A Gated-mode Single-Photon Detection System for Quantum Key Distribution Using InGaAs Avalanche Photodiodes

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Abstract. We have established a gated-mode single-photon detection system for quantum key distribution using pigtailed InGaAs avalanche photodiodes, which are mounted in a special designed liquid nitrogen cryostat. With a 50GHz digital sampling oscilloscope, the gated-mode single-photon detection process is illustrated easily. The performance of two diodes as single-photon detectors at a 1310nm wavelength has been investigated. At the operation temperature 223K, from one sample, we have obtained a quantum efficiency of 11.2% with a dark count probability per gate of 0.77×10^{-5}.

Keywords: single-photon detection system, quantum key distribution, InGaAs avalanche photodiodes, 50GHz digital sampling oscilloscope

We choose InGaAs avalanche photodiodes (APD), whose reverse bias voltage exceeds the breakdown voltage slightly during a few nanoseconds that is so called gated-mode, for the quantum key distribution (QKD). [1, 2, 3, 4] In our detection system, the APDs can be easily mounted in a special designed liquid nitrogen cryostat, whose temperature can be changed from 77K to 323K with 0.1K step. So we can investigate the performance of APDs within a wide dynamic range. By a single mode fiber and SMA type semi-rigid coaxial cables the single-photon signal and the bias are applied to the APD. And also, with the steely vacuum shell around, it can shield the environmental disturbance effectively.

Figure 1 shows the schematic setup of measuring the dark count probability P_{dark} and the quantum detection efficiency η, which are essential parameters for QKD. It is similar to the schemes mentioned in reference 3 and 4. In this experiment, the voltage pulse generator produces rectangular pulses with an amplitude of 2.52V and a full width at half maximum (FWHM) 4.266ns at a frequency of 10KHz. It also triggers the laser pulse generator that produces the pre-trigger signals and the pulse laser signals. The half-height point on the rising slope of the pre-trigger signal is chosen as the time reference point of the experiment system. There is a constant delay (about 74.625ns) between the reference point and the laser

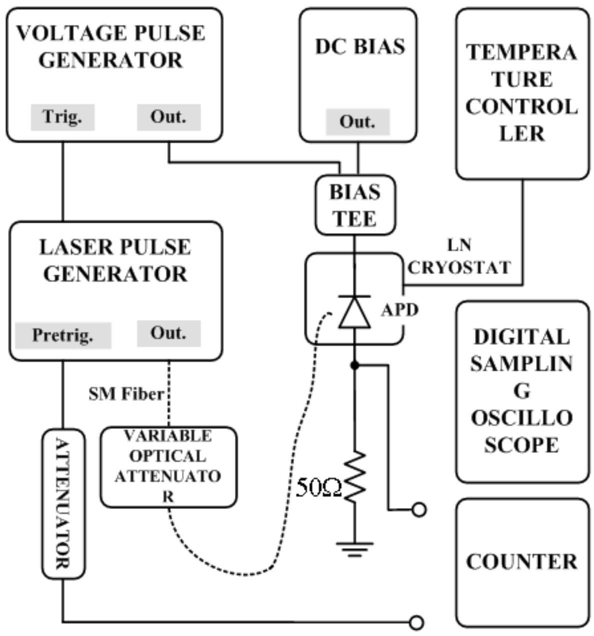

FIG. 1. Schematic diagram of the experiment setup to measure the dark count probability and the quantum efficiency of the gated-mode single-photon detection system

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signal. The laser pulse has a FWHM 34ps and an area 6.92pVs, which is provided by the inside area-function of the oscilloscope. After calculation, the pulses are attenuated to single-photon level per pulse by a variable optical attenuator (0-110dB, 0.1dB step).

The performance of two low noises APDs of the same type and from the same manufacturer is investigated in this experiment. Sample 1 has 47.3V and sample 2 has 45.2V breakdown voltage and almost the same dark current level 10^{-13}A at temperature 223K. Discrimination and counting of the APD output are performed by the digital sampling oscilloscope and photon counter. By disconnecting or connecting the optical fiber, the illumination of the APD can be turned off or turned on. Using the photon counter we can measure P_{dark} and the light count probability P_{count}. Taking the Poissonian statistics of the number of photons per pulse into account, we can estimate the η (see reference 3).

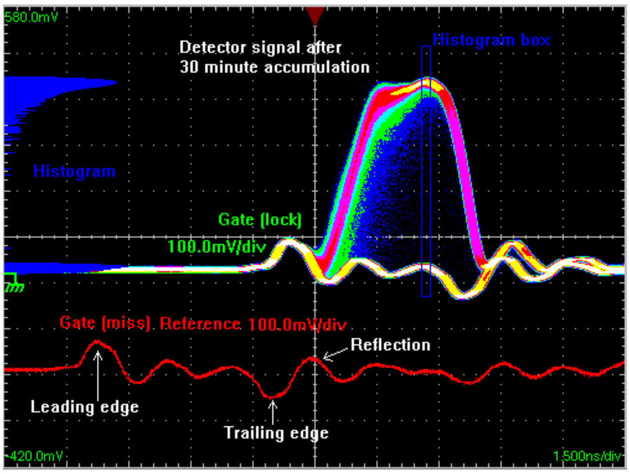

FIG. 2. Output of an APD at 223K and 50V DC bias. The curve "Gate (miss)" indicates the asynchronous between gate signal and single-photon signal. The curve "Gate (lock)" illuminates the gated-mode detection operating. The histogram shows the distribution of the sampling points.

The figure above illuminates the synchronousness and the single-photon detection process. It is the sample 1 at 223K with 50V DC bias and about 0.6 photons per pulse. The curve named "Gate (miss)" is the output of the APD when the photon does not arrive within the gate time. The over-shootings named "Leading edge" and "Trailing edge" indicate the position of the voltage gate pulse. The reflections following it may lead to similar effect as after-pulse when avalanche happens. We choose strictly the threshold level and the count gates' position and width of the photon counter to eliminate the influence of reflections. The curve named "Gate (lock)" shows the avalanche output by tuning the delay of the voltage pulse generator to achieve synchronousness. We can see the single-photon detection happening. The histogram after 30 minute accumulation gives the distribution of the sampling points. Those who have high amplitude (280mV-440mV) indicate the sum of the dark-count points and photo-count points. The peak at 0mV represents that no photon arrives (mainly because of the Poissonian statistics) or the APD does not act with the single-photon signal. It is helpful to fixing on the proper setup of the photon counter. From sample 2, at 223K, with a 43.25V DC bias and a 300mV threshold of the photon counter, we obtain a η of 11.2% with P_{dark} of 0.77×10^{-5}.

In conclusion, the performance of a gated-mode single-photon detection system using InGaAs avalanche photodiodes is investigated by a simple method cooperating use digital sampling oscilloscope and photon counter. From one sample, we achieved a quantum efficiency of 11.2% with a dark count probability 0.77×10^{-5} per gate.

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