Integrated Chip for Continuous-variable Quantum Key Distribution using Silicon Photonic Fabrication

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Abstract: A continuous-variable quantum key distribution system based on silicon photonic chip is designed and tested. A proof-of-principle test shows the secure key-rate can reach 1.92 Mbit/s at 0 km and 37 kbit/s at 45 km distance. © 2018 The Author(s)

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1. Introduction
Quantum key distribution (QKD) is an emerging technology that utilizes some basic theory in quantum mechanics to ensure the absolute communication security. Continuous-variable QKD (CV-QKD) using the weak coherent state as the information carrier. Since the single photon manipulation and detection technique on-chip is not mature yet, CV-QKD becomes a promising method to achieve next-generation miniaturized secure communication [1-2]. In this paper, an integrated silicon photonic chip for CV-QKD GG02 coherent-state protocol is designed and tested. The size of the chip is 0.8 x 6 mm, which contains all the required components. The reduced size is essential for future use in portable devices. A proof-of-principle test is conducted, which shows the secure key rate can reach 1.92 Mbit/s at 0 km distance and 37 kbit/s at 45 km distance per transmission band.

2. Design and theoretical analysis
Figure 1 shows the system design for CV-QKD and image of some important components. 1550-nm wavelength laser is coupled to the transmitter chip via a grating coupler. Then the laser passes a 1:99 beam splitter. The weaker portion is the signal (S) and the stronger portion is the local oscillator (LO). The signal light is randomly modulated to get a Gaussian distribution on both x and p quadrature. The signal and LO light are multiplexed in polarization by a 2D grating coupler and transmitted in a normal single mode fiber. After the transmission line, the polarization drift is compensated by a polarization controller (PC) and then coupled back to the receiver chip. On receiver chip, the 2D grating coupler demultiplexes the signal and LO. Then another phase modulator is used to randomly select the measured quadrature. Then both signal and LO goes to a balanced homodyne detector.

Fig. 1: (a) Schematic of the continuous-variable quantum key distribution system. (b) Microscopic image for the MZI amplitude modulator. SEM image for (c) the 2D grating coupler and (d) the carrier injection modulator. (e) Chip packaging.
3. Results and discussions

A proof-of-principle test is conducted with a self-built off-chip homodyne detector in this paper. Figure 2(a) shows the balance testing of the detector. The result shows a 40-dB extinction ratio between the balance and imbalance case. Figure 2(b) gives the measured variance at detector output as a function of input laser power. The total noise variance consists of the electronic noise of the circuit and the shot noise from the light source. The fitting result shows that the detector is shot noise limited. Figure 2(c) shows the noise spectrum of the system. The oscilloscope noise is the lowest and the electronic noise of the detector is about 30 dB higher. The shot noise has 5-10 dB signal to noise ratio at the 1-10MHz band. White noise from function generator is used to randomly modulate the signal as required by the protocol. A 10-shot-noise-unit (SNU) modulation spectrum is shown in figure 2(c).

Figure 3(a) (figure 3(b)) shows the cross-correlation between the white noise on AM (PM) and homodyne output when the output of homodyne detection is locked to AM measurement. The inset shows the Gaussian key sent by Alice on $x$ (or $p$) as a function of the Gaussian key measured by Bob. A good correlation between AM and output, while a poor correlation between PM and the output is observed, which indicate the base selection function is performing well. Based on the measured excess noise, modulation variance and transmittance, a secure key rate-transmission distance curve is plotted in figure 3(c). The testing band is 2.5-3.5 MHz. The total excess noise measured is 0.12 shot noise unit (SNU) and the modulation variance used is 5.02 SNU. Consider the total insertion loss of 0.7 dB at the receiver side, the secure key rate can reach 1.92 Mbit/s at 0 km distance and 37 kbit/s at 45 km distance per transmission band (normal 1550-nm optical fiber with 0.3 dB/km loss).

4. Conclusions

In conclusion, a proof of principle test of CV-QKD on integrated silicon photonic chip is performed. The calculated secure key rate can reach 1.92 Mbit/s at 0 km distance and 37 kbit/s at 45 km distance per transmission band. The well-functioning of such on-chip system will move forward the miniaturization and practical use of CV-QKD.

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5. References
