LSO/Photodiode and LSO/Avalanche Photodiode Detectors

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Abstract

Ce-doped lutetium oxyorthosilicate ($Lu_{2(1-x)}Ce_{2x}(SiO_4)O$ or "LSO") is a new single crystal inorganic scintillator that has a number of attractive properties including high emission intensity (~75% of NaI(Tl)) and short decay time (~40 ns).[1] The high emission intensity of LSO may make photodiodes or avalanche photodiodes viable alternatives to photomultiplier tubes in some applications. The purpose of this investigation was to characterize the operating parameters and to assess the performance of these detectors under laboratory conditions.

I. INTRODUCTION

Silicon photodiodes (PD's) and avalanche photodiodes (APD's) have been under development for a number of years as replacements for photomultiplier tubes, especially in applications where space is limited. The primary advantage of PD's and APD's is their extremely small size, typically only a few millimeters thick including packaging, compared to photomultiplier tubes which are usually a few inches long. Their main disadvantage is a relatively thermal high noise threshold, especially above room temperature. The noise is associated primarily with surface leakage current.

The scintillators most commonly used in the past with PD's and APD's are CsI(Tl) and $CdWO_4$. Both of these scintillators have good emission intensity at relatively long wavelengths (480 and 560 nm, respectively) where PD's and APD's have high quantum efficiency.[2] Although the scintillation emission of LSO is peaked at a shorter wavelength (420 nm), its high emission intensity helps to compensate for the somewhat lower sensitivity of the PD's and APD's at this wavelength. This fact taken together with recent improvements in leakage current and spectral response of PD's and APD's prompted the present investigation.

II. EXPERIMENTAL

The first detector was constructed by coupling a 10 mm diameter x 2 mm thick LSO scintillator crystal to a 10 mm diameter APD. The APD was obtained from Radiation Monitoring Devices, Inc. and the LSO crystal was grown at Schlumberger-Doll Research.[3] The APD was packaged in an aluminum housing with a quartz window. Therefore, in the final detector assembly, the scintillator crystal was separated from the APD by the quartz window. The operating conditions for this detector were comparable to those typically used for photomultiplier/scintillator detectors, i.e., a bias voltage of 1300 volts; an amplifier gain of 100, and shaping times from 0.25 to 6 μs.

After testing the first detector, a second detector was constructed in which the same LSO crystal was coupled directly to an APD with no window. This assembly was sealed in an aluminum package whose dimensions were 16 mm diameter. x 10 mm thick, thus providing a very compact detector.

A third detector was constructed by coupling a 10 x 10 x 2 mm LSO crystal to a PD from eV Products. In this assembly, the crystal, PD, and pre-amp were all packaged in an aluminum housing 32 mm diameter. x 34 mm thick.

III. AVALANCHE PHOTODIODE RESULTS

The first detector was used to measure the pulse height as a function of gamma-ray energy from several radioactive sources of various energies. The pulse height is defined here as the centroid of the full energy gamma ray peak in the pulse height spectrum. As seen in Fig. 1, the energy response is linear within experimental error from 33 to 1332 keV.

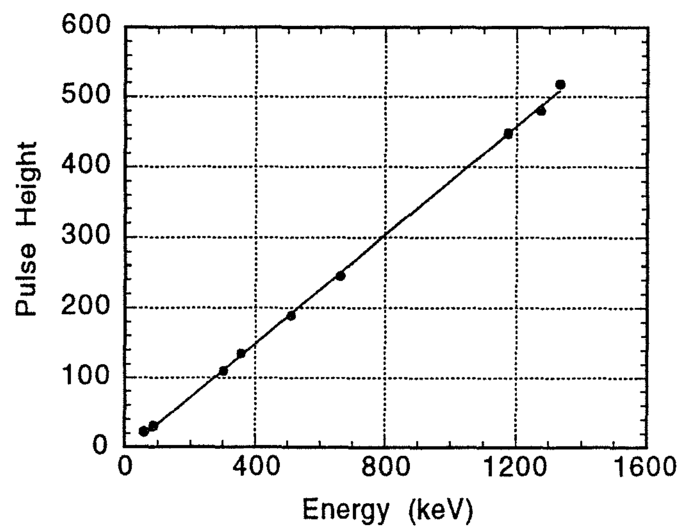

Fig. 1. Pulse height (channel number of photopeak) as a function of gamma-ray energy.

In order to achieve the best energy resolution and highest signal-to-noise at a given temperature, both the bias voltage and the amplifier shaping time must be optimized. Fig. 2 shows the signal-to-noise as a function of bias voltage for 0°C, 10°C, and 20°C. In these measurements, the signal-to-noise was defined to be the ratio of the pulse height of 662 keV gamma rays to the thermal noise threshold. It can be seen that the optimal bias voltage decreases and the signal-to-noise increases as a function of decreasing temperature. This effect has been attributed to the longer acceleration path of free carriers in the colder material.[4]

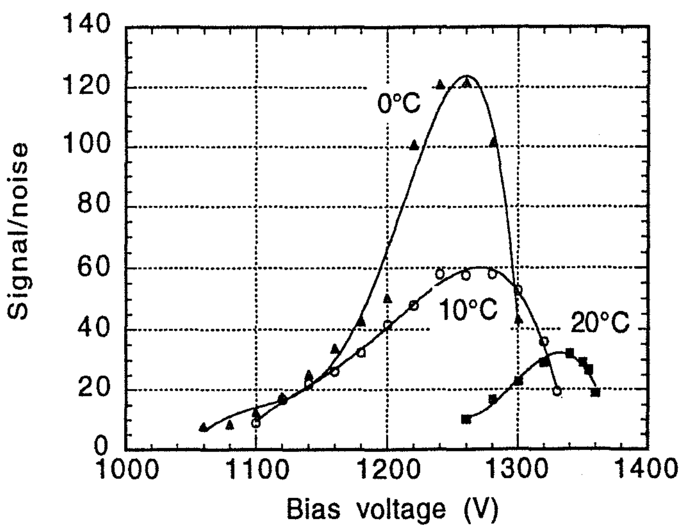

Fig. 2. Signal-to-noise as a function of bias voltage at three temperatures.

Previous studies have shown that the optimal amplifier shaping time is often a compromise between two effects. Long shaping times may be necessary to collect the entire scintillation signal, especially at low temperatures and with slow scintillators such as CsI(Tl) and $CdWO_4$. On the other hand, short shaping times minimize the noise contribution. With the use of LSO, the situation is simplified. Since the scintillation decay time is only 40 ns and is not strongly temperature dependent, shaping times as short as 0.25 μs integrate essentially all of the signal from the crystal while keeping the noise contribution low. Fig. 3 shows the improvement in signal-to-noise as the shaping time was decreased from 6 μs to 0.25 μs at 10°C and 20°C. The energy resolution was essentially independent of shaping time.

Figure 4 shows the pulse height spectrum of ^{137}Cs obtained with this detector at room temperature. The energy resolution is 10.3% which is the same as when the crystal was coupled to a Hamamatsu R878 photomultiplier tube. The only significant difference in the two spectra is the noise threshold of 30 keV observed with the LSO/APD detector. The LSO/PMT detector had negligible noise.

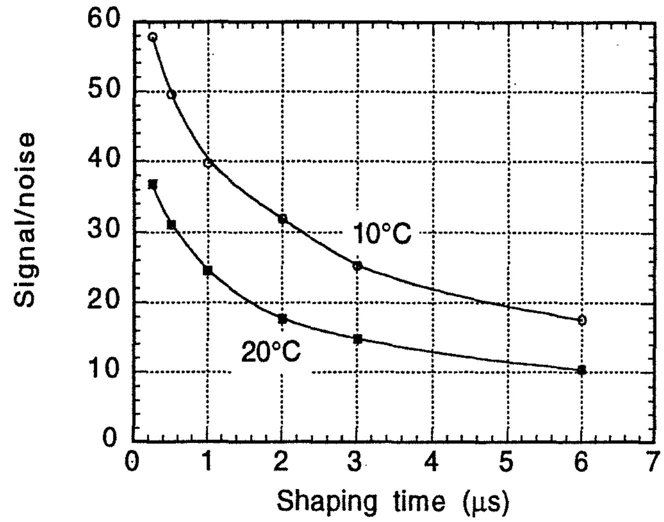

Fig. 3. Signal-to-noise as a function of amplifier shaping time for two temperatures.

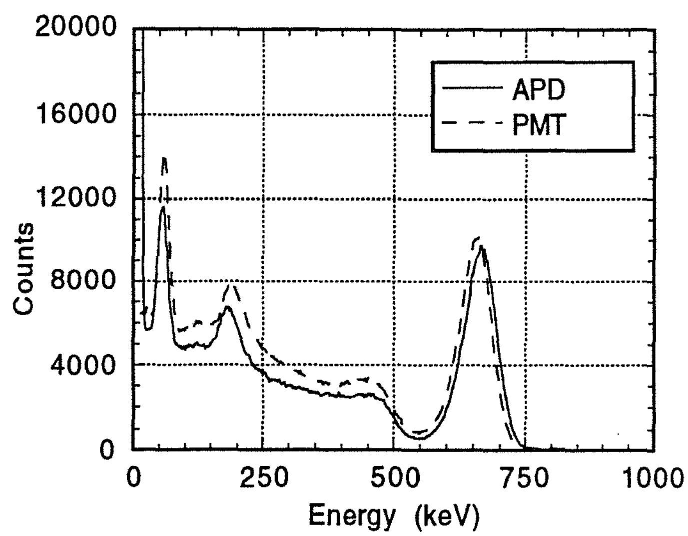

Fig. 4. Comparison of ^{137}Cs pulse height spectra measured with an LSO crystal coupled first to a PMT and then to an APD.

IV. Photodiode Results

Figure 5 shows a ^{137}Cs pulse height spectrum taken with the LSO/PD detector at room temperature. This zero-gain device shows significantly higher thermal noise relative to the gamma-ray signal compared to the avalanche devices which have intrinsic gains of 100-200. For the LSO/PD detector, the noise threshold corresponds to an equivalent gamma-ray energy of 140 keV. The energy resolution of the 662 keV line is 14% at room temperature. Significantly improved performance should be achievable at lower temperatures.

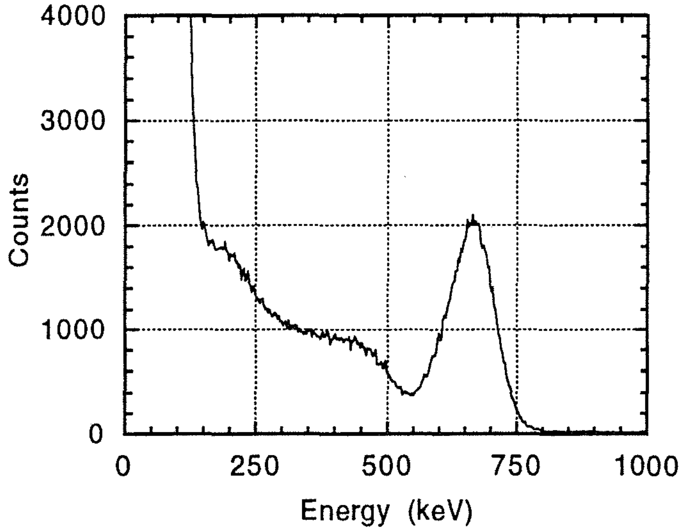

Figure 5. ^{137}Cs pulse height spectra measured with an LSO crystal coupled to a photodiode.

V. SUMMARY

Some of the key performance parameters of the detectors studied here are summarized in Table 1. The PMT and the APD gave the same energy resolution when used with LSO although the APD displayed a thermal noise threshold of 30 keV compared to <5 keV for the PMT. The PD resulted in poorer energy resolution of 14% and also a considerably higher noise threshold of 140 keV.

One notable advantage of LSO scintillators over CsI(Tl) and $CdWO_4$ when used with APD detectors is the short decay time of 40 ns. This allows the use of much shorter amplifier shaping times, 0.25 μs for LSO compared to 3-20 μs for CsI(Tl) or $CdWO_4$, which dramatically improves the count-rate capability of the detector as well as improves the ratio of signal to noise.

Table 1. Comparison of the three types of photodetectors used with LSO scintillator crystals.

	LSO/PMT	LSO/APD	LSO/PD
Energy resolution (662 keV)	10.3%	10.3%	14%
noise threshold (at 20°C)	<5 keV	30 keV	140 keV

VI. REFERENCES

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