PERFORMANCE TEST OF PIN PHOTODIODE READ OUT FOR γ-RAY SPECTROSCOPY

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1. Introduction

Photodiodes are semiconductor light sensors that generate a current or voltage when illuminated by light. Silicon PIN photodiodes can serve as a detectors for X-ray and gamma ray photons when coupled to a scintillator. Major applications of PIN photodiodes are in the arena of medical equipment (notably PET, CT scan), cobalt treatments, environmental monitoring and research.

A comprehensive study on the performance of CsI(Tl) scintillator with silicon photodiode read-out for γ-detection was carried out at the MSU-IIT High Energy Physics Laboratory. PIN diode is one of the most important semiconductor devices today used to detect high energy and nuclear particle radiation.

This study is motivated by the need for several applications to identify γ-rays with good energy resolution. The choice of the CsI(Tl)-PIN diode as sensor has been dictated by some consideration in terms of cost, complexity and ruggedness compared to NaI(Tl) scintillator with photomultiplier tube (PMT) read-out[1].

PMTs are capable of converting optical signals into electrical pulses with outstanding gain, bandwidth product and low noise but they have several drawbacks that limit their convenience in some applications.They require kilovolt power supplies, sensitive to magnetic fields and are relatively expensive.

Silicon photodide on the other hand , have stable gain, require less than 100V power supplies and insensitive to magnetic fields and can be made in small sizes. However, PIN photodiodes are unity gain devices and have low quantum efficiency at violet and UV wavelengths, which makes them very sensitive to electronic noise and limits the energy and timing resolution when measuring γ-radiation with scintillators[2].

A. Pin Photodiode

When light strikes on the surface of the photodiode, the electron within the crystal structure becomes stimulated. If the light energy is greater than the band gap energy Eg, the electrons are pulled up into the conduction band leaving holes in their place in the valence band. These electron-hole pairs (e-h) occur throughout the P-layer, depletion layer and N-layer materials. In the depletion layer the electric field accelerates these electrons toward the N-layer and the holes toward the P-layer. In this manner, the electron-hole pairs that are generated in proportion in the amount of incident light are collected in the N and P-layers. This results in a positive charge in the P-layer and negative charge in N-layer [3].

B. The Inorganic Scintilator

Inorganic scintillators are mainly crystals of alkali halides containing a small activator impurity. It makes use of the fact that certain materials when struck by a nuclear particle or radiation emit a small flash of light. When coupled to an amplifying device these scitillation can be converted into an electrical pulse that can be analyzed and counted electronically to give information concerning the incident radiation[4].

CsI(Tl) scintillator is commonly used with photodidoes for γ-detection because of its high light output (56,000photons/MeV) and appropriate emission wavelength with a good match with the spectral spectrum to silicon photodiode.

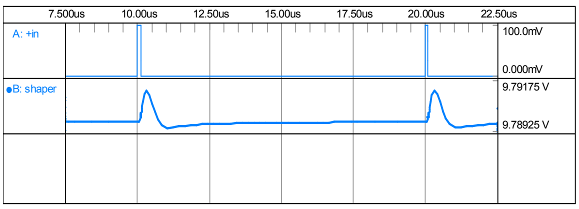
C. Charge Sensitive Preamplifier (CSP)

A large number of applications require extremely low noise detection systems, based on small capacitance and low leakage current detectors[5]. A lot of efforts have been put so far in the development of various circuits implemented in different technologies for read out system. The charge sensitive amplifier is widely used at the front-end as its conversion gain is independent of anode capacitance variations. In our present work we describe a charge sensitive preamplifier (CSP)made temporarily in a breadboard.The CSP is OPA111 JFET operational amplifier with the feedback capacitor of 2pF. The resistor Rf is direct current feedback that determines the fall time of the CSP's output signal which has been set to 20 µs. The CSP is supplied from +15V and -15V.

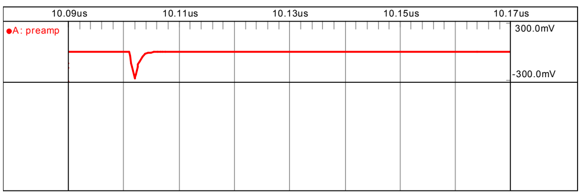
The primary purpose of the preamplifier is to provide an optimum coupling between the detector and the rest of the counting system. Also to minimize any sources of noise, which will be transmitted along the pulse that would degrade the energy resolution of the system. A charge sensitive preamplifier is used to amplify the photodiode output and a 10.0pF capacitor at the input of the preamplifier is used to couple a test pulse voltage to the system and obtain the conversion factor relating output voltage to number of electrons input.

D. Shaping Amplifier (SA)

Because of the low gain in the charge sensitive amplifier, the shaping amplifier follows the CSP to provide an additional gain. The shaping amplifier is capacitively coupled to the CSP and uses a RC-CR shaping to achieve a minimal noise, good linearity and of course low power consumption. To observe the outputs of the CSP and shaping amplifier, we tested the electronic read out with a test pulse (100mV) to the input of the charge sensitive preamplifier. Figure 1 shows the simulated SPICE response of the CSP and the shaping amplifier to a pulse charge injected into the CSP. The shaper output response is good but the the amplifier gain is very low in our performance testing.



(a)



(b)

Figure 1. (a) Charge injection input signal and Shaping amplifier output near gaussian shape (b) Long tail pramplifier signal output

E. The Multichannel Analyzer

To measure an energy spectrum of any radioactive material or sources means to record the pulse height distribution produced by the particles emitted from the source, which is achieved with the help of PCA II that acts as the multi-channel Analyzer or (MCA). Multichannel analyzer was used in a PHA mode, MCA sort out the incoming pulses according to their height and store the number of pulses of particular height in a corresponding channel number[6].

F. Application of PIN photodiode

PIN diodes have been widely used for detecting γ-ray and X-ray spectroscopy. Si PIN detectors are also used In the detection and specrtroscopy of β-particles or other externally Incident electrons. The block diagram of a typical spectroscopy is shown in Figure 2.

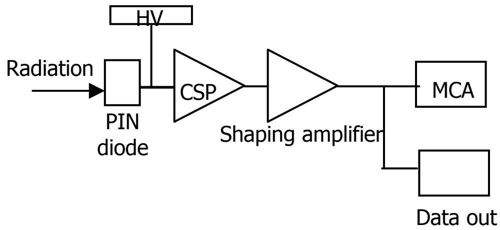


Figure 2. The basic block diagram of a typical spectroscopy

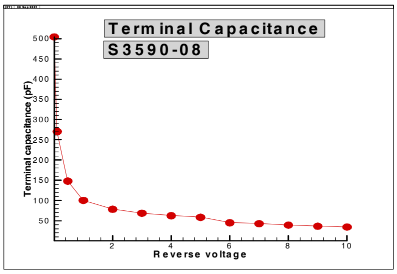
2. Experimental Details

The PIN photodiode used is Hamamatsu S3590-08 (100mm square effective active area , ceramic package) mounted in close coupling to the inrganic scintillator crystal which is cesium iodide doped with thalium, CsI(Tl) with a dimension 2x5x6cm^3. Aluminum foil is used to wrap the photodiode-scintillator to shield or prevent the background light from entering the photodiode. At the same time, the aluminum foil collects the generated light effectively onto the photodiode.

Before adhering the scintillator to the PIN photodiode we do performance test for the S3590-08. When operated at room temperature (25^{o}C) with an 30V reverse bias, this photodiode has terminal capacitance and dark current of ~140pF and ~90nA respectively. PIN diode and preamplifier combination got its sensitivity at ~4mV/MeV. But because of this high front end capacitance, the energy resolution for the detector system has been dominated by electronic noise.

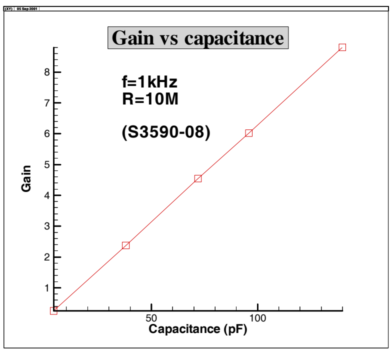
In our set-up the PIN photodiode have been covered in an aluminum foil and totally covered with black tape, to screen it from light and act as a shield from external noises. In the Figure 2, the detector is then connected to preamplifier and shaping amplifier for capacitance and leakage current measurement. We have calculated the equivalent noise charge for a single shaping time of 0.2μs. The calculated ENC for the given values of the I_D and C_D is ~ 2200 electrons.

A readout approach using a charge-division network (CSP) has been used for spectroscopic measurement. Presently we carried the performance testing without the scintillator attached to the photodiode. Figure 3 shows some of the results taken.



(a)

The capacitance of the photodiode increases as the gain of the system increases.



(b)

Figure 3. (a) Terminal Capacitance vs Reverse voltage (b) Gain vs Capacitance

3. Results and Discussion

We developed a PIN photodiode read out system for γ-spectroscopy. We have observed good gain linearity over capacitance during the injection of a known charge. The output signal pulse from the detector irradiated with known γ-sources was not observed. From the measured values of the equivalent noise charge (ENC), we understand that the detection efficiency is very poor and noise dominated. The preamplifier and shaping amplifier time constants will influence the effects of the signal. The bad efficient result explained due to the large noise contribution of the CSP and the Shaping amplifier are due to the stray capacitances.

4. Conclusion

We have shown that PIN photodiode can be used as a radiation detector but selection of materials needed should be properly chosen. In our present work the shaping amplifier should be modified to get a near Gaussian shape amplified output enough for Pulse Height Analysis using an MCA. Further work is needed to determine the optimum PIN photodiode scintillator detector performance and it will be addressed in the future paper.

Acknowledgments

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