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Orbital angular momentum swapping of light via biexciton coherence

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ABSTRACT

In this paper we study orbital angular momentum (OAM) transfer between applied lights via biexciton coherence and exciton spin coherence. The quantum dot derives by two control fields that couple to a biexciton state which leads to the destructive interference, while a weak probe light interacts by one of the ground-level exciton transitions. In this scenario, a new weak signal light can be generated via the four-wave mixing (FWM) mechanism in a second ground-level exciton transition. We will study the role of exciton spin relaxation as well as intensity of coupling lights on the exchange efficiency of FWM mechanism. We will also discuss the spatially dependent optical effects via OAM state and azimuthal angle of vortex light.

1. Introductions

It is widely known that optical vortex light can contain orbital angular momentum (OAM), which equates to the vortices of a helical phase $exp(il\varphi)$. The topological charge is represented by the parameter l, which relates to the winding number [1]. Applications for optical vortex light in the OAM state include information technology and quantum communications [2–5]. Numerous research teams have exhaustively investigated the interactions of different quantum systems with optical vortex lights [3,4,6–8]. Several phenomena, such as electromagnetically induced transparency (EIT) [9], electromagnetically induced grating (EIG) [10,11], atom-photon entanglement [12], and the production of novel structure light [13] have been comprehensively studied using optical vortex lights. For instance, Hamedi et al. [9] investigated the azimuthal modulation of the EIT phenomena in a combined-tripod-lambda (CTL) five-level atomic system. They found that the spatially dependent optical transparency can be controlled by varying the OAM number of optical vortex lights. Asadpour et al. [11] also covered the EIG phenomena in a four-level N-type atomic system using composite optical vortex light. They realized that by changing the OAM number and azimuthal angle of the composite vortex light, the diffraction grating could be altered and the probe energy can transfer from zero order to higher orders. In order to convert OAM data from coherent optical vortex light to a freshly produced signal beam, four-wave mixing (FWM) procedures have recently received substantial attention [14–16]. It has been reported that the multi-order fluorescence signals in a Pr^{3+}:Y_2SiO_5 crystal can generate twin beams by the parametric amplification four-wave mixing process and triplet beams by the parametric amplification six-wave mixing (PA SWM) process [16]. Furthermore, it was shown that the OAM state of light can be switched between by two weak optical fields through noise-induced coherence [17]. In another study, OAM was switched from a strong coupling light to a produced signal beam in an atomic medium with three levels of broken symmetry using nonlinear three-wave mixing (TWM) [18]. In contrast to EIT regimes, they have concluded that the Autler-Town splitting (ATS) can improve exchange efficiency. It has also been discussed about how different techniques might be used to transform the OAM state of light in a quantum well waveguide [19]. The exchange efficiency has been studied in the EIT, coherent population trapping (CPT), and spin coherence regimes in the quantum well waveguide. They found that in the spin coherence regime, it is possible to transfer the OAM state of light from coupling light to a generated weak signal light and that the exchange efficiency can be improved. Semiconductor quantum wells and quantum dots nanostructures have potential use in quantum and photonic devices due to their large nonlinear coefficients and band gap tunability [20–26]. Asadpour and his colleagues have

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