Control of Optical Absorption and Dispersion in a Quantum Dot Near a Graphene Monolayer

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An important current problem in nanophotonics deals with the optical properties of quantum systems, like quantum dots and molecules, near plasmonic nanostructures [1]. When a V-type quantum system is placed near a plasmonic nanostructure, then the anisotropic Purcell effect can lead to quantum interference in spontaneous emission [2], which strongly modifies the optical properties of the quantum system [3-5]. Graphene also supports plasmons that leads to quantum interference in spontaneous emission in a nearby V-type quantum system [6]. However, the degree of quantum interference in graphene is small in comparison to metallic and metal-dielectric nanostructures [2] or carbon nanotubes [6] and takes values very close to 0.333 [6].

Here, we study the optical absorption and dispersion properties of a V-type quantum dot (we use a typical system with a ground state and the two left-right circularly polarized exciton states) near a graphene monolayer. The quantum dot interacts with two mutually orthogonal, circularly polarized laser fields with the same frequencies and different phases and electric-field amplitudes, which couple the ground state with the exciton states. We take that both laser fields are weak and calculate the absorption and dispersion spectra of one of the laser fields in the presence of the other field near the graphene monolayer. For the calculation of the absorption and dispersion spectra, we use the density matrix equations for the quantum dot. The spontaneous decay rates that enter the density matrix equations are calculated by electromagnetic simulations and we found that are strongly influenced, specifically enhanced, by the graphene monolayer. The enhancement of the spontaneous decay rates is anisotropic, and it is different for the component of the electric dipole moment parallel to the graphene monolayer from the component of the electric dipole moment perpendicular to the monolayer. This is the anisotropic Purcell effect that leads to quantum interference and coherent coupling between the exciton states of the quantum dot [2-6]. We find that although the degree of quantum interference induced by graphene is small, the existence of quantum interference leads to strong modification of the absorption and dispersion spectra. In addition, we show that one can use the relative electric-field amplitudes and the phase difference of the two laser fields for efficient control of the optical properties of the system. Effects such as switching between complete absorption to optical transparency and gain without inversion are shown for different parameters of the laser fields, only in the presence of the graphene layer and if the effects of quantum interference are accounted for.

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