Fiber-tip dielectric multilayer filters for Dark Current noise mitigation in SNSPD applications: Design, Development and Characterization.

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Abstract

High-performance superconducting nanostrip single-photon detectors (SNSPDs) have been widely demonstrated to be high-performance single-photon detectors (SPDs) in many fields, such as quantum information, quantum optics and light detection and ranging [1,2]. The detection efficiency (DE) of an SNSPD has greatly improved thanks to significant developments in suitable geometries and material innovations [1]. However, the false detection rate, or dark count rate (DCR), which represents the noise level of the SNSPD, is one of the key parameters for practical applications. For example, the quantum bit error rate (QBER) in quantum key distribution (QKD) is proportional to the DCR, which limits the communication distance of QKD. Improvements in DCR are still needed. The DCR is dominated by the background blackbody radiation at room temperature through the optical fiber. By introducing a cold filter on the fiber end-face, the background DCR can be strongly suppressed. To achieve this, a narrowband dielectric filter was designed and fabricated directly onto the end-faces of single-mode (SM) and multimode (MM) silica fibers. The structure utilizes alternating layers of titanium dioxide (TiO_2) and silicon dioxide (SiO_2), optimized for maximum transmittance at 1550 nm. The design phase employed an analytical model implemented in MATLAB and validated through Finite Element Method with COMSOL. Fabrication was carried out via electron-beam evaporation, utilizing planar glass substrates as reference samples for structural and optical characterization [3]. Analyses using spectroscopic ellipsometry and atomic force microscopy confirmed film uniformity, with surface roughness consistently below 5 nm. Experimental testing via optical spectrum analyzer demonstrated excellent agreement between SM and MM fiber samples, indicating that filter performance remains robust despite the presence of higher-order modes (figure 1). Although a systematic blueshift was observed due to minor deviations in deposited layer thicknesses, the close correspondence between numerical and experimental results validates the proposed design methodology and the overall fabrication process. Preliminary tests of the DCR and photon counting rate (PCR) at 1550 nm of an NbN-based SNSPD will be performed and presented on-site using SM and MM fibres with fabricated filters.

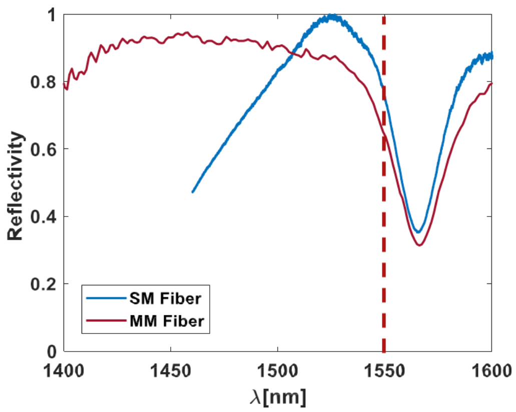

Figure 1: Reflectivity spectrum of SM and MM optical fiber.

Reference

[1] L. You, Superconducting nanowire single-photon detectors for quantum information, Nanophotonics 9, 2673 (2020).
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[3] Neilson, J., et al.,. Optimizing nanostructure deposition process for optical applications. *Micro & Nano Letters* (2024).