High quantum efficiency photon-number-resolving detector for photonic on-chip information processing

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Abstract: We demonstrate a high-efficiency, photon-number resolving transition edge sensor, integrated on an optical silica waveguide structure. The detector consists of three individual absorber/sensor devices providing a total system detection efficiency of up to 93% for single photons at a wavelength of 1551.9 nm. This new design enables high fidelity detection of quantum information processes in on-chip platforms.

OCIS codes: (270.5570) Quantum detectors; (270.5290) Photon statistics; (270.5585) Quantum information and processing

1. Introduction

Scalable quantum information processing is a necessary requirement for future complex applications. Optical on-chip technology already allows complex guiding and processing of quantum signals [1]. An important ingredient for future high-fidelity quantum processing is a high quantum efficiency single photon detector. Recent works have implemented single photon detectors on an optical waveguide circuit [2]. This work shows the development of an on-chip photon-number resolving detector with the highest quantum efficiency reported so far. Further, we realize a detector that can be used for photon-subtraction applications, since its embedded design and accurate control of its quantum efficiency allow for very well mode-matched beamsplitting operation and detection.

2. Device design

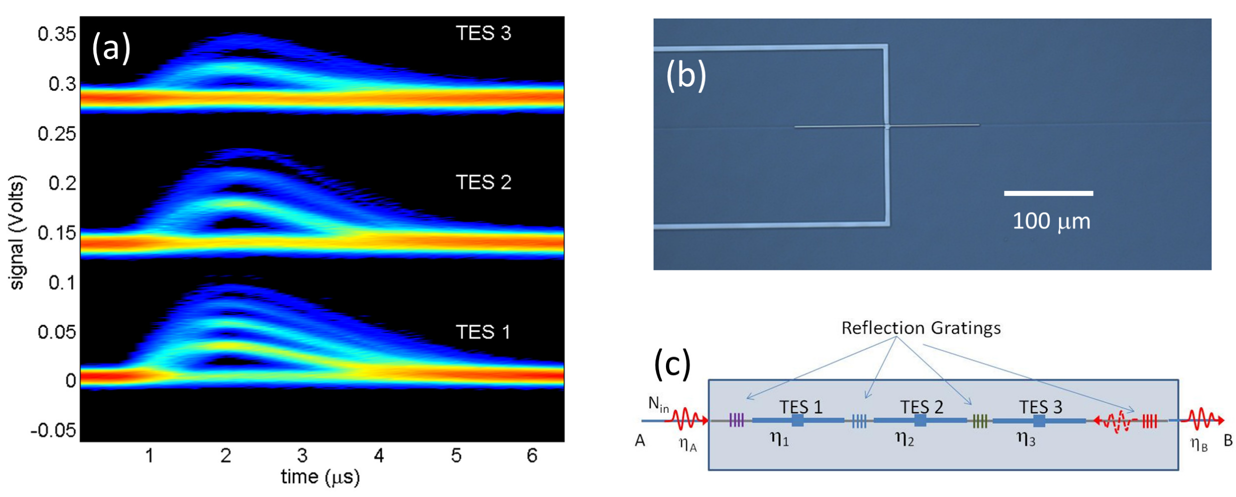

Fig. 1. (a) Histogram of the three in-line TESs. (b) Microscope image of one fabricated device . (c) Schematic device design, employing reflection gratings for in-suitu loss measurements and three tungsten TESs.

In contrast to directly absorbing single photon detectors, we employed a design with a fin absorber connected to a transition edge sensor (TES). In our case, a 100 µm long, 4 µm wide fin of tungsten was placed on either side of the TES on top of a UV-written silica-on-silicon waveguide. The TES was a 10x10 µm sensor. Photons that are absorbed in the tungsten fins generate a heat pulse traveling along the absorber towards the TES. In order to increase the speed of the traveling heat pulse, we added an 80 nm thin, 2.5 µm wide gold bar on top of the tungsten absorber fins. The fabricated device is shown in the microscope image in Fig. 1(b). The TES can be identified by the niobium contact leads emerging from the top and bottom. The absorbers are placed exactly on top of the 5.5 µm wide silica waveguide and connect to either side of the TES. Figure 1(c) shows the schematic design of the waveguide-detector device. In order to increase the overall absorption of the detector we placed three in-line absorber/sensors on top of the waveguide. By embedding reflection gratings at different wavelengths we were able to perform in-situ loss measurements [3]. A high-reflector was placed at the end of the detector array to allow double-pass absorption for a wavelength of 1551.9 nm.

2. Results

Figure 1(a) shows the response of the TES detector array, while sending photon pulses from side A to B. The light is first absorbed by TES 1 (bottom) with any undetected signal being transmitted along the guide to be subsequently absorbed by TES 2 (middle) and TES 3 (top). The graph shows the TES output trace densities for 4096 individual laser pulse responses for all three detectors, measured simultaneously. Photon number resolution of each of the TESs is well observed. The different photon numbers are observed, due to the energy resolution of the TES and the coherent state input. The mean photon number response decays as the light pulse travels from A to B, owing to the absorption of each of the previous detectors. The derived detection efficiencies for the TM input polarization are 46.7 ± 0.7%, 46.6 ± 0.5% and 46.2 % ± 0.6% for TES 1, TES 2 and TES 3, respectively. The combined efficiency of all three detectors is 84.7±1.1%. This is the efficiency with which a photon inside the waveguide will be detected by either of the three detectors. This does not account for the coupling efficiency from the optical fiber to the waveguide. In this case the coupling efficiencies are 17.5 ± 1.3% and 11.7 ± 1.7% for the A and B side, respectively. When tuning our laser to the high-reflector wavelength of 1551.9 nm, we observe a quantum efficiency of 93%, as the photons now pass each absorber/sensor twice. The classical in-situ measurements of the detector absorption [3], based on the embedded gratings yielded an absorption of 45%, 47% and 50% for TES 1, TES 2 and TES 3, respectively. This is in very good agreement with the results obtained by photon counting and from our optical modeling and shows the ability to accurately tune the detection efficiency of each of the detectors.

3. Conclusion

In conclusion, we show a photon-number-resolving device that is capable of measuring single photons in an embedded waveguide structure with nearly unity quantum efficiency. This allows for the efficient photon-number-resolved detection of on-chip photonic states as required for integrated quantum information processing applications. Further, the ability to tailor the detection efficiency of each detector enables a partially reflecting beamsplitter and a very well mode-matched number resolving single photon detector using just one single element placed on top of the waveguide structure. We will show how such a design allows for a range of photon-subtraction/addition experiments to be carried out on-chip for the first time.

4. References

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