off-resonance light. There are several approaches to investigate optical Stark shift in atomic systems. The first one is the measuring of the shift of resonance line caused by the trapping laser light in the dipole trap [2,3]. This permits the direct measurement of optical Stark shift. This approach requires cold and trapped atoms.

Direct measurement of the light-shift in vapor cells is rather difficult. The main problem is it's hard to reach high intensity of the off-resonance laser light trough a long vapor cell to have a detectable light shift. Typically, the light shift is on order of several kilohertz or even less than the natural linewidth (several MHz) [4]. Because of this problem optical Stark shift investigates with methods of CPT spectroscopy.

Here we demonstrate a new approach to measure optical Stark shift. We use a conventional sub-Doppler spectroscopy with a high intense off-resonance laser field and the microcell with rubidium atoms. The use of microcell gives the possibility of a sharp focusing of laser beam and this, in turn, to reach a several megahertz light-shifts. Moreover, it is open the opportunity to demonstrate an experimental scheme of atom-laser interaction with a zero light-shift by using an appropriate pulsed laser radiation [5].

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***Oral report***

# Dual-pumped microring resonators for coherent computing, soliton generation and quantum light sources

**D.A. Chermoshentsev[1,2,3], A.E. Shitikov[1], N.Yu. Dmitriev[1], N.S. Tatarinova[1,2], A.K. Vorobyev[1,2], A.N. Danilin[1,4], V.E. Lobanov[1], I.A. Bilenko[1,4]**

[1] *Russian Quantum Center, 143026 Skolkovo, Russia*
[2] *Moscow Institute of Physics and Technology, 141701, Dolgoprudny, Russia*
[3] *Skolkovo Institute of Science and Technology, Moscow 143025, Russia*
[4] *Faculty of Physics, Lomonosov Moscow State University, 119991 Moscow, Russia*

d.chermoshentsev@gmail.com

The development of integrated photonics in the last decade allows the production of high-quality integrated circuits capable of performing different complex tasks. These circuits rely on precisely adjusting single or multiple microring resonators to manipulate and control the light flow. This enables coherent computing, a basis for developing coherent Ising machines or optical neural networks [1, 2]. Additionally, microring resonators have been extensively explored for their application in quantum light sources [3]. Microring resonators offer a compact and scalable approach to generating and manipulating single photons, entangled photon pairs, and other quantum states of light. This opens possibilities for implementing quantum key distribution protocols, cryptography, and quantum computing circuits. One of the promising approaches to implementing optical computing devices, quantum radiation sources, and soliton generation sources based on microresonators is bichromatic pumping. The performance of degenerate optical parametric oscillators (DOPO) in such a system makes it possible to encode spin values into phase states to solve combinatorial optimization problems or generate squeezed states of the light. Nevertheless, the practical realization of such a process and detailed characterization of its dynamics are essential tasks of modern photonics.

We conduct a theoretical and experimental investigation of the realization of OPO and DOPO in a bichromatically pumped microresonator. We characterize the stationary and dynamical properties of such a system and analyze the process of soliton generation. We propose the scheme of turnkey soliton generation. We estimate the values of the oscillation threshold in such a system and determine the optimal parameters of the microring resonator to realize the DOPO in a degenerate four-wave mixing process. We show that two self-injection locked diode lasers [4, 5] can be used as a compact, turnkey device for generating stable soliton crystals and squeezed states of the light.

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***Oral report***

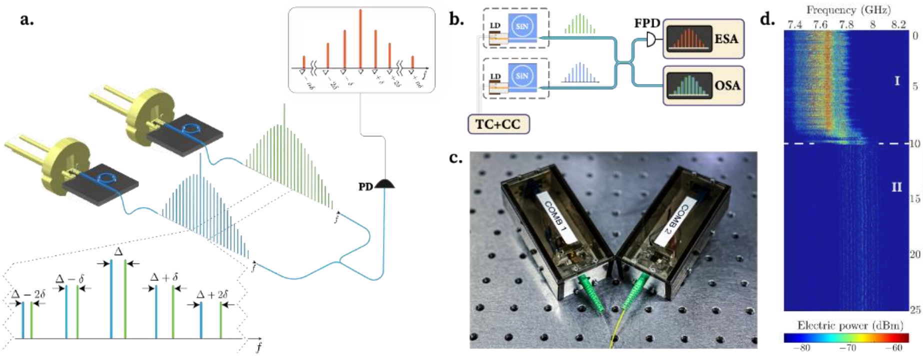
# Hybrid integrated dual-comb source

**N.Yu. Dmitriev[1], V.E. Lobanov[1], A.E. Shitikov[1], D.A. Chermoshentsev[1], I.A.Bilenko[1,2]**

[1] *Russian Quantum Center, 143026, Skolkovo, Russia*
[2] *Faculty of Physics, Lomonosov Moscow State University, 119991, Moscow, Russia*

nkdmitriev@gmail.com

Combining all the benefits of Fourier transform infrared (FTIR) spectroscopy in a chip-scale spectroscopic sensor looks promising for mobile and wearable platform development. Dual-comb spectroscopy enables the down-conversion of optical absorption spectra into the RF range for fast measurements using a single photodetector (PD) [1,2] (Fig. 1a,b). To demonstrate the technology viability for applications, the critical task is to integrate laser diode (LD) and $Si_3N_4$-chip with the high-Q microresonator (MR) into the




compact, autonomously operated device.

Here, we report a comprehensive study of dual-comb integration and introduce the first hybrid integrated dual-comb source for the SWIR range based on commercially available low-cost components (Fig. 1c). With the assembled prototypes and successfully down-converted a 300-nm broad optical spectrum to a 600-MHz wide RF signal (Fig. 1d). Our findings establish that electrically driven soliton microcombs comprising integrated SiN high-Q MRs combined with self-injection locked semiconductor LDs are a promising platform for highly integrated energy-efficient dual-comb sources flexible for different tasks and suitable for out-of-the-lab and industrial applications [3,4].

*Acknowledgments*

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***Oral report***

## A conditionally exactly solvable 1D Dirac pseudoscalar interaction potential

**A.M. Ghazaryan[1], A.M. Ishkhanyan[1], and V.P. Krainov[2]**
[1]*Institute for Physical Research, Ashtarak, 0204 Armenia*
[2]*Moscow Institute of Physics and Technology, Dolgoprudnyi, 141701 Russia*
ghazaryanastghik2.7@gmail.com

We study an analytically solvable pseudoscalar interaction potential for the one-dimensional stationary Dirac equation, which consists of power terms proportional to $x^{-1}$, $x^{-1/3}$, and $x^{1/3}$. This potential is classified as conditionally exactly solvable due to the fixed strength of the first term at a specific constant. We present the general solution to the Dirac equation in terms of non-integer index Hermite functions, which are distinct from the conventional integer index Hermite polynomials. We analyze the energy spectrum of the bound states and the eigenfunctions and compare the results with the case without the $x^{-1/3}$ term.

***Oral report***

## Nonlinear spatiotemporal dynamics of liquid crystals under the illumination of inhomogeneous light field

**A. Mirzoyan, V. Grigoryan, M. Rafayelyan**
*Yerevan State University, 1 Alek Manukyan St, Yerevan*
g_vahram@ysu.am

Numerous studies on light-matter interactions in liquid crystals (LCs) have been carried out for the past several decades. In general, the nonlinear response of LCs to the electromagnetic field is very rich and depends on many factors such as the phase of the LC, boundary conditions, illumination size, illumination power, LC temperature, and all of them both at molecular and supramolecular scales [1]. The interaction becomes even more complex when inhomogeneous electromagnetic fields are considered in the problem, as they give rise to a wide variety of defects and their intricate interactions within the LC.

Our work involves both theoretical investigations and experimental studies on the nonlinear light-matter interaction in liquid crystals illuminated by intense and arbitrarily inhomogeneous light fields. The theoretical basis for our research is the Frank-Oseen model. Near the Freedericksz transition of nematic liquid crystals with negative anisotropic permittivity and homeotropic anchoring, this model transforms into an anisotropic Ginzburg-Landau equation. It describes the tilt amplitude of the director from the vertical axis, taking the three-dimensional to two-dimensional limit through a thin film approximation [2].

Simulations are conducted using incident modulated light as inhomogeneous electromagnetic field. We investigate the self-organization of topological defects and their spatiotemporal dynamics based on the characteristics of the Gaussian distribution of the incident modulated light (mean and standard deviation). It is demonstrated that appropriately choosing the parameters of the modulated light can induce chaotic behavior in the system.

In addition to the theoretical investigations, we also perform experimental work to study the interaction between modulated light and a nematic BSO (Bismuth Silicon Oxide) LC cell. The use of BSO enhances the sensitivity of the LC cell. In the experiment, we employ a digital micromirror device (DMD) as a light modulator, which modulates the light in amplitude. This experimental setup allows us to explore the effects of modulated light on the LC cell and further validate our theoretical findings.

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***Oral report***

## Spin-orbit modal beam shaping

**V. Hakobyan[1], K. Singh[2], D. Coursault[1], Y. Lei[3], P. Kazansky[3], A. Forbes[2], E. Brasselet[1]**

[1] *Université de Bordeaux, CNRS, LOMA, UMR 5798, Talence, France*
[2] *School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
[3] *Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK*

Vagharshak.hakobyan98@gmail.com

Modality is a generic concept of wave-optics at the basis of optical information and communications. One of the challenges of photonics technologies based on optical orbital angular momentum consists in the production of a modal content for both the azimuthal and radial degrees of freedom. A method to produce various optical vortex modes of the Laguerre-Gaussian (LG) type relying on the spin-orbit interaction of light has been reported a few years ago [1]. Recently, this experimental attempt has been reported using either nanostructured glass technology [2] or dielectric metasurfaces [3].

Here we will present the quantitative modal characterization of previously realized modal vortex beam shapers made out of nanostructured silica glass [2] for the modes ($l = 1,2,3$: $p = 0$) and we will discuss how the design has been improved in order to reach maximum modal capabilities in terms of beam shaping and modal content. The structural characterization of the fabricated devices is made via polarimetric imaging of the samples. The principle of this technique consists of determining the output Stokes parameters (S0, S1, S2, S3) on the entire surface of the optical elements. The modal performance has been characterized via modal decomposition method. The approach is to introduce the light field as a sum of LG modes (orthonormal basis in cylindrical coordinates) each weighted by a complex expansion coefficient [4,5]. We have experimentally determined the amplitude square of the complex expansion coefficients, which show the power fraction of each mode.

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***Oral report***

## Excitation density effects in the luminescence yield and kinetics of $MAPbBr_3$ single crystals

**A. N. Belsky[1], N.A. Fedorov[1], I.A. Frolov[2], I.A. Kamenskikh[2], P.Martin[1], E. D. Rubtsova[2], I. N. Shpinkov[2,3], D.A. Spassky[3,4], A.N. Vasil'ev[3], B.I. Zadneprovsky[5]**

[1] *CELIA, CNRS-CEA-University of Bordeaux, 33405 Talence, France;*
[2] *Faculty of Physics, Lomonosov Moscow State University, 119991 Moscow, Russia;*
[3] *Institute of Nuclear Physics, Lomonosov Moscow State University, 119991 Moscow, Russia;*
[4] *University of Tartu, 50090 Tartu, Estonia;*
[5] *All-Russian Research Institute for Synthesis of Materials, Alexandrov, Russia*

ikamenskikh@bk.ru

Luminescent Z-scan technique with time resolution is applied to the study of luminescence properties of $CH_3NH_3PbBr_3$ single crystals representative of the family of hybrid organic-inorganic lead perovskites successfully applied recently in photovoltaics and currently investigated as potential nanosecond scintillators. The 3rd harmonic of Ti-sapphire laser ($\lambda$ = 266 nm) with the pulse duration of 26 fs and 1 kHz frequency was applied for the luminescence excitation creating the charge carriers with the estimated density from $10^{17}$ to $10^{21}$ $cm^{-3}$ in the temperature range from 13 to 300 K. Temperature and excitation density dependence of the luminescence yield and kinetics is interpreted with the consideration of temperature dependent binding of electrons and holes into excitons, saturation of defects responsible for the non-radiative relaxation channel competing with exciton creation; absorption saturation resulting in the increased penetration depth of the excitation radiation and hence the increased contribution of the re-absorption.

***Oral report***

## Signal-to-noise ratio of thermoelectric single-photon detectors for detection pixel's different designs

**A. A. Kuzanyan, A. S. Kuzanyan, V. R. Nikoghosyan, S. R. Harutyunyan**

*Institute for Physical Research of NAS of Armenia, Ashtarak, 0204 Armenia*

astghik.kuzanyan@gmail.com

Single-photon detectors play a crucial role in enabling a wide range of experiments in fields such as quantum optics, spectroscopy, astrophysics, and high energy physics. In this study, we present a fast and efficient thermoelectric detector designed specifically for the registration of single photons with energies ranging from 7.1 to 124 eV. Our detector utilizes multilayer detection pixels, which consist of a W absorber, a $La_{0.99}Ce_{0.01}B_6$ thermoelectric sensor, a W heat sink, and an $Al_2O_3$ substrate. The operating temperature of the detector is set at 1 K. We conducted computer simulations using the equation of heat transfer from a limited volume, employing the three-dimensional matrix method. By simulating the heat propagation processes, we are able to

determine the temperature at any area of the detection pixel at any given time following photon thermalization. We examine the temporal dependence of the temperature in different regions of the detection pixels, considering various layer thicknesses and detection pixel surface areas of 4 or 1 μm$^2$. These data serve as a basis for determining the signal parameters on the sensor, such as the equivalent power of phonon and Johnson noise, as well as the signal-to-noise ratio (SNR).
The key findings of our study can be summarized as follows. We observe that the temporal dependencies of the temperature at various distances from the center of the surface of the layers exhibit a consistent pattern across different layers when considering the absorption of photons with varying energies. However, it is important to note that the specific numerical values of these temperature temporal dependencies are not the same for the surfaces of different layers. The maximum average temperature of the layer surfaces is reached within femtoseconds, and this parameter is greater for higher energy photons and for detection pixels with a surface area of 1 μm$^2$. The signal decay time to the background for photons with 7.1 to 124 eV energies varies within 1.9 – 3.2 ps. This corresponds to the terahertz count rate of the detector. The equivalent noise power decreases with increasing photon energy, attributable to the longer decay time of the signal to the background. Additionally, for all absorbed photon energies, the equivalent noise power is greater for detection pixels with smaller surfaces. The signal power also increases with higher photon energies and is greater for detection pixels with smaller surfaces. The calculated SNR values are greater than 1 for all considered energies and reach a value of 460 for $E$ = 124 eV. Higher SNR values can be achieved by considering the signal at higher measurement bandwidths $\Delta f$. Based on the obtained results, we can confidently assert that the single-photon thermoelectric detector holds significant potential for widespread use in various applications.
This work was supported by the Science Committee of the Ministry of Education, Science, Culture, and Sport of the Republic of Armenia, in the frames of the research project №21T-1C088.

***Oral report***

## Generation of EIT resonances with $\Delta F$ = +2 transitions of Cs $D_2$ line

**R. Momier[1,2], A. Sargsyan[2], A. Tonoyan[2], D. Sarkisyan[2], C. Leroy[1]**

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

[2] *Institute for Physical Research, NAS of Armenia, Ashtarak-2, 0204 Armenia*

rodolphe.momier@u-bourgogne.fr

It is well known that many of the most-used techniques in modern atomic physics were first demonstrated in hot atomic vapors. Nowadays, optical processes occurring in Alkali vapors confined in spectroscopic cells have important applications in various fields, such as optical atomic clocks, atomic magnetometers, atomic gyroscopes, etc. Therefore, the investigation of the peculiarities of atomic transitions is of utmost importance. Moreover, relatively cheap lasers are available for the main optical transitions ($D$ lines) of most alkali atoms making them convenient to study experimentally. Here, we study the $\Delta F = \pm 2$ (forbidden) transitions occurring between the Zeeman sublevels of Cesium $D_2$ line. One of the most important peculiarities of these transitions is that when applying an external magnetic field, the magnetic-field induced mixing of Zeeman states leads to a significant increase of the transition probabilities. We use for the first time the $\sigma^+$ ($\Delta m = +1$) $\Delta F = +2$

transitions of Cesium $D_2$ line as probe radiation to form EIT resonances [1] in strong magnetic fields (1 - 3 kG), while the coupling is resonant with $F_g = 4 \rightarrow F_e = 5$ transitions. Due to the large frequency shift of the transitions with respect to the external magnetic field, a strong 12 GHz shift was observed making these results useful for potential applications in frequency stabilization [2]. Sufficient spectral resolution is obtained experimentally by probing a Cesium vapor confined in a cell which thickness is of the order of the wavelength of the optical line (852 nm). Preliminary calculations taking into account the geometry of the cell [3] are in reasonable agreement with the experiment.

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***Oral report***

## Spectroscopic investigation of $Yb^{3+}$ in YAG ceramic and crystalline hosts: impact of fabrication process on lattice defects

**B. Patrizi[1], G. Demirkhanyan[2,5], R. Kostanyan[2,5], D. Zargaryan[2], A. Santonocito[1], A. Pirri[3], J. Li[4], Y. Feng[4], T. Xie[4], L. Wu[4], M.Vannini[1], G. Toci[1]**

[1] *National Institute of Optics, INO-CNR, Sesto Fiorentino, FI, Italy*
[2] *Institute for Physical Research, NAS of Armenia, 0204, Ashtarak, Armenia*
[3] *Institute of Applied Physics IFAC-CNR, 50019, Sesto Fiorentino, FI, Italy*
[4] *Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai, 201899, China*
[5] *Armenian State Pedagogical University, 0010, Yerevan, Armenia*

barbara.patrizi@ino.cnr.it

We will present our recent results on the spectroscopic investigation of $Yb^{3+}$ in crystal and ceramic YAG, developed for high power laser applications [1]. High resolution emission and absorption spectroscopy at cryogenic temperature shows that the fabrication procedure has an impact on the host lattice defects that in turn influence the fine structure of the energy levels of Yb. In particular, the zero phonon emission line connecting the two lowest levels of the $^2F_{5/2}$ and $^2F_{7/2}$ of $Yb^{3+}$ features different shapes depending on the host nature (crystals and ceramics), as well as among ceramics with different fabrication processes. Underlying fine structures can be identified by proper line fitting analysis. In some cases the lattice defect includes the allocation of $Yb^{3+}$ ions in the octahedral $Al^{3+}$ site, beside the common $Y^{3+}$<->$Yb^{3+}$ substitution in the dodecahedral site, as we demonstrated in [1].

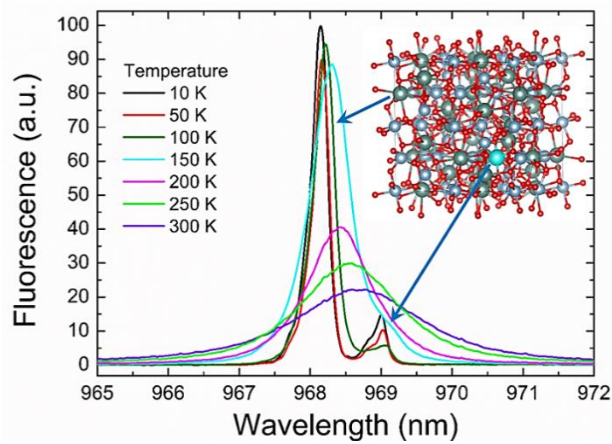


**Fig.** Temperature-resolved emission spectra of a 10%Yb:YAG ceramic showing the effects of the substitution of $Yb^{3+}$ in octahedral and dodecahedral sites.

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***Oral report***

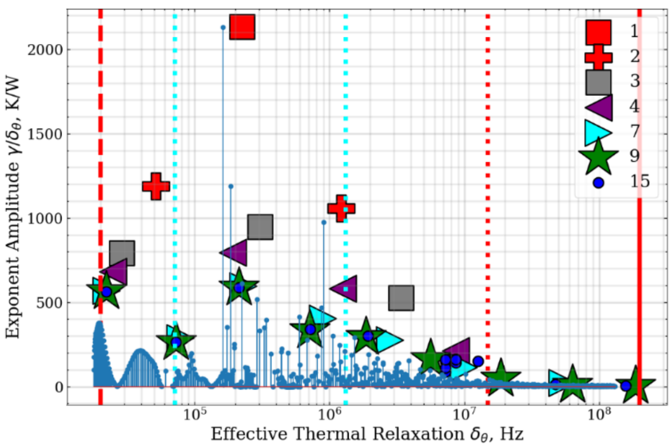
# The photonic microchip thermal parameters definition via the thermal mode decomposition

**V. I. Pavlov[1,2], N.M. Kondratyev[3], V. E. Lobanov[4]**

[1] *Russian Metrological Institute of Technical Physics and Radio Engineering, Russia*
[2] *Faculty of Physics, Lomonosov Moscow State University, Moscow, Russia*
[3] *Technology Innovation Institute, Abu Dhabi, United Arab Emirates*
[4] *Russian Quantum Center, Moscow, Russia*

pvi044@gmail.com

Effective thermal parameters are important for simulation of thermal effects in integrated photonic microchips strongly influence the dynamics of nonlinear process, e.g. generation of dissipative Kerr solitons [1] or platicons [2] and self-injection locking [3]. We studied different methods of effective parameters estimation in such systems and showed that the commonly used simplified model can be inconsistent with direct numerical approach. We compared the theoretical effective parameters with those obtained by using two methods.




In the first method, we obtain the effective parameters by approximating the temperature dependence by the sum of exponents (different symbols is number of exponents). As for the second method, we solved the eigenvalue problem in the thermal domain and calculated the overlap integral of the mode shape corresponding to eigenvalues with the shape of the heat source (stem plot). As result we compared various methods for estimating effective thermal parameters of high-Q optical microresonators and proposed a more accurate method based on thermal mode decomposition.

RQC team is supported by Russian Science Foundation (project 22-22-00872).

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***Oral report***

# Van der Waals and Dipole-Dipole interactions in optical nanocells

**A. Sargsyan[1], R. Momier[1,2], C. Leroy[2], D. Sarkisyan[1]**

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

[2] *Laboratoire Interdisciplinaire Carnot de Bourgogne, UMR 6303 CNRS - Université de Bourgogne, 9 Av. Alain Savary, BP 47870, 21000 Dijon Cedex, France*

sargsyanarmen85@gmail.com

To register the absorption or selective reflection of laser radiation in a nanocell filled with an atomic vapour of Cesium or Rubidium at thicknesses smaller than 100 nm, it becomes necessary to increase the atomic density. It is shown that both van der Waals (vdW) and Dipole-Dipole interactions (DD) cause a similar "red" shift in the frequency of resonances of about the same order, which largely increases the total frequency shift [1]. Previously, unaccounted-for DD interaction led to an erroneous overestimation of the value of the $C_3$ coefficient of the van der Waals interaction. We experimentally show that varying the nanocell thickness from 100 nm to 30 nm leads to a decrease in the value of the coefficient

$C_3$, i.e. we observe the so-called "retardation" of the vdW effect recently predicted in theoretical papers. This was made possible by using our unique high-temperature nanocells, allowing us to reach high vapour densities [1].

This work was supported by the Science Committee of RA, in the frame of project No 1-6/23-I/IPR.

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***Oral report***

## Polaron delocalization in Ag-doped ZnO films

**A.R. Sarkisian, A.A. Kuzanyan, N.R. Aghamalyan, M.N. Nersisyan, S.I. Petrosyan, A.R. Poghosyan, I.A. Gambaryan, R.K. Hovsepyan, G. R. Badalyan, Y.A. Kafadaryan**

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

Aramasd13@gmail.com

The polaron delocalization as a function of temperature and magnetic field is studied by the presence of polaron features in the optical properties such as decay rate, energy, loss energy function and optical conductivity. It is shown that delocalization of a polaron in AgZnO begins at T ≥250 K. At temperatures T ≥350 K, the polaron dissociates into many hyperfine weakly localized states due to the formation of a hydrocarbon adsorbate acting as charge trapping center. The frequency dependences of the optical conductivity determined in the range 900–4000 cm–1 at fixed temperatures between 190 and 360 K show a localization-delocalization crossover near 1900 cm–1 (0.235 eV). At frequencies below 1240 cm–1, the carriers are localized, and dc-conductivity satisfies the criterion of the Mott-VRH model with the hopping energy of 0.43×T3/4 meV.

***Oral report***

## Singularities in orbital angular momentum shaping from Bragg-Berry cavities

**S. Shvetsov, V. Grigoryan, R. Hakobyan, R. Alaverdyan, M. Rafayelyan**

*Institute of Physics, Yerevan State University, 1 Alex Manoogian, 0025, Yerevan, Armenia*

SergeyShvetsov@ysu.am

Liquid crystal materials are widely used for the modulation of light beams because of their high optical transparency, large anisotropy, and flexible orientational structure. Cholesteric liquid crystals (CLCs) possess a supramolecular spiral structure forming Bragg reflection for circular polarized light.

Light reflected from CLC cells acquires the Bragg-Berry phase modulation: the geometrical phase according to the patterned alignment on the cell substrate. This effect is used to create broadband reflecting phase plates for the generation of optical vortices, which are light beams with angular orbital momentum. In particular, the alignment of

CLCs forming a topological defect with the half-integer strength l results in forming the optical vortex with the charge 2l, which shows the angular momentum of $2l\hbar$ per photon. The combination of the CLC q-plate and the ordinary mirror allows one to obtain spin-to-orbital angular momentum mapping caused by the interference of two optical vortices with opposite charge signs [2].
To further enhance this scheme, we have introduced a tunable retarder between the Bragg-Berry q-plate and the mirror. This retarder serves as an anisotropic defect layer, allowing multiple reflections in the CLC-mirror cavity. As a result, a pronounced modification of the angular distributions of phase and amplitude profiles of the reflected light beam is obtained. In particular, by adjusting the retardance of the defect layer, we can achieve optical beams with an azimuthal singularity in the phase gradient distribution, which can be considered as a number of vortex components with high charges. These beams are of great interest because of the phase divergence in the form of linear singularity, which, to the best of our knowledge, has not been previously observed. Both experimental results and theoretical considerations are presented.

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***Oral report***

# Laser cleaning as a part of complex restoration method for multi-layered painting objects

**A.V. Vasilieva[1], A.K. Kareva[2], O.B. Kafarova[2], I.V. Starostina[2], V.A. Parfenov[1]**

[1]*St. Petersburg State Electrotechnical University "LETI" named after. V.I. Ulyanova, 5 Prof. Popova street, 197022, St. Petersburg, Russian Federation*
[2] *St. Petersburg State Academy of Art and Industry named after A.L. Stieglitz, 13 Solyanoj pereulok, 191028, St. Petersburg, Russian Federation*

anastasiastru@mail.ru

The method of laser cleaning has been studied since the end of the last century in the field of cultural heritage conservation and restoration [1]. There are examples of laser cleaning of stone surfaces [2, 3], metal artifacts [3], as well as gypsum objects covered with black crusts [4]. However, the diversity of cultural heritage objects, their complexity and uniqueness do not allow creating a universal technique for laser cleaning of artifacts.
Separately, the issue of the need to use laser cleaning in the restoration of painting objects is considered [5]. The main problem of the universal use of laser cleaning for painting restoration is the inhomogeneous distribution of paint layers over the surface of the object, as well as the variety of paint pigments that interact with laser radiation differently. Therefore, often restorers avoid using laser to clean such objects and prefer traditional cleaning methods using chemical solvents. But there are some cases when the traditional cleaning technique does not contribute to the effective removal of surface paint layers.
For example, the authors of this study had work experience with a painted gypsum bas-relief of the 18th century [6]. It was proposed to use a combined cleaning method using laser radiation with a wavelength of 1064 nm and a chemical solvent. The developed technique made it possible to solve the complex problem of cleaning a multilayer object,

which the traditional method did not solve to the full extent. In continue of this research, the basic principles of the combined technique will be discussed. The applicability limits of this method will be showed in the restoration example of wooden painted objects (late 18th - early 19th century).

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***Oral report***

## Calculation of miscibility regions for BN-Si-C ternary solid solutions

**L.S. Yeranyan, A.V. Margaryan, K.M. Gambaryan**

*Yerevan State University, Center of Semiconductor Devices and Nanotechnologies, 1 Alex Manoogian, 0025, Yerevan, Armenia*

lyeranyan@ysu.am

Boron nitride (BN) is renowned for its outstanding physical properties, exceptional thermal and chemical stability, electrical insulation properties and high thermal conductivity. It finds applications in high-temperature electronics, optoelectronics, lubrication in extreme conditions of temperature, heat sinks and thermal management systems [1, 2]. The introduction of Si and C atoms into BN at the same time can effectively modify its mechanical, optical and electronic properties, in particular, C and Si exhibit amphoteric behavior as impurities, which could occupy B lattice sites and act as donors, replace N atoms as acceptors [3]. Optical bandgap with the value from 0.63 [4] up to 6.4eV could be obtained depending on dopants concentrations.

In this study, we investigate the unstable and metastable mixing regions of the BN-Si-C solid solution system for both cubic and wurtzite phases of BN and C, using the strictly regular solution model [5] combined with DLP model for the calculation of mixing enthalpies of semiconductor alloys in terms of lattice parameters of constituents [6]. Binodal and spinodal points for binary solutions at different temperatures were calculated. Additionally, we estimated a range of compositions in BN-Si-C system, which would enable the achievement of a solid solution lattice matched to BN.

Theoretical calculations confirmed the existence of an immiscibility gap in the system, which exhibits a significant dependence on temperature and concentrations. In contrast to the BN-Si And Si-C compounds, BN-C binary solution does not exhibit immiscibility regions at all considered temperatures due to their identical crystal structures and practically matched lattice parameters. The highest possible temperature, at which unstable region first appears on cooling, is approximately 9300K and 9700K for cubic and wurtzite phases correspondingly. As the system cools, the unstable region expands into a stripe-like shape along the straight line connecting the $(BN)_{0.5}Si_{0.5}$ and $Si_{0.5}C_{0.5}$ binary critical points.

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***Oral report***

## Application of picosecond-delay laser pulse pairs for materials processing

**A.S. Yeremyan[1], M.L. Sargsyan[1,2], M.M. Sukiasyan[1,2], and N.W. Martirosyan[1]**

*[1] CANDLE Synchrotron Research Institute, 31 Acharyan st. 0022, Yerevan, Armenia*
*[2] Yerevan State University, 1 Alek Manukyan st. 0025, Yerevan, Armenia*

yeremyan@asls.candle.am

Temporally shaped ultrashort laser pulses have attracted considerable interest due to a number of applications including the study of the dynamics of the laser-matter interactions, materials processing, etc. A common approach to shaping the optical waveforms is the creation of a stack of time-delayed pulses. A versatile method to implement this is by using an optical delay line which allows for polarization-selective splitting of pulses into pairs of sub-pulses with a time delay that can be varied from 0 to 100s of picoseconds. Moreover, the energy contrast of pulse pairs can be varied in a wide range which provides another control parameter and extends the range of applications.
In this talk, we report the results of application of time-offset, ultrashort pulse pairs as a tool to control the processes of material modifications induced by laser and electron beam irradiation.
In the laser irradiation experiments, the structural modifications induced in BK7 glasses are studied depending on the time offset and energy contrast of pulse pairs. The damage threshold was determined by microscopy studies and real-time optical transmission measurements during a space-selective irradiation. It is found that, compared with the case of single-pulse irradiation, the damage threshold reduces when irradiated by pairs with delays of up to ~20 ps. The possible mechanisms responsible for the observed effect will be discussed.
In another study, time-delayed pulse pairs are used to drive the AREAL linac (CANDLE SRI, Armenia) to generate temporally shaped relativistic electron bunches. The latter are further used for irradiation of CdS thin films deposited on glass substrates. The characteristics of the e-bunches depending on the laser pulse parameters, as well as optical and structural properties of irradiated films will be presented and discussed.
The work was supported by the Science Committee of RA, in the frames of the research project No. 21T-2F294.

# *Abstracts of Poster reports*

***Poster report***

# Effect of gamma- and electron-irradiation on the natural obsidian and artificial glasses

**N. R. Aghamalyan[1], I. A. Gambaryan[1], E. A. Kafadaryan[1], M. N. Nersisyan[1], H. T. Gyulasaryan[1], G. N. Chilingaryan[1], V. V. Bagramyan[2], V.G. Khachatryan[3]**

[1]*Institute for Physical Research, NAS of Armenia, Ashtarak, Armenia*
[2]*Institute of General and Inorganic Chemistry after M.G. Manvelyan, NAS of Armenia, Yerevan, Armenia*
[3]*CANDLE Synchrotron Research Institute, Yerevan, Armenia*

natagham@gmail.com

Natural (translucent obsidian) and artificial glasses (perlite, $PbO\text{-}SiO_2$, and $PbO\text{-}SiO_2\text{-}CdO\text{-}Ga_2O_3$) were irradiated at room temperature by $Co^{60}$ radiation source with the γ-photons average energy of 1.25 MeV and with different doses from 5 up to ~900 kGy, as well as by 5 MeV electron beam energy irradiations with doses from $10^6$ up to $10^9$ Gy (AREAL-Advanced Research Electron Accelerator Laboratory, 20 MeV electron linear accelerator) were performed. It is known that ionizing radiation influences on the optical properties of glass materials depending on the composition as well as due to the presence of defects in the glass matrix. The influence of dose on the formation of paramagnetic centers have been investigated by electron paramagnetic resonance (EPR) spectroscopy, the absorption and reflection spectroscopy in the UV, visible and IR ranges for characterization of natural (translucent obsidian) and these artificial glasses. The difference in transmittance spectra between the pristine sample and those irradiated with different doses made it possible to distinguish three absorption bands, which are responsible for Fe3+ ions in different environments. The EPR measurements showed signals characteristic for Fe3+ ions. The studied materials turned out to be resistant to the formation of non-bridging oxygen hole centers paramagnetic defects in the range of the indicated doses of gamma and electron irradiations.

***Poster report***

# Source of slow atoms based on conical magneto-optical trap

**E.S. Aleinikova, D.S. Kupalov, E.V. Ivanchenko**

*Russian Metrological Institute of Technical Physics and Radio Engineering, Mendeleevo, Moscow region, Russia*

aleinikova@vniiftri.ru

(i) One of the key elements of atomic fountains is a cold-atom source. For convenience the source should be simple, reliable and robust with a high flux of loaded atoms. While maintaining the same measurement accuracy on the rubidium fountain, a higher atom flux makes allows to reduce the time of the measurement cycle of the fountain and improve the signal-to-noise ratio. One of the methods to achieve this is to use the conical magneto-optical trap as a source of slow atoms. We have developed the conical magneto-optical trap [1] as a source of slow atoms on the rubidium fountain.
(ii) MOTs in a conical configuration are more compact, less sensitive to mechanical influences

and less demanding to vacuum optics than the previously used LVIS and 2D-MOT, while the fluxes of atoms in them are the same [2]. Our MOT consists of a conical mirror reflector in a vacuum chamber, a single laser beam and a magnetic field produced by pair coils in anti-Helmholtz configuration. Cooling and repumping laser beams were combined in a one polarization-maintaining optical fiber. Because of the four holes in the reflector, the cloud of trapped atoms is observable and controllable. We have also used the conical MOT as a source of slow rubidium atoms. In this case, atoms are first captured in the trap and then pushed through the hole at the apex of the reflector. A beam of laser-cooled atoms will be directed into the capture area of the fountain's main trap.

(iii) Due to its relative simplicity, controllability and compactness, a magneto-optical trap, using a single laser beam, realized in a conical configuration can become a useful tool for atomic fountains and other atomic sensors (for example, a gravimeter [3]). The main characteristics of the atomic beam were measured. The obtained results prove that the conical MOT can be successfully used on the atomic rubidium fountains. In the future, we want to continue researching the conical MOT and try to use it for the atomic rubidium fountain.

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***Poster report***

## Light Signal Amplification on V-type atomic system

**S. Petrosyan[1], A. Aleksanyan[2]**

[1]*Institute for Informatics and Automation Problems, NAS, 0014, Yerevan, Armenia*
[2] *Institute for Physical Research, NAS, 0203 Ashtarak, Armenia*

arthuraleksan@gmail.com

In this work by numerical analysis the population dynamics of the V-type atomic system in the field of Gaussian pulses are investigated [Fig. 1]. We used two types of techniques. In the first technique, there is an interaction with two Gaussian-shaped laser pulses, which are not in the two-photon resonance condition during the whole process. The laser pulses duration is fixed and show no difference. In the second technique, there is an interaction with two Gaussian laser pulses, where the transition $|2\rangle \rightarrow |1\rangle$ is symmetrically and linearly scanned close to its resonance frequency [1-3], which is expressed as

$$\Delta_{1,2}(t) = \Delta_{1,2}(0) \cdot \left(1 - \frac{2t}{T_C}\right)$$

with $t$ the time, $T_C$ the consideration time, $\Delta_{1,2}(0)$ the detuning in the beginning of the process.

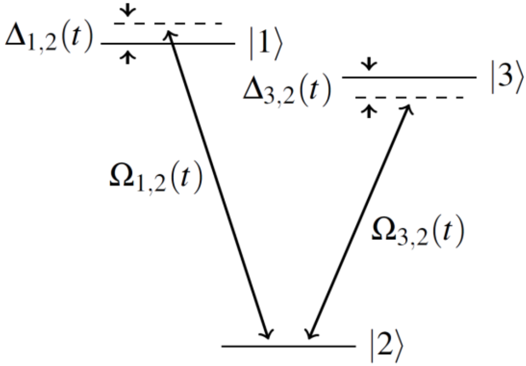


Fig. 1: V-type atomic system levels scheme

Detailed analyses of the numerical solutions of the non-stationary equations for the density matrix of the three-level V-type system is carried out.

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***Poster report***

# Ferroelectric Field-Effect Transistor Based on ZnO:Li-LiNbO$_3$ and ZnO:Li-TGS Heterostructures for IR Pyrodetectors

**A. Arakelyan, A. Poghosyan, R. Hovsepyan, N. Aghamalyan, Y. Kafadaryan, H. G. Mnatsakanyan**

*Institute for Physical Research, National Academy of Sciences of Armenia, Ashtarak-2, 0204, Republic of Armenia*

ariga@inbox.ru

We have developed and studied a new type of pyroelectric IR photodetector based on ferroelectric-field-effect transistor heterostructures with higher sensitivity and detectability than traditional pyroelectric photodetectors. Model samples of ferroelectric field-effect transistor were prepared using ZnO:Li films as a transistor channel and LiNbO$_3$ or TGS crystals as a pyroelectric sensitive element.

In the present work we fabricated and studied heterostructures based on semiconductor film and ferroelectric crystal, ZnO:Li, LiNbO$_3$ and ZnO:Li, TGS. As distinct from traditional pyrodetectors with metallic electrodes and current meter, in the structure we propose the pyroelectric sensitive element (LiNbO$_3$ or TGS) has no electrodes and the temperature variation is recorded by the external electrostatic field of ferroelectric. Such structures have high pyroelectric sensitivity and low level of noise.

We developed a novel type of pyroelectric IR-radiation detector based on ferroelectric–field-effect transistor heterostructure. We fabricated a model of noncooled ferroelectric–field-effect transistor using ZnO:Li films as the channel of field-effect transistor and bulk LiNbO$_3$ or TGS crystals as pyroelectric sensitive element. The best samples of new-type pyrodetector fabricated on the basis of TGS crystals, have sensitivity $R_V = 10 - 100$ V/W and detectability $D^* = 1 \times 10^9$ cm Hz$^{1/2}$/W which exceeds well the sensitivity and detectability of traditional detectors using the same pyroelectric crystals.

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***Poster report***

# Intraband impurity transitions in gapped graphene systems

**A. A. Avetisyan, A.P. Djotyan**

*Physics Department of Yerevan State University, A. Manoogian 1, Yerevan-0025*

artakav@ysu.am

One of the most promising mechanisms for generation of terahertz radiation in the far-infrared region is based on optical transitions between the energy levels of shallow impurity centers in semiconductor nanostructures [1]. From theoretical and technological point of view, it is very interesting to investigate the optical response of gapped graphene systems - graphene monolayer and multilayers, containing the Coulomb centers, since such systems can play the role of alternative source of terahertz radiation. The bound states exist here for arbitrary weak impurity potential.

In this work we focus on the problem of intraband optical transitions between lowest energy states of shallow donor in doped monolayer and bilayer graphene systems with opened energy gap.

We suggest an analytical method based on the variational approach in the momentum space [2] for the Coulomb problem in graphene systems. On the base of this approach we calculated the ground state and 2P state energies of an impurity electron in doped monolayer and bilayer graphene with opened energy gap. The suggested method is more appropriate for systems with complicated dispersion law of charge carriers, e.g. for gapped bilayer and multilayer graphene [3, 4]. It is shown that the energies can be tuned in the region of few ten meV.

On the base of the lowest energies obtained, the intraband transitions of the shallow donor electron from the ground state to 2P excited state in doped monolayer and bilayer graphene are investigated.

The possibility of the intraband transition energy tuning by the gate voltage, dopants concentration and tight binding parameters can be promising for applications in nano- and optoelectronics for construction of new devices.

*Acknowledgements*

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***Poster report***

## Raman spectroscopy of Tm-doped lithium niobate bulk crystals

**N. Babajanyan[1], N. Mkhitaryan[1,2], F. Voskanyan[2], E. Kokanyan[1,2]**

[1]*Armenian State Pedagogical University after Kh. Abovyan, Yerevan, Armenia*
[2] *Institute for Physical Researches, National Academy of Sciences of Armenia, Ashtarak, Armenia*

narababajanyan@gmail.com

Due to their unique electro-optical, nonlinear-optical, piezoelectric, and electrorefractive properties, lithium niobate crystals have consistently been the center of attention for numerous research groups seeking to discover new and enhance existing properties. Bulk lithium niobate crystals doped with various concentrations of thulium ions have been grown using a modified Czochralski method.
In recent years, thulium-doped lithium niobate crystals have demonstrated their potential as materials for optical refrigeration [1]. In light of this, it becomes crucial to study the influence of these dopant ions on the properties, particularly the crystal structure, of the crystals.
The crystal structures were investigated using Raman spectroscopy. Experiments were conducted to obtain Raman scattering spectra of samples with various, Y(ZZ)Y and Y(ZX)Y, configurations, utilizing laser excitation at wavelengths of 532 nm and 785 nm. A comparative analysis of the obtained results was performed, considering the laser wavelengths and dopant ion concentrations.

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***Poster report***

## Study on the morphology and elemental composition of the $BiBO_3$-doped $Bi_2Sr_2Co_2O_y$ thermoelectric ceramics

**G.R. Badalyan[1], G.N. Kakhniashvili[2], I.G. Kvartskhava[2], A.A. Kuzanyan[1], A.S. Kuzanyan[1], N.G. Margiani[2], G.A. Mumladze[2]**

[1] *Institute for Physical Research, NAS of Armenia, Ashtarak, 0204, Armneia*
[2] *Georgian Technical University, 77 Kostava str., Georgia*

gbadalyan@mail.ru

In the future, thermoelectric power converters should make to significantly reduce the role of traditional non-renewable energy sources. At the same time, there will be an equally important opportunity for the utilization and use of waste heat, which is one of the main polluting factors. In this regard, the importance, including for laser technology, of obtaining competitive and at the same time non-toxic thermoelectric materials is obvious.

The results presented in the report are part of a comprehensive study of a promising thermoelectric $Bi_{2-x}Sr_2Co_2O_y$:$(BiBO_3)_x$ system (x=0, 0.025, 0.05, 0.1, 0.15, and 0.20) prepared by solid-phase synthesis. Morphology and elemental composition of these samples were investigated by a VEGA TS 5130 MM SEM, equipped with an INCA Energy 300 microanalytical system. Images of an undoped sample and the result of its elemental EDX microanalysis are shown below.

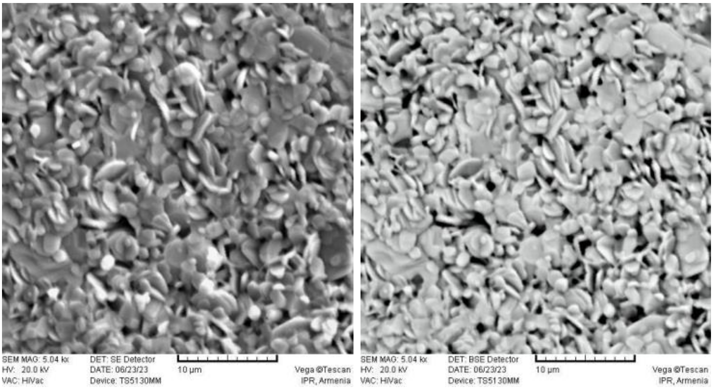


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**Fig. 1.** The resulting chemical formula of the sample: $Bi_2Sr_{1.9}Co_{2.07}O_{8.52}$.

Ceramics consists mainly of plate-shaped granules. The morphology does not change significantly from sample to sample. The granules are densely packed, the number of pores is small. Their sizes are mainly in the range from 0.8 to 3.9 µm, the pore sizes are from 0.8 to 2 µm. The undoped sample is homogeneous, while the BiBO3 doping leads to the appearance of secondary phases containing Bi, Co, and less often Sr (possibly their oxides). The amount of impurity phases increases in heavily doped compositions, and a less dense packing of granules is noticeable.

This work was supported by the the International Science and Technology Center (ISTC) Project #GE-2776/Enhancing the thermoelectric conversion performance of cobalt-based oxide materials through doping and microstructure modulation.

***Poster report***

## Thermal quantum correlations, quantum Fisher information, and quantum teleportation of a spin1/2 Heisenberg trimer system

**F. Benabdallah**[1], **K. El anouz**[2], **J. Strecka**[3], **M. Daoud**[4,5]

[1]*LPHE-Modeling and Simulation, Faculty of Sciences, Mohammed V University, Rabat, Morocco*
[2]*Laboratory of R &D in Engineering Sciences, Faculty of Sciences and Techniques Al-Hoceima, Abdelmalek Essaadi University, Tétouan, Morocco*
[3]*Department of Theoretical Physics and Astrophysics, Faculty of Science, P. J. Safarik University, Park Angelinum 9, 040 01 Kosice, Slovakia*
[4]*ICTP, Strada Costiera 11, 34151 Trieste, Italy*
[5]*Department of Physics, Faculty of Sciences, University Ibn Tofail, Kenitra, Morocco*

fadwa_benabdallah@um5.ac.ma

In this work, we provide a comprehensive description of multi-qubit quantum correlations due to their significant importance in quantum information processing and quantum communication. To achieve this goal, we investigate quantum correlations within both pure and mixed states of a tripartite quantum system, referred to as a spin-1/2 Heisenberg trimer (see **Fig.1**), which includes exchange anisotropy and cyclic three-spin interactions in the presence of an external magnetic field, both at zero and nonzero temperatures.

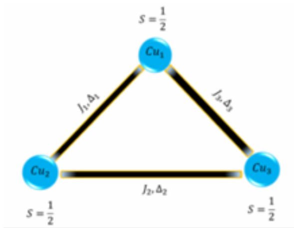


**Fig.1** A schematic structure of the trinuclear $Cu_3^{II}$ complex represented by the spin 1/2 XXZ Heisenberg trimer (three-qubit) model with the corresponding magnetic exchange interaction with $J_i$(i=1,2,3) is the exchange coupling between the particle and $\Delta_i$(i=1,2,3) is the exchange anisotropy.

Our study reveals that non-classical correlations, quantified by means of local quantum uncertainty, and entanglement, quantified in terms of negativity, are decisively dependent on intrinsic parameters such as the exchange anisotropy and cyclic three-spin interaction strengths, as well as extrinsic parameters like temperature and magnetic field. Moreover, we explore various applications of this model in quantum information theory and quantum estimation, using quantum Fisher information and quantum teleportation measures.
We found that the average fidelity and quantum Fisher information measures are significantly enhanced when the temperature and magnetic field parameters vanish [1].

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***Poster report***

# Microstructure and Spectroscopic Properties of 10% Yb-YSAG Transparent Ceramics

**G. Demirkhanyan[1], B. Patrizi[2], G. Toci[2], M. Vannini[2], J. Li[4], A. Pirri[3], R. Kostanyan[1], Y.Feng[4], T. Xie[4], L.Wu[4], D. Zargaryan, P. Muzhikyan[1]**

[1]*Institute for Physical Research of NAS, 0204 Ashtarak-2, Armenia*
[2]*Istituto Nazionale di Optica, SNR, 50019, Sesto Fiorentino, Fi, Italy*
[3]*Istituto di Fisica Applicata "Carrara", CNR, 50019, Sesto Fiorentino, Fi, Italy*
[4] *Institute of Ceramics, Chinese Academy of Sciences, Shanghai, 201899, China*

gdemirkhanyan@gmail.com

Based on the modified Strocka's formula [1], an analysis of the lattice constant dependence in 10%Yb-YSAG ceramics was conducted at $Sc^{3+}$ ion concentrations of 0, 0.25, 0.5, 1.0, and 1.5. It was observed that with an increase in the concentration of $Sc^{3+}$, their number in the lattice c-sites also increases, while the number of $Yb^{3+}$ ions in the c-sites simultaneously decreases (Fig. 1). To determine the specific content of $Yb^{3+}$ and $Sc^{3+}$ ions in the c-sites and thus the formula unit, an analysis of absorption coefficients in the

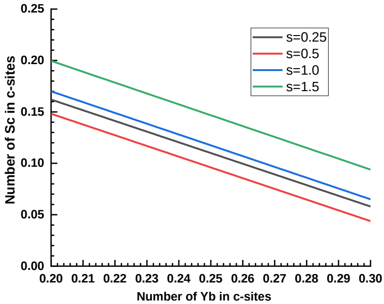


Fig.1 Depend the number of Sc in c-site on the number of Yb in c-sites.

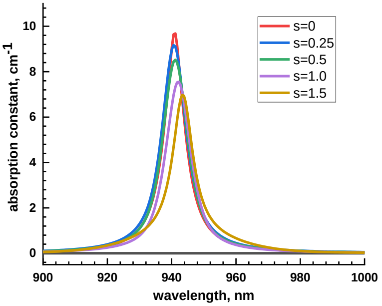


Fig.2 Absorption constant in the region of 941nm at 300K

wavelength range of 941nm was conducted at various $Sc^{3+}$ concentrations (Fig.2). The absorption in the mentioned range was attributed to $Yb^{3+}$ ions localized in the c-sites. The results are presented in Table 1.

Table1. Formula unit of 10%Yb-YSAG at different content of $Sc^{3+}$

| Sc content | Formula unit | Lattice constant, Å [2] |
|---|---|---|
| 0 | $\{Y_{2.72}Yb_{0.28}\}\{Al_{1.98}Yb_{0.02}\}Al_3O_{12}$ | 12.0006 |
| 0.25 | $\{Y_{2.64}Yb_{0.27}Sc_{0.09}\}\{Al_{1.81}Sc_{0.16}Yb_{0.03}\}Al_3O_{12}$ | 12.0204 |
| 0.5 | $\{Y_{2.65}Yb_{0.25}Sc_{0.1}\}\{Al_{1.55}Sc_{0.40}Yb_{0.05}\}Al_3O_{12}$ | 12.0659 |
| 1.0 | $\{Y_{2.63}Yb_{0.22}Sc_{0.15}\}\{Al_{1.07}Sc_{0.85}Yb_{0.08}\}Al_3O_{12}$ | 12.1433 |
| 1.5 | $\{Y_{2.60}Yb_{0.20}Sc_{0.20}\}\{Al_{0.60}Sc_{1.30}Yb_{0.10}\}Al_3O_{12}$ | 12.2189 |

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***Poster report***

# Defect reduction in $Pr^{3+}$-doped garnets by $Li^+$ co-doping according to results of gamma-ray irradiation

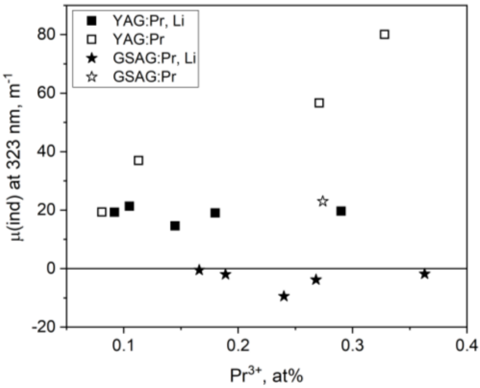
**M.V. Derdzyan[1], K.L. Hovhannesyan[1], I.A. Ghambaryan[1], C. Dujardin[2,3], A.G. Petrosyan[1]**

[1] *Institute for Physical Research, National Academy of Sciences of RA, Ashtarak 0203, Armenia*
[2] *Universite Claude Bernard Lyon 1, Institut Lumière Matière UMR 5306 CNRS, F-69622, Villeurbanne, France*
[3] *Institut Universitaire de France (IUF)*

mderdzyan@gmail.com

$Pr^{3+}$-doped scintillators employing the fast 5d-4f radiative transition of $Pr^{3+}$ ions in the UV part of the spectrum present interest for applications in medical diagnostics, high energy physics and other fields requiring high timing resolution [1]. The radiation resistance of YAG:Pr is quite low and is governed mainly by oxygen vacancies converted under irradiation into F-type centers, which give rise to absorptions in the range of $Pr^{3+}$ emission. In our earlier study [2] it was found that $Li^+$ ions, when introduced in small amounts into YAG:Ce, do not occupy lattice sites but locate in interstitials decreasing the concentration of anion vacancies. In this work the $Li^+$ co-doping approach is extended to the YAG:Pr scintillator. The effect of $Li^+$ in GSAG:Pr, which although not of practical interest, is also tested, since the results may contribute to understanding $Li^+$ incorporation mechanism in multi-component garnets currently under studies.

The figure shows radiation induced absorption coefficients, μ(ind), after 1 kGy dose. While the values for YAG:Pr increase with the $Pr^{3+}$concentration from 20 $m^{-1}$ to 80 $m^{-1}$, the values for $Li^+$ co-doped samples are much lower and remain within 15 - 21 $m^{-1}$. There is an improvement by a factor of 3 for the optimal concentration range of $Pr^{3+}$ for scintillation (0.2-0.3 at%). A stronger effect is seen in GSAG:Pr,Li with even a negative amplitude of induced absorption. The results indicate that $Li^+$ ions in both garnets do not occupy lattice sites and mostly locate in interstitials.

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***Poster report***

## Adiabatic states and suppression of dissipative processes

**E. A. Gazazyan[1,2], G.G. Grigoryan[1]**

[1]*Institute for Physical Research, National Academy of Sciences of Armenia, Ashtarak-2, 0204, Republic of Armenia*

[2]*Institute for Informatics and Automation Problems, National Academy of Sciences of Armenia, Yerevan 0014, Republic of Armenia*

emil@quopt.net

If the quantum systems interact with external fields, the energy levels of these systems change, and so-called dressed states are formed [1]. An example of such states are the adiabatic states.

We consider adiabatic interaction of quantum systems with electromagnetic field in the presence of various dissipation processes. As it is known that in the presence of large intermediate detunings any n-level system can be reduced to an effective two-level system (see Fig. 1), we chose the two-level model as the basic model for a detailed analytical study. We demonstrate the possibility of reducing losses due to dephasing and non-adiabatic corrections by choosing an appropriate design of time-dependent interaction parameters. Simple analytical expressions are derived for both cold and hot atomic ensembles. Efficient population transfer is shown despite the relatively high dephasing rates. The results obtained for the two-level system are applied to a three-level (see Fig. 1) system by using the method of adiabatic elimination.

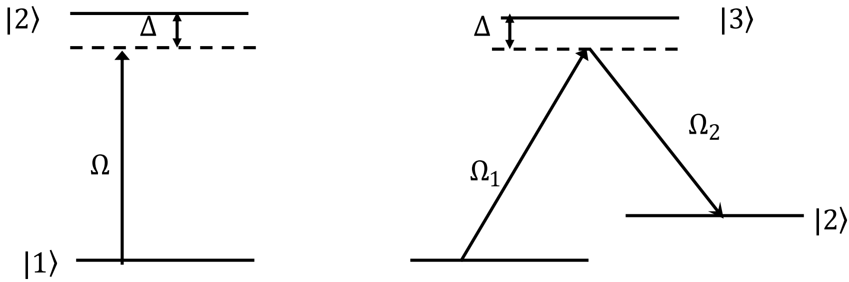


**Fig.1.** Level diagram for a two- and three- level coupling schemes.

*Acknowledgments*
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***Poster report***

# Light-light interaction through a massless vector field

**A. S. Gevorkyan**[1,2], **G. D. Movsesyan**[2]

[1] *Institute for Informatics and Automation Problems, NAS of Armenia, 1 P. Sevak str., Yerevan 0014*

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

g_ashot@sci.am

Recently, within the framework of the stochastic Yang-Mills equations for the gauge symmetry group SU(2)xU(1), the possibility of the evidenc of massless Bose particles with spin-1-*Hions* has been proved [1]. Theoretically, the formation of a vector field from *Hions* in the form of a spin glass and, accordingly, a scalar field as a result of Bose condensation of entangled pairs of *Hions* with spin-0 was justified. The purpose of our experiment was to demonstrate the possibility of manipulating the refractive indices of empty space (vacuum) by exposing the vector field by an external electromagnetic fields.

As is known, light passing through a slit of the order of its wavelength forms a diffraction pattern. We modified this experiment by placing a cylinder behind the diffraction slit, on which a light guide is wound. It is shown that when two independent low-power laser sources of the of light are switched on, one of which is incident on the slit and the other propagates along the fiber, in the individual diffraction zones a redistribution of the light intensity is observed. This effect is so significant that it cannot be explained within the framework of classical or quantum electrodynamics. Latter indicates the formation of a phase object of a complex structure on the path of propagation of a diffracting light and, accordingly, a new, still unknown type of

polarization of the quantum vacuum. As multilateral analysis and numerical estimates show, such polarization can arise as a result of reorientation of Hions spins under the action of an external electromagnetic field.
In other words, this experiment indirectly proves the existence of massless and uncharged particles that fill space or, more precisely, shape space itself. The latter can fundamentally change our understanding of the physical world and its properties.

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***Poster report***

# Vacuum and entangled states in the process of parametric decay of an optical quantum

**M.S.Gevorgyan**, **S.T.Gevorgyan**

*Institute for Physical Research of National Academy of Sciences of Armenia*

gmenua@gmail.com

For the process of non-degenerate parametric decay in an optical cavity, where a photon with energy $\hbar\omega_3$ decays into two photons with energies $\hbar\omega_2$ and $\hbar\omega_1$, where $\hbar\omega_3 = \hbar\omega_2 + \hbar\omega_1$, the possibility of formation of entangled field states in terms of photon number variables between interacting modes of the optical system is investigated. Strong entangled states are shown between the modes with frequencies $\omega_2$ and $\omega_1$ in the case of strong coupling between interacting modes. In the case of weak and very strong coupling between these modes, relatively weak entangled states are formed. In the case of weak coupling, these modes are localized in entangled vacuum states with low values of quantum entropy. For modes with frequencies $\omega_3$ and $\omega_1$ etangled states are formed only in the case of strong coupling.

***Poster report***

# External conversion of tungsten gamma radiation with radioactive impurity

**V.S. Arakelyan, G.R. Badalyan, R.N. Balasanyan, I.G. Grigoryan, R.B. Kostanyan**

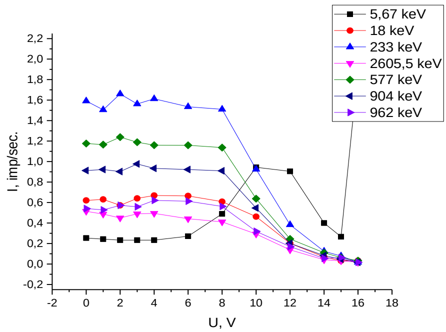
*Institute for Physical Research, National Academy of Sciences of Armenia, Ashtarak, Armenia*

irina.g.grigoryan@gmail.com

The paper presents the results of experimental studies on the implementation of nuclear processes in ordinary water using electric pulses with steep fronts applied to radioactive electrodes. A classical electrolyzer was chosen as the object under study, where ordinary water was used as an electrolyte, and tungsten cylindrical rods containing radionuclide impurities were used as electrodes. The presence of such impurities is confirmed by the registration of γ - radiation, using a γ - spectrometer brand <<GammPRO>>. The accumulation time for measurements is 300 sec. When exposed to a tungsten electrode by electrical pulses with certain parameters, suppression of the intensities of γ-radiation was observed. The phenomenon was observed only when the

tungsten electrodes were in the aquatic environment. The figure shows the dependence of the intensity of gamma radiation on the magnitude of the amplitude of electrical impulses.

It follows from the graphs a certain correlation between the magnitude of the increase in the intensity of bremsstrahlung with energy of 5.67 keV [1] and the decrease in the intensity of gamma radiation. It is known that the nucleus of an atom, which is in an excited state, can go into the ground state not only by emitting a γ-quantum, but also by transferring the excitation energy to one of the electrons of the atomic shell. Such a process is called the internal conversion of γ-radiation [2].




The presented phenomenon differs from internal conversion in that it is induced from the outside, i.e. external conversion of γ-radiation is observed.

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***Poster report***

# Characterization of few-layer nanographene clusters prepared by solid phase pyrolysis method: structure and magnetic properties

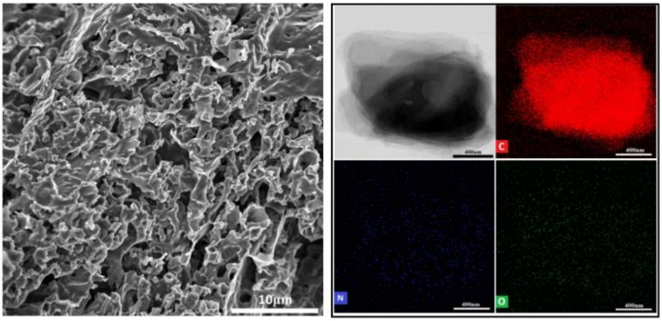
**H. Gyulasaryan[1], D.B. Tolchina[2], L.A. Avakyan[2], V.V. Srabionyan[2], A.T. Kozakov[3], A.V. Nikolskiy[3], I.V. Pankov[4], A.A. Tsaturyan[4], A.V. Emelyanov[5], R.G. Chumakov[5], E.G. Sharoyan[1], A.S. Mukasyan[6], L.A. Bugaev[2], A.S. Manukyan[1]**

*[1]Institute for Physical Research, National Academy of Sciences of Armenia, Ashtarak 0203, Armenia*
*[2]Faculty of Physics, Southern Federal University, Zorge str., 5, Rostov-on-Don, 344090 Russia*
*[3]Institute of Physics, Southern Federal University, Stachki Ave., 194, Rostov-on-Don, 344090 Russia*
*[4]Institute of Physical and Organic Chemistry, Southern Federal University, Stachki Ave., 194/2, Rostov-on-Don, 344090, Russia*
*[5]National Research Center "Kurchatov Institute", Kurchatov sq., 1, Moscow, 123182, Russia*
*[6]Department of Chemical and Biomolecular Engineering, University of Notre Dame, Notre Dame, IN 46556, USA*

gharut1989@gmail.com

The study of ferromagnetism in 2D nanographite or nanographene materials composed solely of s- and p-electrons is a rapidly advancing field of science. Recent research, both experimental and theoretical, has suggested that the unique electronic structure of carbon can give rise to ferromagnetic correlations that persist even at high temperatures. Investigations have shown that by replacing certain carbon atoms in a graphene sheet with trivalent atoms like B or Si, it is possible to induce a significant magnetic moment in the system. This kind of doping not only affects the electrical properties but also enhances the porosity and surface area of nanographene. In particular, nitrogen-doped graphene clusters have attracted interest in various applications such as spintronics, supercapacitors, Li-ion batteries, fuel cells, field-effect transistors, and photocatalysis.

In this work, nitrogen-containing carbon samples were synthesized by solid-phase pyrolysis of metal free phthalocyanine and phthalonitrile at various pressures (p). Complex structural and magnetic studies were performed to reveal the structural features of the samples, their dependencies of the synthesis conditions and relationship with the nature of magnetization in the synthesized samples.




***Poster report***

## Forecasting of light-matter interaction in liquid crystals with physics-informed neural networks based on the complex Ginzburg-Landau equation

**A.A. Hayrapetyan[1], V.D. Yeranosyan[2], H.R. Janesian[2], M.S. Rafayelyan[1]**

*[1] Yerevan State University, Institute of Physics, 1 Alex Manoogian*
*[2] American University of Armenia, College of Science and Engineering, 40 Marshal Baghramyan*

aleqsandr.hayrapetyan@ysu.am

The Complex Ginzburg-Landau (CGL) equation plays a paramount role in describing the behavior of complex nonlinear physical systems, particularly in the modeling of light-matter interaction in liquid crystal (LC) systems [1]. Namely, the CGL equation is used to model the spatiotemporal complexity of far-from-equilibrium dynamics in liquid crystals [2]. This study presents a novel application of Physics-Informed Neural Networks [3] (PINNs) to the CGL equation, thereby pioneering a model tailored to its structure for an enhanced prediction of state dynamics. The model, being rooted in the CGL equation represented as

$$\partial A_t = \mu A + (1 + ib)\Delta A - (1 + ia)|A|^2 A,$$

effectively forecasts dynamic states over space and time [1]. In the context of our study, we specifically set the parameters b and a to be equal to zero. However, we deviate from the conventional approach where the bifurcation parameter $\mu$ adjacent to A is a constant. Instead, we introduce a spatiotemporally variable bifurcation parameter denoted by $\mu$, thereby extending the complexity and applicability of our model. In our work, the CGL equation was integrated into the loss function of the PINN. The prediction of the spatiotemporal dynamics were obtained via a dense network and used to retrieve the bifurcation parameter. Notably, our model accurately predicted the bifurcation parameter, $\mu$, which is essential for system dynamics. This novel use of PINNs offers promising progress towards forecasting and controlling spatiotemporal dynamics of liquid crystals under the complex light-matter interaction governed by the CGL equation.

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***Poster report***

# Effect of $Mg^{2+}$, $Ca^{2+}$ and $Li^{+}$ Ions on Radiation Tolerance of GSAG:Ce Scintillator Under Gamma-Ray Irradiation

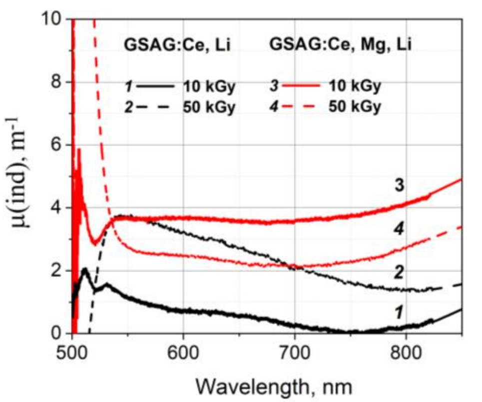
**K.L. Hovhannesyan[1], M.V. Derdzyan[1], I.A. Ghambaryan[1], C. Dujardin[2,3], A.G. Petrosyan[1]**

[1] *Institute for Physical Research, National Academy of Sciences of RA, Ashtarak 0203, Armenia*
[2] *Universite Claude Bernard Lyon 1, Institut Lumière Matière UMR 5306 CNRS, F-69622, Villeurbanne, France*
[3] *Institut Universitaire de France (IUF)*

khovhannisyan9@gmail.com

GSAG:Ce crystals attracted a renewed interest, since unlike gallium multicomponent garnets, they can be grown using Mo crucibles, instead of highly expensive Ir [1]. These crystals possess moderate light yield (10160 ph/MeV) and scintillation decay time (70-120 ns) which, as expected, can be improved by optimizing the composition. High radiation hardness is of crucial importance, when considering applications in high energy physics. In this work radiation tolerance is studied in a series of GSAG:Ce crystals with co-dopants which in other garnets have proved efficient to shorten the scintillation decay time and modify the defect structure [2].

GSAG:Ce single crystals with $Mg^{2}$+, $Ca^{2+}$ and $Li^{+}$ ions were grown by the Bridgman method. The samples were irradiated to 10 and 50 kGy doses by a $^{60}Co$ gamma-ray source. GSAG:Ce without co-dopants exhibits radiation induced absorption coefficient, μ(ind), of around 3 $m^{-1}$, however the initial transmission is low due to as-grown color centers. The least values of μ(ind) are revealed in $Li^{+}$ and $Li^{+}$:$Mg^{2+}$ co-doped crystals, as presented on the Figure. For the Li+ co-doped crystal μ(ind) is increasing with the dose. Unlike, for the $Li^{+}$:$Mg^{2+}$ containing crystal, μ(ind) is decreased after the second dose indicating that the color centers formed under exposure to a lower dose in the course of irradiation with a higher dose are either modified or destroyed.




The work was supported by SCS Armenia (project 21AG-1CO30).

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***Poster report***

# The influence of a random component in the structure of a periodic grating on the diffraction pattern of a plane wave in the near field

**A. Zh. Khachatrian**

*National Polytechnic University of Armenia*

ashot.khachatrian@gmai.com

The problem of the influence of structural disorder of the periodic distribution of slits of a flat grating on the character of the diffraction of a plane wave field is considered. It is assumed that all the slits of the diffraction grating are identical and the waves emanating from them are spherical. The random components of the diffraction grating are the positions of the slits, which on average determine the ideal periodic structure. The problem consider in the near field approximation, when the observation screen is perpendicular to the grading plane. In the case the diffracted field intensity is given by (see, for example, [1]):

$$I(\vec{\rho},t)=\frac{1}{2}\left(\frac{a}{R_0}\right)^2\sum_{p=1}^{N}\sum_{p'=1}^{N}\cos^2\left[\frac{(\vec{r}_p)^2-(\vec{r}_{p'})^2}{2R_0}k-\frac{\vec{\rho}(\vec{r}_p-\vec{r}_{p'})}{R_0}k\right], \tag{1}$$

where $R_0$ - distance between the grating and the screen, $k$ - the wave number, the vector $\vec{r}_p$ indicates the $p$-th slit position in a grating, the vector $\vec{\rho}$ indicates the position of the observation point on a screen.

In accordance with the above mentioned the vector $\vec{r}_p$ has deterministic and random components;

$$\vec{r}_p=\vec{l}_p+\vec{\Delta}_p, \tag{2}$$

where $\vec{l}_p$ indicates the location of $p$-th slit in the ideal grating, and $\vec{\Delta}_p$ is the random vector with middle values of components equal to zero. Our consideration is devoted to investigation of the intensity expression (1) averaged over randomness in the locations of the slits. In particular we have investigated the influence of randomness on the Talbot effect, which as it is known, appears when $R_0=d^2/\lambda$ ($k=2\pi/\lambda$). Note, due to the wide range of applications, this issue has recently become the subject of intensive research [2-5].

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***Poster report***

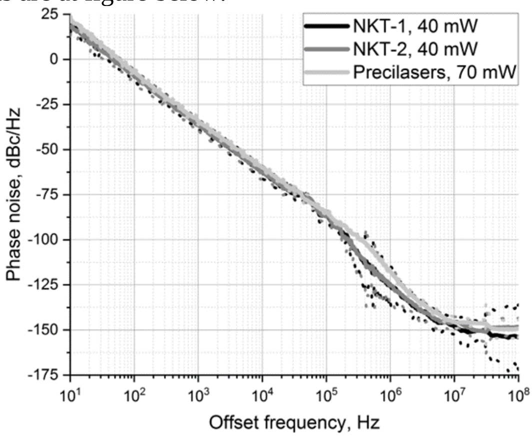
# Application of three-corned hat to phase noise measurements of single-frequency lasers

**K.A. Zagorulko[1], A.V. Kozlov[1,2], N.P. Khatyrev[1]**

[1]*Russian Metrological Institute of Technical Physics and Radio Engineering, Mendeleevo, Russia.*
[2]*National research nuclear university MEPhI (Moscow engineering physics institute), Moscow, Russia*

AlexKozlowV@yandex.ru

Single-frequency lasers (SFLs) are widely used in various application areas [1]. For many applications, the most important parameter of the SFLs is the phase noise (PN). Optical PN spectra are measured using optical heterodyne method [2]. The RF beat note signal of the laser under test and the heterodyne laser (HL) can be measured with a photodiode. However, there is no HL for devices with ultralow PN. In this case, another laser with close PN can be used. Thus, the sum of the noise of the two lasers is measured. It is impossible to calculate the noise of each of the lasers. To solve this issue we applied the three-corned hat (TCH) method [3] for PN measurements of lasers. Three lasers with similar PN are required. TCH is to perform a pairwise PN measurements for all lasers. A highly linear photodiode and a R&S FSWP8 PNA were used to measure beat note signal of two fiber lasers Koheras BASIK by NKT Photonics and fiber laser by Precilasers. Measurement results are at figure below.




In conclusion, we applied TCH for PN measurements of SFLs. Separate noise components of different lasers were calculated with their uncertainties.

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***Poster report***

# Thermoelectric photodetector for 7.1 eV single photon detection

**A.A. Kuzanyan, A.S. Kuzanyan, V.R. Nikoghosyan, S.R. Harutyunyan**

*Institute for Physical Research of NAS of Armenia, Ashtarak, 0204, Armenia*

akuzanyan@yahoo.com

Research in the ultraviolet (UV) region of the electromagnetic spectrum spans various fields including astronomy, cosmology, planetary science, bio-imaging, and medical applications. Accurate detection of faint objects and single photons is often necessary in these studies. Photomultiplier tubes (PMTs), the first technology for photon-counting in the far UV region, suffer from limitations such as low dark count rate, large size, high bias voltages, sensitivity to magnetic fields, low efficiency, and large volume. Deep UV Avalanche Photodiodes (DUVAP) offer improved performance compared to PMTs. Today, superconducting nanowire detectors (SNSPDs) exhibit exceptional characteristics, setting new records in the field [1]. Thermoelectric single-photon detectors (TSPDs) hold great promise as the foundation for a next-generation of single-photon detectors [2].

In this study, we present computer simulation results of heat propagation in TSPD detection pixels following the absorption of photons with 7.1 eV energies ($\lambda = 175$ nm). We consider TSPD multi-layer detection pixel designs with different dimensions and materials, including a W absorber, $La_{0.99}Ce_{0.01}B_6$ sensor, and W heat sink on an $Al_2O_3$ substrate. The simulations, performed using the finite difference method, demonstrate that the maximum change in temperature occurs at the center of each layer. Temperature decreases as the layers move away from the photon thermalization zone. The average temperature difference at the sensor boundaries is significantly larger than at the heat sink boundaries. Decreasing the sensor thickness leads to higher temperatures at the sensor-heat sink interface. When the surface of the detection pixel is reduced by a factor of 4, the difference in average temperatures at the sensor boundaries amplifies, while the previously observed patterns remain unchanged. With an increase in the thickness of the absorber, the equivalent noise power increases linearly and is greater for the detection pixel with a surface of 1 μm$^2$. However, the signal power is higher for a 0.01 μm sensor thickness across all absorber thicknesses, resulting in a signal-to-noise ratio (SNR) greater than 1 for an absorber thickness of 0.04 μm. Examining higher energy photon signals can further improve the SNR.

The work was supported by the Science Committee of RA, in the frames of project N 1-6/23-I/IPR.

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***Poster report***

# Enhancement of Power Factor in $B_4C$-added $Bi_2Sr_2Co_{1.8}O_y$ Thermoelectric

**A.A. Kuzanyan**[1], **N.G. Margiani**[2], **G.A. Mumladze**[2], **I.G. Kvartskhava**[2], **V.V. Zhghamadze**[2], **G.R. Badalyan**[1], **A.S. Kuzanyan**[1]

[1]*Institute for Physical Research of NAS of Armenia, Ashtarak, 0204, Armneia*
[2]*Georgian Technical University, 77 Kostava str., Georgia*

astghik.kuzanyan@gmail.com

Thermoelectrics may generate clean energy by transforming waste heat directly into electricity. The wide-scale implementation of thermoelectric generators is expected to advance with the development of high-performance materials. The findings of p-type thermoelectric cobaltites attracted the interest of researchers worldwide. Cobaltites are useful, with many attractive characteristics such as excellent chemical robustness, low cost, environmental friendliness, and safe application in air. Nonetheless, the application of cobaltites remains a challenge due to their comparatively low performance when compared to conventional ones. Introduction of suitable dopants and additives is viable way to improve the functional characteristics of thermoelectrics. In this study, $Bi_2Sr_2Co_{1.8}O_y$ + x wt % $B_4C$ (x = 0, 0.15, 0.50, and 0.80) samples have been prepared via the solid-state reaction. Temperature dependences of electrical resistivity (ρ) and Seebeck coefficient (S) were measured, and power factor $PF = S^2/\rho$ was calculated.
In the whole temperature range of 20-700 ºC, the Seebeck coefficients are positive and increase with the increasing temperature. This indicates that synthesized materials are p-type conductors. All the thermoelectrics prepared in this study possess similar S values across the whole temperature range. At the same time, the addition of $B_4C$ significantly increases the apparent density of $Bi_2Sr_2Co_{1.8}O_y$ system up to 90 % of the theoretical density, which benefits electrical conductivity. As a result, the PF value of $B_4C$-added samples increases. The maximum PF value of 0.094 mW/K$^2$•m was reached in $Bi_2Sr_2Co_{1.8}O_y$ + 0.15 wt % $B_4C$ composition at 700 ºC, which is nearly 2-fold higher compared to the reference one.
This work was supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG) PHDF-22-442/Influence of borax doping on the thermoelectric performance of layered cobaltites.

***Poster report***

# Application of Strong Light-Induced Dichroism in Rubidium Vapor in the Bell-Bloom and Hanle Configurations for Detecting Weak Magnetic Fields

**A.O. Makarov**[1,2], **V.I. Vishnyakov**[1], **D.V. Brazhnikov**[1,2], **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*

werklore@mail.ru

Atomic magnetometers (AMs) have found many applications in fundamental physics (e.g., searching the dark matter or the permanent electric dipole moment of the neutron) as well as in applied sciences: medicine, biology, geophysics, space missions, etc. These quantum devices are based on laser spectroscopy of alkali-metal vapors and demonstrate subpicotesla sensitivity.

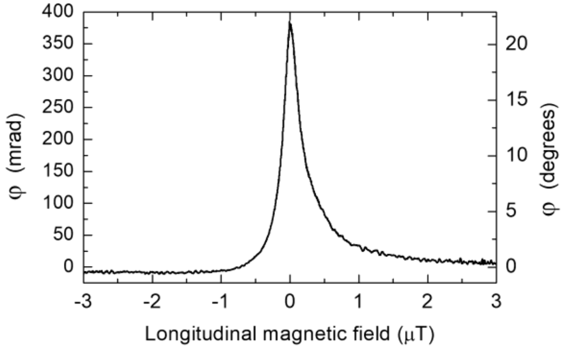


**Fig. 1.** Observation of giant NMOR in a $^{87}$Rb vapor cell caused by a linear dichroism.

Here we study two modifications to the standard atomic magnetometry schemes. The first one concerns the Bell-Bloom method of scalar magnetic field measurements. This method commonly uses a modulated light beam with circular polarization. We propose to use an elliptically polarized beam and a polarimeter to monitor a change in the beam's ellipticity which is caused by a circular dichroism. In our experiments, we used a buffer-gas-filled 5 mm long $^{87}$Rb vapor cell. The second modification deals with a nonlinear magneto-optical rotation (NMOR) of the linear polarization of the probe light wave. We exploit the scheme with two counter-propagating waves with a mutual angle between their linear polarizations equaled to 45°. A rotation angle as large as 22° has been observed at the vapor cell length of 20 mm [1]. The estimations show that both techniques have good prospects for developing AMs of subpicotesla sensitivity. The work was supported by Russian Science Foundation (Grant no. 23-12-00195).

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***Poster report***

## Laser vibrometer with a tapered component

**A. E. Martirosyan, R. B. Kostanyan, P. H. Muzhikyan**

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

arturmart01@gmail.com

Vibration sensors or vibrometers, often based on accelerometers or laser technology, measure the vibration level of a machine or its components, and careful analysis of obtaining results allows one to diagnose defects of various structures. Relatively cheap portable vibrometers using piezoelectric-type acceleration sensors are suitable for measuring the general vibration of mechanical equipment [1].

In this article, a pyramidal horn is used as a vibrating element, through which a helium-neon laser beam is passed. The horn is made of a metal sheet with a nickel-plated inner surface that provides an almost complete reflection of the incident beam. The horn's exit diameter is 3 mm, the apex angle $\varphi$ and length are equal to $16^0$ and 100 mm, respectively.

A vibration source attached to the horn vibrates it, which causes the laser beam to shift (after reflections) longitudinally at the horn's exit window. We indicate that this shift of about one order of magnitude exceeds the vibration level of the horn's walls. This effect can be explained with the help of [2], whence it follows that with the deviation of the horn apex half-angle by $\Delta\varphi$, the longitudinal path of the ray after multiple reflections in the horn shifts by Cot ($\varphi/2 \pm\Delta\varphi$). The vibration of beam at the edge of the horn's exit window results in modulation of the output laser beam power observed by the detector and oscilloscope.

In the experiment, the vibration source vibrates the horn in the frequency range of 10 Hz - 10 KHz. The maximum modulation of the beam is observed in the range of 100 - 200 Hz, when the modulation amplitude reaches 70% of the beam power with the vibration source turned off. In this range, the transverse vibration of the source is 14 μm.

The obtained results show that the sensitivity of the presented simple setup makes it possible to detect small vibrations with an amplitude of 1 nm, which is 3 orders of magnitude higher than the sensitivity of piezoelectric vibrometers [1].

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***Poster report***

## Effect of air-annealing on the optical properties of YAG:Ce,Li crystals

**A. Novikov, A.G. Petrosyan**

*Institute for Physical Research, NAS of Armenia, Ashtarak 0204, Armenia*

Artur.novikov80723@gmail.com

Due to high light yield (25000 ph/MeV) and reasonably fast scintillation decay time (70 ns), yttrium aluminum garnet doped with $Ce^{3+}$ ions ($Y_3Al_5O_{12}$:Ce; YAG:Ce) is often used in scintillator and phosphor applications. The scintillation decay time can be noticeably shortened, if a part of $Ce^{3+}$ is converted to the $Ce^{4+}$ state, as revealed in YAG:Ce and LuAG:Ce crystals co-doped with divalent impurities [1,2] or subjected to air-annealing [3], which are efficient ways to stabilize $Ce^{4+}$ states. In this work we have studied the effect of co-doping with monovalent $Li^+$ combined with post growth air-annealing on optical properties of YAG:Ce,Li.

Single crystals of YAG:Ce и YAG:Ce,Li were grown by the vertical directional crystallization. Absorption spectra of crystal samples in the form of 1 mm thick plates with similar $Ce^{3+}$ concentration have been measured at room temperature in the 190-1100 nm range before and after air-annealing carried out on pairs of crystals (1300 C/24 h). Comparison has shown that absorption in the range below 350 nm is higher in annealed $Li^+$ co-doped sample. Absorption in this range is commonly assigned to ionization of $Ce^{3+}$ and ligand to metal charge transfer to $Ce^{4+}$ ions [2]. According to the difference spectra, absorption between 200 and 310 nm induced by air-annealing is twice higher in the $Li^+$ co-doped sample, thus indicating a higher efficiency of $Ce^{3+}$ to $Ce^{4+}$ conversion. The observed decrease of $Ce^{3+}$ absorption band intensity at 340 nm after annealing is more pronounced in $Li^+$ co-doped crystal. As shown in our previous work [4], $Li^+$ ions, when introduced into YAG in small amounts, do not substitute for lattice sites but are located at interstitials with charge compensation maintained via reduction of oxygen vacancies. Thus, a higher efficiency of $Ce^{3+}$ to $Ce^{4+}$ conversion in the process of air-annealing in the $Li^{+}$-containing sample is directly related to the smaller concentration of oxygen vacancies. Scintillation decay measurements may answer whether the suggested way can be an alternative to the divalent co-doping approach.

The work was supported by SCS Armenia (project 21AG-1C030).

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***Poster report***

# Copper oxide nanoparticles synthesized by laser ablation in liquid media: morphology, structure and optical properties

**N. Tarasenka[1], N. Tarasenko[1], S. Pashayan[2], V. Anishchik[3], A. Butsen[1, 4], V. Kornev[1], S. Zlotski[3], O. Korolik[3]**

*[1]B. I. Stepanov Institute of Physics, NAS of Belarus, Nezalezhnasti Ave., 68,220072, Minsk, Belarus [2]Institute for Physical Research, NAS of Armenia, 0204, Ashtarak-2, Armenia*
*[3] Belarusian State University, Nezalezhnasti Ave. 4, 220030, Minsk, Belarus*
*[4] Belarusian State Technological University, Sverdlov str., 13a, 220006, Minsk, Belarus*

stpashayan@gmail.com

Among different of NPs synthesis methods an approaches based on laser ablation in liquids (LAL) have important advantages [1-2]. LAL is a plasma-assisted process, which takes place in a liquid environment at room temperature and pressure without the addition of any harmful chemicals. LAL method makes it possible to obtain NPs of metals and their oxides in most cases. Oxide nanostructures have a wide range of applications in the optoelectronic, laser technology, solar cells, sensors and detectors, biomedicine and catalysis, etc. [1-3]. Copper oxide NPs synthesized in various liquid-phase media are considered as objects in this study. Quasi spherical NPs with similar morphology were obtained by focusing the radiation of the $Nd^{3+}$: YAG laser (LOTIS TII, LS2134D, Belarus), operating in a double-pulse mode at 1064 nm, on a surface of Cu or CuO target.

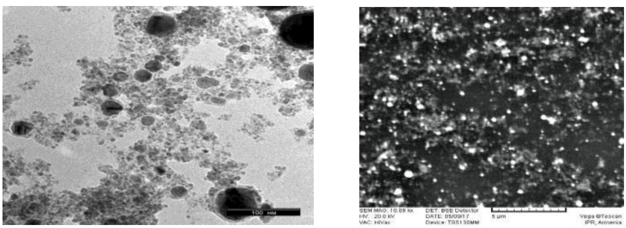

**Fig. 1.** TEM (left) and SEM (right) images of CuO NPs

Structural, morphological and optical properties of the formed NPs have been investigated by SEM, TEM, EDX, XRD, UV-Vis and Raman spectroscopy. It is shown that the composition and morphology of NPs can be controlled by varying the composition and properties of the target and the liquid medium in which synthesis process takes place. It has been established that laser ablation in acetone also leads to the formation of the NPs of metallic copper, but the change of the solvent to distilled water allows forming mainly oxide NPs. However, when the CuO target is ablated, a weak broad plasmon band with a peak of about 633 nm (1.96 eV) is observed in water, which indicates the formation of copper metal NPs along with oxide nanostructures. Thus, LA in a liquid can serve as a tool to obtain NPs of a controlled morphology, composition and internal structure.

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***Poster report***

# Nonlinear light absorption in titanium carbide (MXene)

**P. Petrosyan**

*Yerevan State University, Yerevan, Armenia*

petrospetrosyan00@gmail.com

MXenes comprise a new class of 2D transition metal carbides, nitrides, and carbonitrides that exhibit unique light–matter interactions. Recently, 2D $Ti_3CNT_x$ ($T_x$ represents functional groups such as - OH and - F) was found to exhibit nonlinear saturable absorption (SA) or increased transmittance at higher light fluences, which is useful for mode locking in fiber-based femtosecond lasers [1]. Several experimental groups have obtained noticeable nonlinearities in MXenes that were interpreted in terms of saturation of the nonlinear absorption coefficient and the transmission in a two-level atomic system [1,2]. However, the fundamental origin and thickness dependence of SA behavior in MXenes remain to be understood. In this communication we calculate the nonlinear absorption in $Ti_3C_2T_x$ taking into account band structure of this 2D material. The peculiarities of nonlinear absorption caused by complex density of states of the charge carriers are identified. The saturation intensities for realistic band structure of carriers are calculated demonstrating good agreement with experimental data.

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***Poster report***

# Field-effect transistor based on zinc oxide films with the use of diffuse technology

**N.R. Aghamalyan[1], A.A. Arakelyan[1], R.K. Hovsepyan[1], Y.A. Kafadaryan[1], H.G. Mnatsakanyan[1], A.R. Poghosyan[1], T.A. Vartanyan[2]**

[1] *Institute for Physical Research, Ashtarak-2, Armenia*
[2] *Univ. of Information technology, Mechanics and Optics, Sankt-Petersburg, Russian Federation*

apoghosyanipr@gmail.com

A new technology has been developed for local diffuse doping of certain sections of a ZnO film with donor (Ga) and acceptor (Li) impurities to create a transparent field-effect transistor with an n-type channel. The field effect and electrophysical and photoelectric characteristics of the obtained transistors were studied. Field-effect phototransistors based on these structures have been developed and their photoelectric characteristics have been studied; the mechanism of photoelectric amplification in them is proposed.

Diffuse doping was carried out in three stages. The first one is deposition of ZnO:Li and ZnO:Ga films on the sapphire substrate as diffuse layers. In this case, the regions of the acceptor and donor impurities do not intersect. The second is the deposition of the main layer of ZnO. As a result, we obtain a sandwich consisting of two layers: the lower layer is a diffuse layer, the upper layer is a ZnO film. By controlling the thicknesses of the diffuse and the main layer, the desired impurity concentration can be obtained. The third stage is the process of thermal diffusion: the temperature must be sufficient for diffusion into the ZnO film and not sufficient for diffusion into the substrate. This technology has allowed to create a field-effect transistor in which the Li concentration in the channel was 0.8 at.%, and the Ga concentration in the drain-source region was 2 at.%.

A comparative analysis of the electrical parameters of transparent transistors obtained by diffuse doping with the data of transistors obtained by doping with donor and acceptor impurities during film growth is carried out.

***Poster report***

## Optical detection of IR laser pulses in transparent ferromagnetic crystals

**Y. Sahakyan**

*Yerevan State University, Alek Manukyan 1*

yuri.sahakyan@edu.ysu.am

Ferrimagnetic materials have found extensive utility across diverse scientific and technological fields, particularly, to control of electromagnetic radiation, recording and storage information, etc. In recent decades, many studies have been carried out on the nonlinear interaction of IR and optical radiation with ferromagnets. However, the results of these studies are interpreted by different authors differently and remain the subject of debate [1,2]. Therefore, further research is needed to identify the mechanism of these nonlinear interactions.

In this work, we experimentally study the optical detection of infrared laser pulses ($\boldsymbol{\lambda}$ = 1.06 μm) in various transparent ferrimagnets, particularly, in single crystals of yttrium iron garnet ($Y_3Fe_5O_{12}$) and yttrium orthoferrite ($YFeO_3$) at room temperature. It is shown that the experimentally obtained magnitudes of the detected signals strongly depend on the magnetization degree of ferrimagnetic samples and correlate well with their static magnetization curves.

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***Poster report***

# Use of lasers for restoration of the original color appearance of decorative iron-based metal artworks

**M. Salhab[1], V. Parfenov[1], I. Ruzankina[1,2], O. Zotov[3], O. Vasiliev[4]**

[1]*St. Petersburg Electrotechnical University "LETI", Saint Petersburg, Russia*
[2]*KU Leuven, Leuven, Belgium*
[3]*Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russia*
[4]*Laser Center LLC, Saint Petersburg, Russia*

mhmadsalhab@gmail.com

One of the most difficult tasks of modern museum work is the restoration of decorative decoration, the so-called "bluing". Bluing is the process of obtaining a layer of iron oxides of various colors (blue, yellow, and some others) on the surface of carbon, low-alloy steel, or cast iron. As a result of environmental influences, primarily corrosion, the bluing may be damaged or may disappear completely. To restore the original color of such objects, it is necessary to approach them with maximum accuracy without harming the surface of the product.
Traditional methods of restoration, including chemical and mechanical treatment, can lead to damage to the surface of the object, which makes them unsuitable for use in relation to cultural heritage objects. Laser treatment can be considered a potential alternative to traditional restoration methods since it provides a non-contact surface treatment method.
At the moment, lasers are already widely used in the preservation of Cultural Heritage, but mainly for the characterization of the chemical and structural compositions of objects and the removal of natural and anthropogenic pollution from their surfaces [1–3]. Because this work is focused on the study of the use of lasers for the reconstruction of lost bluing, the obtained results may be considered a new approach to the use of lasers for the restoration of artworks.

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***Poster report***

# Anisotropic elastomers for laser beam steering

**M. Sargsyan[1], G. Gevorgyan [1], M. Hakobyan[1], R. Hakobyan[1], M. Reynolds[2], H. Gleeson[2]**

[1]*Institute of Physics, Yerevan State University, Yerevan 0025, Armenia*
[2]*School of Physics and Astronomy, University of Leeds, Leeds, UK*

maqsim.sargsyan@ysu.am

The demand for precise laser beam steering has led to the exploration of new materials and devices. Liquid crystal elastomers (LCEs) have emerged as promising candidates due to their unique mechanical and optical properties [1, 2]. LCEs can change shape and optical characteristics in response to external stimuli such as heat, light, and mechanical forces, making them ideal for creating adjustable optical devices [3, 4]. Additionally, unlike liquid crystal-based

beam steerers, LCE-based ones not only provide complete optical control, but also can be easily integrated, making them highly attractive for compact and efficient optical systems [5, 6]. Of particular interest are mechanically-tunable devices, which can use elastomers' anisotropy to achieve controlled deformation, thus enabling dynamic control over laser beam deflection and polarization. However, the creation of those LCE-based devices remains challenging, primarily due to the need to fully understand their mechanical properties for proper design and integration. In this study, we measured the five elasticity coefficients entering the elastic free energy density expression of monodomain nematic LCE. By connecting measured strains and elasticity coefficients and using data obtained from tensile experiments, we estimated the elasticity coefficients for acrylate-based auxetic LCEs [7, 8]. Additionally, we compared these results with previous calculations for acrylate-amine-based LCEs [9]. The results obtained support ongoing efforts to fully understand the properties of LCEs and to develop mechanically-controlled devices. Continued research and advancements hold the potential to transform laser beam steering technology, enhancing performance and expanding functionality in industrial and scientific fields.
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***Poster report***

## Exploring the true rotatory power of frustrated cholesteric liquid crystals through experimental polarization studies

**T.M. Sarukhanyan, M.S. Rafayelyan, M. Sargsyan, G. Gevorgyan, R. Hakobyan, R.B. Alaverdyan**

*Yerevan State University, Institute of Physics, Alek Manukyan 1, 0025, Yerevan, Armenia*

tatevik.sarukhanyan@ysu.am

Liquid crystals continue to be the focus of researchers due to the controllability of their properties that, for example, can result in a change in light polarization. Optical and topological properties of LCs are often studied under specific boundary conditions. Notably, when an LC with negative dielectric anisotropy is subjected to homeotropic boundary conditions and has a thickness and periodicity nearly equal, it can form a frustrated LC structure (see figure). This unique structure can be induced and manipulated using an external electric/magnetic field or intense light illumination or both electric/magnetic field and intense light illumination. If the sample is thin enough and the applied external voltage is high enough the translationally invariant configuration (TIC)

is generated [1].
In this work, we investigate the behavior of input light polarization passing through a frustrated cholesteric liquid crystal (FLC) layer that is inside the crossed linear polarizers. Our experiments reveal the existence of discrete voltage values that give rise to a pure rotatory power in the frustrated cholesteric liquid crystal layer. Specifically, these voltage values cause the FLC layer to exhibit a remarkable ability to rotate the plane of light polarization.

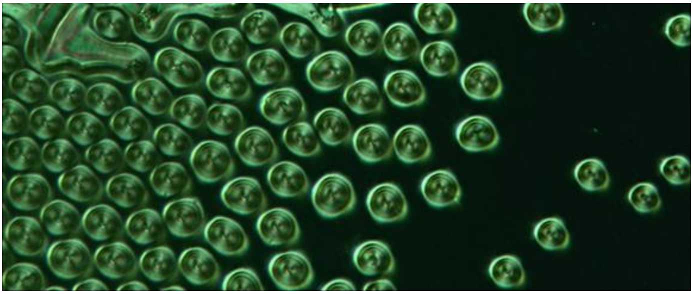

**Fig. 1.** Frustrated liquid crystal structure under a polarizing microscope

By exploiting the controllable properties of liquid crystals, we demonstrate the potential for precise modulation and manipulation of light polarization in the FLC layer. This work opens up exciting possibilities for novel applications in optics, photonics, and display technologies.

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***Poster report***

## Noise sensitivity in the spectral phase measurement technique based on dispersive Fourier transform

**M. Sukiasyan[1,2], A. Avetisyan[1], A. Kutuzyan[1]**

[1]*Yerevan State University, Department of Physics, Ultrafast Optics Laboratory, Yerevan, Armenia*
[2]*CANDLE Synchrotron Research Institute, Yerevan, Armenia*

minas.suqiasyan@ysu.am

Both spectral distribution and spectral phase information are important for accurate pulse reconstruction. The accuracy of pulse reconstruction depends on the quality and accuracy of the spectral measurements. The spectral distribution of intensity measurements is usually performed with higher accuracy than phase measurements. As a result, errors in the reconstruction of the pulse shape are mainly associated with inaccuracies in phase measurements.
To evaluate the effect of noise on the accuracy of the pulse reconstruction, we performed numerical simulations by introducing noisy phase data. This procedure can be implemented in pulse reconstruction experiments to test and evaluate the accuracy of various pulse characterization methods. We apply this procedure to the technique to measure the spectral phase of the ultrashort light pulses based on dispersive Fourier transformation (DFT) or frequency-to-time mapping [1,2].

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***Poster report***

## Controlled quantized adiabatic transport in a superlattice Wannier-Stark ladder

**R. G. Unanyan[1], N. V. Vitanov [2], M. Fleischhauer[1]**

[1] *Fachbereich Physik, University of Kaiserslautern-Landau, Kaiserslautern, D-67663, Germany*
[2] *Department of Physics, St Kliment Ohridski University of Sofia, 5 James Bourchier Blvd, 1164 Sofia, Bulgaria*

unanyan@physik.uni-kl.de

The Born–Fock theorem is one of the most fundamental theorems of quantum mechanics and forms the basis for reliable and efficient navigation in the Hilbert space of a quantum system with a time-dependent Hamiltonian by adiabatic evolution. In the absence of level crossings, i.e. without degeneracies, and under adiabatic time evolution all eigenstates of the Hamiltonian keep their energetic order, labeled by a conserved integer quantum number. Thus, controlling the eigenstates of the Hamiltonian and their energetic order in asymptotic limits allows one to engineer a perfect adiabatic transfer between a large number of initial and target states. The fidelity of the state transfer is only limited by adiabaticity and the selection of target states is controlled by the integer invariant labeling the order of eigenstates. We show here, for the example of a finite superlattice Wannier-Stark ladder, i.e. a one-dimensional lattice with alternating hopping amplitudes and constant potential gradient, that such an adiabatic control of eigenstates can be used to induce perfectly quantized single-particle transport across a pre-determined number of lattice sites.

***Poster report***

## Bi-directional sensing of magnetic field with Cs atomic vapour

**A. Mozers, L. Bušaite, D. Osīte, A. Nikolajevs, F. Gahbauer, M. Auzinsh**

*Laser Centre, University of Latvia, Rainis Boulevard 19, LV-1586 Riga, Latvia*

arturs.mozers@lu.lv

We present a method for magnetic field measurements based on an ensemble of atoms interacting with an optical field. This setup is sensitive along two orthogonal magnetic field components using just two beams from the same laser source. We implement a pump-probe geometry from Le Gal et al [1] where a linearly polarized ($\mathbf{E_p}$) pump beam creates atomic alignment that interacts with the magnetic field ($\mathbf{B_z}$) and the state of the system is probed by a linearly polarized ($\mathbf{E_{s1}}$) probe beam. The implemented pump-probe geometry requires that the angle between the pump ($\mathbf{k_p}$) and probe ($\mathbf{k_s}$) beams is 35.3 degrees which

in turn means that the light from both beams can enter the vapour cell from the same optical port resulting in a more compact system. When an external magnetic field ($\mathbf{B_z}$) is applied in a direction perpendicular both to $\mathbf{E_p}$ and $\mathbf{E_{s1}}$ the initially aligned state starts to precess around $\mathbf{B_z}$. Because $\mathbf{E_{s1}}$ lies in the x-y plane and makes a $\pi/4$ angle with respect to the y-axis, the probe beam yields a dispersive dependence of the absorption on the transverse magnetic field component $\mathbf{B_z}$. For the system to be senstive to magnetic field along x-axis ($\mathbf{B_x}$) we rotate the polarization of the probe beam around $\mathbf{k_s}$ until the $\mathbf{E_{s1}}$ lies in the z-y plane. We implement this rotation of the plane of polarization experimentally by the use of an electro-optic modulator. This enables us to detect two orthogonal components of the external magnetic field from a single experimental setup.

We have performed simulations of the absorption signals for various Cs D1 transitions and studied how the signal is dependent on the Rabi frequency. We have also obtained experimental signals with several combinations of pump and probe beam intensity ratios for all Cs D1 hyperfine transitions. We have also considered the signal shapes for the case when the external magnetic field is in an arbitrary angle with respect to the z-axis in the x-z plane.

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