Resolution and efficiency of silicon drift detectors (SDD) compared with other solid state X-ray systems

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Abstract

Silicon Drift Detector (SDD) belongs to a new kind of solid state X-ray detectors which are small and easy to use and particularly well suited for X-ray spectroscopy. In this work we have compared their characteristics with that of three other types of solid state detectors suited for detecting X-ray in the 3-50 keV region. We have analyzed the energy resolution, the efficiency and other characteristics of Silicon Drift Detectors (SDD) in comparison with other X-ray detectors as Si-PIN, PIPS and liquid nitrogen cooled germanium detector. Our results, that have been gathered under usual laboratory conditions, give to the user useful information on the specific properties of these detectors.

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1 Introduction

There are many ways to detect X-rays, all of which detect incoming photons by their interaction with the detector material. That interaction produces a signal, which can take different forms a.e.: an electric current, a light pulse or even heat. Proportional counters and microchannel plates have poor resolution and are not suited to X-ray energy spectroscopy and thus will not be considered here. For forty years, solid state detectors, based on electron-hole pair creation in cooled, reverse polarized semiconductors, have been considered as the most suitable detectors for X-ray spectroscopy in the 3-50 keV region. More recently, single photon calorimeters, that detect temperature pulses from ultra cold absorber, have reached a new milestone in resolution (6 eV @ 6 keV) but are not yet widely available and will not be discussed here [1–3]. Liquid nitrogen solid state detectors have been available for more than 40 years. Their performances are good but, because of the bulky Dewar vessel, they are not convenient to handle. In the last 10 years, Peltier cooled Si-PIN wafers, commonly used in small systems, have steadily improved resolution and are now widely in use. More recently, new kinds of detectors have been designed: PIPS and SDD. As Si-PIN, they are very small (< 1 cm³), they do not need liquid nitrogen cooling and are well suited for mobile X-ray spectroscopy devices. In this study, we will compare the characteristics of four different kinds of solid-state X-ray detectors under real experimental conditions.
2 Semiconductor detectors

2.1 Si(Li), Ge(Li), Ultra LEGe, etc...

Ge and Si detectors are available for more than forty years. They are formed by a large semiconductor junction that is reverse biased (crystal size of cross-sectional area up to 50 cm$^2$ and thickness up to 30 mm). When a photon interacts with the material within the depleted volume of the detector, electrons and holes are produced. These charges are swept by the electric field to the electrodes and converted into a voltage pulse by a charge sensitive amplifier. The amplitude of the pulse is related to the photon energy and, thanks to a suitable device, it is possible to obtain the energy spectrum of the radiation. To reduce the leakage current and improve the resolution, the semiconductor crystal is cooled down to 77 K with liquid nitrogen. As low energy X-rays are easily absorbed, the detector has not to be very thick but its geometry has to be carefully designed to avoid losses and special fabrication techniques have been developed to improve the overall characteristics of these detector [4]. The model which will be tested hereafter is an Ultra-LEGe (ultra low energy germanium) detector model GUL0035P from Canberra Eurisys SA [5].

2.2 Si-PIN (Silicon-PIN wafer)

We have considered the Si-PIN type X-ray detectors that were originally developed for use in satellite instrumentation and have been in commercial use since 1993. The detector is prepared by starting with a wafer of almost intrinsically pure silicon. Thin p and n regions are then diffused into each side of
the wafer surface forming a diode with an intrinsic (I) region between the two doped layers. That thick layer increases the active volume of the detector and improves the efficiency of the detector for X-rays [6]. The detector used for our comparison was a XR-100T Amptek Si-PIN placed in similar experimental conditions as in the other measurements.

2.3 PIPS (Passivated Implanted Planar Silicon)

The PIPS diode is constructed by implanting a wafer of high purity silicon having a p-type conductivity with high temperature ions to give the bombarded region a n-type conductivity. A thick and very well defined p-n junction is thereby formed. Ohmic contacts (usually 30 to 50 nm of Al) are deposited on both side of the substrate to complete the diode. Depletion thickness of up to 0.7 mm can be obtained by that method. For low energy photon detection, specially designed PIPS detector are available [7]. They are Peltier cooled and sealed in a hermetic enclosure containing the detector, the FET preamplifier and its electronic. The model used here is a prerelease Canberra detector similar to the SXP-190-500 model (8 mm$^2 \times 500 \ \mu$m).

2.4 SDD (Silicon drift detector)

Silicon drift detectors (SDD) consist of a thin cylinder of fully depleted silicon in which an electric field, parallel to the surface, drives electrons towards the anode located at the center [8,9]. The field is created by many concentric ring electrodes and the anode is directly connected to an integrated FET acting as a current preamplifier. Even if SDD works well at room temperature, the best
performances are obtained at a temperature around -20 C (Peltier cooler).

SDD X-ray detectors have been developed at MPI München since 2000 and are manufactured exclusively by KETEK GmbH [10]. Two SDD detectors have been tested for this work (models of the AXAS family from KETEK [11]).

2.5 Experimental conditions

The characteristics of the detectors have been obtained under different experimental conditions. The $^{55}$Fe X-ray data have been recorded by placing a capsule containing a small amount of $^{55}$Fe$^*$ in front of the detector. The XRF spectra were produced by looking at the fluorescent spectra induced by irradiating the target with an X-ray beam (1 mm diameter) produced by an Oxford Instrument Serie 5000 X-ray tube (W anode, 35-40 kV). The PIXE data were recorded on the experimental PIXE setup of the IPNAS laboratory using a 2.58 MeV $p^+$ beam accelerated by the variable energy cyclotron of the University of Liège [12,13]. For all measurements the counting rate was kept below 2 kHz in order to avoid pile-up and reduce the influence of the electronic system [4,14].

3 Results and discussion

3.1 Resolution

Resolution is a measure of the width (full width half max.) of a single energy peak at a specific energy. The values presented in Table 1 for $^{55}$Fe have been obtained by fitting a gaussian doublet to the $K_\alpha$ (5.90 eV) and $K_\beta$ (6.49 eV)
Table 1

<table>
<thead>
<tr>
<th>detector</th>
<th>specified (@6keV)</th>
<th>$^{55}Fe$</th>
<th>XRF</th>
<th>PIXE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultra-LEGe</td>
<td>140</td>
<td>160</td>
<td>-</td>
<td>154 ± 1</td>
</tr>
<tr>
<td>X-PIPS</td>
<td>185</td>
<td>-</td>
<td>210 ± 1</td>
<td>-</td>
</tr>
<tr>
<td>SDD 1</td>
<td>150 – 160</td>
<td>160</td>
<td>175 ± 2</td>
<td>-</td>
</tr>
<tr>
<td>SDD 2</td>
<td>&lt; 132</td>
<td>132.8 ± 0.4</td>
<td>-</td>
<td>139 ± 1</td>
</tr>
<tr>
<td>Si-PIN</td>
<td>177</td>
<td>193 ± 3</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

lines of $^{55}Mn^*$. The XRF and PIXE values have been deduced from the fitting of the $K\alpha$ line of $Fe$ (6.40 eV) observed in the fluorescent spectra of a sample containing a small amount of iron. For each measurement, the counting rate was below 200 cps and the detectors were coupled to the full experimental setup without special care.

In each case, the value of the shaping time constant has been chosen to get the best resolution under our experimental conditions. The values given in the table are thus representative of the resolution that can be achieved in real experiments.

All our observed resolutions are close to the fabricant quoted values. We observe only a small and systematic degradation that could be explained by the fact that our measurements were made under real conditions (no special shielding from the generator or other laboratory equipment and without optimizing the electronic acquisition chain). Let us note that AMPTEK, the main maker of SI-PIN [15], claims now to have reached an ultimate resolution of 149 eV under special conditions [16]. The resolution obtained in normal operation is close to 200 eV (see [17,18]). We did not include Si-PIN detector in our efficiency comparison as we had not a recent detector of that type at our
disposal. We have also measured the resolution of an old (1996) XR − 100T Amptek Si-PIN that has been used extensively as an intensity monitor for a strong X-ray source. The radiation damage was obvious: at 5.9 keV, the observed resolution was 740 eV! (far from the quoted 242 eV) [19]. Those results have not been included in the table.

3.2 Efficiency

The intrinsic efficiency of a detector varies with the photon energy and is usually given by the constructor in the data sheet of the detector. However, when the detector is used in an experiment, the effective efficiency depends on local factors, as size of the active region, screening, shielding, geometrical disposition, distance from the target, etc... The results presented hereafter are thus representative of typical experiments.

3.3 Comparison SDD/PIPS

The efficiencies of two of our detectors have been compared by recording XRF spectra of a target containing Cr, Pb and Cd under the same conditions. The electronic rise times were chosen to give the best resolution for the SDD (1 μs) and for the PIPS (10 μs). Our results are presented on Fig. 1. The two detectors have similar efficiencies, around 11 keV, and we observe that the SDD efficiency is better at low energy whereas the PIPS is more efficient above 10 keV.
3.4 Comparison SDD/X-LEGe

The data of Fig. 2 have been obtained by comparing vacuum PIXE spectra of a biological sample. The 2.5 MeV proton beam was produced by a Van de Graaff accelerator and the two detectors were successively positioned at the same place, outside the vacuum chamber and behind a mylar window of 100 µm. As the surface of SDD (5 mm²) detector was smaller than that of the X-LEGe (30 mm²), the SDD spectrum has been recorded with 6 times more beam charges.
4 Summary

The characteristics of four different solid state detectors, best suited for detecting X-ray in the 3-50 keV region, have been compared. Our results show that the fabricant quoted resolution is a lower limit that can be approached easily under normal conditions. The SDD type diode is particularly attractive as it has the best resolution and a reasonably good efficiency. The new PIPS detectors are cheaper and present also a very good compromise as well as Si-PIN. Three of them are Peltier cooled and very small and thus particularly suitable for incorporation in XRF portable systems. The LEGe detector is still very attractive but suffers from the fact that it has to be cooled with (expensive) liquid nitrogen and thus is not easily movable.
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References


