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POSSIBILITY OF PHOTON COUNTING IN NEAR INFRARED (0.8$\sim$1.5μm) REGION BY Ge-APD

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1. INTRODUCTION

Photon counting is an effective method of extremely weak light detection and has been studied for a long time [1)]. Photomultiplier tube (PMT) as a photon counting detector has wide detection areas and high sensitivity at the wavelength of ultra violet and visible region. PMT, however, has a quite low quantum efficiency at the wavelength of near infrared region over $1\mu m$. Avalanche photodiode (APD) has high quantum efficiency at this wavelength region, and several studies used APD have been made recently [2~5)].

The purpose of our study is aerosol observation by lidar with laser wavelength of $1.0 \sim 1.5\mu m$. We have studied on germanium avalanche photodiode (Ge-APD) cooled thermoelectrically by Peltier device and by liquid nitrogen. In this paper we report an experimental study on the possibility of photon counting by Ge-APD and discuss the application to a lidar.

2. EXPERIMENTAL APPARATUS

The experimental apparatus is shown in Fig.1. The detector device is Ge-APD (FPD-13R51KS: Fujitsu) with multiple mode optical fiber (core diameter: $50\mu m$). The APD was attached to the block of copper that was soldered to the bottom of stainless steel vessel. Temperature was measured by copper-constantan thermocouple with diameter of $0.127mm$. The dewar was evacuated to about $5 \times 10^{-2} Torr$ by vacuum pump for keeping out of dewdrop. The APD was biased by high precision stabilized power supply and the voltage and temperature were measured by multimeter. Output signal from APD was amplified by preamplifier that had gain of $42dB$ and bandwidth of $300MHz$, and it was discriminated and counted by dual channel gated photon counter (SR400: Stanford Research Systems).

The light source was a $1.3\mu m$ light emitting diode (LED) and was measured previously by optical power meter (ML910A, MA9302A: Anritsu). The light intensity was decreased by inserting calibrated neutral density filters. The light was introduced to the Ge-APD through the optical fiber.

Synchronous single photon counting (SSPC) technique was used in the experiment. The LED was driven in $10kHz$ rectangular pulses with turn-on and turn-off states, and the pulse counter gate was opened for $30\mu s$ for each state. The net photon pulses was obtained by subtracting the dark pulses in turn-off state from the photon and dark pulses in turn-on state. The mean number of photon pulses was obtained after averaging over 2×10^5 times.

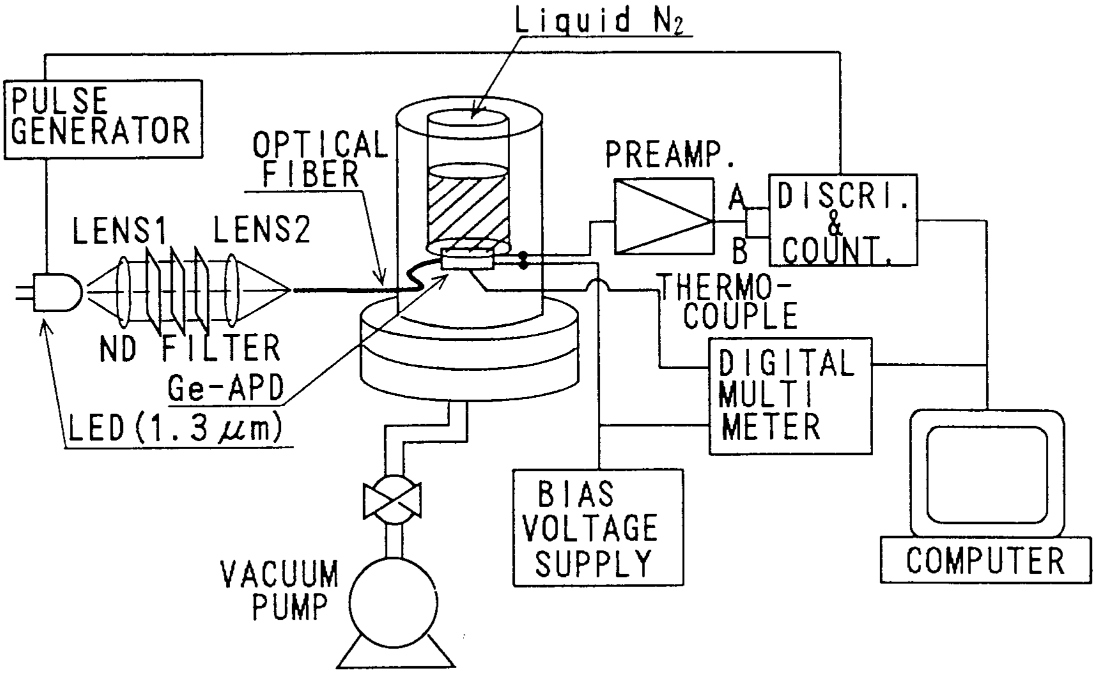

Fig. 1: Schematic structures of the detector and experimental setup

3. EXPERIMENT

The variations of dark and photo current with bias voltage are shown in Fig.2. At the low bias voltage the dark current at liquid nitrogen temperature is decreased by a factor of 10^5 or more compared with that at room temperature. The slope of current near the breakdown voltage is increasing with decreasing temperature.

The differential pulse height distribution measured at liquid nitrogen temperature for an incident optical power of $2.8 \times 10^{-11} W$ is shown in Fig.3. It is found that the signal can be separated clearly from noises. From this result, it is suggested that the Ge-APD cooled by liquid nitrogen is applicable to a photon counting detector in near infrared region.

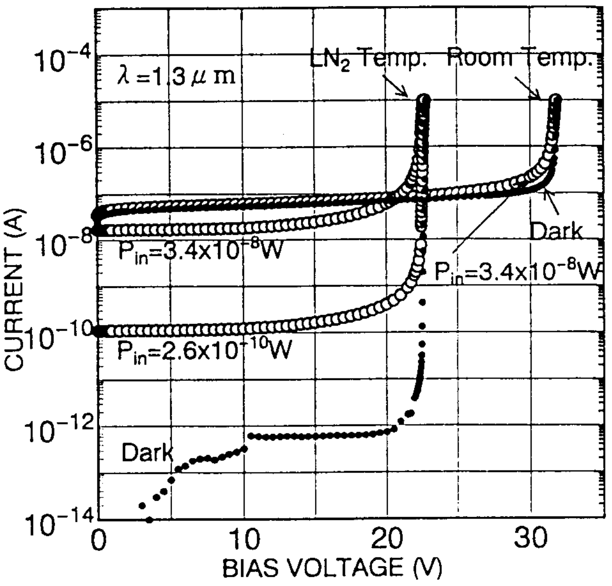

Fig. 2: Characteristics of bias voltage vs. dark and photo current

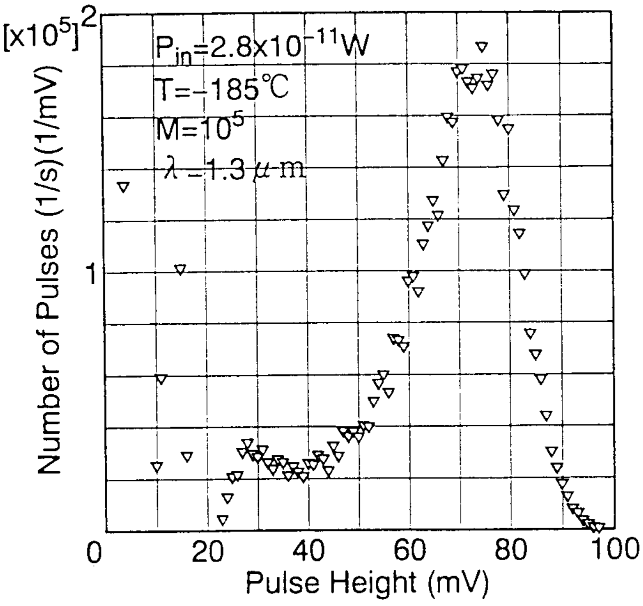

Fig. 3: Differential pulse height distribution

The variations of the number of output pulses with the incident optical power at liquid nitrogen temperature and at $-45°C$ are shown in Fig.4, respectively. The dynamic range at liquid nitrogen temperature of about $30dB$ ($2.3 \times 10^{-14}W \sim 2.8 \times 10^{-11}W$) is obtained, which is similar to that at $-45°C$. The lower detectable limit is improved by a factor of 10 compared with that at $-45°C$ because of reduction of the dark pulses. However the upper detectable limit is decreased by a factor of 10 compared with that at $-45°C$ because the bandwidth of the APD is decreasing with increasing the multiplication gain ($M = 2 \times 10^3 \rightarrow 10^5$).

The dependences of signal-to-noise ratio on incident optical power also are shown in Fig.4. The signal-to-noise ratio is given as

$$SNR = \frac{N_s}{\sqrt{N_s + 2N_d}} \tag{1}$$

where N_s is the number of signal pulses and N_d is the number of dark pulses, respectively. The SNR at liquid nitrogen temperature is improved by a factor of 25 compared with that at $-45°C$, because of reduction of the number of dark pulses and of increase of the number of the signal pulses. It is found that the incident optical power of $10^{-14}W$ is detectable at $SNR = 10$.

The receiving photon number per gate of $6.6\mu s$ ($1km$ resolution) in our lidar system is about $1 \sim 100$ counts after averaging over 100 laser shots. This means the number of photon is $10^5 \sim 10^7/s$ and the optical power is $10^{-14} \sim 10^{-12}W$. This suggests that Ge-APD detector has the possibility for applying to a lidar.

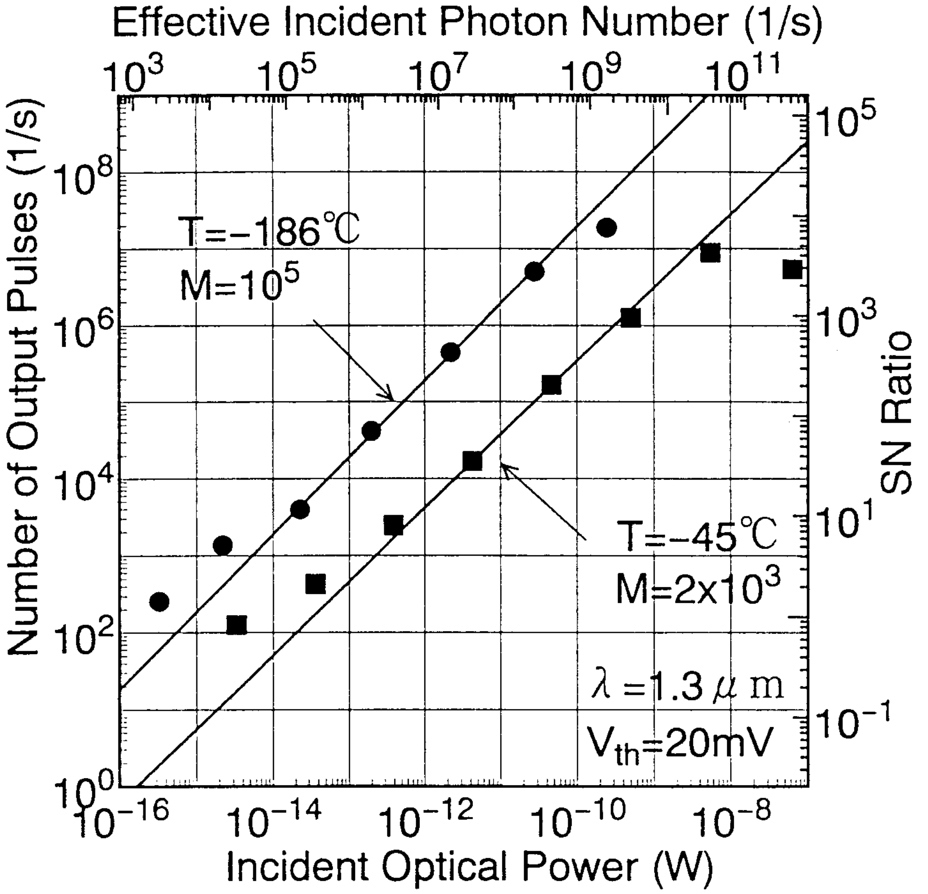

Fig. 4: Measured characteristics of incident optical power vs. output pulses and signal-to-noise ratio

4. CONCLUSIONS

Experimental studies have been made on weak light detection using Ge-APD cooled by liquid nitrogen. The dark current at the low bias voltage is decreased by a factor of 10^5 compared with that at room temperature. From the differential pulse height distribution, it is suggested that the Ge-APD cooled by liquid nitrogen is applicable to a photon counting detector in near infrared region. The dynamic range of about $30dB$ ($2.3 \times 10^{-14}W \sim 2.8 \times 10^{-11}W$) is obtained. The incident optical power of $10^{-14}W$ is detectable at $SNR = 10$.

This detector is available for photon counting eye-safe lidar. We are now planning to test a lidar with this detector.

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