Storage and processing of polarization qubits in three-level media

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Abstract

The propagation of electromagnetic pulses in multilevel media has been widely investigated in the last decades. Three level atomic media interacting with two optical fields in a Λ configuration have been among the most considered systems, leading to a large variety of phenomena, such as coherent population trapping, electromagnetically induced transparency or slow light. More recently, the development of quantum technologies for quantum information applications has triggered a renewed attention on the subject. In particular, the propagation of weak pulses in a Λ medium in the presence of strong driving fields has been considered in detail, giving rise to proposals and implementations for quantum state storage and processing.

In this work, we study the propagation of a single-photon pulse whose two polarization components are coupled with the two transitions of a coherently prepared Λ-type three-level medium, i.e., a phaseonium medium, which presents artificial inhomogeneous broadening. We combine some of the non-trivial propagation effects characteristic for this kind of coherently prepared systems with the controlled reversible inhomogeneous broadening (CRIB) technique [1] to propose novel quantum information processing applications [2].

On the one hand, we address the use of the Λ system as a quantum filter. This proposal is based on the fact that part of the incident pulse, the antisymmetric normal mode, which is uniquely determined by the preparation of the atoms in the phaseonium state, propagates without distortion. On the other hand, we show that the orthogonal component associated with the symmetric normal mode can be completely absorbed and retrieved in the backward direction with high efficiency using the CRIB method. In this case, the system can be used to implement a quantum sieve or, considering both orthogonal modes, a tunable polarization qubit splitter. Moreover, we also demonstrate that both field components can be completely and independently absorbed by imposing a position dependent phase coherence in the phaseonium medium. Then, by applying the CRIB technique, both components can be recovered on-demand, thus implementing a quantum memory for polarization qubits.

References

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