A Study of CsI(Tl) Scintillator with Optimized Conditions of Large Area Avalanche Photodiode

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Avalanche photodiode (APD) is a kind of photodiode that internally amplifies the photocurrent by an avalanche effect. The quantum efficiency of the APD is about 80% which is 5 times higher than that of typical photomultiplier tube (PMT). A 16 mm diameter of beveled-edge large area avalanche photodiode (LAAPD) made by Advanced Photonics was used for the CsI(Tl) scintillator characterization. A CsI(Tl) crystal was attached to LAAPD and energy spectra were measured with various γ-ray sources. Optimization of energy resolution of the CsI(Tl) crystal was performed with different shaping time constants by shaping amplifier and with different gains by high voltage variation. The absolute light yield and energy resolution of CsI(Tl) crystals were measured with the LAAPD for 662 keV γ-rays from a ^{137}Cs source. The LAAPD was calibrated with X-ray of ^{55}Fe source for the calibration of the number of e-h pairs per channel. The absolute light yield of newly developed $SrCl_2$ scintillation crystal is determined by this method. This study shows that it is possible to use the LAAPD for the characterization of newly developed scintillation crystal and for the photo-sensor of scintillation detector.

KEYWORDS: avalanche photodiode, quantum efficiency, CsI(Tl) scintillator, absolute light yield

I. Introduction

For many years, scintillation detection has been based almost exclusively on the light readout by photomultiplier tube (PMT). Its internal gain is very high and sufficient signal-to-noise ratio is available. Several disadvantages of using PMTs are that it is sensitive to magnetic field, has relatively low quantum efficiency for input light signal (10-20%), and power consumption is rather high. Photodiodes are semiconductors that generate a current or voltage when illuminated by light. They can operate at much higher light levels than other detectors. Also, they have an excellent quantum efficiency (close to 80%) in the visible and near infrared. However they have no internal gain that significant noise contribution to the signal is the serious drawback of photodiode [1].

Avalanche photodiode combines the benefits of both the PMT and photodiode. The quantum efficiency close to the 80% in the visible and near infrared. And gain of up to several hundred in the total collected charge is possible [2-4].

We measure absolute light yield of CsI(Tl) and newly developed $SrCl_2$ crystal using 16 mm LAAPD (Large Area Avalanche Photodiode) made by Advanced Photonix Inc.(API) .

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II. Large Area Avalanche Photodiode

The silicon avalanche photodiode (Si APD) is a photon detection device that offers high internal gain. It is ideal for use in high speed, low light level applications. API also offers several patented large area configurations (LAAPD) enhanced for a variety of regions of the spectrum. These are available with built-in thermoelectric coolers to reduce the dark current and enhance performance. Package options include hermetically sealed windows or windowless configurations [3].

The "beveled-edge" diode is a p^+n junction in which the n-type resistivity is chosen so as to make the breakdown voltage very high, typically 2,000 V. APDs were developed by Advanced Photonix Inc. belongs to this type. This type of APDs yields a wide depletion layer and high avalanche gain (≥100). APDs produced by API allowed getting the best energy resolutions measured ever with different scintillators. Furthermore, its wide depletion layer of ≥ 50 μm depth, it can be used in direct detection of soft X-rays in the device. The internal construction of LAAPD produced by API is shown schematically in **Figure 1**. **Figure 2** shows the quantum efficiency of windowed and windowless LAAPD [3].

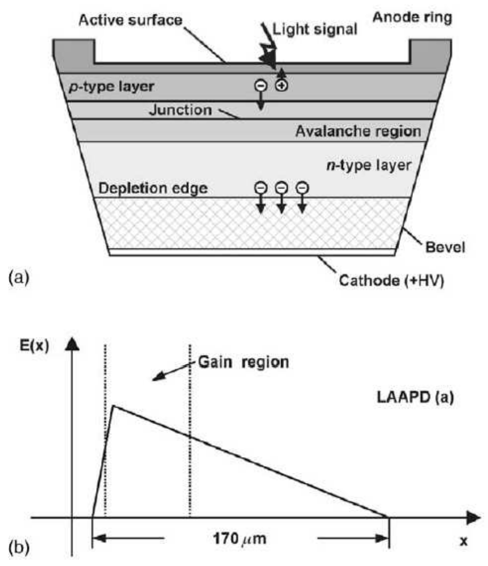
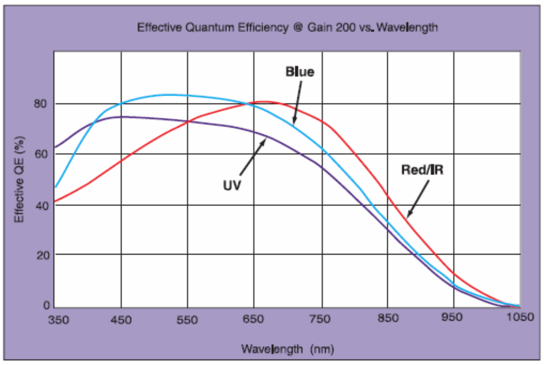
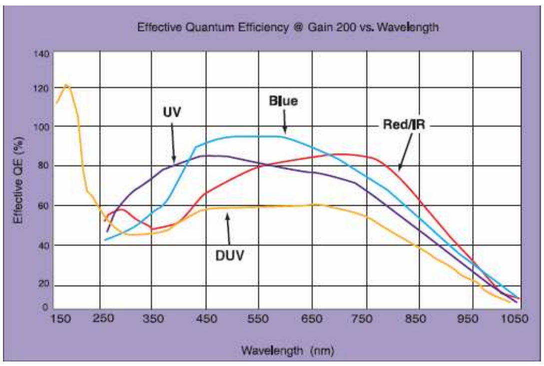


Fig. 1 Schematic cross-section of a LAAPD (a) and electric field profile (b), according to Advanced Photonix, Inc. [2].



(a)



(b)

Fig. 2 The quantum efficiency of (a) windowed LAAPD (b) windowless LAAPD [3].

III. Experimental Setup

This study is performed with the CsI(Tl) (ϕ17㎜×340㎜) made by Bicron. The scintillator crystal properties are presented in **Table 1.**

Table 1. Properties of CsI(Tl) crystal.

Property	Value
Light yield (Photons/MeV)	40,000 ~ 60,000
Density (g/cm^3)	4.53
Decay Time (ns)	~1,050
Peak Emission (nm)	550
Hygroscopicity	slight

A CsI(Tl) crystal is attached to blue sensitive windowed (630-70-74-501) or UV sensitive windowless (630-70-73-510) LAAPD and pulse height spectra are measured with ^{57}Co (122 keV), ^{137}Cs (662 keV), ^{22}Na (511 keV and 1,275 keV) and ^{60}Co (1,173 keV and 1,333 keV) γ-ray sources. Signals from LAAPD is fed to a low noise preamplifier and then shaping amplifier. The portable 25 MHz flash analog to digital converter (FADC) board is used for signal digitization, and digitized signal was readout by Linux based computer through USB2. The data are analyzed with the C++ based data analysis program, ROOT package [5]. We use object oriented ROOT package for the data taking and analysis. The schematic is diagram is shown in **Figure 3.**

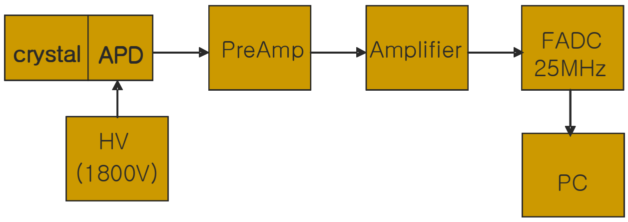


Fig. 3 Schematic diagram of the experimental setup.

IV. Results

1. Optimization Test of LAAPD

The contribution of LAAPD noise depends on device parameters such as LAAPD leakage current, capacitance, operating gain by high voltage (HV), and shaping time constant. A higher gain obtained by higher HV power allows reducing preamplifier noise while increases excess noise factor. Shorter shaping time in the spectroscopy amplifier (AMP) reduced the noise due to the LAAPD dark current while too short shaping time will affect to the signal-to-noise ratio since it may not allow a full integration of the signal from the scintillator. Thus optimization of gain by HV and shaping time constant is necessary for good energy resolution of the crystal.

First, we performed the gain optimization of LAAPD by changing HV from 1,760 V to 1,880 V with a shaping time of 4 μs. The energy resolution of CsI(Tl) with LAAPD is determined by 662 keV γ-ray from a ^{137}Cs source. The best energy resolution of CsI(Tl) crystal is obtained in the HV range of 1,780 ~ 1,820 V as shown in **Figure 4-a)**. Then, shaping time is changed from 0.5 to 10 μs with HV of 1,800

V. The energy resolution of CsI(Tl) with different shaping time is shown in **Figure 4-b)** and optimized shaping time constant is in the range of 3 ~ 5 μs. The HV of 1,800 V and the shaping time constant of 4 μs are used for further study.

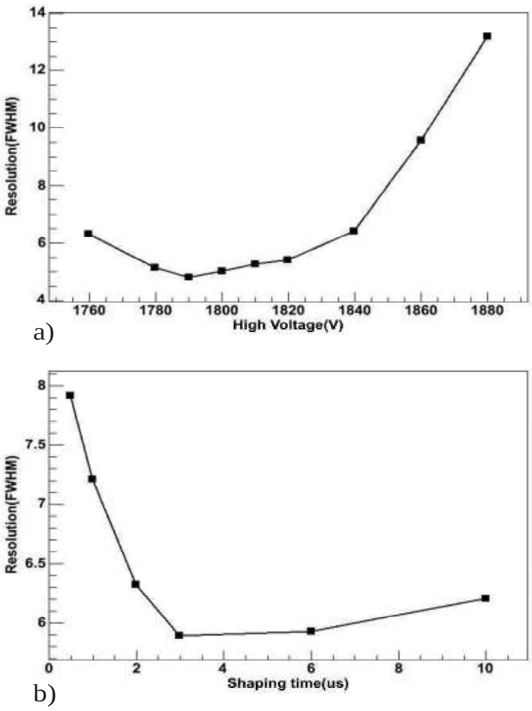


Fig. 4 Energy resolution of CsI(Tl) crystal with a) different HV and b) different shaping time constant.

2. Number of Electron-hole Pairs and Absolute Light Yield

The absolute light yield of CsI(Tl) crystal is measured with the LAAPD for 662 keV γ-ray from a ^{137}Cs source. The LAAPD is calibrated with X-ray of ^{55}Fe source for the calculation of the number of electron-hole (e-h) pairs per channel. The X-rays, directly observed with the LAAPD, allows using the X-ray peak as a good reference to measure number of e-h pairs. **Figure 5** shows the pulse height distribution of 5.9 keV X-ray from ^{55}Fe source using the amplifier gain of 100 and shaping time constant of 4 μs. The number of e-h pairs per channel is determined to be 3.34 and noise is measured to be 250 electrons rms.

The 662 keV γ-ray detection in the CsI(Tl) crystal with the LAAPD is carried out by the amplifier gain of 20 and shaping time constant of 4 μs. Then number of e-h pairs per MeV is determined by

$$Y_{e-h} = \frac{P_{peak}}{P_{X-ray}} \frac{E_{X-ray}}{E_{ion}} \frac{1}{E_\gamma},$$

where P_{peak} is 662keV energy peak position(channel) from a ^{137}Cs γ-ray source. $P_{x\text{-}ray}$ is 5.9 keV peak position from a ^{55}Fe X-ray. E_{ion} is 3.6 eV which is needed to make one e-h pair in LAAPD. **Table 2** presents the number of e-h pairs measured with CsI(Tl) scintillator coupled to the LAAPD.

To obtain the absolute light yield Y_{ph}, we use

$$Y_{ph,APD} = \frac{Y_{e-h}}{R_{PTFE}} \frac{1}{Q.E},$$

where Q.E is the quantum efficiency and R_{PTEF} is the reflection coefficient of teflon layer wrapping. The Q.E of 0.8 and the R_{PTEF} of 0.9 is used for the absolute light yield determination.

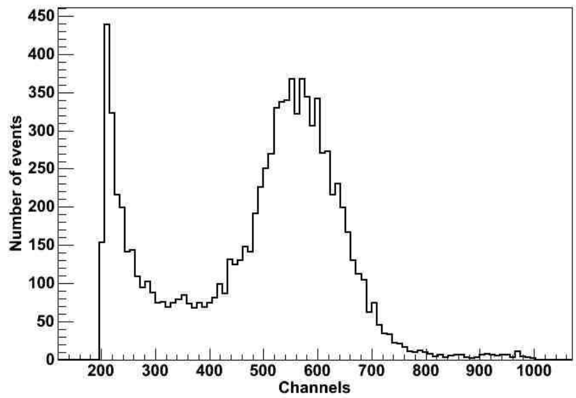


Fig. 5 Pulse height spectrum detected directly in LAAPD by 5.9 keV X-ray from a ^{55}Fe source.

Table 2. The number of e-h pairs and absolute light yield by 662 keV γ-ray irradiation for CsI(Tl) crystal.

Property	Value
Number of e-h pairs (e-h/MeV)	37,000
Absolute light yield (ph/MeV)	52,000

3. Energy Resolution

The energy resolution study was carried out with γ-rays from ^{137}Cs, ^{22}Na and ^{60}Co radioactive sources. To get the best energy resolution, optimized conditions are determined by previous section is used. **Figure 6** shows the energy spectra of various γ-rays measured using CsI(Tl) crystal coupled to the UV-enhanced LAAPD. The energy resolution of CsI(Tl) crystal is obtained to be 4.9% ± 0.18% (FWHM) with 662 keV γ-rays as shown in **Figure 6**. This result is comparable to those reported in Reference [6,7].

4. $SrCl_2$ Crystal Test

It is possible to use the LAAPD for the characterization of newly developed scintillation crystal. A single $SrCl_2$ crystal was grown by the Czochralski method and detail description can be found in Reference [8]. We measure the number of e-h pairs and absolute light yield of this crystal coupled to the UV-enhanced LAAPD with 4 μs shaping time constant. **Figure 7** shows the pulse height spectrum of $SrCl_2$ crystal irradiate with the 662 keV γ-rays from a ^{137}Cs source. The number of e-h pairs of $SrCl_2$ is determined to be 14,000 e-h/MeV and the absolute light yield is obtained to be 20,000 ph/MeV. The relative light yield of $SrCl_2$ crystal is approximately 40% of CsI(Tl) crystal. The energy resolution of the crystal is obtained to be 9.6% by LAAPD for 662 keV ^{137}Cs γ-ray source. If we use the green extended PMT, a little worse energy resolution of 10.5% is obtained.

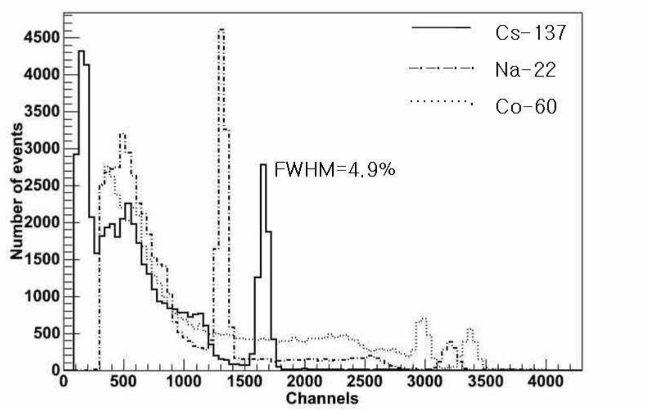


Fig. 6 Pulse height spectra in CsI(Tl) crystal irradiate with various γ-ray source.

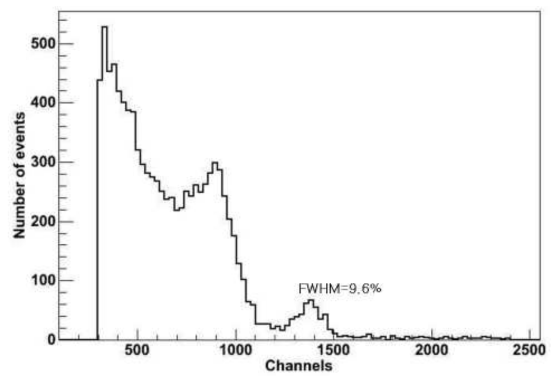


Fig. 7 Pulse height spectrum in $SrCl_2$ crystal irradiate with ^{137}Cs γ-ray source.

Also newly developed $Ba_{0.20}Sr_{0.80}Cl_2$ scintillation crystal is characterized by this method and absolute light yield of the crystal is measured to be 23,000 ph/MeV. The detail description of this crystal is described in Reference [9].

V. Conclusions

In this study, we measure the number of e-h pairs and the absolute light yield of scintillators using optimized conditions of LAAPD. The number of e-h pairs of CsI(Tl) is obtained to be about 37,000 e-h/MeV and the absolute light yield is obtained to be about 52,000 ph/MeV for 662 keV ^{137}Cs γ-ray source. Energy resolution of CsI(Tl) is 4.9% using LAAPD for 662 keV ^{137}Cs γ-ray source while about 7% of energy resolution is obtained with this crystal using the green extended PMT.

We determine the number of e-h pairs of newly developed $SrCl_2$ scintillation crystal to be 14,000 e-h/MeV and the absolute light yield to be 20,000 ph/MeV.

This study shows that it is possible to use the LAAPD for the characterization of newly developed scintillation crystal and for the photo-sensor of scintillation detector.

Acknowledgement

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