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Semiconductor Radiation Detector (II)

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Abstract

Description is given of a *p-n* junction type semiconductor detector. By a shallow diffusion of phosphorous into *p-type* silicon wafer, a *p-n* junction detector was manufactured. The characteristics of the detector as an alpha particles spectrometer was measured. Since the characteristics of the detector depends on surrounding conditions; i. e., the temperature, the humidity, etc., the effects of these factors were investigated. The *p-n* junction detector must be operated under dark and dry surroundings and below room tenperature.

I. Introduction

Recently it has been known in heavy charged particles physics that semiconductor radiation detectors can be used as detectors for the particle spectromters. There are twe types; one is a surface barrier detector and the other is a *p-n* junction detector. Previously the author published papers[1,2] on germanium surface barrier detectors. In this paper is given the characteristics of a silicon *p-n* junction detector.

By a thin diffusion of phosporous into *p-type* silicon wafer, a *p-n* junction detector was prepared and used for the energy spectrometer for heavy charged particles. The construction of the detector is simple as shown in Fig. 1. But the process of preparation is not easy.

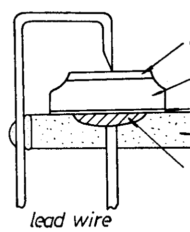

Fig. 1. *p-n* junction petector.

II. The *p-n* diffused type detector

Shallow diffusion of phosphorous forms a *p-n* junction on one surface of a bulk of highresistivity *p-type* silicon. By applying a reverse bias on the junction,

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1) W. T. MIYAO, Synosis of the lecture delivered at the Meeting of the Institute of Applied Physics of Japan, Oct. 1961.

2) W. T. MIYAO, Proc. Faculty of Eng. KEIO Univ. Vol. 13 No. 50 (1960).

a depletion region is formed on both sides of the junction, as shown in Fig. 2. An incident alpha particle creates hole-electron pairs in the depletion region, and subsequent collection of carriers produces a voltage pules. The width of the depletion region on each side is given by

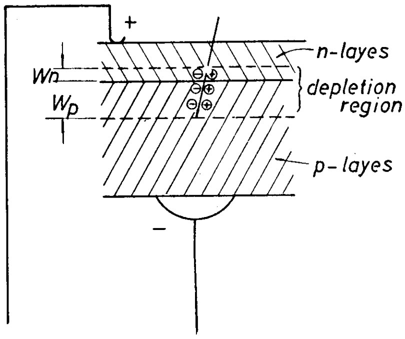

Fig. 2. Depletion region in the junction.

$$W=\left\{\frac{\varepsilon(V_0+V)}{2\pi eN}\right\}^{1/2} \tag{1}$$

where ε is the dielectric constant of silicon, V_0 the barrier height, V the bias voltage, e the electronic charge, and N the excess density of donors. The ratio of the width of the *p-layer* to that of the *n-layer* is given approximately by

$$\frac{W_p}{W_n}=\left\{\frac{\sigma_n}{\sigma_p}\right\}^{1/2} \tag{2}$$

where σ's are conductivities. Therefore, most of the depletion region is in the *p-layer.*

III. Preparation of detector elements

The procedure of making a *p-n* diffused type detector is outlined as follows. A single-crystal of *n-type* silicon ($\rho=100^{\Omega cm}$) is cut into pellets 1 mm thick and 2×2 mm^2 in area. The both sides of a pellet are lapped carefully with No. 3000 carborundum. The pellet is put in a glass capsule together whith a small amount of of phosphorus oxide and is sealed after evacuation, as shown Fig. 3. The capsule is kept in an electric furnace at 1000°C for 3 hrs to form a *n-type* layer on the

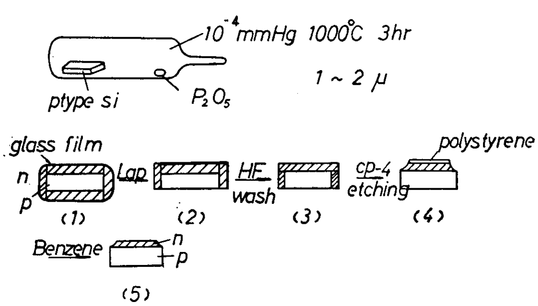

Fig. 3. Procedure of making the *p-n* junction detector.

surface of the *p-type* bulk. The *p-n* junction is covered with glass film. After one of the faces is lapped with carborundum. the pellet is washed with *HF* solution to remove the surface glass firm. After the surface of the *n-layer* is covered with polystyrene, the pellet is etched with *CP*-4. Finally, removing polystyrene with benzene, the *p-n* junction sample is prepared ready to use. The bottom of the junction is nickel-plated by the electrodeless plating method. A copper wire is soldered to it as an ohmic contact.

IV. Experimental method

Figure 3 is a schematic diagram of the measuring equipment use to determine the characteristics of the detector as an alpha particle spectrometor. An alpha particle incident on the detector produces a voltage pluse in the *p-n* junction. This pulse was amplified with a preamplifier and a linear amplifier, and was analyzed with a single channel pulse height analyzer. The geometry of the alpha source was such that alpha particles struck at nomal incidence the sensitive surface and the distance between both was about 5 mm. The bias voltage was supplied by a battery through an *RC* filter to cut off the noise.

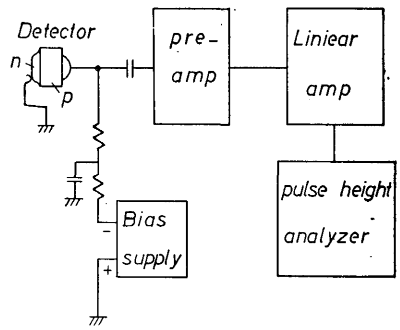

Fig. 4. Schematic digram of the measuring aparatus.

V. Experimental results

(a) Dependence of the voltage pulse height on the reverse bias.

It is known that the pulse height is proportional to $V_b^{1/2}$. Dependence of the voltage pulse height on the reverse bias was measured, and is shown in Fig. 5. The pulse height increases with the reverse bias. But, since the noise level increases at the same time, an optimum point must exist. Actually, the pulse height saturates at about 5V, whereas as the noise begins to increase rapidly at about the same voltage. The signal to noise ratio is roughly 7.0 at 5 V bias, Fluctutions of the data are related to the resolution of the detector, from which the resolution of the detector was determined as about 9.0%.

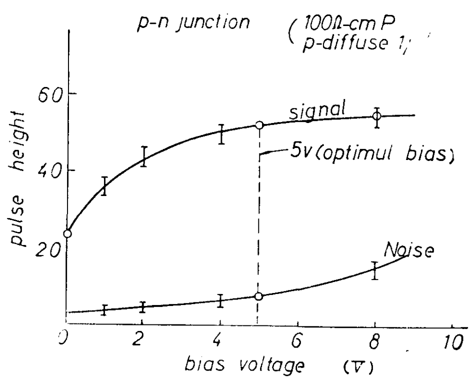

Fig. 5. Dependence of pulse height on bias voltage.

(b) Dependence of the diode characteristics on temperature.

A simple test of the quality of the

detector is to measure its characteristics as a diode. A good detector has good diode characteristics, because the value of the reverse current shows the potential barrier formation. It is well known that the behavior of a semiconductor is sensitive to the ambient temperature. As the temperature increases, free electrons acquire enough energy to jump over the energy gap. Thus, the reverse current increases with temperature.

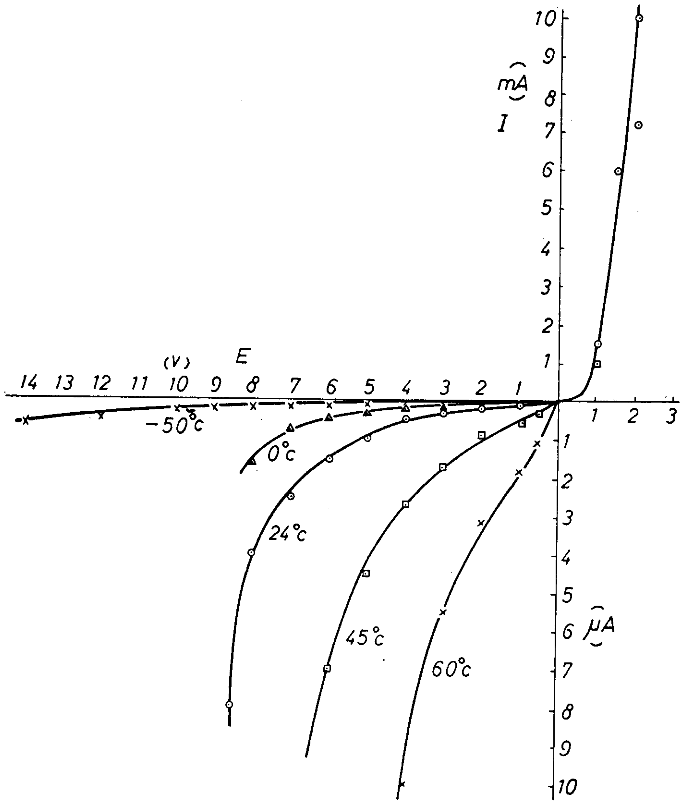

Fig. 6. Dependence of diode characteristics on temperature.

Fig. 6 shows the depandence of the characteristics of our diode on the ambient temperature. In order to obtain a good resolution and a high signal to noise ratio, the reverse current must be below 1 μA. Thun, it was found that the ambient temperature must be kept below 0°C. By the way, the reverse current depends on the temperature following the squation;

$$I = Ae^{-\frac{\phi}{kT}} \tag{3}$$

which is verified from the plot in Fig. 7. The energy gap of Si can be determined from the gradient of the curve in this figure as 1.0 eV.

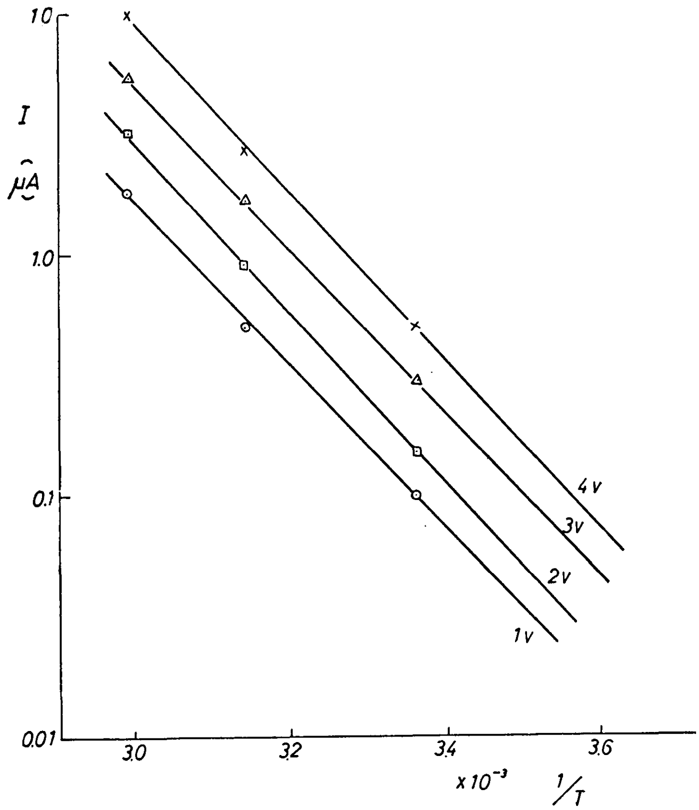

Fig. 7. Reverse current vs. $1/T$ curves.

(c) Measurement of energy spectrum of $^{210}P_0$.

A capsule containing the detector was suspended in ice water, and the energy spectrum was obtained with a single channel pulse height analyzer. Fig. 8 shows a spectrum of alpha particles from a $^{210}P_0$ source taken with the Si p-n junction detector at 5 volt bias. The full width at half maximum, i. e. 9 %, is actually large compared with what has been obtained with recently manulfctured detectors. One of the reasons is that the $^{210}P_0$ source was weak and uncollimated.

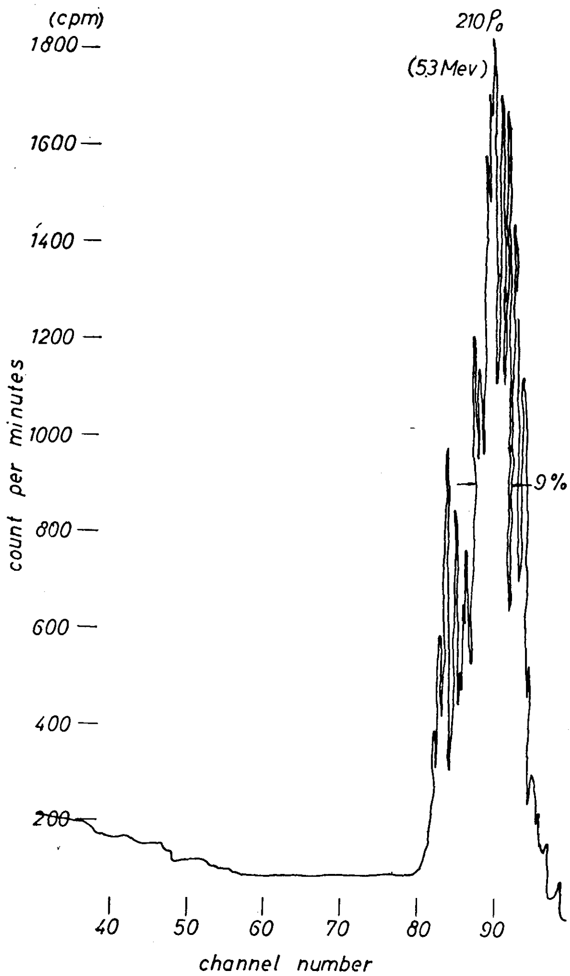

Fig. 8. Energy spectrum of $^{210}P_0$ measured with p-n junction detector.

VI. Discussion

(a) Photoeffect of the detector.

Semiconductor detectors are sensitive to photons just as photo diodes are. The photoeffect of the semiconductor detector was measured. Here an incandescent lamp was used to irradiate the sensitive area of the specimen. Under various light intensity, the diode charcteristics of it was determined as shown in Fig. 8.

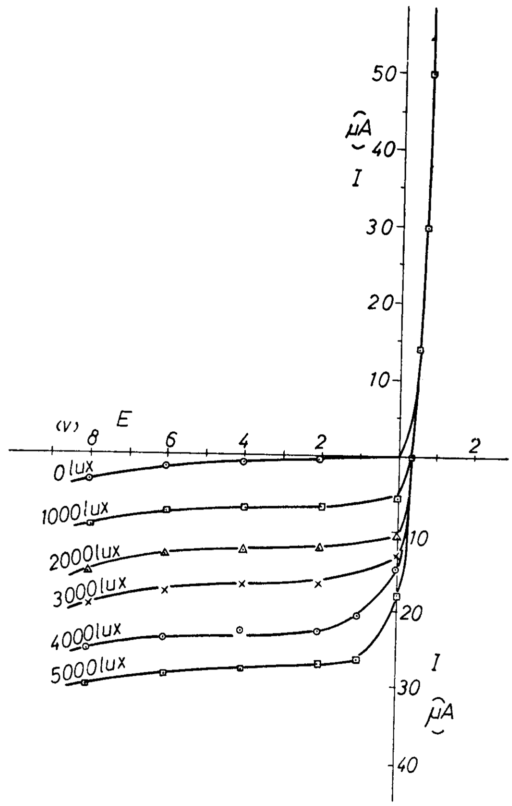

Fig. 9. Photo effect of the *p-n* junction.

(b) Effect of humidity on diode characteristics.

As one of the experimental conditions, the humidity effect of the detecter must be considered. Because P_2O_5 as diffusing material becomes wet quickly in air, the *n-layer* is very sensitive to humidity Fig. 10 shown the effect of the humidity upon the diode characteristics of the detector. With increasing humidity the reverse current increases extraordinarily fast, making it necessary to keep the inside of the capsule of the detecter dry with use of silicagel. The time variation of the reverse current after the speciment was displaced from dry to wet condition is shown in Fig. 11.

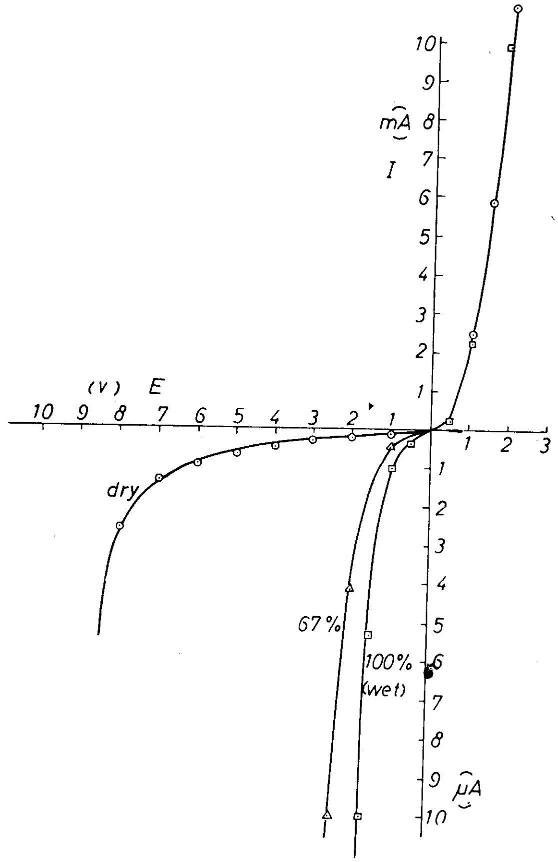

Fig. 10. Dependence of diode characteristics on humidity.

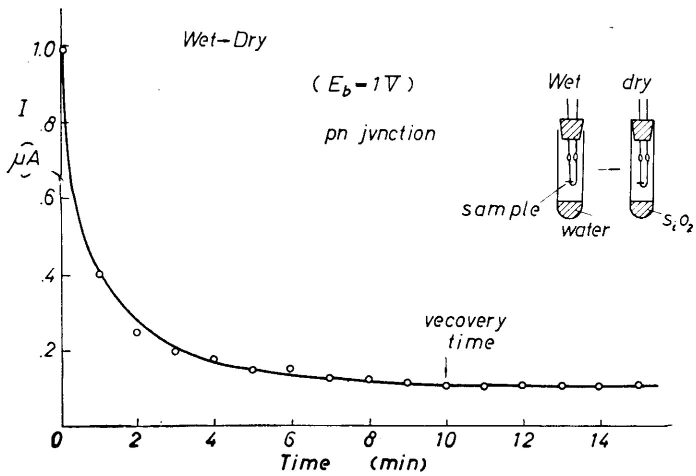

Fig. 11. Recovery of diode characteristics with time as displaced from wet to dry surrourdinas.

(c) Dependence of capacitance of the detector on the reverse bias.

Since the width of the depletion depends on the bias voltage, the capacitance C_b of the detector is given from shottoky's theorem as $C_b \propto V_b^{-1/2}$. If the charge is the same, the smaller is the capacitance, the higher is the pulse height, so that it is better that the construction of detector is made small.

Dependence of the capacitance of the detector on the revarse bias as given above was verified experimentally by the pulse method as shown in Fig. 12.

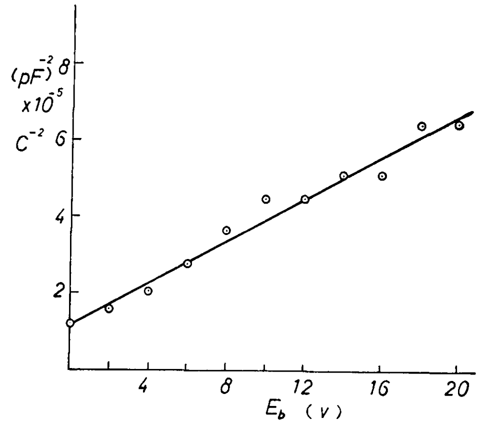

Fig. 12. Dependence of equivalent **capacitance** on bias voltage.

VII. Conclusion

A semiconductor detector hase many advantages over gaseous counters. It is small in size, having a good resolution, a fast rise time and no back ground.

On the other hand, it has several disadvantages in that its characteristics is very sensitive to the surrounding conditions such as the temperature, the humidity and light. Therefore, it was concluded that the *p-n* junction detector must be operated under dark and dry surroundings, and below room temperature. Within our experimental limits, a quantitative analysis of the response for alpha particles was almost imposible. However, this detector can be used for alpha particle detection sufficient for practical use, permitting qualitative analysis of the results.

Acknowledgement

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