Measurements of Low-energy X-rays with a Detector Using a Plastic Scintillator and an MPPC

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(Received February 26, 2019)

An MPPC (Multi-Pixel Photon Counter) has some advantages of a low-voltage operation and easily making a multi-element type detector, when comparing with a photomultiplier tube. We tried to detect soft X-rays of less than 6 keV with a scintillation detector using an MPPC. The detector consists of a plastic scintillator (Pilot-U, 5 mm in diameter and 1 mm thick) and an MPPC (Hamamatsu Photonics, S13360-6642, 3×3 mm², pixel size: 25 μm, without a resin window). We measured pulse-height spectra using a charge-sensitive preamplifier, cooled down to −10°C. The detector could clearly distinguish 6 keV X-rays from noise signals. We also measured time spectra of X-ray pulse structure of 2-ns intervals in the multibunch operating mode of the Photon Factory ring. A time resolution (Full width of half-maximum) of 0.51±0.06 ns was obtained at a bias voltage of +60.0 V and at −10°C, using a fast amplifier having a gain of 100.

KEYWORDS: Soft X-ray, Synchrotron radiation, Scintillation detector, Plastic scintillator, MPPC, Time resolution

1. Introduction

A Geiger-mode avalanche photodiode (APD) operates in a large gain of 10⁵-6, at a low voltage of ~50-70 V. The device is made of silicon and its photon sensitivity for 300-600 nm is available like a photomultiplier (PM) tube. That is therefore called as a Si-PM. Comparing with a proportional- or linear-mode APD, the large gain will also be useful to obtain an output pulse caused by a low energy X-ray. In synchrotron radiation researches using soft X-ray region, channel electron multipliers, like microchannel plates (MCPs), are often used for detecting soft X-rays of <several keV as well as electrons. Si-PMs (or MPPCs [1]) have an advantage in fabricating a pixelated detector operated in a low voltage, comparing with MCPs. Observation of spin structure in a magnetic thin film is planned with the fluorescence-yield depth resolved XAS technique [2]. In this method, a two-dimension pixelated detector for soft X-ray region is much useful. We also expected fast response of nanosecond order in measuring time spectra for X-rays. We therefore tried to use the Si-PM as a photodetector coupled with a fast plastic scintillator.

2. A scintillation X-ray detector using a plastic scintillator

A prototype detector using a fast plastic scintillator (Pilot U, 2.5 mm×2.5 mm, 1 mm
thick) and an MPPC (Hamamatsu Photonics S13360-6642, 3 mm×3 mm, pixel size: 25 μm, V_{op}=+56.21 V) was fabricated, as shown in Fig. 1. Figure 1(a) shows outside of the prototype detector. The detector case was made of aluminum. Inside of the case, the scintillator and the MPPC device were mounted on a copper holder and their temperature was controlled with a Peltier device, as shown in Fig. 1(b). The temperature was monitored by a Platinum 100 Ω resistor. Pilot U (equivalent to EJ-230, Eljen Technology) has a fast decay time of 1.4 ns of its scintillation light, of which yield is 10,200 photons/MeV [3]. The MPPC device has no resin window for a better efficiency of scintillation light. The 1-mm thickness of the scintillator corresponds to an X-ray efficiency of 87% at 6 keV [4].

3. Performance of the detector tested by using synchrotron 6 keV X-rays

3.1 Measurement system

Performance of the detector was tested by using synchrotron 6 keV X-rays at beamline BL-14A of the Photon Factory (PF) ring.

Pulse-height spectra were measured with a charge-sensitive preamplifier (Canberra 2005, gain: 22.7 mV/pC) and a normal spectroscopy system shown in (A) of Fig. 2. Time spectra of X-ray pulse structure in the multibunch mode operation of the PF ring were recorded with the detector. The measurement system for time spectra is shown in (B) of
Fig. 2. A wideband amplifier of gain 100 (Phillips Scientific 6954) was used for a low-voltage operation of MPPC. Outputs from the fast amplifier were inverted to be negative by an inverting transformer (Picosecond Pulse Labs, Model 5100) and an output waveform is shown in Fig. 2. Timing was picked up with a constant-fraction discriminator (ORTEC 935, CFD) and time spectra were obtained with a time-to-analog converter (ORTEC 566) and a multichannel analyzer.

3.2 Experimental results

The count rate of the charge-sensitive preamplifier in (A) of Fig. 2 was adjusted to be ~1k cps with copper filters. The applied bias voltage was first set at +58.0 V and the temperature was 20°C. The pulse-height spectrum at the condition is shown in Fig. 3(a). After that, the scintillator and MPPC were cooled from 20°C to −10°C to suppress the thermal noise and obtain a larger gain of MPPC. X-ray signals were able to be fairly separated from the noise signals at −10°C and +60.0 V, as shown in Fig. 3(b). The MPPC gain increased to 2.3 times by a peak-position of 135 ch in Fig. 3(a) and the signal-to-noise ratio was 1.1 (= 305/271ch).

Figure 4 shows a time spectrum of X-ray peaks with 2.0 ns interval. A time resolution of 0.51±0.06 ns (Full width at half maximum, FWHM) was obtained with the prototype detector. The detector condition was the same as that shown in Fig. 3(b). The threshold level of the CFD was −220 mV to the averaged pulse amplitude of −350 mV, and the amplifier output rate was ~49k cps.
4. Conclusion

The experimental results mean that the scintillation detector using a fast plastic scintillator and an MPPC can be useful in time spectroscopy measuring 6 keV X-rays in sub-nanosecond timing by cooling. At lower energies of X-rays, we need a larger light yield of a scintillator and/or a lower noise level of an MPPC.

Acknowledgment

The experiment was executed under the approval of the Photon Factory Advisory Committee (proposal no. 2016G047).

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