On-chip detection and modulation for continuous-variable quantum key distribution

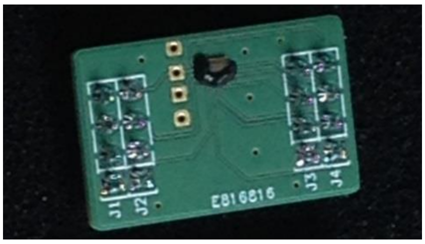
Mauro Persechino[1,2], Melissa Ziebell[1,3], Paul Crozat[3], André Villing[1],
Delphine Marris-Morini[3], Laurent Vivien[3], Eleni Diamanti[2], Philippe Grangier[1]
1. Laboratoire Charles Fabry, Institut d'Optique, CNRS, Univ Paris Sud, F 91127 Palaiseau, France
2. Laboratoire Traitement et Communication de l'Information, CNRS, Télécom ParisTech, F 75013 Paris, France
3. Institut d'Electronique Fondamentale, Univ Paris Sud, CNRS, F 91406 Orsay, France

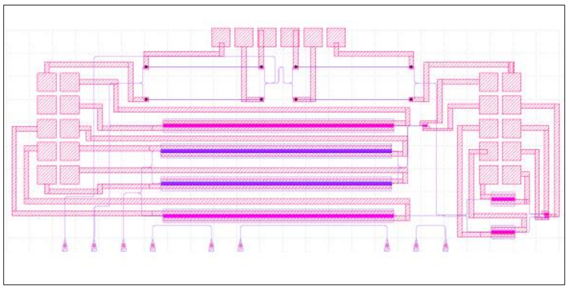
Despite the great progress in quantum key distribution (QKD) implementations in the recent years, QKD remains a technically demanding and costly technology, which hinders its widespread use for high-security applications. The photonic integration of QKD devices can play a crucial role in this direction by reducing their size and cost by several orders of magnitude. Recent efforts for QKD system integration include the implementation of an InP-based emitter and SiN-based receiver for QKD protocols relying on single-photon detection [1].

Here we report on the on-chip demonstration of the main functionalities of continuous-variable (CV) QKD, which requires standard telecommunication technology and in particular no photon counting [2]. Our demonstration is based on a Si chip (Fig. a), which comprises all the components of a CV-QKD system, including attenuators, amplitude and phase modulators, and homodyne detectors (Fig. b). Silicon photonics [3] allows for CMOS compatible technology development and wide scale production of the developed devices, and has been widely used in classical optical communications. Device requirements, however, differ significantly for CV-QKD operation: for instance, high extinction ratio and low loss modulators are required. In addition, homodyne detectors based on Si-integrated Ge photodiodes must be optimized to reach shot noise limited performance, which is more challenging than for the InGaAs photodiodes typically used in 'bulk' systems [2].

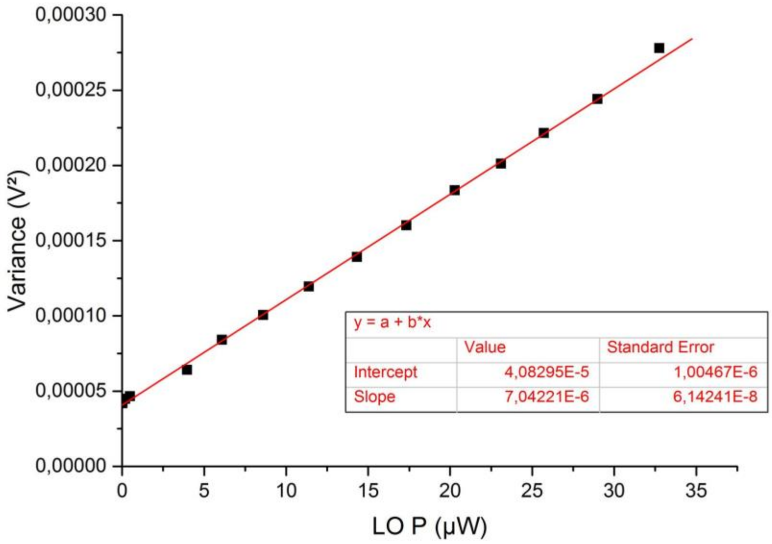
The CV-QKD emitter (Alice) and receiver (Bob) are integrated into a surface area of roughly 2.4 x 1.0 mm², but they have also been tested independently, having one chip for the modulation and one for the homodyne detection (0.7 x 0.5 mm²). Modulation and attenuation are performed using carrier injection/depletion and thermal effects in PIN diodes. In Fig. b, the local oscillator (LO, the phase reference required in CV-QKD) path is shown in blue and the signal path in red. We first tested the modulation devices: the phase modulator is a PIN junction, the dephasing is generated by changing the refractive index with carrier injection. The same device inserted in a Mach-Zehnder interferometer provides the variable attenuation and amplitude modulation functionalities required in the signal path. We found a maximal extinction ratio of ~20dB. For a stronger and steady attenuation thermal devices are used, achieving more than 35dB attenuation. Subsequently, we measured the variance at the output of the independent homodyne detector as a function of the LO power, and obtained the linear relationship expected from a shot noise limited (SNL) detector (Fig. c). The device performance can be fully characterized by measurements of the correlations between the modulated signal sent by Alice and the sifted data received by Bob.

Our results were obtained under typical CV-QKD system operation conditions (100 ns pulses at 1550 nm and 1 MHz repetition rate, as in [2]) and are compatible with the generation of secret keys; hence, they illustrate the potential of Si-integrated CV-QKD for the widespread use of this technology in communication networks.


(a)


(b)

(c)



[1] P. Sibson et al, quant-ph arXiv:1509.00768 (2015).
[2] P. Jouguet, S. Kunz-Jacques, A. Leverrier, P. Grangier, E. Diamanti, Nature Photon. 7, 378 (2013).
[3] L. Vivien and L. Pavesi, Handbook of Silicon Photonics, CRC Press (2013).