Semiconductor quantum dots: sources of entangled photon pairs

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We report on polarization sensitive, second order intensity correlation measurements [1] of photons emitted due to recombination cascades of quantum dot confined electron-hole pairs. We show that the cascaded emission from **neutral** quantum dots is strongly correlated, such that the emission from the confined two electron hole pair state (biexciton) and that from the one pair state (exciton) has the same **linear** polarization [2]. The cascaded emission from singly **charged** quantum dots, on the other hand, is markedly different and more interesting. We show, for the first time, that the cascaded emission from the charged biexciton state and that from the charge exciton state are oppositely **circularly** polarized

The intermediate state in the radiative cascade of the charged quantum dot case (the charge exciton) has a half integer spin. Therefore, it is doubly degenerate (Krammers' theorem). This is not the case for the intermediate neutral exciton state, where the total spin is an integer and the Krammers' degeneracy is removed by the electron-hole exchange interaction. As a consequence, the polarization states of the sequentially emitted photons from the charged quantum dots are **entangled**, as we demonstrate for the first time, using polarization sensitive, correlation measurements

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Thermal management of a large-area VCSEL under optical pumping

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The emission properties of a vertical cavity surface emitting laser (VCSEL) are very sensitive to temperature shifts, and to several extents, a VCSEL under operation is subject to a non negligeable heat production in the gain medium as well as in the substrate in the case of optical pumping. Heating can modify the optical properties of the structure : a red shift of the gap wavelength and an increase in the optical length of the cavity, translating into a decrease of the gain and even an extinction of the laser. Thus, knowing the temperature distribution with a correct accuracy in the device under operation is of higher interest for designers.

We present here an analytical method using transfer matrices, Hankel-Transform to calculate the transverse and longitudinal temperature distribution possibly combined with a Laplace-Transform method for the transient response. It is applied to devices consisting of large-area (more than 100 µm) VCSELs based on the AlGaAs system grown on a GaAs substrate of typically 300-400 microns thick. In the steady-state regime the model shows a very good agreement with the experimental measurements of temperature increase[1] under laser operation. The model also gives the heat dissipation characteristic times of arbitrary stacks.

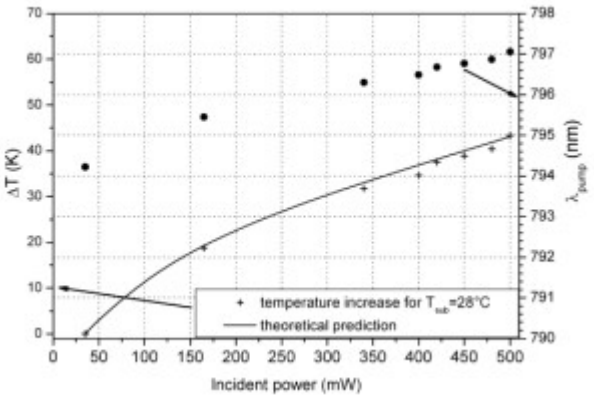

Fig1. Temperature increase of a VCSEL with a low pump transmission coefficient

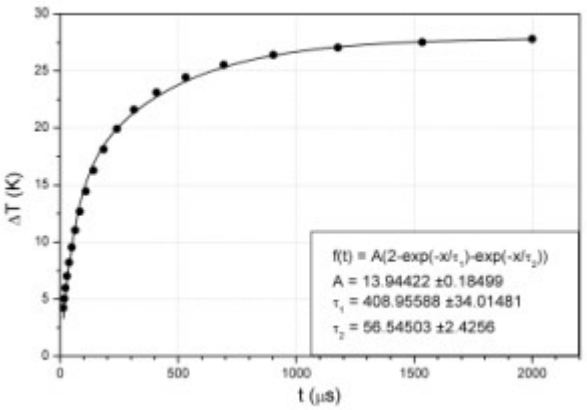

Fig2. Transient response of the temperature increase at the centre of the active layer for 300mW pump

[1] Y.Ménesguen and R.Kuszelewicz, submitted to IEEE J. of Quantum Electronics

Fidelity in atom optics billiards with chaotic and mixed dynamics

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Optically trapped ultra cold atoms are a paradigm system for the study of dephasing, due to their extreme isolation from the environment and the relative ease of applying external perturbations [1]. We trap ^{85}Rb atoms at temperature of ~20 μK in a wedge billiard The classical dynamics in this trap has both chaotic and mixed phase space regimes, depending on the wedge angle (see Fig. 1). We perform microwave (MW) echo spectroscopy to measure an "echo coherence" which is closely related to the fidelity, defined as the overlap between two initially identical states evolved with slightly different (or perturbed) Hamiltonians [1]. The perturbation is caused by the slight difference in dipole potential of atoms in the different internal states, and is inherent to dipole traps. We show experimentally (see Fig. 2) two regimes for the echo coherence decay. First for weak perturbations a non-monotonic fidelity evolution is seen as echo revivals for both chaotic and mixed phase space dynamics. These revivals result from a dominant dynamical time scale related to the spatial symmetry of the perturbation and are enhanced in the mixed phase space case due to the existence of low periodicity orbits. For stronger perturbations a perturbation-independent regime is observed, in which a monotonic decay in fidelity is seen for both chaotic and mixed phase space dynamics. A semiclassical model predicting these results is suggested[2].

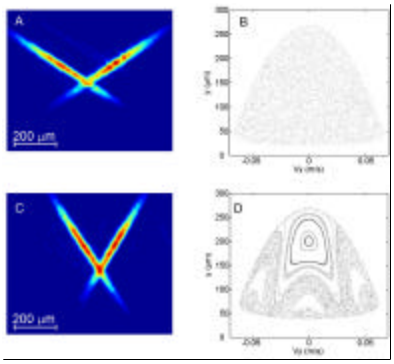

Fig. 1 CCD images of atom optics billiards [A, C]. Calculated Poincar'e surface of section reveal both classically chaotic [B] and mixed phase space [D] regimes, depending on the angle between the light sheets.

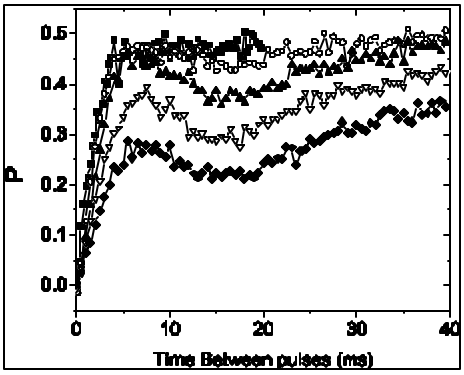

Fig. 2 Echo signal (P), where P=0.5 indicates complete loss of coherence, for a light sheet wedge with chaotic classical dynamics, for different perturbation strengths.

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Multiplex CARS Microspectroscopy of a Stratum Corneum Model System

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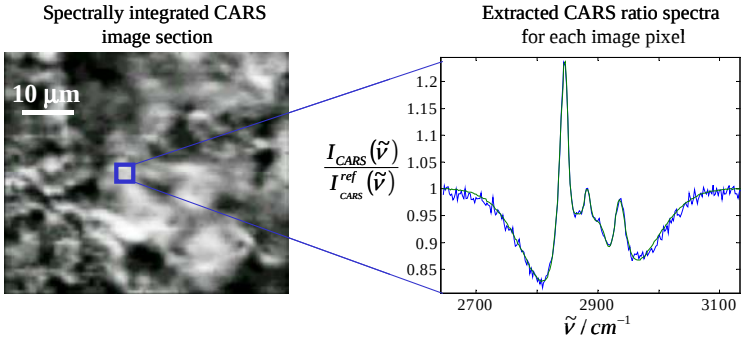
In recent years, coherent anti-Stokes Raman scattering (CARS) microscopy has emerged as a novel analytical tool that uses the intrinsic molecular vibrational properties of a microscopic sample as contrast mechanisms through optical microscopy. It has been demonstrated to exhibit high sensitivity, spatial and temporal resolution, noninvasiveness, and three-dimensional sectioning capability. In particular, the possibility of CARS microscopy for spatially and frequency resolved spectroscopic measurements provides a wealth of information in the noninvasive characterization of mesoscopic objects within a complex heterogeneous system (e.g. a biological cell or tissue). As such, multiplex CARS microspectroscopy using a picosecond pump pulse and a femtosecond Stokes pulse having a broad spectral bandwidth allows for simultaneous acquisition of the Raman spectra over a wide range of Raman shifts. It allows the chemical identification of unstained molecules on the basis of their characteristic Raman spectra and the extraction of their physical properties, e.g. their molecular structures.

In this work, we report on the point-by-point spectral mapping by means of multiplex CARS microspectroscopy of a lipid model system of stratum corneum, the top most barrier on the epidermis that prevents the penetration of external reagents through the skin. Investigations are carried out on model lipid mixtures consisting of ceramides, stearic acid and cholesterol, the three main lipid species of stratum corneum. Based on its characteristic Raman band at 2933 cm^{-1}, the spectral analysis reveals evidence for the formation of cholesterol-rich domain structures in the electroporated stratum corneum model system.

Multiplex CARS spectral imaging of a Stratum Corneum model systems



Nonlinearly induced cooling in a two-level system

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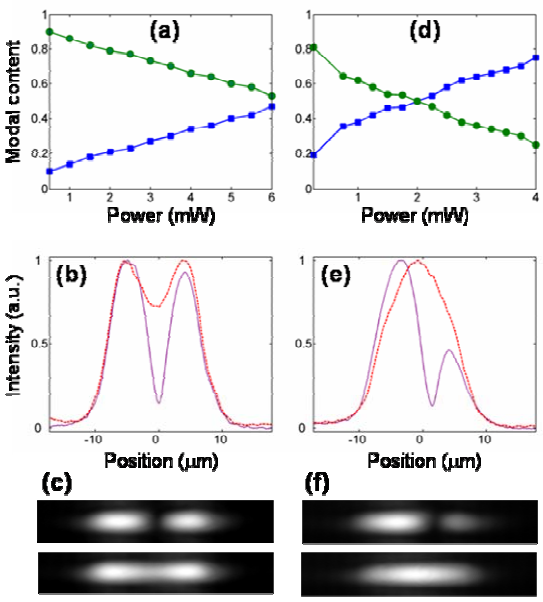
We report experimental demonstration of nonlinearly induced energy transfer from a higher waveguide mode into its fundamental, lowest-order mode. This process is equivalent to nonlinear cooling in a quantum system with two bound states. A field containing a substantial component of the excited state transfers irreversibly a large fraction of the power to the ground state while shedding some energy into radiation modes. Silberberg and Stegeman [1] showed that nonlinear coupling between modes leads to periodic power exchange among them. Recent studies on stability criteria for these states [2,3] have shown a dramatic difference when the continuum of radiation modes is included in the interaction: It enables an efficient and irreversible transfer of excitation to the ground state. We report here the first experimental observation of such a process in a nonlinear optical waveguide embedded in an infinite slab waveguide. The figure shows experimental results for a double-moded waveguide. Two sets of measurements are shown, of the same waveguide, with different modal content of the excitation at the waveguide input. The input contained 0.1 (0.2) of the total power in the ground state in the left (right) column. The top row (a,d) shows the modal content at the waveguide output, expressed in terms of the intensity-fractions of mode-1 (squares) and mode-2 (circles), as a function of the output (average) power. The middle row (b,e) shows cross sections of the intensity profile at the waveguide output, for low power (i.e. linear, in solid line) and maximal power (dashed line). The bottom row (c,f) gives photographs of the intensity measured at the waveguide output, for low power (top) and maximal power (bottom).



These results clearly demonstrate an increase in the ground-state content that is induced by the nonlinear process, equivalent to effective cooling of the system.

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Quantum lithography with classical light

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The smallest spot in optical lithography and microscopy is generally limited by diffraction. Quantum lithography, which utilizes interference between groups of N entangled photons, was recently proposed to beat the diffraction limit by a factor N. Here we propose a simple method to obtain N photons interference with classical pulses that excite a narrow multiphoton transition, thus shifting the "quantum weight" from the electromagnetic field to the lithographic material. We show how a practical complete lithographic scheme can be developed and demonstrate the underlying principles by a two-photon interference experiment in atomic Rubidium, where we obtain focal spots that beat the diffraction limit by a factor of 2.

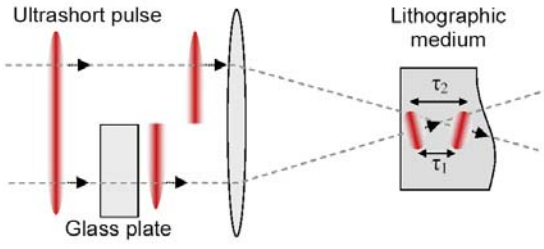

Fig. 1: Schematic setup for generation of sub diffraction limited spots by quantum interference. A glass plate delays half of a planar ultrashort pulse with respect to the other half. As a result, the non-linear lithographic medium at the focus is excited by two consecutive pulses with a space-variant relative delay; thus generating a space-dependent two-photon interference.

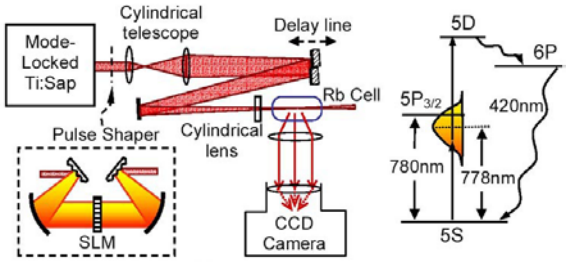

Fig. 2: Experimental configuration and relevant level diagram for atomic Rb. The cylindrical telescope weakly focuses the beam into the Rb Cell, the delay line controls the interference and the CCD records the image of the fluorescence spot. The cylindrical lens in front of the cell tightly focuses the beam in the perpendicular dimension.

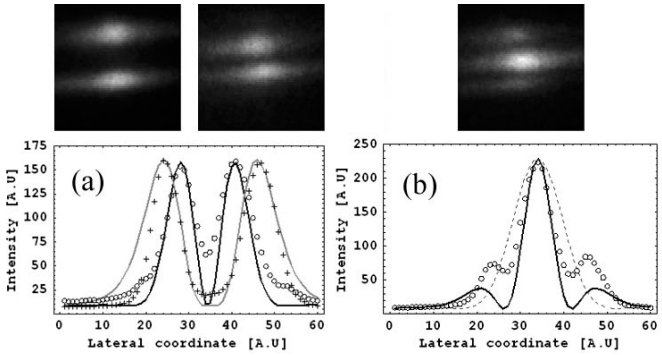

Fig. 3: Experimental results. (a) images and transverse cross sections of "dark spots" (destructive at the center) for a short relative delay (crosses) and a long relative delay (circles), demonstrating the double resolution of two-photon interference compared to one-photon interference. (b) is the corresponding two-photon "bright spot" as compared to the diffraction limited one-photon spot (dashed).

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Nanoscale Domain Engineering in Ferroelectric Crystals for Nonlinear Optical Applications

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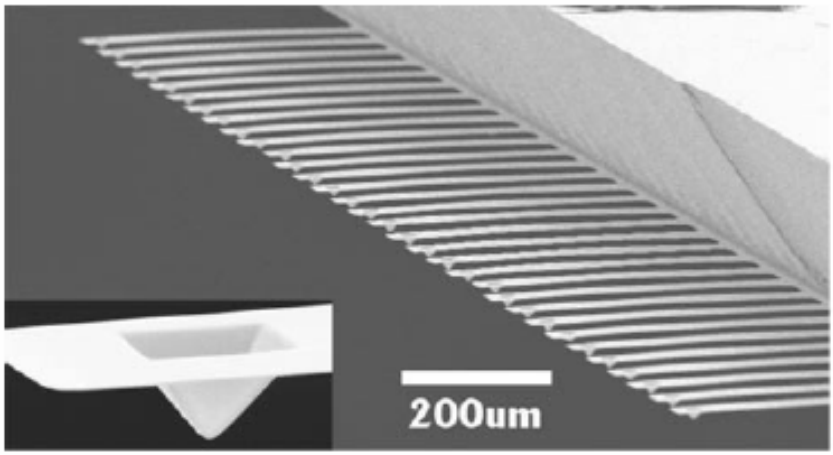
Several ferroelectric single crystals like Lithium Niobate (LN), $RbTiOPO_4$ (RTP), and $RbTiOAsO_4$ (RTA) can be used for diverse non-linear optical applications. Our recently developed high voltage atomic force microscope (HVAFM) opened the way for fabrication of nanoscale ferroelectric domains in thick crystals[1]. It has already been demonstrated to tailor stable one- and two-dimensional ferroelectric domain structures with sizes below 500 nm in LN, RTP and RTA single crystals.

In LN the tailored domain patterns have been observed using electrostatic force microscopy and etching techniques. By repeatedly etching the crystal we have been able to directly observe domain wall interaction with nanoscale pinning centers inside the crystal. This observation may lead to a better understanding of nanodomain growth dynamics in ferroelectric crystals.

One of the main obstacles to practical nanoscale ferroelectric optical devices is the writing speed of the structure when using a single HVAFM tip. We report on the application of atomic force microscopy tip arrays (shown below) for nanodomain engineering in ferroelectric crystals. Using a multiple-tip array, it is shown that domain writing in 200-micrometer thick RTP crystals results in a regular one-dimensional domain grating that penetrates throughout the bulk crystal as in the case of single tip writing. This multiple tip approach paves the way to the use of scanning probe microscopy for fabrication of various nanodomain configurations for advanced optoelectronic and microelectronic devices.



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Enhanced Second-Harmonic Generation by Complex Metal Nanostructures

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We report both an experimental observation [1] of unique polarization properties of the second harmonic generation (SHG) from complex, rough metal surfaces and theory [2] that explains this behavior and predicts unusual dephasing and spatial correlation phenomena on the nanoscale. I experiment, the second harmonic (SH) radiation is completely depolarized; there is also evidence that this SH radiation is also dephased, i.e., it has nature of the hyper-Raleigh scattering. It was also found that the fundamental and SH hot spots of radiation do not correlate [3].

We have developed theory based on Green's function method in spectral representation that as employed for both analytical and numerical calculations. The results for the distribution of local fields are shown in Fig. 1. Comparing the left and right panels, there is almost no correlation between the fundamental and SHG: the "hottest" spots are completely different.

The theoretically obtained SH polarization is displayed in Fig.2 (left panel), which shows the complete randomization of the SH local field directions (depolarization). This effect, which is in a full agreement with the experiment, is due to the ruggedness of the surface on the nanoscale. The dephasing calculation results are shown in Fig. 2 (right panel) where phase vectors are displayed for all cells of the system. Obviously, the phase vector evolution from a point to point of the system resembles diffusion: the trajectory of the phase vector is random with repeating loops leading to the complete loss of the phase memory.

In conclusion, we have established experimentally and theoretically strong depolarization and dephasing of the SHG in random nanostructured metal surfaces. This effect may find significant application in diagnostics and nanooptics of metal nanostructures,

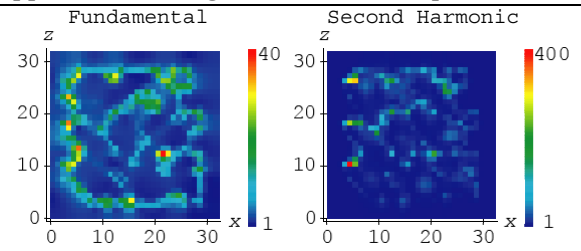

Fig. 1. Intensities of local fields on the nanoscale as predicted by theory [2]. Left panel: fundamental; right panel: SH at the surface of the system. Relative intensities are indicated by the color bars. The scale is in nanometers

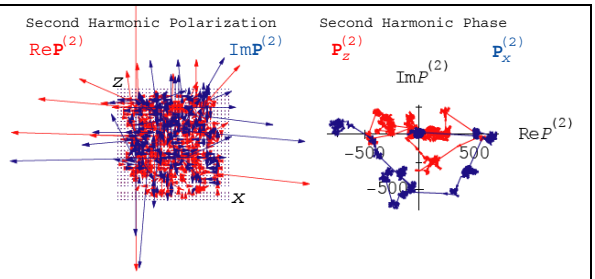

Fig. 2. Vectors of SH polarization in the plane of the system (left panel) and in the phase plane (right panel).

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Ground-state Coherence in the Presence of Spontaneous Scattering of Photons

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The experimental realization of Quantum Information Processing requires the encoding of quantum bits into physical two-level quantum systems. Due to their long decay time, pairs of hyperfine ground-states of single atoms provide a good candidate for the encoding of a qubit [1]. Superpositions of hyperfine ground-states can be coherently manipulated and entangled via optical Raman transitions. Spontaneous scattering of photons can therefore impose a fundamental limit to the fidelity of qubit manipulation using light [1].

In this work we experimentally study the coherence of ground-state superpositios of a single trapped $^{9}Be^{+}$ ion, in the presence of off resonance laser light [2]. Both population and coherence relaxation rates are measured with different laser detuning from the atom resonance frequency. The two rates are found to be in good agreement, indicating that it is only inelastic Raman spontaneous scattering of photons which affects the ground-state coherence. Raman inelastic scattering of photons is largely suppressed at a laser detuning which is much larger than the fine splitting of the excited state. It is therefore argued that laser light can be used to manipulate ground-state superpositions with arbitrarily small infidelities.

The research was supported by ARDA/NSA & NIST.

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Coherent control with real fields: Applying weak-field strategies to the strong-field regime

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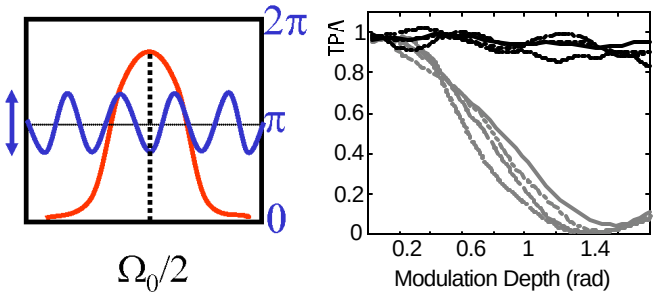
In the weak-field regime, the interaction between an electric field E and matter is described by processes involving a finite number of photons. In this regime, the coherent control of the excitation relies on the manipulation of these photons and of their interferences. This is achieved by the shaping of the spectrum of the N-photon field E^N [1]. In the strong-field regime, where the electric field area is on the order of π, such a spectral description of the interaction is not relevant anymore. Since non-perturbative effects (spectral broadening or Stark shift) have a complex dependence on the field spectrum, applying to strong fields the coherent control strategies developed for weak fields is in the general case not possible. We show that a weak-field approach is however relevant for a large class of electric fields characterized by a symmetry that cancels these effects. These fields, described with a *real* temporal envelope on a carrier wave, only reside in a single quadrature. This approach is demonstrated in a two-photon absorption experiment in atomic Cesium.



The two-photon absorption (TPA) in atomic Cesium is measured for shaped fields having an area of approximately 0.3, 0.6, 2.4 and 3π at the beam focus. The exciting pulses spectral intensity (red) is symmetric around half the two-photon absorption frequency $\Omega_0/2$. Their sinusoidal spectral phase (blue) is either symmetric (gray) or anti-symmetric (black) and lead to a *real* two-photon exciting field E^2. As a result, the normalized TPA as a function of the modulation depth (blue arrow) behaves similarly for the different intensities corresponding to weak [1] or strong fields. In particular, a "dark-pulse" corresponding to a 1.4 value of the modulation depth induces no two-photon absorption, independently of its intensity.

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Dynamics of the order parameter in a rapid quench from the Mott-insulator to the superfluid regime

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A Bose Einstein condensate occupying the ground state of an optical lattice was observed to undergo a quantum phase transition from a superfluid phase into a Mott-insulator as the depth of the lattice is adiabatically increased [1], in striking agreement with the prediction of the Bose-Hubbard model. Alternatively, when the strength of a deep lattice is rapidly quenched oscillations of the condensate fractions were predicted for large site-occupation numbers [2]. We study the exact many body dynamics and calculate the condensate fraction following a sudden reduction of the strength of the underlying optical potential in small 1D lattices with near-unity site occupation (corresponding to typical experimental conditions). We find that the overlap of the wave function with the initial ground state is inversely-correlated with the condensate fraction (see figure). We calculate the visibility of the interference fringes in the time-of flight image as a function of time [3]. We find a regime where the tunneling time $\hbar/J$ is the characteristic time scale for the condensate buildup and discuss the connection to a recent experimental observation [1]. Our exact yet finite-size results are compared to the prediction of the mean field decoupling approximation and to the time dependent Ginzburg Landau equation.

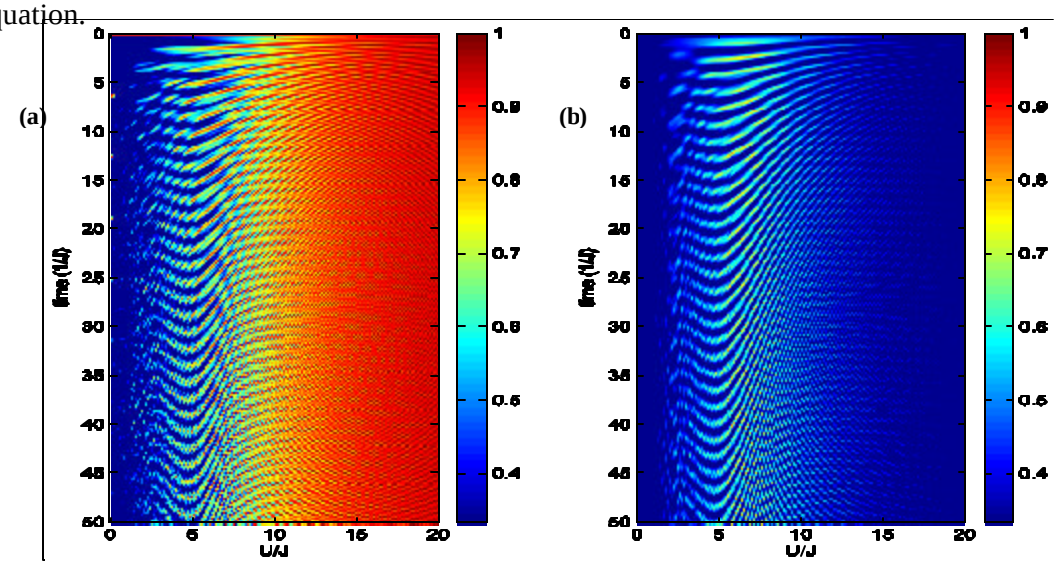

Figure: Overlap of the wave function with the initial Mott-insulator ground state **(a)** and condensate fraction **(b)** as a function of time and U/J, the ratio between the onsite interaction strength U and the tunneling element J. U/J is controlled by varying the depth of the optical lattice with typical values ranging from 0.5 to 500.

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Coherent control of photoemission

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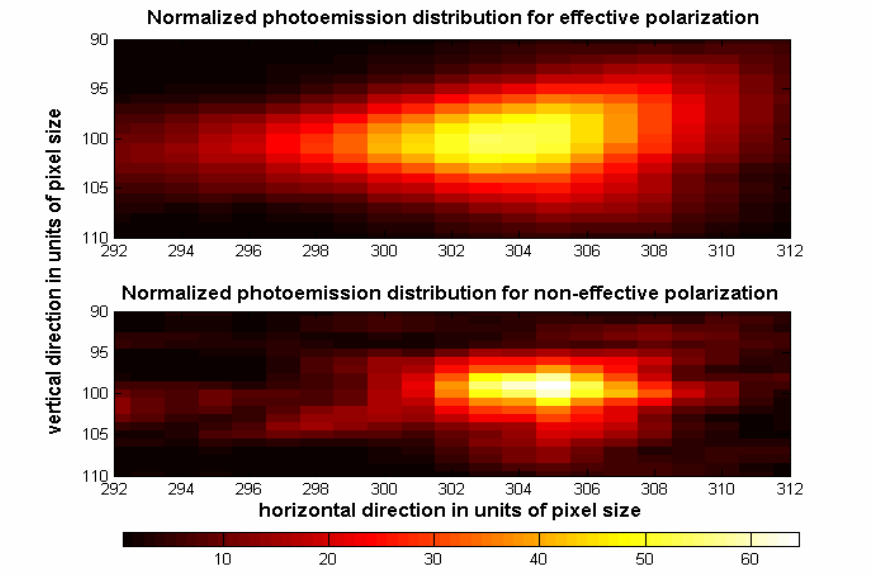
Our goal is to control the angular distribution of photoelectrons emitted from a metal surface by coherent properties of a laser pulse. Control is achieved by pulse shaping of a short pulse laser and inducing photoemission from a gold surface by two-photon process.

Both phase manipulations (such as a π phase step) of the pulse spectrum and polarization have an effect on both the intensity and shape of the angular distribution of the photoemission. The p-step phase causes the narrowing of the angular distribution. Figure 1 shows that the non effective polarization causes a narrower angular distribution of the photoemission signal in comparison to the effective polarization. When an organized organic layer is adsorbed on the gold substrate, it causes asymmetry of the photoemission distribution.



Near-field imaging of nonlinear pulse propagation in planar silica waveguides

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In studies of spatiotemporal solitons [1] it is desirable to obtain full characterization of the beam along the entire length of propagation. For that purpose we use a near-field scanning optical probe [2] to collect the evanescent wave of a beam propagating inside a nonlinear planar silica waveguide. In combination with numerical simulations, this tool allows detailed studies of the complex spatiotemporal propagation dynamics of 60-fs pulses in the anomalous dispersion regime [3]. Of particular interest is the case where the diffraction length is much shorter than the dispersion length: beyond a certain threshold power the beam suddenly focuses, and our probe shows that in this situation the main part of the beam propagates through the sample with little variation of its width (Fig. 1a). However, it is accompanied by satellite peaks that gradually spread away. As the input power is further increased, broadening of the central peak and faster spreading of the satellite peaks are observed (Fig. 1b). Our simulations reveal that the formation of the two spatial features is accompanied by spectral filtering (Fig. 2): the on-axis spectrum is strongly red-shifted, while that of the satellite peaks more or less coincides with the input spectrum. This remarkable coupled spatial-spectral filtering effect results from the interplay of self-phase modulation, stimulated Raman scattering and high-order dispersion, and evidence for it is also found in spectral measurements of the output beam.

Fig. 2. (right) Spatiotemporal contour plots (left) and power spectra (right) from the simulation of narrow-beam excitation and 1.12 MW input peak power: (a) Z=0; (b) Z=13.6 mm; (c) Z=24.5 mm.

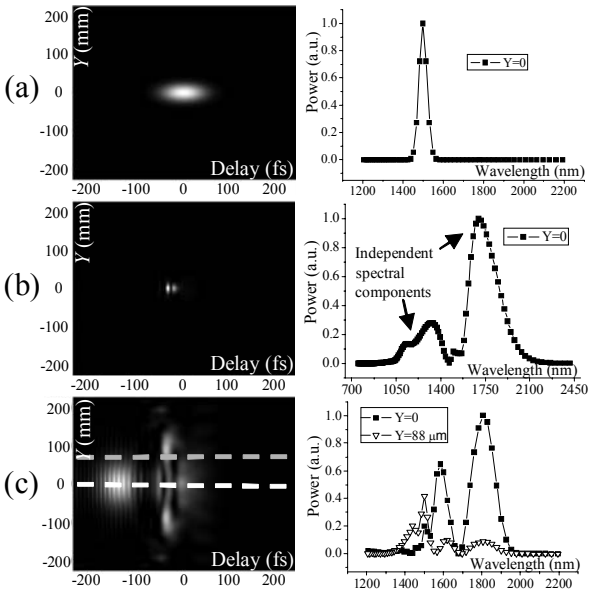
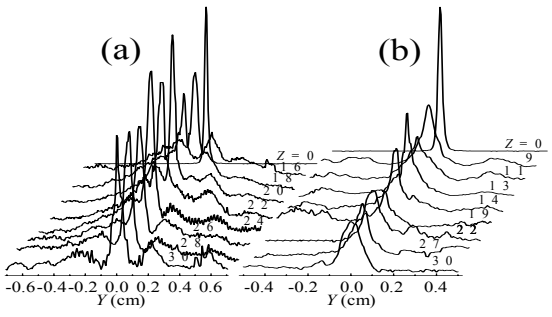


Fig. 1. (below) Experimental spatial cross-sections for narrow-beam excitation and two input peak powers: (a) 0.86 MW; (b) 1.12 MW.



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Charge-transfer effects in Raman Scattering of Individual Molecules.

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Surface-enhanced Raman scattering (SERS) has recently been shown to yield huge enhancement of the scattering cross-section, enabling the study of molecular surface dynamics on the single molecule level. There are two main contributions to the SERS effect. The first and dominant factor is the electromagnetic (EM) enhancement, which occurs at special areas on the metal surfaces, the so-called "hot-spots". The second is the chemical enhancement which depends on the adsorbed molecule, and involves charge transfer (CT) interactions with the metallic surface.

Fluctuations of the intensities of particular bands in the Raman spectrum of individual dye molecules have been experimentally observed in our lab. In particular, the amplitude and rate of the fluctuations of two low frequency bands (614 and 773cm^{-1}) in the spectrum of rhodamine 6G were shown to be larger than those of all the other bands. From the dependence of these fluctuations on laser intensity, as well as medium viscosity, we concluded that they reflect variations in the CT interaction due to lateral diffusive motion of the molecules, which sample different local work function values while moving on the surface of the metal.

In order to gain further understanding of the source of fluctuations, we are currently using two new experimental tools. The first is single-molecule Raman polarization spectroscopy. Our data shows that the fluctuating bands are polarized differently than other bands (Figure), and allows us to quantitatively characterize their Raman scattering tensor. In a second experiment we combine an electrochemical cell with our Raman spectrometer in order to actively control the interaction of molecules with the surface and probe their response.

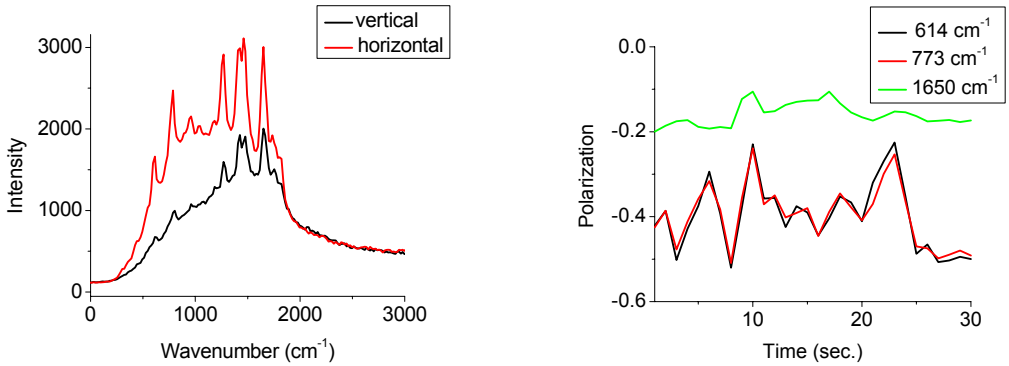

Figure. Left: Polarized Raman spectra from an individual rhodamine 6G molecule. Right: Time dependence of the polarization ratio for three bands, showing differences which can be attributed to different scattering tensors.

Dressed-state approach to matter-wave mixing of Bosons

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We use the Schwinger-Boson mapping to describe the spectrum and dynamics of matter-wave mixing in cold atomic vapor. We demonstrate the solution of a non-interacting two-wave mixing problem (Fig. 1(a)). Interactions between modes are then added. When the chemical potential is smaller than the driving Rabi frequency, the interactions can be treated as a perturbation over the non-interacting solution. For smaller Rabi frequency, there is a point of dynamical instability in the Gross-Pitaevskii equation, at which the numerical diagonalization differs considerably from the perturbative result (Fig. 1(b)).

We then analyze the spectrum and dynamics of three-wave mixing of Bogoliubov quasiparticles over a BEC. Both the dynamics and spectrum of a mode $\mathbf{k}$, populated by N excitations, and subject to Beliaev damping into quasi continuum of modes, are altered due to the presence of an additional mode $\mathbf{q}$, populated by M excitations [1]. We study the spectrum and dynamics by treating the three-wave mixing locally as a two-wave mixing problem, multiplied by a factor representing the third field. By comparison to direct diagonalization we find this approximation to be valid even for small seeds, $M<N$ (Fig. 1(c)). We use this approximation to understand the underlying cause for the splitting in the spectrum of the Beliaev damping products. This splitting should be experimentally observable in the time of flight images, which correspond to the momentum distribution of the collided quasi-particles.

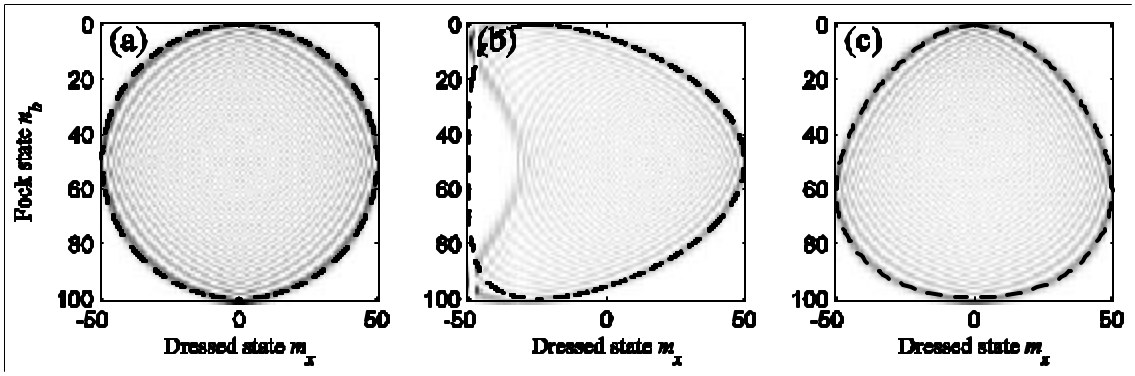

Fig.1

The amplitudes squared of the transfer matrices between dressed state m_x and Fock state n_b for the different wave-mixing Hamiltonians. The dashed line matches the matrix in the perturbative limit. (a) Two wave mixing of N=100 particles. This matrix is an N+1 dimensional representation of a rotation by Õ/2. (b) Interacting two wave mixing in the presence of dynamic instability. (c) Three-wave mixing with an initial seed of M=50.

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LASER COOLING IN A FEEDBACK-CONTROLLED OPTICAL SHAKER

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We propose a novel generic approach (optical shaking) to laser cooling of neutral atoms and molecules based on the feedback controlled interaction of particles with strong non-resonant laser fields. The method combines the elements of Sisyphus cooling[1] and of stochastic cooling techniques[2]. In the optical shaker, an ensemble of pre-cooled and trapped particles interacts with a standing wave produced by counter-propagating laser beams (Figure 1). The feedback loop includes photo-detectors recording the intensity of the beams after they cross the interaction region, and an electro-optical modulator that provides sudden phase changes in the laser beams (optical shaking) based on the detectors readings[3].

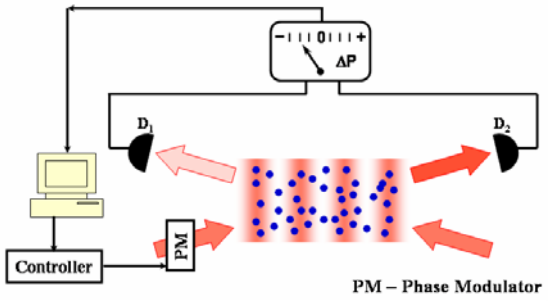

Figure 1. Proposed scheme of optical shaker.

We suggest several feedback algorithms that force the particles to transfer their energy to the electromagnetic field[3]. The numerical simulation of shaking an ensemble of 10^3 particles confined in a one-dimensional harmonic trap demonstrates a decrease of the particle's mean energy (Figure 2) together with phase space volume compression. We provide an analytical estimation of the cooling rate, which is in a good agreement with the numerical results. We present an analysis of the mechanisms that affect the cooling rate, such as feedback loop response time, laser beam phase and intensity jitter, and heating due to residual light scattering and dipole force fluctuations. The initial simulations show that optical shaking is feasible with available laser technology. The optical shaker does not suffer from the density limitations of resonant laser cooling schemes, and opposite to evaporative cooling it does not lead to the loss of trapped particles.

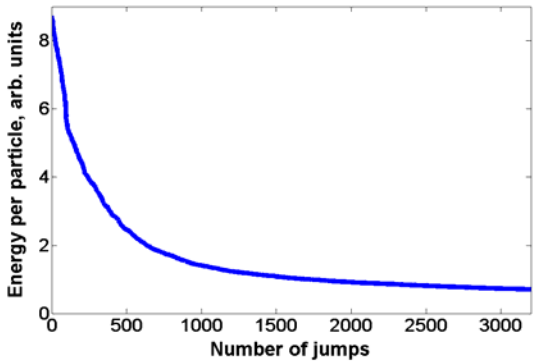

Figure 2. Average particle energy as a function of number of controlled phase jumps for an ensemble of 10^3 particles in a one-dimensional harmonic trap.

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Nonlinear and electro-optic applications of sub-micron poled ferroelectric crystals

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By applying a high voltage through the tip of an atomic force microscope, it is possible to periodically-pole ferroelectric crystals with sub-micron resolution. This represents nearly an order of magnitude improvement in poling resolution with respect to the commonly used technique of electric field poling. The higher resolution opens new possibilities in nonlinear optics and in electro-optics applications. It allows backward and non collinear quasi-phase-matched frequency conversion, as well as electro-optic Bragg reflection and deflection.

Quasi-phase matched non-collinear second harmonic generation was demonstrated using a 200 μm thick RTP crystals [*Opt. Express.* **12** 2236 (2004)]. The high voltage atomic force microscope (HV-AFM) was based on a modification of the Autoprobe CP AFM (Veeco, Inc). The domain reversal was performed by applying a high dc voltage (650 V) to the scanning HV-AFM tip having a radius of curvature of 50 nm. The fabricated domain grating comprised of 26 squares with 75×75 μm^2 area and had a total dimension of 1×0.15 mm^2. Optical microscopic inspection of the fabricated domain grating, following chemical etching, indicated that the reversed domains propagated smoothly without significant change in their width throughout the crystal thickness from the *C*+ to the *C*- polar face. The RTP sample enabled to generate non-collinear second harmonic wave of a Q-switched Nd:YLF laser. As the crystal was rotated, we have observed several distinct angles in which the second harmonic light was generated at relatively high efficiencies. These angles correspond to different orders of non-collinear quasi-phase-matching in the crystal, as shown in Table 1.

Order	**Calculated**		**Measured**		
m	θ_ω	$\theta_{2\omega}$	θ_ω	$\theta_{2\omega}^+$	$\theta_{2\omega}^-$
1	3.09	29.85	3	30	32
2	17.8	35.57	18	35	34
3	35.02	49.26	35	48	-
8	39.68	39.68	40	39	-

Table 1: Calculated and measured fundamental input angle and second harmonic output angle (both in air) for different QPM orders of non-collinear second harmonic generation. The angles are given in degrees.

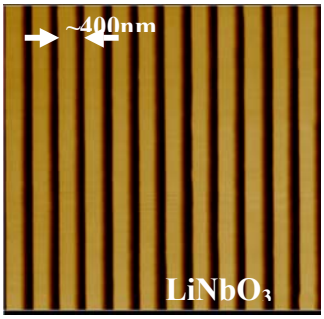

Fig. 1: AFM image of C+ side of $LiNbO_3$, following high resolution poling using the HV-AFM and selective etching.

Another application that is enabled by the high poling resolution is electro-optic Bragg reflection. The ferroelectric domain reversal also reverses the sign of the electro-optic r_{33} coefficient in the material. Hence, by applying a DC voltage on the Z axis of the periodically poled crystal, an electro-optic grating is induced. When an input light is sent into the device at the Bragg angle, it will be deflected (or reflected) from the material, and the efficiency of the process is determined by the applied DC voltage. The high resolution of the HV-AFM technique enables to reach very large angles between the input and output beams, and potentially achieve back reflection, if the poling period becomes $\lambda/2n$, where λ, and n are the wavelength and refractive index, respectively. Recent experiments have shown that these poling periods can be obtained in $LiNBO_3$ and RTP, thus potentially enabling the realization of voltage controlled optical reflectors.

Decoherence Rates Measurement in Light Storage Medium

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In light storage experiments an ensemble of atoms is driven into a coherent superposition using two radiation fields. The quantum state of one of these fields can be mapped onto long-lasting spin excitations of the atomic ensemble (specifically, coherence terms in the atomic density matrix). After a certain time the stored light field can be retrived from the atomic ensemble [1,2]. The storage time is limited by decay processes that change the internal state of the atoms. These processes consist of changes in the population of different atomic levels ("depolarization", T_1), and loss of coherence between these levels ("decoherence", T_2).
We present a simple experimental technique to measure the rates of these processes in an EIT medium consisting of a low density Rubidium vapor and a Ne buffer gas. The effects of the medium parameters on the decay rates were explored, and long decoherence rates of a few miliseconds were measured. These rates were also compared to the decay time of stored light in the same medium. Finally we present an explanation for the similar time scales we measured for both the depolarization and decoherence.

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Nano-lithography using multilayer light masks

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Atom lithography is a novel technology using laser-controlled deposition of neutral atomic beams for nanofabrication and high resolution doping of materials[1]. So far, single optical standing waves (light masks) have been used to manipulate the atoms, and typical minimal feature size achieved is about 20 nm. However, focusing by a single sinusoidal standing wave suffers from severe spherical and chromatic aberrations, thus limiting the resolution and leading to a considerable overlap (pedestal) of the deposited features. Recently, it was theoretically shown that focusing by several successive light-induced standing waves may simultaneously reduce both spherical and chromatic limitations and create extremely focused (spatially squeezed) atomic groups[2,3,4]. For a cloud of trapped cold *Cs* atoms, the enhanced spatial squeezing using this approach was demonstrated by the group of M. Raizen[5]. Currently, we are preparing to the first experimental realization of high-resolution atom lithography using multilayer light masks, which will be performed by the Stuttgart group. In this connection, we investigate theoretically the focusing of *Cr* atoms by a double-layer light mask in the framework of the particle optics approach. Monte Carlo simulations are done both for thermal beams and mono-energetic atoms at various collimation conditions. Operation of the double-mask is analyzed both in paraxial approximation and in the regime of deep nonlinear focusing. Thin-thin, thin-thick and thick-thick lens combinations are considered. We optimize the double-lens performance and provide parameters for the minimal spot-size of the deposited atoms. It is shown that even such a simple configuration may considerably reduce the imaging problems, improve the quality of focusing and enhance the contrast ratio of the deposited structures.

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Mutual Injection Locking of Microwave and Optoelectronic Oscillators

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Optoelectronic oscillators are employed in numerous systems demanding high-quality microwave signals. Despite its apparent advantage of being simple to construct, the original scheme presented in [1] has a major flaw: the long storage cavity - responsible for the excellent spectral purity defines naturally closely spaced modes which are hard to filter out and hence degrade the overall performance. Several corrective routes have been proposed, the most widely known of which is the use of an extremely narrow band intra - cavity microwave filter [1]. A second common solution employs a dual optoelectronic-loop configuration [2]. The narrow filter deprives the undesired modes of sufficient gain whereas the dual loop prevents the parasitic modes from satisfying the phase condition. The later is often preferred since it does not require any exotic components.

In this paper we propose and demonstrate a new scheme for the implementation of phase-condition filtering with one of the loops being purely electrical. That is: a microwave Photo-HBT based oscillator of medium quality ($Q \approx 300$) capable of self sustained oscillations at 4.73 *GHz* drives a Mach-Zehnder modulator (fed optically with a CW signal). The modulated optical signal is propagated through a 3 *km* long dispersion shifted fiber and is incident upon the optical window of the Photo-HBT thereby closing the optoelectronic loop. By controlling the loop gain within each of the two loops, each can be brought to self oscillate. However, the interim state, in which ***none*** of the loops has sufficient gain for self sustained oscillations but the coupled system does oscillate, is of extreme importance since only modes common to both loops oscillate while others are suppressed.

Depending on the relative gain contributed by either loop, its individual characteristics become correspondingly evident exactly as in case of two mutually injection-locked oscillators [3]. We demonstrate that operating at a point close to optimal allows for a phase noise of $-110\ dBc/Hz$ (at 10 *kHz* offset) and the closest parasitic mode is suppressed to below $85\ dBc$.

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Electrooptic light modulation with polymeric resonant grating waveguide structures

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Grating waveguide structures (GWS) are planar multilayer structures. In their most basic configuration they are comprised of a surface relief grating, a waveguide layer and a substrate. When such GWS are illuminated with an incident light beam, most of the light is directly transmitted while the rest is diffracted, trapped in the waveguide layer, and subsequently, partially rediffracted outwards. At a specific wavelength and angular orientation of the incident beam, a "resonance" condition occurs, where the rediffracted beam destructively interferes with the transmitted beam, so that the incident light beam is then completely reflected.

In this work we present for the first time to our knowledge, experimental results evidencing light modulation at a wavelength of 1.55μm, in an active polymer-based resonant GWS for which the resonance wavelength can be dynamically varied. The active part of the GWS is comprised of a linear electro-optic (e.g. Pockels) polymer, forming the waveguide and grating layers, leading to 1nm spectral bandwidths (Ref. 1). The configuration of the active polymer-based GWS is schematically presented in fig. 1. An externally applied field modulates the refractive index of the waveguide and grating layers resulting in modulation of the reflected intensity, when the structure is illuminated with an incident beam of a fixed wavelength of 1.55 μm. The reflected modulation response to an applied voltage pulses is presented in Fig. 2. Light modulation has been readily detected at frequencies up to 1MHz. We expect that these results can be significantly improved by reducing the needed applied voltage as well as increasing the response bandwidth, by using more advanced polymers that would have greater refractive index changes and lower scattering losses, and by resorting to adapted electrode configurations for increasing the bandwidth. Using the above, the frequency range can be in principle upgraded to GHz and beyond. In addition, such polymer based GWS can be fabricated with relatively simple spin coating technology, yielding a very cost effective light modulator and in our proposed configuration no cumbersome pig tailing and butt-end coupling is needed.

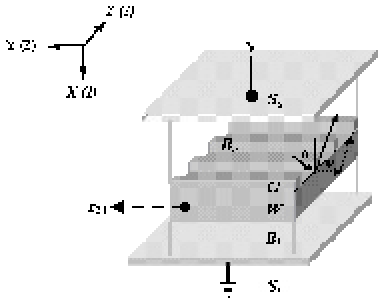

Figure 1. Schematic of an active polymer-based grating waveguide structure with an electo-optic polymer. S_l- lower substrate, B_l- lower buffer, *W*- waveguide, *G*- grating, B_u- upper buffer, S_u- upper substrate.

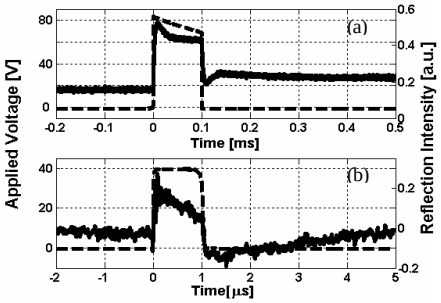

Figure 2. Reflection modulation response to an applied voltage pulse. (a) Pulse duration of 0.1ms; (b) pulse duration of 1μs. Dashed curve- applied voltage; solid curve- detected reflection modulation at resonance wavelength.

Ref. 1: *Towards ultranarrow bandwidth polymer based resonant grating waveguide structures*, T.KATCHALSKI, E.TEITELBAUM, A.A.FRIESEM, G.MARTIN-FUCHS, R.HIERLE, J.ZYSS Appl. Phys.Lett. (84), 472(2004) [and APL (85), p.2145, 2004].

Population transfer enhancement in pump-dump experiments.

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Previously reported Two-Dimensional Time-Delayed CARS ((TD)^{2}CARS) was shown to be an efficient method for producing and monitoring highly excited vibrational wavepakets[1]. The addition of adaptive pulse shaping into this technique[2] yielded significant enhancement of the measured CARS signal from the excited vibrational wavepackets.

To interpret the observations, we applied a perturbative analysis based on a combined spectral-temporal treatment of the sequential excitation of the molecule. We show that the population transfer process is a result of the interference of quantum amplitudes of different pathways, and the relative phase of the spectral components of both the pump and the dump pulses affect this interference. By proper choice of these phases, one can either enhance or completely destroy the population of a preselected state. The frequency components contributing most to any transfer of population are those resonant with the intermediate and final transitions, and the optimal spectral phases of both pump and dump pulses may be defined in terms of a complex spectral contribution functions. The interaction of each pulse within a sequential multiphoton process is influenced by the temporal windowing imposed by the presence of the other pulses. The pulse shape resulting from this analysis qualitatively fits the experimentally observed pulse shapes, including the double hump feature depicted in (**D**), indicating better population transfer to the probed states. Based on this combined spectral and temporal approach, one may think of selective preparation of arbitrary vibrational wavepackets in multilevel systems.

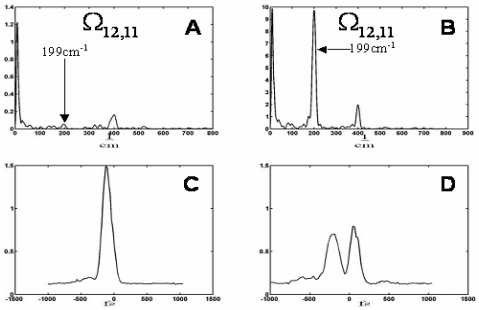

Figure 1 Generated wavepacket (Spectrum of CARS signal) around state $\nu = 11$ by non-optimized pump and dump (**A**) and by an optimized pump pulse (**B**). The pulses are depicted in (**C, D**) respectively.

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Self focusing in a medium with nonlinear microstructure

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Over the last decade it has become possible to manufacture optical media in which the *linear* index of refraction is periodically modulated. Extensive research has been done on propagation of light in such media, referred to as photonic crystals. Recent advances now make it possible to design micro- and nanostructures in which the *nonlinear* index of refraction is periodically modulated [1]. To the best of our knowledge, no research was done on this problem since the models of the photonic crystals problem, such as Floquet-Bloch waves analysis, cannot be applied here.

In this work, we offer an analytical approach to the problem of propagation of light in a medium with a fast periodic variation of the nonlinear index of refraction, i.e., where ν, representing the ratio of the microstructure period and the incident beam width, is small. We show, analytically and numerically, that this periodic modulation destabilizes the bound states (solitons) of these structures, independent of the exact details of the microstructure. Furthermore, we show that a soliton can become stable in such a medium only after it has undergone significant focusing to the point that its width is of the order of the refraction index period, in agreement with [2].

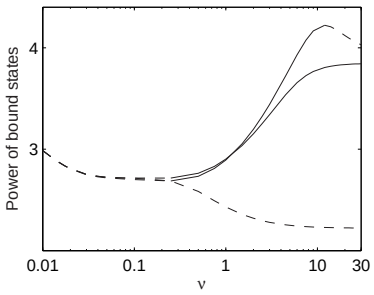

Figure 1: Power curves of solitons of Kerr medium with 3 different nonlinear microstructures as a function of ν. A negative (positive) slope represents an unstable (stable) bound state. We see that wide beams (small ν) are unstable while narrower beams ($\nu \geq 1$) are stable only in some cases.

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Near-infrared optical amplification by non homogeneous heating of silicon

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We report a new configuration and mechanism of optical amplification in silicon. It is based on local heating of silicon slabs. The slabs were of commercial-type with no special treatment. Gain was observed at near-infrared wavelengths (1.3 μm and 1.5 μm) and was evidenced in various heating configurations including irradiation by pulsed and continuous lasers at different geometries, and by heating the samples with microwave irradiation. We report also the achievement of optical gain in silicon-on-insulator waveguides by continuous laser irradiation at the vicinity of the waveguides. At the mentioned irradiated conditions, the samples exhibited an anomalous luminescence spectrum. An amplification mechanism is proposed based on local bending of valence and conduction bands, in conjunction with hot carrier injection out of the heated spot. According to it, the transfer of charge carriers between the hot spot and neighboring regions creating areas where the carriers' distribution is non-thermal and population inversion is enabled.

Fully three dimensional breather solitons can be created using Feshbach resonance

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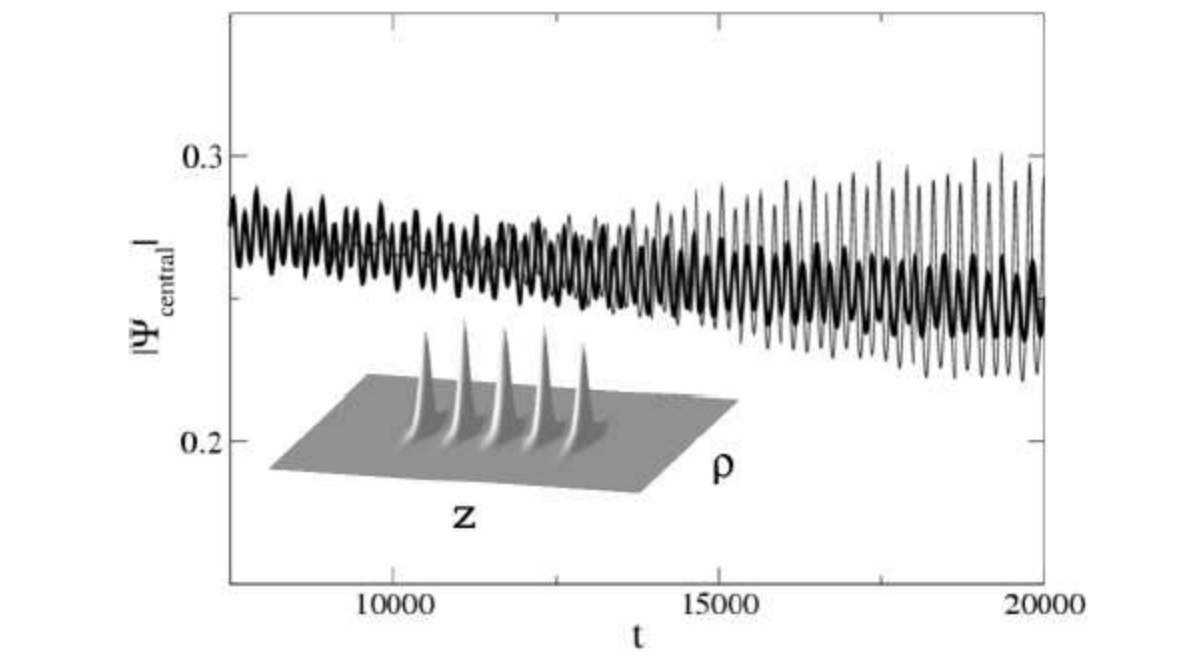
We investigate the stability properties of breather solitons in a three-dimensional Bose-Einstein Condensate with Feshbach Resonance Management of the scattering length and confined only by a one dimensional optical lattice. We compare regions of stability in parameter space obtained from a fully 3D analysis with those from a quasi two-dimensional treatment. For moderate confinement we discover a new island of stability in the 3D case, not present in the quasi 2D treatment. Stable solutions from this region have nontrivial dynamics in the lattice direction, hence they describe fully 3D breather solitons. We demonstrate these solutions in direct numerical simulations and more importantly, suggest a way of creating robust 3D solitons in experiments in a Bose Einstein Condensate in a one-dimensional lattice.



The dynamics of the maximum of the central peak in multipeak soliton in the lattice.

Femtosecond laser material processing: how short is short?

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Ultrafast laser systems have been gaining increasing popularity for material processing [1,2], but the cost and complexity of operation of ultrashort laser systems prevents them from becoming the standard tool in material processing. We address the question of how short the pulse should be for specific applications and propose a method for real-time monitoring of the ablation. The experiments were carried out for silicon in air, with an amplified regenerative laser system delivering up to 1 mJ of pulse energy at the wavelength 800 nm with adjustable pulse width ranging from 100fs to 30ps. The laser was focused onto a polished flat surface of silicon, and each single pulse was fired at a fresh sample region. The intense laser pulse generated an expanding plasma plume with a characteristic sharp Si I atomic line at 288.15 nm and a broad emission spectrum [3].

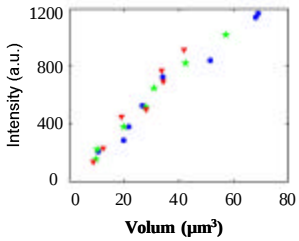

Fig 1. Si I intensity vs ablated volume at pulse widths 120 fs, 350 fs, and 3 ps.

We find that the intensity of the spectroscopic signal correlates very well with the ablated volume as measured by atomic force microscope (Fig. 1) thus offering an excellent tool for on-line monitoring of the ablation process. Next we varied the pulse duration, and used adaptive optimization of the pulse shape by using genetic algorithm with the optical signal as a feedback. We found that the shortest pulse is not always the best in terms of ablation efficiency and quality. At low laser fluence, shorter pulses seem to be the most effective, whereas at higher energies the quality of holes from long pulse is better and the efficiency is almost as high, Fig. 2.

Finally, we applied the method to the processing of metallic multilayer structures, and were able to remove or address one layer at a time based on this optimization of pulse shape and pulse intensity.

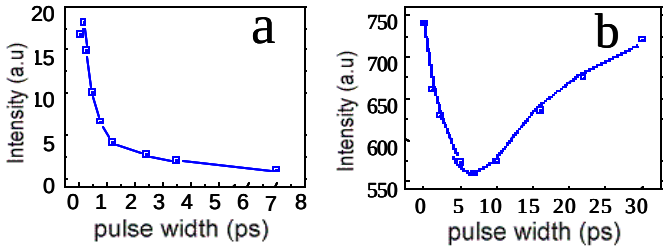

Fig 2. Optical signal with respect to the pulse width for two given pulses: (a) 300 mJ/cm^2; (b) 2 J/cm^2.

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Giant interaction and entanglement of slow-light photons

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Among the various schemes of current interest for quantum computation and quantum communication, those based on photons have the advantage of using very robust and versatile carriers of quantum infornation (QI). Efficient and scalable devices for QI processing with photons would require *deterministic* schemes capable of entangling ultra-weak few-photon fields with high fidelity. Yet the main impediment towards their realization is the weakness of optical nonlinearities in conventional media. A promising avenue for deterministic two-photon entanglement has been opened up by studies of giantly enhanced cross-phase modulation in the regime of electromagnetically induced transparency (EIT), wherein the ultrahigh sensitivity of the slow-light EIT dispersion to a small Stark-shift of the atomic level results in an appreciable nonlinear phase shift, impressed by one ultraweak field upon another [1]. Notwithstanding this promising sensitivity, large conditional phase shifts and entanglement of single photons faces serious challenges in spatially uniform media, due to the group velocity mismatch between the interacting photons and their spectral broadening (chirp). Recently, several theoretical schemes have been put forward by us, which resolve these difficulties and pave the way to deterministic quantum logic with photons A. Giantly enhanced cross-phase modulation and high-fidelity entanglement is predicted between slow-light polaritons whose propagation is strongly affected by photonic bandgaps of spatially periodic media [2]. B. Even better results are achievable when single-photon slow-light polaritons in three-level atomic vapors couple via long-range dipole-dipole interactions [3]. This mechanism can give rise to chirp-free giant cross-phase modulation and high-fidelity entanglement even for a moderate transverse confinement (weak focusing) of the incident photons.

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Coherent Control and the Phase Locking of Two-Photon Processes

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We demonstrate phase locking between two pairs of nanosecond laser pulses generated from independent sources. These four laser pulses are produced experimentally by mixing two uncorrelated dye laser beams with a third uncorrelated beam, thereby generating two additional laser frequencies. Using one particular combination of our four laser frequencies, we can generate two identical sum frequencies in further stages of frequency mixing. These sum frequencies are *coherent,* despite being generated separately, and we observe stable interference fringes with measured modulation depths of $\pm 40\%$.

Well-defined phase relationships for nanosecond lasers are difficult to achieve, but they can be especially useful for two-photon *vs.* two-photon coherent control experiments. Such experiments are currently underway in our laboratory, where we are attempting to control the electronic branching ratio for the sequential two-photon photodissociation reaction,

$$\mathrm{Na_2}(\mathrm{X}^1\Sigma_\mathrm{g}^+) + \hbar\omega_1 \rightarrow \mathrm{Na_2}(\mathrm{A}^1\Sigma_\mathrm{u}^+);$$
$$\mathrm{Na_2}(\mathrm{A}^1\Sigma_\mathrm{u}^+) + \hbar\omega_2 \rightarrow \mathrm{Na}(3\mathrm{s}) + \mathrm{Na}^*(3\mathrm{p}, 4\mathrm{s}, 3\mathrm{d}).$$

We will also discuss some unusual features of the optical system, which functions as a type of interferometer.

Electro-optic confocal microscopy: a new instrument for high resolution electric field mapping in molecular and biomaterials

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Nonlinear microscopy based on two-photon fluorescence or second harmonic generation has been recently applied to the measurement of membrane potentials in neurons with an intrinsic sub-wavelength resolution and a significant penetration depth.[1-3] This optical method offers an interesting complement to the more traditional patch-clamp technique, which is sterically limited by the dimension of the electroded micropipettes and might provoke damages to the cell. The multiphotonic excitation in nonlinear microscopy requires however high power short pulses, which entails photo-bleaching and photoxydative degradation. We propose here an alternative and challenging method that only requires a low power continuous laser and is expected to reach a highly sensitive measurement of transmembrane potentials.

A major motivation in our laboratory is the detailed mapping of the electric field distribution, either in polymer based electrooptic devices, Langmuir-Blodgett films or nano-structured nonlinear media or, in the longer range, complex neuronal networks. We are developing a set-up that will allow neurons activity imaging in a spectral window permitting a 1mm depth optical penetration. This technique is based on the electro-optical effect in nonlinear media, in which a variation of the refractive index of the cell membrane is induced by the transmembrane potential, thus imparting a phase shift to the laser beam passing through the measurement point. This phase shift is measured using sensitive homodyne detection. A confocal microscope system is included to allow a three dimensional resolution and a possible cartography of the response. The large-scale imaging will allow addressing important issues such as the relation between the localization of potential transients and the morphology of the neurons, which is of central relevance in the realm of current neurophysiological studies.

We will present the first stage of the experiment implementation, which requires model samples that exhibit an electro-optic activity. Such samples are based on a thin polymer film (thickness of a few microns) containing grafted nonlinear chromophores, spin coated on a set of planar gold electrodes on which the electric field is applied. Molecular microcristals are also used as efficient systems for the estimation of the set-up sensitivity, which up to now reaches 2.10^{-6} rad.s

Among future samples to be investigated are $\chi^{(2)}$ Langmuir-Blodgett films (which are relevant systems for mimicking biological membranes) and large neurons from invertebrates, doped with active nonlinear dyes. A french-israeli cooperative project together with Prof. A. Lewis (Hebrew University, Jerusalem), R. Marks (Ben-Gurion University, Beer-Sheva), and Profs. D. Cattaert and P. Meyrand (Univ. of Bordeaux) will be launched in 2005 and will allow exploring complementarities between electrooptic microscopy and various alternative techniques such as voltage-sensitive sensitive second-harmonic generation and fluorescence on naturally grown (hippocampus) as well as artificially grown neural systems.

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A Self Starting Ultra Low Jitter Pulse Source Based on Coupled Optoelectronics Oscillators with an Intracavity Fiber Parametric Amplifier

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The increasing demand on information capacity has initiated intense research efforts on the development of new optical sources with the capability of providing narrow optical pulses at high repetition rates. The timing stability of such pulse sources is a key issue for optically time domain multiplexed and optical sampling systems. An attractive scheme for low jitter pulse sources are various forms of self starting optoelectronic oscillators whose configuration encompasses optical pulse generation [1]-[3].

In this paper we propose and demonstrate a new type of a self starting low jitter pulse source based on mutual injection locking of an optoelectronic oscillator which includes an intra cavity optical parametric amplifier (OPA) and a phototransistor based oscillator. The incorporation of the OPA as an intra cavity element yields short pulses with the superb jitter properties of coupled optoelectronic oscillators [4]. The new system generates 3 *ps* pulses at 10 *GHz* with a timing jitter of 30 - 40 *fs*.

The experimental setup consists of strong pump signal (λp=1543.5 nm) and modulated at 10 GHz using a Mach-Zehnder modulator driven by the amplified output of a 10 GHz phototransistor based oscillator. Pump pulses with 20 ps width and 10 GHz repetition rate are obtained by using the nonlinear modulator response and an adequate filtering of the pump spectrum. The amplified pump is combined with a weak CW signal (λ_s=1559 nm) and launched into a 500 m long highly nonlinear fiber (HNLF). Since the parametric gain varies exponentially with pump power, the modulated pump turns into a sharp pulse at the signal and idler wavelengths. The filtered signal or idler propagates in a 10 km long dispersion shifted fiber (DSF) before being amplified, filtered and fed back into the optical port of the phototransistor thereby closing the optoelectronic loop. The optoelectronic and microwave oscillators are mutually injection locked with the locked system exhibiting ultra low noise [4] and consequently the jitter of the nonlinearly generated pulses is very low.

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Theory beyond the dipole approximation of cold atoms in an electromagnetic field: Formation of optical lattices due to quadrupole interactions

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Abstract

Optical lattices are expected to be formed due to the non vanishing dipole transition probabilities induced by the laser field. We derive here a perturbation theory beyond the conventional dipole approximation which provides field/atom coupling potential terms that so far have not been taken into consideration in theoretical studies. We show that a 1D optical lattice might be formed due to the quadrupole field/atom coupling potential term that appears in our perturbational expansion, when the light-induced dipole transition matrix elements become small.

Coherent control and spectroscopy of non-radiative transitions: long-range electron transfer

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The possibilities of the optical control of molecular dynamics using properly tailored pulses and nonlinear optical spectroscopy have been the subject of intensive studies in the last few years. The aim of the present paper is to extend the concepts and ideas of population transfer and transient four-wave mixing spectroscopy, developed for optical transitions, to non-radiative transitions controlled with strong electromagnetic field. As an example we consider the long-range electron transfer (ET) in mixed-valence transition metal complexes with a large difference (~70 *D*) in permanent dipole moments between donor and acceptor electronic states when a direct dipole transition between the states is forbidden. Interaction of strong electromagnetic field with such systems leads to modulation of their energetic spectrum by the field frequency *w* similar to the spectrum of a frequency-modulated wave. This modulation alters the relative arrangement of the configurational surfaces corresponding to different electronic states during the electromagnetic pulse action that enables us to realize a number of "non-radiative" analogies to the optical control and nonlinear optical spectroscopy.

We considered a donor/acceptor system with two electronic states |1> (before the charge transfer) and |2> (the electron on the acceptor site) in a solvent. We have obtained equations for the components of the pseudospin vector of such a system. In generalization of the Rabi frequency for an optical transition we have introduced the *generalized Rabi frequencies* for non-radiative ET induced by strong electromagnetic field. It enabled us to apply the doubled-sided Feynman diagrams to transient four-wave mixing spectroscopy of radiationless transitions. We have shown that it is possible to realize "non-radiative" analogies to pump-dump process and adiabatic rapid passage for the donor-acceptor population transfer [1], and to transient four-wave mixing spectroscopy. In particular, we predict existing so called "non-radiative" photon echo: a photon echo, which is based on radiationless transitions.

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Adiabatic theorem for non-hermitian time-dependent non-periodic systems

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Abstract

It has been discussed before that in the conventional quantum mechanics (i.e., hermitian QM) the adiabatic theorem for systems subjected to time periodic field holds only for bound systems and not for open ones (where ionization and dissociation take place) [W. Kohn *et al*, Phys. Rev. A **56**, 4045 (1997)].

Here with the help of the (t,t') formalism we derive an adiabatic theorem for open systems. The (t,t') method [Peskin and Moiseyev, J. Chem. Phys., **99**, 4590 (1993)] enables us to use an analytical expression for the time evolution operator even when the Hamiltonian is explicitly time dependent (not necessarily time periodic) and even when the field intensity is very large and perturbation theory is not applicable.

The use of the complex scaling transformation plays a key role in our derivation. For example, the spectrum of the Floquet Hamiltonian is changed dramatically. Rather than a continuous spectrum that is responsible for the absence of an adiabatic limit for $N(number-of-basis-functions) \to \infty$ in the conventional QM, the resonances are associated with a point spectrum and are separated from the continuum that is rotated into the lower half of the complex energy plane.

As a numerical example we apply the adiabatic theorem we derived to a model Hamiltonian of atoms which interact with strong laser pulses. We show that the generation of odd-order harmonics and the absence of even-order harmonics, even when the pulses are short, can be explained with the help of the adiabatic theorem we derived. The conditions for generation of all kind of high-order harmonics on the basis of the non-hermitian adiabatic theorem are presented.