Large-scale reconfigurable continuously-coupled integrated optical circuits for photonic quantum information processing

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Abstract: Quantum photonic platforms are emerging as the most promising to prove a computational advantage. Here we present a novel reconfigurable integrated interferometer for large scale implementation of Boson Sampling based on the continuous-coupling of waveguides.

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1. Introduction

One of the advantages of photonic platforms in quantum information processing is the possibility to decompose any unitary transformation of single- and multi-photon states in a sequence of elementary linear optical units. In literature, two universal and equivalent schemes have been proposed to realize any transformation by mean of beam splitters and phase shifters [1, 2]. They have found straightforward experimental implementations in integrated photonic devices, which offer in addition the ability to reconfigure the circuit by exploiting tunable phase shifters. The limitations of the discrete decomposition regard the high sensitivity to fabrication imperfections and photon losses. The main reason of such unfavorable behaviors, that become crucial for the realizations of large-scale instances of photonic circuits, is the scaling of the optical elements and of the circuit depth required to realize m-port interferometers. Nowadays, photonic Boson Sampling and, more recently Gaussian Boson Sampling, require complex optical circuits and high degree of reconfigurability to prove a quantum computational advantage [3, 4]. This works aims at finding and investigating alternative decompositions that mitigate the current limitations of integrated devices. A possible solution is given by the continuous coupling model of radiation among waveguides arranged in 1D or 2D lattices. In this approach the geometry of the lattice determines the Hamiltonian of the system. The unitary transformation that represents the operation of the optical circuit derives from the integration of the Hamiltonian over the interaction length, i.e. the circuit's portion in which the waveguides exchange the radiation. This architecture results in higher compactness, less circuit depth and photon losses compared to the previous mentioned decompositions [5]. In the following we illustrate the performances of such devices for implementing experimentally a large number of random extracted unitary transformations and for performing Boson Sampling. Then, we discuss a possible procedure to obtain a full programmable photonic processors based on the technology presented in this work.

2. Results

In Fig1 we report the integrated device that is madeby 32 continuously-coupled single-mode waveguides arranged in a 3D layout that display in the cross section a 8×4 triangular lattice. The chip has been fabricated thanks to the 3D capabilities of the femto-second laser writing technique [6]. The waveguide positions are randomly modulated from the lattice's position along the propagation coordinate z. These modulations are necessary to introduce randomness in the resulting the circuit transformation, which make the device suitable for a Boson Sampling experiment. The chip is equipped with 16 resistive heaters that have been patterned with the same laser-writing technology on the gold film placed on the top surface of the device. The dissipated power induced by currents applied to the resistors produces thermal gradients in the substrate and thus locally changes the refractive index of the waveguides. This allows to change dynamically the transformation U implemented in the integrated device. We have tested the reconfigurability of the system by comparing the sub-matrix reconstructed by injecting