Laser annealing heals radiation damage in single-photon avalanche photodiodes

Jin Gyu Lim,[1, 2, *] Elena Anisimova,[1, 3] Thomas Jennewein,[1, 3, 4] and Vadim Makarov[1, 2, 3]

[1] *Institute for Quantum Computing, University of Waterloo, Waterloo, ON, N2L3G1 Canada*
[2] *Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, ON, N2L 3G1 Canada*
[3] *Department of Physics and Astronomy, University of Waterloo, Waterloo, ON, N2L 3G1 Canada*
[4] *Quantum Information Science Program, Canadian Institute for Advanced Research, Toronto, ON, M5G 1Z8 Canada*

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A dark count rate of single-photon avalanche photodiodes (SPADs) is a crucial parameter for both terrestrial and space-basedquantum communications. We have experimentally demonstrated that laser annealing may be an effective method to heal radiation damage the SPADs suffer in a low-earth orbit. Our laser annealing has reduced the dark count rate of irradiated Si SPADs by a large factor of 41 to 758, without significantly impairing their photon-counting performance.

Previous studies have shown that the dark count rate of Si SPADs increases dramatically after irradiation by protons [1–3]. Subsequent thermal annealing of irradiated SPAD samples in a +100 °C hot-air oven reduces their dark count rate by up to 6.6 times [4]. Laser annealing of non-irradiated SPADs reduces their dark count rate by up to 5 times [5]. We have thus decided to try laser annealing on irradiated samples.

We have tested three Si SPAD models, listed in Table I. All samples were irradiated under a 100 MeV proton beam, to simulate radiation exposure in a 600 km altitude polar orbit [4]. For annealing, we applied a multimode continuous-wave 808 nm laser beam focused within the SPAD photosensitive area, in a sequence of 60 s long sessions of incremental power. After each annealing session, we have characterized the dark count rate, photon detection efficiency, afterpulsing, and timing jitter. The experimental results (Table I) show that the dark count rate has decreased by a large factor for all the models tested, regardless of whether they have been thermally pre-annealed or not. We have also observed a moderate increase in afterpulsing probability (which however remained acceptable for quantum communications) and no changes in other photon detection characteristics.

Laser annealing or an equivalent technology thus shows promise for inclusion into SPAD-based single-photon detectors for space applications. We hope this will help achieve longer useful detector lifetimes in orbit, and contribute to the development of space-based quantum communications [6].

TABLE I. **Summary of laser annealing results.** Photon counting performance was characterized at −80 °C.

Manufacturer & device model	**Thermally pre-annealed?**	**Radiation dosage**	**Equivalent time in 600 km polar orbit**	**Best dark count rate reduction factor**	**Annealing power at best dark count rate reduction**
Excelitas C30902SH	No	10^9 p/cm^2 @ 100 MeV	6 months	150 times	0.8 W
Excelitas SLIK	2 h @ +100 °C	10^8 p/cm^2 @ 100 MeV	3 weeks	41.7 times	1.8 W
Laser Components SAP500S2	4 h @ +80 °C, 1 h @ +100 °C	4×10^9 p/cm^2 @ 100 MeV	2 years	758 times	1.4 W

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* j29lim@uwaterloo.ca