Plenary and Invited Lectures

Transformation of optical beams using nonlinear photonic crystals

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Modulating the quadratic nonlinear coefficient is often used in nonlinear optics applications for compensating the phase mismatch between interacting waves. The progress in modulation techniques, mainly by electric field poling of ferroelectric crystals, enables to explore new applications, based on all-optical control of the phase, amplitude and polarization of the nonlinearly generated waves. This enables the realization of functional nonlinear optical devices, such as nonlinear lenses, switches, polarization rotators, deflectors and beam shapers. I will review the recent progress in this field.

An example of a functional nonlinear device is an all-optical deflector, that was realized in our group by specially designed stoichiometric $LiTaO_3$ crystal [1]. The nonlinear coefficient of the structure was modulated at a fixed period in the propagation direction, and in a quadratically chirped period in the transverse direction. Continuous angular deflection of the second harmonic wave up to ~2.3° was experimentally demonstrated.

Another example is nonlinear beam shaping with specially designed nonlinear photonic crystals. It allows in addition to frequency conversion of a beam, means of controlling the beam shape, by engineering the phase and amplitude of the generated beams. Moreover, by using an additional pump beam, it enables to parametrically amplify the generated beam. A recent demonstration is the generation of accelerating Airy beams at the second harmonic from a fundamental Gaussian beam [2]. The envelope of these Airy beams, described by Airy functions centered around a parabolic trajectory in space, is the only non spreading solution in one dimension. The nonlinear optical device also enables to all-optically control the Airy wave-packet caustics, as well as the acceleration rate and direction of the beams. Hence, the nonlinear beam shaper enables all-optical control in applications such as micro-manipulation of small particles and curved plasma channel generation [3].

References

[1] T. Ellenbogen, A. Ganany-Padowicz and A. Arie, “Nonlinear photonic structures for all-optical deflection,” Opt. Exp. 16, 3077 (2008).

[2] T. Ellenbogen, N. Voloch-Bloch, A. Ganany-Padowicz, and A. Arie, “Nonlinear generation and manipulation of Airy beams,” *Nature Photonics* 3, 295 (2009).

[3] P.Polynkin, M. Kolesik,J. V. Moloney, G. A. Siviloglou, and D. N. Christodoulides, “Curved plasma channel generation using ultraintense Airy beams,” Science **324**, 229 (2009).

Optical properties of nitride nanostructures

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The optical emission of the basic semiconductor nitrides (GaN, AlN, and InN) covers the optical region from the ultraviolet (200 nm) to the near infrared (1.4 µm) with many applications as laser emitters in mass storage devices or telecommunications, but also as LEDs in lighting. The lack of a suitable substrate to the crystal growth made part of the nitride community to concentrate on self-assembled quantum dots (QDs), which are shown to grow in an stressed state by the embedded material and the substrate, but with a good crystal quality. More recently, the growth of nanowires (NW) or nanocolumns (NC) has shown that some of the problems existing in the previous nanostructures can be overcome.

In this talk we will summarize our work on GaN/AlN/SiC QDs, growth on both polar and non-polar surfaces. The desired ultraviolet emission is reestablished when the QDs are grown on non polar faces of the material, and a more predictable result is obtained. In particular, we will present photoluminescence and Raman scattering measurements in both kind of dots, and compare the results with a model calculation. The possibility of growing NCs open new concepts of heterostructures, in the radial or axial direction, or even more complex heterostructures. We will show a few particular results on InN and GaN NCs and NCs heterostructures and the physics behind them.

Optical waveguides in rare-earth ion doped lithium niobate crystals produced by ion implantation: a recent overview

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Lithium niobate ($LiNbO_3$) is one of the most useful materials for diverse optical applications due to the combination of many excellent properties (e.g. electro-optic, nonlinear optic, luminescent, photorefractive features). When doped with some rare-earth (RE) ions, such as Nd^{3+} and Er^{3+}, $LiNbO_3$ crystals become good gain media for the generation of continuous wave lasers [1].

Optical waveguides, which can confine light propagation to small dimensions of order of several microns, are basic components for integrated photonic applications [2]. In waveguide configurations, related properties of the substrate materials could be considerably improved with respect to those of the corresponding bulks [3].

Ion implantation is a well-known technique for material modifications. It offers intriguing versatility for waveguiding structures fabrication in numerous optical substrates, including crystals, glasses, semiconductors, and organic materials [4]. Both one dimensional planar and two dimensional channel/ridge waveguides have been realized by using implantations of diverse ion beams [5].

$LiNbO_3$ is also one of the most well-known materials for various applications as passive and active waveguide devices [1,6]. In addition, $LiNbO_3$ crystals have received the most extensive attentions, compared with other substrates treated by ion beam technology. In this work, we present an overview of the our recent research progress on ion implanted optical waveguides in RE-doped $LiNbO_3$ crystals, by giving detailed fabrication methods, related mechanisms and luminescent properties. The potential photonic applications of these waveguides are also mentioned briefly.

References

[1] L. Arizmendi, Phys. Status Solidi (a) 201, 253 (2004).
[2] G. Lifante, *Integrated Photonics: Fundamentals*, John Wiley & Sons, Atrium 2008.
[3] D. Kip, Appl. Phys. B 67, 131 (1998).
[4] F. Chen, X. L. Wang, K. M. Wang, Opt. Mater. 29, 1523 (2007).
[5] F. Chen, Cri. Rev. Solid Stat. Mater. Sci. 33, 165 (2008).
[6] W. Sohler, H. Hu, R. Ricken, V. Quiring, C. Vannahme, H. Herrmann, D. Büchter, S. Reza, W. Grundkötter, S. Orlov, H. Suche, R. Nouroozi, and Y.H. Min, Optics & Photonics News, Jan. 2008, pp. 24-31

3D structures created inside photo-refractive crystals by tightly focused single femtosecond pulses

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We demonstrate that the interaction of intense femtosecond pulse with photorefractive crystal differs drastically from that of long pulse and cw illumination. The major difference relates to the fact that the fs-laser field intensity is three orders of magnitude larger than the field of spontaneous polarization inherent to the ferroelectrics. It was found that 150 fs, 800 nm, laser induced changes in the refractive index, which could be experimentally detected at 3.8±0.5 nJ energy per pulse in Fe: $LiNbO_3$ and 5.2±0.5 nJ in pure $LiNbO_3$ crystal, corresponding to intensity of TW/cm^2 and 1.37 TW/cm^2 respectively [1,2]. The breakdown intensity was found to be ≤10 TW/cm^2. Therefore, the high number density of excited electrons modifies the dielectric function leading to the transient negative change in the refractive index, $\Delta n / n \approx -4 \cdot 10^{-2}$. The high frequency laser field prevents the stationary charge distribution during the short pulse. The diffusion and recombination of charge carriers continues over a nanosecond time scale, after the end of the pulse. The main driving force for the current after the end of the pulse is the field of spontaneous polarization in the ferroelectrics: the current terminates when the field of charge separation balances this field. Modification of refractive index is independent of light beam polarization, in agreement with experiments, and saturates at $\Delta n / n \approx 4 \cdot 10^{-3}$ in semi-quantitative fit to the experimental data [3].

In this talk I recollect briefly the known features of refractive index changes by low intensity and long pulses and major properties of ferroelectric crystals. Then I present thorough analysis of physical phenomena during the pulse and after the end of the pulse followed by the experimental data, their interpretation and comparison with the theory

Summing up, it is demonstrated that single fs laser pulses focused in the bulk of ferroelectric crystals to the depth of 50 microns can form 3D arrangements of the micron-size laser-affected spots with the minimum separation of 2 microns. These arrangements could be detected (read), erased and re-written that makes tightly focused femtosecond pulses appropriate for the applications for 3D optical memory.

References

[1] S. Juodkazis, V. Mizeikis, M. Sudzius, H.Misawa, K. Kitamura, S. Takekawa, E. G. Gamaly, W. Z. Krolikowski, and A. V. Rode, *Applied Physics A*, 93:129-133 (2008).

[2] E. G. Gamaly, S. Juodkazis, V. Mizeikis, H. Misawa, A. V. Rode, W. Z. Krolikowski and K. Kitamura, *Current Applied Physics,* 8, 416-419 (2008).

[3]. E.G. Gamaly, S. Juodkazis, V. Mizeikis, H. Misawa, A.V. Rode, W.Z. Krolikowski, Modification of refractive index by a single fs-pulses confined inside a bulk of photorefractive crystal, (PRB, 2009, Submitted)

Bose Gas in Flatland

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Physics of a Bose gas in two dimensions (2D) is quite different from the usual 3D situation. In an infinite homogeneous 2D system, conventional long-range order is always destroyed by long wavelength thermal fluctuations, and Bose-Einstein condensation is not possible. Nevertheless, a 2D fluid can become superfluid at a finite critical temperature. Below the transition temperature the system is in a state with "quasi-long-range" order, in which there is no conventional order parameter but the first order correlation function decays only algebraically with distance. This unusual phase transition is described by the Berezinskii-Kosterlitz-Thouless (BKT) theory, and is associated with binding and unbinding of quantum vortices with opposite circulations. This theory defines a general framework in which we think about a wide range of 2D systems, from superfluid He films to 2D crystals and 2D arrays of Josephson junctions.

Most recently, we have experimentally studied BKT physics in (quasi-)2D ultracold atomic gases. I'll give an introduction on these experiments and summarize our current understanding of these systems.

A 2D Model for the FDTD Simulation of Split Ring based Metamaterials

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In this paper ab-initio calculations of the properties of split ring based metamaterials are presented without assuming an effective permeability unequal one. To this end a two dimensional simulation model including split ring resonators embedded in a medium with a polaritonic permittivity, providing a low plasma frequency, is introduced. Using the finite difference time domain (FDTD) method large scale simulations of this structure are presented. It was found from these ab-initio calculations that split ring resonators embedded in a polaritonic substrate material exhibit a negative refraction and backward waves and thus show a behaviour which can be modeled with a negative permeability. By constructing supercells it is possible to overcome anisotropy effects. However, for realistic material parameters, e.g. for Ag, for the chosen geometry the propagation length is of the order of one wavelength jeopardizing applications. Despite the often used concept of "long wavelength limit" FDTD results prove that this limit is seldom realized.

Semiconductor cavity quantum electrodynamics with single quantum dots

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Semiconductor cavity quantum electrodynamics (cQED) with single quantum dots as artificial atoms and high quality factor microcavties is a rapidly developing research field [1]. Solid state platforms are a prerequisite for a more widely spread exploitation of cQED effects, which hold promise for the realization of several key devices for quantum information processing and nano-optoelectronics, like single photon sources or ultra-low threshold lasers. Semiconductor systems are particularly attractive because they offer routes for electrical carrier injection or electro-optical tuning.

This contribution will focus on the presentation of cQED experiments in high-quality factor micropillar cavities containing semiconductor quantum dots. After a general introduction into semiconductor cQED with micropillar cavities, the recent progress made in our group on electrically driven micropillar cavities will be reported [2, 3]. By developing a process for planarizing and electrically contacting quantum dot micropillars we fabricated electrically driven devices with quality factors up to 16.000. Such devices feature pronounced cQED effects, like enhanced spontaneous emission, photon antibunching, high-β lasing and electro-optical tuning in both the weak or strong coupling regime.

Spatial determinism in cQED experiments is of major importance for the exploitation of related effects on a larger scale or for the realization of more complex device functionalities, e.g. the deterministic photonic coupling of remote quantum dots via spatially separated cavities and waveguides. Another main part of the talk will therefore discuss our recent progress made in the field of device integration of site-controlled quantum dots into photonic crystal as well as micropillar cavities [4-6].

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References

[1] J.-M. Gérard, “Solid-state cavity-quantum electrodynamics with self-assemled quantum dots”, in „Single Quantum Dots” edited by P. Michler, Springer, Berlin, 2003
[2] Böckler et al. Appl. Phys. Lett. 92, 091107 (2008)
[3] Kistner et al., Opt. Express 16, 15006 (2008)
[4] Schneider et al., Appl. Phys. Lett. 92, 183101 (2008)
[5] Sünner et al. Opt. Lett. 33, 1759 (2008)
[6] Schneider et al., Appl. Phys. Lett. 94, 111111 (2009)

Optical label-free biosensors: principles and applications

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In the last two decades there has been a tremendous effort towards development of biosensor technologies for detection and identification of chemical and biological species. Optical affinity biosensors are devices that incorporate a biological recognition element which specifically recognizes a particular analyte and an optical transduction system which allows observation and quantification of the interaction between the analyte and the biomolecular recognition element. In recent years numerous optical transduction methods have been developed, including both label-based methods such as fluorescence spectroscopy and label-free methods such as optical interferometry, spectroscopy of guided modes of optical waveguides, and surface plasmon resonance. Label-free optical biosensors present a unique technology that enables the direct observation of molecular interaction in real-time and offers benefits of rapid and sensitive detection of chemical and biological species with potential applications in numerous important areas including proteomics, medical diagnostics, environmental monitoring, food safety and security.

This paper reviews principles of the main types of optical label-free affinity biosensors. Special attention will be given to optical biosensors based on surface plasmon resonance (SPR) which represent the most advanced and developed optical label-free biosensor technology [1-2]. Selected results of SPR sensor research at the Institute of Photonics and Electronics, Prague will be presented. These results include advances in SPR sensor method (multiple-surface-plasmon spectroscopy, spectroscopy of long-range surface plasmons) and SPR instrumentation (mobile SPR sensors for field use, SPR sensor platforms for parallelized observation of biomolecular interactions). Moreover, applications of SPR biosensors for detection of chemical and biological analytes related to medical diagnostics (hormones, antibodies), environmental monitoring (endocrine disrupting compounds) and food safety (foodborne pathogens and toxins) will be discussed.

References

[1] J. Homola (ed.): Surface Plasmon Resonance Based Sensors, Springer Series on Chemical Sensors and Biosensors, Springer, 2006.
[2] J. Homola: Surface Plasmon Resonance Sensors for Detection of Chemical and Biological Species, Chemical Reviews 108, 462-493 (2008).

Doing photonics with Dirac fermions in graphene

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In this talk, we review the recent studies of a novel material known as graphene, a ballistic transport of electrons in which has tantalizing analogies with geometrical optics of metamaterials. When subjected to non-uniform electric and/or magnetic fields, graphene is expected to demonstrate such phenomena as ideal transmission of matter waves across barriers, negative refractive index, quantum mirages and cloaking, etc. Similar behaviors can also occur in artificial graphene-like systems created with the use of cold atoms in hexagonal optical lattices or in photonic crystals of the proper symmetry.

Spatial nonlinear optics in periodic lattices in lithium niobate

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Artificially structured materials, called meta-materials, lead to many radically new optical properties. The current vigorous search for negative refractive index materials may be one of the most notable examples. Other examples of such periodic materials are arrays of weakly coupled waveguides, which exhibit many new phenomena due to their unique diffraction properties and involved optical nonlinearities. In the first part of this talk I will provide an overview of our results obtained in waveguide arrays fabricated in lithium niobate crystals. In these samples localized optical defect states - so-called discrete solitons - can be formed, and the nonlinear interaction that takes place when two or more solitons intersect or propagate close enough to each other within the nonlinear array may be used to guide, steer, and switch light beams. The second part is devoted to recent experiments where additional linear and nonlinear periodic modulations play a dominant role, e.g. for the formation of spatial frequency combs or Rabi-like transitions of Floquet-Bloch modes.

Dynamical Symmetry Breaking in Dual-Core Nonlinear Systems

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Fundamental models of various physical media based on configurations with two parallel cores (waveguides) amount to systems of linearly coupled equations. The simplest example is the model of dual-core optical fibers or planar waveguides, which amounts a system of coupled nonlinear Schrödinger (NLS) equations for amplitudes of electromagnetic waves in the two cores [1],

$$iu_z + (1/2)\ u_{\tau\tau} + \left|u^2\right|\ u + v = 0,$$

$$iv_z + (1/2)\ v_{\tau\tau} + \left|v^2\right|\ v + u = 0. \qquad (1)$$

An obvious symmetric soliton solution to this system, with $u = v$, loses its stability through a *symmetry-breaking bifurcation* (SBB) of the *subcritical* type, when its energy exceeds a certain critical value. The SBB simultaneously gives rise to stable asymmetric solitons. SBBs accounting for the transition between symmetric and asymmetric solitons were studied in detail too in a number of other models. Some of these models also originate in nonlinear optics, describing dual-core fiber Bragg gratings with the intrinsic Kerr nonlinearity [2], linearly coupled waveguides with the quadratic [3] or cubic-quintic [4] nonlinearities, or a set of two parallel discrete waveguide arrays [5] (in the latter case, the SBB predicts the transition between discrete symmetric and asymmetric solitons). In addition to that, a number of works treated the SBB in models of Bose-Einstein condensates confined to a set of two parallel "cigar-shaped" traps, coupled by tunneling of atoms [6, 7]. Generic features of the SBB are that it happens with symmetric solitons in models with the self-focusing intra-core nonlinearity, and with antisymmetric solitons in the case when the nonlinearity is self-defocusing, which is most typical to BEC settings. In the latter case, the localized states featuring the bifurcation are actually *gap solitons* [2, 7], and the SBB is a bifurcation of the *supercritical* type, in contrast to that in system (1). While a majority of the studies of the SBB were dealing with one-dimensional (1D) models, a 2D model for the BEC trapped in two parallel "pancake"-shaped field configurations was studied too [8]. Actually, the nonlinearity can give rise to SBB not only in models supporting solitons, but also in other settings, a recent example being the bifurcation studied in a 1D model with a double-well *pseudopotential,* i.e., a nonlinear potential, described by the following equation [9]:

$$iu_t + (1/2)u_{xx} + \left[\delta(x-a) + \delta(x+a)\right]\ |u|^2 u = 0$$

All the above-mentioned models describe conservative media. The SBB was also studied in dissipative nonlinear models, *viz*., in a system of two linearly coupled complex Ginzburg-Landau equations with the cubic-quintic nonlinearity [10]. In that case, the bifurcation happens to solitary pulses ("*dissipative solitons*").

The presentation will aim to give an overview of basic models, results, and physical applications of the symmetry-breaking phenomena in conservative and dissipative nonlinear media.

References

[1] N. N. Akhmediev and A. Ankiewicz, Phys. Rev. Lett. **70**, 2395 (1993); P. L. Chu, B. A. Malomed, and G. D. Peng, J. Opt. Soc. Am. B **10**, 1379 (1993).

[2] W. C. K. Mak, B.A. Malomed, and P. L. Chu, J. Opt. Soc. Am. B **15**, 1685 (1998).

[3] W. C. K. Mak, B. A. Malomed, and P. L. Chu, Phys. Rev. E **55**, 6134 (1997); E **57**, 1092 (1998).

[4] L. Albuch and B. A. Malomed, Mathematics and Computers in Simulation **74**, 312 (2007).

[5] G. Herring, P. G. Kevrekidis, B. A. Malomed, R. Carretero-González, and D. J. Frantzeskakis, Phys. Rev. E **76**, 066606 (2007).

[6] A. Gubeskys and B. A. Malomed, Phys. Rev. A **75**, 063602 (2007); M. Matuszewski, B. A. Malomed, and M. Trippenbach, *ibid*. A **75**, 063621 (2007).

[7] M. Trippenbach, E. Infeld, J. Gocalek, M. Matuszewski, M. Oberthaler, and B. A. Malomed, Phys. Rev. A **78**, 013603 (2008).

[8] A. Gubeskys and B. A. Malomed, Phys. Rev. A **76**, 043623 (2007).

[9] T. Mayteevarunyoo, B. A. Malomed, and G. Dong, Phys. Rev. A **78**, 053601 (2008).

[10] A. Sigler and B.A. Malomed, Physica D **212**, 305 (2005).

Photonic Crystals: Properties and Applications

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Photonic Cystals (PhCs) are structures with spatially periodically varying refractive index For electromagnetic waves with wavelengths of the order of the periodicity this causes remarkable behaviour: In some wavelength ranges,"gaps", transmission is blocked, in other ranges "negative refraction"occurs, as if the structure has a negative refractive index.

This behaviour is explained in an powerful analogy to the electronic states in a (e.g. semiconductor) crystal. Methods used for quantum mechanical calculationsÂ can be extended to PhCs to explore the bandstructure of their electromagnetical modes complementing methods like the FDTD one for the wave propagation.

The properties of PhCs can be utilized in a number of applications: e.g., waveguides for integrated optics to allow communication at infrared frequencies within integrated circuits and microcavities as resonators for lasers and frequency multiplexing. Not all applications are technical - the brilliant colours of certain butterfly wings are also due to PhCs.

Femtosecond Laser Microfabrication - a Novel Technology in Photonics

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Microfabrication of photonics devices by means of intense fs laser pulses has emerged as a novel technology during the last decade [1]. A range of photonic structures and devices has been demonstrated recently based on permanent modification of refractive index after fs inscription (see e.g. [2] and references therein). This technology has the great potential but it also reveals intrinsic difficulties. A broad class of technological issues relates to the complexity of inherently nonlinear processes involved in fs pulse propagation and material modification. Additionally, there are numerous application-specific constraints to be considered, notably the common requirement for a refractive index modification pitch size much smaller than the inscribing wavelength. Nonlinear propagation of intense fs laser pulses is an extremely complicated phenomenon featuring complex multi-scale spatiotemporal dynamics of the laser pulses [3, 4]. From the numerical standpoint, the problem is extremely stiff as the propagating fs pulse undergoes very fast evolution. We have utilized a principal approach based on FDTD modeling of the full set of Maxwell's equations coupled to the conventional Drude model for generated plasma. Nonlinear effects are also included such self-phase modulation, multi-photon and plasma absorption. Such an approach resolves most problems related to extremely tight focusing, when paraxial approximation is not applicable and correctly describes creation of and scattering on inscribed structures of subwavelength size. Optimization has been performed in terms of the geometry of the distribution of the residual electron-hole plasma left behind the fs laser pulse. The recombination of this plasma is a primary mechanism for the energy transfer and eventual modification of the material. The plasma density relates to the material temperature [5]. After a complex thermoplastic relaxation [6] the frozen profile of refractive index has a spatial dimension of about a half of that of the original cloud of plasma [5].

We present a consistent introduction to theoretical description of femtosecond pulse propagation in the context of laser microfabrication and describe the state of the art experiments.

References

[1] H. Misawa and S. Juodkazis, ed., *3D Laser Microfabrication. Principles and Applications*, Wiley-VCH, Weinheim (2006).

[2] V. Mezentsev, J. Petrovic, M. Dubov, I. Bennion, J. Dreher, H. Schmitz, and R. Grauer, Proc. SPIE 6459, paper 64590B (2007).

[3] A. Couairon, A. Mysyrowicz, Physics Reports **441** 47-189 (2007)

[4] L. Berge, S Skupin, R Nuter, J Kasparian, and J-P Wolf, Rep. Prog. Phys. **70** 1633-1713 (2007)

[5] X. Zhang, X. Xu, and A. Rubenchik, Appl. Phys. **A79**, 945-948 (2004)

[6] J.S. Petrovic, V. Mezentsev, H. Schmitz, and I. Bennion, **39**, 939-946 (2007)

Cavity Optomechanics

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Recent years have witnessed a remarkable convergence of interests in atomic, molecular and optical physics, condensed matter physics, and nanoscience. Specific examples include the use of ultracold atomic and molecular systems as quantum simulators of solid-state systems, the demonstration of the analog of cavity QED effects with superconducting boxes, and the laser cooling of nanoscale cantilevers, leading to the emerging field of *cavity optomechanics*. Cavity optomechanics provides a rich testing ground for fundamental physics, while at the same time presenting considerable potential for applications in quantum control and sensing.

A central element of the generic cavity optomechanical system is a Fabry-Pérot type cavity with one end-mirror vibrating about its equilibrium position under the effect of radiation pressure. Recent experimental advances in nanofabrication and in non-equilibrium cooling have brought these macroscopic oscillators closer than ever before to operating in the quantum regime. From a fundamental point of view, interest in this frontier lays in the fact that quantum mechanics has never been tested at such a macroscopic scale. Also, building on related successes in atomic physics, it is now possible to explore the interaction of cold atomic and molecular systems with macroscopic-scale quantum nanomechanical oscillators. From a practical point of view it is also important to explore the behavior of mechanical oscillators in the quantum regime since they can serve as sensors whose precision is fundamentally restricted by quantum mechanics. After a general introduction to cavity optomechanics, the talk will discuss several examples that illustrate its applications in coherent control and sensing. We will also show how these systems open the way to the exploration of a completely new regime of interaction between light, ultracold atoms and quantum mechanical nanostructures.

Biomimetic nanostructured thin layers synthesized by advanced pulsed laser technologies for mineralized tissues, fast repairing and regeneration

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Calcium Phosphates (CaPs) are the best substitutes for human bones and as such a primary candidate for the manufacturing of medical implants. Unfortunately, they do not withstand stress in bulk and break when subjected to mechanical pressure.

A new generation of biomimetic implants are developed which combine the high stress resistance of metals with excellent biocompatibility, bioactivity, and resorbability provided by thin CaP coatings.

We pulsed laser deposited (PLD) simple or doped CaPs on different substrates using a KrF* (λ = 248 nm, $\tau \sim 25$ ns) UV laser source in controlled atmospheres of oxygen or water.

We demonstrated that the prime advantages of PLD as applied to calcium phosphates were its capacity of yielding pure, crystalline, stoichiometric nanofilms and its flexibility that allowed good control of their morphology, phase, crystallinity, and chemical composition.

Given the growing evidence of their beneficial effect on bone, ranelate- and alendronate-based drugs incorporated into calcium phosphates were used in PLD experiments.

Hybrid organic-inorganic nanocomposites obtained from soluble salts of calcium, phosphorus, and polymer were deposited by matrix assisted pulsed laser evaporation (MAPLE). Human plasma proteins (e.g., fibronectine, colagen) were applied by MAPLE for biomaterial activation by increasing both protein adsorption and cell adhesion at the biointerface.

A major advantage of the MAPLE technique is that it allows the deposition of high molecular mass compounds at very low temperatures thus preventing organic phase decomposition.

A major attention was given to a porous interface which can improve bone bonding, serving as a matrix for endogenous or exogenous cell adhesion and facilitating certain cell processes including mitosis, synthesis, and migration. The potential role of a porous structure as a delivery vehicle for exogenous cells has become increasingly important in a wide variety of tissues and organs in the light of recent advances in the investigation of cell therapy for local repair.

All synthesized nanostructured layers were optimized following investigations by complementary physicochemical techniques (SEM, TEM, SAED, XTEM, GIXRD, XPS and FTIR). Biocompatibility, bioactivity and biodegradability were evaluated by *in vitro* and *in vivo* tests.We demonstrated that human osteoblasts proliferate faster, reach a normal morphology and remain viable when cultured on PLD and MAPLE coatings.

Moreover, we proved that the presence of strontium ranelate in the CaP coatings enhances osteoblast activity and differentiation, while it inhibits osteoclast production and proliferation, preventing undesirable bone resorption.

Crystalline alendronate-doped hydroxyapatite with different bisphosphonate content have been successfully deposited on Titanium substrate by MAPLE technique. Our data demonstrate that it is possible to use MAPLE to synthesize coatings coupling the bioactivity of HA with the local availability of alendronate, and accordingly suitable to promote bone formation and prevent bone resorption.

In-vivo pull out tests of different doped CaPs clearly showed that these coatings have strongly activated and enhanced the bone repairing.

Ultracold Molecules

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The success of laser cooling of atoms which culminated in the production of the Bose-Einstein condensate and atom laser, has inspired research in more complex ultracold systems. Intensive research into cold molecules over the last decade has opened new and exciting prospects such as the development of ultrahigh precision spectroscopy, coherent control of chemical reactions and new techniques for quantum computing. Atomic cooling techniques, however, cannot be generalized to molecules due to the complex internal energy level structure and subsequent unavailability of a closed-loop cooling cycle; instead, alternative cooling approaches must be taken.

Several competing techniques for cold molecule generation have been demonstrated and can be divided into two groups: the direct cooling of molecules and the association of cold molecules from cold atoms. The former approaches are efficient in the stabilization of molecules into the lowest vibrational levels but are unable to cool them translationally to sub-mK temperatures. On the other hand, methods that use cold atoms as the starting point for the formation of molecules, such as photoassociation, association via Feshbach resonances and three-body collisions, produce translationally cold molecules but with substantial vibrational energy. Very recent results showed that further stabilization of these molecules into the lowest ro-vibrational levels is possible and the ground state of both homo- and hetero-nuclear dimers has been reached.

In this lecture I shall review state-of-the-art research in ultracold molecules. Several answers to the question: Why cold molecules? will be offered through examples of emerging new physics and applications. The most successful routes to ultracold molecule formation will be explained and compared to the currently investigated alternative techniques. Special emphasis will be put on the role of optical techniques used for the stabilization into low lying vibrational states, such as stimulated Raman adiabatic passage, frequency combs and coherent control. The lecture will be concluded by a general overview of the contribution of cold-molecule research to our understanding of physics and chemistry.

Overcoming Parametric Stochastic Barrier

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Parametric interaction in high-confinement fiber was recently used to set new records in frequency conversion, band-invariant amplification and fast coherent signal processing. In contrast to conventional four-photon mixing platforms, new classes of fibers are capable of net gain mixing over ranges exceeding 100THz, spanning visible to infrared bands. While ultrawideband wavelength conversion represents the most widely recognized application, immediate future holds exciting prospects in ultrafast, real-time processing and coherent control.

Current generation of high-confinement fiber is fabricated with exceeding precision: its transverse variations are expressed in multiples of silica molecular diameters. With nanometer-scale radial precision maintained over kilometers, high-confinement fibers stand among the most precisely fabricated structures in modern engineering. Unfortunately, even molecular-scale core fluctuations pose a basic barrier: an arbitrary-wide mixer cannot be constructed from randomly fluctuating waveguide. In simple terms, small uncertainties in waveguide geometry have destructive impact on long-scale phase matching between interacting optical waves. This fundamental limitation is known as stochastic parametric barrier and is principal obstacle on a path to practical parametric device construction.

Rather than insisting on unphysical waveguides (requiring sub-molecular radial control), an alternative approach is required. Indeed, it is possible to map nanoscale fiber fluctuations exactly and then use the information to synthesize arbitrary mixer response. To accomplish this, we introduced new energy delivery method based on localized four-photon mixing. The technique improves the sensitivity of existing dispersion mapping methods by orders of magnitude and is applicable to arbitrary waveguide type. The talk will describe the effort that led to the ability to sense molecular-scale geometry variations along km-long fiber for the first time. Implications of the new technique will be illustrated on general mixer applications.

Cold atom ratchets: beyond 1D rocking ratchets

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Brownian motors, or ratchets, are devices which ``rectify" Brownian motion, i.e. they can generate a current of particles out of unbiased fluctuations.

We experimentally implemented a Brownian motor using cold atoms in an optical lattice. This is quite an unusual system for a Brownian motor as there is no a real thermal bath, and both the periodic potential for the atoms and the fluctuations are determined by laser fields.

With the help of such a system, we investigated experimentally the relationship between symmetry and transport in a 1D rocking ratchet, both in the periodic and in the quasiperiodic case. We then went beyond 1D rocking ratchets, demonstrating 1D gating ratchets. We also realized 2D rocking ratchets and demonstrated a rectification mechanism unique to these high-dimensional ratchets.

References

[1] P.H. Jones, M. Goonasekera, and F. Renzoni, Phys. Rev. Lett. 93, 073904 (2004).
[2] R. Gommers, P. Douglas, S. Bergamini, M. Goonasekera, P.H. Jones and F. Renzoni, Phys. Rev. Lett. 94, 143001 (2005).
[3] F. Renzoni, Contemp. Phys. 46, 161 (2005).
[4] R. Gommers, S. Bergamini and F. Renzoni, Phys. Rev. Lett. 95, 073003 (2005).
[5] R. Gommers, S. Denisov and F. Renzoni, Phys. Rev. Lett. 96, 240604 (2006).
[6] R. Gommers, M. Brown, and F. Renzoni, Phys. Rev. A 75, 053406 (2007).
[7] R. Gommers, V. Lebedev, M. Brown, and F. Renzoni, Phys. Rev. Lett. 100, 040603 (2008).
[8] M. Brown and F. Renzoni, Phys. Rev. A 77, 033405 (2008).
[9] V. Lebedev and F. Renzoni, Phys. Rev. A, in press.

Nonlinear Metamaterials

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Nonlinearity adds an extra degree of freedom for metamaterial design, so that the properties of the same piece of the artificial material can be tuned dynamically. As an example of nonlinear effect, the material can be transparent for weak electromagnetic wave, and it becomes opaque once we increase the input power. Nonlinear effects have already shown their unique usefulness in optics and telecommunications, and this suggests that the nonlinear metamaterials can bring us very unusual functionalities.

The theoretical study of hypothetical nonlinear metamaterial [1] shows that the hysteresis-type dependence of the magnetic permeability on the field intensity allows dramatic changes of the material properties. As a first step towards creating tunable bulk nonlinear metamaterials we studied the dynamic tunability of the magnetic resonance of a single nonlinear split-ring resonator [2]. We demonstrated different tuning regimes of metamaterial [2]. In addition, at higher powers the nonlinear response of the split-ring resonator becomes multi-valued, indicating that the memory effect can be potentially observed in nonlinear metamaterials.

We fabricated tunable two-dimensional nonlinear magnetic and nonlinear electric metamaterials by placing varactors in each of the split-ring resonators or each of the electric resonators of the structure. First of all, we measured a very pronounced shift of the resonance itself, and then measured the transmission through the nonlinear metamaterial with wires and split-ring resonators for different power levels [3]. We also observed intensity-suppressed transparency, when the frequency of our wave is at the left edge of the resonance. The material is transparent for low-level signals, however, when we increase the power, the frequency is shifted to the region of positive susceptibility, and the material becomes opaque. As a result, we observe strong suppression of the beam transmission by 20 dB in magnetic metamaterial, and almost 50dB in electric metamaterial.

Left-handed materials at optical frequencies are closely related to the field of plasmonics. Nonlinear plasmonics is not a well developed area, and before studying nonlinear optical metamaterials, we study fundamental nonlinear effects of the wave propagation along metal surfaces. Firstly, we study nonlinear modes in a subwavelength slot waveguide created by a nonlinear dielectric slab sandwiched between two metals [4]. We present the dispersion diagrams of the families of nonlinear guided modes and reveal that the symmetric mode undergoes the symmetry-breaking bifurcation and becomes primarily localized near one of the interfaces. We also find that the antisymmetric mode may split into two brunches giving birth to two families of non-linear antisymmetric modes. In addition, we study nonlinear propagation of surface Plasmon polaritons along an interface between a metal and a dielectric with nonlinear Kerr response.
We demonstrate numerically self-focusing of a plasmon beam at large powers and soliton formation even in the presence of losses. We develop an analytical model for describing the spatial plasmon-solitons, and observe a good agreement with the results of numerical studies.

[1] A.A. Zharov, I.V. Shadrivov, and Yu.S. Kivshar, Phys. Rev. Lett. 91, 037401-4 (2003).
[2] D.A. Powell, I.V. Shadrivov, Yu.S. Kivshar, and M.V. Gorkunov, Appl. Phys. Lett. 91, 144107-3 (2007).
[3] I.V. Shadrivov, A.B. Kozyrev, D.W. van der Weide, and Yu.S. Kivshar, Appl. Phys. Lett. 93, 161903-3 (2008).
[4] A.R. Davoyan, I.V. Shadrivov, and Yu.S. Kivshar, Opt. Express 16, 21209-21214 (2008).

Quantum cascade lasers with improved thermal properties and their application in optoacoustic sensors

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One of the top priorities in the development of quantum cascade laser (QCL) sources is the optimization of the heat transport dynamic, since for the widespread application of these laser sources it is necessary to extend the CW operation at RT in a large range of wavelengths. Thus understanding the heat dissipation processes and their interplay with the electrical and optical characteristics are key issues for the realization of QCLs with improved thermal management. To address these topics we have performed extensive experimental studies on the thermal properties of state of art QCLs operating at low wavelengths. The experimental approach is based on the investigation of the band-to-band photoluminescence (PL) signals, collected during device continuous wave operation and detected by means of an InGaAs-array, a Si-CCD detector or an intensified Si-CCD. From the analysis of PL data we measured the electron temperatures, the lattice temperature and the heat diffusion dynamics. Using these data as inputs, we validated a two–dimensional anisotropic thermal model allowing us to extract the heat dissipation patterns, the in-plane and the cross-plane ($k_{\perp}$) active region thermal conductivities and the thermal boundary resistance both in mid-IR and in THz QCLs based on different material systems and heat sinking configurations. We will review here our results and as possible application we will describe the realization of an optoacoustic sensor based on mid-infrared QCLs for trace gas detection.

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Quantum control of linear susceptibility in five-level atoms via dressed interacting ground states, with a focus on group velocity control

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In recent years, quantum engineering of the atomic susceptibility in multi-level atoms has led to the ability to create anomalous dispersion along with vanishing absorption or gain. Several experiments have been performed starting with Wang, Kuzmich, and Dogariu [Nature vol. 406, p. 277 (2000)] showing that one can achieve large anomalous dispersion leading to superluminal and negative group velocities (v_g) for light pulses without significant attenuation or reshaping. These experiments revitalized interest in the century old problem of how fast information propagates via electromagnetic radiation, first dealt with by Sommerfeld who defined a signal velocity different from v_g that is always $\leq c$ to be consistent with relativity. Unfortunately, anomalous dispersion has not found significant wider application outside of the foundations of physics. At the same time, electromagnetically induced transparency (EIT) has been used to create linear susceptibilities with extremely large normal dispersion that can be used to slow light pulses down to a few meters per second and even to a complete stop by storing them in the atomic polarization.

We generalize EIT to a five level atom in which two driven ground state doublets, denoted {|b>, |b'>} and {|c>, |c'>}, interact with an excited state, |a> and analyze the susceptibility for a probe field on the |a><-->|b> transition. We call systems with this level configuration "dressed interacting ground states" (DIGS) systems. We study the DIGS configuration under two sets of initial conditions. In the first, we find that the EIT spectrum is modified to include two new features located within the transparency window, whose widths and locations can be tuned by the drive fields. In the vicinity of these features, we find small windows of very large dispersion and suppressed absorption, permitting group velocities up to two orders of magnitude slower than an identically configured EIT system, without the additional couplings.

In the second case, when the population of |c'> exceeds the population of |b>, the absorption resonances already described become amplification resonances. For larger populations in |c'>, the dispersion between these amplification line changes sign becoming anomalous, leading to a prediction of superluminal and negative group velocities. Varying the rate of incoherent pumping from ground to excited states can smoothly change the group velocity in the system from sub- to superluminal. Our system under realistic experimental conditions should yield negative group velocities two orders of magnitude larger than the best experiments to date. We discuss the prospects for experiments that smoothly vary group velocities from sub- to superluminal and the implications for the signal velocity.

We also consider a manifestation of the DIGS level configuration in a double well Bose-Einstein condensate. Here, coherent tunneling between the well replaces the electromagnetic couplings between ground states. In this case, the new features could be used to precision measurements of atomic tunneling and non-local control of light propagation.

Optical capability of runaway electron preionized diffuse discharges and its applications for excilamps and lasers

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This paper presents the results of experimental investigations of diffuse (volume) nanosecond high pressure discharges in a non-uniform electric field at a time resolution of a recording system being equal to ~100 ps. A runaway electrons preionized diffuse discharge (REP discharge [1]) was use for pumping different gas lasers, for creation VUV and UV excilamps, for modification and cleaning of metal surfaces. It is shown that conditions of obtaining a diffuse discharge without a source of additional ionization are extended at the voltage pulse duration reduction. It was found that the main energy deposition into the REP discharge plasma occurred after attaining maximal voltage at a gap. A REP discharge is formed due to the gap pre-ionization by runaway electrons and X-ray quanta. At a negative polarity of the electrode with a small radius of curvature, a volume (diffuse) discharge formation is determined by preionization with runaway electrons which are generated due to the electric field amplification near the cathode and in the gap. At a positive polarity of the electrode with a small radius of curvature, the X-ray radiation, generated at the runaway electrons braking at the anode and in the gap, is of great importance in a volume discharge formation. A REP discharge has two characteristic stages. In the first stage, the ionization wave overlaps the gap during a fraction of a second. The discharge current is determined by the conductivity current in the dense plasma of the ionization wave and the displacement current in the remaining part of the gap. The second stage of the discharge can be related to the anomalous glow discharge with a high specific input power. During the second stage, the gap voltage decreases and the cathode spots formed as a result of explosive electron emission can participate in the electron emission from the cathode. At the increase of the voltage pulse duration and specific input power, the REP discharge transforms into a spark discharge form. A REP discharge is easily realized in various gases and at different pressures.

Reference

[1] V. Tarasenko, E. Baksht, A. Burachenko, I. Kostyrya, M. Lomaev, D. Rybka, Plasma Devises and Operation, Vol.16, No.4, 267 (2008).

Photonic crystals as new materials for dynamic holography

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For many tasks connected with image processing in real time the methods of dynamic holography are widely used. The holographic image reconstruction of the volume object illuminated by laser pulses of nano- and picosecond duration is usually realized in stimulated Raman scattering (SRS), stimulated Brillouin scattering (SBS) and stimulated Raleigh wing scattering (SRWS). Different types of stimulated scatterings of light allow to realize optical image reconstruction and processing simultaneously at several frequencies with high efficiency conversion. Optical nonlinearities of the active medium used such as for example Kerr effect or nonlinear absorption give the additional possibilities for real time imaging techniques such as phase contrast, contrast improvement and contrast reversal and lead to practical applications. In spite of the great progress in dynamic holography it is still subject to improve particularly for developing of the new materials which can be used as active medium. One of the perspective kind of such materials are photonic crystals – materials that possesses a periodic dielectric constant with a length scale of the same order as the wavelength of the electromagnetic radiation used. One-, two- and three-dimensional photonic crystals exhibit the remarkable properties, which can be effectively used for photon fluxes processing due to the existing of the photonic band gap. Different types of modes defined by the periodical structure of photonic crystal and the possibility of different photonic crystal structure production lead to the important possible applications. Large values of the electromagnetic field localization in some spectral regions lead to the strong enhancement of nonlinear wave-matter interaction in comparison with bulk crystals.

Very important kind of 3-D photonic crystals is globular photonic crystal built of globules (balls) with diameter, which may be comparable with visible light wavelength. In nature such crystals exist as mineral - opal, consisting of silica nanospheres. Space among these spheres (or globules) is filled with different inorganic materials. Recently technology of synthetic opal matrixes production is developed. Such opal matrixes have 3-D periodical structure and are built of ordered close-packed silica globules with diameter 200-600 nm, organizing 3-D phase-centered cubic lattice. Empty cavities among these globules have octahedral and tetrahedral form. These cavities can be filled with organic or inorganic materials, for instance, semiconductors, superconductors, ferromagnetic substances, dielectrics, displaying different types of nonlinearities and.

In the case of the different kinds of molecular medium infiltrating the opal crystals some types of stimulated scatterings with high efficiency conversion can be observed. Volume image reconstruction was realized in stimulated Raman scattering and stimulated Globular scattering (SGS) excited in nanocomposites - synthetic opal matrixes filled with different nonlinear medium. The local field enhancement near the surface of the silica nanospheres in synthetic opal matrixes leads to the nonlinear optical light - matter interaction enhancement and such samples can be effectively used as phase and amplitude nonlinear filters in optical Fourier technique for image processing.

Actual and Next Generation Access Photonic Networks

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All optical networks are evolving fast, special in these last years when strong governmental efforts have been redirected in order to push economy and create new jobs in the actual crisis environment. Clearly, photonic components have a crucial role in the actual scenario, since, when approaching the common end user, they have to be fully tested proved and specially mature enough to have very low prices and high reliability. For this reason, in this work we will observe the driving forces of access networks and following, we will look into the future perspectives of these scenarios observing the existing next generation proposals and eventual solutions.

We will start by observing the deployment status in the various countries, as well as the economic and legal drivers that lie behind [1-3]. From that point an overview on the existing technologies will be made, specifically regarding APON, BPON, GPON and EPON [4-5]. These networks have evolved and are sharing spectrum with some legacy services like video overlay. A short description of the topologies and requirements from the physical layer, namely the optical components will be given.

From the basis presented before, a set of new solutions that are coming to front are going to be presented, are examples PIEMAN [6], SARDANA [7] and NGOA. Special interest and evidence will be given to the SARDANA and the NGOA since those are solutions in which the author has involvement. SARDANA is a more research oriented project, founded by the EC 7th framework program, and therefore several are the requisites that have to be met and with them there are several technological barriers that have to be faced by the optics and, simultaneously, solutions that have to be found, eg. remote amplification, remote reconfiguration, resilience, etc. Another, NGOA, is a more industrial type project of Nokia Siemens Networks, where the objective is to find a reliable cost efficient solution for the next generation passive optical network, fully functional and able to meet the requisites of 2012+.

References

[1] FTTH council, http://ww.ftthcouncil .eu
[2] Light reading, http://www.lightreading.com/
[3] OFC NFOEC, http://www.ofcnfoec.org/
[4] ITU-T, http://www.itu.int/ITU-T/index.html
[5] IEEE, http://standards.ieee.org/
[6] PIEMAN http://www.ist-pieman.org/about.htm
[7] SARDANA http://www.ict-sardana.eu/

Quantum dots as detectors and sources of mid- and far-infrared radiation: theoretical models

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In the last two decades, semiconductor nanostructures, such as quantum wells, wires and dots, have been recognized as sources and detectors of radiation in the mid- and far-infrared region of the spectrum. Much of a success has been obtained with quantum well based intraband devices, such as quantum cascade lasers and quantum well infrared photodetectors. However due to longer carrier lifetimes in quantum dots, it is expected that optoelectronic devices based on intraband transitions in self-assembled quantum dots would have superior performance to their quantum well counterparts.

Theoretical modeling of the electronic structure, optical and transport properties of quantum dots plays an important in role in guiding the development of new types of such devices, as well as in understanding the rich physics of existing devices and improving their designs. This presentation will review the theoretical methods for treating the physical processes in quantum dots and the most important experimental achievements in this field. The examples of the application of the methods to the simulation of quantum dot infrared photodetectors [1-2], design and simulation of optically pumped intersublevel quantum dot lasers [3] and quantum dot quantum cascade lasers [4-5] will be also presented.

References

[1] N. Vukmirović, D. Indjin, Z. Ikonić, and P. Harrison, Appl. Phys. Lett., 88, 251107 (2006).

[2] N. Vukmirović, Z. Ikonić, I. Savić, D. Indjin, and P. Harrison, J. Appl. Phys., 100, 074502 (2006).

[3] N. Vukmirović, Z. Ikonić, V. D. Jovanović, D. Indjin, and P. Harrison, IEEE J. Quantum Electron., 41, 1361 (2005).

[4] N. Vukmirović, Z. Ikonić, D. Indjin, and P. Harrison, Phys. Rev. B 76, 245313 (2007).

[5] N. Vukmirović, D. Indjin, Z. Ikonić, and P. Harrison, IEEE Photonics Tech. Lett. 20, 129 (2008).

Storing classical and non-classical light in atomic media

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The conceptually simplest approach to a memory for light is the storage of a single photon in a single atom. In free space that process is inefficient in view of the atom's cross section of order of the light wavelength λ squared, and the diffraction limitations imposed on focusing light to a small area $A \sim \lambda^2$ (see, however, Ref. [1]). Cavity QED techniques with ultrahigh-finesse resonators can be used to reach the so-called strong-coupling limit where the Rabi frequency associated with the exchange of a single excitation is large compared to all decoherence processes. However, such an approach, while highly successful (see, e.g., Refs. [2,3]), is also technically difficult, and its efficiency often limited by mirror loss.

Alternatively, light can be absorbed with near-unit probability in an optically dense atomic ensemble. Under appropriate conditions, the light is not absorbed by definite individual atoms, but as a collective excitation of the ensemble that can, e.g., be described in terms of Dicke states [4] or dark-state polaritons [5]. This approach is closely related to slow-light propagation in atomic media [6], and allows the adiabatic mapping of quantum states of light onto atoms.

Non-classical states of light can also be generated by detection where under appropriate conditions a quantum measurement, e.g. the detection of a single photon, prepares a collective excitation in the ensemble [7,8]. We will review techniques for the quantum storage of light in atomic ensembles, and discuss recent experiments such as the heralded storage of the polarization state of a single photon where a photon is detected, stored, and recreated without touching its – potentially undetermined – polarization state [9].

References

[1] M.K. Tey et al., Nature Physics **4**, 924 (2008).
[2] D. Boozer, A. Boca, R. Miller, T. E. Northup, and H. J. Kimble, Phys. Rev. Lett. **98**, 193601 (2007).
[3] T. Wilk, S. C. Webster, H. P. Specht, G. Rempe, and A. Kuhn, Phys. Rev. Lett. **98**, 063601 (2007).
[4] R. H. Dicke, Phys. Rev. **93**, 99 (1954).
[5] M. Fleischhauer and M. D. Lukin, Phys. Rev. Lett. **84**, 5094 (2000).
[6] L. V. Hau, S. E. Harris, Z. Dutton, and C. H. Behroozi, Nature (London) **397**, 594 (1999).
[7] L.-M. Duan, M. D. Lukin, J. I. Cirac, and P. Zoller, Nature **414**, 413 (2001).
[8] J. K. Thompson, J. Simon, H. Loh, and V. Vuletic, Science **313**, 74 (2006).
[9] H. Tanji, S. Ghosh, J. Simon, B. Bloom, and V. Vuletić, Phys. Rev. Lett. **103**, 043601 (2009).

Experimental quantum state engineering using linear optics and parametric down-conversion

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Superposition and entanglement are the essence of new and promising technologies, including quantum communication and quantum computation. The present talk contains the results of several experiments, all dealing with linear optics and entangled multi-photon states. Up to four, either in path-or in polarization entangled photons could be generated via the process of spontaneous parametric down-conversion and manipulated by using an interferometric setup. Depending on which sort of entangled state was created, different experiments concerning quantum information processing or quantum metrology could be demonstrated. Recently, also a six-photon Dicke state could be generated. These Dicke states are of certain interest because of allowing interesting applications in multiparty quantum networking protocols such as open-destination teleportation, telecloning, and quantum secret sharing.

Quantum transport of atoms in Fourier-synthesized optical lattices

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Quantum transport has in 'conventional' lattices proven to be a powerful method for characterization of the band structure. Here I will describe experiments studying the transport of atomic Bose-Einstein condensates in periodic potentials of variable spatial symmetry. For a realization of lattice potentials with variable symmetry, a conventional lattice of $\widetilde{\lambda}/2$ spatial periodicity is superimposed with a fourth-order lattice potential of $\lambda/4$ periodicity. The high periodicity lattice is realized using dispersive properties of multiphoton Raman transitions. In recent experiments, we have realized quantum ratchet transport of atoms in the absence of dissipation within the interaction time (Hamiltonian regime). The ratchet transport arises from broken spatiotemporal symmetries of the driven potential, resulting in a desymmetrisation of transporting Eigenstates (Floquet states). The results provide a proof of principle demonstration of a quantum motor.

Plasmonic nanophotonics

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