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A scheme for generation of multi-photon GHZ states with cross-Kerr nonlinearities

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Abstract. With the help of cross-Kerr nonlinearities and homodyne measurement, we propose a scheme to generate three-photon GHZ states. Under the same framework, multi-photon GHZ state can be also realized. Compared with the previous ones, our scheme is much more simplified and lower errors. Moreover, only some linear elements and weak cross-Kerr mediums are employed, which make our scheme more feasible in the experiment.

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Key words: GHZ state, cross-Kerr nonlinearity, quantum entanglement

1 Introduction

Entanglement is an important resource of quantum computation and quantum information processing (QIP) [1-6]. It is one of the most important ingredients of various intriguing phenomena [7-9]. The property of entanglement has been investigated both in bipartite systems [10, 11] and multipartite systems[12,13]. At present, multipartite entanglement has attracted increasing interest because of its superiority during QIP. For example, the Greenberger-Horne-Zeilinger (GHZ) state is an important class of multipartite entangled states. GHZ state maximally violates Bell-type inequalities; the mutual information of measurement outcomes is maximal; it is maximally stable against (white) noise, and one can locally obtain an EPR state shared between any two of the three particles from a GHZ state with unit probability. Additionally, GHZ state can be employed as a quantum channel for quantum key distribution [14] and quantum secret sharing [15] and so on. In recent years, there has been much progress on the experimental generation of highly entangled states. Five-photon entanglement has been observed and used to

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realize open-destination teleportation [16]. Six-particle GHZ states and eight-particle W states have been demonstrated in ion traps [17, 18].

Consequently, preparation of GHZ states have been attracted by many researchers. For example, Huang *et al.* have generated a three-qubit GHZ state by only one-step quantum operation [12]. Yang [19] provided a preparation of N-qubit GHZ entangled states in cavity QED, and Sharma *et al.* [20] have generated GHZ state in a quantum dot molecule, and so on.

Recently, as possibility of long-distance transmission with relatively low decoherence and quite simple manipulation of the states with linear optics, much attention has been paid to optical cross-Kerr medium, and this cross-Kerr effect involves two optical field modes, one is called signal mode and the other probe mode. A weak interaction between photons in these two modes is induced by passing them through nonlinear Kerr media. Cross-Kerr nonlinearity provides a good tool to construct the quantum non-demolition detection (QND), which has the potential of being able to condition the evolution of our system without the necessity of destroying the single photons [21-23], and which, with a cross-Kerr medium and a coherent state, can be used for checking the parity of the polarizations of two photons, operating as a controlled-Not (CNOT) gate [21], and analyzing the Bell states [24]. Recently, cross-Kerr nonlinearity has been used for many researches, for example, the generation of cluster state [25,26] and Dicke states [27].

The Hamiltonian of cross-Kerr nonlinear media can be described by $H_{QND} = \hbar\chi\hat{n}_p\hat{n}_s$. The symbol $\hat{n}_p(\hat{n}_s)$ denotes the number operator for the mode probe (signal), and $\hbar\chi$ is the coupling strength of the nonlinearity, which is determined by the property of the material used. Initially, if we consider the signal state have the form $|\varphi\rangle_s = a|0\rangle_s + b|1\rangle_s$, the probe beam is in a coherent state $|\alpha\rangle_p$, then the cross-Kerr interaction causes the combined signal-probe system to evolve as

$$\psi(t)_{out} = U_{ck}|\varphi\rangle_s|\alpha\rangle_p = e^{(iH_{QND}t)/n}(a|0\rangle_s + b|1\rangle_s)|\alpha\rangle_p = a|0\rangle_s|\alpha\rangle_p + b|1\rangle_s|\alpha e^{i\theta}\rangle_p \tag{1}$$

where $\theta = \chi t$ and t is the interaction time. We observe immediately that the Fock state $|n\rangle_s$ is unaffected by the interaction with the cross-Kerr nonlinearity but the coherent state picks up a phase shift directly proportional to the number of photons n_s in the signal $|n\rangle_s$ state. If we could measure this phase shift we could then infer the number of photons in the signal mode. This can be achieved simply with a homodyne measurement and conditional on the results of the homodyne measurement [24]. In our scheme, we employ the model proposed by Guo *et al.* [25](as shown in Fig. 1) to realize three-photon GHZ state.

Obviously, our scheme also possesses the advantages as well as theirs, and our scheme can be easily scaled to multi-photon GHZ state, which may be useful for quantum computation and quantum communication.

The paper is arranged as follows: In Section 2, the model is introduced and a scheme is proposed for the generation of the GHZ state of three photons. In Section 3, the scheme in Section 2 is scaled to N-photon GHZ state. The conclusion and the discussion will be shown in Section 4.