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Measurement of X-ray spectra using a $Lu_2(SiO_4)O$-multipixel-photon detector with changes in the pixel number

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HIGHLIGHTS

- Zero-dark-counting X-ray detection was performed under pre-Geiger mode.
- 200-ns-width event pulses were produced by a high-speed amplifier.
- X-ray spectra were measured using three LSO-MPPC detectors.
- Energy resolution improved with decreasing MPPC pixel number.

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ABSTRACT

To measure X-ray spectra with high count rates, we developed a detector consisting of a $Lu_2(SiO_4)O$ [LSO] crystal with a decay time of 40 ns and a multipixel photon counter (MPPC). The photocurrents flowing through the MPPC are converted into voltages and amplified by a high-speed current–voltage amplifier, and event pulses from the amplifier are sent to a multichannel analyzer to measure spectra. We used three MPPCs of 100, 400 and 1600 pixels/mm^2, and the MPPCs were driven under pre-Geiger mode at a temperature of 20 °C. At a tube voltage of 100 kV and a tube current of 5.0 μA, the maximum count rate was 12.8 kilo-counts per second. The event-pulse widths were 200 ns, and the energy resolution was 53% at 59.5 keV using a 100-pixel MPPC.

1. Introduction

To measure X-ray spectra, we usually use a fairly available cadmium telluride (CdTe) detector with a photon energy resolution of 1% at 122 keV, and the detector has been applied to a linear X-ray scanner in a photon-counting energy-dispersive computed tomography (ED-CT) systems (Matsukiyo et al., 2011; Sato et al., 2012; Shimamura et al., 2014; Hagiwara et al., 2014). Subsequently, a preclinical ED-CT system with a CdTe detector array (Feuerlein et al., 2008; Wang et al., 2011) has been developed to perform enhanced *K*-edge CT using contrast media in Medical Imaging. However, it was difficult to increase the count rate to reduce X-ray exposure time for ED-CT without pileups of the event pulses produced by the photon absorptions.

Recently, we have developed a low-energy-resolution ED-CT systems (Oda et al., 2011; Maeda et al., 2012) using a short-decay-time scintillators and a multipixel-photon-counter (MPPC) module. Using a zinc-oxide (ZnO) single crystal (Simpson et al., 2003; Sugimura et al., 2011; Sato et al., 2012), although the count rate has been increased to 15 megacounts per second (Mcps), it is difficult to measure the X-ray spectra owing to 1-Mcps dark count rate. In view of this situation, a zero-dark-counting detector with a 400-pixel MPPC and a cerium-doped yttrium aluminum perovskite [YAP(Ce)] crystal have been developed and applied in an ED-CT system (Kami et al., 2014). The energy resolution of the detector was approximately 100% at 59.5 keV, and the energy resolution of a detector consisting of $Lu_2(SiO_4)O$ [LSO] and an MPPC should be measured because the light yield of the LSO is higher than that of the YAP(Ce). Furthermore, there are three MPPCs of 100, 400 and 1600 pixels/mm^2, and we are interested in the characteristics of the LSO-MPPC detector with changes in the pixel number.

In the present research, our major objectives are as follows: to

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develop three LSO-MPPC detectors, to measure X-ray spectra with energies below 100 keV, to determine energy resolution with changes in the pixel number, and to develop a product of a photon counting module. Therefore, we carried out zero-dark-counting high-speed photon detection using LSO single-crystal scintillators and three MPPCs and measured X-ray spectra.

2. Experimental methods

2.1. Spectrum measurement using LSO-MPPCs

Fig. 1 shows the block diagram for measuring γ- and X-ray spectra using an LSO-MPPC detector. There are three MPPCs of 100, 400 and 1600 pixels/mm^2 (S12571–100C, -050C and -025C, Hamamatsu), and we developed three LSO-MPPC detectors. The structure of the LSO-MPPC detector is shown in the same figure, and an LSO crystal of $1.0 \times 1.0 \times 1.0$ mm^3 is stuck on the light-receiving surface of the MPPC and is covered with an Al cap with a 0.2-mm-thick Al window. The detector is shielded using an Al case with a 25-µm-thick Al window and a BNC connector.

To measure spectra without a lead pinhole, we used an X-ray generator (RXG-0152, R-tec) to produce low-dose-rate X-ray beams by decreasing tube current in the range from 1.0 µA to 2.0 mA. The X-ray photons from an X-ray tube are detected by the LSO-MPPC detector placed 1.0 m from the X-ray source, and the photocurrents flowing through the MPPC are converted into voltages and amplified by a current–voltage (*I–V*) amplifier. The event pulses from the amplifier are sent to a multichannel analyzer (MCA; MCA4000, γPGT) to measure spectra with the change in the tube voltage and the insertion of a 5.0-mm-thick aluminum (Al) filter.

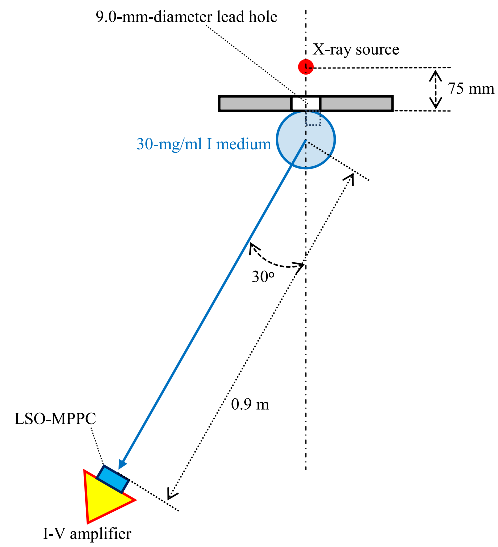

Fig. 2. Experimental arrangement for measuring X-ray spectra from a glass vial filled with 30-mg/ml I medium.

The photon energy was determined by two-energy calibration using monochromatic γ photons with an energy of 59.5 keV from an americium 241 (^{241}Am) source and X-ray-fluorescence Kα photons of iodine (I) with an average energy of 28.5 keV. The

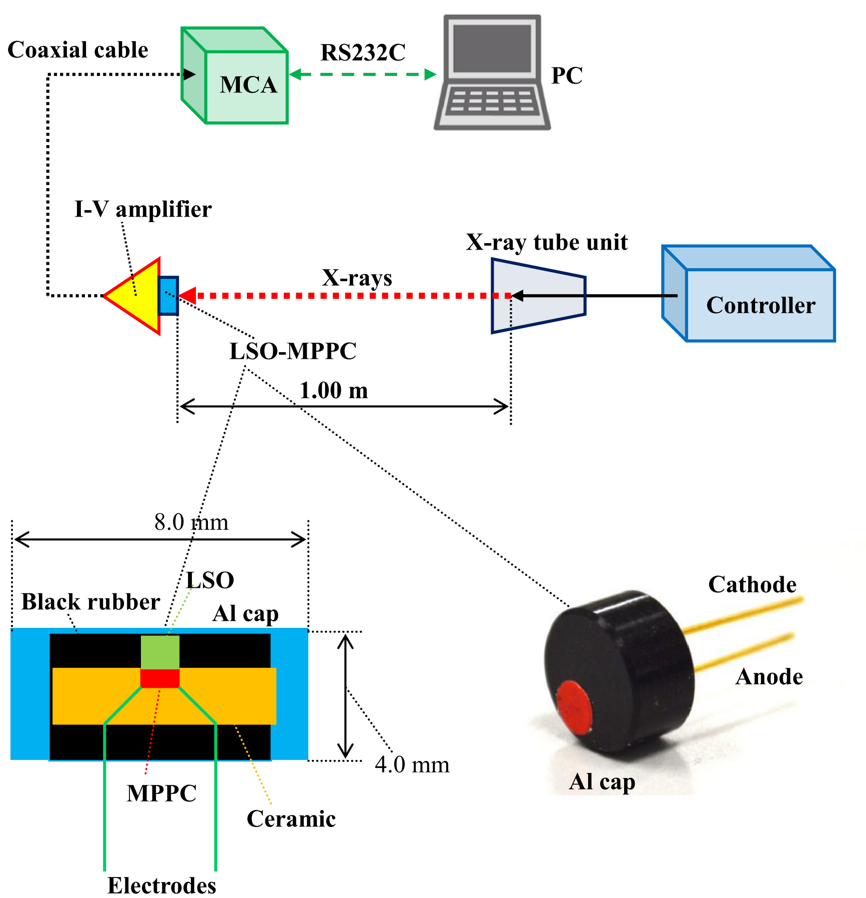

Fig. 1. Block diagram for measuring γ- and X-ray spectra using an LSO-MPPC detector, a high-speed *I–V* amplifier, and an MCA. The structure of the LSO-MPPC detector is shown in the same figure.