Testing the suitability of avalanche photodiodes for quantum communications in the low-Earth-orbit radiation environment

Elena Anisimova[1, 2], Brendon Higgins[1], Jean-Philippe Bourgoin[1, 2], Miles Cranmer[1], Eric Choi[1], Danya Hudson[3], Louis P. Piche[3], Alan Scott[3], Vadim Makarov[1, 2, 4] and Thomas Jennewein[1, 2, 5]

1. Institute for Quantum Computing, University of Waterloo, Waterloo, ON, N2L 3G1 Canada

2. Department of Physics and Astronomy, University of Waterloo, Waterloo, ON, N2L 3G1 Canada

3. COM DEV Ltd., 303 Terry Fox Dr, Kanata, ON, K2K 3J1, Canada

4. Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, ON, N2L 3G1 Canada

5. Quantum Information Science Program, Canadian Institute for Advanced Research, Toronto, ON, M5G 1Z8 Canada

Cryptographic techniques that utilize fundamental quantum mechanics, such as quantum key distribution (QKD), are going to be the safest option for secure communication in approaching era of quantum computers. Satellite-based quantum communications will be an important component in achieving world-wide QKD in the near term. For satellites acting as quantum receivers, this will necessitate single photon detectors (SPDs) capable of operating with sufficient fidelity in the space environment. However space radiation severely impairs the performance of avalanche photodiodes (APDs), causing a fast increase of their dark count rate and rapidly making quantum communication impossible. Previous radiation tests of APDs demonstrated high increase of dark count rate (e.g., [3]). Recent tests used mitigation by cooling to overcome the increased dark count rate, using temperature as low as −20 °C [1]. However no tests have demonstrated sufficiently low dark count rate [2] for QKD throughout a reasonable lifetime of a quantum receiver satellite (more than 1 year). Here we show experimentally that effects of radiation doses equivalent to up to 2 years in orbit are successfully mitigated by cooling and thermal annealing, allowing the APDs to be used in the quantum satellite. Afterpulsing, efficiency and jitter of the irradiated SPDs have been tested and shown to be in the range acceptable for QKD.

A polar orbit at 600 km altitude providing global coverage was chosen for our quantum satellite. Predicted radiation doses were calculated by COM DEV, using estimated shielding levels and the online SPENVIS radiation modeling tools. Samples were irradiated by a 100 MeV proton beam at the TRIUMF facility (Vancouver) with doses equivalent to 3 weeks, 6 months, 1 year and 2 years in the orbit. The following samples were tested: silicon APDs C30921SH, SLIK (Excelitas), SAP500S2 (Laser Components), photomultiplier tubes H7422P-40 (Hamamatsu). One group of APDs was operating in photon counting regime under high-voltage bias during the irradiation, and exhibited a higher rate of damage. All samples survived irradiation and remained functional photon detectors, with the only significant effect being the increase of the dark count rate.

The increased dark count rate after irradiation was successfully mitigated by cooling the APDs down to −86 °C. In all SLIK samples, the dark count rate at that temperature was acceptable for satellite QKD (Fig. 1). Thermal annealing at up to +100 °C was applied. It reduced the dark count rate after irradiation further, by up to a factor of 5.

This study paves the way for a straightforward implementation of a compact SPD package for the quantum satellite, using minimal radiation shielding and a mix of radiative and low-power thermoelectric cooling for APDs. Further prototyping for a Canadian quantum satellite is currently in progress.

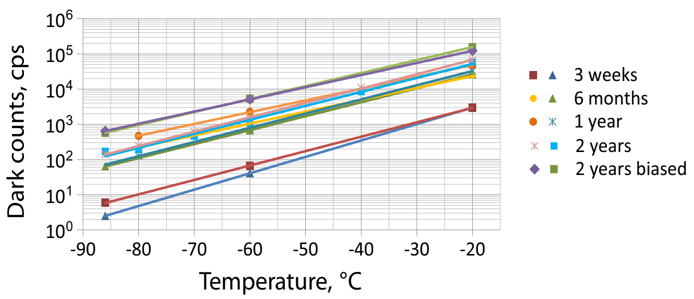

Fig. 1. The cooling effect on the measured dark count rate for SLIK APDs after various levels of irradiation (equivalent radiation time listed). Two samples were tested at each radiation level.

References

[1] Y. C. Tan *et al.,* Opt. Express **21**, 16946 (2013).

[2] J.-P. Bourgoin *et al.,* New J. Phys. **51**, 023006 (2013).

[3] H. Sun *et al.,* Proc. IEEE Radiation Effects Data Workshop 2001, p. 146 (IEEE, 2001).