Frequency-up-conversion single-photon detector at a telecom-wavelength with a high-efficiency gated silicon avalanche photodiode

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Low-noise, high-detection-efficiency single-photon detector (SPD) at telecom-wavelengths is demanded for quantum information and communication technologies (QICT), as well as eye-safe optical imaging and sensing technologies. An InGaAs/InP single-photon avalanche photodiode (SPAD) has been widely used as the practical SPD at telecom-wavelengths. However, in those applications, the InGaAs/InP-SPAD suffers from a high dark count rate and afterpulses, especially in the case that the photon detection efficiency (PDE) is enhanced (> 20%). The alternative approach is using an efficient silicon (Si) SPAD and a frequency-up-conversion (FUC) device [1]. Recently, a FUC system with a net FUC efficiency of higher than 60% has been achieved with an ultra-low noise count rate [2]. In order to reduce Raman-induced noise photons, the FUC system employed the pump laser at 1.9 μm, and thus the wavelength of signal photons was converted from 1550 nm to 860 nm at which the Si-SPAD had a relatively low PDE (~45%). Therefore, the overall PDE at 1550 nm was < 30%, despite the use of the efficient FUC system. In this work, we adopted a gated Si-SPAD whose PDE at ~ 860 nm was strongly enhanced, which resulted in drastic improvement of the overall PDE of the FUC-SPD.

Figure 1 shows the schematic diagram of the FUC-SPD. The setup was constructed with components similar to [2], except for the use of the gated Si-SPAD. Weak coherent pulsed light at 1546 nm was used as a photon source. The photons at 1546 nm are injected into the FUC system based on a periodically poled lithium niobate waveguide (PPLNW) pumped by a cw laser at 1.95 μm. Then, the wavelength of the photons is converted into 862 nm. The frequency-up-converted photons are led to the Si-SPAD. A quantum efficiency of the Si-SPAD we used is ~ 75% at 862 nm. The Si-SPAD is gated with 4-ns-long and 40-V-high voltage pulses at a repetition frequency of 0.5 MHz. The achieved PDE is limited by the intrinsic quantum efficiency [3].

Figure 2 shows the overall PDE at 1546 nm as a function of the pump laser power coupled to the PPLNW. The overall PDE increased as the pump laser power was made higher. At a pump laser power of 64 mW, the maximum PDE of 45.6% (FUC efficiency: 61%) was obtained. This value is 1.5 times higher than that previously obtained in [2]. The noise count probability of 3.3×10^{-5} per 4 ns 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 4ns gate. Therefore, the Raman-induced noise photons occurred with a probability of 1.5×10^{-5} per 4 ns gate. This noise level is comparable to that reported in [2].

In conclusion, we demonstrated the efficient single-photon detection at 1546 nm using the FUC system and the gated Si-SPAD. Thanks to the very high PDE of the gated Si-SPAD, the overall PDE as high as 45% was achieved without a significant increase of the noise counts.

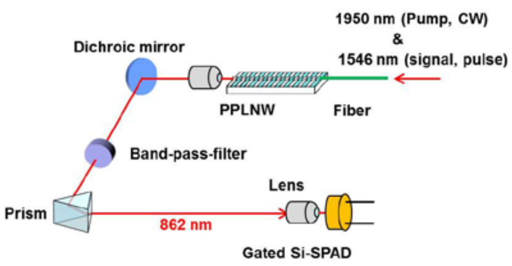

Fig. 1. Experimental setup.

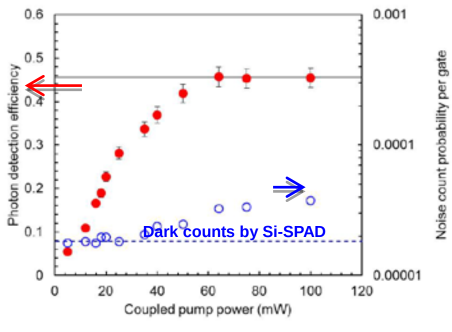

Fig. 2. Experimental results.

This work was partially supported by JSPS KAKENHI Grant Number 26390087.

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