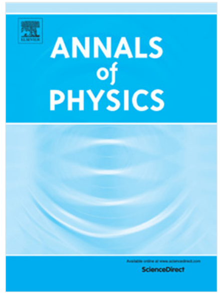

Heralded quantum gates for atomic systems assisted by the scattering of photons off single emitters

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Heralded quantum gates for atomic systems assisted by the scattering of photons off single emitters

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Quantum logic gates are essential in quantum information processing. Here, we propose three heralded schemes for universal quantum gates, including the controlled-NOT, Toffoli, and Fredkin gates on atomic systems, assisted by the scattering of photons off single emitters in one-dimensional waveguides. Interestingly, our schemes can turn faulty scattering processes of photons off atoms into the detection of the photon polarization. Furthermore, auxiliary atomic qubits are not needed and only one photon medium is adopted. With current technology, we discuss the feasibility of these universal quantum gates, concluding that they are feasible and scalable in solid-state quantum systems. We provide a different method for realizing universal quantum gates, and it may be useful in quantum information processing in the future.

Keywords: Heralded quantum gates; one-dimensional waveguides; atom-waveguide systems; scattering property

I. INTRODUCTION

Quantum logic gates are the key components in quantum computing. It has been proven that two-qubit entangling gate together with single-qubit operations can implement any n-qubit unitary operation [1–3]. The controlled-not (CNOT) gate is a universal two-qubit gate and attracts much attention. The “small-circuit” structure and optimal synthesis for two-qubit systems have been well studied [4–7], while it is quite complex for multiqubit systems. In the domain of multiqubit gates, three-qubit Toffoli and Fredkin gates are universal and have attracted much attention[8]. In experiment, it needs at least six CNOT gates to construct a Toffoli gate and requires two CNOT gates and three controlled-$\sqrt{NOT}$ gates for synthesizing a Fredkin gate. Therefore, it is meaningful to find efficient schemes for implementing a Toffoli gate and a Fredkin gate directly. Moreover, quantum logic gates play an important role in complex quantum algorithms (such as the famous Shor algorithm [9] and Grover/Long algorithm [10, 11]), error correction [12], phase estimation algorithm [13], and fault tolerant quantum circuits [14].

In the last decades, there are some important proposals for implementing universal quantum gates based on various physical systems, such as superconducting qubits [15, 16], nuclear magnetic resonance [17–20], photons [21–26], quantum dots [27–32], diamond nitrogen-vacancy center [33–36], moving electrons [37], and so on. For example, in 2001, using only beam splitters, phase shifters, single-photon sources, and photon-detectors, Knill *et al.* [21] presented an efficient scheme for photonic quantum computation. In 2008, with a charged quantum dot inside a microcavity, Hu *et al.* [38] put forward a meaningful platform for quantum information processing, which is based on giant circular birefringence and giant Faraday rotation. In 2012, Romero *et al.* [39] proposed a realistic scheme for constructing an ultrafast two-qubit controlled-phase gate, with state-of-the-art circuit quantum electrodynamics technology. Recently, Wei and Deng constructed some quantum circuits for universal quantum gates on electron spins, by utilizing quantum dots [31] or nitrogen-vacancy centers [34]. Remarkable progress has been made on quantum computation and quantum information processing in both theory and experiment [40–43].

Different from the works mentioned above, our schemes for universal quantum gates are based on the scattering of single-photon off emitters in a one-dimensional (1D) waveguide, which has revealed some interesting features of photon transport [44, 45]. In this regime, the so-called Purcell regime [46], the coupling between the emitter and the waveguide is stronger than the atomic decay rate, but weaker than the waveguide loss rate. Such a 1D waveguide can be realized by superconducting transmission line [47], a line defect in photonic crystals [48] and a conducting nanowire [49], which generates a strong coupling between the emitter and the waveguide modes. Until now, many schemes have been proposed to study the transport property of photons scattering off emitters in 1D waveguides, such as controllable two-level system in the coupled-resonator waveguide [50], coupling a Λ-type emitter to a Sagnac interferometer [51], and using two waveguides to control the transport of the single-photon [52]. Specifically, when a resonant single photon is incident upon a two-level emitter, the spontaneously emitted photon interferes with the

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