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3D photonic quantum chips and quantum simulation

Hao Tang[1], Yao Wang[1], Yuan Chen[1], Jun Gao[1], and Xian-Min Jin[1],
[1] School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, China

Abstract

Photon can be generated, manipulated and detected comparatively easier than other quantum particles, and can be transferred in a long distance without coupling with environment. Photon therefore is a promising candidate for realizing quantum information processing. However, the limitations of bulk optics have become key bottlenecks preventing quantum technologies from realizing in practice. Alternatively, integrated photonics provides an elegant way to scale up quantum systems. In this talk, we will present our endeavors recently delivered in Shanghai Jiao Tong University on femtosecond laser direct writing of 3D photonic quantum chips and the applications in quantum computing and quantum simulation.

Applying quantum simulation to real physical and computational problems has been a main thought of quantum information science since Feynman raised the concept of quantum computing. Quantum simulation is to use the Hamiltonian of a quantum system to simulate the Hamiltonian of the target system. The mapping needs not to be highly strict, but only to be able to produce some expected features of the target system, and even some qualitative results instead of full quantitative details are very valuable. In the two major genres of quantum computing, the universal (or digital) one and the analog one, the former is more prone to the influence of errors and rely more heavily on error corrections. On the other hand, the analog quantum computing has the advantages of the lower resource requirements and the higher tolerance level to imperfections of the quantum system.

Photons propagating through coupled waveguide arrays can be described by the Hamiltonian:

$$H = \sum_{i}^{N} \beta_i a_i^\dagger a_i + \sum_{i \neq j}^{N} C_{i,j} a_i^\dagger a_j \tag{1}$$

where β_i is propagating constant in waveguide i, $C_{i,j}$ is the coupling strength between waveguide i and $j$that mainly depends on waveguide spacing can be obtained via a coupled mode approach. By using femtosecond laser direct writing technique, we are able to map the Hamiltonian into a 3D photonic chip. We perform analog quantum computing [1, 2] and quantum simulation [4] by Hamiltonian engineering through freely tuning β_i and $C_{i,j}$, as well as by introducing high dimensions. However, it is still very challenging to precisely characterize and detect 3D photonic quantum chips composed of thousands of modes, which might be solved by quantum machine learning and quantum imaging. address The machine learning of quantum states [5] and quantum imaging [6].

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