Enhancement of NbTiN Superconducting Nanowire Single-photon Detectors using Local Helium Ion Irradiation

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Superconducting nanowire single-photon detectors (SNSPDs) play a crucial role in photonic quantum technologies as well as in other faint light detection technologies. Their excellent performance metrics, consisting of high detection efficiency in the visible and near IR, low dark count rate and low timing jitter make them a prime choice for applications that require the detection of single photons like quantum key distribution, photonic quantum computing, or deep space optical communication.

Among the materials most used for SNSPD fabrication are Nb-based superconductors like NbN and NbTiN as well as silicides such as WSi and MoSi. Typically, Si-based detectors are better suited for long wavelength detection due to their low critical temperature, while Nb-based detectors offer faster detector response (low timing jitter and fast reset times). In this work, Helium ion irradiation is used as a post-fabrication tool to improve the sensitivity of detectors made from NbTiN and MoSi. Electrical transport measurements reveal an increased resistance and decreased critical temperature originating from ion-induced defects in the superconductor. Following irradiation, the system detection efficiency of a 10 nm thick detector, made from NbTiN and operated at 4 K increases from below 2% to 43% at 780 nm, while the internal detection efficiency saturates and the switching current is significantly reduced [1].

Furthermore, a method to mitigate current crowding, an inherent issue of meander-type SNSPDs reducing the maximum applicable bias current, in high fill factor SNSPDs (250nm wire width, 100nm gap) is investigated. By irradiating only the straight segments of the detector without the 180° turns we generate two regions – an area with an increased photon sensitivity in the straight segments of the detector and an area at the turns with a high switching current density to counteract the reduction in switching current due to current crowding. This allows to enhance sensitivity and simultaneously keep a high switching current [2]. Above 90 ions/nm^2, switching currents of locally irradiated detectors are comparable to straight wires without any bends and significantly higher than that of the fully irradiated SNSPDs. With this technique, we achieve unity quantum efficiency for photons with wavelengths of 780 nm and 1550 nm at 1 K and dark count rates down to 7 mHz.

Finally, retrapping current measurements are performed to extract the thermal boundary conductance of the SNSPDs. The results indicate that irradiation-induced morphological changes reduce the thermal boundary conductance (SNSPD to substrate), thereby contributing to the enhanced detection efficiency [3].

These findings show that He ion irradiation is a valuable post-processing tool to fabricate high performance SNSPDs.

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