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Cadmium Telluride (CdTe) Compound and Silicon (Si) Semiconductor Materials Detectors for X-Ray

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Abstract

There are different approaches and also materials to construct a detector for x-rays. the available semiconductor materials, Silicon (Si) is mainly used for charged particle detectors and soft X-ray detectors. Cadmium Telluride (CdTe) compound semiconductors for x-ray detectors have experienced a rather rapid development in the last few years, due to their appealing performance. In this paper we review the physical properties of semiconductor detectors for x-ray. In particular, we focus on compound semiconductor detectors. In addition, Si detector has better energy resolution achievement. However, it does not have good detection efficiency for higher energy above (40Kev). While CdTe detector supplies higher detection efficiency for x -rays about 100% for up to 100 keV in energy. The response functions of Si detector to reduce small x-ray, which has limited sensitivity for energy about 30keV. The XR-100T is high performance for x-ray and gamma ray detector by using 241Am (59.5keV), so the cooler are mounted the input FET a feedback components to the Amptek to charge sensitive preamplifier. Both the Si and CdTe detectors are connected to the PX2 combined amplifier and power supply,

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that was provide the voltage needed to operate XR-100T CdTe. The PX2 T CdTe amplifier has a Rise Time Discrimination circuit, measure the FWHM energy resolution of 55Fe (5.89) the peak in each spectrum hence a graph of energy resolution. Moreover, the Rise Time Discrimination So the escape peak of 55Fe was determined with Si detector was 11.66 keV, also k- sell x-ray energy was calculated to 5.77keV and the Rise Time Discrimination effect was studied on the spectrum when is it switched on and off. Its influence was found in decreasing the noise of the spectrum.

Keywords: Cadmium Telluride, Silicon (Si), materials, x-ray, radiation detector, semiconductor, channel number, Energy.

Introduction

Silicon (Si) is a chemical element, and its atomic number 14. It is a hard, brittle crystalline solid with a blue-grey metallic luster, and is a tetravalent metalloid and semiconductor. It is a member of group 14 in the periodic table; carbon is above it; and germanium, tin, lead, and flerovium are below it. It is relatively unreactive. Because of its high chemical affinity for oxygen. Cadmium telluride (CdTe) is a stable crystalline compound formed from cadmium and tellurium [1].

Semiconductor detectors, originally developed for particle materials applications, are now widely used for x-ray spectroscopy in a large variety of fields, as x-ray fluorescence analysis, x-ray astronomy, where the applications as focal plane detectors and diagnostic medicine are of particular interest. semiconductor detectors have a several unique properties such as high detection efficiency, excellent energy resolution, and possibility of development of compact and tough detection systems, silicon (Si) detectors are the key detectors in the soft x-ray band (< 15 keV). In addition, among the compound semiconductors, cadmium telluride (CdTe) and cadmium zinc telluride (CdZnTe) have been considered very appealing for hard x-ray detectors and are now widely used for the development of spectrometer prototypes for medical and astrophysical applications [2].

X-rays are a form of electromagnetic radiation similar to radio waves, microwaves, visible light and gamma rays. X-rays are similar to gamma rays; the main difference is the producing way, X-rays are produced by electrons external to the nucleus. Traditionally X-rays had longer-wavelengths and lower energy than gamma rays but this is obsolete with modern X-ray production methods.

X-ray photons are highly energetic and have enough energy to break up molecules and hence damage living cells. When X-rays hit a material some are absorbed and others pass through. Generally, the higher the energy the more X-rays will pass through. It is this penetrating power that allows us to take internal images of the human body or objects. X-rays cannot be steered by electric and magnetic fields like alphas, betas or other charged particles [3].

The electromagnetic radiation includes x-rays and gamma rays, x-rays released in the rearrangement of electron shells of atomic that were produced by the deceleration of an electron radiate especially when it hits the target of high atomic number. The most important impact of the x-rays or gamma rays is very low energy so energy resolution for low energy gamma rays and x-rays irradiation on the cathode side is best.

There are many semiconductor detectors which are used in research where an accurate measurement effect which is predominant mode of -interaction for gamma ray and x-ray of relatively low energy which also enhanced for absorber materials of high atomic number Z

silicon detector and cadmium telluride detector-each of which has advantages in certain application-were used for detection of x-rays [4,5].

Semiconductor detectors are the main substitute for the scintillation detectors in medical imaging systems. Silicon and germanium materials were old semiconductors studied by Van Heerden in 1945 as radiation detectors. These detectors, have a lower carrier creation energy and low scatter count. Unfortunately, Si with a low stopping power for high-energy photons is restricted to low-energy photons. Besides, Ge works at cryogenic temperatures because of its small bandgap. For these reasons, materials with a high atomic number and ability to function at room temperature such as CdTe are probable materials for using in X and gamma rays detectors.

XR- 100T Silicon detector

Si detector with pettier cooling, have come into common use, delivering a resolution of 150 ev FWHM at 5.9 kev. The Si detector combines a low atomic number with bandgap energy (1.12ev) for Si (300k) and 1.16 for Si (77k) also, the ionization energy is 3.61 ev per e-h pair for Si (300k) and 3.76 ev per e-h pair for Si (77k). Good energy resolution requires a relatively small bandgap, so, to excite an electron-hole pair it most reducing the average ionization energy. The number of charge carries excited per unit deposited energy is increased by using small ionization energy. Si detector has a high efficiency, is close to 100% for charged particles, but so is gas counters. For gamma rays and x-rays, efficiency is very poor because of the small sensitive volumes and the low Z number [5,7]. Figure 1 shows Cadmium telluride (CdTe) detectors.

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Figure 1 Si X-ray detector-XR- 100T Silicon detector [7]

Cadmium telluride (CdTe) detectors

The high atomic numbers of CdTe (48for Cd and 52 for Te) with a large band gap energy (1.52eV), and high density (5.85 g/cm3) with a high resistance (109 Ω) provide a better absorption characteristics [6], and ionization energy (4.43ev per eh pair). The probability of photon electric absorption per unit path length is 100 times larger than in Si for typical gamma-ray energies. The response function of a CdTe detector has some important difference from that of Si detectors and these differences must be understood and quantified to achieve accurate quantitative x-ray analysis results. Since Si detectors have been the detectors of choice for quantitative x-ray spectroscopy but they have limited sensitivity at energies above 30 Kev [4,7].

Energy resolution achievable in CdTe detector is generally not comparable with that obtainable in Si or Ge, because of rather poor collection efficiency of holes, Figure 2 shows Cadmium telluride (CdTe) detectors.

Application of this material therefore most involve situation in which high gamma rays detection efficiency per unit volume is at a premium. The most CdTe detectors is detectors are relatively small and usually planar in design, as a result of the charge carrier transport difficulties [7,8].

Figure 2 Cadmium telluride (CdTe) detectors [7]

Electronic pulse rejection and correction techniques have been successfully applied to CdTe detectors to improve energy resolution. it can be applied effectively to simple pulse counting if spectroscopic information is not required and can also be operated in current mode in high gamma ray fluxes which is possible to temperatures up to 70 ^{o}c [7].

Theory

The intrinsic detection efficiency of a detector (εINT) generated by preamplifier, so preamplifier noise must also be minimised if the excellent resolution is to be realised in practice. Also being charge-sensitive, they must be low-noise devices and usually, based on field effect transistor (FET), So [5,7];

$$\varepsilon INT = 1\text{-}I(x)I_0=1\text{-}e^{-\mu x} \quad (1)$$

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Where I(x) is the intensity of photons, (x) a thickness of detector, (I_0) is the intensity initially incident on the detector, μ is the linear attenuation coefficient. So, it can found the detection efficiency as function of the photon energy E:

$$\varepsilon INTE = 1 - e^{-\mu E \chi} \quad (2)$$

The energy resolution FWHM of Si detector for higher photon energies evaluates using expression:

$$R(E) = [R(5.9keV)^2 - 120^2 + 2440E]^{1/2} \quad (3)$$

Where is R (5.9keV) the measured FWHM resolution at 5.9keV.

The energy resolution can be achieved with silicon detectors is almost as good as that obtainable with CdTe as shown in Figure 3.

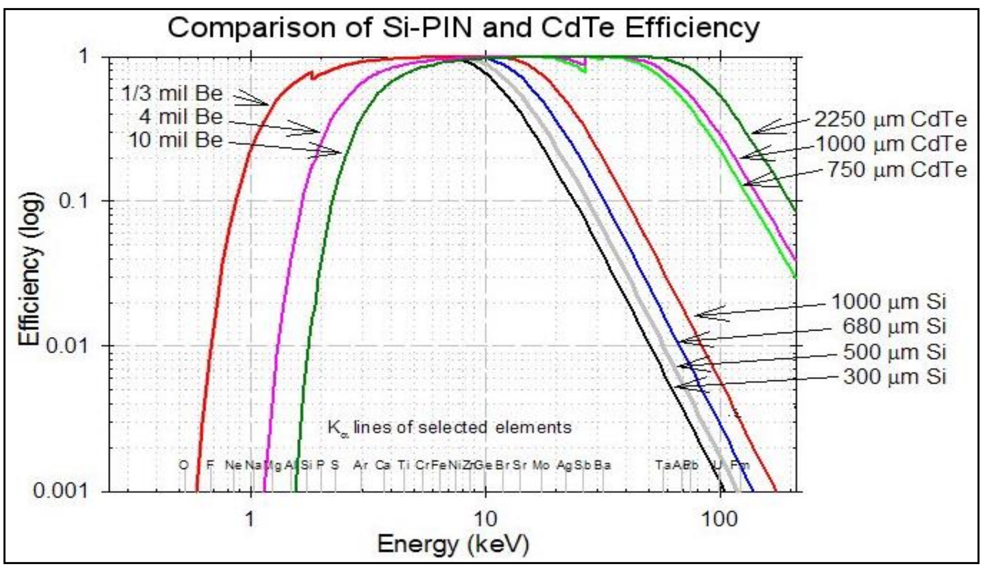

Figure 3 comparison of Si-PIN and CdTe Efficiency [7].

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Silicon detector has good energy resolution performance, due to the c combination of a high quality Si detector. For the cadmium detector, a higher bias voltage of 400v is required to ensure complete electron /hole collection.

Electron /hole Paris created by radiation which interacts with the CdTe detector result in fluctuations of change collection time.

Experimental Methods

This experiment was 3 parts as following:

Part 1

It was used Si detector, which has a good resolution to measure x-ray spectrum. The following equipment was connected as in Figure 4.

- XR-100T silicon detector;
- PX2 amplifier
- Power supply and a separate shaping amplifier.

The output of the detector preamplifier was to the NIM mounted shaping time and the UNIPLR output of the shaping amplifier was connected to the MCA INPUT [7,8].

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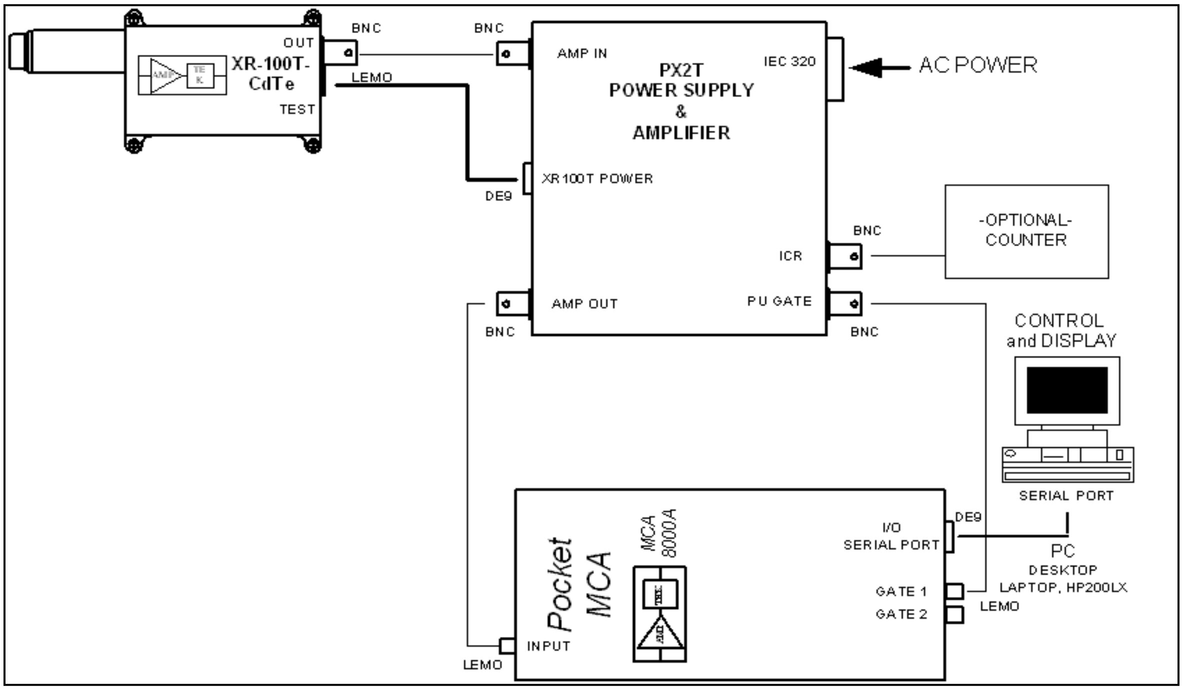

Figure 4 XR100T-CdTe/PX2T-CdTe/MCA800A [7]

Energy calibration of the silicon detector

- By using 241Am (59.5) kev source to produce x-ray and gamma ray peaks. The following steps done;
- Value was set on shaping amplifier; coarse gain=30x, fine gain=1, shaping time=1µs and input polarity was negative.
- When acquired spectrum appeared, the value of fine gain was adjusted and changed to a 100x to get best spectrum.
- A copy of a ^{142}Am was printed and all peaks were identified.
- The energy calibration of the spectrum was done by using maestro MCA software and the information of each peak was recorded.
- A graph of energy (kev) vs channel number was plotted.

Peak intensities

By using Si detector to produce x-rays and gamma rays, to get good statistics from the ^{241} Am spectrum for longer time (10 minutes) was gained by using ROI as before. The peak intensities (net area) and peak energy of each ROI was recorded. The data will be used in the part 3.

Energy resolution of ^{55}Fe:

This part of experiment was carried out by using the low energy ^{55}Fe (5.89)kev. Check the MCA lower level discriminator low energy. The red plastic cap from the front the detector was removed. A new spectrum was acquired by placing ^{55}Fe source close to the detector. A series of the spectrum of the ^{55} Fe photon peak was obtained to acquire at different amplifier shaping times, in the range 0.5μs to 12 μs. The FWHM energy resolution of the mean peak spectrum was measured. The preceding part was used to record the centre and the FWHM of each energy peak to calculate energy resolution. Then the graph of energy resolution vs shaping time was plotted.

Finally, the shaping time was set to the maximum value (12μs) to acquire ^{55}Fe spectrum for several minutes. The experimental results show weak silicon escape peak below the (5.89) keV photon peak. The k-shell x-ray energy have been calculated in silicon, the results were compared with a data book value.

Part 2

The second part of this experiment was carried out by using XR-100Cd detector, whit PX2T-CdTe amplifier and power supply.

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Spectroscopy performance of the CdTe detector:

This section of experiment the internal shaping amplifier within PX2T-CdTe amplifier were used with a shaping time constant of 3 µs. The following settings on the PX2T-CdTe amplifier was checked:

- Gain is 2 and the Rise Time Discrimination (RTD) was active.
- 142Am source was used to get high spectrum of 142Am (59.5kev) in the middle of the spectrum.
- The spectrum of a142Am was printed and identified to compare with spectrum which was obtained from Si detector, than the calibration of the spectrum was done and the information of each peak was recorded.
- A plot of graph of the energy (kev) vs channel number was made to compare with the linearity and gain of silicon which was made in part 1.

peak intensities

for longer time (10munites) was get good statistics from 241Am spectrum by using the ROI as before, the peak intensities (net area) and peak energy of each ROI was recorded, (no error in the net area). and energy of each ROI were recorded to be used in part 3.

Rise Time Discrimination of the CdTe detector

- The ^{142}Am spectrum was acquired with the Rise Time Discrimination RTD off (non-active);
- A copy of this spectrum was printed to compare with previous spectrum acquired when the RTD was active.

Part 3

In final part of this experiment:

The peak intensity which was recorded previously from the Si and CdTe detectors, was used for plotting graph of Si detector efficiency vs photon energy, this was after calculate ratio of the Si/CdTe peak intensities for each peak, and plot this ratio as a function of peak energy.

Result and discussion

Energy calibration of ^{241}Am from Si and CdTe detector

This section of experiment is divided into parts, where the Si detector and CdTe detector with ^{241}Am (59.5keV) source was used which cause X-ray fluorescence that will larger absorption length than electron and will escape from the surface of the detector, the result will be gamma ray photon and escape peak as shown in Table 1&2.

Part 1

From the Si detector the x-ray spectrum energies were calibrated, all mean peaks were measured and the channel number was determined from peak identification, Table 1.

Figure 4 shows the result obtained from x-ray spectroscopy

Table 1 channel number and peak energy for ^{241}Am determined by MAC

Energy calibration	Peak energy	Channel number
^{241}Am	59.5	2069.93
^{241}Am	26.5	923.39
Np-Lx	20.7	734.07
Np-LX	17.7	614.65
Np-LX	13.9	488.00

part 2

The spectrum of source ^{241}Am (59.5keV) was done by using CdTe detector. The x ray spectrum was collected, the energy was calibre and the data was recorded. Table 2 shows the relationship between the channel number and energy (keV).

Table 2 shows the relationship between the channel number and energy (keV).

Peak identification	Peak energy(keV)	Channel number
Am241	59.59	3399
Am241	26.3	1514.75
Np-Lx	20.7	1204.85
Np-Lx	17.7	1025.85
Np-Lx	13.9	810.72

Figures 4-5 show the relationship between the channel number and energy (keV). From the Si and CdTe detectors respectively as it can been seen from the figures that the plotted graphs reveal a linear relationship between the channel number and energy (keV), which can be presented as y=ax+b, where y axis represent the channel number and x represent energy(keV).

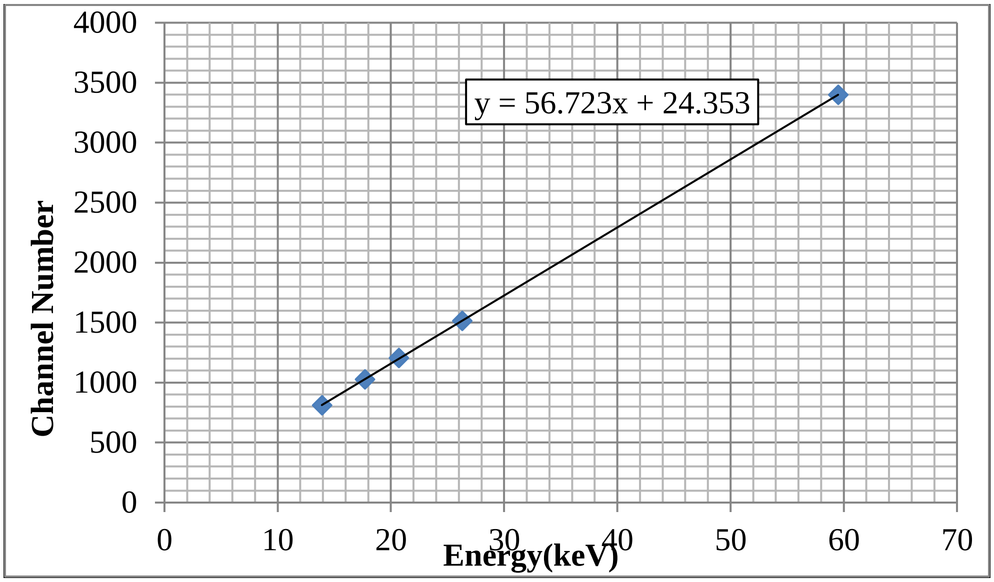

Figure 5 Energy (keV) of CdTe detector vs channel number.

Peak intensities and efficiencies

It was observed during the experiment that the ^{241}Am spectrum for a long time was acquired to get good statistics by using the same ROI from the Si and CdTe detector. The peak intensities (net area) and peak energy of each ROI was recorded. Table 3,4 show the relationship between the peak intensities (net area) and peak energy of ^{241}Am by using Si detector and CdTe detector.

Table 3 peak intensities and peak energy for Si detector

Peak identification	Peak intensities	Peak energy
Am241	2667±131	59,56
Am241	2137±168	26.17
Np-Lx	5359±289	20.86
Np-Lx	38332±608	17.53
Np-Lx	36445±658	14.00

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Table 4 peak intensities and peak energy for CdTe detector

Peak identification	Peak intensities	Peak energy
Am241	66497±471	59.5
Am241	15264±318	26.25
Np-Lx	35008±532	20.82
Np-Lx	136941±861	17.68
Np-Lx	58944±547	13.9

Efficiency was calculated by using this relative:

Relative efficiency = peak intensities (net area) of Si / peak intensities (net area) of CdTe.

Figure 6 shows the ratio of Si/CdTe peak intensities agents the energy of each peak. it can seen clearly the high efficiency of CdTe detector; which was 100% over full energy range, so the Si detector was not as good efficiency as CdTt detector.

Table 5 Ratio of peak intensities of Si to the peak intensities of CdTe intensities peak vs Energy peak

Energy	peak intensities of Si (1)	peak intensities of CdTe (1)	Relative efficiency (Si/ CdTe) (1)	peak intensities of Si (2)	peak intensities of CdTe (2)	Relative efficiency (Si/ CdTe) (2)
59.5	2667+131	66497+471	0.04178	2667-131	6649-471	0.037868
26.3	2137+168	15264+318	0.14792	2137-168	15264-318	0.131741
20.7	5359+289	35008+531	0.15892	5359-289	35008-531	0.14705
17.7	38332+608	136941+861	0.28257	38332-608	136941-861	0.277219
13.9	36445+658	58944+547	0.62367	36445-658	58944-547	0.61282

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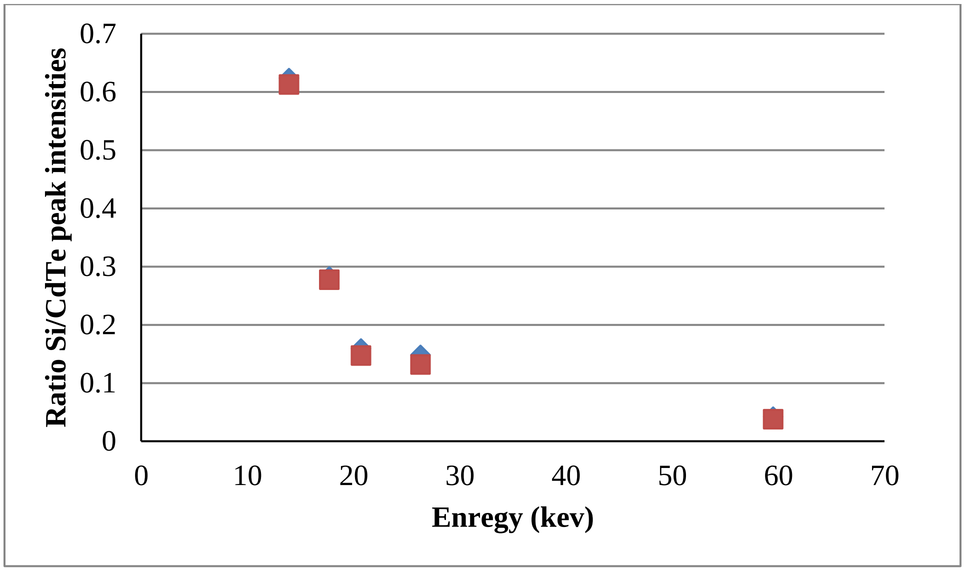

Figure 6 Ratio Si/ CdTe intensities peak vs Energy peak.

Energy resolution of ^{55}Fe

Table 6 represents the energy resolution of law energy ^{55}Fe (5.89keV) source, in the range of 0.5 µs to 12 µs by using Si detector. As calculated from equation 4:

$$R(E) = [R(5.9KEv)^2 - 120^2 + {}^{244}E]^{1/2} \qquad (4)$$

Table 6 Energy resolution vs shaping time for ^{55}Fe

Shaping Time	Shaping Time
0.5	13.92
1	11.70
2	11.35
4	8.89
8	9.26
12	1

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Figure 7 shows the relationship between energy resolution and shaping time, which was a clear in series spectrums were obtained with difference shaping time of (0.5,1,2,4,8,12)µs. The graph shows a good energy resolution of Si detector was with a long shaping time of amplifier due to reducing noise as it was increasing in shaping time.

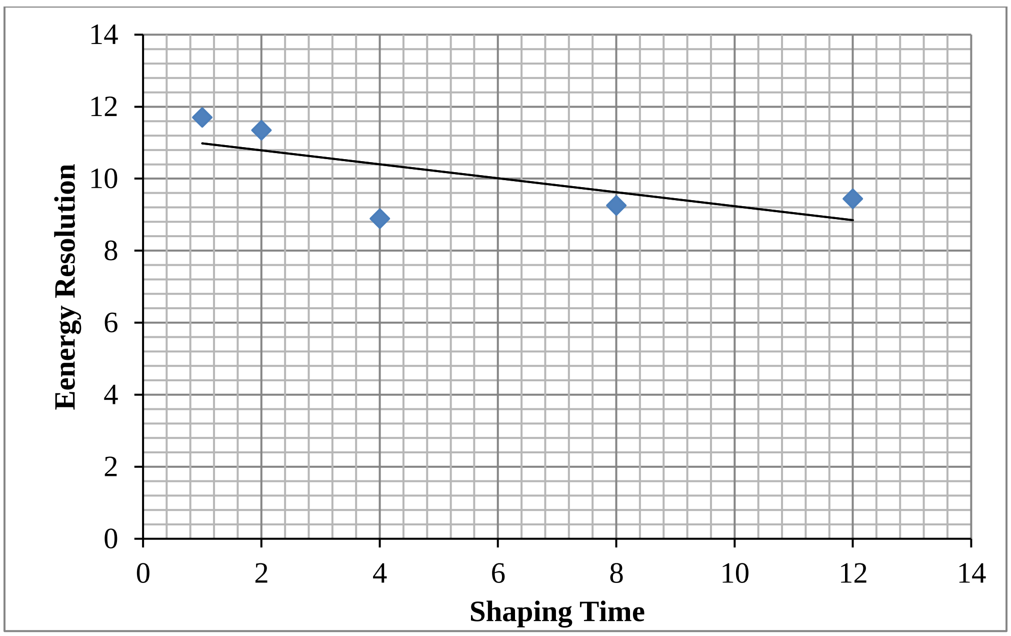

Figure 7 Show the shaping Time vs Energy Resolution

Rise time discrimination of PX2T-CdTe amplifier

In this part of experiment with the CdTe detector by using ^{241}Am when the (RTD) off (not active), the PX2T-CdTe amplifier had rise time discrimination (RTD) to refuse pulses that had a scrawny shape with lower energy resolution. However, when the (RTD) was active, the shaping pulses had clearly shape were internally gated and only pulses corresponding to good x-ray events were allowed to be sent to

(MAC) for analysis. Figure 8 shows the spectrum of ^{241}Am from CdTe detector with the (RTD) was off.

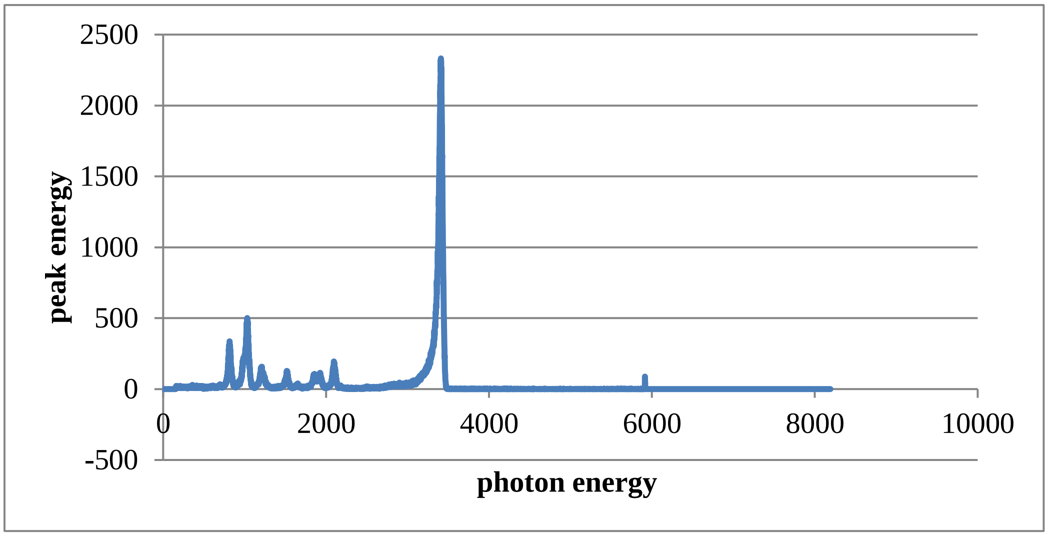

Figure 8 Function of peak energy vs. photon energy.

Conclusion

The general features of x-rays and gamma rays spectra and the performance characteristic of have been investigated. The collected spectra of x-rays and gamma rays present. The Si detector and CdTe detector have advantages in certain application. CdTe detector has high atomic number to translate into significantly higher x-rays and gamma rays photon absorption has much higher than Si detector, also the detection efficiency per unit thickness has better than Si detector for x-rays with stopping power 100% efficiency up 50kV and 5% at 100kV and good operate at shorter shaping time, so the CdTe detector can be improved by cooling to reduce the leakage current is high enough to improve the energy resolution. While Si detector must be cooled in low noise amplifier, also the Si detector has better energy resolution than the CdTe detector lowest 25kev, for Si detector energy resolution of photon approximately 40keV; also Si detector has good spectrum characteristics and peak background. The PX2T-CdTe amplifier has a rise time discrimination circuit was practical to the linear amplifier to reduce tailing effect even further.

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