Telecom-Band Single-Photon Detector Using Sinusoidally Gated Avalanche Photodiode for Gigahertz Clocked Systems

Naoto Namekata(1), Shunsuke Adachi (1), Shuichiro Inoue (1)
1: Institute of Quantum Science, Nihon University,
1-8-14 Kanda-Surugadai, Chiyoda-ku, Tokyo, 101-8308, Japan
nnao@phys.cst.nihon-u.ac.jp

Abstract

The gated InGaAs/InP avalanche photodiode is the most practical single-photon detector for fiber-based quantum key distribution system. We demonstrate that the sinusoidally gated avalanche photodiode can operate with a gigahertz gating. When the gating repetition frequency was 1.5 GHz, the detection efficiency was 5.1% with a dark count probability per gate of 5.1×10^{-7} and an afterpulsing probability of 2.3%.

Introduction

In the quantum key distribution (QKD) based on the optical fiber links, it is important to develop the single-photon detector (SPD) at the telecommunication wavelength (1550 nm) with high quantum efficiency and low dark counts. Moreover, in practical use, the SPD is required to operate with a high repetition rate. The potential SPDs, an upconversion detector (1 and a superconducting single-photon detector (SSPD) (2, have been reported. Although these SPD can be operated with greater than gigahertz clock systems, they have drawbacks that make them difficult to apply to practical QKD systems. The upconversion detector suffers from background noise counts with a high detection efficiency, while the SSPD requires cryogenic environment (<4K).

The other potential SPD is gated InGaAs/InP avalanche photodiode (APD) that can be easily applied to practical QKD, and recently the gated APD operated at high gating frequency has been reported (3,4. We have developed the high speed SPD using sinusoidally gated (SG-) APD (3. The SG-APD has high quantum efficiency (~10%) with a low dark count probability per gate (~10^{-5}). Then, it achieved a gating repetition frequency of 800 MHz (4, and was utilized for the high-speed QKD experiment (5.

In this letter, we show the recent progress of the SPD based on the SG-APD. Optimizing the electronics incorporated into the SPD, the missing avalanche signals drastically decreased. As a result, our SPD has been achieved a gating frequency of 1.5 GHz with a low afterpulsing probability.

Sinusoidally gated avalanche photodiode

The tested InGaAs/InP APD is AGD-25-SE-1-T8 (Princeton Lightwave). The APD chip is mounted on the three stages Peltier cooler, and they are housed in TO-8 package. The APD module was used as the single-photon detection element after it was fiber-pigtailed. Figure 1 shows the schematic diagram of the SG-APD. The APD was driven by the gated passive quenching circuit (3. The sinusoidal voltage with a frequency of ω was used as the gate voltage. The output from the APD passed through the band elimination filters (BEF) centered at a frequency of ω to remove the gate voltage transferred from the APD. Here, the elimination ratio of the BEFs was 80~100 dB at ω. The outputs (avalanche signal) distilled by the filters were amplified by 40 dB and discriminated

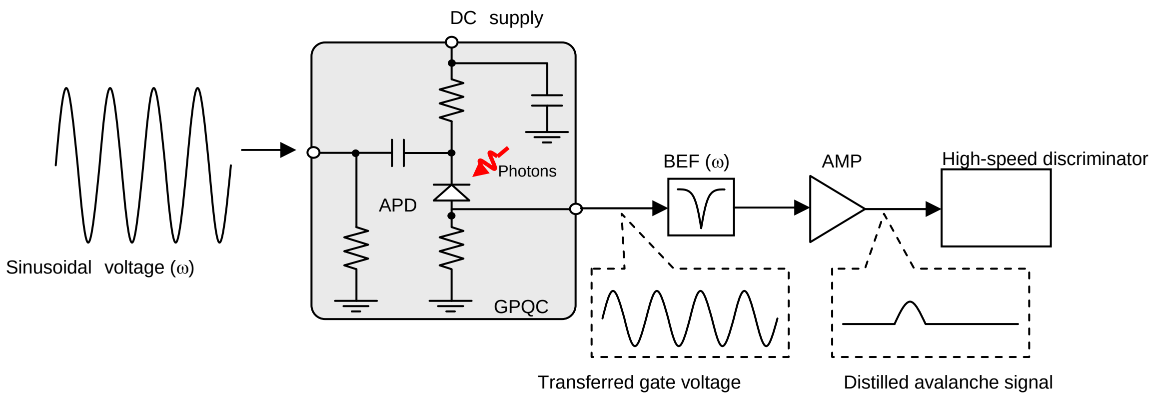

Figure 1: Single-photon detection using the sinusoidally gated avalanche photodiode.
GPQC: Gated passive quenching circuit, BEF: Band elimination filter, AMP: Amplifier.

by a high-speed discriminator that accepted subnanosecond pulses.

Our SPD module containing the APD, the Peltier cooler and the GPQC is highly compact (dimension: 80 × 50 × 80 mm), which is advantageous to the application to practical QKD systems.

SPD performances

We measured the quantum efficiency (for the 50 ps optical pulse at 1550 nm), the dark count probability and the afterpulsing probability of the SG-APD. The APD was cooled at -35 degree Celsius. Figure 2 (a) shows the relation between the quantum efficiency and the dark count probability per gate when the frequency of the sinusoidal gate voltage was 1.03, 1.20, and 1.50 GHz. As shown in the figure, at a gating frequency of 1.03 GHz, the dark count probability per gate was 1.4×10^{-6} with a quantum efficiency of 10%. As regards 1.50 GHz, the dark count probability per gate was 5.1×10^{-7} with a quantum efficiency of 5.1%. The dark count probabilities are one order of magnitude lower than that obtained previously. Figure 2 (b) shows the relation between the quantum efficiency and the afterpulsing probability. The intrinsic afterpulsing probability would be higher than the measurement results plotted in the figure, since the discriminator we used has a 50 ns dead time in which the avalanche signals were not detected (Maximum detection rate: 20MHz). At a gating frequency of 1.03 GHz, the afterpulsing probability is only 1.7% with a quantum efficiency of 10%. As regards 1.20 GHz and 1.50 GHz, the quantum efficiency must be reduced to 5~7% so that the afterpulsing probability is decreased to several percent. At 1.50 GHz, the afterpulsing probability was 2.3% with a quantum efficiency of 5.1%.

We investigated a jitter characteristic of our SG-APD by use of a time interval analyzer. The measured histogram of the photon-detection events showed that our SPD had a timing jitter of less than 100 ps (FWHM). However, since a tailing feature exists in the jitter characteristic, a fraction (1~2%: depends on the quantum efficiency) of the detection events caused the erroneous clicks.

Conclusions

We demonstrated that the SG-APD can be operate at gating frequency of greater than 1 GHz with high quantum efficiency at telecommunication wavelength, a low dark count probability and a low afterpulsing probability. The SG-APD will be able to realize a long distance QKD with high communication rate.

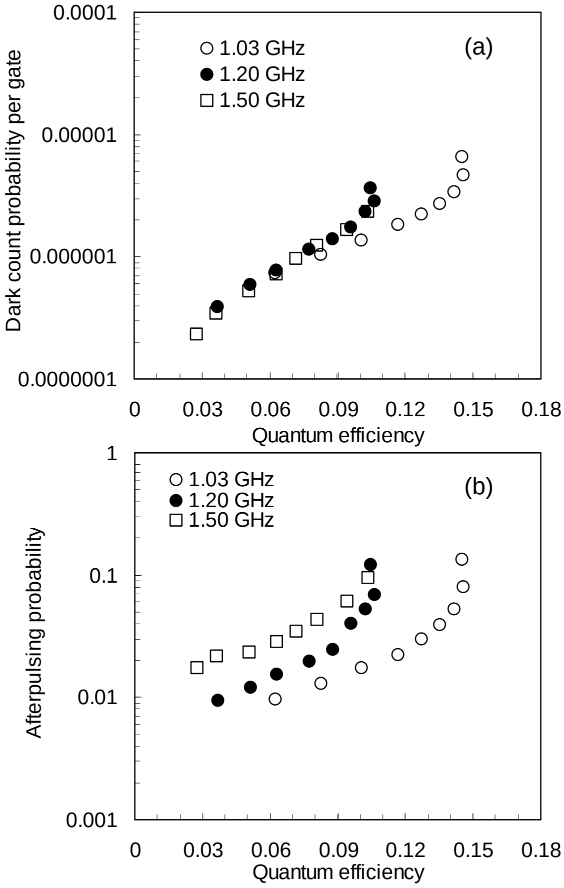

Figure 2: Performances of the SG-APD when the gating frequency was set to 1.03, 1.20, and 1.50 GHz. (a) the relation between the quantum efficiency and the dark count probability per gate. (b)the relation between the quantum efficiency and the afterpulsing probability

Acknowledgements

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