PROCEEDINGS OF SCIENCE

Study of PPDs with multi-wavelength laser microscope system

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Measurement of PPD (Pixelated Photon Detector) characteristics with various wavelengths is important for understanding and improvement of the sensor performances. We have been developing a new pulsed laser microscope system whose wavelength is continuously tunable from 410 nm to 2200 nm by using OPO laser system. Laser spot can be focused to $\sim$2 μm, small enough to measure pixel-by-pixel performance of PPD. Based on the feedback from commissioning, we have made several improvements which are essential for further detailed studies of the PPD. In this report, we will report improvements of the laser microscope system and test measurements using the new system.

International Workshop on New Photon-detectors,
June 13-15, 2012
LAL Orsay, France

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PoS(PhotoDet 2012)007

1. Introduction

Measurement of PPD (Pixelated Photon Detector) characteristics with various wavelengths is important not only for variety of applications but also for understanding and improvement of the sensor performances. By using different wavelength lights, we can study sensor behavior in various depths, thanks to their different penetration lengths to silicon. Recently it was reported that the voltage dependence of PDE (photon detection efficiency) varied with wavelength[1]. Its behavior reproduced results from device simulation[2]. They used combination of four monochromatic LEDs for light sources. To investigate further in more detail, focused lights with continuous wavelength could be useful. On the other hand, it would be difficult to measure PDE precisely in the presence of cross-talk and after-pulsing using a halogen lamp with a monochrometer.

Thus we are motivated to develop a new laser microscope system which generates tunable multi-wavelength light using optical parametric oscillators (OPO) in a nonlinear crystal. Such microscope system can probe position dependence and uniformity of PPDs which are essential parameters when designing PPD pixel layouts.

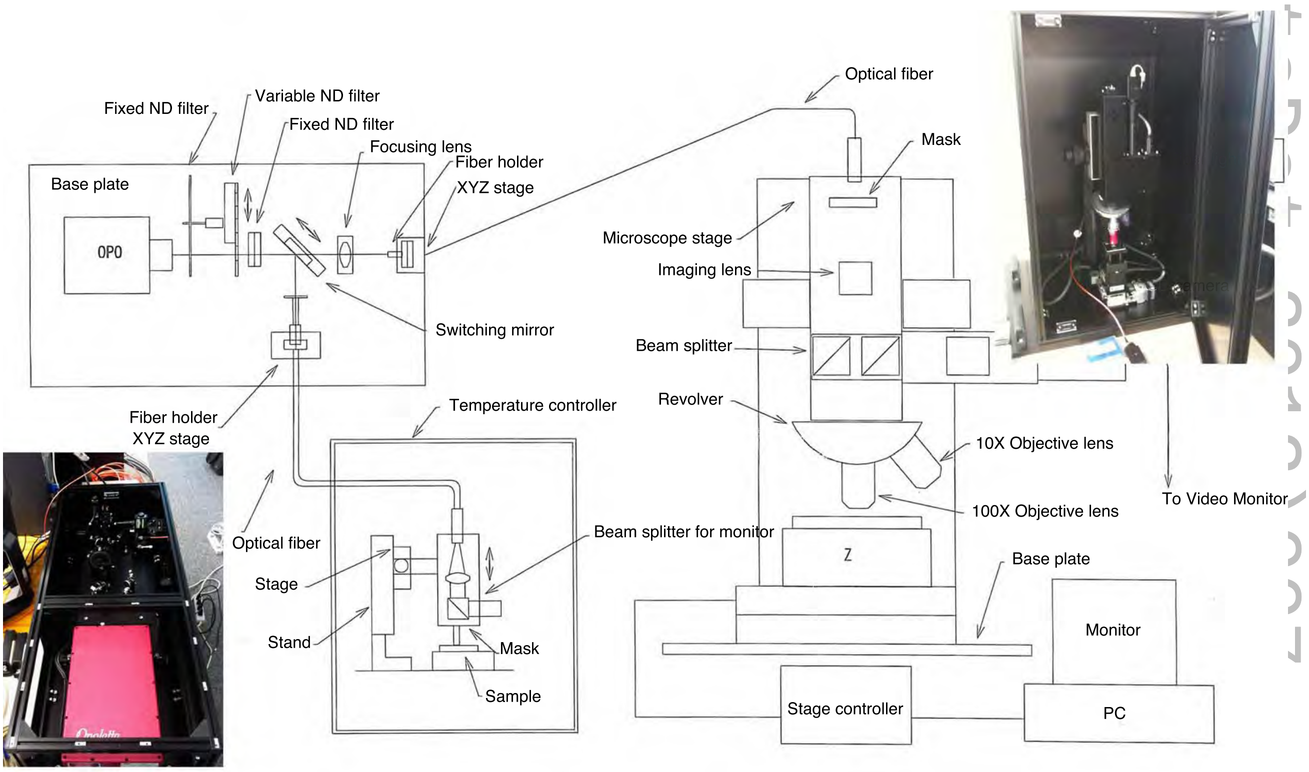

Figure 1: Schematic drawing with photos of the laser microscope system

Table 1: OPO laser specification[4]

Wavelength Tuning Range	410 – 2200 nm
Peak OPO Energy	3.5 mJ
Spectral Line width	$\sim$ 4– 7 cm^{-1}
Polarization	Signal: Horizontal, Idler: Vertical
Pump Laser	Nd:YAG (355 nm)
Repetition Rate	20 Hz
Pulse length	5 ns
External Trigger	Lamp and Q-Switch

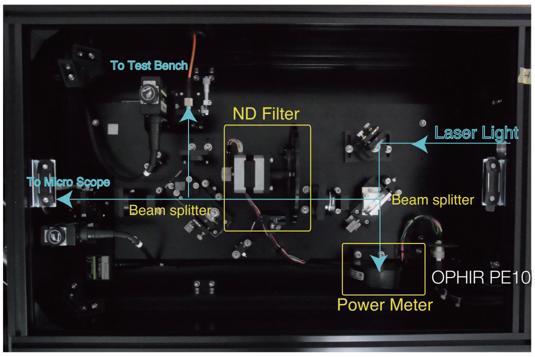

Figure 2: Modification in the laser optical system.

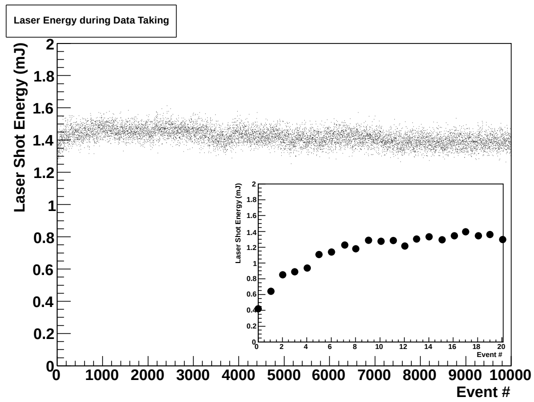

Figure 3: Time variation of the laser shot energy for 10000 pulses (500 sec)

2. Multi-wavelength laser microscope system

Figure 1 shows schematic drawing the whole system and Table 1 summarizes the specification of the OPO laser source. Wavelength can be continuously tunable from 410 nm to 2200 nm by using PC control system. The pulse width and repetition, are respectively, 5 ns and 20 Hz. Laser light is fed into the microscope system through optical fiber and is focused to $\sim 2\mu$m, small enough to measure pixel-by-pixel performance of PPDs. Laser output is also transported to another bench, where we can test temperature and humidity dependence of the sensors.

2.1 Evaluation and Refinement of the laser system

The system has already started commissioning and we have checked basic performance of the system. The results basically reproduce the catalog specification. Alignment of the microscope system was successfully done and a spot size of about 2 μm was achieved. Line width is very sharp in the whole wavelength and there observed no contamination[3]. During the commissioning and the pilot measurements, however, we found several issues in the laser system. Stability of the laser output power was not as stable as expected. In addition, repetition rate is rather low (20 Hz at maximum) and it takes a long time to accumulate the good statistical data. Thus, we refined the system to improve the laser performance as described below.

2.1.1 Laser Power monitoring and stabilizing

We installed the pyroelectric laser energy sensor (OPHIR PE10 and Pulsar) as shown in Fig.2 to measure the energy of the laser light shot-by-shot. Now we can monitor the fluctuation of the laser energy while we measure the photon sensor response using the same shot.

Figure 3 shows an example of the laser energy fluctuations during a data taking period for gathering 10000 events. It is clearly seen that the energy rapidly increase in the first few tens of pulses and then become stable. Using the energy information in the off-line analysis, we now could correct or eliminate the effect of the laser power fluctuation. We also installed temperature control system which keep the temperature of the whole laser system constant.

2.1.2 Automating measurement

In the previous measurements, we need to take a manual operation by an operator: e.g. exchanges of the sensor samples, adjustments of bias high voltage, laser tuning to the optimum value for the sensor performance measurements and so on. As a result, there existed large overhead costs and possible human errors. Now we add a new stage control system with wide span, which enables to switch several sensors for comparison as shown in Fig.4. And remote-controlled ND filter was installed, which can be adjust the laser power to relevant value for photon sensor calibration. Every parameter can now be set by remotely and we do not need touch the setup during whole data-taking periods. In the future, we plan to develop a full-automated system for various parameter scans, wave length, high voltage, pixel position, and etc.

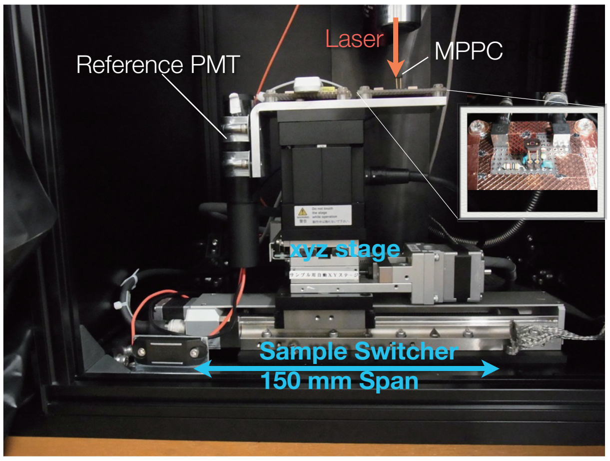

Figure 4: New wide-span stage for switching samples.

3. Measurement of PDE with a focused laser light

To check these improvements and evaluate the performance of the new system, we made a pilot experiment, which measure PDEs of a MPPC with several wavelength and with varied bias voltages.

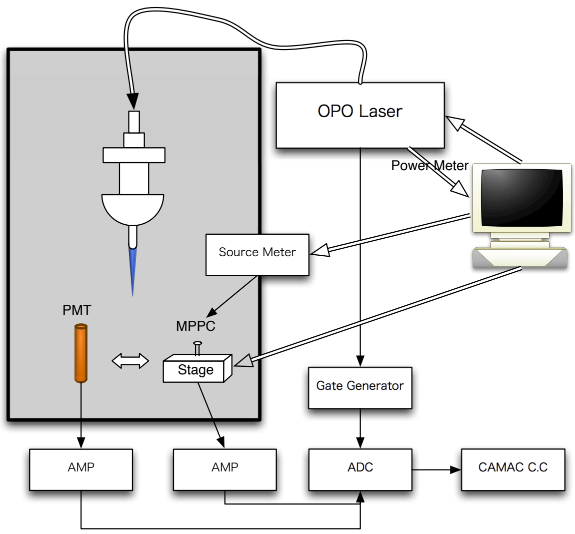

Figure 5: Experimental setup for the pilot measurements of PDEs.

3.1 Experimental Setup

The setup for the measurement is shown schematically in Figure 5. The laser light from the microscope alternately irradiated two photon sensors, a MPPC and a reference PMT. The MPPC was used to measure the PDE and the reference PMT was used to normalize the light output from the laser microscope with use of the power meter information. For the MPPC, we used a Hamamatsu S10362-11-50c with a 1 mm^2 sensor area and pixel size of 50 μm $\times$ 50 μm. For the reference PMT, we used a Hamamatsu H4535MOD having a ϕ15 mm photo cathode area. The reference was calibrated with a reliable light source. The detailed data on its quantum efficiency and its collection efficiency was provided by the manufacturer. The output signal from each sensor was amplified and charge-integrated over 150 ns gate by a charge sensitive ADC. From the ADC distributions, we derived the number of photoelectrons for each sensor as described later. Finally we obtained the PDE of the MPPC by comparison with the reference data and its photo detection efficiency (i.e. quantum efficiency $\times$ collection efficiency).

3.2 Estimation of number of photoelectrons

In the data, several photoelectron peaks are clearly discernible up to four photoelectrons. The large fraction of three or four photoelectrons may indicate the existence of crosstalk and/or after-pulsing. In obtaining the mean number of photoelectrons from this distribution, we used the probability of zero photoelectron (pedestal) instead of the whole ADC distribution to eliminate crosstalk, after-pulsing, and/or pileup effects as follows:

If we assume that the distribution follows Poisson statistics, the probability of detecting n photoelectrons is :

$$P(n) = \mu^n e^{-\mu} \tag{3.1}$$

where μ is mean number of photo electrons. Although existence of the crosstalk, after-pulsing and pileups onto the same pixel, could distort the probability distribution, the probability of zero photoelectrons is not be affected:

$$P(0) = N_{ped}/N_{all} = e^{-\mu} \tag{3.2}$$

where N_{ped} and N_{all} indicates number of pedestal events and all events, respectively, after collecting the dark noise count rate. Thus, the mean of number of photoelectrons is obtained from the following equation:

$$\mu = -ln(N_{ped}/N_{all}) \tag{3.3}$$

3.3 Results

The preliminary result was shown in Fig.6. We obtained bias voltage dependence of PDE (0.25 $\sim$ 1.1 V) with twelve wavelengths (410, 435, 460, 485, 510, 535, 560, 585, 610, 660, 710, 760 nm). For every bias voltage, we clearly observed the bumpy structure which was not seen in the data sheet. We are now investigating the cause of these structures and have not found the clear answer yet. We checked the stability of the reference PMT and found no problem. Anti-reflective coating on the surface of the MPPC might cause them. We will continue measurements with more statistical and with more wavelengths as well as different types of MPPC/SiPM with various surface conditions.

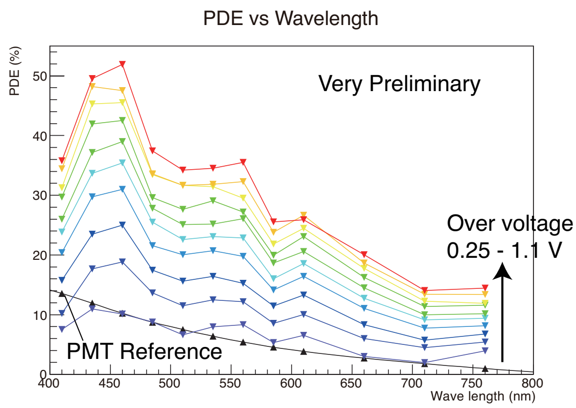

Figure 6: Very preliminary result of wavelength dependence of MPPC PDE.

4. Summary

We have developed an OPO laser microscope system, which can be utilized to study PPDs. After the first commissioning run, we have improved the system which enabled more reliable measurements. In the pilot measurement with the new system, it worked well as we expected although there were strange behavior in the wavelength dependence of the PDE. To understand the result, we continue measurements as well as position scans with deferent types of the MPPC. We will also test other PPDs, such as Zecotek SiPM, AdvanSiD, SenSL and etc. and compare results.

References

[1] D. Orme, "Measurement of PDE of MPPC with different wavelength of light", Proceedings of Science, International Workshop on New Photon Detectors (PD09), June 24–26, 2009, Shinshu University Matsumoto JAPAN. Pos(PD09)019

[2] H. Oide, T. Murase, H.Otono, S. Yamashita, "Studies on Multiplication Effect of Noises of PPD, and a Proposal of a New Structure to Improve the Performance" Nuclear Inst. and Methods in Physics Research, **A 613** (2010), pp. 23–28.

[3] K. Yoshimura and I. Nakamura, "Multi-wavelength study of PPDs using an OPO tunable pulse laser microscope system", Nuclear Instruments and Methods in Physics Research, **A 695** (2012), pp 197–201.

[4] http://www.opotek.com/data_sheets/Opolette_355II_UV.pdf