Hybrid approach for optical quantum computing

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Abstract: We describe a hybrid approach to quantum computing in which linear optical elements are used to perform the logic operations while relatively small nonlinear effects are used to avoid the need for ancilla photons.

OCIS codes: (200.4560) Optical logic

In many respects, single photons are the ideal choice of qubits for quantum information processing, since optical fibers can be used to make connections between devices or for long-distance transmissions. Knill, Laflamme, and Milburn [1] have shown that the necessary quantum logic operations, such as a controlled-NOT (CNOT) gate, can be implemented using linear optical elements, additional photons (ancilla), and post-selection based on the results of measurements made on the ancilla. Here we consider a hybrid approach that combines the best features of linear optics techniques and more conventional nonlinear approaches. In particular, we show that relatively small nonlinearities can be used to eliminate the need for the ancilla photons.

An example of a linear optics approach is the CNOT gate [2] shown in Fig. 1. It consists of nothing more than two polarizing beam splitters, a polarization analyzer and detector, and a single ancilla photon. This device is expected to perform the correct logical operation whenever a photon is detected in each of the detectors, which occurs with a probability of ¼. The experimental results from such a device are shown in Fig. 2.

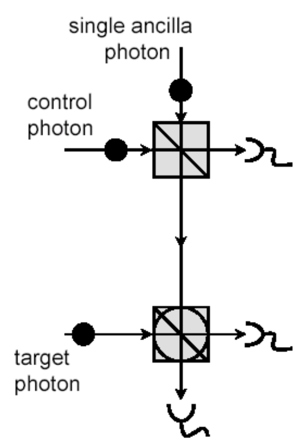

Fig. 1. Controlled-NOT logic gate implemented using two polarizing beam splitters and an ancilla photon.

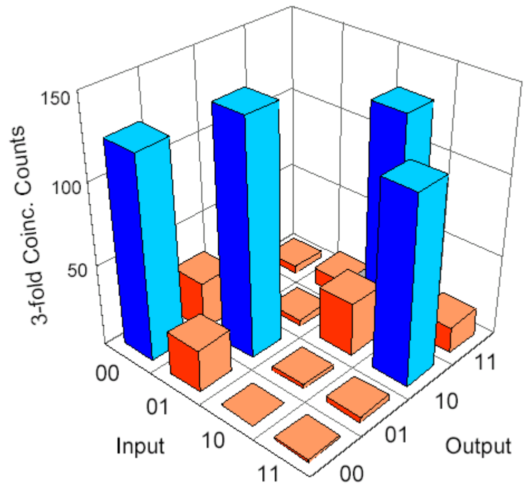

Fig. 2. Experimental results from an optical CNOT gate in the coincidence basis.

The probability of a successful operation of these devices can be made arbitrarily close to unity in the limit of a large number N of ancilla. However, the generation of the ancilla in the necessary entangled states may require a large amount of additional resources [3].

We will describe a new approach [4] in which small nonlinearities can be combined with linear optical techniques to eliminate the need for the ancilla. This avoids the additional resources that would have been required to generate the ancilla and it may have other advantages as well. A hybrid approach of this kind combines the best features of both linear and nonlinear techniques while avoiding many of the challenges associated with either approach alone.

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3. J.D. Franson, M.M. Donegan, and B.C. Jacobs, quant-ph/0303137.
4. J.D. Franson, B.C. Jacobs, and T.B. Pittman, submitted to Nature.