Bull. Inst. Chem. Res., Kyoto Univ., Vol. 60, No. 2, 1982

A Rectangular Si(Li) Detector Adopted to Position Sensitive Counter Telescope

Norihiko KOORI, Hideaki KONISHI† and Yuzuru MATSUMOTO

Received March 15, 1982

A simplified method is described to prepare Si(Li) detectors with a large rectangular sensitive area which are adoptable to a position sensitive counter telescope for the study of fast-neutron induced reactions.

KEY WORDS: Large semiconductor detector/ Counter telescope/ Instrumentation for neutron-induced reactions/

I. INTRODUCTION

Silicon detectors with a large sensitive area have been developed for detection of primary cosmic rays[1] and for monitoring environmental α-rays.[2] These have a circular sensitive area of $20\sim40\,cm^2$. Thick silicon detectors are essential for applications except detection of low energy α-particles. Thick silicon detectors with a large rectangular sensitive area have not been reported because of no need of rather particular specification for detectors.

A counter telescope with large solid angle is indispensable to measure charged particles from reactions induced by fast-neutrons, because the intensity is generally low. The authors developed a position sensitive counter telescope (PSCT) with both large solid angle (i. e. wide angular acceptance) and good angular resolution introducing 2 position sensitive proportional counters into the counter telescope.[3] It was needed as a energy detector for this PSCT a thick silicon detector that has a large rectangular sensitive area (larger than $15\times60\,mm^2$) and a thickness enough to stop 14 MeV protons (thicker than 1.5 mm).

The lithium drifted (Si(Li)) silicon detector assures easily of the required thickness. One can say that methods of preparation of ordinary size Si(Li) detectors have been established in the years of 1960's.[4,5] However, a problem has not been solved how one can obtain the rectangular sensitive area of required large dimension.

A method of preparation of the Si(Li) detector with large rectangular sensitive area will be described with obtained performances in this article.

II. METHOD OF PREPARATION

1. Starting Material of Silicon Wafer

桑折範彦, 小西秀明, 松本 譲: Department of Nuclear Engineering, Kyushu University, Fukuoka, 812.

† Present address: Nittetsu Plant Engineering, Kita-Kyushu, 805.

Silicon crystal rods of larger diameter than 70 mm are not uniform in the resistivity and carrier life time in the peripheric region of the rods. In this work, a commercially available p-type silicon crystal rod (30 mm $\phi \times 70$ mm$l$)[6] is chosen and sliced along the central axis to obtain rectangular wafers with uniform resistivity and carrier life time. The properties of the crystal are as follows: Dislocation free crystal pulled up in a vaccum floating-zone. The crystal axis is $<1, 1, 1>$. The resistivity $\rho \geqq 1000\,\Omega \cdot$cm, the life time of minority carriers $\tau \geqq 700\,\mu$sec, and the density of oxygen content $\leqq 10^{16}$ atoms/cm^3 (0. 2 ppm).

2. Evaporation and Diffusion of Lithium

After lapping (finally with Al_2O_3 powders of 2000 mesh), washing (with C_2HCl_3, CH_3OH and distilled water under ultra sonic agitation, in turn) and etching for 10 min (with standard 3:1:1 etchant of HNO_3, HF and CH_3COOH), the wafer is heated upto 300°C with a heater and a mask (18×61 mm^2) for evaporation in a vaccum evaporator. Metallic lithium is evaporated through the mask onto the wafer, and then the temperature is kept for 16 min at 300°C to make a n^+ Li diffused layer of about 0. 5 mm thick. The wafer is cooled down rapidly without thermal shock. The Li contamination on the surfaces except the evaporated region should be removed by lapping, washing and etching procedures.

3. Lithium Drift Operation

The wafer i. e. n^+-p diode is mounted on an automatic drifting apparatus, that is schematically explained in Fig. 1. On the p-side of the diode, the alloy of Ga-In is painted over an area of about 16×60 mm^2 for electric contact with the devices. Initially, the reverse bias of 350 V is applied at the diode temperature of about 120°C. The

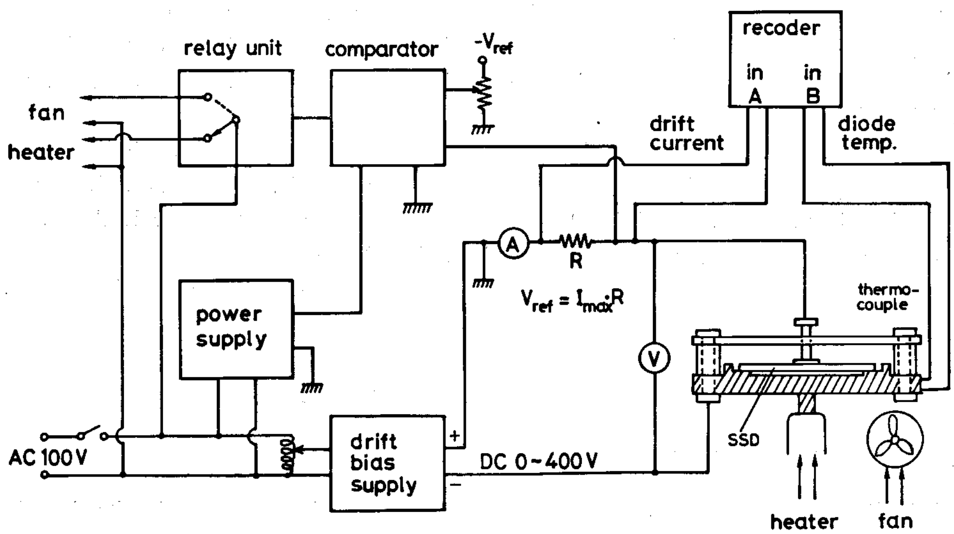

Fig. 1. Blockdiagram of automatic lithium drifting apparatus.

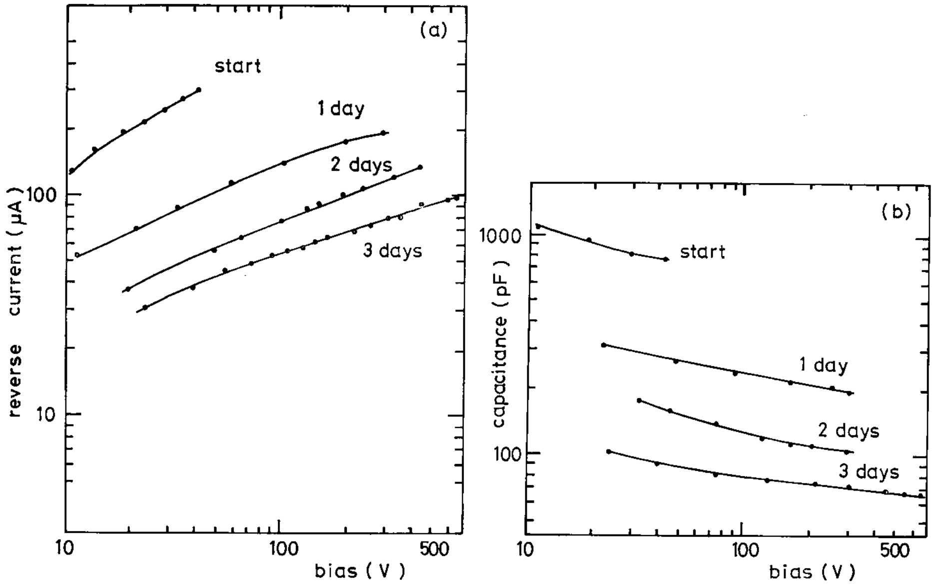

Fig. 2. Variation of the diode characteristics during the Li drift operation.

reverse current (drift current) is kept at 8 mA by controlling the diode temperature with a fan or a heater plate. The diode characteristics (reverse current vs. bias and capacitance vs. bias) are measured every day at room temperature in order to estimate the thickness of Li compensated intrinsic layer. A variation of the characteristics is shown in Fig. 2. A measure of the capacitance corresponding to the intrinsic layer is calculated by the ormula: $C(\mathrm{pF})=1.05\cdot A(\mathrm{cm}^2)/W(\mathrm{cm})$. The capacitance is about 77 pF for the case of $A=1.8\times6.1\ \mathrm{cm}^2$ and $W=0.15$ cm.

The Li drift operation is terminated when the intrinsic layer reaches to the initially p-side of the diode. Then, the electron injection from the electric contact increases the reverse current, for which the automatic drifting apparatus decreases the diode temperature. Time spent until the termination is about 80 hours. It seems that the mobility of Li ions do not change so much by the crystal axis, which is different from the case of ordinary circular Si(Li) detectors. The spread of the intrinsic layer on the p-side surface is observed by staining in hydrofluoric acid for 20 min after lapping of the p-side surface. Generally, the spread is not uniform at this stage. The drift operation should be repeated at the diode temperature of 100°C and the reverse bias of 160～200 V for about 40 h., after lapping, washing and etching procedures. Now, the electric contact is taken at only peripheric part of the p-side surface to spread the intrinsic layer over the surface. After the second drift operation, the spread of the intrinsic layer stained by hydrofluoric acid is obtained about $17\times60\ \mathrm{mm}^2$, which is required for the application, as shown in Fig. 3.

4. Formation of Surface Barrier Junction

The wafer is immersed in hydrofluoric acid for 3 min and conserved in a desiccator

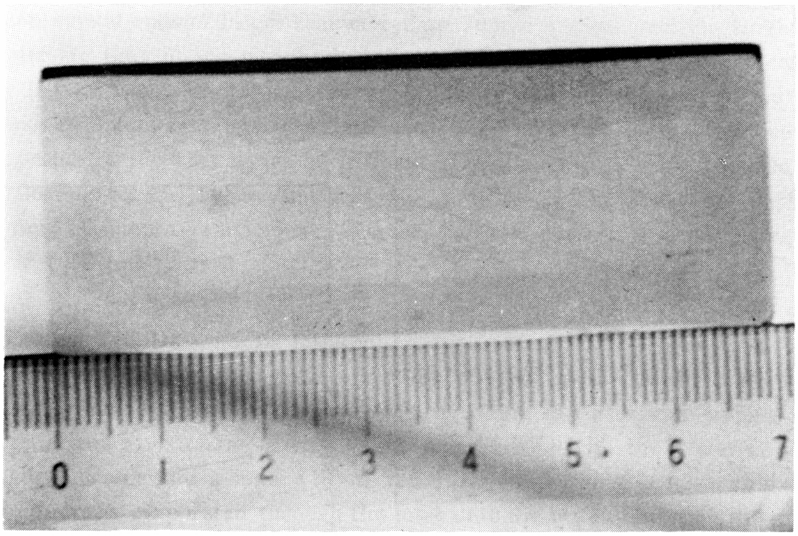

Fig. 3. Stained intially p-side surface after cooled drift operation.

for 2 days to make oxidation layer on the surface, after lapping, washing and etching procedures. Gold is evaporated on the revealed intrinsic layer to form a surface barrier junction, and aluminum is evaporated on the n^+ Li-layer of the other side for the ohmic contact. The evaporated areas are 15×60 mm^2. It is important to assure the evaporated Au area is included in the intrinsic area. This surface barrier Si(Li) detector is mounted in a detector case.

The diode characteristics after the mounting in the case are shown in Fig. 4.

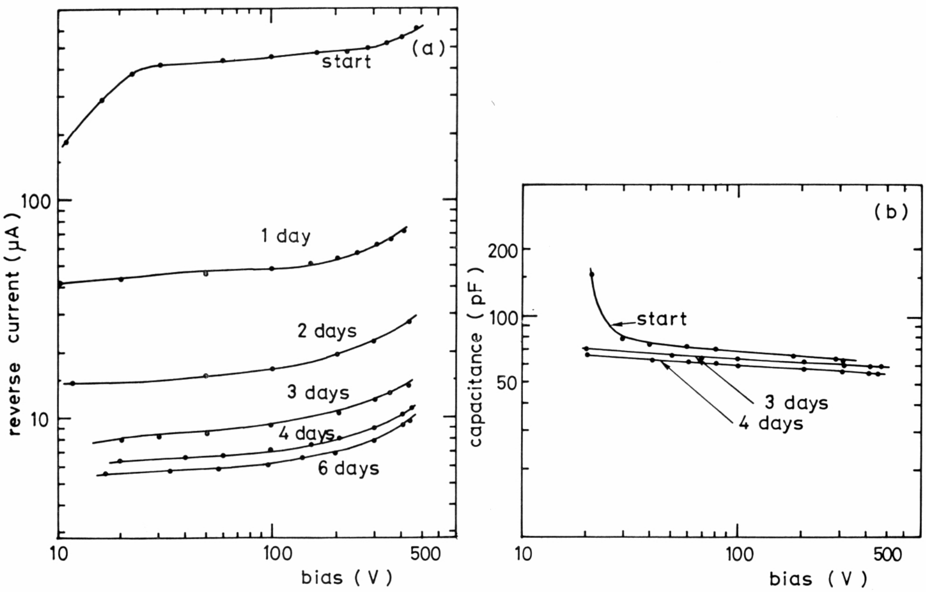

Fig. 4. Variation of the diode characteristics during the cleanup drift operation.

Conservation of the detector biased at a low bias in a test chamber improves the characteristics very much as shown in the figure. This improvement is resulted by the effects that the over-compensated Li ions are drifted away to establish higher resistivity in the intrinsic layer and that the periphery of the intrinsic layer is adjusted to the Au evaporated area.

III. PERFORMANCES

The surface barrier Si(Li) detector has a rectangular sensitive area of $15\times60\,mm^2$ and thickness of 1.8 mm. The detector was operated at a reverse bias voltage of 100 V, where the reverse current was several μA and its capacitance was about 60 pF. Particles incident to the Au evaporated side of the detector where the surface barrier was implanted. The uniformity of counting efficiency along the longer axis was measured by using ^{210}Po α-particles through a 1 mm slit. Typical energy spectrum of the 5.3 MeV α-particles is shown in Fig. 5 (a). The FWHM of the peak correspond to about 100 keV, which includes the attenuation of α-particles in the source itself. The energy resolution is good enough to use in the experiment of neutron induced reactions. Fig. 5 (b) shows the uniformity of about 2.1% in the standard deviation, that means no insensitive part in the Si(Li) detector. Fig. 6 shows a energy spectrum of protons and α-particles from the ^{28}Si(n, p)^{28}Al and ^{28}Si(n, α)^{25}Mg reactions, respectively, with 14.1

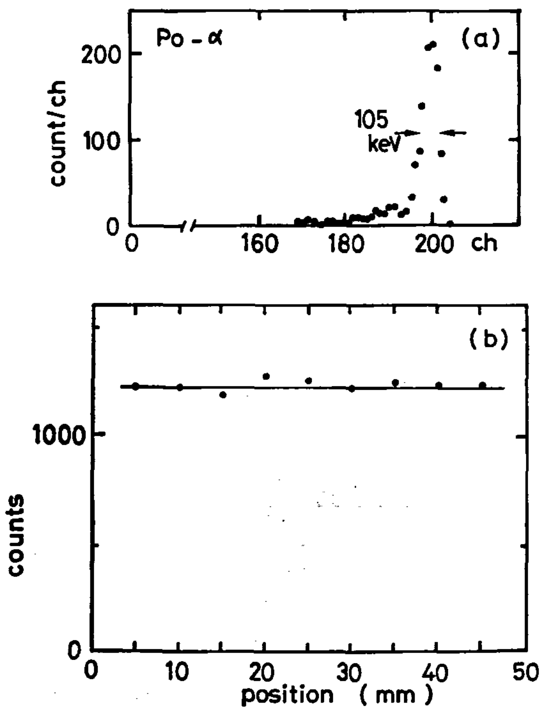

Fig. 5. Typical spectrum of ^{210}Po α-particles (a), and counting efficiency over the sensitive area (b).

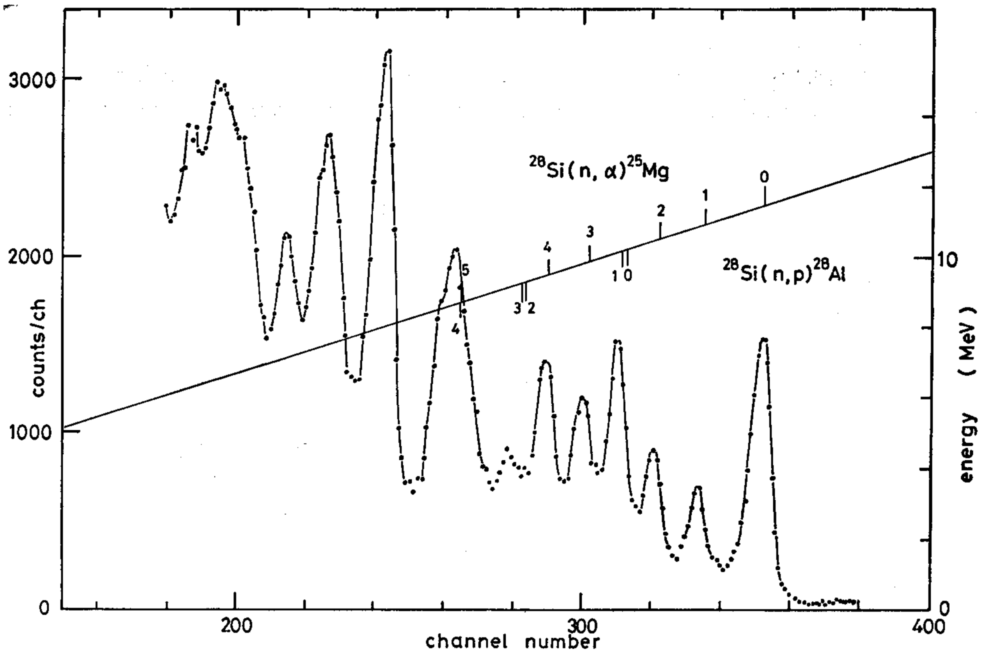

Fig. 6. Pulse height spectrum from the rectangular Si(Li) detector irradiated by 14 MeV neutrons. The peaks correspond to the excited levels of ^{28}Al and ^{25}Mg.

MeV incident neutrons. This spectrum can be used for the energy calibration of the pulse height from the detector during the experiment. The FWHM of the peak corresponding to the ground state of ^{25}Mg is about 230 keV, which includes the spread of the incident neutron energy and other contributions from noise sources. The reverse current increased gradually by the irradiation of 14 MeV neutrons during the experiment. Appreciable deterioration was observed in about one month experiment, where the total irradiation was estimated to be about 10^{11} neutrons. The characteristics could be recovered by the re-evaporation of Au and Al after lapping, washing and etching procedures. When the radiation damage in the bulk of intrinsic layer is accumulated, the recovery by the re-evaporation is not effective procedure. The preparation should be tried from the drift operation at low temperature.

IV. CONCLUDING REMARKS

This surface barrier Si(Li) detector with a rectangular sensitive area of $15 \times 60\ mm^2$ was successfully adopted to the position sensitive counter telescope that had both a large solid angle of 40.0 msr and a good angular resolution of 5°, and covered a angular range of 35°.

It is essential for the preparation of large rectangular Si(Li) detectors that a good starting material of silicon crystal should be sliced along the central axis to obtain rectangular wafers. The lithium drift operation is achieved similarly to the case with normally sliced circular wafers. The spread of the intrinsic layer on the initially p-type surface must be larger than the required sensitive area.

ACKNOWLEDGEMENTS

The authors are very indepted to Professor I. Kumabe for his continuous encouragement and valuable discussions.

REFERENCES

(1) M. Yoshimori and S. Uchiyama, *Nucl. Instru. & Meth.*, **130**, 143 (1975).
(2) H. Shiraishi, *Genshiryoku koogyo*, **27**, no. 9, 52 (1981).
(3) N. Koori, T. Goto, H. Konishi, and I. Kumabe, *Nuc. Instru. & Meth.* to be published.
(4) F. S. Goulding, *Nucl. Instru. & Meth.*, **43**, 1 (1966).
(5) S. Shirato, M. Tanaka, N. Koori, I. Ogawa, M. Tsukuda, and E. Tajima, SJC-T-68-4 (1968), University of Tokyo.
(6) Shin-etsu Chemical Industry Co., Tokyo.