Use of Si-PIN Photodiode X-Ray Detector for PIXE

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Introduction

Si-PIN Photodiode type detector (hereafter SPINP for short) is one of the X-ray detectors which have shown significant improvement in resolution recently. It is reported that the most advanced detector has a specification value of FWHM of 250 eV at 5.9 keV[1]. This value is worse only by 150 eV than the typical value of conventional Si(Li) detectors. The remarkable advantage of the detector is its high operability due to the Peltier (thermoelectric) cooler and low voltage bias. The detector with the cooler and its preamplifier are housed in a box of the size of 9.5×4.4×2.9t in cm. Disadvantage of this detector is still in the small size of crystal, both in area and thickness, especially the latter; this might cause the low detection efficiency for the higher energy X-rays. In this paper, basic characteristics of this detector and feasibility to PIXE, especially to bio-PIXE are investigated.

Basic Characteristics of Si-PIN Photodiode Detector

First, the basic characteristics of a SPINP detector (Model XR100T, Amptek, Inc.) have been studied using some radioactive X-ray sources, such as Fe-55, Sr-85, Cd-109 and Am-241. Related nuclear data for these sources were taken from the reference[2]. Energy resolution of the detector was derived as the FWHM value at each peak energy from the Gaussian peak fitting to the source spectra in the energy range from 4 to 26 keV. The relation between the resolution and X-ray energy was obtained by the least-squares method by assuming that FWHM of each peak was expressed by the quadratic sum of energy dependent and independent terms. The resultant curve shifts from that of an old Si(Li) detector by about 100 eV as shown in Fig. 1. At 5.9 keV, the observed value of 249 eV is quite consistent with the nominal value of the specifications given by the detector manufacturer, and is about twice of that of the commercially available Si(Li) detectors with the maximum performance. Intrinsic efficiency of SPINP was calculated by assuming a simple slab geometry having the thicknesses of 300 μm with 0.025-mm beryllium window.

The calculated efficiency curve is compared with the measured data for Fe-55 and Cd-109 sources and also with measured data for a typical Si(Li) detector in Fig. 2. The observed data are consistent with the calculation. The calculated curve is almost the same with that of the conventional detector below 10 keV because the Si(Li) detector has similar window structure, while the curve begins to decrease at 8 keV, and becomes a half of the maximum around 15 keV due to the insufficient thickness of SPINP. The energy 15 keV corresponds to the energy of characteristic K X-rays of the elements with atomic numbers around 40. Finally the efficiency value is only as low as a tenth of that of the Si(Li) detector above 20 keV.

Applicability to PIXE

Applicability of SPINP to PIXE has been studied in a condition of in-air PIXE in which we intend to use this type of detector in most cases. A SPINP detector was mounted in the assembly for the beam exit of ViaPIXE[3)] (Vertical beam in-air PIXE system) of Dynamitron laboratory at Tohoku University[4)]. Fig. 3 shows the beam exit assembly together with the SPINP detector having 6 inch extension rod.

As the first example, typical spectra of PIXE measured by both the SPINP detector (upper) and a Si(Li) detector (lower) for a layer of ZnCdS on aluminum foil are shown in Fig. 4. The ZnCdS scintillator has usually been used for the beam monitor at the sample position and for the purpose of the detector energy calibration in Via PIXE. In the lower channel regions of the spectra, peaks from several elements: aluminum, argon, iron, and zinc are clearly observable. The peaks of cadmium are also in the higher channel regions. The peak of argon is due to the excitation of argon in the beam path between the beam exit foil (Kapton foil ;12.5 μm) and sample position.

An inspection does not reveal significant difference, especially in the separability of each peak, between the spectra of both detectors, though the peak shape of the Si(Li) detector is sharper. While, one could notice the cadmium counts of an order of magnitude lower in the SPINP spectrum as mentioned before. Another feature of the spectrum by SPINP is that clear shoulder structure exists in the low energy side of the Zn Kα line peak. This type of structure was also found in the spectra from the radioactive sources, but the shape of the structure sometimes changed with time. This may be due to the insufficient charge collection in the detector, but further study is needed to prove this.

Fig. 5 shows the spectrum of a standard sample (SRM 1833) mounted on a Mylar foil measured with the SPINP detector. The peaks of titanium, iron, zinc, and lead can be clearly identified, whereas the peaks of sulfur, chlorine, argon, potassium, and calcium can hardly be separated. The interference is due to the strong argon peak. These peaks could be partially separated in the spectrum measured by the Si(Li) detector. The result of the spectrum decomposition by the pattern analysis method[5,6)] is also shown in Fig. 5. The solid line represents the whole fit and the dotted lines indicate each single component including the background. The agreement between the experimental data and fitted ones is fairly good. The previous extensive simulation study has shown the feasibility of the pattern analysis method to such bad resolution spectra for the SUS316 case[7].

In the case of the bio-samples, usually a known amount of yttrium, indium or silver is added as an internal standard for the determination of the absolute concentrations. These three elements have been chosen because these are usually not contained in bio-samples with a few exceptional cases. But, for SPINP, silver and indium might not be suitable because the efficiency for the K-lines of these elements is very low as mentioned above. In this case yttrium is preferable, if the yttrium is not contained or the amount of yttrium is negligible small in the sample.

Conclusions

The basic characteristics of a new Si-PIN photodiode detector were examined by a set of X-ray sources, and they were consistent with the catalogue data given by the manufacture. Feasibility of this detector to PIXE was also investigated in an actual condition of PIXE. In conclusion, this type of detector can be applied to PIXE from the view points of the efficiency and resolution, if they are interested in the common lower Z elements below about 40; K-X rays from these elements can be observed with almost the same efficiency as conventional Si(Li) detectors. It can be expected that rather poorer resolution of the detector does not introduce significant drawback in the spectrum analysis if we use the pattern analysis method.

According to the manual of the SPINP detector, the detector shows that the rise time of pulses varies with the location of the detection. This needs to use a longer shaping constant in the main amplifier than in the case of the conventional Si(Li) detector; a triangular fixed shaping time constant of about 12 μsec is used in the amplifier provided by the manufacturer to realize the highest resolution. If we use the detector in a high counting rate condition, this could cause deterioration of the detector performance. The counting rate effect on the performance remains to be uninvestigated.

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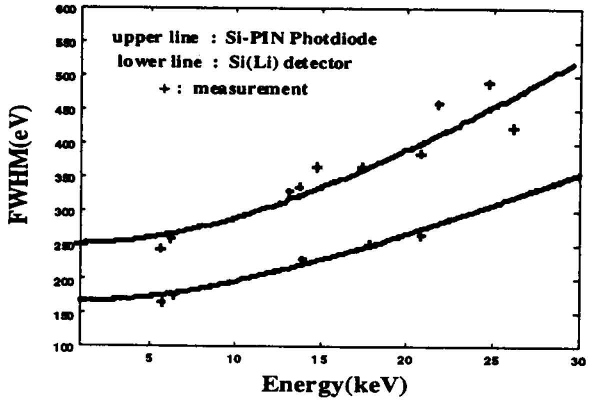

Fig. 1. The relation between the resolution and X-ray energy for a SPINP detector measured by using the X-ray sources compared with the data for a Si(Li) detector. The least squares fitting curves are also shown.

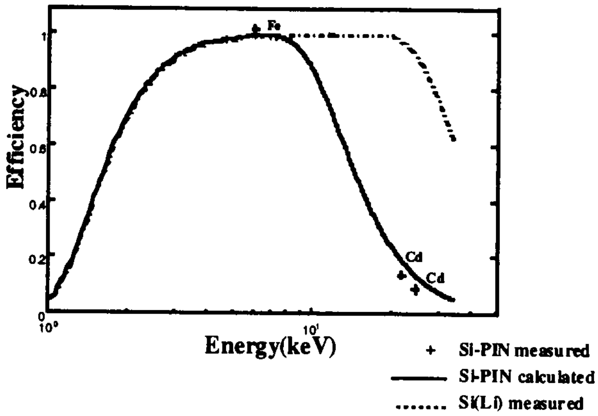

Fig. 2. The relation between the efficiency and X-ray energy calculated by a slab geometry for SPINP, compared with the experimental data using the X-ray sources and also the data for a Si(Li) detector.

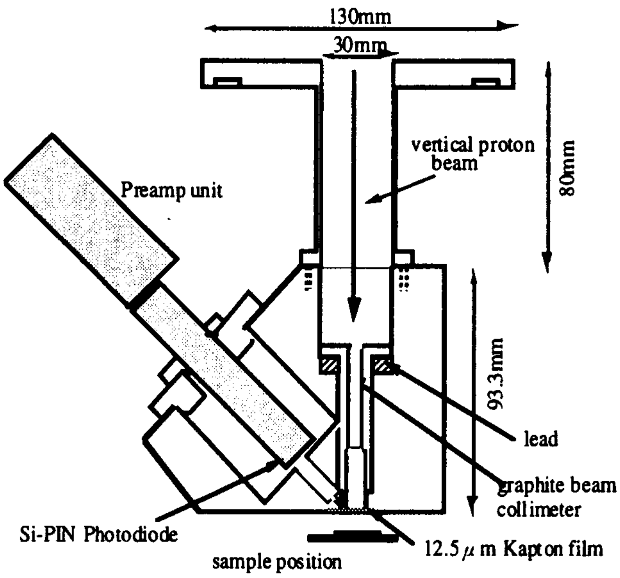

Fig. 3. The set up of the beam exit assembly together with the SPINP having 6 inch extension rod.

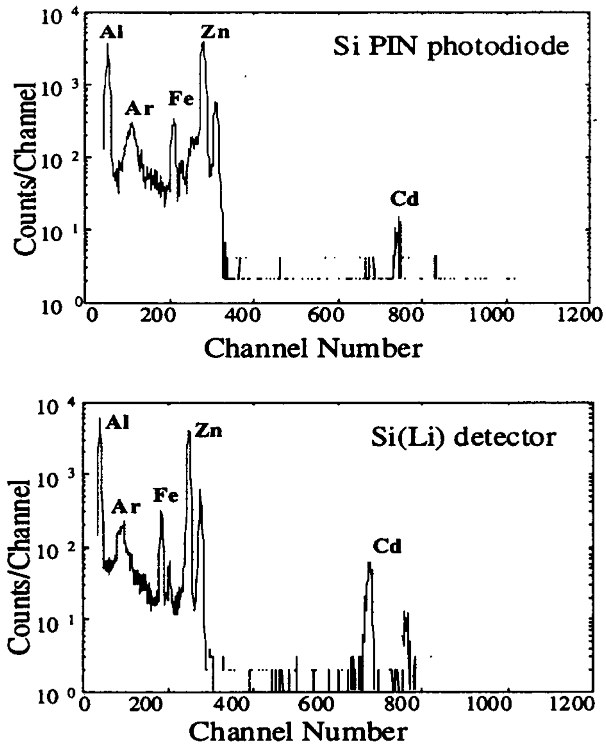

Fig. 4. Typical spectra of PIXE measured by both SPINP (upper) and Si(Li) detector (lower) for the same layer of ZnCdS on aluminum foil, respectively.

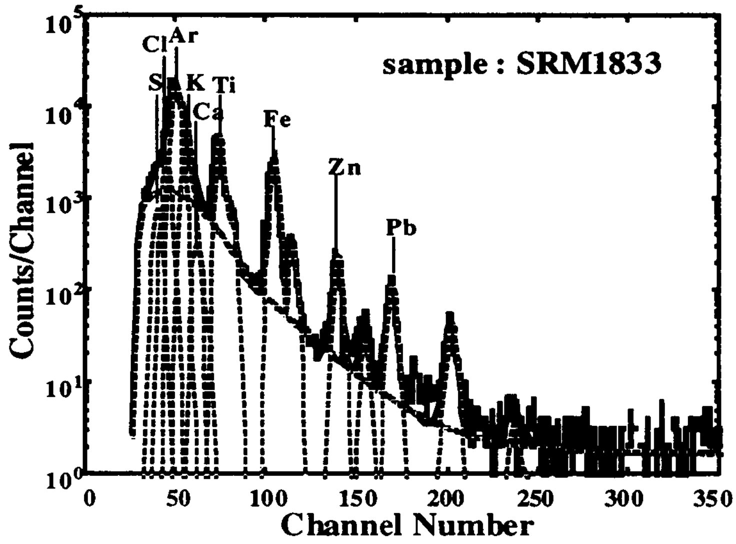

Fig. 5. A measured spectrum by SPINP for a bio-sample on Mylar backing. A result of decomposition by the pattern analysis method is also shown.