Deterministic Generation of a Cluster State of Polarization Entangled Photons

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We report on the first deterministic generation of a highly entangled, one dimensional state of photons [1]. The quantum state generated, called a "cluster state," is an important resource for quantum information processing. Specifically, it is a platform for measurement based quantum computing [1,2], which utilizes cluster states in conjunction with single qubit measurements.

Measurement based schemes are among the most fault-tolerant quantum computing architectures [2]. They are highly resilient to qubit losses [3], and the use of photon polarization as a qubit facilitates high fidelity single qubit measurements. These advantages make photonic cluster states excellent platforms for quantum computing. Constructing a photonic cluster state poses a formidable challenge. A deterministic source generating this state is the most resource-efficient solution to this challenge, superior to interferometric methods [4] utilizing sources of single photons or even entangled photon pairs [5].

Our demonstration follows the proposal of Lindner and Rudolph [6], which uses repeated optical excitations of an electronic spin confined in a single semiconductor quantum dot. We use a dark exciton [7,8], instead of the electron, and demonstrate a more practical realization of the proposal of Ref [6]. The optical recombination of the excited dark exciton results in entanglement between the emitted photon polarization and the dark exciton spin. After recombining, the dark exciton spin state continues to precess and timed re-excitation [7,8] leads to another photon emission, whose polarization state is entangled with that of the previous photon and the spin of the dark exciton. Repeating this procedure generates a one dimensional string of polarization entangled photons, which remains entangled even if the spin state of the dark exciton is traced out and/or photons from the strings are lost [3, 4, 6]. Using such a string, cluster states capable of running arbitrary quantum algorithms can be efficiently generated from, for example, two coupled quantum dots [9]. Our demonstration presents a breakthrough in quantum technology: we realize a deterministic photonic source, greatly reducing the resources needed for linear optics based quantum information processing.

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