Single- and Multi-photon detection at telecom wavelengths using waveguide-integrated superconducting nanowires

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Superconducting single photon detectors (SSPDs) offer broad optical bandwidth, low dark count rate, high detection efficiency and timing resolution [1]. Integrating those elements atop waveguide provide essential components for full scalable on-chip quantum photonic technology [2,3].

Here we demonstrate that niobium nitride (NbN) nanowire superconducting single photon detectors atop silicon nitride Si$_3$N$_4$ nanophotonic waveguide not only provide single photon capability but also can be used to discriminate large number of photons when operated under different biasing conditions.

We present also a theoretical model that accurately fits our experimental results and allows us the extract the internal quantum efficiency of the waveguide integrated detectors.

![Fig. 1](image)

**Fig. 1.** (a) Measured detection probability at different bias currents for a 120nm wide nanowire. (b) Fit result of the detection probability curve for a 120nm wide nanowire taken at 0.5$I_c$, showing single and double photon pure detection regimes. (c) Calculated internal quantum efficiency for the different detection regimes. In all the plots, the red curve indicate the single photon detection regime, the blue one two photons regime and the green on three photons regime.

At near-infrared wavelengths, using a highly attenuated pulsed laser we measured the SSPDs detection probability as the ratio between the detector count rate and the laser repetition rate, in dependence of the average number of photons per pulse in the waveguide. As shown in Fig. 1(a), biasing a 120nm wide nanowire detector near to the critical current, the detection probability grows linearly with the number of incoming photons. On the other hand, at low bias currents, this proportionality becomes non-linear, which on a log-log scale translates into a change in the detection curve slope. This is indicative of a change in the detection regime from single- to multi-photon. Similar behaviour occurs when applying identical bias condition to detectors with different nanowire width. Saturation of the detection probability curve indicates that all the incoming pulses are detected.

As depicted in Fig. 1(b), adapting the theoretical model formalism proposed by Elezov et al. [7], to the waveguide integrated design, in which the irradiation is not homogeneous along the wire, we accurately fit our experimental data. Applying the same model, we extracted the internal quantum efficiency (IQE) within the different detection regimes of the integrated detectors, as shown in Fig. 1(c).

It is then possible to design opportunely the waveguide integrated SSPDs for detecting simultaneous arrival of a specific number of photons rather than a single photon.

References