JKAU: Eng. Sci., **vol. 13 no. 2,** pp. 35-42 (1421 A.H. / 2001 A.D.)

Energy Resolution of CsI (TL) Crystal Coupled with PIN Photodiode

MOHAMMED AL-ESHEIKH
ADEL ABDENNOUR and AHMED KADACHI
Electrical Engineering Department, College of Engineering
King Saud University, Riyadh, Saudi Arabia

ABSTRACT. The emission spectrum of the CsI (Tl) scintillation crystal does not match well with the spectrum sensitivity of the standard photo-multiplier. This is the main handicap limiting the use of this crystal for radiation detection. However, the production of the new photodiodes, with better characteristics, is likely to be a good candidate as a readout device for this crystal. One way to investigate this possibility is to study the energy resolution of the CsI (Tl) crystal coupled with a new large area PIN photodiode. The purpose of this paper is to determine the different contributions affecting this resolution including that of the readout device.

1. Introduction

The cesium iodine crystals activated with talium CsI (Tl) have the highest scintillation light yield (photon/Mev) of the most used scintillation crystals[1, 2]. The use of this crystal for radiation detection was limited by the mismatch of its emission spectrum (λ_{max} = 560 nm) and the spectrum sensitivity of standard photo-multiplier (PM). Due to this, the photoelectron yield (Phe/Mev) obtained for this crystal is drastically reduced and becomes about half of that obtained with sodium iodine NaI (TL) crystal[3].

The continuous progress in manufacturing semiconductor devices was able to produce photodiodes (PD) with better characteristics such as large sensitive area, low noise and high quantum efficiency (> 70%)[1]. These improvements give the opportunity to use PD as a readout device for scintillation crystals instead of PM. The energy resolution is known as one of the most indicative parameters of the quality of detection system. This parameter is sensitive to the type of crystal, the energy of the photon and the readout device. Therefore, the study of the main factors affecting such resolution will indicate the contribution of the PD readout device in the detection system.

2. Energy Resolution

The energy resolution R is defined as the full width at half maximum (FWHM) of the peak in pulse light spectrum divided by its energy as given by the following relation:

$$R = \left(\frac{\Delta E}{E}\right) FWHM$$

Another convenient way to write this resolution is to express it in the form of quadratic sum of different sub-resolution[4, 5].

$$R = (Ri^2 + Rs^2 + Rd^2)^{1/2}$$

where Ri is the intrinsic resolution, Rs is the statistic spread resolution and Rd is the readout device resolution.

The intrinsic resolution, Ri depends on the type, homogeneity, size of the scintillation crystal and other parameters[4]. Therefore, it is difficult to be independently calculated or measured. However, it can be deduced from the measured resolution, R when Rs and Rd are known.

The statistic spread resolution, Rs depends on many parameters such as the wavelength (λ) of scintillation photon, the incidence angle of the photons and the photoelectron collection efficiency of the detection system[5]. In general, this resolution is inversely proportional to the square root of the incident radiation energy. When the average number of primary photoelectron created (Ne) is known, Rs can be estimated by the following equation[4, 6].

$$Rs = 2.35 \frac{1}{\sqrt{\overline{Ne}}}$$

The readout device resolution, Rd is due to the contribution of the photodiode and the electronic noise[7]. The calculation of this resolution is difficult but can be easily measured independently using a precision pulse generator.

3. Experimental Set Up

For good photoelectron detection efficiency, the size of the PIN active area was selected as close as possible to the size of the crystal. The main characteristics of the scintillation crystal CsI (Tl) and the photodiode PIN used in this experiment are presented in Table 1[6, 7]. This cylindrical crystal is surrounded by a reflector material, canned in aluminum housing and assembled with the PIN to form the detector. The contact between the crystal and the PIN was done with a thin layer of silicon oil and surrounded by aluminum casing to avoid light penetration.

TABLE 1. Main characteristic of the CsI (Tl) crystal and the PIN photodiode used.

CsI (Tl)		**PIN (Type S-3590-08)**	
Density (g/cm^3)	4.51	Max reverse voltage VR (Volts)	100
Max wavelength, λ_{max} (nm)	550	Dark current (pA) at VR = 50 V	2.5
Low wavelength cutoff (nm)	320	Thermal capacitance pFat VR = 50V	70
Primary decay time (μs)	1.0	Photosensitivity A/W at λ_{max}	0.28
Size (ϕ – H) mm	11.5-25.0	Active area (mm^2)	10 × 10

The electronic chain is composed of standard nuclear instrument modules (NIM) for gamma spectrometry as shown in Figure 1.

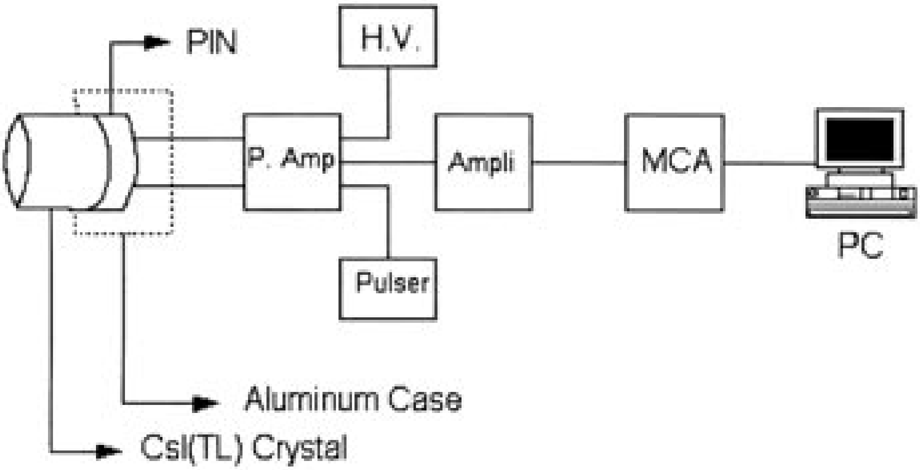

FIG. 1. Block diagram of the experimental set up.

3.1 Electronic Setting

The objective of the electronic setting is to obtain the highest energy resolution, which is sensitive to the charge collection of the PIN. Therefore, the main setting parameters that must be determined are the adequate reverse voltage for the PIN, the shaping time constant, and the reduction of the charge sensitive preamplifier noise. The use of a mono-energetic source, ^{137}Cs with different reverse voltages of the PIN and different shaping time constants of the amplifier was able to determine those parameters. The plot of the energy resolution versus reverse voltage with different time constants is shown in Figure 2. The graph shows that the highest resolution was obtained at 50 Volts with 4μs.

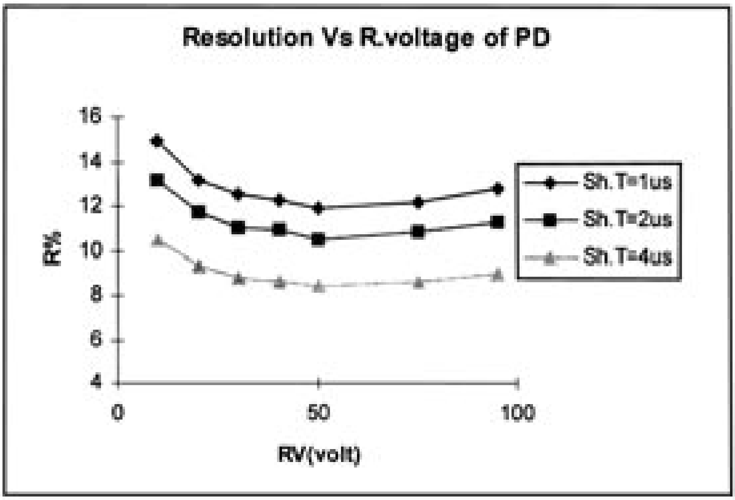

FIG. 2. Resolution vs reverse voltage, V_R.

3.2 Measurements and Calibration

Two types of calibrations were necessary to determine the total energy resolution and the different sub-resolutions. The first one was the energy calibration of the detection system, which was done using different mono-energetic and multi-gamma sources covering the energy range between 59 Kev and 1836 Kev. The centroid and the energy resolution, R of all peaks present in each spectrum were also determined by standard softword gamma analysis.

The second type of calibration for the absolute charge to determine the photoelectron yields Ne versus energy that is required to estimate the statistic resolution Rs. For this calibration, the method indicated in ref.[1] was followed. The PD was used directly without the scintillation crystal to detect low gamma energy. The spectra of ^{241}Am (59.5 Kev) and ^{57}Co (122 Kev) were measured with PD only and used to calibrate a precision pulse generator. The absolute charge calibration was determined from the position of the photopeak in the pulse height spectra and the known energy loss per electron-hole pair in silicon (3,62 ev). The curve of the photoelectron yields Ne versus energy shown in Figure 3, was obtained with a pulse height of known charge from the calibration pulse generator.

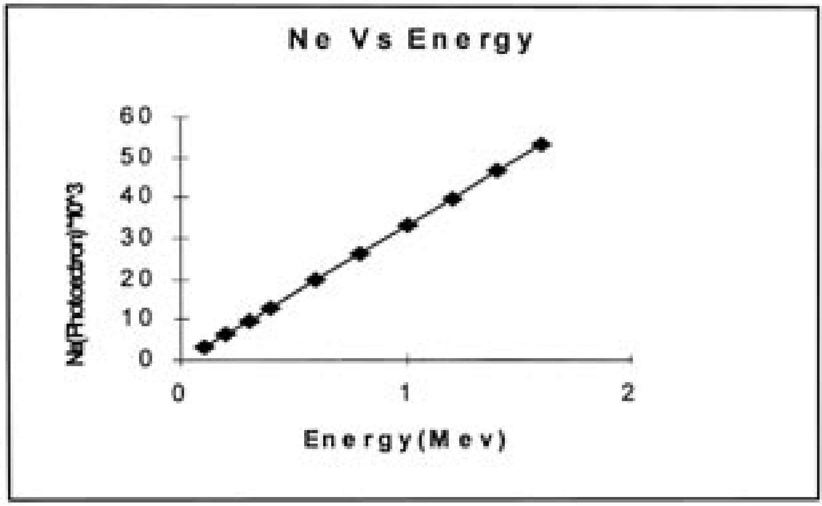

FIG. 3. Absolute charge calibration *Ne* vs energy.

The measurement of the readout device resolution, *Rd* was performed also using the pulse generator calibrated in terms of energy. The spectrum of ^{137}Cs source was used to calibrate the pulse generator. Therefore, the measurement of the resolution at different peaks created by this calibrated pulse gives the only resolution of the readout device as shown in Figure 4.

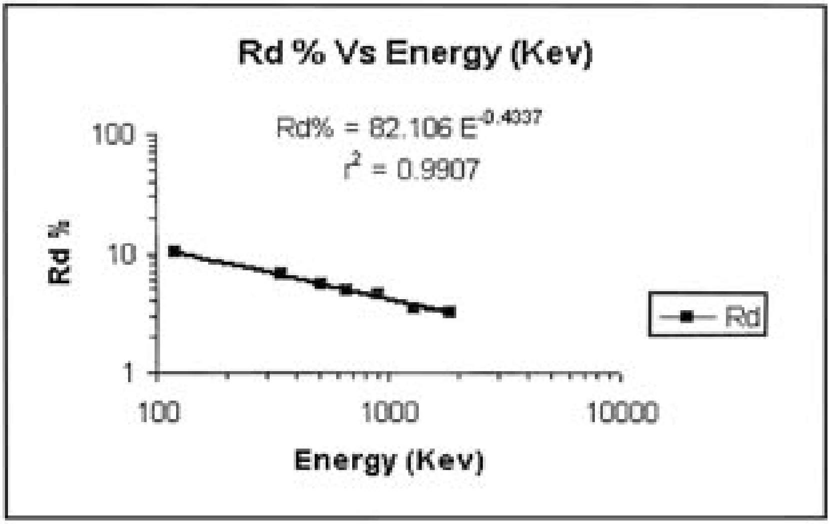

FIG. 4. Readout resolution, *Rd* vs energy (Mev).

4. Discussion

The total energy resolution, *R* of each peak present in all measured source spectra was determined using the FWHM of the peaks and their energy position. The fitting of this resolution versus energy is, in general, a power function. However, the parameter and the exponent of this function depend certainly on the size of the crystal[3, 9]. The following relation gives the power function obtained in this work.

$$R = 141.85\ E^{-0.481} \quad ; \text{ where } E \text{ is expressed in Kev}$$

The static spread resolution, *Rs* depends on the photoelectron yield of the incident photon. This resolution is calculated from the number of the photoelectrons, Ne was determined using the charge calibration (see Figure 3). The Ne value 35200 ph-e/Mev obtained is in good agreement with the published data 35900 ph-e/Mev[1]. The statistical contribution in the resolution of CsI (Tl) coupled with PD is relatively low comparatively to other contributors. This is due to the high photoelectron yield produced by this crystal.

The readout device resolution, *Rd* was measured independently using a pulse generator calibrated in term of energy. This resolution is sensitive to the reverse bias of the PIN photodiode and the shaping time constant of the amplifier. For this reason, an optimal setting of these parameters was necessary (see Figure 2). The best, *Rd* resolution obtained is presented in Figure 4.

The intrinsic resolution, *Ri* was deduced quadratically from the resolution *R* and the known *Rs* and *Rd*.

Figure 5, shows a plot of the total resolution and the different sub-resolution. All these resolutions follow a power function decreasing with the increasing photon energy. Also it can be observed that the descending order in terms of contribution to the total resolution is *Rd, Ri* and *Rs* respectively.

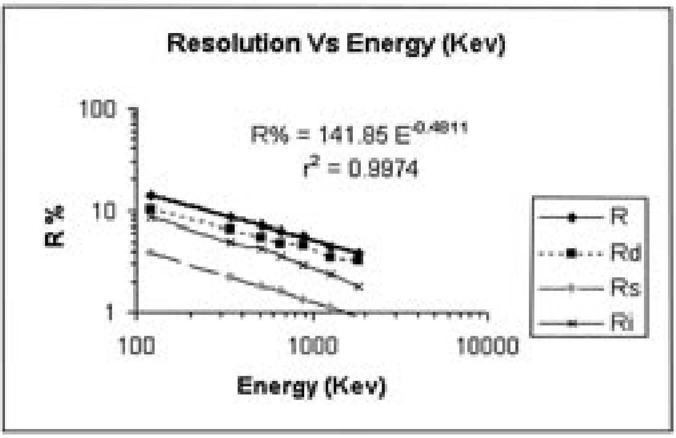

Fig. 5. All resolutions vs *E*, photon energy (Mev).

5. Conclusions

The scintillation crystal CsI (TL) coupled with PIN as a readout device instead of PM has a small size and immunity to magnetic field. Also, due to better matching of the emission spectrum of this crystal with the quantum efficiency of the PIN the energy resolution becomes better, especially for high gamma energy. At low energy, the resolution improvement is lost due to the importance of noise. The readout device resolution is the most important contributor to the total energy resolution. Therefore, reduction of this component through the improved technology by shifting the peak sensitivity of this device to lower wavelength and low current leakage will make it an ideal readout device even at low energy gamma and will lead to large-scale application in nuclear physics and medicine.

Acknowledgements

The authors gratefully acknowledge the College of Engineering Research Center at King Saud University for their financial support.

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قدرة تحليل الطاقة للبلورة CsI(TL) المقرونة بالشرائح الضوئية من نوع PIN

محمد آل الشيخ ، عادل عبد النور و أحمد كداشي
قسم الهندسة الكهربائية ، كلية الهندسة ، جامعة الملك سعود
الريـــاض - المملكة العربية السعودية

المستخلص . الطيف المنبعث من البلورة الوميضية CsI(TL) أثناء تفاعلها مع أشعة جاما لا يتوافق تمامًا مع حساسية طيف المضاعف الفوتوني العادي . ويعدّ هذا أهمُ عائق أمام الاستغلال الكامل لإمكانيات هذه البلورات في عملية الكشف عن الإشعاع . لكن مع توفر جيل جديد من الشرائح الضوئية (Photodiode) بخواص محسنة أصبح من الممكن استعمالها كجهاز قراءة فعال لهذه البلورات .

وتعدّ دراسة قدرة تحليل الطاقة أفضل طريقة لفحص إمكانية استعمال هذه البلورة الوميضية مقرونة بالشرائح الضوئية (PIN Photodiodes) ذات المساحة الكبيرة . إضافة إلى هذه الدراسة فقد تمّ تحديد العوامل المؤثرة على قدرة التحليل بما في ذلك تأثير جهاز القراءة .