№ 2/2013

SCIENCE NEWSLETTER

of the Faculty of Physics, Lomonosov Moscow State University

80th Anniversary of the Faculty of Physics

In 1933 Physics-Mathematics Faculty of Lomonosov Moscow State University was spilt into the Faculty of Mechanics and Mathematics and the Faculty of Physics, so that in November 2013 the Faculty of Physics celebrated its 80th anniversary. The respective commemorative meeting was organized at the Intellectual Center-Fundamental Library of Moscow State, and Prof. Nikolay N. Sysoev, dean of the Faculty, delivered a report on the history, nowadays, and the future of our Faculty of Physics.

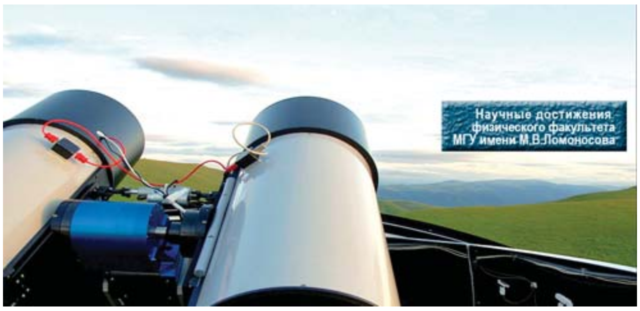
Rector of Lomonosov Moscow State University, Prof. Victor A. Sadovnichii, as well as many other MSU deans, rectors and the directors of the Universities and institutes from allover Russia congratulated the Faculty of Physics and its staff members and students with this wonderful date.

The Academic Chorus of Lomonosov Moscow State University, amateur student groups, and wellknown in Russia bard and musician Sergey Nikitin, our former graduate, were also a part of the program of the commemorative meeting.

Within the frame of 80th anniversary, the Alumni Association of the graduates from the Faculty of Physics organized a conference on "Fundamental science as a precursor of the novel social-valuable technologies and business-organization of modern high-tech businesses", which was a forum for the leading Russian scientists. Plus to that, a Concert of Physical Arts was organized at the MSU Palace of Culture that hosted both the legendary opera "Archimedes" and the best performances from the last "2013 Physicists Day".

In This Issue:

Discovery of optical transients with the help of the telescope-robots MASTER network

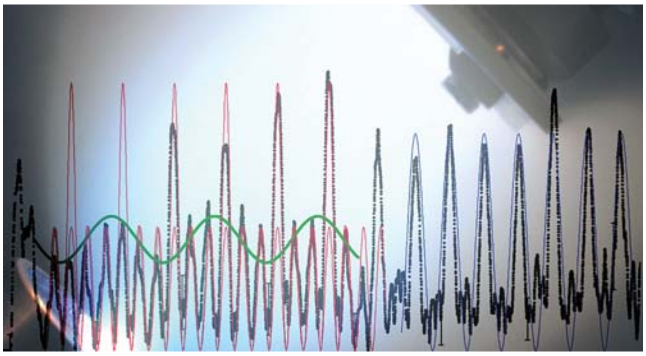


Physicists from Lomonosov Moscow State University discovered with the help of the network of the telescope-robots MASTER two potentially dangerous asteroids and over 180 optical transients — supernova stars, nova and recurrent nova stars, flares of the active nuclei of the galaxies, detection of the glares of unknown origin, etc.

The network of the telescope-robots MASTER has been constructed by a group of scientists from the Division of Astronomy, Faculty of Physics, and Steinberg Astronomical Institute, Lomonosov Moscow State University, headed by Prof. V.M. Lipunov with an aim to register and study the own optical radiation from the gamma-ray bursts, which is the immediate task of the modern astronomy.

In 2013, the major results obtained with the help of the MASTER network are the discovery of the two potentially dangerous asteroids 2013 SW2 и 2013 UG1 and of over 180 optical transients — first kind supernova star, nova and recurrent nova stars, flares of the active nuclei of the galaxies, detection of the glares of unknown origin, and discovering of small bodies of the Solar system (dangerous asteroids and comets inclusive). Plus to that, photometric and polarization measurements of the own optical radiation in 25 areas of the gamma bursts were made in most cases for the first time.

Efficient laser-plasma excitation of phonons with terahertz frequencies in the bulk of a transparent dielectric



Researchers from the Faculty of Physics, Lomonosov Moscow State University have discovered a new mechanism of quasi-resonant excitation of coherent terahertz phonons in a bulk of dielectric with extremely large energy input up to 100 kJ/cm^3. The results of this work were published in *Laser Physics Letters* 10, p.076003, (2013).

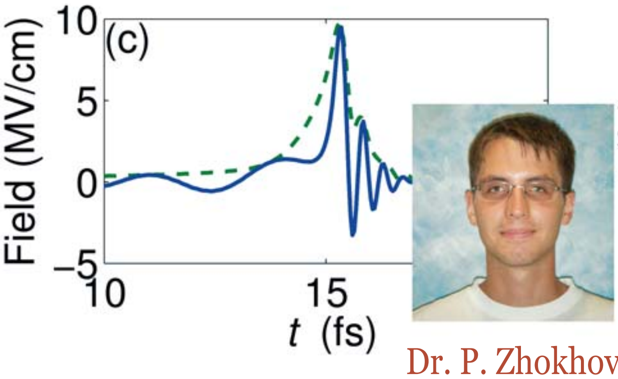
Range of phenomena occurring in the interaction of tightly focused femtosecond laser radiation with dielectrics is quite broad: from multiphoton and tunneling ionization, plasma electrons heating in the laser wave, impact ionization and excitation of coherent phonons and shock-wave propagation and as a result the formation of residual micromodifications. Study of the excitation and relaxation of coherent phonons should be given special attention. They not only give an idea of the vibrational properties of substances, but also can be used to control the molecular and collective motions, get special non-equilibrium states and facilitate chemical or structural changes that cannot be realized under normal conditions.

In their paper, the researchers of the Physics Faculty of Moscow State University, working at the Department of General Physics and Wave Processes, focused mainly on the study of these energy transfer processes: from laser to plasma (due to ionization and heating of the plasma electrons on the time duration of the laser pulse), from laser to phonons (at times of the laser pulse duration) and from plasma to phonons (at the thermalization time of the electron plasma). The main feature of the work is to study the excitation of coherent phonons in the bulk crystals under extreme conditions determined by the laser intensity up to 10^{13} W/cm^2, exceeding the ionization threshold of the medium. In this case, to the process of excitation of coherent phonons by impulsive stimulated Raman scattering one can add the effective laser energy transfer processes in the crystal lattice through the plasma electrons. Laser-induced plasma promotes effective local heating medium, which may lead to a strong change in the frequency of soft Raman active modes in crystals near phase transitions and phonons anharmonicity.

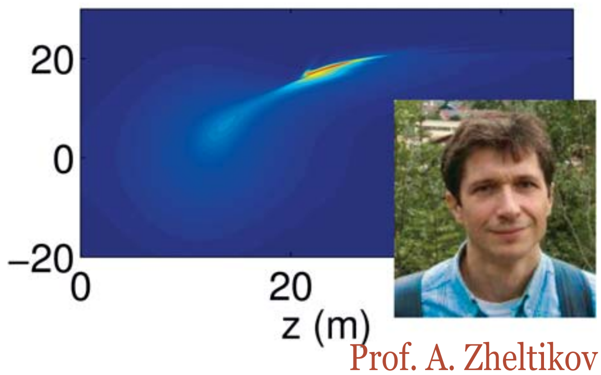
What is the mechanism of excitation and relaxation of coherent phonons in the extreme conditions of laser-induced plasma creation? It was found that the modern theory of the generation of coherent phonons (transient stimulated Raman scattering and displacive mechanism) cannot even outline the key results of the experiments: a strong change of the phonon frequency, the time delay of the maximum amplitude of the phonon modes. It turns out that the first due to stimulated Raman scattering "seed" coherent phonons with terahertz frequencies are generated, and the plasma absorbs a significant part of the laser pulse energy. Plasma energy is then quasi-resonantly transferred from plasma electrons to appeared "seed" coherent phonons. Quasi-resonant nature of energy conversion is possible due to the large amplitude of coherent phonons oscillations, which leads to a synchronous modulation of the dielectric bandgap. Such effective energy transferring from plasma electrons to coherent phonons occurs in phase with the vibrations of coherent phonons when the bandgap becomes minimal. Proposed mechanism for the generation of coherent phonons gives the complete explanation of the observed phenomena.

To perform the work a unique set of engineering equipment purchased under the M.V. Lomonosov Moscow State University Development Program was used.

Attosecond shock waves



Dr. P. Zhokhov



Prof. A. Zheltikov

Existence of optical shock waves of attosecond duration in the propagation of powerful near-infrared laser pulses in low-pressure helium is predicted by the collaboration of physicists from Moscow State University and Texas A&M University.

One of the most exciting applications of the modern nonlinear optics employ the light pulses of ultimately small durations. The development of femtosecond (1 fs $=10^{-15}$ s) lasers brought an opportunity to visualize and control chemical reactions. Attosecond technologies (1 as = 10^{-18} s) will give tools to visualize and control motion of electrons in the atoms and develop, for instance, atomic transistor — elementary unit of the ultrafast quantum electronics of the future.

Existing technologies of attosecond pulse generation are rather complicated and yield low conversion efficiency and low attosecond pulse energy. In the joint work of phyisicists from Moscow State University and Texas A&M University the generation of powerful, multigigawatt attosecond pulses during formation of three-dimensional optical shock waves was simulated.

Formation of the shock waves, or abrupt changes of physical parameters, exhibiting wave-like propagation properties, is a general property of nonlinear wave dynamics and takes place in many branches of physics: astrophysics, nonlinear acoustics, seismology, fluid dynamics and detonation physics. Large class of the shock waves appears when the wave propagation velocity depends on the wave amplitude, which causes the leading edge of the pulse to steepen (if the pulse peak travels faster than the pulse wings) or the trailing edge to steepen (if the pulse peak travels slower than the pulse wings). In nonlinear optics the one-dimensional shock waves are known to exist in the optical fibers. It is also known that one-dimensional shock waves distort the shape of the light pulse, but do not change its duration.

Numerical simulations, performed using the "Lomonosov" and "Chebyshev" supercomputer clusters of the Moscow State University, demonstrate that in the three-dimensional case of free-space propagation the nonlinear spatio-temporal dynamics of the powerful femtosecond (with the initial duration 20–50 fs) laser pulse leads to the formation of the shock wave of attosecond duration (approx. 300 as). Specifically, the propagation medium is chosen to be helium, because helium has the largest transparency band (around 5×10^{15} Hz = 21 eV) among the noble gases, and minimum duration of the shock wave is determined by absorption and dispersion at the edges of the transparency window. Laser pulse with central wavelength 800 nm, duration 30 fs FWHM, power 1.4 TW (or 0.8 Pcr, where Pcr is the cirtical self-focusing power) is loosely focused in the low-pressure helium (helium pressure is 0.02 bar). The formation of the attosecond wave is predicted past the linear focal point, after ~ 20 m of propagation in helium.

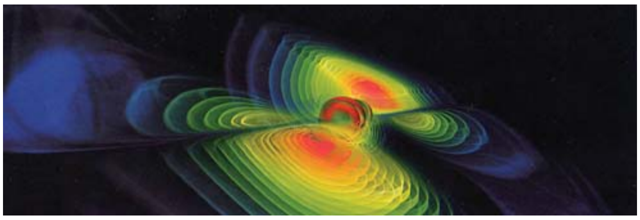
At the attosecond shock wave formation point the energy flux is relatively low (< 2 J/cm^2), which allows one to separate the attosecond pulses using the spectral filter. Such attosecond shock waves will foster the investigation of the laws of nonlinear optics at attosecond time scales and also comprise a promising tool for visualization and control of the electron wavefunctions in atoms. The details of the work are published in *Physical Review Letters*, vol. 110, page 183903 in 2013.

Parallel multisite long-term optical dynamic brain interrogation in freely moving mice

Seeing the big picture of functional responses within large neural networks in a freely functioning brain is crucial for understanding the cellular mechanisms behind the higher nervous activity, including the most complex brain functions, such as cognition and memory. As a breakthrough toward meeting this challenge, implantable fiber-optic interfaces integrating advanced optogenetic technologies and cutting-edge fiber-optic solutions have been demonstrated, enabling a long-term optogenetic manipulation of neural circuits in freely moving mice. Here, we show that a specifically designed implantable fiber-optic interface provides a powerful tool for parallel long-term optical interrogation of distinctly separate, functionally different sites in the brain of freely moving mice. This interface allows the same groups of neurons lying deeply in the brain of a freely behaving mouse to be reproducibly accessed and optically interrogated over many weeks, providing a long-term dynamic detection of genome activity in response to a broad variety of pharmacological and physiological stimuli.

The results of this work have been published in (1), *Scientific reports*, 3, (2013).; (2), *Applied Physics Letters*, 102, 161113 (2013).

Squeezed light enhances sensitivity of the LIGO gravitational waves detector



Physicists from Moscow State Univ. within LIGO International collaboration show that the LIGO detector demonstrates with the injection of squeezed states the best broadband sensitivity to gravitational waves ever achieved.

The existence of gravitational waves was predicted by Einstein almost a century ago. Now, a global network of gravitational wave observatories is seeking to detect gravitational radiation generated by astrophysical sources. In essence, these devices are huge (kilometer-scale) Michelson interferometers, which can measure tiny (attometer-scale) variations of their arm lengths (see Fig.1). Two largest and most sensitive of them, LIGO Hanford Observatory (LHO) and LIGO Livingston Obsevratory (LLO), are operated by the LIGO Scientific Collaboration (LSC) — a group of scientists from many institutions worldwide, including the Faculty of Physics, Lomonosov Moscow State University. In the end of 2011, a squeezed light with reduced quantum fluctuations was injected into the LHO interferometer, resulting in the best broadband sensitivity to gravitational waves ever achieved http://www.nature.com/nphoton/journal/v7/n8/full/nphoton.2013.177.html

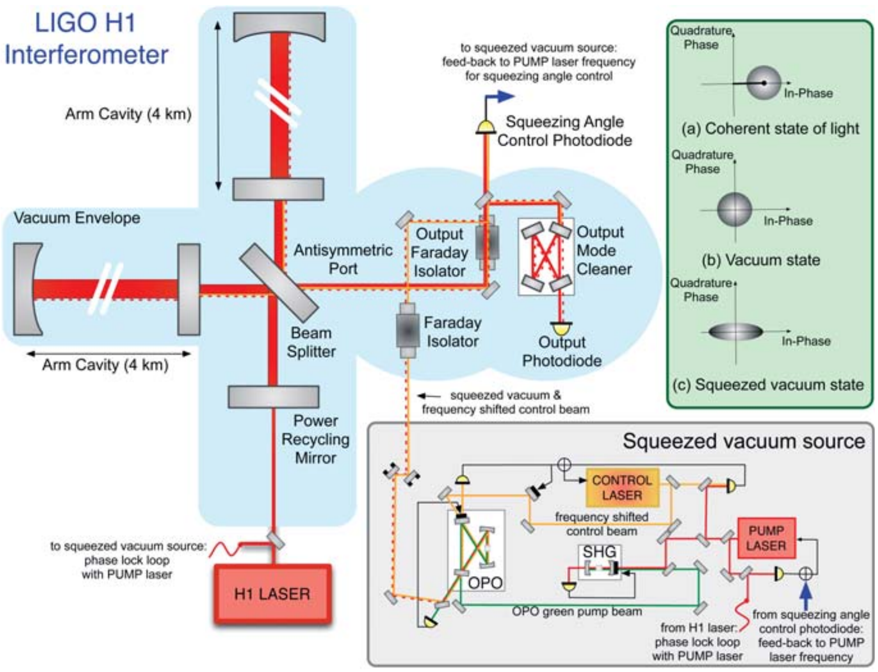


Fig. 1

Scientific News

An electromagnetic field can be described by two non-commuting conjugate operators, known as "phase" and "amplitude" quadratures. A coherent state of light has equal uncertainties in both quadratures, with the uncertainty product limited by the Heisenberg uncertainty principle. For a squeezed state, the uncertainty in one quadrature is decreased relative to that of the coherent state. Note that the uncertainty in the orthogonal quadrature is correspondingly increased, always satisfying the Heisenberg inequality (see the green box in Fig. 1).

The grey box in Fig. 1 shows a simplified schematic of the squeezed state source used in the LHO squeezing experiment. The "pump laser" for the squeezed vacuum source is phase-locked to the main laser of the interferometer ("H1 laser"), and it emits 1.064 nm light, which drives the second harmonic generator (SHG) to produce light at 532 nm. This light, in turn, pumps the optical parametric oscillator (OPO) and produces squeezed vacuum at 1.064 nm via degenerated parametric down-conversion process.

During the reported experiment, the quantum noise was the limiting noise source above 400 Hz and contributed significantly to the total noise down to 150 Hz. The significantly improved sensitivity due to squeezing in this experiment is shown in Fig.2.

The performance without squeezing shown by the red curve. The blue curve shows the improvement in the sensitivity resulting from squeezing, with a 2.15 dB reduction in the noise. This constitutes the best broadband sensitivity to gravitational waves ever achieved.

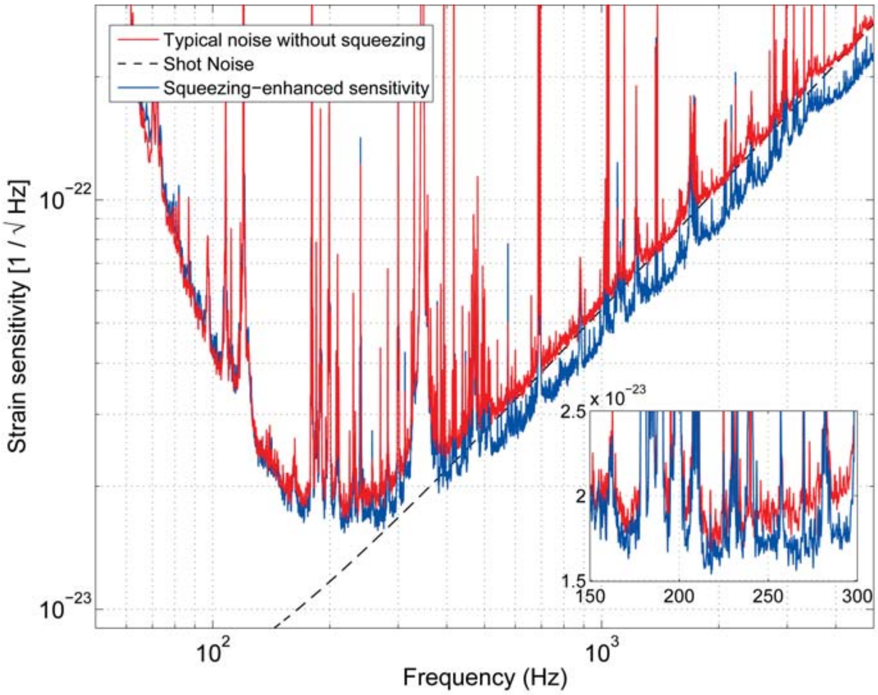


Fig. 2

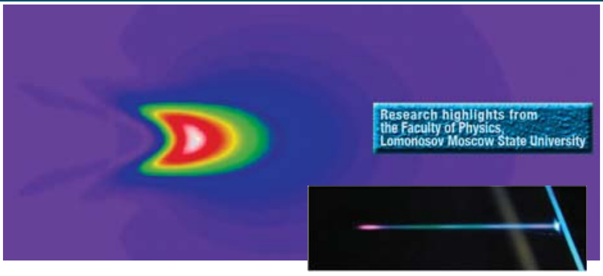
Antisunward structure of thin current sheets in the Earth's magnetotail was predicted

Physicists from Moscow State Univ. in collaboration with researchers from IKI RAS first constructed a two-dimensional quasi-adiabatic model of a thin current sheet in the magnetotail based on its longitudinal inhomogeneity. They predicted an antisunward structure of thin current sheets in the Earth's magnetotail.

A self-consistent kinetic model of thin current sheets (TCS) was developed, taking into account the inhomogeneity of TCS parameters in the antisunward direction. It was shown that the charged particle dynamics depending on the magnetic field distribution in the downtail direction completely determines the magnetotail equilibrium structure. We demonstrate that transient ions as well as electrons are the main current carriers in this system, but the first ones support mostly the background (1D) structure of the current sheet. The influence of electrons and quasi-trapped ions is found to vary depending upon downtail distance along the sheet. Assuming the conservation of the so-called quasi-adiabatic invariant, we show that quasi-trapped particles are distributed along the current sheet in such a way that they concentrate in the region with large values of normal magnetic field component. As a result quasi-trapped ions can dominate near the earthward edge of TCS. In contrast, the electron current becomes stronger in the TCS tailward region where the normal magnetic field component becomes weaker, and field line curvature drifts are enhanced. Our quasi-adiabatic model predicts that thin current sheets in the Earth's magnetotail should have weakly 2D configuration which, similar to its 1D analog considered earlier, conserves the multiscale "matreshka" structure with multiple embedded layers.

The results of this work have been published in H.V. Malova, V.Yu. Popov, D.C. Delcourt, A.A. Petrukovich and L.M. Zelenyi. Antisunward structure of thin current sheets in the Earth's magnetotail: implications of quasi-adiabatic theory, J. Geophys. Res, VOL. 118, 4308–4318 (2013).

LIGHT BULLETS AND SUPERCONTINUUM SPECTRUM FROM FEMTOSECOND FILAMENT

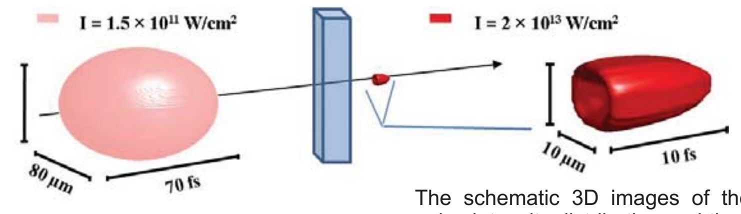


The physicists from MSU numerically predicted and in collaboration with colleagues from the Institute of Spectroscopy RAS experimentally detected the light bullet formation at the filamentation of femtosecond laser pulses under anomalous group velocity dispersion in fused silica. [*Optics Letters*, 38 (1), 16, (2013), *Laser Physics Letters* 10, 105401 (2013), *Quantum Electron.*, 43, 326, (2013)].

The generation of a few-cycle optical pulses and the broadband coherent supercontinuum are the actual tasks of the modern optics. These techniques play a role in the development of the data transmission systems, time-resolved spectroscopy, medical diagnostics, etc. The methods of the pulse parameters control by the dispersion properties of the media could be used in fundamental and applied aspects of the laser physics and nonlinear optics. The formation of the localized in space and time high-power wave packet with soliton-like properties light bullet is the most interest.

During the propagation in the transparent medium, the intense femtosecond pulse induces the formation of autended filament, that could be considered as a self-guiding system. The nonlinear process of pulse propagation in such system is similar to the pulse propagation in optical fibers, photonic crystals and other guiding structures. So there are common regularities between the formation of solitons in nonlinear optical structures with optimal mode dispersion and the formation of light bullets at the filamentation of femtosecond pulse in transparent dielectrics. Narrow filament with high light intensity results from the dynamic balance of Kerr self-focusing and defocusing of the pulse in self-induced laser plasma. Together with Kerr self-focusing, the pulse undergoes the compression that is due to the self-phase modulation. But in presence of the self-phase modulation the dispersion starts playing a significant role. In case of anomalous group velocity dispersion and the positive self-phase modulation, the wave packet continues to compress during nonlinear propagation resulting in a light bullet formation. Such light bullet could be considered as a generalization of the time soliton in a 1D+1 guiding structure on the 3D+1 dimensions in transparent dielectric.

The physicists from the MSU numerically predicted and clarified the regularities of the light bullets sequence formation during 1800-nm pulse filamentation under anomalous GVD in fused silica. The peak intensity of light in the bullet reaches ~$5x10^{13}$ W/cm^2, its duration is about ~ 10 fs and radius is ~ 10 μm.

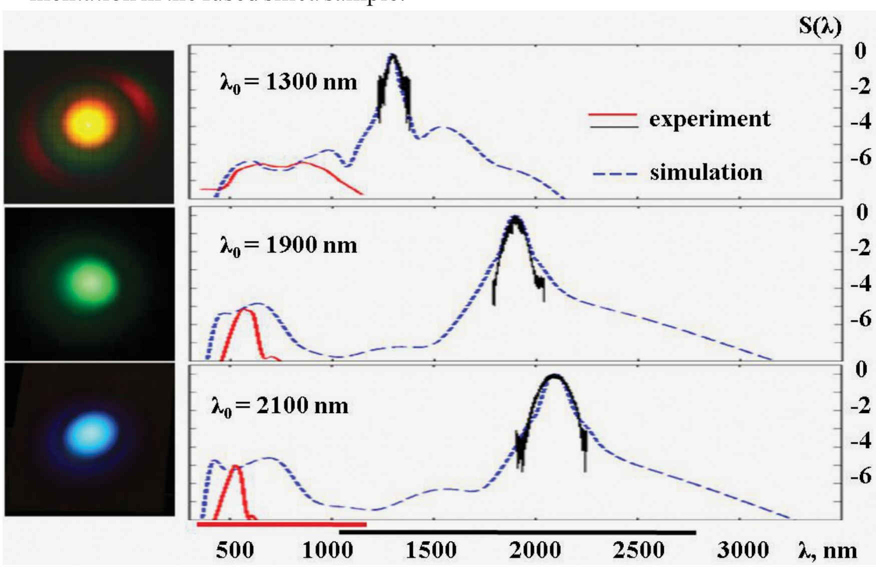


The schematic 3D images of the initial pulse intensity distribution and the form of light bullet at the output plane of the fused silica sample.

Based on the numerical prediction, the experimental registration of the light bullets sequence was performed in the Institute of Spectroscopy RAS. The minimal light bullet duration reaches the value about two optical cycles: 13.5 fs, that was obtained from the autocorrelation measurements of the self-compressed 1800-nm bullet formed during filamentation in the fused silica sample.

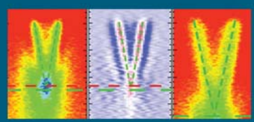
The appearance of the light bullet corresponds to the sharp broadening of the frequency-angular spectrum of the initial pulse. We predicted numerically and investigated experimentally the formation of the isolated anti-Stokes wing in the visible region of the light bullet spectrum. [*Optics Letters*, 38 (1), 16, (2013), *Quantum Electron.*, 43, 326, (2013)].

The images of the conical emission of supercontinuum and spectra of supercontinuum at the filamentation of 1300-nm pulse under zero group velocity dispersion; and of 1900-nm & 2100-nm pulses under anomalous group velocity dispersion, that corresponds to the light bullet formation and the anti-Stokes wing emission.



The light bullet formation is accompanied by plasma generation, that defocuses the pulse tail and provides the shock-front formation. Sharp intensity gradient at the pulse tail causes the broadening of the blue side of the pulse spectrum. So each light bullet formation occurs together with the "flash" emission of short wavelength components and the spectrum of suprecontinuum becomes asymmetrical. But during the light bullet propagation in the dispersive medium, the destructive interference of the spectral components leads to the formation of the dip, that separates the anti-Stokes wing from the central part of the spectrum.

The spectroscopic measurements were performed in the Center of joint researches, Institute of Spectroscopy RAS using the IR correlometer ASF 20 and IR spectrometer ASP-IRHS from Russian manufacturer "Avesta-Project".



Vladimir Kulbachinskii

Magnetic phase diagram of the topological insulator

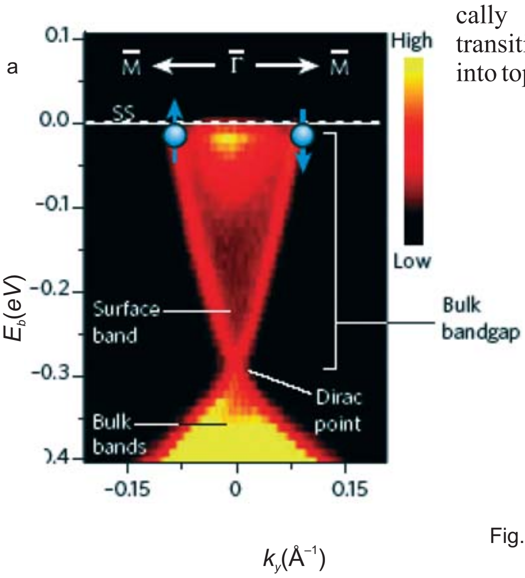
The easiest way to describe a topological insulator is as an insulator that always has a metallic boundary when placed next to a vacuum or an 'ordinary' insulator. These metallic boundaries originate from topological invariants, which cannot change as long as the material remains insulating. The first topological insulator to be discovered was the alloy Bi_xSb_{1-x}, the unusual surface bands of which were mapped in an angle-resolved photoemission spectroscopy (ARPES) experiment. In ARPES experiments, a high-energy photon is used to eject an electron from a crystal, and then the surface or bulk electronic structure is determined from an analysis of the momentum of the emitted electron. Although the surface structure of this alloy was found to be complex, this investigation launched a search for other topological insulators.

The search for topological insulators culminated in the recent discovery of topological insulator behaviour in Bi_2Se_3 and Bi_2Te_3. These 'next-generation' materials both show topological insulator behaviour up to higher temperatures than does the original material (Bi_xSb_{1-x}), with bulk bandgaps of about 0.25 eV, and have the simplest surface state that is allowed.

Fig. 1a shows the measured surface state of Bi_2Se_3 and a theoretical idealization of its state, including the electron spin shown by blue arrows. Theoretical idealization of the electronic structure of Bi_2Se_3, showing the rotation of the spin degree of freedom (red arrows) as an electron (with energy E) moves around the Fermi surface (with Fermi energy EF) is in fig. 1b. (J.E. Moore, *Nature* 464, 2010). The surface state of the next-generation topological insulators is closely related to the Dirac electronic structure of graphene, which has a linear energy-momentum relationship like that of a relativistic particle (and is known as a Dirac cone). Graphene, which consists of a single layer of carbon atoms, has been an extremely active subject of research in recent years: it is interesting both structurally, because it is the most 2D material possible, and electronically, because of its linear energy-momentum relationship. The main difference between the surface of a topological insulator and that of graphene is that the topological insulator has only one Dirac point and no spin degeneracy, whereas graphene has two Dirac points and shows spin degeneracy. This difference has far-reaching consequences, including the possibility of generating new particles that have applications in quantum computing.

In the latest paper (*PRL* (2013) vol. 110, 136601) by the researcher from Faculty of Physics, MSU, together with his colleagues from Korea, China, Japan and USA proposed a phase diagram for $Fe_xBi_2Te_3$ ($0 \leqslant x \leqslant 0.1$ single crystals, which belong to a class of magnetically bulk-doped topological insulators. The evolution of magnetic correlations from ferromagnetic to antiferromagnetic gives rise to topological phase transitions, where the paramagnetic topological insulator of Bi_2Te_3 turns into a band insulator with ferromagnetic-cluster glassy behavior around $x{\sim}0.025$, and it further evolves to a topological insulator with valence-bond glassy behavior, which spans over the region from $x{\sim}0.03$ up to $x{\sim}0.1$. This phase diagram is verified by measuring magnetization, magnetotransport, and angle-resolved photoemission spectra. Our experiments verified magnetically controlled topological phase transitions by doping magnetic ions into topological insulators.

a



b

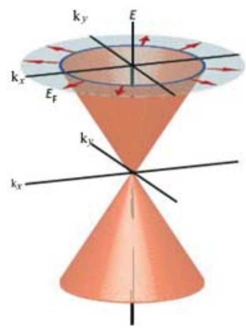


Fig. 1

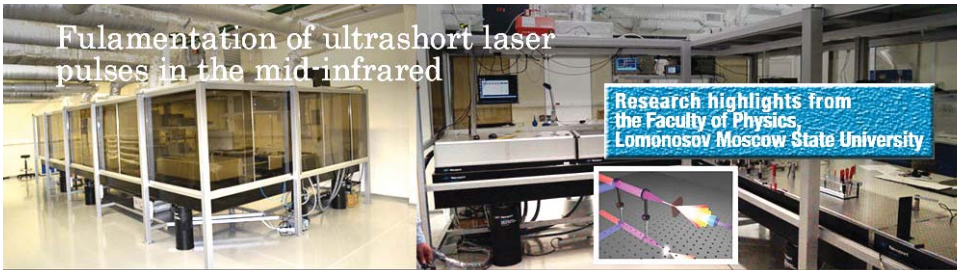
Record 500 km unrepeatered 100 GB/s transmission

Physicists from Moscow State Univ. in collaboration with researchers from T8 NTS and Corning Inc. reached the record 500 km unrepeatered 100 GB/s transmission.

In this work it was experimentally demonstrated 500 km unrepeatered transmission of a single-channel 100 Gb s^{-1} dual polarization quadrature phase shift keyed (DP-QPSK) signal. Such long distance transmission is achieved through the use of an advanced configuration of remotely pumped optical amplifiers (ROPAs), chromatic dispersion precompensation and ultra-low-loss Corning SMF-28 ULL optical fiber. Excellent long-term bit error ratio (BER) performance is observed. To the best of our knowledge this is the longest unrepeatered 100 Gb s^{-1} transmission reported to date.

The results of this work have been published in *Laser Physics Letters*, Vol. 10, 075107 (2013).

First filamentation demonstration of ultrashort laser pulses in the mid-IR



Joint research by physicists from M.V. Lomonosov Moscow State University and Vienna University of Technology enable the first observation of the mid-infrared laser filamentation phenomenon.

Filamentation of ultrashort laser pulses is one of the most exciting recent discoveries in optical physics. As a physical phenomenon, it involves a complex, strongly coupled spatiotemporal dynamics of optical field waveforms in nonlinear, fast-ionizing media, giving rise to unique regimes of ultrafast electrodynamics. This regime of short-pulse propagation The balance between self-focusing and plasma self-defocusing makes the pulse propagate much longer than the Rayleigh range with a very high intensity. It results in a dramatic enhancement of nonlinear processes occurring in the filamentation zone. This phenomenon enables high intensity pulse compression and efficient nonlinear wavelength conversion with gas media. In ultrafast optical science, laser filamentation finds growing applications as a powerful technique of pulse compression, enabling the generation of high-peak-power carrier-envelope-phase (CEP) stable few-cycle optical field waveforms within a broad frequency range from the deep ultraviolet to the near- and mid-infrared. Apart from a large variety of new spatiotemporal nonlinear optical phenomena, femtosecond filaments open new perspectives in many important applications, such as remote spectroscopy of the atmosphere, triggering of high-voltage discharges, water condensation, terahertz emission sources and others.

To date, experimental research on femtosecond pulse filamentation has been almost exclusively carried out at the wavelength of 0.8 μm. Femtosecond filamentation with long-wavelength sources presents a daunting challenge because of the enhancement the critical power of self-focusing with the laser wavelength. Realization of femtosecond mid-IR filamentation would allow one to overcome the shortcomings of the current 0.8-μm technology. First, mid-IR supercontinua are needed to reach the molecular fingerprint region (fundamental vibrational and rovibrational transitions) above 2.5 μm. Second, the combination of a longer wavelength and a high intensity would ensure that tunneling is the predominant ionization mechanism and would enhance the THz emission from the filament. Finally, the higher critical power allows generating single filaments of energy up to 25 times higher than at 800 nm.

The joint research by physicists from M.V. Lomonosov Moscow State University and Vienna University of Technology enable the first observation of the mid-infrared laser filamentation phenomenon in atomic and molecular gases. Highly efficient generation supercontinuum distribution over the beam at the output of a cell with (a) N_2 and (b) O_2 at p = 4atm for an input pulse width of 80 fs and an initial energy of 9 mJ. Of more than three-octave spanning spectral continuum, covering the entire range from UV to 5.5 μm, is demonstrated in argon. In the molecular gases N_2 and O_2, we find that the output supercontinuum spectra strongly contrast from that observed in argon by displaying a clear red-shift.

To understand the filamentation of ultrashort mid-IR pulses, we perform a 3D supercomputer numerical modeling on Chebyshev and Lomonosov supercomputers at Moscow State University. Results of numerical modeling of filamentation demonstrate good agreement with the experiment and confirm experimental observations that efficient generation of low order harmonics together with the spectral broadening of the fundamental pulse is the main mechanism of ultra-broadband continuum generation in argon. We interpret the red-shift in nitrogen and oxygen as governed by enhanced Raman effect, enabling highly efficient wavelength downshift of ultrashort pulses towards mid-IR. More specifically, the filamentation of 80 fs, 10 mJ laser pulses centered at 3.9 μm in N_2 generates a Raman-shifted millijoule supercontinuum spanning from 2.5 μm to 6 μm, while filamentation in oxygen yields over 65% conversion efficiency into the Stokes region.

This work has been published in *Optics Letters* 38, 3194–3197 (2013).

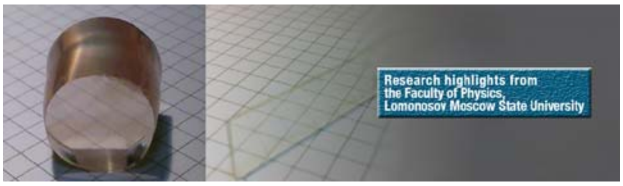
Nodeless superconductivity in FeSe

Physicists from Moscow State Univ. in collaboration with the researchers from Switzerland made a revolutionary step in creation of compact, stable generators of ultrashort laser pulses.

We investigate the temperature dependence of the lower critical field $H_{c1}(T)$ of a high-quality FeSe single crystal under static magnetic fields H parallel to the c axis. The temperature dependence of the first vortex penetration field has been experimentally obtained by two independent methods and the corresponding $H_{c1}(T)$ was deduced by taking into account demagnetization factors. A pronounced change in the $H_{c1}(T)$ curvature is observed, which is attributed to anisotopic s-wave or multiband superconductivity. The London penetration depth $\lambda_{ab}(T)$ calculated from the lower critical field does not follow an exponential behavior at low temperatures, as it would be expected for a fully gapped clean s-wave superconductor. Using either a two-band model with s-wave-like gaps of magnitudes $\Delta_1 = 0.41 \pm 0.1$ meV and $\Delta_2 = 3.33 \pm 0.25$ meV or a single anisotropic s-wave order parameter, the temperature dependence of the lower critical field $H_{c1}(T)$ can be well described. These observations clearly show that the superconducting energy gap in FeSe is nodeless.

The results of this work has been published in: M. Abdel-Hafiez, J. Ge, A.N. Vasiliev, D.A. Chareev, J.Van de Vondel, V.V. Moschalkov, and A.V. Silhanek. *Phys. Rev.*, B 88, 174512 (2013).

Terahertz wave generation in periodically polarized crystals

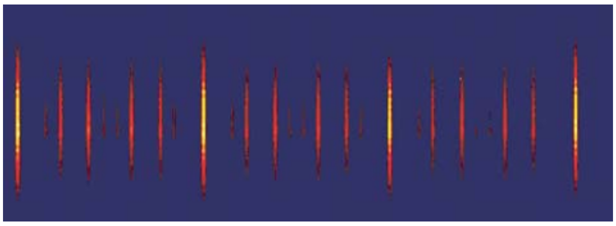


Physicists from Lomonosov Moscow State Univ. in collaboration with Natl Tsing Hua Univ. (Taiwan) demonstrated that the efficacy of laser energy transfer into the THz wave energy can increase with increasing the nonlinear periodically poled crystals even under the essential absorption of the THz radiation.

Optical parametric mixing is a popular scheme to generate an idler wave at THz frequencies, although the THz wave is often absorbing in nonlinear optical material. It is widely suggested that the useful material length for co-directional parametric mixing with strong THz-wave absorption is comparable to the THz-wave absorption length in the material. Here we show that, even in the limit of the absorption loss exceeding parametric gain, the THz idler wave can grows monotonically from optical parametric amplification over a much longer distance in a nonlinear optical material until pump dep-letion. The coherent production of non- absorbing signal wave can assist the growth of the highly absorbing idler wave. We also show that, for the case of an equal input pump and signal in difference frequency generation, the quick saturation of the THz idler wave predicted from a much simplified and yet popular plane-wave model fails when fast diffraction of the THz wave from the co-propagating optical mixing waves is considered.

The results of this study have been published in *Optics Express*, 21(2), 2452 (2013) and in *Laser Physics Letters*, 10(5), 055404 (2013).

Temporal solitons in optical microresonators



Physicists from Moscow State Univ. in collaboration with researchers from Switzerland made a revolutionary step in creation of compact, stable generators of ultrashort laser pulses.

Temporal dissipative solitons in a continuous-wave laser-driven nonlinear optical microresonator were observed. The solitons were generated spontaneously when the laser frequency was tuned through the effective zero detuning point of a high-Q resonance, which led to an effective red-detuned pumping. Transition to soliton states were characterized by discontinuous steps in the resonator transmission. The solitons were stable in the long term and their number could be controlled via pump-laser detuning. These observations are in agreement with numerical simulations and soliton theory. Operating in the single-soliton regime allows the continuous output coupling of a femtosecond pulse train directly from the microresonator. This approach enables ultrashort pulse syntheses in spectral regimes in which broadband laser-gain media and saturable absorbers are not available. In the frequency domain the single-soliton states correspond to low-noise optical frequency combs with smooth spectral envelopes, critical to applications in broadband spectroscopy, telecommunications, astronomy and low noise microwave generation.

The results of this work has been published in: T. Herr, V. Brasch, J.D. Kost, C.Y.Wang, N.M.Kondratiev, M.L.Gorodetsky, and T.J.Kippenberg. *Nature Photonics*, December 2013 (advance online publication).

AWARDS

Winners of the UMNIK-2013 competition

The final tour of the Recearch & Inovation Competition for young scientists took place on November 1st, 2013, at the Faculty of Physics, Lomonosov Moscow State University. This competition was organized by the Fund for supporting small enterprises in research and innovations under support by the Federal Agency for Science &Innovations and the Federal Agency for Education of the Russian Federation. Each winner received up to 400000 rubles for two years. The jury selected 25 winners this year, out of which 9 are from the Faculty of Physics Lomonosov Moscow State University.

Section "Novel devices and apparatus”

- **Daria Daigen**, "Development of a compact device for diagnostics of nanomaterials for their suitability to be used in photo-catalytic filters and gas sensors”;
- **Denis Zotov**, "Sensor for complex study of live single cells”;
- **Andrey Sviridov**, "Setup for ultrasound diagnostics of oncological tumors using silicon nanoparticles”;
- **Alexander Kurenkov**, "High-precision convertors of displacements based on the micro-size high-sensitive magnetic field sensors”;
- **Ilya Mukha**, "Development of multi-functioning running magneto-optical sensor based on the surface plasmon resonance”;
- **Anton Minnekhanov**, "Photocatalytic filter for air cleaning from tocsin impurities based on the alloyed titanium dioxide”;
- **Alexander Frolov**, "Femtosecond laser pulses convertor based on the magnetoplasmonic crystals”.

Section "Novel Materials and Technologies”

- **Anna Kharlamova**, "Production of novel "thick" amorphous microwires with the help of modified Ulitovsky-Tailor method and monitoring of their properties”.

Section "Medicine of the Future”

- **Olga Zhulyabina**, "Cellular biochip for immune status detection".

Science contest for young scientists of the Faculty of Physics

The Science Contest for the young scientists of the Faculty of Physics was organized in November, 2013. It was devoted to the 80th-anniversary of the Faculty of Physics. As a result, 6 best research works submitted to the contest were selected as the winners of the I to III degree.

First degree diploma were awarded to:

Evgeniya Smetanina, PhD student of the Chair of General Physics and Wave Processes, for her work on "Filament light bullets and their spectral characteristics".

Evgeniya Smetanina studied both theoretically and experimentally the dynamics of space-time compression of a powerful femtosecond laser radiation and the laws of high-power light bullets formation with the pulse duration of a few periods of the light wave were revealed, as well as the laws of broadband coherent supercontinuum generation due to the filamentation of the laser radiation in dielectric media. Possible practical applications of the results of Evgenya's work are the time-resolved spectroscopy of ultrafast processes in molecular compounds and in biological molecules, time-resolved probing and ecological monitoring of the environment.

Petr Yuldashev, researcher with the Chair of General Physics and Condensed Mater Physics, for his work on "Medical and aero-acoustic applications of high amplitude acoustic waves with raptured acoustic waves".

Petr Yuldashev studied nonlinear and diffraction wave effects that occur at propagation of acoustic waves with raptures in inhomogeneous media, focusing and reflection from the borders. This research is initiated by the novel medical applications, which use raptured waves, such as extra-corporal shock-wave therapy and noninvasive ultrasound surgery, which destroys the oncological tissues with the help of a powerful focused ultrasound beam. Similar problems are also under the active study, if one analyzes the problems of aero-acoustics the ecological sequences of the propagation of the powerful shock wave and powerful nonaeroacoustical noise in the atmosphere in connection with the engineering of the new generations of the ultrasound air-liners.

Second degree diploma were awarded to:

- **Irina Kolmychek**, Assistant Professor with the Chair of General Physics, for her work on "Generation of magnetoinduced second harmonic in magnetic nanostructures and thin films";
- **Elena Popova**, researcher with the Chair of Mathematics, for her work on "Modeling of the solar magnetic activity".

Third degree diploma were awarded to:

- **Vladimir Zverev**, postdoc with the Chair of General Physics and Condensed Matter, for his work on "Magneto-thermal properties of the heavy rare-Earth metals in the region of magnetic phase transitions";
- **Yulia Ryzhikova**, researcher with the Chair of Optics and Spectroscopy, for her work on "Novel opportunities for improving characteristics of the optical systems and diagnostic tools".

Prof. **Anatoly M. Cherepaschuk**, Academician, head of the chair of Astrophysics and Astronomy with the Faculty of Physics, and director of the Sternberg Astronomical Institute, Lomonosov Moscow State University, received the 2013 Russian Government award in the field of education "for the development of innovative educational center Moscow Planetarium that serves for popularization of research and implementation the effective education technologies".

Prof. **Alexander N. Vasiliev**, head of the chair of Low Temperatures and Superconductivity with the Faculty of Physics, Lomonosov Moscow State University, was awarded the 2013 Lomonosov award of the II degree for research for the series of his work on "Quantum basic states of the matter: superconductivity and magnetism – unity and conflict of opposites".

Prof. **Alexander M. Saletskii**, head of the chair of General Physics with the Faculty of Physics, Lomonosov Moscow State University, received an order "For merits before Fatherland" of the I degree given by the decree No 760 of 4th of October 2013 of the Russian President for "the achievements in education and many years of fruitful activity".

Associate Prof. **Alexander A. Shishkin**, chair of Mathematics with the Faculty of Physics, Lomonosov Moscow State University, was awarded the 2013 Lomonosov award for education.

Congratulations to all the awardees!

DISSERTATIONS

In May 2013, Alexander Shkurinov, Associate Professor of the Department of General Physics and Wave Processes, defended his Dr.Sci. thesis on **"Temperature dynamics of polarization sensitive nonlinear media response under the interaction of ultrashort laser pulses with molecules in the bulk and on the surface".**

The thesis analyses polarization nonlinear optical phenomena, caused by the dependence of nonlinear response of the medium on the state of polarization of light waves interacting with it. This constitutes one of the main parts of wave optics and these phenomena serve as the basis for practical techniques for the study of various substances.

The new phenomena studied in the present work are related to different spectral ranges of electromagnetic radiation: from UV to far IR. It is for the first time that various nonlinear optical and polarization effects of terahertz (THz) frequency range have been analyzed. Active application of THz radiation was limited by the absence of appropriate laboratory equiment for its generation and registration. The appearance of widely available sources of ultrashort femtosecond pulses led to a new direction of research in THz frequency range closely connected with laser physics, — THz pulse spectroscopy and THz spectrochronography.

Along with other promising applications, THz pulse radiation is widely used in semiconductor and nanotechnologies, crystallography and molecular spectroscopy. Unlike visible light and near IR spectroscopy, which study the main electron transitions and vibrations connected with intramolecular movements and intermolecular vibrations, THz frequency spectral response often provides information about low-frequency molecule vibrations, slow motion of molecular groups and collective excitation of phonon type in the solid state phase.

THz pulse spectroscopy suggests generation and simultaneous detection of broadband radiation. At the same time spectral information received by the researcher is analogous to that received using IR Fourier-spectroscopy. The main difference and specific feature of this method is the opportunity to simultaneously get dependencies of spectral dispersion of indicators of absorption and refraction for the studied substances. Due to the fact that temporal response for spectral analysis in pulse spectroscopy is primary when this substance goes through electromagnetic field pulse of subpicosecond duration, the analysis of temporal profile of the field at the time of passing through a substance, also bears information about the dynamics of vibrational, rotational and relaxation processes taking place under the action of electromagnetic field pulse. The study of the temporal dynamics of THz field pulse forms the basis for the development of THz spectroscopy technique with time resolution, which is analogous to the method of spectrochronography.

Yuri.A. Koksharov

"Electron magnetic resonance in heterogeneous systems with reduced dimensionality"

This Dr. Sci. dissertation is devoted to studying of various types of nanoparticles, quasi-two-dimensional crystals, conjugated polymers and ultrathin films by the electron magnetic resonance (EMR) spectroscopy. Diversity of objects of research requires careful consideration of EMR signals, which are very manifold qualitatively (paramagnetic, ferro-magnetic, superparamagnetic signals were studied) and quantitatively (the linewidth variation comes up three orders of magnitude). The general attribute of all investigated systems is sufficient lack of homogeneity of chemical composition, crystal and agnetic structures, morphology etc.

Considerable effort was expended to develop computer methods to analyse various signs of different types of heterogeneity in EMR spectra. Our experimental data show strong sensitivity of EMR spectra to chemical inhomogeneity of magnetic nanoparticles, temperature EMR anomalies in ferromagnetic nanoparticles, unusual relaxation properties of EMR centers in paramagnetic nanoparticles and conjugated polymers. Some low-dimensional antiferromagnetic systems can be successfully studied by the method of "natural spin probes" as proved in experiments on goethite nanoparticles, HTSC, and related systems. In conclusion, the dissertation establishes some important classes of interconnection between structural and EMR features of various heterogeneous systems with reduced dimensionality.

In march 2013 associate professor **Alexander P. Pyatakov** defended doctor of science thesis on **"Magnetoelectric and flexo-magnetoelectric effects in multiferroics and magnetic dielectrics".**

This thesis is devoted to the physics of magnetoelectric phenomena that is a rapidly developing field in condensed matter science. In contrast to the textbook electromagnetism, the magnetoelectricity describes the coupling of static magnetism and electricity: the constant electric field gives rise to the magnetization while the constant magnetic field induces electric polarization in the magnetoelectric media. Multiferroics, i.e. media with coexisting magnetic and electric ordering also demonstrate magnetoelectric coupling.

In spite of the tempting possibility of the magnetoelectric transformation without energy loss in spintronics and sensor technique these media are not widely represented in technology due to the scarcity of room temperature multiferroics. Therefore the motivation of the study in the thesis was to widen this bottleneck of the magnetoelectric science with the new mechanisms of magnetoelectric coupling.

The plot of the thesis is based on the uncovering of the unusual properties of magnetic inhomogeneities and structures: spin spirals, domain walls, magnetic vortices. The above mentioned objects are related to the flexomagnetoelectric effect, that can be seen in the title of the thesis. It was introduced by A. Pyatakov by analogy to the flexoelectric effect in liquid crystals (see Fig.) and was adopted by several groups throughout the world to designate the class of magnetoelectric phenomena related to the magnetic inhomogeneities. The experimental and theoretical study of the effect enables A. Pyatakov to control magnetic domain walls with electric field and to enhance the properties of high temperature multiferroics that is of practical interest for spintronics applications.

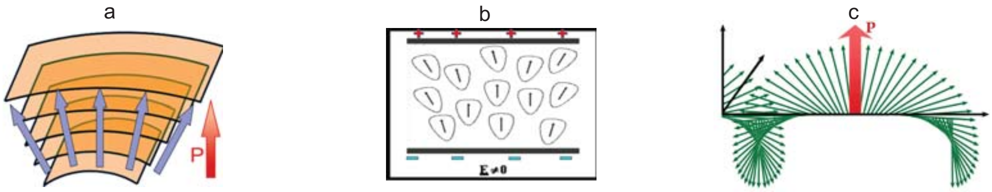


Fig. Flexoelectric effect, i.e. the emergent electric polarization due to: a) strain gradient in dielectric crystals b) fan-shaped molecular structures in nematic liquid crystals c) spin cycloid structures in magnetically ordered media.

On February 14, 2013, an associate professor of Department of Photonics and microwave physics **Vladimir Belotelov** defended his doctoral thesis on **"Plasmonic heterostructures and photonic crystals with tunable optical properties"**.

Research carried out in this thesis, is devoted to theoretical and experimental studies of the optical radiation interaction with nanostructures whose optical properties can be modified by external influences: by magnetic field or by intense laser irradiation. Specially selected periodic structure of plasmonic and photonic crystals leads to resonant phenomena, resulting in significant enhancing of optical and magneto-optical effects in desired wavelength range. This opens great opportunities to create new optical elements, in which various optical radiation characteristics are modulated effectively with frequency up to 1 THz.

One of Dr. Belotelov's main results is creation of novel nanostructured material — magnetic plasmonic crystal, which allows to control effectively the polarization and intensity of light and plasmonic oscillations by means of magnetic field or optical irradiation. This material is very promising for information technology. Its unique feature is possibility to work both in long distance optical zone (with propagating light) and near-field optical zone (with localized waves — with plasmon-polaritons and with waveguide modes).

In this thesis magneto-optical effects resonant amplification in magnetic plasmonic crystals was first time investigated and theory for this amplification was created. Transverse Kerr effect resonant 10^3-fold amplification and Faraday effect resonant 10-fold amplification in comparison with magnetic films without plasmonic layer were demonstrated.

In addition, a magneto-optical intensity effect was predicted and experimentally demonstrated. This effect arises in plasmonic crystals on account of waveguide modes excitation in meridionally magnetized waveguiding layer, i.e. it magnetized in the film plane and along the waveguide mode propagation direction.

The theory of Faraday effect and other magneto-optical effect resonant amplification in magnetic photonic crystals was created and analytical expressions for Faraday angle were obtained. These expressions agree well with experimental data. Inverse transverse Kerr effect was theoretically predicted.

Transmission and reflection coefficients control as well as surface plasmon-polariton in plasmonic crystal control were first time demonstrated using femtosecond laser pulse (pulse energy density ~ 500 mkJ/cm^2). Also the plasmon resonance modulation in plasmonic crystal was experimentally obtained using subsurface acoustic wave pulse at frequencies up to 110 GHz.

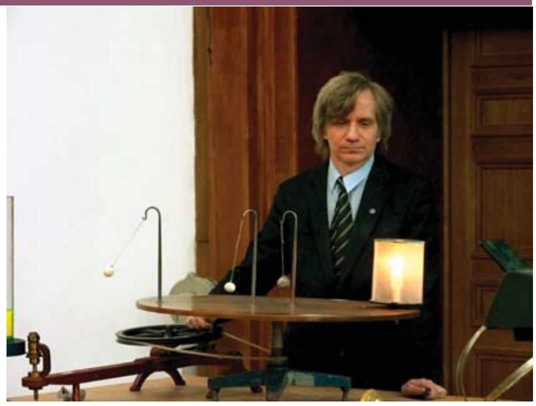
Physics Department hosted a meeting of the Presidium of the Educational-Methodological Unit on Physics

On November 14 to 16, 2013, Physics Department of Lomonosov Moscow State University hosted a meeting of the Presidium of the Educational-Methodological Unit (EMU) on Physics of the classical university education in connection with the 80th anniversary of the Faculty. More than 30 deans of the faculties of physics from allover Russia took part in this meeting.

The meeting discussed the issues of practical implementation of the Law on Education, on a new graduate-level education, participation in the International Conferences on Physical Education, etc. All the participants of this meeting took part in the 80th anniversary commemorative meeting where the warmly congratulated the dean of the Faculty, staff members, and the students of the Faculty of Physics, Lomonosov Moscow State University. They also stated in their greetings “a great and fruitful work of the Faculty of Physics who coordinates activities in the field of physical education within the Russian universities”.

FACE-TO-SCHOOL

Lectures on Physics for the schoolboys and their teachers



In the Fall of 2013, under umbrella of the joint program "Moscow State to the Schools" between the Lomonosov Moscow State University and the Department of Education of the Moscow City Hall, the Faculty of Physics organized a series of events, of which the most significant was the Lectures on Physics. Its program consisted of 12 lectures under the following three directions:

- Series of 5 lectures "Real Physics" is targeted at the experimental demonstrations in various fields of Physics, which help attendees to meet with a broad range of physical phenomena and discover many new, interesting and unusual manifestation of the physical laws;
- Series of 5 popular science lectures "Portrait of Modern Physics" is targeted at the hot news and cutting-edge research in physics of elementary particles, cosmology, biophysics, nanophysics, etc.;
- Two master-classes on using experimental physical demonstrations in teaching of Physics that were mainly targeted at the teachers, though it attracted quite a bit of schoolboys.

Lectures were organized every week, in the period of September 13th to November 29th, in the main Physics Hall. Over 100 physical experimental demonstrations were made during the series of lectures in preparation of which took part 26 faculty members. Besides these lectures, a special methodological booklet on using experiments in the teaching of Physics was publlished and distributed among the teachers attending these lectures.

The Lectures on Physics raised a great interest in Moscow. Most popular were the lectures under the "Real Physics" topic that regularly attracted over 400 attendees! The lecture "In the world of high voltage" also was filmed by two Moscow TV channels — TV-center and Moscow-24".

80th Anniversary of the Faculty of Physics

SCIENCE NEWSLETTER № 2/2013
Faculty of Physics, Lomonosov Moscow State University

Edited by N.N. Sysoev, V.N. Zadkov, A.A. Fedyanin, N.B. Baranova
Design typesetting by I.A. Silantyeva

Signed to print on 2014, 200 pcs.

Faculty of Physics, Lomonosov Moscow State University
119991 Moscow,GSP-1, Leninskie Gory 1, str. 2

Printed from a computer layout by Moscow University Publishers