An NbTiN superconducting single photon detector implemented on a $LiNbO_3$ single mode nano-waveguide at telecom wavelength

(Student paper)

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ABSTRACT

Fiber-coupled superconducting nanowire single photon detectors are a ubiquitous tool for quantum optics experiments as they offer near unity detection efficiency over a broad wavelength range, low dark count rate, excellent time resolution and high saturation rate. Nevertheless, advancing quantum optics experiments and applications beyond the few-photon limit requires large scale integrated systems of quantum sources and detectors. In recent years there has been a tremendous progress with integrating single photon detectors with a variety of photonic platforms. This includes attempts on ion-diffused waveguides in $LiNbO_3$, a non-linear and electro-optic material with widespread use for signal processing, frequency conversion, and quantum optics devices. However the realization of superconducting detectors on single mode waveguides remains elusive. Here we present an NbTiN superconducting single photon detector integrated directly on a $LiNbO_3$ single mode nanophotonic waveguide at telecom wavelength, with a high critical current density and a dark count rate of 3 mHz at 99% of its critical current.

Keywords: SNSPD, lithium niobate integrated optics, integrated detector, NbTiN, lithium niobate-on-insulator.

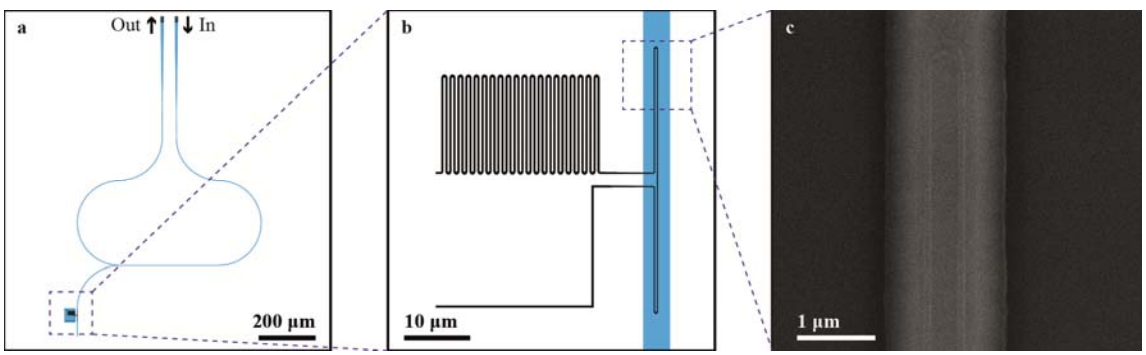

Figure 1: a) Schematic of the circuit. b) Schematic of the SNSPD above the waveguide. c) SEM micrograph of the SNSPD.

1. INTRODUCTION

Superconducting nanowire single photon detectors (SNSPDs) revolutionized quantum optics experiments, they offer unique properties combining near unity single photon detection efficiency [1], [2], mHz dark count rate [3], few picoseconds time resolution [4], [5] and tens of MHz detection rate [2]. SNSPDs have made a number of fundamental physics studies possible, and have become the detector of choice for many applications such as in LiDAR [6], quantum key distribution [7], biomedical imaging [8] and CMOS testing [9]. Making use of the evanescent coupling of the light field propagating in waveguides, it has been demonstrated that SNSPDs are the perfect candidates for on-chip detector integration [10]. Such integration has been demonstrated with several platforms, such as silicon-on-insulator, silicon nitride-on-insulator, diamond, and GaAs/AlGaAs [11]. Lithium niobate ($LiNbO_3$) is a particularly attractive photonic material as it possesses a wide transparency window from 0.4 to 5 µm, nonlinear- and electro-optical properties [12] and it is widely used for classical but also quantum integrated optics [12]. The relatively large geometries of traditional LN waveguides [13] does not allow an efficient coupling to SNSPDs as afforded by nanophotonic circuits on other platforms. Integrating SNSPDs on $LiNbO_3$ nanophotonic waveguides is thus of paramount importance. Here we integrate a niobium titanium nitride (NbTiN) SNSPD on a single-mode $LiNbO_3$-on-insulator (LNOI) photonic wire. NbTiN superconducting detectors have been shown to offer high time resolution and high count rates, while they can be operated at a temperature as high as 3 K due to the high critical temperature of the material. Furthermore, the etched, slab geometry of our waveguides allows for short bending radii and therefore space-efficient circuits.

2. FABRICATION AND CHARACTERIZATION

We first fabricated the LNOI waveguide circuit, starting from a commercial thin film LNOI wafer, which offers an index contrast between the waveguide core and the bottom cladding of 0.7. The patterning of the LNOI layer followed the process described in [14], involving electron-beam lithography and dry etching of the LiNbO3 using Ar-milling. This enables the simultaneous fabrication of sub-micron waveguides, grating couplers and tapers for coupling in and out of chip as well as markers and pedestals for the SNSPD. The LNOI photonic circuit consists of a 50:50 Y-splitter, with the input port terminated by a grating coupler, one output port terminated by an SNSPD, and the second output port terminated by another grating coupler (Figure 1.a). We subsequently deposited a 9 nm thick NbTiN film on the LNOI circuit using magnetron co-sputtering in an Ar and N_2 gas mixture from two ultra-pure targets of Nb and Ti at room temperature. The detector was patterned on top of the LNOI waveguide into an 78 µm long and 85 nm wide hairpin nanowire by electron-beam lithography. After development, the pattern was transferred to the NbTiN by dry etching with CF_4 and O_2 chemistry (Figure 1.b and c). Additionally, we fabricated test structures and measured LNOI waveguide losses of 19 dB/cm with a dedicated room-temperature setup. The device was mounted on a PCB and placed on an XYZ nano-positioner in a cryostat operated below 100 mK. The detector was DC biased with a commercial SNSPD driver from the company Single Quantum, featuring a bias tee, 2-stage room-temperature amplification and an internal counter. Laser light was coupled through the input grating coupler using a 40x objective mounted next to the sample, and through four optical windows.

3. RESULTS

We measured the IV characteristics of the device and our structure exhibits a critical current of 48.5 µA, which corresponds to a high current density of 63.3×10^9 A/m^2. Figure 2.a shows a typical pulse of the detector at a bias of 48 µA, with a 1/e dead time of 4.5 ns extracted from the exponential decay fit. Using an attenuated pulsed laser at 1546 nm, we recorded the coincidence histogram between the synchronization signal of the laser and the SNSPD pulses, revealing a FWHM timing jitter of 60 ps, as reproduced in Figure 2.b. Moreover, we measured a dark count rate of 3 mHz over a period of 27 minutes when the detector was biased at 99% of its critical current, as shown in Figure 2.c. The predicted detection efficiency of the waveguide-integrated device is 97% from simulations. We are currently working on extracting the efficiency value from the measurements and the loss calibration.

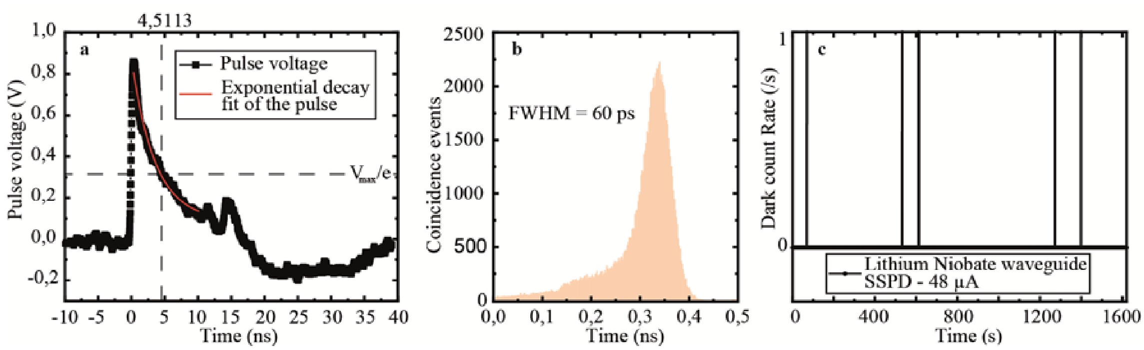

Figure 2: a) Pulse of the SNSPD and exponential fit of the pulse decay. The ripples originate from the readout configuration. b) Timing jitter measurement of the device, measured with a pulsed laser. c) Measurement of a dark count rate of 3 mHz of the device biased at 99% of its critical current.

4. CONCLUSION

We demonstrated the first NbTiN SNSPD implemented on a LNOI circuit. LNOI nanophotonic waveguides provide an excellent confinement of the light field and allow for low footprint devices. The hybrid LNOI-SNSPD device was successfully operated at telecom wavelengths and cryogenic temperatures, exhibiting a high critical current and a low dark count rate. The results represent a step towards the implementation of on-chip, low timing jitter and high-bandwidth single photon detection capabilities of SNSPDs on LNOI, a promising new platform for integrated quantum photonics.

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