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Plenary talks

QuantArm 2014

A New Concept For High Accuracy And High Speed Laser Ranging Based On a Frequency Shifted Feedback Laser For Industrial Applications

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Central to this presentation will be the discussion of a novel concept for laser ranging, suitable for industrial applications. It is based on a so-called cavity-internal frequency shifted feedback laser (fsf-laser). In such a laser, the typical frequency-space mode structure is overcome by shifting the frequency of the circulating laser field at each round trip via an acousto-optical frequency shifter and feeding back only the frequency-shifted part. Injection seeding of such a device with a narrow band phase-modulated laser leads to a comb-structure in the continuous wave output spectrum (different from the well-known comb structure in the spectrum of mode-locked femto-second lasers). Part of this radiation field is sent to a reference surface the other to the object. Superposition of the two coherent multi-component reflected or scattered radiation fields on a fast photo diode leads to a complex response. The detector response is monitored as the frequency of the phase modulation is tuned. At a specific modulation frequency all the components contributing to the signal are in phase and a signal, orders of magnitude above the noise floor, results. The distance of the object is easily and accurately derived from the modulation frequency, leading to this maximum. Depending in the layout of the fsf-laser system, an accuracy of about 1 micrometre over distances of a few meters (with > 1 kHz rate of data taking) or 0.1 mm over distances of several ten meters (with about 1 MHz rate of data taking) can be achieved.

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New Halides Scintillators for Gamma Radiation Detection

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Large efforts in recent years to discover new scintillators have so far confirmed the superior performance of halide scintillators. The alkali halides NaI(Tl^+) and CsI(Tl^+) discovered more than 65 years ago are still dominating the market for applications that requires very large crystals and economical scintillators despites some limitations in their performance. The newer halide $LaBr_3$:Ce^{3+} with superior performance is not as widely used mainly due to its high cost. This compound is very hygroscopic and crystals are produced with low yield due to defect and crack formation. Compounds containing alkali-earth halides and more complex halides (ternaries and quaternaries) have the potential to provide new choices for scintillators with energy resolution now less than 3%. The specifics of crystal growth of these new compounds and relevant properties will be discussed as they relate to fabrication of detectors for various applications.

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Surface Interactions In Matter-Wave Optics And Interferometry

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Atom-surface interactions [1] are a key feature in coherent atom optics and interferometry making use of material micro- and nano-structures as atom beam splitters. On one hand, van der Waals/Casimir-Polder-induced elastic scattering by transmission or reflection nano-slit gratings alters the atomic diffraction pattern. On the other hand, inelastic transitions between energy levels induced by the non-scalar part (of the *quadrupolar* type) of the van der Waals surface interaction do occur, paving the way to novel types of coherent beam splitters. For instance, exo-energetic "*van der Waals – Zeeman*" transitions among Zeeman sub-levels of the metastable state of rare gases, induced by the surface interaction potential in the presence of a static magnetic field, have been be observed, thanks to the small deflection angle they cause to the atomic trajectories [2]. In the talk, we will review these surface effects, their velocity dependence [3], their distance range [4] and their potential applications (atomic Fresnel bi-prism, etc.).

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Non-Local Nonlinear Optics With Rydberg Gases

Michael Fleischhauer
University of Kaiserslautern

Photons do not easily interact with each other and nonlinear processes on the few-photon level can usually be realized only under very special conditions. Recently it was shown that coupling of weak light fields to atoms involving Rydberg states may change this picture. Under conditions of electromagnetically induced transparency (EIT) such a coupling leads to the formation of Rydberg polaritons which are quasi-particles with tunable composition and effective mass, and strong, non-local interactions. The latter can turn photons into hard-sphere objects with a finite avoided volume in two particle correlations or lead to bound states of photon pairs, i.e. photonic molecules. I will explain the physics of Rydberg polaritons, review the experimental status and discuss interesting many-body effects arising from the long-range interaction such as the formation of Wigner crystals of individual photons.

Coherent Matter-Wave Splitting On An Atom Chip

Shimon Machluf, Yonathan Japha, Ron Folman
Ben-Gurion University of the Negev, Israel

Atom Chips are tool for trapping, guiding and manipulating matter-waves. To realize their potential it is important to achieve coherent splitting close to the surface. Here we use the Stern-Gerlach effect to do just that.

Quantum Communication

Nicolas Gisin
University of Geneva, Switzerland

Quantum communications is the art of transferring a quantum state from one location to a distant one. On the fundamental side, quantum communication is fascinating because it illustrates the power of entanglement and of non-local quantum correlations. On the application side, quantum communication is already relatively advanced with Quantum Random Number Generators and Quantum Key Distribution (QKD) systems having found niche markets. On the academic research side quantum communication has still a long way to go until a functional quantum repeater can extend the distances to continental scales. Quantum repeaters are based on quantum teleportation, the most fascinating application of entanglement.

Additionally, quantum repeaters require quantum memories with memory times close to a second; this represents one grand challenge for quantum communication. Entangling two quantum memories, that is two crystal, raises the fascinating question of “what is large entanglement?”.

Quantum Optics And Quantum Information Using Cold Rydberg Atoms In An Optical Cavity

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Novel stimulating perspectives have appeared recently to implement photon-photon interactions, by using for instance cold Rydberg atoms in an optical cavity [1, 2]. We will present some recent experimental [1, 2] and theoretical [3] developments, and discuss open perspectives for quantum information processing and communications.

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Cooperative Quantum Optics In Dense Thermal Vapours

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Many of the work-horse techniques of contemporary atomic physics experiments were first demonstrated in hot vapours, such as coherent population trapping (CPT), electromagnetically induced transparency (EIT), slow light, stored light, and important breakthroughs such as the experimental demonstration of quantum memory for light and studying the quantum interface between light and atomic ensembles. These media are ideally suited for quantum-optics experiments as they combine (I) a large resonant optical depth; (II) long coherence times; (III) well-understood atom-atom interactions. These features aid with the simplicity of both the experimental set up and the theoretical framework. Most of these studies utilized a dilute vapour, where the possibly deleterious effects of atom-atom collisions are negligible. However, recent work in our group, and elsewhere, shows that cooperative effects and atom-atom interactions do not only modify but can beneficially enhance certain phenomena.

At Durham we have studied experimentally and theoretically the effects of dipole-dipole interactions on the absorption and dispersion of atomic vapours. Our model calculates the absolute susceptibility that enables quantitative predictions in the vicinity of the D lines. The model was a crucial component in our experimental measurement of the cooperative Lamb shift, the first measurement of this phenomenon, 40 years after its prediction. In a related experiment we measured the refractive index of high-density Rb vapour in a gaseous atomic nanolayer, thereby answering the question of what is the theoretical maximum refractive index of an atomic vapour. We will present ideas of how to generate heralded single photons in a dense thermal ensemble where strong dipole-dipole interactions dominate the dynamics.

Ultimate Time Resolution In Scintillator-Based Detectors

Paul Lecoq
CERN, Switzerland

The future generation of radiation detectors is more and more demanding on timing performance for a wide range of applications, such as time of flight (TOF) techniques for PET cameras and particle identification in nuclear physics and high energy physics detectors, precise event time tagging in high luminosity accelerators and a number of photonic applications based on single photon detection.

The time resolution of a scintillator-based detector is directly driven by the density of photoelectrons generated in the photodetector at the detection threshold. At the scintillator level it is related to the intrinsic light yield, the pulse shape (rise time and decay time) and the light transport from the gamma-ray conversion point to the photodetector. When aiming at 10ps time resolution fluctuations in the thermalization and relaxation time of hot electrons and holes generated by the interaction of ionization radiation with the crystal become important. These processes last for up to a few tens of ps and are followed by a complex trappingdetrapping process, Poole-Frenkel effect, Auger ionization of traps and electron-hole recombination, which can last for a few ns with very large fluctuations.

This talk will review the different processes at work and evaluate if some of the transient phenomena taking place during the fast thermalization phase can be exploited to extract a time tag with a precision in the few ps range.

The light transport in the crystal is also an important source of time jitter. In particular light bouncing within the scintillator must be reduced as much as possible as it spreads the arrival time of photons on the photodetector and strongly reduces the light output by increasing the effect of light absorption within the crystal. It concerns typically about 70% of the photons generated in currently used scintillators.

A possible solution to overcome these problems is to improve the light extraction efficiency at the first hit of the photons on the crystal/photodetector coupling face by means of photonic crystals (PhCs) specifically designed to couple light propagation modes inside and outside the crystal at the limit of the total reflection angle.

Cold Individual Atoms Conquer k-Space and Meet Each Other

Dieter Meschede

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Cold atoms undergoing quantum walks in a deep optical lattice are coherently delocalized on a very large Hilbert space lattice sites. With electric quantum walks of single atoms momentum-space phenomena such as Bloch oscillations or Anderson like localization are realized in a single experiment, and a step towards quantitatively testing the "quantumness" at ever more macroscopic levels can be taken. Controlled interaction of exactly two atoms in such situations remains a daunting but highly attractive experimental challenge. We are zeroing in.

Beyond the Heisenberg Uncertainty

Eugene S. Polzik

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Some operations on quantum states are not restricted by the Heisenberg uncertainty principle. A famous example is teleportation, which for an oscillator allows for both the position and the momentum be transferred without adding noise. It turns out, perhaps even more surprisingly, that a trajectory of an oscillator can be *measured* with an accuracy exceeding that predicted by the Heisenberg uncertainty [1]. For this the trajectory must be monitored in the reference frame of another oscillator with an effective negative mass. Secondly, the monitored oscillator and the reference oscillator should be in an entangled state. In the talk I will first present a magnetic oscillator with a negative mass/frequency. I will review the recent teleportation experiment between two magnetic oscillators [2]. I will then describe progress towards tracing a trajectory of a mechanical oscillator entangled with a magnetic reference oscillator [3] with the precision not restricted by the Heisenberg uncertainty principle. Finally, I will outline perspectives for performing similar operations with an electrical oscillator [4].

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Governing the Incorporation of Rare Earth Ions In Sol-Gel Silica Towards the Realization of Scintillating Optical Fibres

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The recent progresses in the development of scintillating rare-earth (RE) doped silica fibres for real time in-vivo medical dosimetry applications and high energy physics detectors are described.

First, the incorporation features of RE^{3+} ions in sol-gel silica are reviewed considering dopant concentrations and synthesis parameters. Structural (TEM, XRD) and vibrational (Raman, FTIR) studies, coupled to optical investigations, have allowed to find the most suitable RE concentrations and synthesis conditions for optimizing both radioluminescence efficiency and RE dispersion, avoiding the formation of aggregates [1, 2].

Nano-aggregates are indeed formed for RE concentrations exceeding 1 mol%. Amorphous clusters are detected for Gd, Tb, and Yb dopings. Moreover, cluster formation turns out to be sensitive to glass sintering conditions: amorphous Ce-based clusters are detected in Ce-doped glass sintered in reducing conditions, while CeO_2 nanocrystals are formed under oxidizing conditions. In the case of Eu doping crystalline and highly luminescent $Eu_2Si_2O_7$ nanoaggregates are formed [3, 4 and references therein].

After a general description of advantages and challenges for the use of optical fibre based dosimeters during radiation therapy treatment and diagnostic irradiations, recent results obtained by using cerium and europium doped silica optical fibres in medical applications are reviewed [5]. Finally, the perspectives and open problems for the employment of doped silica fibres in high-energy physics detectors are discussed.

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Regular talks

QuantArm 2014

A New Synthesis Method of Nanoparticles: the Pulsed Laser Ablation In Liquid

David Amans[1], Julien Lam[1], Abdul-Rahman Allouche[1], Frederic Chaput[2], Gilles Ledoux[1], Karine Masenelli-Varlot[3], Vincent Motto-Ros[1], Christophe Dujardin[1]

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Original optical properties of inorganic nanoparticles are the focus of interest in numerous fields, from therapeutic to quantum optics. The potential applicative optical properties can be up-conversion, scintillation, high luminescence quantum yield, thermo-luminescence, photo-stimulation or a long coherent lifetime. Pulsed laser ablation in liquids (PLAL) is a versatile bottom-up method, which allows to quickly synthesize nanoparticles. In this frame, we have produced various doped oxides[1–2] and even diamond[3]. However, during the synthesis of colloidal solutions, the stabilization of small units is a recurring problem. The use of complexing molecules dissolved in the ablation liquid solves this problem. In the case of doped-sesquioxide, we have shown that 2-[2-(2-Methoxyethoxy)ethoxy] acetic acid agent implies a sharpening and a shift of the size distribution, with a median size lower than 5nm[2]. From an empirical point of view, PLAL has proved its reliability for the synthesis of nano-particles, but the nucleation of the nanoparticles in the gas phase and their growth is not clear, due to the difficulty of following the gas composition as well as the thermodynamic parameters. Such information can be obtained from the optically active plasma during its short lifetime, as a result of a quick quenching due to the liquid environment. For this purpose, we followed the laser ablation of an α-Al_2O_3 target in water[4], which lead to the synthesis of γ-Al_2O_3 nanoparticles. The AlO blue-green emission and the Al^{I} $^2P^0$-^2S doublet emission provided the electron density, the density ratio between the Al atoms and AlO molecules, and the rotational and vibrational temperatures of the AlO molecules.

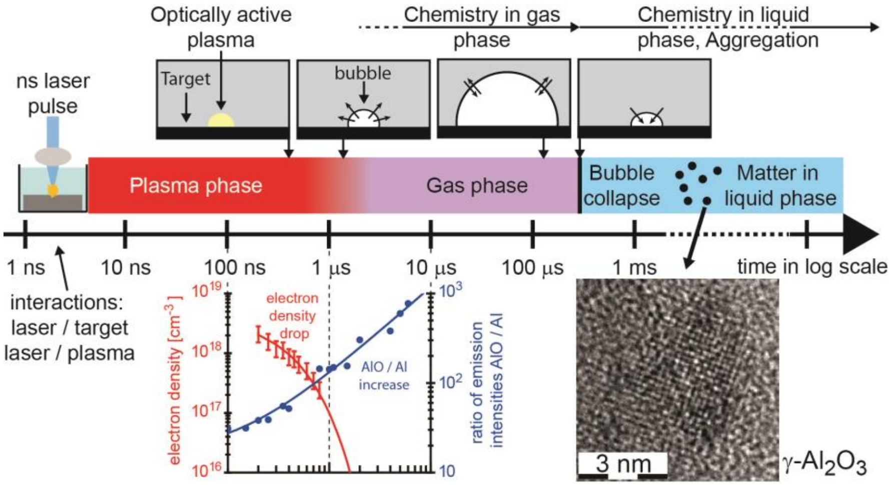

Figure 1: Main stages occurring during the relaxation of the system for each laser pulse.

Indeed, we are still lacking of information concerning what can happen after the plasma extinction when the ablated materials is confined in a gas bubble. It seems reasonable to consider such a system as a chemical reactor. We then developed different numerical tools used in computational chemistry to simulate the physical properties of the Al_xO_y molecules. These outcomes are first blocks (i) towards the predication of spectroscopy signatures from molecules bigger than the diatomic ones, and (ii) to predict the chemical reactions.

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Quantum And Classical Parametric Processes In PT-Symmetric Quadratic Nonlinear Couplers With Loss

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Photonic structures composed of coupled waveguides with lossy regions offer new possibilities for shaping optical beams and pulses compared to conservative structures. A directional coupler made of parallel waveguides with different absorption characteristics can represent an optical analogue of complex parity-time (or PT)-symmetric potentials, where the beam dynamics can demonstrate unique features due to phase transition effects [1, 2], and unusual switching regimes can be obtained in nonlinear structures [3, 4].

We consider waveguides made of material with quadratic nonlinear response, and study the effect of absorption in one of the waveguides, which can be introduced in hybrid metal-dielectric structures. We study the photon-pair generation through spontaneous parametric down-conversion (SPDC) and generation of signal and idler modes through optical parametric amplification (OPA) in a PT-symmetric coupler. Scheme of the experimental setup designed to characterise the photon-pair correlations (SPDC) by measuring the coincidences from the two single photon detectors is presented in Fig.1(a) and Fig.1(b) is scheme for measuring the powers of signal and idler modes generated in OPA.

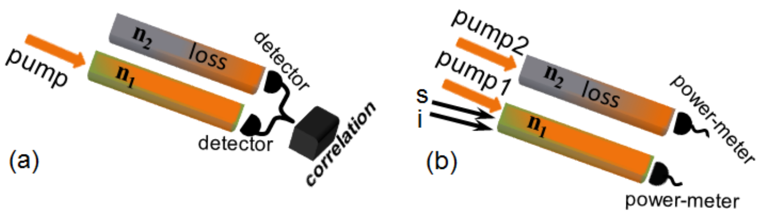

Figure 1: Schematic of (a) SPDC and (b) OPA in nonlinear PT-symmetric coupler with absorption in the second waveguide only.

We derived Schrodinger-type equations for the biphoton wavefunction in the quantum regime of SPDC, and classical OPA operation. We find nontrivial results, in particular for the case of the pump coupled only to the second waveguide with losses. When the loss coefficient is below the PT-symmetry breaking threshold, generated photons can couple between the waveguides similar to quantum walks in conservative nonlinear couplers [5] in both SPDC and OPA cases. When losses exceed the PT-symmetry breaking threshold, the quantum walks are suppressed.

These results suggest new possibilities for photon generation and control in structures with loss, such as hybrid plasmonic waveguides.

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Casimir-Polder In the Near-Field Van Der Waals Regime: Experimental Observation of Temperature Effects For Cs*/Sapphire

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The temperature dependence of the Casimir-Polder interaction addresses fundamental issues for understanding vacuum and thermal fluctuations. It is highly sensitive to surface waves, which, in the near field, govern the thermal emission of a hot surface. We use optical reflection spectroscopy to monitor the atom-surface interaction between a Cs*($7D_{3/2}$) atom and a hot sapphire surface at a distance ~ 100 nm. In our experiments [1], that explore a large range of temperatures (500–1000 K) the hot surface is at thermal equilibrium with the vacuum. The observed increase of the interaction with temperature, by up to 50 %, relies on the coupling between atomic virtual transitions in the infrared range and thermally excited surface-polariton modes. We extrapolate our findings to a broad distance range, from the isolated free atom to the short distances relevant to physical chemistry. Our work also opens the prospect of controlling atom surface interactions by engineering thermal fields.

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Hot Topics In Magnetometry

Dmitry Budker
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There are many new developments in atomic vapor based magnetometers, as well as in solid-state magnetometers based on nitrogen-vacancy (NV) color centers in diamond. These include both the advent of new techniques, as well as various novel applications ranging from zero- and ultralow-field nuclear magnetic resonance (ZULF NMR) to the study of superconductors to fundamental-physics tests. I will present a selection of these, with a bibliography of our group's and our collaborators' work available at http://budker.berkeley.edu/.

Preparation of Two- And Three-Qubit Entangled States In Systems of Mutually Coupled Qubits

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We consider systems of two and three qubits, mutually coupled to one another by means of Heisenberg-type exchange interaction, and, in turn, interacting with incident laser fields. We show that these systems allow one to create maximally entangled Bell states, as well as three qubit Greenberger-Horne-Zeilinger (GHZ) and W states. In particular, we point out, that some of the target states are the eigenstates of the initial bare system. Due to this, one can create entangled states by means of pulse area and adiabatic techniques, when starting from a separable (non-entangled) ground state. On the other hand, for target states, not present initially in the eigensystem of the model, we apply the robust stimulated Raman adiabatic passage (STIRAP) and pulse techniques, that create desired coherent superpositions of non-entangled eigenstates.

Coherent Control by Phase Modulated Short Laser Pulses: Applications In High-Order Harmonics Generation And Acceleration of Particles

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In this contribution, we consider two important applications of phase-modulated (frequency-chirped) laser pulses: In generation of high-order harmonics in gases and in laser ionization of alkali metals for generation of extended columns of high homogeneity laser plasma needed for proton-driven wake-field acceleration of particles. We show: i) that it is possible to significantly enhance the efficiency and to control the spectrum of the high-order harmonics generation in gases by robustly creating coherent superposition between atomic ground and excited states using combination of phase modulated and spectrally limited laser pulses; ii) that extended volumes of laser plasma of high homogeneity may be efficiently generated by pre-excitation of the atoms to their higher excited states or superposition of these states using short phase modulated laser pulses. Such pre-excitation may significantly soften conditions on the peak intensity of the ionizing laser pulses for multi-photon, tunnel or over-the-barrier ionization providing optimal conditions for generation of extremely homogeneous columns of laser plasma.

We will present our latest results obtained in Wigner Centre for Physics directly connected to ELI-ALPS (Extreme Laser Infrastructure – Attosecond Laser Pulse Source) project in Hungary and AWAKE-experiment at CERN that will use proton bunches for the first time ever to drive plasma wake-fields to accelerate electrons to the TeV energy scale.

Multiphoton Blockades Beyond the Fundamental Limit

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The realization of quantum devices with photon-photon interaction has become an interesting and important research topic in applied quantum technologies. The key element for obtaining of these interactions is a strong Kerr-nonlinearity that exceeds the dissipation rates and gives rise to many important applications at level of few-photons.

In this way, here we want to address the phenomenon of photon blockade (PB) based on strong photon-photon interactions. In PB the next photon can resonantly entering a cavity only if the first photon has left it. PB experimentally demonstrated in atomic, solid-state QED, and superconducting hybrid systems. We consider one-photon and multiphoton blockades for a Kerr-nonlinear dissipative resonator that can be realized at least with two physical systems: a qubit off-resonantly coupled to a driven cavity or superconducting devices based on Josephson junction.

At first, we strongly demonstrate that for the case of a continuous wave (cw) pumping of the Kerr-nonlinear resonator there are fundamental limits for PB. It is connected with the limits on populations of lower photonic-number-states (n = 0, 1, 2, 3) due to cw excitations in the nonlinear dissipative cavity. Second, we present comparative analysis of one-photon, two-photon and three-photon blockades in the pulsed regimes in addition to the results obtained for the case of PB in cw driving field. More importantly, considering Kerr-nonlinear resonator driven by a sequence of Gaussian pulses, we demonstrated that PB due to pulsed excitation can be more effective for a suitable photon pulses at deterministic times. Thus, PB is realized beyond the fundamental limits established for cw excitations. This improvement is due to a quantum control of decoherence in Kerr-nonlinear resonator by applying of suitable tailored e.m. pulses. We analyse photon-number effects and investigate phase-space properties of PB on the base of photon number populations, the second-order correlation functions and the Wigner functions in phase space. Generation of photonic Fock states due to PB in the pulsed regime is analyzed in details.

Single Photon And Multi-Photon State Generation In a Single Atom-Cavity QED System

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Single photon and multi-photon state generation on demand is a crucial task for implementation of quantum information processing. We present a mechanism to produce indistinguishable single-photon pulses on demand from an optical cavity. The sequences of two laser pulses generate, at the two Raman transitions of a four-level atom, the same cavity-mode photons without repumping of the atom between photon generations. Photons are emitted from the cavity with near-unit efficiency in well-defined temporal modes of identical shapes controlled by the laser fields. The second-order correlation function reveals the single-photon nature of the proposed source.

Deterministic generation of traveling light of $1 \leq n \leq 2F$ photons is achieved, when a circularly polarized laser pulse completely transfers the atomic population between Zeeman sublevels of the ground hyperfine state F through far-detuned Raman scattering, thus producing linearly polarized cavity photons. We describe analytically the evolution of optical field taking into account the spontaneous losses and the cavity damping. We analyze the photon statistics showing that it is close to Poissonian light. We show also that this technique provides a deterministic source of a train of identical multiphoton states with a definite number of photons if a sequence of left- and right-circularly polarized laser pulses is applied. The scheme expands the possibilities for using complex internal states of light to transmit data.

Topological Growing Scheme For Laughlin States In Synthetic Gauge Fields

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We consider ultracold atoms and photons in the presence of periodic lattice potentials and an artificial gauge field. When additional local interactions are taken into account, ground states with topological order can be found [Sørensen et al., PRL 94, 2005]. While the Hamiltonians required for an analogue quantum simulation of such systems have already been realized [Aidelsburger et al. and Miyake et al., PRL 111, 2013], the preparation of their ground states is yet an unsolved problem.

In this talk, a scheme for preparing highly correlated Laughlin states of bosons will be presented. The latter are introduced into the system one-by-one from a coherent reservoir, allowing to grow the many-body state in a time t ~ N scaling linear with system size. To this end, hole-type excitations are prepared in the initial state, which are consequently replenished by a single boson. This can e.g. be achieved by adiabatically piercing the system with a local potential, or using a topologically protected Thouless pump. Single bosons, on the other hand, can be introduced by making use of the incompressibility of the Laughlin state itself. In this way, we effectively pump weakly interacting composite fermions into our system.

Temporal And Spatial Correlations In Off-Resonantly Driven Ultracold Rydberg Gases

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When exciting dense, ultracold gases to Rydberg states on resonance, the number of excitations within a finite volume is limited due to the long-range van der Waals interaction. Away from resonance initial excitation is suppressed, however an excited atom shifts surrounding atoms into resonance and facilitates further excitations. We model such systems using Monte Carlo wavefunction approaches and classical rate equations and compare with experimental results on small mesoscopic samples, where the presence of Rydberg excitations can be monitored by continuous ionization.

For extended systems under strong driving, the system reaches a stationary state with high density of excitations. We show that such a system is closely related to a classical system of hard disks. For these models it is well known that in dimensions larger than one, phase transitions from fluid to solid occur at sufficiently high densities. Using the rate equation approach we discuss the presence of this transition in the driven Rydberg system and the significance of the softness of the van der Waals potential.

Quantum Key Distribution With Time-Bin Coding For Secure Satellite Communication

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Quantum key distribution (QKD) is a technique that provides the creation of two identical random strings of symbols (a cryptographic key) for two remote users, with guaranties that a third party has a negligibly small quantity of information about the key. Currently, technical solutions are actively being sought for creating global QKD networks based on satellite communication. A low energy-consuming method is based on coding information through a time interval of photon emission [1–4]. However, the protocols [1–4] use a set of linearly independent states of the information carrier and therefore are sensitive to an attack with unambiguous discrimination of the carrier states.

In our work we show that the time-bin coding protocol on four linearly independent states [2, 3] is completely insecure at losses of 7.2 dB, while the level of losses in the satellite links may be from 10 to 60 dB. We present a QKD protocol on attenuated laser pulses with time-bin coding based on four linearly dependent states, having no loss restrictions. We analyze the resistance of this protocol to a number of realistic intercept–resend attacks, including a "detector blinding" attack.

We present also our quantum-optical random number generators [5, 6] providing true random numbers for the keys. We also discuss our original technique for characterization of afterpulsing effect in single-photon detectors with high precision, which is indispensable for production of high-quality random numbers and their reliable transmission via a quantum channel.

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Quantum Time-Dependent Level Crossing Models

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We discuss the level-crossing field configurations for which the quantum time-dependent two-state problem is solvable in terms of the confluent Heun functions. These configurations belong to fifteen four-parametric families of models that generalize all the known 3- and 2-parametric families for which the problem is solvable in terms of the Gauss hypergeometric and the Kummer confluent hypergeometric functions. Analyzing the general case of variable Rabi frequency and frequency detuning, we mention that the most notable features of the models provided by these classes originate from an extra constant term in the detuning modulation function. Due to this term the classes suggest numerous symmetric or asymmetric chirped pulses and a variety of models with two crossings of the frequency resonance. The latter models are generated by both real and complex transformations of the independent variable. In general, the resulting detuning functions are asymmetric, the asymmetry being controlled by the parameters of the detuning modulation function. In some cases, however, the asymmetry may be additionally caused by the amplitude modulation function. We present an example of the latter possibility and additionally mention a constant amplitude model with periodically repeated resonance-crossings. Finally, we discuss the excitation of a two-level atom by a pulse of Lorentzian shape with a detuning providing one or two crossings of the resonance. Using series expansions of the solution of the confluent Heun equation in terms of the regular and irregular hypergeometric functions we derive particular closed form solutions of the two-state problem for this field configuration. The sets of the involved parameters for which these solutions are obtained define curves in the 3D space of the involved parameters belonging to the complete return spectrum of the considered two-state quantum system.

Photo-Double Ionization of Nitrogen

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The double ionization by a single polarized photon is one of the principle experimental means to study the electronic structure of atoms and molecules and to probe electron-electron correlation, which is the main cause of double ionization [1]. An abundant literature is available for the particular case of (ɣ; 2e) photo-double ionization, where the two ejected electrons are detected in coincidence [2].

In spite of the large interest on molecular dications in astrophysics and plasma science, dications being abundant in the ionosphere of many planets and in interstellar clouds, no multiply differential cross sections (MDCS) are available for the (ɣ; 2e) photo-double ionization of diatomic targets. More, the detection in coincidence of N+ fragments in the dissociative case has never been tempted. This can permit the observation of two centre interference phenomena [3], as it has been done recently in an (e;2e) simple ionization experiment of diatomic hydrogen by electrons [4].

We have determined the MDCS of the $(\gamma, 2e)$ photo-double ionization of N_2 for fixed and randomly oriented internuclear axis. We have applied in the theoretical part a correlated product of a two-centre wave describing the two-centre continuum of the two ejected electrons [5], which satisfies the exact asymptotic conditions. The vertical ionisation from the $3s\sigma_g$ orbital of the fundamental level to the ${}^1\Sigma_g$ et ${}^3\Pi_u$ of N_2^{2+} dication were considered [6, 7].

Our results give the optimal directions of the ejection, which we confirm partially by recent experimental measurements [7]. We verify also the expected symmetry properties of the MDCS and make a comparison with the results obtained by the parametric Gaussian method [6, 7].

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Ce-Doped LGSO Fiber Crystal Grown by Micro-Pulling Down (μpd) Technique And Characterization

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$Lu_xGd_{1-x}SiO_5$:Ce (LGSO:Ce) single crystals were declared as fast and bright scintillators with high density [1–3]. They are an appropriate choice for the introscopy, PET and high energy physics applications. It was shown that the best combination of characteristics is observed at $x \approx 0.5$ and C2/c monoclinic space symmetry [4]. Optimization of activator (Ce^{3+}) content in LGSO:Ce is the point of this work.

LGSO was grown by μ-PD technique with varied within 0.01–1.5 at.% Ce^{3+} concentration. The present work is devoted to the correlation between the optical-scintillation properties and the structure of the material. In general, LGSO is a continuous series of solid solutions between $P2_1/c$ GSO and C2/c LSO compositions based on the substitution of lutetium and gadolinium cations. The distribution of

Lu^{3+} and Gd^{3+} between 7-fold and 6-fold cation positions was studied and compared to the bulk crystals. The luminescence spectrum of LGSO:Ce consists of subbands attributed to CeO_7 and CeO_6 polyhedrons. The absorbance spectra of the fibers indicate the different quality of the samples and falls in the course of the growth procedure improvement. The highest light yield is achieved at the Ce^{3+} concentration at 0.5 at.% (fig. 1). A fiber with degraded properties with 1 at.% Ce^{3+} concentration was chosen to study the distribution of Ce^{3+} and Gd^{3+} cations in the compound and causes of fiber cracking.

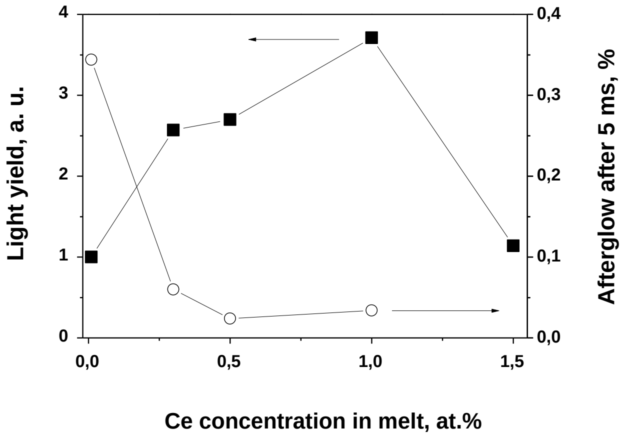

Figure 1: Relative light output and afterglow after 5 ms in LGSO:Ce fibers vs. Ce concentration.

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One-Dimensional Hubbard-Luttinger Model For Carbon Nanotubes

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The Hubbard-Luttinger model [1–2] is developing for qualitative description of one-dimensional motion of conducting interacting Pi-electrons in carbon single wall nanotubes at low temperatures. The standard Landau Fermi-liquid theory is inapplicable in the one-dimensional case. Low-lying excitations in a one-dimensional electron gas are described in terms of interacting bosons. The Bogolyubov transformation allows us to obtain a system of non-interacting quasi-bosons. Then operators of Fermi-excitations and Green functions of fermions are introduced. Finally, the electric current is derived as a function of voltage difference on contact between a nanotube and a normal metal. Deviations from Ohm law are discussed which are produced by electron-electron short-range interaction. Theoretical results are compared to experiments [3–4].

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Approximate Method of Partition Function Calculation for Spin System with Arbitrary Connection

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The proposed method of the free energy calculation is based on the approximation of the energy distribution in the microcanonical ensemble by the Gaussian distribution with the beforehand calculated values of the first two momentums. We hope that our approach will be effective for the systems with long-range interaction, where large coordination number ensures the correctness of the central limit theorem application. However, the method provides good results also for systems with short-range interaction when the number of the nearest neighbors is sufficiently small ($q \sim 4$). When comparing with the known results for the Ising model on planar and cubic lattices, and on the Bethe lattice, we see that our method provides good results for qualitative and quantitative description of the behavior of these spin systems. The error in the estimate of the critical temperature is ~10% for q = 4, and it decreases up to 3% for q = 6. The difference of the free energy from its exact value manifests itself only in the narrow vicinity of the critical temperature. It does not exceed 3% for q = 4 and it decreases as 1/q.

Undoped And Ce-Doped LuAG Single Crystal Fibers Grown by Micro-Pulling Down Technique For Homogeneous Dual-Readout Calorimeters

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Recent developments in micro-pulling-down crystal growth technology has allowed for the growth of shaped single crystal inorganic scintillators, such as cerium activated multi-component oxides (e.g. Lutetium aluminum garnet, LuAG). Inorganic fiber shaped scintillators of 2 mm in diameter and as long as 20 cm have been grown for a novel type of dual-readout calorimeter [1–3]. LuAG crystals have been selected because it combines a high density (high stopping power), a high refractive index (strong Cerenkov signal) and good doping capabilities (fast and intense scintillation). In addition, this material shows good mechanical and chemical properties that favor fibers single crystal growth under stationary stable regime. The objective of this research international program is to investigate the properties of fibers by selecting undoped LuAG and scintillating LuAG activated by Ce dopant, instead of self-activated scintillators, it would be possible to mix both doped and undoped fibers of the same material, which would then behave respectively as scintillators and Cerenkov radiators. So, the recent performed results on the quality of the grown LuAG single crystal fibers (fig 1) provide a unique opportunity to develop efficient dual readout calorimeters based on fibers design.

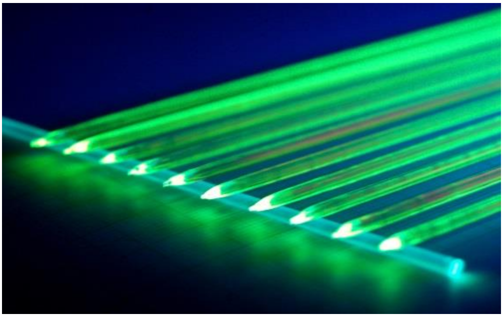

Figure 1: Ce-doped LuAG single crystal fibers grown by μ-PD technique.

This work was conducted in the frame of the Crystal Clear collaboration and is supported by French National Agency for Research under grand agreement ANR-10-BLAN-0947 (INFINHI), Ukrainian–French collaboration DNIPRO, Project N° 28317ZC and the European Union FP7/2007–2013 under grant agreements 256984-EndoTOFPET-US and 295025-IPERA.

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Quantum Repeater Without Long-Lived Quantum Memories

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Quantum repeaters hold the promise to prevent the photon losses in communication channels. Despite the serious efforts applied recently to achieve scalable distribution of entanglement over long distances, the probabilistic nature of entanglement swapping and realistic times of quantum memory make the implementation of quantum repeaters an outstanding experimental challenge. I will present a quantum repeater based on the deterministic storage of a single photon in atomic ensembles confined in distant high-finesse cavities. The use of an input single-photon instead of a write laser in the original DLCZ scheme, allows to solve the problem of multiple atomic spin excitations. Also, a high-finesse cavity is employed to maximally enhance the Raman conversion of input photon into forward-scattered Stokes photon. I will then show that this system is capable of distributing the entanglement over long distances with a much higher rate as compared to previous protocols, thereby alleviating the limitations on the quantum memory lifetime by several orders of magnitude.

Francium Trapping At LNL

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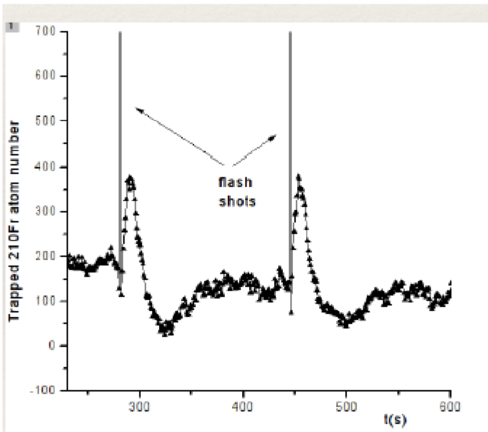
A brief review of the Francium trapping experiments at the INFN-LNL facility will be discussed in the wide context of Atomic Parity Non-Conservation, which, as long as acquiring more precise and new spectroscopic data on the Francium isotopes, is the ultimate goal of the experiment. Due to its instability, Francium atoms must be produced continuously by a nuclear fusion-evaporation reaction into a heated Gold target hit by a beam of accelerated Oxygen ions. Francium is then extracted in the ionic form and guided by an electrostatic line to the actual science chamber, where the ions are neutralized.



Atoms are then cooled down and trapped in a Magneto-Optical Trap to ensure both the availability of a sufficiently populated and stable atomic sample and to eliminate the Doppler broadening which would affect the precision of the measurements. A review of the recent improvements to the experimental apparatus and to the detection techniques that led to a sensitivity better than 5 atoms will be presented. A summary of the recent results obtained by our collaboration and a short outlook for the immediate future will be given. For example, in the picture a typical signal of application of Light–Induced Atom Desorption to the optimization of the trapping efficiency is reported.

Thin Scintillators For Synchrotron Radiation Applications

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The European Synchrotron Radiation Facility (ESRF) provides increasingly smaller X-rays beam (down to 50nm beam size) combined with higher brilliance (10^{13}-10^{14} X-ray photons/sec/mm^2). While direct detection exhibits an excellent signal-to-noise ratio, it suffers from radiation damage and a limited perspective of spatial resolution. Indirect X-ray detectors are then of outstanding importance for high flux and/or sub-micrometer resolution. Detectors based on converter screens are used for beam diagnostic and X-ray imaging applications. Detectors used for both applications consist of a converter screen (phosphor or scintillator screen), a front-end optics and an image sensor device (CCD or CMOS). The scintillator converts the X-rays into a visible light image, which is projected onto the image sensor by the light optics.

In the two last decades, the ESRF has mainly worked and developed new single-crystal films grown by Liquid Phase Epitaxy for imaging applications. The imaging detectors, especially high-resolution, suffer from low stopping power and radiation damage. The strategies based on mono-layer, multi- layer and scintillating performances, as well as the challenge associated with growth techniques such as substrate considerations, will be presented. On the other hand, for ultra-fast imaging applications, decay time and afterglow have to be sufficiently short and the converter screen must also emit in the visible band to be compatible with standard front-end optics. The limitations of our standard scintillators (Eu-doped garnet, Tb-doped garnet, Tb-doped orthosilicate) and the results of our development on perovskite will be discussed.

More recently, a request for beam monitoring has been made. The requirements are not the same as for an imaging application. In imaging, the absorption must be the highest possible but the beam position monitor application requires the highest transmission possible for on-line analysis. As part of the ESRF Upgrade, new X-ray beam viewers are under development. Two main developments are ongoing at the ESRF as regards non-transmissive and transmissive beam viewers. The first is the development of non-transmissive X-ray beam instruments. They are installed along beamlines for diagnostic and focusing applications, and are dedicated to white, monochromatic and focused X-ray beams. The 'semi- transparent' sensors used to evaluate in situ the position and shape of the beam are a powerful diagnostic device to compensate the variation of the beam by feedback correction. The primary goals are to achieve sub-micron position resolution, and to be able to measure the 'profile' of the beam shape. For white beam, cooled polycrystalline CVD diamond is currently used; it offers excellent X-ray transmission and good scintillating performance, but it suffers from radiation damage. Our monochromatic beam energies range from a few keV to hundreds of keV, with most users at 5–40 keV. At the higher energies, X-ray transmission is not a problem for thin scintillators in the thickness range 10μm to 20μm, but to keep the absorption down to 5% is a real challenge at lower energies. A possible method is the deposition of thin film (sub-micron) scintillating films on a suitable X-ray transmissive substrate. The performances of the thin YAG:Ce and p-CVD diamond used as a scintillator will be discussed. Transmissive beam viewers for low X-ray energy application have required the development of Lu_2O_3 scintillators deposited by PLD on thin alumina matrix used as a substrate. Results of these transmissive sensors will be presented. X-ray imaging capability (see figure 1) has been also investigated and will be discussed.

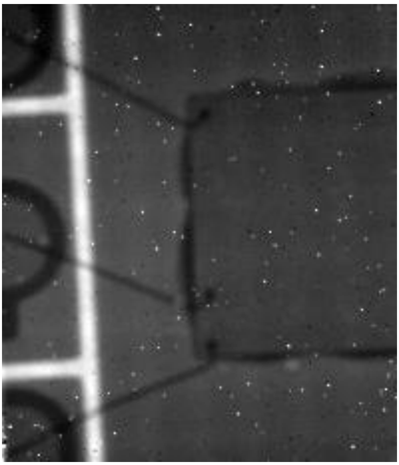

Figure 1: X-ray image of credit card microchip recorded with 500nm Lu_2O_3:Eu thick, pixel size 3.75μm.

Near Resonant Kapitza-Dirac Diffraction of Initially Prepared Momentum State For Multipath Atom Interferometry

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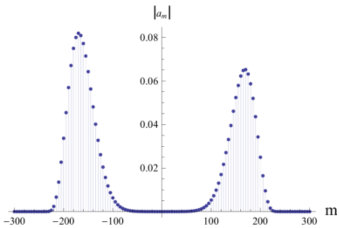
The further progress in atom interferometry needs essential increment in split angles of atomic momentum states, and one of the direct paths to achieve it is the near resonant Kapitza-Dirac diffraction. Its study in Raman-Nath approximation with initial state prepared in discrete superposition of momentum states exhibited new perspectives to this problem [1, 2]. Presented here Bloch-Flocke consistent theory confirms the obtained earlier results about the effective expanding and of two-bunch splitting of the initial distribution (see the figure) for short interaction times. It also reveals the possibility of formation of table-type distribution required for multipath atom interferometry.



For longer interaction times the theory predicts onset of increasing irregularities in the diffraction pattern.

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Nonadiabatic Chemical Dynamics And Molecular Functions

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Nonadiabatic transition is a transition among electronically adiabatic states in molecular systems. The most popular and important one is a transition at conical intersection of adiabatic potential energy functions.

A variety of chemical and biological phenomena are governed by this non-adiabatic transition, if not directly, but indirectly in the midst of the processes. In other words, the non-adiabatic transition makes one of the most important key mechanisms in chemical and biological dynamics. Since the basic analytical Zhu-Nakamura theory [1] is now available to treat the transitions, it is possible to comprehend the dynamics of realistic chemical and biological systems with the effects of transitions taken into account properly. Another important quantum mechanical effect of tunneling can also be taken into account. These can be done by running classical trajectories. Furthermore, it becomes feasible to control chemical dynamics by controlling the non-adiabatic transitions at conical intersections, and also to develop new molecular functions by using peculiar properties of non-adiabatic transitions. These may be realized by designing laser fields based on the optimal control theory. The non-adiabatic chemical and biological dynamics is expected to open a new dimension of science [2].

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Relaxation Dynamics of a Quantum Emitter Resonantly Coupled to a Metal Nanoparticle

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Presence of a metal nanoparticle near a quantum dipole emitter, when a localized surface plasmon mode is excited via the resonant coupling with an excited quantum dipole, changes dramatically the relaxation dynamics: an exponential decay changes to step-like behavior. The main physical consequence of this relaxation process is that the emission, being largely determined by the metal nanoparticle, comes out with a substantial delay. A large number of system parameters in our analytical description opens new possibilities for controlling quantum emitter dynamics.

Optical Measurements Beyond the Quantum Limit

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Optical measurements are used in a wide range of applications: from reading a bar-code in a supermarket to detection of gravitational waves ripples in space-time continuum. The precision of many optical experiments has already reached the so-called “quantum standard limit” set by the Heisenberg uncertainty principle for the amplitude and phase of an electromagnetic field. It may possible to bypass this limit, however, using so-called “squeezed” states of light. These non-classical optical states are characterized by the modified spectrum of quantum fluctuations, that allows reduce the measurement uncertainty below the standard quantum limit for coherent laser field.

In this talk, I will describe the generation of squeezed vacuum via the degenerate resonant four-wave mixing in near-resonant Rb vapor, responsible for polarization self-rotation of elliptically polarized light. The same nonlinear interaction causes generation of a quadrature squeezed vacuum in the polarization orthogonal to a linearly polarized optical pump laser field. I will discuss the spectral and spatial properties of the generated squeezed vacuum field, as well as its application to study superluminal propagation of quantum fluctuations. Then I will provide several

examples of optical measurements based on coherent light-atom interactions, and potential enhancement of their performance using squeezed optical fields.

Laguerre-Gaussian Laser Modes For Atomic Physics Experiments: Atom Channeling And Information Storage.

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Laguerre-Gaussian laser modes are ring of light having a helical phase. The phase structure is known to be responsible of an orbital angular momentum (OAM) of light. This quantity is quantified by an integer ℓ and the Laguerre-Gaussian mode basis constitutes an way to encode the information.

The two properties–annular intensity and helical phase–are used in the context of atomic physics either to manipulate the atoms or to store quantum information in an atomic ensemble.

This talk will present the Laguerre-Gaussian laser modes, theirs properties and the methods to generate them. Then two examples will be given in atomic physics:

(1) Long-distance channeling of cold atoms exiting a 2D magneto-optical trap by a Laguerre-Gaussian laser beam [1].

In this experiment done in Orsay, by using a blue-detuned laser, shaped into a Laguerre-Gaussian (LG) mode we channel atoms exiting a 2–dimensional magneto-optical trap (2D-MOT) over a 30 cm distance. Compared to a freely propagating beam, the atomic flux (about 10^{10}at/s) is conserved whereas the divergence is reduced from 40 to 3 milli-radians. So, 30 cm far the 2D-MOT exit, the atomic beam has a 1 mm diameter and the atomic density is increased by a factor of 200. Such a LG-channeled-2D-MOT with a high-density flux is a promising device for many applications as loading a 3D-MOT. The device has been studied versus the order of the LG mode (from 2 to 10) and versus the laser-atom frequency detuning (from 2 to 120 GHz). A clever version in which the LG mode frequency is locked to the repumping transition allows us to run the setup with two lasers instead of three.

(2) Storage and Non-Collinear Retrieval of Orbital Angular Momentum of Light in Cold Atoms [2]

Using a nonlinear interaction of OAM beams with an atomic vapour via four-wave mixing (FWM) processes it has been demonstrated that OAM can be stored and retrieved, allowing atomic memories.

Differently from the previous observations, we demonstrated that the stored OAM beam is retrieved along a non-collinear direction. The experiment in collaboration with Tabosa's group (Recife) is performed in cold Cs atoms from a MOT, using a delayed FWM configuration with a writing beam W with topological charges ℓ = 0, 1, 2, 3. The phase structure of is stored into the Zeeman coherence grating induced by the incident writing beams and is restored when a reading beam is switched on. The retrieved beam, monitored by a CCD camera, shows the transfer and conservation of OAM.

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Fano Resonance In H-Like Nanostructures

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Recently the Fano resonance (FR) in metallic nanoparticles (MNP) attracts large interest due to possible applications conditioned by its high sensitivity with respect to geometry and properties of surrounding media [1]. It was revealed that the complexes of nanoparticles provide more possibilities for the realization and controlling of FR [2, 3]. Our numerical calculations based on the data of [4] for relatively large gold spheroidal particles and rods provide the resonance of bright dipolar and dark quadrupolar modes when the aspect ratio of the longer particle is approximately twice larger than the shorter one [5,6]. In this communication we present for the first time the results of calculations devoted to the peculiarities of FR in H-like structures when the longitudinal-transversal coupling is suppressed. In case of H-like structure the electric field of the incident light is polarized along the shorter rod exciting dipole plasmon mode that in its turn induces dark quadrupole mode in the vertical rods. We show that under this condition strong dipole-quadrupole coupling (DQC) gives rise to FR. We introduce a measure for the efficiency of FR, which is the ratio of the absorbed powers of quadrupole and dipole modes. This quantity for H-like structure can reach the value of 10.

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Laser-Based Nanoparticles And Their Applications

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In recent years, the fabrication of nanoparticles via pulsed laser ablation in liquids has become a reliable alternative to conventional chemical synthesis approaches. A broad variety in both particle materials and used solvents, combined with high fabrication speed highlights the process.

In this work we present the synthesis of ultrapure surface-functionalized nanoparticles with photosensitive molecules (DNA, peptides, proteins, polymers) in high quantities in a single-step procedure using ultrashort-pulsed laser ablation, combined with in-situ bioconjugation. Functionality of the generated nanomaterials and nanocomposites are demonstrated through medical applications especially in the field of polymeric implants, contrast agents, local drug delivering materials and opto-medical sensors.

The work covers the topics of laser physics, (nano)material science, engineering, chemical analytics, biomedical applications and shows the first working laser-based medical immunoassays and therefore addresses a broad scientific community.

Behavior of ^{39}K Atomic Transitions On D_1 Line In External Magnetic Field

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A number of magneto-optical processes running at interaction of a narrow-band laser radiation with atomic vapors are employed in laser technology, metrology, designing of high sensitivity magnetometers, problems of quantum communications, information storage etc. [1]. As it is known, the energy levels of atoms undergo frequency shifts and changes in their transition probabilities in an external magnetic field B [2].

The magnetic field required to decouple the electronic total angular momentum J and the nuclear magnetic momentum I is given by $B >> B_0 = A_{hfs}/\mu_B$, where A_{hfs} is the ground-state hyperfine coupling coefficient and μ_B is the Bohr magneton [3]. For such strong magnetic fields when $\boldsymbol{I}$ and $\boldsymbol{J}$ are decoupled (Hyperfine Paschen Back (HPB) regime) the eigenstates of the Hamiltonian are described in the uncoupled basis of J and I projections (m_J ;m_I). Among all the alkali metals, ^{39}K atom has the smallest value of the ground state hyperfine coupling coefficient: $A_{hfs}(^{39}K) = h \times 231$ MHz. Consequently, the magnetic field required to decouple total electronic angular momentum $\boldsymbol{J}$ and nuclear spin momentum $\boldsymbol{I}$ (HPB regime) is $B >> B_0$ (^{39}K) = 160 G. Note that B_0 (^{85}Rb) ≈ 0.7 kG and B_0 (^{87}Rb) ≈ 2.4 kG.

Thus B_0 (^{39}K) value is more than 4 times smaller than that for ^{85}Rb and 15 times smaller than that for ^{87}Rb. This means that complete HPB regime for ^{39}K can be observed for much smaller external magnetic fields. It is demonstrated that the implementation of recently developed setup based on narrowband laser diodes, strong permanent magnets and one-dimensional nanometric-thin cell filled with K metal allows us to study behavior of any individual atomic transition of ^{39}K atoms D_1 line in a wide range of magnetic fields (10–2500 G). It is experimentally demonstrated that from twelve Zeeman transitions allowed at low B-field in ^{39}K, spectra in the case of σ^+ polarized laser radiation, only four transitions (with fixed and the same frequency slopes) remain in absorption spectra at $B > 300$ G. A complete hyperfine Paschen-Back regime for relatively low magnetic fields $B \geq 1.6$ kG has been observed.

The theoretical model very well describes the experiment. Possible applications will be presented.

The research leading to these results has received funding from the European Union FP7/2007-2013 under grant agreement no. 205025—IPERA.

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Nano-Cell Filled With Potassium Vapor: Applications In Atomic Spectroscopy

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A one-dimensional nano-metric-thin cell (NTC) filled with potassium metal has been fabricated and implemented for the first time. The design of a NTC is similar to that of extremely thin cell described earlier [1]. The NTC allows to exploit variable vapor column thickness L in the range of 50–1500 nm (L is the thickness of the gap). The NTC is filled with a natural potassium (93.3% ^{39}K, and 6.7% ^{41}K).

It is demonstrated for the first time for K that (as it was earlier demonstrated for the NTC filled with Cs/Rb) the key parameter determining the spectral width, the shape of the line, and the absorption in the NTC filled with potassium, is the ratio L/λ with λ being the wavelength of the laser radiation resonant with the atomic transition (for D_1 line, $\lambda = 770$ nm). It was in particular shown that the spectral width of the resonant absorption reaches its minimum value at $L = (2n + 1)\lambda/2$ (n is an integer); this effect has been termed the Dicke coherent narrowing (DCN). It is also demonstrated that for $L = n\lambda$ the spectral width of the resonant absorption reaches its maximum value, close to the Doppler width (~ 800 MHz). The Absorption spectrum of ^{39}K atomic vapor containing in NTC $L = \lambda/2 = 385$ nm is shown in Fig. 1a. There is a strong spectral narrowing, which allows to separate atomic transitions between hyperfine sublevels (see diagram in Fig. 1b).

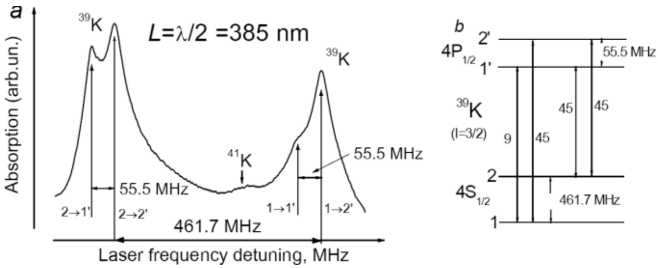

Figure 1: (a) Absorption spectrum of 39K atomic vapor containing in NTC L = λ/2 = 385 nm, tunable diode laser radiation (λ = 770 nm, line-width 1 MHz) is used. (b) Diagram of energy levels of 39K, D_1 line.

The theoretical model well describes the experimental results. Possible applications will be presented.

The research leading to these results has received funding from the European Union FP7/2007-2013 under grant agreement no. 295025—IPERA.

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Electronic And Optical Properties of Quantum Rings And Quantum Dashes

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Quantum rings and dashes are zero-dimensional objects which are subjected to intensive research [1–3]. Due to their unique geometry these structures are considered as potential element base for new generation semiconductor devices. The electron spectrum of such systems can be flexibly manipulated both by the variation of geometrical size and by the influence of external fields. In addition in QRs desirable conditions for the examination of Aharonov-Bohm effect for confined states can be realized [1]. In this presentation we are planning to present the results of investigation of one- and two-electronic states and interband optical absorption in quantum rings on spherical surfaces [4, 5]. We have also observed the Stark effect in these structures and have shown that the space curvature leads to the linear Stark shift. Another class of problems is related with the energy levels degeneracy in quantum dashes. It is shown that there are triply degenerate levels described by Pythagorean triples in such systems, modeled by rectangular parallelepiped. The transformation between primitive triples takes place by the Γ(2) modular group, which corresponds to the spinor transformations. Based on these results the nature of interband absorption is discussed and the opportunity of the "visualization" of Pythagoreans triples by means of interband absorption spectrum is shown.

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Photonics And Electronics of Nanostructured Metal Films

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Physical vapor deposition of metals onto dielectric supports in known to lead to the formation of nanostructured films of complex morphology that depends on numerous factors. The most important of them is the wetting ability of the metal with regard to the particular substrate. When the metal-substrate pair is fixed, the film structure is governed by the rate of deposition and the substrate temperature. Many studies were devoted to the optics of silver deposits on transparent dielectric substrates like sapphire and quartz. While at the high deposition rates and low substrate temperature silver forms continuous films very well suited to measuring its bulk optical properties, at low deposition rates and high substrate temperatures granular films comprising separated silver nanoparticles may be obtained. These granular silver films contributed considerably to the field of plasmonics [1]. In particular, silver nanospheres possess a collective electronic excitation with the resonance in the violet range of visible spectrum. Laser excitation at the resonance wavelength leads to the considerable enhancement of the electric field in the nearest neighborhood of the nanoparticle as well as in its interior. The latter leads to complete deformation of the transmission spectrum of the film that is dominated by the strong plasmon band, while the former serves as the basis of numerous applications like surface enhanced Raman scattering (SERS), enhanced nonlinear optical effects, in particular, second harmonic generation (SHG).

Local field enhancement due to the plasmon excitation localized in the silver nanoparticles may lead also to less studied phenomena that are described below. Being illuminated with light some organic dye molecules undergo structural transformations that may be used for information storage and processing. In the case of supported 2D films, the optical density becomes rather low. Absorption efficiency of the dye layer as well as the rate of the photoinduced transformations may be enhanced by spin-coating of dye layers on the substrates that were coved by plasmonic nanoparticles beforehand. To understand the optical properties of the hybrid material consisting of the silver nanoparticles and dye molecules it is important to take into account the influence of the [2]

Another less studied but interesting phenomenon that may be enhanced in the near fields of the metal nanoparticles is the photoconductivity of the granular metal films. Conductivity of granular metal films is related to the donating of the metal electrons to the trap states in the surface region of the dielectric support that is followed by the hops between the trap states at different locations. Experimentally it was found that Illumination leads to both the enhancement and reduction of the current depending on the wavelength of light and the nature of substrate. In the case of the quartz substrate it was shown that the photocurrent is always positive and reaches its maximum value at the wavelength correlated with the wavelength of maximum extinction.

Dark conductivity of granular silver films was shown to possess strong nonlinearity and hysteresis loops when the voltage applied to the film is cycled in the range from zero to about 50 V. This phenomenon may be employed for compact nonvolatile and rewritable memory devices.

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Semiconductor Devices For Quantum Technologies

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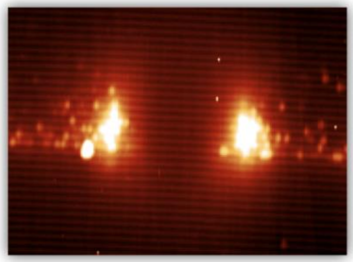
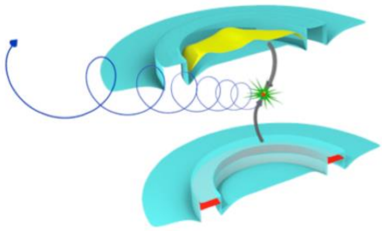
In the present day there is only one commercial application of quantum information processing (QIP), quantum key distribution, and the market embracing it is small. The development of further applications requires the realisation of a suite of practical devices that are able to create, buffer, process and repeat quantum information. Semiconductor structures have dominated digital information's history, as their ease of use and scalability are both ideal in meeting market demands. In the Quantum Technology Centre at Lancaster University we are developing semiconductor devices for practical applications of QIP, and in this talk I will discuss our progress.

Semiconductor nanostructures have received much attention in this field; we have used them to demonstrate entangled photon emission [1] and largely solved the problem of inhomogeneity [2] resulting from fabrication. The solid-state environment facilitates simple control with an electric field, making it possible to fabricate diodes for quantum light sources [3] and photonic buffers [4].

Two serious challenges remains; cryogenic temperatures are typically required, and coupling to nuclear spins limits coherence time. We are developing solutions to these problems, investigating deep-confining systems and reducing dephasing by encoding information on the hole-spin rather than the exciton's, as the p-like wavefunction of heavy-holes suppresses the nuclear interaction.





The figure above shows a cross-section through a GaSb quantum ring system, created at Lancaster and UCLA, alongside an illustration of its band-structure [5]. This material system is appealing as it has a type-II band alignment; confining holes, but not electrons, making it an ideal host for hole-based schemes. Further to this the combination of its confining potential and hole-mass are sufficient to allow room-temperature operation, and it shows promise for achieving telecoms wavelength compatibility.

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The Hyperfine Paschen–Back Faraday Effect

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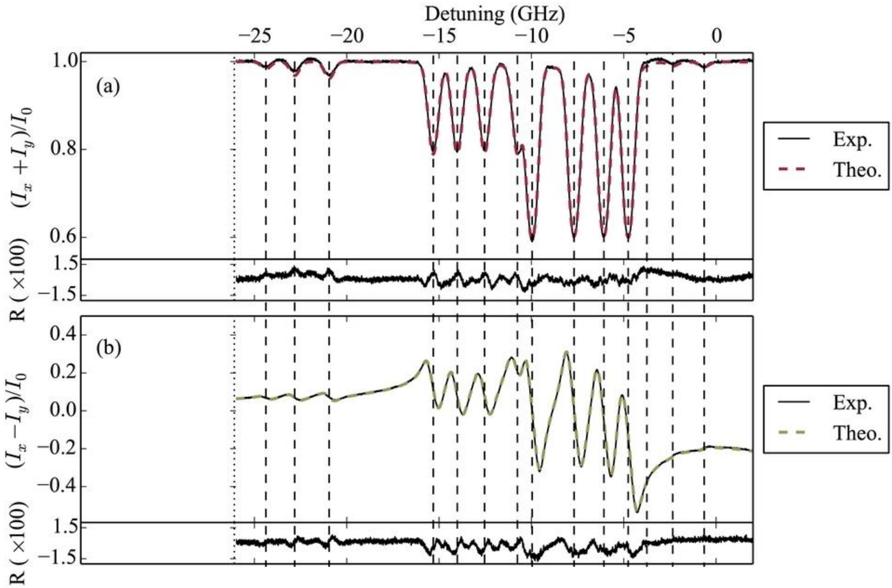
The Faraday effect in thermal atomic vapours is proving to be useful in many applications, providing high sensitivity in relatively simple experiments [1]. The Faraday effect arises due to a magnetic field producing circular birefringence. We study the Faraday effect in a thermal atomic vapour both experimentally and theoretically at magnetic fields of order Tesla [2]. We use a micro-fabricated vapour cell [3] placed within a small permanent ring magnet, achieving a magnetic field of ~0.6 T. At these large fields alkali-metal atoms enter the hyperfine Paschen-Back regime [4, 5], where the nuclear and the total electronic angular momenta are decoupled. We show that in this regime the Faraday rotation spectra have useful properties, which opens the door to using the spectra to measure large magnetic fields very precisely. These Faraday spectra could also provide a way to easily measure the atomic refractive index as well as giving a highly temperature stable error signal for far of resonance laser locking.



Transmission (top) and Faraday spectra (bottom) for rubidium-87 in a magnetic field of ~5.5 kG. We see excellent agreement between experiment and theory.

Recently our theoretical model has been released as a public program [6], which predicts the absorptive and dispersive properties of an alkali-metal vapour. This allows many optical devices to be designed, such as Faraday rotators/filters [7], optical isolators [8] and circular polarisation filters. Fitting routines are also provided with the program, which allows the user to perform optical metrology, by fitting to experimental data.

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Posters

QuantArm 2014

Sub-Doppler Spectroscopy In a Confined Vapour: Towards Three-Dimensional Confinement

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When a vapour is confined, the collisions to the confinement wall usually cause a broadening of the transitions. However, velocity selective processes and the coherent enhancement of some transient contributions can lead to sub-Doppler contributions because of the confinement. In the optical range, this had been demonstrated for a one-dimensional confinement with micro- or nano-cells of a small thickness. A two-dimensional confinement in a hollow fiber had shown sub-Doppler contributions, but only equivalent to macroscopic nonlinear saturated absorption spectroscopy.

Here, we describe experiments [1] showing that a thermal vapor confined in a three-dimensional nanostructure can exhibit sub-Doppler features in a linear regime. We perform reflection spectroscopy on a Cs vapour cell whose window is covered with a thin opal film (typically, 10 or 20 layers of ~ 1µm or 400 nm diameter spheres). We demonstrate, both experimentally and through a modeling [2] that the sub-Doppler structures observed for a large range of oblique incidence angles (~ 30–50°) originate from the interstitial regions of the opal, hence corresponding to a three-dimensional submicrometric confinement. We also show that the partially porous nature of the glass spheres allows some LIAD effects.

In a different set of experiments, an atomic vapour is confined in glass medium with large size pores (tens of µm) randomly distributed. The effect of scattered light and fluorescence have been distinguished [3]. Also, sub-Doppler features evolving non-linearly with the irradiating intensity are observed, originating in a saturated absorption process induced by the backscattered light [4].

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Studies of γ-Irradiation Induced Absorption Centers In Luag:Pr Single Crystals

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Low radiation tolerance has been reported for LuAG:Pr scintillator crystals grown so far by either Czochralski or Bridgman methods showing 100–200 m^{-1} induced absorption in the range of emission (300–400 nm), after 10^3 Gy dose [1, 2]. In this presentation γ-irradiation (^{60}Co; 10^3–10^5 Gy dose) induced centers were studied in differently grown Bridgman LuAG:Pr crystals, as well as in those with additional co-dopant impurities. Wide and intense absorption bands appear in LuAG:Pr at 280–300, 375 and 600 nm (associated with Yb^{2+} [2, 3]) and at 254 and 307 nm (partly due to Fe^{3+}, Fe^{2+}, and O^- centers [4]). Variation of the valence state of Pr ions in the course of irradiation was traced on f-f line intensities of Pr^{3+} ions evidencing the latter efficiently compete with other types of traps in capturing charged particles. Comparison of differently grown crystals has shown that the absorption induced by γ-irradiation in the low-concentrated LuAG:Pr (0.1 at.%) at 350 nm can be below 35 m^{-1}, after the dose 10^3 Gy, Fig. 1. A stronger induced absorption was observed in LuAG:Pr,Sc which may be due to large trace amounts of Si, Fe and Mn in the raw Sc_2O_3.

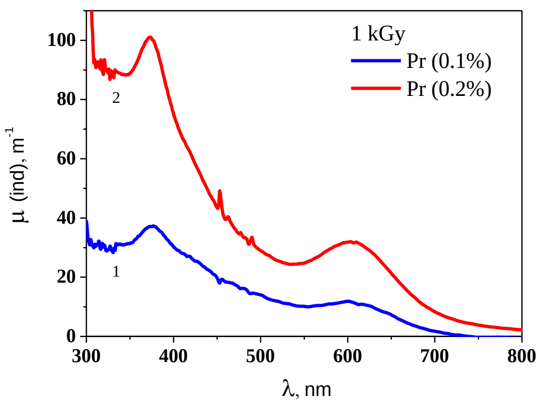

Figure 1: γ-irradiation induced absorption in LuAG:Pr (0.1 and 0.2 at.%) crystals.

The support of the International Associated Laboratory (CNRS–France & SCS–Armenia) IRMAS and of the European Union FP7/2007-2013 under grant agreements 295025-IPERA is acknowledged. This work is carried out in the frame of Crystal Clear collaboration.

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Coherent Propagation, Storage, And Retrieval of Laser Pulses In Five-Level Medium

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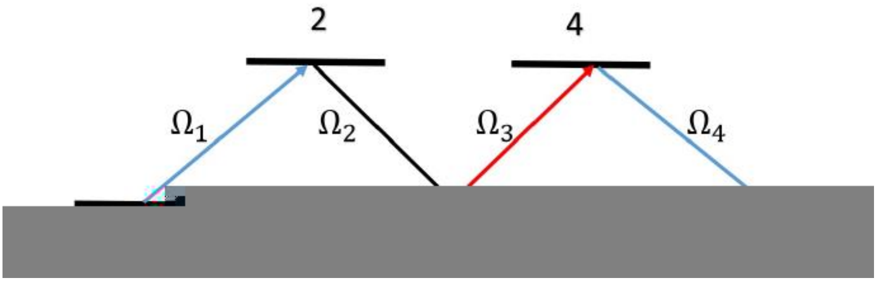
Despite a huge number of publications, light storage remains in the focus of attention of researchers, since it is one of key components in optical (quantum) information processing [1, 2]. We demonstrate in this report a new technique to store optical information in media of five-level systems and study the advantages of this technique.

Storage procedure is based on the formation in a five-level system interacting with the field of three laser pulses, of a state similar to the dark state in a three-level system [3] (see figure for notations):

$$|\Lambda_1\rangle = |\psi_1\rangle cos\theta - |\psi_2\rangle sin\theta$$

where $|\psi_1\rangle$ and $|\psi_2\rangle$ are superposition states of two-level system $1 \to 2$ and $5 \to 4$.



As distinct from the known atomic dark states in an M-system [4], the levels 2 and 4 are at interaction with laser fields populated (see figure), but the population of level 3 remains zero. Information is stored into the coherence ρ_{51}, which exactly reproduces, after turning off the interaction, the shape of the pulse Ω_2 Since the coherence ρ_{31} remains zero during all time of interaction, the same medium can be used again for storage of the pulse Ω_1. For this purpose, the pulses Ω_1 and Ω_2 should before the first storage be divided into two beams and one part of each pulse should be sent to a delay line for the second storage. For numerical calculations we used parameters corresponding to D_2 line of ^{87}Rb atom. The pulses $\Omega_1 = \Omega_4$ were assumed to be polarized linearly, while the pulses Ω_2 and Ω_3 circularly. Note that at the second storage we can write the pulse Ω_2 instead of Ω_1; in this case we must change the succession of turning on the pulses and exchange their polarizations.

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Non-Linear Stimulated Raman Exact Tracking

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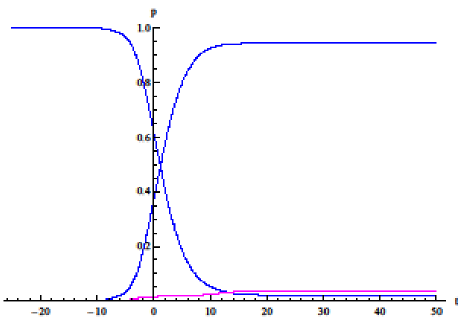
We consider a nonlinear three-level quantum system governed by the following system of coupled first order differential equations: $ic_{1t} = P c_1^* c_2$, $ic_{2t} = P c_1^2 + S c_3$, $ic_{2t} = S c_2$ (1), where c_1, c_2 and c_3 are the atomic, excited molecular and molecular-state probability amplitudes, respectively. P and S are the pump and Stokes Rabi frequency (assumed time-dependent and real), $\Delta(t)$ is the detuning. The system obeys the normalization $|c_1|^2 + 2|c_2|^2 + 2|c_3|^2 = 1$ [1]. Starting with the initial condition $c_1(t_i) = 1$ at the initial time t_i when the Rabi frequencies are real, from the solution of the Schrödinger equation we can say that $c_1(t)$ and $c_3(t)$ are real, and $c_2(t)$ is purely imaginary.

In the case of exact resonance, the governing set of the time-dependent Schrödinger equations for the corresponding three-level system is reduced to the following ordinary differential equation of second order for the third level's probability amplitude:

$$c_{3,zz} + c_3 + \frac{P}{S}\left[1 - c_{3,z}^2 - c_3^2\right] = 0$$

From this equation we get the values for pump and Stokes pulses for an exact tracking. We can determine $P(t)$ that corresponds to a chosen $S(t)$ and $c_3(t)$:

$$P(t) = -S(t)\frac{c_{3,tt} - c_{3,t}S_t / S + S^2 c_3}{(1 - c_3^2)S^2 - c_{3,t}^2}$$



Thus we obtain exact dynamics of quantum transfer for non-linear systems via stimulated Raman processes controlled by pulsed external fields. The external fields are designed by an inverse-engineering construction from the tracking of an admissible given solution, which allows to obtain exact tracking solutions. It can be seen that we need stronger pump pulse than the Stokes pulse, contrary to the case of ordinary linear stimulated Raman adiabatic passage.

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Saturated-Absorption Spectroscopy In Rb Filled Micrometer-Thin Cell: Applications In Strong Magnetic Fields

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The existence of cross-over resonances makes saturated-absorption (SA) spectra very complicated when external magnetic field B is applied. It is demonstrated for the first time that the use of micrometric-thin cells (MTC, $L \approx 40$ μm) allows application of SA for quantitative studies of frequency splittings and shifts of the Rb atomic transitions in a wide range of external magnetic fields, from 0.2 up to 6 kG (20–600 mT). We compare the SA spectra obtained with the MTC with those obtained with other techniques, and present applications for optical magnetometry with micrometer spatial resolution and a broadly tunable optical frequency reference [1].

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Wigner Crystallization of Photons Via Storage of Interacting Rydberg Polaritons

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Coupling light to Rydberg states of atoms under conditions of electromagnetically induced transparency (EIT) leads to the formation of strongly interacting quasi-particles, termed Rydberg polaritons. Confined to one spatial dimension the low energy physics of the system can be described by a Luttinger liquid theory giving rise to the formation of quasi-crystalline correlations for sufficiently strong interactions. Using density-matrix renormalization group we calculate the ground state of the system and extract the Luttinger K-parameter. We find that under typical stationary slow-light conditions kinetic energy contributions are too strong for formation of a crystal. We find, however, that storing a light pulse in a gas of Rydberg atoms by turning the polaritons into stationary spin excitations creates quasi-crystalline order over a finite length [1]. We analyze the dynamics and resulting correlations for a translational invariant system in terms of a time-dependent Luttinger liquid theory and address the effects of non-adiabatic corrections and initial excitations. We compare the analytical results with numerical few-particle calculations employing exact wave-function calculations for two particles and the Multiconfigurational time-dependent Hartree method for bosons (MCTDHB) [2].

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Properties of Luag:Ce Scintillator Crystals With Divalent Impurities

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LuAG:Ce is a promising scintillator considered for medical imaging and high energy physics applications. For the latter application improvement of the radiation tolerance, while conserving high scintillation performance, is among the major requirements. The goal of this work was (a) to define the compositions of LuAG:Ce co-doped with Ca^{2+} which could be grown as quality single crystals using the Bridgman method, and (b) to evaluate optical properties and radiation tolerance of developed materials. The motivation for introducing a divalent co-dopant was to create trap centers, which could compete in electron capture with intrinsic and trace impurity defects giving rise to absorption in the range of emission. Correlation was traced between the concentration of the introduced divalent co-dopant and absorption in the UV (at 200–260 nm) related partly to presence of Ce^{4+} ions [1–2] and intrinsic defects, Fig. 1. A strong dependence of γ-irradiation induced color centers in the visible on the relative concentrations of Ce and the divalent co-dopant ion was observed. The optimal growth conditions and Ce/Ca ratios were determined providing for low (< 1 m^{-1}) induced absorption in the range of emission, after 10^3 Gy, while conserving high scintillation performance.

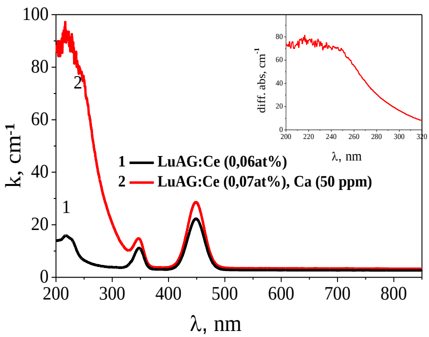

Fig. 1. Absorption in as-grown LuAG:Ce and LuAG:Ce,Ca and the difference spectrum (inset).

The support of the International Associated Laboratory (CNRS–France & SCS–Armenia) IRMAS and of the European Union FP7/2007-2013 under grant agreements 295025-IPERA is acknowledged. This work is carried out in the frame of Crystal Clear collaboration.

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Selective Reflection of Light from Rb_2 Molecular Vapor

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We report the first observation of selective reflection of light from an interface of a dielectric window and molecular vapor of Rb_2 dimers formed in all-sapphire sealed-off rubidium vapor cell (temperature up to 520°C, atomic and molecular densities up to 10^{18} and 3×10^{16} cm^{-3}, respectively). The selective reflection signals were recorded on various rovibronic components of $1(X)^1\Sigma^+_g$ – $1(A)^1\Sigma^+_u$ bound-bound electronic transition of Rb_2 by scanning a diode laser frequency in a spectral range of 851–854 nm. Only selective reflection signals corresponding to groups of several rovibronic transitions have been recorded, which was attributed to high spectral density, large collisional broadening, and low oscillator strength of individual rovibronic transitions.

Coherent Propagation of a Single Photon In a Lossless Medium of Cold Atoms

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[2]*Centre of Strong Field Physics, Yerevan State University, Armenia*

In this work we investigate the propagation of single photon pulse in a lossless medium and how it can be stored for a long time and retrieved on demand in a desired state. While most work has considered the interaction in the steady-state regime, here 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. We consider a cold ensemble of Λ-type atoms confined inside a hollow core of a single-mode photonic-crystal fiber as a medium and 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 the outgoing photon displays an oscillating temporal distribution, which is the quantum counterpart of a classical field ringing, while 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.

Complete-Return Spectrum of a Quantum Two-State System At Double Level-Crossing

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The general semiclassical time-dependent two-state problem is considered for a specific field configuration providing both non-crossing and term-crossing processes with one or two crossing points. The model includes the original constant-detuning non-crossing model as a particular case. We show that the governing system of equations is reduced to a Heun equation. When inspecting the conditions for returning the system to the initial state at the end of the interaction with the field, we develop a generalized approach for finding the higher-order approximations, which is applicable for the whole variation region of the involved input parameters of the system. We examine the general surface in the 3D space of input parameters, which defines the position of the n-th order return-resonance, and show that the section of the general surface is accurately approximated by an ellipse. We find a highly accurate analytic description through the zeros of a confluent hypergeometric function. From the point of view of the generality, the analytical description of mentioned curve for the whole variation range of all involved parameters is the main result of the present contribution.

Creation of a Photonic Time-Bin Qubit Via Parametric Interaction of Quantum Fields In a Driven Λ-Type Atomic Medium

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Institute for Physical Research, NAS of Armenia

A method of preparing a single photon in temporally-delocalized entangled modes is proposed and analyzed. An ensemble of cold atoms with level configuration depicted in Fig.1 is considered. Two quantum fields E_1 and E_2 copropogate along the z axis of pencil-shape medium and interact with the atoms on the transitions $1 \rightarrow 3$ and $2 \rightarrow 3$ respectively, while the electric dipole forbidden transition 1-2 is driven by a classical radio-frequency (rf) field with Rabi frequency Ω inducing magnetic dipole or an electric quadrupole transition. Due to the cyclic parametric conversion of the quantum fields and the group delay each pulse experiences a temporal splitting into well-separated subpulses. The separation between the time bins can be controlled using the different atomic-level configurations to obtain different group velocities of quantum fields. Since the process is completely coherent, at the output of the medium the time-delocalized and entangled single photon state is formed. As a consequence, the single-photon "time-bin entangled" states are generated with a programmable entanglement, which is easily controlled by driving field intensity. Moreover, since the two well-separated pulses undergo the same losses, the entanglement between them is almost insensitive to losses and easier to purify, so that the proposed scheme can be regarded as a robust source of narrow-bandwidth single-photon qubits.

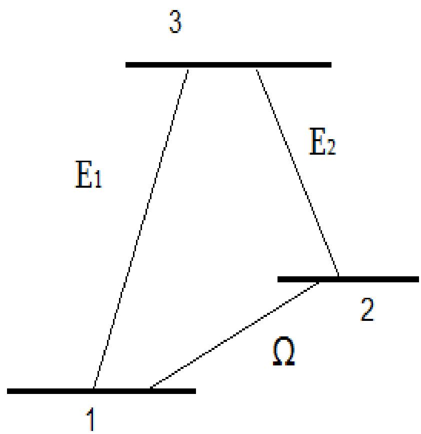

Figure 1: Level scheme of atoms interacting with quantum fields $E_{1,2}$ and classical rf driving field of Rabi frequency Ω.

Superluminal Propagation And Population Transfer In W-Type Resonance Media

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Effects of superluminal propagation attracts much attention currently. This is caused by many experimental works appearing from late nineties, where superluminal propagation phenomena are observed in different media (predominantly alkali-metal vapors) with different number of pulses in different frequency ranges (see, e.g., [1]). Theoretical studies were mainly restricted to the models of Λ system. In this paper we consider propagation in media of W-type atomic systems interacting with three laser pulses nearly resonant with corresponding transitions. Atomic dynamics is described by Schrödinger equations for the amplitudes of atomic states in the resonance approximation and the dynamics of the envelopes of laser pulses by the Maxwell equations in the approximation of slowly varying amplitudes. In the first nonlinear approximation for medium dispersion we obtained analytical solution, which demonstrates superluminal behaviour. The criterion of applicability of the group velocity concept is obtained. At longer distance the pulse shape and hence the optical information it carries, suffers essential distortion, since with the increase in traveling length the influence of higher-order corrections for the dispersion, as well as energy exchange processes result in pulse deformation. The correct solution to the problem is in full agreement with the causality principle, and the possible group advance is always much shorter than the pulse duration. The length of validity of the presented solutions reaches several centimetres in room-temperature rubidium vapour cell. We also study in detail the process of adiabatic population transfer in this system and its peculiarities during propagation in the medium. We demonstrate the possibility of complete population inversion and obtain conditions where transfer from lower to upper level has hundred-per-cent efficiency and occurs also superluminally.

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Spectral Properties of Interacting Rydberg Polaritons

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In a recent experiment by O. Firstenberg et al., Nature (London) 502, 71 (2013) demonstrated that repulsive and attractive polariton–polariton interactions can be observed in an atomic medium with strong interaction between Rydberg atoms. The theoretical description of this experiment remains far from understood. Here we introduce the Green's function approach to this problem and derive an effective Hamiltonian of two polaritons.

Study of Cs D_2 Line, Fg = 3 → Fe = 5 Atomic Transitions In a Strong External Magnetic Field

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For the first time it is observed experimentally and shown theoretically the magnetic field-induced modification of probabilities for seven components of $6S_{1/2}$, Fg = 3 → $6P_{3/2}$, Fe = 5 transition of the Cs D2 line, initially forbidden by selection rule (DF = 2). For the case of excitation with circularly polarized laser radiation, the probability of the Fg = 3, $m_F = -3$ → Fe = 5, $m_F = -2$ transition becomes the largest amongst 25 transitions of the Fg = 3 → Fe = 2, 3, 4, 5 group in a wide-range magnetic field of 200–3200 Gs. Moreover, the modification is the largest for D2 line of alkali metals. A half-wave-thickness cell (cell length along the beam propagation axis is $L = \lambda_{res}/2 = 426$ nm) filled with Cs has been used in order to avoid Doppler broadening, leading to separation of all atomic transitions in the absorption spectrum when an external magnetic field B is applied. For B > 3000 Gs, the group of seven transitions Fg = 3 → Fe = 5 is completely resolved and is located at the high frequency range of Fg = 3 → Fe = 2, 3, 4 transitions. The applied theoretical model coincides with the experimental curves well.

Summer School Lectures

QuantArm 2014

Population Transfer Between Quantum States to Perfection: Stimulated Raman Adiabatic Passage (STIRAP)

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In many areas of science (e.g. physics, chemistry, quantum information) controlled modification and in particular efficient transfer of population between quantum states is wanted. Many schemes are known that allow varying the usually thermal population distribution. Of particular interest are means for selective and efficient transfer of population from quantum state i to quantum state f. “Efficient” means that nearly 100% of the population residing initially in state i reaches state f. This also implies high selectivity as no other quantum state receives population. Traditional techniques such as Raman scattering, optical pumping or stimulated emission pumping fail to reach the goal. Spontaneous emission, which channels population into other levels, is a main problem. STIRAP solves that problem through a surprisingly simple, but at first glance very puzzling, sequence of radiative interactions: The quantum system is first exposed to the radiation field which connects the final state with an intermediate state (thus, it does not couple to the quantum state which carries initially the population) before the second radiation field couples the initial state to the same intermediate one. The basic phenomena and the physics building blocks of this process, the concept of which is now applied in very many areas, are presented and explained.

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Atom-Wall Interaction: Principles And Optical Techniques of Detection

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Atom-surface interaction covers a variety of situations, corresponding to very different distances, or energy ranges. Aside from chemisorption, in which the atomic structure itself is deeply modified, the field of "atom-surface interaction" encompasses situations such as exotic bound atom-surface states - at nm from the surface, up to very long-range interaction (up to few μm) in the retarded regime of the Casimir-Polder interaction.

The lecture will review challenges in this field, and will focus on the description of the techniques of optical spectroscopy that bring information on the atom-surface interaction, including an update of the works performed by the Paris13 U. group and others [1].

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Analytic Models of Quantum Two-State Problem

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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.

Description of Optical Properties of Quantum Nanostructures On the Base of the Stationary Adiabatic Method

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Within the last decade due to the precision methods of growing semiconductor quantum dots (QDs) have been implemented zero-dimensional structures having a non-trivial geometry: ellipsoidal, lens-shaped, layered, ring-shaped, quantum dashes etc. Availability of complex geometry allows us to implement a flexible manipulation of the energy levels of the charge carriers located in such structures. One of the effective quantum-mechanical approximate analytical methods is the stationary adiabatic method. In this approximation, the Hamiltonian of the quantum mechanical system can be separated into fast (f) and slow (s) parts, and each of which is described by its own set of variables. It is noteworthy, that the coordinates of the fast subsystem parametrically depend on the coordinates of the slow one [1]. The stationary adiabatic method can be successfully used to describe QDs which have the area of the localization of charge carriers in different directions significantly differ from each other. In such cases, the Hamiltonian of the system can be represented as the sum:

$$\hat{H}\left(\vec{x}_f,\vec{x}_s\right)=\hat{H}_1\left(\vec{x}_f\left(\vec{x}_s\right)\right)+\hat{H}_2\left(\vec{x}_s\right)+\hat{V}_{\text{int}}\left(\vec{x}_f,\vec{x}_s\right),$$

where the first two terms of the Hamiltonian operator are respectively the fast and slow subsystems, and the last term describes the interaction between these subsystems. This form of the Hamiltonian allows us to search wave function of the system as a product

$$\Psi\left(\vec{x}_f, \vec{x}_s\right) = \Phi_1\left(\vec{x}_f\left(\vec{x}_s\right)\right)\psi_2\left(\vec{x}_s\right),$$

where the first multiplier is the wave function of the fast subsystem, and the second of the slow one.

Knowledge of the wave functions and the energy spectrum of charge carriers allow us to calculate the coefficient of interband optical absorption in the studied structures.

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Thin Layers of Atomic Vapors: Spectroscopy And Photophysics

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Spectroscopy and photophysics are tightly related: spectroscopy provides powerful tools to study photophysical processes while photophysics sets limitations on the purity and the relevance of the information given by spectroscopy. If the atomic spectroscopy is used to provide information about the wavelengths and natural line widths of atomic transitions then the interatomic collisions are responsible for the shifts and broadening that are to be accounted for. Otherwise, serous errors may occur. On the other hand, these shifts and broadening being properly treated provide invaluable information about the collisions themselves. From this point of view, thin vapor layers sandwiched by transparent dielectric media are of special interest because of the dramatic role that in this case is played by the atom-wall collisions. Two objectives are pursued in the studies: to learn more about the collisional processes and their outcomes and to find the ways of using very this thin layers in frequency standards, magnetic field sensors and other important optical devices [1].

The influence of the atom-wall collisions on the spectroscopic characteristics of the thin atomic layers is manifold [2]. Most important, all atoms eventually collide with the surface of the wall. There are nonzero probabilities for several processes that follow the collision. At least some atoms are trapped at the surface attractive potential, spend some time diffusing over the surface, and then, desorb from the surface. Most probably, the atom leaves the surface in the ground state. If the sample is illuminated with the light resonant to the atomic transition from the ground state to one of the excited states then the atom starts its resonant transition from the ground state to the excited state only after the desorption process is completed. This is the consequence of the enormous shift and broadening of the atomic transition when the atom is trapped in the surface potential. Hence, the atom that leaves the surface is in the transient state. Depending on the laser light intensity and detuning, this transition may be better described by either perturbation theory in the case of small intensity and large detuning, or Rabi oscillations in the case of large intensity and small detuning. In either case, the excited state population oscillates as the atom moves out of the surface. It is important to note that the 1D grating of excited state population survives after averaging over the velocity distribution. The period of this grating is larger than the resonance wavelength and may be tuned to match the wavelength of another transition. Thus, a host of new interference phenomena are expected to show up.

When an atom in the excited electronic state collides with the surface, probability of its quenching is rather high. Nevertheless, other processes took place as well. One interesting example is an "incomplete quenching" of highly excited atoms. In this case the atom undergoes nonadiabatic transition to the lower excited state and bounces off the surface without transition to the ground state. To be operative this process should include the participation of surface modes that provide for the mechanism of repulsion at relatively large distances from the surface [3].

The spectral line shapes are influenced by the photophysical processes that took place during the atom-wall collisions. In the case of the "incomplete quenching" after an atom-wall collision the atom acquires a definite part of the energy released in the collision processes. This leads to the appearance of the fast moving atoms. Hence, the Doppler shift grows and the overall shape of the spectral line undergoes considerable changes.

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Investigation of Defects In Scintillating Materials

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The fundamental knowledge of defects in a material is of crucial importance in order to understand the energy transfer and trapping processes occurring during irradiation with ionizing radiations, especially if application for radiation detection as scintillator or dosimeter is foreseen.

Point defects can give rise to localized energy levels in the forbidden gap, trapping free carriers during irradiation; in a scintillator, carrier trapping by defects can compete with the prompt scintillation process.

In the research field of scintillators such defects are qualitatively separated in two broad families, usually named "deep" and "shallow" traps. Deep traps are those with a lifetime much longer with respect to the scintillation decay time. They trap carriers in a stable way and they lower the intensity of scintillation light. On the other hand, "shallow" traps have a lifetime longer but comparable with respect to the scintillation decay time, so that carrier de-trapping from such states and subsequent radiative recombination causes slow scintillation tails and thus alters the timing properties of the scintillator.

Thermally stimulated luminescence (TSL) studies are frequently employed for the investigation of traps; wavelength resolved measurements, where the amplitude of the TSL emitted light is measured both as a function of temperature and wavelength, allow to find simultaneous information about traps and centres and are particularly useful for a satisfactory understanding of the trapping-recombination processes.

The lecture is devoted to a description of the investigation of traps by wavelength resolved TSL measurements, with emphasis on experimental aspects, data analysis, and correlations with other techniques like scintillation decay, electron paramagnetic resonance, optical absorption. The discussion is also grounded on useful examples concerning TSL studies in selected scintillator materials featuring different trapping-recombination mechanisms, like crystalline silicates, perovskites, garnets, tungstates, and glasses.

Training Lectures

How to Write a Good Proposal

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This tutorial addresses a topic, which is crucial for everyone actively involved in scientific research including the responsibility for generating the needed funds through proposal writing. The success of proposal writing does depend in a competitive environment on many aspects beyond scientific quality of the idea underlying the project. In this presentation important questions that need to be addressed by the proposer will be discussed. In particular, the difference of the approach to writing a scientific paper will be emphasized.

The Technology Transfer Process And IP Search

Ditta Bezdán
Intelligentsia Consultants Sárl, 1 rue de Mamer, L-8081 Bertrange, Luxembourg

The presentation covers basic concepts of technology transfer and guides through the process step by step, also providing a set of measures on how to track progress. The short overview of the technology transfer process starts from research and discovery and ends at commercialization. After the initial overview, the second half of the presentation covers more detailed information regarding how to protect intellectual property and what are the initial steps to be taken prior to patenting.

Market Research, Valuation And Promotion

Giles Brandon
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The presentation dives into further details regarding the marketing step of the technology transfer process, covering information about marketing research (techniques and result analysis), marketing strategy, planning and management and examples of marketing practices. The second half of the presentation expands on technology valuation approaches and royalty rate examples.

Licensing And Negotiations

Ditta Bezdán
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The presentation covers concepts of licensing, reasons for licensing, provides a comparison between licensing versus selling and an overview of its advantages and disadvantages. Then preparatory steps of the license negotiations and the overview of a license agreement are discussed further in detail. The second part of the presentation covers information about the importance and steps of negotiation in the licensing process.

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For Notes