Note

A Radiation Detector Fabricated from Silicon Photodiode†

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A silicon photodiode is converted to a low energy charged particle radiation detector. The window thickness of the fabricated detector is evaluated to be $50 \mu\text{g}/\text{cm}^2$. The area of the depletion region is 13.2 mm^2 and the depth of it is estimated to be about $100 \mu\text{m}$. The energy resolution (FWHM) is 14.5 keV for α -particles from ^{241}Am and 2.5 keV for conversion electrons from ^{109}Cd , respectively.

Key Words: silicon photodiode, radiation detector, energy resolution, alpha particle, americium-241, conversion electron, cadmium-109

1. Introduction

Silicon photodiodes are essentially photovoltaic cells of a p-n junction type. When irradiated with photons of an energy sufficient to produce electron-hole pairs in silicon, a photocurrent is induced without application of external power supply. The external reverse voltage, however, is often supplied in order to achieve a wide range of linearity and the fast response to incident photons. As the reverse bias voltage increases, the depth of depletion layer also increases, and accordingly the capacitance between the two electrodes of the cell decreases. This resembles the characteristic behavior of an ordinary semiconductor radiation detector. It is, therefore, expected that the photodiode may be applied to the radiation detection. In the present work, a silicon photodiode was converted to detect α - and low energy β -rays, and its energy response and resolution was studied.

2. Detector Fabrication and Measurement System

The detector window should be thin enough for detecting α - and low energy β -rays. Before fabrication the front cover cap and surface coating of silicon photodiode (Hamamatsu Photonics S1722-01, p-i-n junction type) were removed carefully. The active area of the detector slice is 13.2 mm^2 ($4.1 \text{ mm}\phi$) and the edge of the junction is coated with epoxy resin to protect the periphery of active area against edge breakdown¹⁾. The detector slice is housed inside a brass capsule. Electric lead of the front surface of the slice is connected to the brass capsule and the back side lead is connected to a Microdot S-93 connector, through which the electrical signal is taken. Figure 1 shows a cross section of the fabricated detector schematically.

A measurement system composed of Canberra 2001A preamplifier, Canberra 2021 spectroscopy-amplifier and ORTEC 7100 multichannel analyzer was used for the performance evaluation of the detector. During the experiments, both the standard radiation sources and the fabricated detector were placed in a vacuum

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Fig. 1 Schematic cross-sectional drawing of the fabricated radiation detector (not to scale).

chamber. All the measurements were done at room temperature.

3. Experimental Results and Discussion

The leakage current of the fabricated detector was measured as a function of bias voltage. The obtained results are shown in Fig. 2. The leakage current increases gradually as the bias voltage increases, and reaches about only 0.7 nA at a bias voltage as high as 100 V. The Canberra 2001A preamplifier is essentially designed for high resolution γ -spectroscopy and is supposed to be used together with a cooled germanium-detector. The detector series bias resistance of the preamplifier is kept as high as 10 G Ω . The bias voltage drop across the resistor, therefore, is less than 7 V in the present detector, since the leakage current is 0.7 nA at most. The depth of the depletion layer is estimated to be about 100 μm from the capacitance and the active area of the fabricated detector.

Figure 3 shows a typical pulse-height distribution of α -particles from ^{241}Am . Two peaks at 5.443 and 5.486 MeV are clearly separated.

Fig. 2 Leakage current as a function of bias voltage.

Fig. 3 Energy spectrum of α -particles from ^{241}Am .

The energy resolution which is expressed in FWHM, is 14.5 keV for both peaks.

To estimate the thickness of detector window, the shift of peak channel of α -spectrum was measured as a function of the incident angle θ of α -particles with respect to the normal of the detector surface. The detector window is assumed to be composed of silicon oxide layer only. The relation between the thickness x_{Si} of the detector window and the shift ΔN of the peak channel is expressed by the following equation;

$$\Delta N \varepsilon = \left(\frac{dE}{dx} \right)_{\text{Si}} x_{\text{Si}} \left(\frac{1}{\cos \theta} - 1 \right), \quad (1)$$

where ε is the calibrated energy per channel, which is 5.8 keV/ch in the present experiments, and $(dE/dx)_{\text{Si}}$ is a stopping power of silicon for α -particles and is assumed to be 136 eV/nm (13.6 eV/ $\text{\AA}$)²⁾. In Fig. 4, the obtained values of ΔN are shown as a function of $\{(1/\cos \theta) - 1\}$. Open circles and closed triangles indicate the results for bias voltage V_d setting of 50 and 100 V, respectively. Straight lines were obtained by means of the least square method. From the slopes of these lines and Eq. (1), the thickness of the detector window is evaluated to be about 210 nm (2100 $\text{\AA}$), which amounts to 50 $\mu\text{g}/\text{cm}^2$.

In Fig. 5 is shown the pulse-height distribution of conversion electrons from ^{109}Cd . The energy resolution is 2.5 keV (FWHM) for two peaks appearing at 62.523 and 84.231 keV. The test pulser yields a peak of 2.0 keV (FWHM) width. A small shoulder observed at the right-hand side of the peak at 84.231 keV may pro-

Fig. 4 Shift of the peak channel of α -spectrum as a function of $\{(1/\cos \theta) - 1\}$. The symbol θ denotes the incident angle of α -particles with respect to the normal of the detector surface. ($1 \text{ nm} = 10 \text{ \AA}$)

pably be due to the presence of γ -rays (88 keV) from ^{109m}Ag . The value of FWHM for α -particles becomes 5.8 times greater than that for conversion electrons. This degradation in energy resolution is mainly attributed to the energy self-absorption of α -particles in source itself. A dashed line in the figure represents a background noise distribution. The highest noise energy is about 6 keV.

From these results, it can be concluded that the radiation detector fabricated from silicon

Fig. 5 Energy spectrum of conversion electrons from ^{109}Cd .

photodiode shows satisfactory characteristics for measurements of natural α - and low energy β -rays.

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