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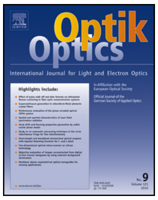

Short note

A scheme for efficient construction of large scale cluster state

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ABSTRACT

We present a scheme to efficiently construct large scale cluster state. In this scheme, the control-phase gate is deterministic, which is useful in the realization of scalable one-way quantum computation.

1. Introduction

There have been many kinds of models to realize quantum computation [1], among which one-way quantum computation (OWQC) is a special one. Proposed by Raussendorf and Briegel in 2001 [2,3], OWQC belongs to the measurement based quantum computation, which uses a particular multi-qubit entangled state—the cluster state—as the central physical resource and the whole computation is driven by feed-forward and a sequence of single qubit measurements. It was shown in Refs. [2,3] that OWQC is universal because any quantum networks can be simulated on the one-way quantum computer. OWQC is attractive due to the good scalability and feasibility in experimental realization. In the last few years, OWQC has attracted much attention and a lot of schemes on it have been proposed [4–6], some of which have been demonstrated in experiment [7].

OWQC can be implemented on many kinds of physical systems, such as quantum dot [8], ion trap [9], NMR [10], Josephson junction [11], photon [12], etc., among which ion trap is considered to be a very promising candidate. In this paper, we take ion trap as an example, and we combine the idea of OWQC [2] and ion trap [13] with the aim to implement OWQC on ion trap.

There have been many different types of ion trap. In early days, linear Paul trap was used to trap a certain number of ions. The main problem of this method is that as the qubit number increases, it becomes more and more difficult to address a single qubit because the distance between the ions becomes smaller and smaller. Later, Cirac and Zoller presented a quantum computer scheme based on ion trap, in which the whole system was a two-dimensional array of ion trap [14]. Compared to Paul trap, the scalability of this ion trap array was much better. The distance between the ions was long enough and hence the influence from each other could be neglected. The coherence performance between any two qubits could be realized via a intermediary qubit-called the head ion. During the performance of two-qubit gates, the head ion needed to be moved from one ion to another to transfer the interaction between any two ions, which might be a great challenge in experimental realization.

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If we want to implement OWQC on ion trap array, the problem mentioned above must be considered. In this paper, we present a new scheme to overcome this problem. In this scheme, we use the photons emitted by the auxiliary ion traps to transmit the interaction between any two distant qubits.

2. The background knowledge

We start with the concept of cluster state [2], which serves as the central resource in OWQC. The cluster state is defined as a coeigenstate of all the operators $A_i = X_i \prod_j Z_j$ of a given lattice geometry, where i denotes an arbitrary lattice site and j runs over all the nearest neighbors of the site i. The X_i and Z_j are Pauli operators. In OWQC, cluster state is the central resource and information is written onto the cluster, processed, and read out from the cluster by single-qubit measurements only. The cluster state thereby serves as a universal substrate for any quantum computation. According to Ref. [3], cluster state can be created efficiently in any system with a quantum Ising-type interaction between two-state particles in a lattice configuration. More specifically, to create a cluster state, the qubits are at first prepared individually in a state $|+\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$, and then brought into a cluster state by performing controlled phase flip (CPF) gates between any qubit and all its neighbors.

3. The implementation of ion-photon mapping

It can be seen that in the preparation of cluster state, the performance of CPF gate is a critical step. If the CPF gate can be performed deterministically, then efficient OWQC can be realized. Now the question is: how to perform a CPF gate between any two ions? In the ion trap array model, the distance between any two ions is long enough and the influence from each other can be neglected. However, it might be very difficult to make an ion interact directly with others. In Ref. [14], an intermediary qubit was used to transmit the interaction. We know that it might be a great challenge in experiment. In this paper, we will use photon as the intermediary qubit to construct the connection between any two neighbouring ions (in fact, the connection between any two remote ions can be constructed this way). This method is usually called ion-photon mapping [13]. And here we will use this idea to construct a 2D cluster state. First, we need an ancillary ion, which must be close enough to the logic ion so that we can make them interact with each other directly. To do so, we put the ancillary and logic ion into one trap. And the whole setup is illustrated in Figs. 1 and 2.

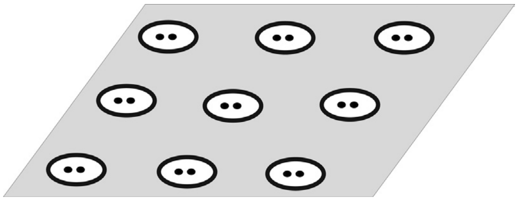

Fig. 1. A 2D ion trap array with 2 ions in each micro-trap. The distance between any two traps is long enough and the interaction between them may be neglected. Local operation may be made between the ions in the same ion trap.

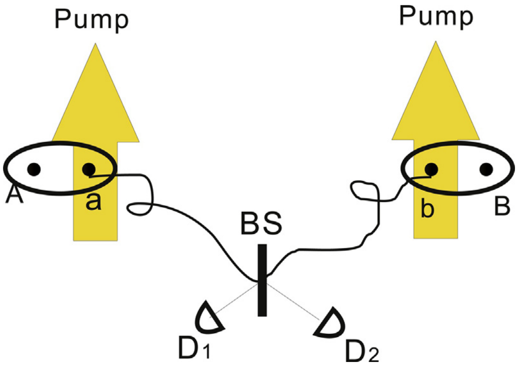

Fig. 2. The realization of CPF gate between any two qubits, say, A and B. 1. Entangle the two ancilla ions a and b by pumping both of them to exited states. The resulting spontaneously emitted photons from these two ions are directed into single-photon detectors through fibers for a Bell-type collective measurement. 2. Perform an adjoint measurement on the logic and ancilla qubits. 3. Perform a CPF gate on b and B. 4. Make a σ_x measurement on qubit b.