Integrated Photonics Chip for Quantum Key Distribution

Silicon photonics technology exploits silicon as an optical medium to build versatile systems. It has a huge and growing market in the field of telecommunication, sensing, display, biomedical instrument, etc. The flexible modularity and stability of silicon photonic systems provide an unprecedented opportunity for next-generation quantum key distribution (QKD). This doctorate thesis focuses on the design, simulation, fabrication and testing of integrated silicon photonic system. Crucial components for silicon photonics applications are designed and tested, such as grating coupler, polarization beam splitter, polarization rotator, modulator, detector, ring resonator, interferometer, etc. Using the available components, quantum key distribution system using GG02 protocol is also demonstrated.

The thesis focused on three parts, the passive components, the active components and the implementation of QKD system. For the passive components, the 2-dimensional grating coupler can be used as a path-polarization mode converter. The polarization beam splitter can be used to separate or combine two polarization state on chip. The polarization rotator can be used to rotate the polarization state between transverse electric and transverse magnetic mode. All the polarization manipulation components are important for expanding the available degree-of-freedom of the photon. Mach-Zehnder interferometer and ring resonator are important components that can be used in the modulator. The performance is also tested.

Active components including modulator and detector are studied in this thesis. The thermal optical modulator and carrier injection modulator are designed and tested. On-chip germanium detector is also characterized. As required by continuous variable quantum information experiment, a self-built balanced homodyne detector using the on-chip detector and off-chip commercialized detector are built and tested. Together with the passive components, a full component library for on-chip linear optics applications is provided.

Specifically, a QKD chip using GG02 Gaussian modulation protocol is designed and fabricated. The basic working principle of the GG02 protocol is analyzed. The secure key rate is calculated based on the total loss and excessive noise of the

system. The test shows the secure key-rate under collective attack can reach 0.83 MHz at 0 km and 9.3 kHz at 100 km distance.

Since the QKD chip is fabricated on the standard silicon photonic platform, it can be integrated onto a single chip with the classical communication device and even the controlling integrated circuit. This will lead to the next generation of a hybrid quantum-classical communication network with more compact components and pave the way to largely expand the market of QKD system.

Publication list

G. Zhang, J. Y. Haw, X. J. Jia, X. L. Su, J. F. Fitzsimons, X. Q. Zhou, W. Ser, L. C. Kwek and A. Q. Liu. "Integrated Silicon Photonic Chip: Continuous-variable Quantum Key Distribution." Nature communication. (Preparation)

Feng, X.[*], **Zhang, G.[*]**, Chin, L. K., Liu, A. Q., & Liedberg, B. (2017). Highly Sensitive, Label-Free Detection of 2, 4-Dichlorophenoxyacetic Acid Using an Optofluidic Chip. ACS sensors, 2(7), 955-960. **([*]Equal contribution)**

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G. Zhang, J. G. Huang, W. Ser, W. B. Gao, Y. D. Chong, J. B. Gong, L. C. Kwek and A. Q. Liu. "Quantum photonic wavelength conversion and modulation using low loss aluminum nitride." Lasers and Electro-Optics (CLEO): Science and Innovations. Optical Society of America, 2017. **(Oral presentation)**