Dynamical Photonic Structures using Electromagnetically Induced Transparency

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Since the birth of quantum mechanics, interference effects between different paths have represented one of the most fascinating signatures of this theory. Systems of three-level atoms show a remarkable example of this effect. If one couples a long-living metastable state to an excited state by means of a strong laser field and one then probes the ground-excited transition of the dressed atom by means of another weak laser field, one will see no absorption and all the radiation will be transmitted through the atomic medium. This phenomenon is called Electromagnetically Induced Transparency (EIT) and it can be explained in terms of quantum interference between different atomic excitation schemes [1, 2].

An atomic medium under EIT conditions shows a polaritonic dispersion, with three branches near the Raman 2-photon transition between the ground and metastable states. The central polariton is characterized by a huge reduction of the group velocity of light which can be controlled by the intensity of the dressing field. The energy of the incoming radiation then coherently oscillates between electromagnetic field and atomic excitations: this gives rise to a trapping effect which eventually slows down the radiation, as it can be seen in a full quantum treatment [3, 4]. In the limit of a vanishing coupling field, all the radiation energy is stored as a coherent collective atomic excitation [5].

In addition to this, slow-light media open the possibility of going beyond the standard stationary medium optics: one can in fact modulate the dressing laser field in order to manipulate in real time a travelling polariton. This is an example of a dynamical photonic structure [6]. We have theoretically suggested a *photon energy lifter* scheme: a process engineered to change the frequency of a slowly varying photon up to $1 GHz$ by acting on the matter degrees of freedom [7, 8].

During the variation of the dressing field, the perturbation in time of the Hamiltonian can induce a coupling between the different polariton bands. Staying well within the adiabatic regime is then crucial to ensure that the system stays on a specific polariton state. This effect is even more crucial in the presence of defects in the atomic medium and can be exploited in view of non-destructively probing new quantum phases of ultracold gases by means of slow light.

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