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Final Report

In accordance with the main objectives of the project, we have developed different novel robust methods and schemes for storage and processing of classical and quantum information involving frequency modulated (chirped) laser. It is important that these schemes are robust against variations of laser radiation parameters as well as those of the resonance conditions. Also, the proposed schemes could be applied in media with both homogeneously and inhomogeneously broadened transition lines, including hot gases (Doppler broadening) and solid-state environment (local electromagnetic fields). Important results are obtained in the field of coherent manipulation of inner and translational quantum states of multilevel atoms with inhomogeneously broadened transition lines and for atoms whose interaction is mediated by metallic nano-wires. An analog to the well-known effect of electromagnetically induced transparency (EIT) has been found for nearly lossless propagation of two frequency chirped laser pulses in an atomic medium with a robust creation of coherence between meta-stable atomic states, without considerable excitation of the atoms. We have proposed another scheme allowing extremely robust creation of coherence in an atomic medium between ground and excited states. The proposed schemes have allowed preparation of a nonlinear resonant medium in coherent superposition states that will have important applications in effective nonlinear wave mixing and generation of high-order optical harmonics.

In more details, we have proposed and investigated a number of novel schemes for transferring population of atomic states to a target quantum state as well as for the creation of arbitrary coherent superposition of meta-stable states of the atoms using frequency chirped laser pulses [1-3]. Coherent control of the created coherences may be performed by variation of the peak amplitudes and phases of the interacting laser pulses. The schemes involve three- and four-level model atoms with lambda and tripod structure of the working levels. The main features of the proposed schemes are their robustness against variations of parameters of the laser pulses and suppression of population of the excited state, in order to minimize the decoherence effect of spontaneous decay of the excited state. We have investigated the applicability of the proposed schemes to inhomogeneously broadened media and media with fast transverse relaxation and have shown that the proposed methods of creation of coherent superposition states may be equally effective in both homogeneously and inhomogeneously broadened media with fast transverse relaxation. In order to model a real experimental situation we have performed numerical simulation of the master equation for density matrix elements of the quantum system taking into account all kinds of relaxation processes [2,3].

We have invented a novel method for phase and amplitude information mapping on populations of atomic meta-stable states which would make long-life storage of information possible [4]. Note that while in EIT-based schemes information writing and storage takes place in the induced coherence, our novel scheme is based on optical information writing and storage in the populations of the meta-stable states that substantially (by orders of magnitude) increases the storage time.

In collaboration with our partners from the group of Prof. M. Fleischhauer from the University of Kaiserslautern, Germany we have analyzed in detail interaction and coherent manipulation of the states of atoms strongly coupled with each other through surface plasmons of a nano-wire. In particular, we have analyzed peculiarities of Dicke sub- and super-radiance in this system and dipole-dipole shift of the atomic levels of such strongly coupled system [5,6]. Note that these recent publications received already more than 60 independent citations.

We have developed a novel scheme of extremely robust creation of maximum coherence between a meta-stable (ground) state and the excited state [7]. Two short laser pulses are used for the coherence creation, one with chirped frequency and the other one with constant carrier frequency. The proposed scheme resembles the one of EIT with a strong frequency chirped laser pulse instead of a weak probe one with constant resonant frequency as in the case of EIT. The obtained coherence is insensitive to variation of the laser parameters in an extremely broad range and allows for creation of the coherence even in the case of tightly focused laser beams with a same phase of the coherence for all atoms of an ensemble. The created coherence is proposed for utilization in coherent preparation of atomic ensembles in different nonlinear optical processes including multi-photon ionization, high-order harmonics and high-order Raman sidebands generation. Such preparation allows drastic (by orders of magnitude) diminishing of the threshold of these processes.

Another field of our research was coherent manipulation of translational states of the atoms by short frequency chirped laser pulses. Here important results were obtained in the theory as well in the experiment in our lab. We have analyzed the behavior of an atomic packet scattered by two crossed standing waves in optical cavities. We have shown that the spatial distribution of the scattered atoms strongly depends on their initial coherent preparation. This property allows visualization of the inner atomic quantum superposition states in the spatial distribution of the atomic wave packet after interaction with the laser field [8,9]. We have performed experiments on coherent acceleration of an atomic cloud of Rb atoms cooled and trapped in magneto-optical trap (MOT), a unique one in Hungary [10,11]. Manipulation of translational states of the Rb cloud is performed by a series of counter-propagating short frequency-chirped laser pulses from diode lasers. We have shown experimentally that the amount of mechanical momentum transferred to atoms from a pair of counter-propagating frequency chirped laser pulses may be substantially increased if the pulses partly overlap in the region of atomic localization. Note, that this experimental result confirmed an effect predicted theoretically in our earlier paper.

An important result have been obtained in the analysis of simultaneous propagation of two strong frequency-chirped laser pulses in an optically thick medium, modeled by an atomic ensemble of lambda-structured atoms. We have shown that there is a matching effect for the Raman-resonant frequency-chirped pulse pair which leads to a quasi-lossless propagation. Furthermore, a well-defined coherent superposition of the atomic ground states is established in the medium as a result of the interaction. In some sense, the obtained effect resembles EIT with two strong pulses with constant frequencies but with substantially different physical mechanism of the matching. While the lossless propagation of the pulses seems similar to the one in the EIT-based schemes, the proposed scheme with frequency chirped pulses produces a much more homogeneous distribution of the coherence at much lower peak intensities of the laser pulses compared to the EIT-based schemes, especially in media with wide Doppler-broadened transition lines [12,13].

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