Programming of a Reconfigurable Integrated Optical Interferometer with a Complex Structure to Prepare a Maximally Entangled Three-photon Quantum State

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The preparation of a maximally entangled three-qubit GHZ state based on a universal six-port integrated optical interferometer created using femtosecond laser writing has been experimentally demonstrated. The processes of state generation and its full quantum tomography were carried out inside a single waveguide structure.

Key words: programmable integrated circuits; dual-rail photonic qubits, post-selected entangled states.

Integrated photonics gives the opportunity to develop miniaturized and tunable chips that perform linear optical transformations over input radiation – light, which makes it possible to process both classical and quantum signals. Of particular interest are universal multiport interferometers, which are theoretically capable of implementing arbitrary unitary transformations. Such devices are promising for use in quantum computing [1]. However, modern interferometer designs are subject to manufacturing imperfections, which reduces their effectiveness and limits their implementation in practical systems.

Here we present an experimental study of a complex interferometric structure (Fig. 1a), which uses alternating multiport beam splitters and phase shifts to provide increased tolerance to potential imperfections in the structure.

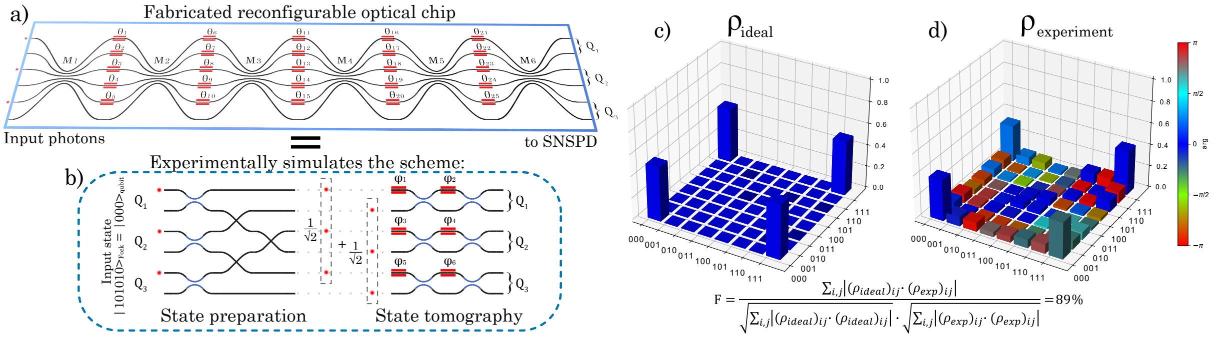

Fig. 1. a) A schematic of the waveguide structure of the six-port chip under study, which is capable of implementing an equivalent transformation to the structure shown in (b). b) A passive interferometer that can prepare the GHZ state of three photons, and three MZIs for the state tomography. c) The ideal density matrix of the GHZ state and the experimentally obtained one (d).

We have manufactured a six-port integrated optical chip based on the [2] architecture using femtosecond laser printing and developed its analytical model. All parameters of the chip, including thermo-optical heaters crosstalk and mode-mixers unitary matrices, were experimentally determined using the proposed earlier calibration technique [3] with a correlation coefficient of 0.99. To demonstrate the versatility of the manufactured interferometer, we implemented a transformation equivalent to the interferometric structure from [4] (Fig. 1b), generating a postselected three-photon GHZ state in a logical basis:

$$|\psi\rangle = 1/\sqrt{2}\left(|000\rangle_L + |111\rangle_L\right) = 1/\sqrt{2}\left(|101010\rangle_{Fock} + |010101\rangle_{Fock}\right). \quad (1)$$

The qubits were implemented using a dual-rail encoding scheme, where the logical basis states were encoded by the spatial distribution of individual photons between a pair of adjacent waveguides.

It is important to emphasize that the universality of our reconfigurable interferometer allowed for the simultaneous generation of entangled states and projective measurements in specified bases, within a single optical chip, without the need for additional interferometric components. A quantum dot with spatial multiplexing was used as the source of single photons [5]. As a result of this experiment, the density matrix of a three-qubit quantum state was measured. The fidelity of the measured state with the ideal GHZ state density matrix appeared to be 0.89 (Fig. 1c and d).

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