Extended Abstract

Single-photon detector (SPD) is the most essential component for a wide range of quantum information communication technologies (QICT), e.g. quantum key distribution [1], photonic quantum computer and simulator [2]. The superconducting nanowire single-photon detector (SNSPD) is the very suit SPD for such applications, since it has a very high photon detection efficiency (PDE) of ~ 90% with low noise (dark) counts [3]. Another potential SPD is a silicon single-photon avalanche diode (Si-SPAD) whose quantum efficiency (QE) in a wavelength range from ~500 nm to ~ 800 nm is ~ 90%. However, the PDE of the Si-SPAD is generally much lower than the QE because of an imperfect avalanche detection probability: the probability that the first excited single-carrier can grow into a detectably large avalanche signal.

Here, we report on a high-efficiency SPD at 780 nm using a Si-SPAD operated with a gated mode. The SPD has been already applied to a frequency-up-conversion (FUC) SPD, which resulted in drastic improvement of the system PDE at a telecommunication wavelength.

In this work, the Si-SPAD was temperature-stabilized at 295 K and operated with the gated mode, using a gated passive quenching circuit modified from [4]. The peak amplitude of the gate pulse was increased up to ~ 40 V, and the pulse duration was set to 4 ns which corresponds to a response time of the Si-SPAD we used. Then, the repetition frequency of the gate voltage pulse was 0.5 MHz at which the afterpulse probability per gate is negligibly small. The gating system achieved to apply the (excess) voltage of ~ 38 V over the breakdown voltage to the Si-SPAD. Although the macroscopically large avalanche signals can be obtained with the high excess voltage, they cannot be discriminated from transient charge pulses which are caused by a capacitor-like response of the gated Si-SPAD. Therefore, to discriminate the avalanche signals, we employed the discharge pulse counting method [5]. The 50-ps pulsed laser at 780 nm was used in order to evaluate performance of the gated Si-SPAD. Finally, we obtained the PDE of 85.2% when the excess voltage was 37 V. The PDE value is almost identical to the QE (85.5%). Moreover, the dark count probability per gate was limited in the order of 10^{-6}~10^{-5}.

The gated Si-SPAD has been applied to FUC-SPD. The FUC system we used has a FUC efficiency of 61% with an ultra-low noise count rate [6]. In order to reduce Raman-induced noise photons, the FUC system employed the pump laser at 1.95 μm, and thus the wavelength of signal photons was converted from 1546 nm to 862 nm. Thanks to a high PDE (75%) of the gated Si-SPAD at 862 nm, the maximum system PDE of 45.6% was achieved at 1546 nm. This value is 1.5 times higher than that previously obtained in [6]. The noise count probability of 3.3×10^{-5} per gate was obtained. The noise counts originate from the dark counts of the gated Si-SPAD and the Raman-induced noise photons. The dark count probability of the gated Si-SPAD was measured to be 1.8×10^{-5} per gate. Therefore, the Raman-induced noise photons occurred with a probability of 1.5×10^{-5} per gate. This noise level is comparable to that reported in [6].

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