Superconducting Nanowire Single Photon Detectors On-Fiber

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We present a novel design of a superconducting nanowire single photon detector (SNSPD) fabricated on a core of a single mode optical fiber. The proposed design allows high overlap between the fiber light mode and the detector, and consequently, our fabricated devices can remain small in dimension and maintain speed of operation, without sacrificing the detection efficiency. The on-fiber fabrication method is detailed, together with experimental results. The proposed method can be exploited in the future for the fabrication of other fiber coupled devices.

Single photon detectors are needed in various fields of science and technology [1–9]. The main figures of merit used to qualify a single photon detector are: the detection rate, the detection efficiency, the jitter, and the dark counts rate. Superconducting nanowire single photon detectors (SNSPD) [10] are considered as a promising technology for an optical detection in the visible to near-infrared band [11]. Achieving high coupling efficiency ($\eta_C$) between the light source and the detector remains an outstanding challenge.

Maximizing $\eta_C$ requires focusing the input light on a detector, which is typically defined as a square (or a circle) with few micrometers side (or diameter), and is operated inside a cryostat. Methods based on free space optics [10] or mechanical cryogenic positioning of an optical fiber in front of the the sample [11] require complicated and expensive instruments, and suffer from poor alignment stability. Alternatively, methods based on fixed alignment of an optical fiber to the sample [12, 13] suffer from a fiber-center to detector-center misalignment (referred hereafter as the center-to-center-misalignment or $x_{CC}$) of a few micrometers at least [14]. For these fixed alignment procedures, an increase in the detector dimensions is inevitable, in order to keep $\eta_C$ high. As the detector recovery time is linearly proportional to its area [15, 16], it is important to keep the detector as small as possible. For example, for a typical device, made of 100 nm wide 5 nm thick niobium-nitride wires folded to an area of 25 $\mu$m$^2$, the recovery time is 2.5 ns [15, 16].

In the present work, we propose an alternative system configuration, in which the detector is fabricated on a tip of an optical fiber. The on-fiber fabrication allows precise alignment of the detector to the fiber core, where the light intensity is maximal, while keeping the device small and fast. The proposed devices are simple to operate, small in size and do not require complicated optical or positioning equipment.

The complete fabrication process is done on the top facet of a zirconia ferrule, taken from a standard flat polished fiber connector (FC-UPC), holding a single mode fiber for the telecommunication bandwidth (Corning SMF-28 [17]). The ferrule facet has a diameter of 2 mm; the fiber having a 125 $\mu$m diameter is epoxy glued concentrically with the ferrule. We evaporate 5 nm thick chromium film followed by a 200 nm thick gold film through a mechanical mask to form bonding pads. Next, a 10 nm thick niobium nitride (NbN) film is deposited using a dc-magnetron sputtering system. The sputtering process is done from a niobium target in a vacuum chamber filled with mixture of argon and nitrogen gasses, while keeping the sample at room temperature [18, 19]. The NbN film is covered in-situ with 100 nm of aluminum.

To pattern the detector, we first narrow the NbN film to a 25 $\mu$m wide bridge using a focused ion beam (FIB) system with a relatively high current (2.1 nA). During this step the aluminum layer protects the NbN film from an exposure to the ion beam, and reduces gallium poisoning [20, 21]. After the first lithography step, the aluminum layer is wet etched. The sample then undergoes a second lithography step, in which a meander is formed, using a low current (9.7 pA) FIB patterning. A fabricated device can be seen in Fig. 1.

The FIB imaging system, which is used to align the detector to the fiber center, allows achieving $x_{CC}$ of less than 1 $\mu$m, limited mainly by the fiber-core to fiber-clad misalignment, given to be $< 0.5 \mu$m by Corning [17].

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To summarize, we demonstrate a SNSPD fabricated on a tip of an optical fiber, with very low misalign-
ment between the incoming light and the detector area. Though we achieve high coupling efficiency, more re-
search is needed in order to increase the system detection efficiency. A future work in this direction may in-
clude adding an on-fiber optical cavity [24], changing the superconducting material to a one more suitable for de-
position on the amorphous SiO₂ fiber [25, 26] and cooling the device to lower temperatures [27].

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