# Silicon PIN Diode for detection of electrons, alphas, X-rays and gamma rays

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## Introduction

It is well known [1] that Si-PIN diodes can be efficiently used to detect alpha particles and low energy x-rays and gamma rays. The detection efficiency of a Si-PIN diode is a function of the thickness of the silicon wafer. For a wafer thickness of 300 microns, the efficiency for detecting gamma rays beyond 10 keV decreases drastically with energy. PIN diodes have an intrinsic capacitance which reduces with increasing reverse voltage to reach the maximum depletion zone to give best detection efficiency. However, increase in reverse bias voltage introduces higher leakage current. This dark leakage current is strongly temperature dependent due to thermal excitation. Dark current approximately doubles for every 10 °C increase in temperature. The dark current can be dramatically reduced by cooling.

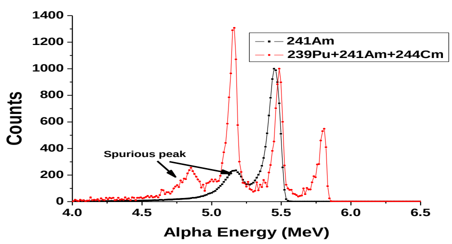


**Fig. 1** The alpha spectra from different sources

In the present work we have tested the performance of a Si-PIN diode detector in detection of charged particles, x-rays and gamma rays. We have also tested the detector after cooling to improve its performance for detecting gammas beyond 100 keV.

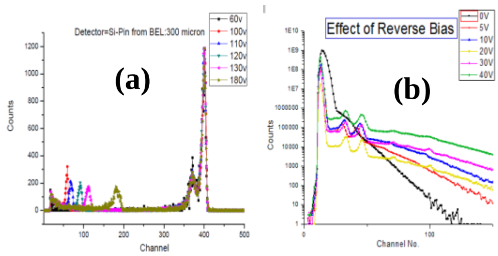


**Fig. 2** The effects of increasing reverse bias on detection of (a) Electrons and alphas from $^{241}$Am (b) X-ray and electrons from $^{152}$Eu.

## Experimental Details

The PIN diode used in the present work is from Bharat Electronics Limited (BEL), Bangalore having an active area of 25mm$^2$ and 300 microns thickness. The variation of its capacitance is shown in Ref [2]. We have used charge sensitive low noise preamplifier (ORTEC 142A or 142B) for the measurements.

- *Detection of alphas*

For alpha detection (Fig.1), the data have been collected with a reverse bias of 60V-70V. However, spurious peaks are found in the spectrum, which could not be explained by edge effects. We are taking more data to understand the origin of these peaks.

- *Detection of X-rays and electrons*

For detection of x-rays and relatively higher energy (>200 keV) electrons, application of adequate reverse bias is important. In $^{241}$Am spectrum (Fig 2a), 60V to 180V reverse bias conditions do not increase pulse height (no change in channel number) of ~5 MeV alpha.

However, with increase in bias, the conversion electron (40 keV) and X- ray- gamma ray peaks (~10-60 keV) become visible due to the increase in their pulse heights (with same amplifier gain). Similarly, for $^{152}$Eu spectrum (Fig 2b), increase in reverse bias improves the X-ray (~40 keV) and conversion electron peaks (75 and 115 keV). To distinguish the X-ray peaks from the conversion electron peaks in the spectrum for $^{152}$Eu, different sets of data were collected with the source covered by gradually increasing layers of plastic (indicated by 1 and 2). We found that the increasing thickness of the plastic cover decreases the electron peak heights, keeping the x-ray peak almost intact (Fig.3).

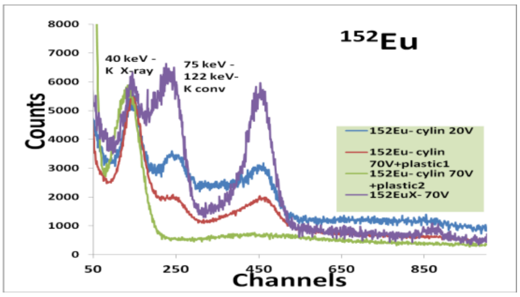


**Fig. 3** The X-ray and conversion electron spectra

- *Cooling the detector*

However, as the detector reverse bias is increased to 180-200V (Fig 2a), the leakage current increases. To work in this domain, one has to reduce dark current by cooling the detector [3,4].

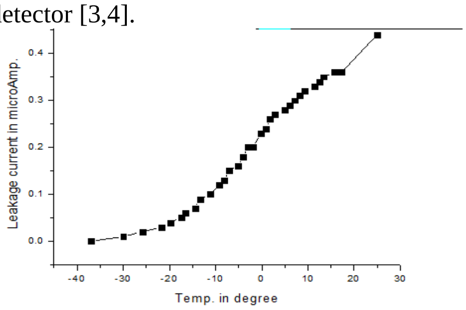


**Fig 4** Variation of leakage current with temperature.

- *Peltier Cooling*

As a first trial, a thermoelectric Peltier cooler *TEC1 12706* is used to cool the PIN diode. The PIN diode was attached to an aluminium base that was cooled with the TEC. The minimum temperature of -13.7 degree is achieved by TEC cooler. However, this cooling system did not work to our satisfaction as the cooling fan attached with the TEC introduced additional noise in the circuit.

- *Liquid Nitrogen cooling*

We then utilized a conventional method for cooling the PIN diode using liquid $N_2$. The effect of cooling was dramatic (Fig. 4). For ~180V, the leakage current decreased from 0.45 μA to zero, when the PIN diode is cooled from room temperature to -37$^0$C along with substantial improvement in the spectrum quality (Fig. 5).

- *To test limit of gamma detection after cooling*

A $^{133}$Ba source covered with a thick plastic to stop the conversion electrons is used for measurement (Fig. 5). The data have been taken at different temperatures to follow the improvement.

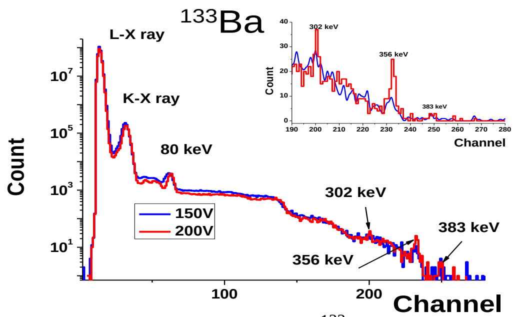


**Fig 5** Gamma ray spectra from $^{133}$Ba source.

The orders of magnitude reduction of efficiency of the detector from L-X rays to 383 keV is evident. The comparison of 150V and 200V reverse bias spectra demonstrates importance of higher bias for better detection of gamma rays >100 keV.

## References

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