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All-optical generation of tensor network states via nonlinearity or post-selection

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Abstract

We devise two loop-based all-optical schemes for generating entangled tensor network states of light. The first scheme is based on embedding a parametric downconversion nonlinearity into an optical loop and enables the robust generation of W and GHZ states, and the use of these states in quantum simulation. The second scheme generates one-dimensional tensor network states including GHZ and cluster states via post-selection using only linear optics, thereby promising unmatched rates and fidelities of generated states.

Tensor network (TN) states efficiently capture the entanglement structure of a wide class of important physical states, such as the ground and thermal states of local Hamiltonians and states that are important in quantum computation, communication and metrology [1, 2]. In the TN states parameterisation, the description of a state requires only a polynomial number of parameters in the number of subsystems. The generation of one-dimensional TN states in the lab could open the possibility of realising novel quantum-enhanced metrology and quantum communication tasks. Moreover, higher dimensional TN states are a useful resource for quantum simulation and computation as the computational effort for simulating these grows quickly in the number of subsystems. Therefore, the experimental generation of one and higher dimensional TN states and their use for quantum information processing is of considerable interest.

Current experimental procedures for generating and manipulating TN states focus on spatial modes of light, but the required experimental resources in these procedures typically increase rapidly with the required state size. Using the temporal modes of light or time bins overcomes this restriction by providing an infinite-dimensional Hilbert space that can be controlled with constant experimental resources. Existing proposals for temporal-mode photonic TN states rely on strongly coupling light to a single atom trapped inside a cavity [3]. While these methods allow the generation of arbitrary 1D TN states whose entanglement is limited only by the number of accessible atomic states, the experimental implementation of these schemes requires two challenging conditions to be met: firstly, the cooling and localising of the atom, and secondly the strong coupling between the atom and the light emitted from the cavity. Here we overcome these challenges in the form of two all-optical schemes for generating TN states of light in one and higher dimensions.

The first scheme [4] exploits the well established optical process of parametric down conversion in order to build entanglement in the generated states, which include W and GHZ states. We demonstrate that implementations of this scheme with current optical devices are capable of determining the ground state properties of the spin-1/2 Heisenberg model and these implementations are demonstrated to be robust against realistic losses and mode mismatch.

We also present a new scheme that uses only linear optics and post-selection to generate GHZ and cluster states in the temporal modes of light. As the optical setup only requires linear optical components, which allow for low-loss operation, this scheme can be used for the generation of long strings of entangled states at unmatched rates and fidelities.

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