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Nonlinear frequency mixing in dielectric-loaded plasmon waveguides and graphene-loaded semiconductor nanowires

Andrey Gorbach

Department of Physics, University of Bath, UK

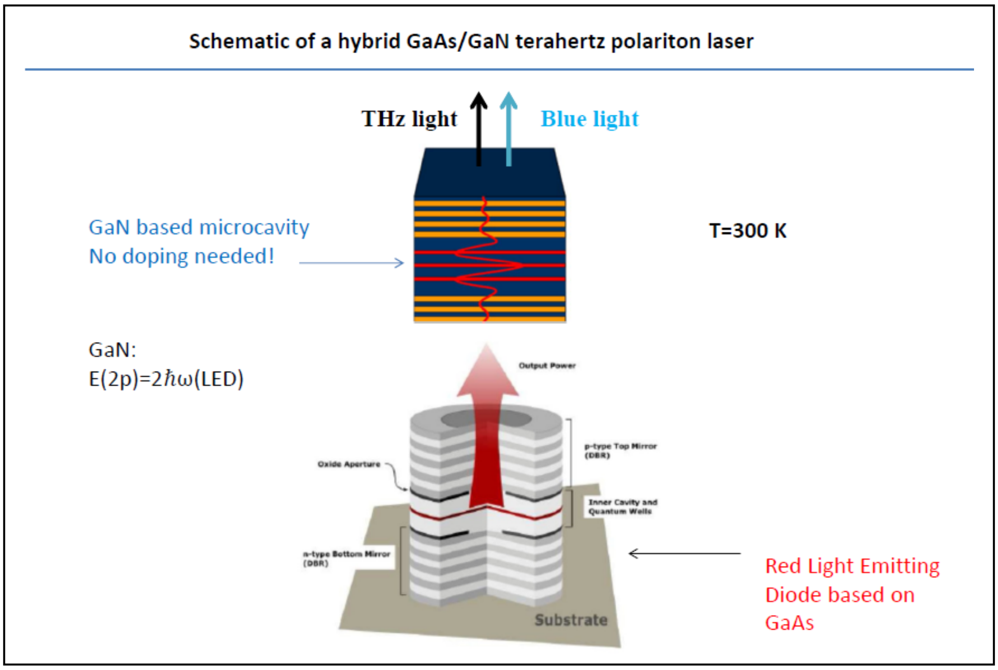
Plasmonic waveguides offer the unique platform for sub-wavelength light guidance and development of on-chip integrated photonic circuits. However, the major drawback of plasmonic waveguides is due to unavoidable and strong ohmic losses. The interplay between losses and particularly strong nonlinear interaction, boosted by the tight light confinement in plasmonic waveguides, becomes the important subject for the development of active plasmonic waveguide components. In this work we consider nonlinear frequency mixing in dielectric-loaded plasmonic waveguides. This particular type of plasmonic waveguides offers the optimum ballance between light confinement and losses. We demonstrate, that in such waveguides the efficiency of nonlinear mixing remains very limited, and novel highly-nonlinear materials are required to further enhance this interaction. One such possible material is graphene, which has been recently suggested to possess the highest non-resonant optical nonlinear response among known materials. We develop modified theoretical tools to describe nonlinear photonic waveguides with graphene, and compare efficiency of nonlinear frequency mixing in graphene-loaded semiconductor nanowires and dilectric-loaded plasmonic waveguides.

Bosonic Cascade Lasers

Alexey V. Kavokin

Mediterranean Institute of Fundamental Physics, 31, via Appia Nuova, 00040, Frattocchie, Rome, Italy

Creation of efficient sources of terahertz (THz) radiation is of high importance for various fields of modern technology, including information transfer, biosensing, security and others. These applications are currently limited due to the lack of compact and reliable solid state sources of THz radiation. Recently we have proposed that the emission rate of THz photons may be increased by bosonic stimulation if the THz transition feeds a condensate of exciton-polaritons [1]. We have developed a quantum theory of vertical cavity surface emitting terahertz lasers. The vertical terahertz lasing coexists with polariton lasing and, consequently, is characterised by a low pumping threshold. The resonant two photon pumping of 2p exciton states in such a cavity may be assured by a conventional vertical cavity light emitting diode (VCLED) emitting in red. The terahertz radiation will be emitted due to the transition from 2p-exciton state to 1s exciton-polariton state, which is expected to be stimulated by the occupation number of the 1s state which may achieve 10000 in the polariton lasing regime. Further improvement of quantum efficiency of bosonic terahertz lasers may be achieved taking advantage of a cascade effect in a parabolic trap where the THz transition between equidistant exciton energy levels is optically allowed [2]. Bosonic cascade lasers are predicted to achieve quantum efficiencies of 500-700% in realistic structures.



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Bottom-up approach to creation of plasmonic nanostructures with the use of singular optical beams

Tigran A. Vartanyan[1], Rafael Drampyan[2]

[1] *National Research University of Information Technologies, Mechanics and Optics (St.Petersburg, Russian Federation)*
[2] *Institute for Physical Research, NAS of Armenia, Ashtarak, Armenia*

Among different approaches to manufacture ordered metallic nanostructures the so called "top-down" technologies are leading. Although these technologies are mature and almost universally applicable, they are not free of shortcomings. The main drawback is the excessive number of steps needed to fabricate a single pattern. In this respect the "top-down" counterpart, the so-called "bottom-up" technologies look favorable. These technologies are based on the self-organized and photoinduced formation of nanostructures. They promises scalability, reduced energy consumption and reduced production of waste. Basically, under proper conditions, metal is deposited exactly at those places of the substrate surface where it is needed. Hence, the number of steps to produce the required structure is reduced. In this contribution we describe one specific process, which can be employed to develop a one-step technology of nanostructure production with lager throughput. We show that light-induced atomic desorption is a reliable tool to control the surface number density of the adsorbed atoms in the course of physical vapor deposition process. We also demonstrate that nondiffracting beams, in particular, Bessel beams are the tools of choice to create complex patterns of illumination intensity on the substrate surface. We also discuss the possibility to employ singular optical beams for pattern creation.

Quantum Optics with Polaritons in Micro-and Nanostructures

Aleksandr P. Alodzhants

Vladimir State University (Russian Federation)

We discuss a novel physical mechanism for the creation of long-lived macroscopic exciton-photon qubits in semiconductor microcavities with embedded quantum wells in the strong coupling regime. The polariton qubit is a superposition of lower branch and upper branch exciton-polariton states. We argue that the coherence time of Rabi oscillations can be dramatically enhanced due to their stimulated pumping from a permanent thermal reservoir of polaritons. We discuss applications of such qubits for quantum information processing, cloning, and storage purposes.

Nonlinear frequency mixing in dielectric-loaded plasmonic waveguides and graphene-loaded semiconductor nanowires

Oleg Egorov

Friedrich-Schiller-University of Jena (Germany)

Plasmonic waveguides offer the unique platform for sub-wavelength light guidance and development of on-chip integrated photonic circuits. However, the major drawback of plasmonic waveguides is due to unavoidable and strong ohmic losses. The interplay between losses and particularly strong nonlinear interaction, boosted by the tight light confinement in plasmonic waveguides, becomes the important subject for the development of active plasmonic waveguide components. In this work we consider nonlinear frequency mixing in dielectric-loaded plasmonic waveguides. This particular type of plasmonic waveguides offers the optimum ballance between light confinement and losses. We demonstrate, that in such waveguides the efficiency of nonlinear mixing remains very limited, and novel highly-nonlinear materials are required to further enhance this interaction. One such possible material is graphene, which has been recently suggested to possess the highest non-resonant optical nonlinear response among known materials. We develop modified theoretical tools to describe nonlinear photonic waveguides with graphene, and compare efficiency of nonlinear frequency mixing in graphene-loaded semiconductor nanowires and dilectric-loaded plasmonic waveguides.

Coherent propagation of a single photon in a lossless medium: 0π pulse formation, slow photon, and dispersive shaping

Shushan Petrosyan[1)] and Yuri Malakyan[1,2)]

[1]*Institute for Physical Research, Armenian National Academy of Sciences, Ashtarak-2, 0203, Armenia*
[2]*Centre of Strong Field Physics, Yerevan State University, 1 A. Manukian St., Yerevan 0025, Armenia*

Single-photon coherent optics represents a fundamental importance for the investigation of quantum light-matter interactions. While most work has considered the interaction in the steady-state regime, we demonstrate that a single-photon pulse shorter than any relaxation time in a medium propagates without energy loss and is consistently transformed into a zero-area pulse. A general analytical solution is found for photon passage through a cold ensemble of lambda-type atoms confined inside a hollow core of a single-mode photonic-crystal fiber. We use the robust far-off-resonant Raman scheme to control the pulse reshaping by an intense control laser beam and show that in the case of cw control field, for exact two-photon resonance, the outgoing photon displays an oscillating temporal distribution, which is the quantum counterpart of a classical field ringing, while for nonzero two-photon detuning a slow photon is produced. We demonstrate also that a train of readout control pulses coherently recalls the stored photon in many well-separated temporal modes, thus producing time-bin entangled single-photon states. Such states, which allow sharing quantum information among many users, are highly demanded for applications in long-distance quantum communication.

Quantum two-state evolution with Heun class of potentials"

Arthur M. Ishkhanyan

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

We present numerous classes of analytically solvable quantum time-dependent two-state models. Each of the classes is defined by a pair of generating functions the first of which is referred to as the amplitude- and the second one as the detuning-modulation function. The classes suggest families of field configurations with different physical properties generated by appropriate choices of the transformation of the independent variable, real or complex. There are many families of models with constant detuning or constant amplitude, numerous classes of chirped pulses of controllable amplitude and/or detuning, families of models with double or multiple (periodic) crossings, periodic amplitude modulation field configurations, etc.

The detuning modulation function is the same for all the classes. The parameters in general are complex and should be chosen so that the resultant detuning is real for the applied (arbitrary) complex-valued transformation of the independent variable. Many useful properties of the detuning functions are due to the additional parameters involved in this function. Many of the derived amplitude modulation functions present different generalizations of the known hypergeometric models.

We present several families of constant-detuning field configurations the members of which are symmetric or asymmetric two-peak finite-area pulses with controllable distance between the peaks and controllable amplitude of each of the peaks. The edge shapes, the distance between the peaks as well as the amplitude of the peaks are controlled almost independently, by different parameters. We identify the parameters controlling each of the mentioned features and discuss other basic properties of pulse shapes. We show that the pulse edges may become step-wise functions and determine the positions of the limiting vertical-wall edges. We show that the pulse width is controlled by only two of the involved parameters. For some values of these parameters the pulse width diverges and for some other values the pulses become infinitely narrow. We determine the conditions for generation of pulses of almost indistinguishable shape and width.

Engineering of 2D and 3D photonic lattices in photorefractive media

Rafael Drampyan

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

The elaboration of new methods and technologies for fabrication of 2- and 3-dimensional (2D and 3D) micro- and nano-scale refractive structures (photonic lattices) in photorefractive materials based on holographic technique are presented.

New Bessel standing wave technique, combined interferometric mask method and Talbot effect based technique were elaborated.

The originality of the first method is based on the formation of Bessel standing wave which provides the formation of 2D photonic lattices with micrometric periodicity in radial direction and recording beam half wavelength submicrometric periodicity in the axial direction.

Last two methods are based on the fabrication of micrometric scale rotational symmetry masks, successfully realized by computer graphic technique, which provides the light modulation and rotational symmetry pattern formation in the transverse plane of the beam. The interferometric-mask method is based on the original combination of mask and interferometric, in particular, standing wave methods, which provides the formation of 3D photonic lattices in photorefractive media.

The diffraction masks image self-replications (Talbot effect) was used for recording of replicated patterns, both integral and fractional, from 1D annular mask in the photorefractive medium.

The elaborated methods are universal and applicable to any photorefractive materials. Created 2D and 3D photonic lattices are promising as guiding and trapping systems, as new photonic bandgap materials, for all optical devices, telecommunications, optical storage, optical computers etc.

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LIST OF PARTICIPANTS

Alodzhants Aleksander, *Vladimir State University (Russian Federation)* alexander_ap@list.ru

Azizbekyan Hrayr, *Institute for Physical Research, National Academy of Sciences of Armenia*
hrayrazizbekyan@gmail.com

Drampyan Rafael, *Institute for Physical Research, National Academy of Sciences of Armenia*
rafael.drampyan@gmail.com

Egorov Oleg, *Friedrich-Schiller-University of Jena (Germany)* oleg.egorov@uni-jena.de

Eramo Giuseppe, *Mediterranean Institute for Fundamental Physics (Rome, Italy)*
eramo.co@gmail.com

Gevorgyan Mariam, *Institute for Physical Research, National Academy of Sciences of Armenia*
mariamgevorgyan89@gmail.com

Haytrapetyan David, *Armenian – Russian (Slavonic) University*

Gorbach Andrey, *Department of Physics, University of Bath, UK* A.Gorbach@bath.ac.uk

Gogyan Anahit, *Institute for Physical Research, National Academy of Sciences of Armenia*
agogyan@gmail.com

Ishkhanyan Arthur, *Institute for Physical Research of NAS of Armenia*
aishkhanyan@gmail.com

Ishkhanyan Hayk, *Institute for Physical Research of NAS of Armenia*

Kavokin Alexey, *Mediterranean Institute for Fundamental Physics (Rome, Italy)*
A.Kavokin@soton.ac.uk

Kibis Oleg, *Novosibirsk University (Russian Federation)*
Oleg.Kibis@nstu.ru

Malakyan Yuri, *Institute for Physical Research, National Academy of Sciences of Armenia*
yumal@inbox.ru

Mantashyan Paytsar, *Institute for Physical Research, National Academy of Sciences of Armenia*
paytsar.mantashyan@gmail.com

Miroshnichenko Anna, *Mediterranean Institute for Fundamental Physics (Rome, Italy)*
annamir@mifp.eu

Papoyan Aram, *Institute for Physical Research, National Academy of Sciences of Armenia*
aram.papoyan@gmail.com

Petrosyan Shushan, *Institute for Physical Research, National Academy of Sciences of Armenia*

Sarkisyan Hayk, *Armenian – Russian (Slavonic) University* shayk@ysu.am

Tevosyan Hovhannes, *Armenian – Russian (Slavonic) University*
hovhannes.tevosyan@gmail.com

Vartanyan Tigran, *National Research University of Information Technologies, Mechanics and Optics (St.Petersburg, Russian Federation)* tigran.vartanyan@mail.ru