A large-number and multilayer quantum walk using silicon nano-photonic chip

Wan, L. X.; Yan, Li Bin; Huang, Jian Guo; Zhang, Gong; Kwek, L. C.; Fitzsimons, J.; Chong, Yi
Dong; Gong, J. B.; Szameit, A.; Zhou, X. Q.; Yung, M. H.; Jin, X. M.; Su, X. L.; Ser, Wee; Gao, Wei
Bo; Liu, Ai Qun

2018

Wan, L. X., Yan, L. B., Huang, J. G., Zhang, G., Kwek, L. C., Fitzsimons, J., . . . Liu, A. Q. (2018).
A large-number and multilayer quantum walk using silicon nano-photonic chip. 2018
Conference on Lasers and Electro-Optics (CLEO): QELS_Fundamental Science, FM1G.2-.
doi:10.1364/CLEO_QELS.2018.FM1G.2

<https://hdl.handle.net/10356/138870>

https://doi.org/10.1364/CLEO_QELS.2018.FM1G.2

© The Author(s). All rights reserved. This paper was published by Optical Society of America (OSA) in 2018 Conference on Lasers and Electro-Optics (CLEO): QELS_Fundamental Science and is made available with permission of the author(s).

Downloaded on 26 Apr 2023 22:21:10 SGT

A Large-Number and Multilayer Quantum Walk using Silicon Nano-photonic Chip

L. X. Wan^{1*}, L. B. Yan^{1*}, J. G. Huang¹, G. Zhang¹, L. C. Kwek^{2†}, J. Fitzsimons^{3†}, Y. D. Chong⁴, J. B. Gong⁵, A. Szameit⁶, X. Q. Zhou⁷, M. H. Yung⁸, X. M. Jin⁹, X. L. Su¹⁰, W. Ser¹, W. B. Gao⁴ and A. Q. Liu^{1†}

¹School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore

²Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore

³Engineering Product Development, Singapore University of Technology and Design, Singapore

⁴School of Physical & Mathematical Sciences, Nanyang Technological University, Singapore

⁵Department of Physics and Centre for Computational Science and Engineering, National University of Singapore, Singapore

⁶Institut für Physik, Universität Rostock, D-18051 Rostock, Germany

⁷State Key Laboratory of Optoelectronic Materials and Technologies and School of Physics, Sun Yat-sen University, Guangzhou, China

⁸Institute for Quantum Science and Engineering and Department of Physics, Southern University of Science and Technology, Shenzhen, China

⁹State Key Laboratory of Advanced Optical Communication Systems and Networks, Institute of Natural Sciences & Department of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai, China

¹⁰State Key Laboratory of Quantum Optics and Quantum Optics Devices, Institute of Opto-Electronics, Shanxi University, Taiyuan, China

* Equal contribution

†Email Address: cqtklc@gmail.com, joe.fitzsimons@quantumlah.org, eaqliu@ntu.edu.sg

Abstract: We experimentally demonstrated 2D quantum walks in a Si₃N₄ chip and study how different parameters affect light distribution. Such scalable quantum device will have a promising application in the field of quantum communication and simulation.

OCIS codes: 270.0270 (Quantum optics), 220.4241 (Nanostructure fabrication)

1. Introduction

Quantum walks (QWs) demonstrate the behavior of particles with superposition and interference in the quantum regime, experiencing superior transport property than classical random walks [1]. Current experimental implementation of QWs rarely demonstrate the control of coupling strengths and widely used laser writing technology have relatively low repeatability. Here, we proposed and fabricated a 3-layer Si₃N₄ QW lattice based on the mature silicon photonic technologies and studied how the coupling strengths can be impacted and manipulated to realize the control of photons. It will pave the way for further realization of QW based simulation tools [2].

Figure 1. Schematic of (a) 1D QW with single layer waveguides; (b) 2D QW with multilayer waveguides; (c) a multilayer QW pattern.

2. Theoretical Model and Design

Figure 1. (a) shows the schematic of a 1D QW in a single layer waveguide lattice. The coherent light is injected into one mode and couples to the nearest modes. Its Hamiltonian can be expressed as

$$H = \sum_{i=1}^n \beta a_i^\dagger a_i + C a_i^\dagger a_{i+1}$$

Where β is the propagation constant, C is the coupling strength and $a_i^\dagger a_i$ are the creating and annihilating operators. Figure 1. (b) shows the schematic of a 2D QW in a multilayer waveguide lattice. The coherent light is injected into the center mode and will couple to the vertical and horizontal modes. Its Hamiltonian is

$$H = \sum_{i,j=1}^{m,n} \beta a_{i,j}^\dagger a_{i,j} + C_H a_{i,j}^\dagger a_{i+1,j} + C_V a_{i,j}^\dagger a_{i,j+1}$$

Where C_H and C_V are the horizontal and vertical coupling strengths. By controlling the C_H and C_V , the system can form some specific pattern and function as an efficiency simulator to study the particle behavior in a 2D periodic potential field. The Figure 1. (c) shows the symmetric coupling pattern at vertical and horizontal directions.

3. Results and Discussions

Figure 2. (a) shows the microscope photo of the fabricated 1D QW waveguides. It has 41 modes and coherent light can be injected into the central mode. We fabricated a series of chips with different coupling lengths and pattern in Figure 3. (a) was captured at $5\ \mu\text{m}$ and $45\ \mu\text{m}$. We could see the light spread to the side and formed a ballistic pattern, which distinguished itself from the classical random walks.

Figure 2. Microscope photo of fabricated (a) 1D QW lattice with 41 modes; (b) 2D QW lattice.

Figure 2. (b) is the TEM image of multilayer waveguides cross section. Each waveguide is $900\ \text{nm} \times 400\ \text{nm}$, horizontal gap is $700\ \text{nm}$ and vertical gaps are different based on fabrication. The input laser light is injected into the center mode of the top layer then coupled to mid layer and bottom layer. As seen in Figure 3. (b), we input the $1550\ \text{nm}$ TE coherent light and compare the normalized intensity distribution with different gaps at the coupling length of $35\ \mu\text{m}$. The green columns are the top layer, the light was injected into the center mode of this layer, the red columns are the middle layer and the blue columns are the bottom layer. The outlined columns are the simulation results. We can see the light spreads to the side of the lattice. The effect of wavelength and light modes on the coupling strength are also studied carefully, the results can be seen from Figure 3. (c), (d) below, the vertical coupling will be more obvious with $1600\ \text{nm}$ light and TM light mode.

Figure 3. (a) Experimental distribution of QW at coupling length of $5\ \mu\text{m}$ and $45\ \mu\text{m}$; (b) Intensity distribution at coupling length of $35\ \mu\text{m}$ with different vertical gaps. The $1550\ \text{nm}$ coherent TE light was injected into the center mode of top layer (green). The colored columns represent the experiment results, green for top layer, red for mid layer and blue for bottom layer. The outlined columns represent the simulation results. (c) Intensity distribution with $1550\ \text{nm}$ and $1600\ \text{nm}$ TM mode light; (d) Intensity distribution with TE and TM modes. The $1550\ \text{nm}$ coherent light was injected.

4. Summary

In conclusion, a multilayer QW using silicon photonic based optical circuit has been demonstrated. This system has the advantage to be scalable relying on current silicon photonic technology and coupling strength controllable. It will be a powerful simulator to study the property of molecules, particle in a periodic fields and so on.

This work was supported by Singapore National Research Foundation under the Competitive Research Program (NRF-CRP13-2014-01).

5. References

- [1] H. Tang, X. F. Lin, X. M. Jin, et al. (2017). Experimental Two-dimensional Quantum Walk on a Photonic Chip. *arXiv preprint arXiv:1704.08242*.
- [2] A. Schreiber, A. Gábris, P. P. Rohde, et al. (2012). A 2D quantum walk simulation of two-particle dynamics. *Science*, 336(6077), 55-58.