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Enhancing entanglement trapping by weak measurement and quantum measurement reversal

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HIGHLIGHTS

- Propose a scheme to enhance entanglement trapping in photonic band gap material.
- Weak measurement and its reversal are performed locally on individual qubits.
- Obtain an optimal condition for maximizing the concurrence of entanglement trapping.
- Entanglement sudden death can be prevented by weak measurement in photonic band gap.

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ABSTRACT

In this paper, we propose a scheme to enhance trapping of entanglement of two qubits in the environment of a photonic band gap material. Our entanglement trapping promotion scheme makes use of combined weak measurements and quantum measurement reversals. The optimal promotion of entanglement trapping can be acquired with a reasonable finite success probability by adjusting measurement strengths.

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1. Introduction

Entanglement is a vital resource for quantum information processing such as quantum computation, quantum metrology and quantum communication [1]. However, realistic quantum systems

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are never completely isolated from the environment. The inevitable interaction between a system and its environment leads to quantum decoherence [2]. For an open multipartite quantum system, decoherence leads to degradation of entanglement and, for some cases, entanglement sudden death (ESD) [3–8]. Thus, tackling decoherence for entanglement protection is a critical issue for quantum information processing. It is therefore of interest to examine the possible schemes that can lead to promotion or preservation of entanglement.

At present, many methods have been proposed to protect entanglement from decoherence and to increase the entanglement such as by entanglement distillation [9–11]. Quantum Zeno effect [12] can also be used to manipulate the decoherence process, but in this method some special measurements should be performed very frequently to freeze the quantum state in order to prevent the degradation of entanglement. We can also deal with decoherence by introducing the decoherence-free subspace [13,14]. However, the decoherence-free subspace requires the interaction Hamiltonian to have an appropriate symmetry, which might not always be present. In most cases, the energy dissipation of individual subsystems of a composite system is responsible for the entanglement degradation. Hence, methods that can prevent the decay of the excited-state population would be applicable. One way widely applied is to place the qubits in a structured environment, say, microcavity [15,16] or in the photonic band gap of photonic crystals [17–19]. In particular, in the photonic band gaps so as to inhibit spontaneous emission, a trapping state is formed and permanent entanglement is observed. This phenomenon, known as "entanglement trapping" [20–22], can lead to effective long-time entanglement protection.

Recently, it is shown that weak measurement and quantum measurement reversal can effectively suppress amplitude-damping decoherence for a single qubit [23–25]. For the case of two qubits, remarkably, the weak measurement and quantum measurement reversal can increase the entanglement, and even can avoid entanglement sudden death [26], see also [27]. For weak measurements [28], the outcome cannot determine the state of the measured system precisely and therefore does not totally collapse the state of the system. Correspondingly partial information is drawn from the measurement yielding a nonunitary, nonprojective transformation of the quantum state. Measurement reversal [29,30] is a probabilistic reversal of a partial quantum measurement, and only certain outcomes of the measurement keep the full information of the initial state and are possible to reverse. The probability of success decreases with increasing strength of measurement, so that the reversible measurement has zero probability for a traditional projective measurement. Probabilistic reversal with a weak measurement has already been demonstrated on a superconducting phase qubit [29], as well as on a photonic qubit [31].

Then, it will be interesting to know whether the method of weak measurement and quantum measurement reversal can be applied to enhance the entanglement trapping in a common photonic band gap. In this article, we show that this method indeed works for this system, and in particular, the entanglement can be trapped in a higher level. The success of this scheme is based on the fact that weak measurement can be reversed and thus the amplitude-damping, the main decoherence in photonic band gap, can be suppressed. We remark that this scheme does not need frequent measurements compared with quantum Zeno effect in suppressing decoherence.

This paper is organized as follows. In Section 2, we describe the model of two qubits interacting with environment of a photonic band gap. We adopt the pseudomode approach to derive their evolution process. In Section 3, we propose the scheme to enhance the entanglement trapping by using weak measurement and quantum measurement reversal. Finally, in Section 4, we present the feasibility of the experimental implementation of this scheme, and provide a brief conclusion.

2. Physical model and dynamics process

We consider a two-qubit system interacting with a common zero-temperature bosonic reservoir. Our chosen specific system consists of two identical two-level atoms (A and B) interacting with a common photonic band gap. The dynamics of two qubits coupled to the reservoir modes can be described by the Hamiltonian

$$H = \omega_0 \sigma_+^A \sigma_-^A + \omega_0 \sigma_+^B \sigma_-^B + \sum_k \omega_k a_k^\dagger a_k + \left[(\sigma_+^A + \sigma_+^B) \sum_k g_k a_k + \text{h.c.} \right], \tag{1}$$

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