# EPITAXIAL SILICON SEMICONDUCTOR DETECTORS

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A review of the epitaxial silicon semiconductor detectors and our proposals are presented.
Calculations of the potential and electric field distributions in the $N^+$-N( or N-$N^+$ ) complex structure are also performed.

## 1. Introduction

The epitaxial growth technique was developed for fabrication of high speed transistors at first and then applied widely on fabrication of integrated circuits, because it also gives a high degree of design freedom to the manufacturing technology of semiconductor.

In general, the active regions of devices in integrated circuits are formed in the epitaxial layer. Therefore, it's crystal growth technique is very important for fabrication of the devices.

In recent years, very excellent epitaxial layers have been obtained owing to many new techniques( for example, perfect crystal device technology, etc. ). On these technical backgrounds, the epitaxial technique has been applied to fabricate semiconductor detectors, and many new types of detectors are now expected to be obtained.

The very thin silicon layer with a good thickness uniformity has been obtained from the high purity epitaxial silicon layer which is grown on a highly doped silicon substrate by performing the selective etching of the substrate.

Ponpon et al[1] and Maggiar et al[2] have obtained the dE epitaxial silicon detector made on a thin n-type epitaxial layer with a Schottky barrier at the surface by performing the selective electro-chemical etching. On the other hand, Osada and his group[3] have fabricated the dE epitaxial silicon detector by using the chemical preferential etching and obtained a good energy resolution( FWHM 116 keV, 5.5 MeV $\alpha$ particles ).

Gruhn et al[4] have made the $N^{++}$-$P^+$-P-$P^+$ complex structure by applying the double epitaxial crystal growth technique and fabricated the epitaxial silicon avalanche detector( ESAD ). By using this detector, they have obtained S/N ratio of 9.4 at an internal amplification of 21 for minimum ionizing particles. The response at room temperature to $^{55}$Fe x-rays( 5.9 keV ) yeilded a resolution of 1.74 keV( FWHM ).

Furthermore, they have made the P-N-$N^+$ complex structure and fabricated the large area epitaxial silicon heavy ion detector( ESD ) with 5 cm diameter and 50 μm thickness. Many heavy ions from a nuclear reaction were detected by using this detector.

In these investigations, they have obtained good results and have demonstrated that the semiconductor detectors utilizing the complex epitaxial layers are very promissing.

## 2. New types of epitaxial silicon detectors

The surface of the epitaxial layer is very clean and is ideally suitable for preparation of Schottky barrier, and the impurity concentration and the thickness of the epitaxial layer are now freely controllable as expected. From these reasons, it is possible to obtain silicon detectors with variety in their functions.

New types of silicon detectors which are obtained by use of the epitaxial crystal growth technique are expected as follows.

1) Epitaxial silicon surface barrier detector with a large area (Fig. 1)
2) Epitaxial position sensitive detector (Fig. 2)
3) Integrated dE-E silicon detector (Fig. 3)
4) Unification of integrated dE-E detector and position sensitive detector (Fig. 4)

These are shown in the figures.

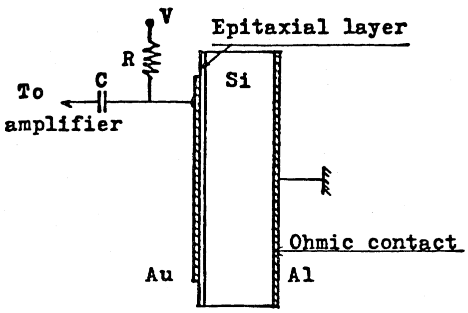


Fig.1. Schematic representation of an epitaxial silicon surface barrier detector with a large area.

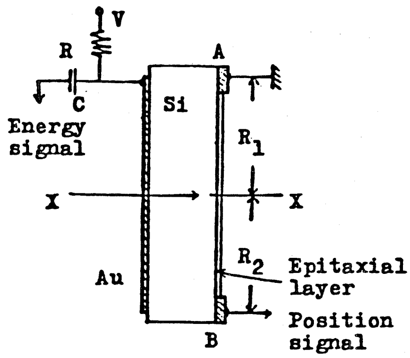


Fig.2. Epitaxial position sensitive detector.

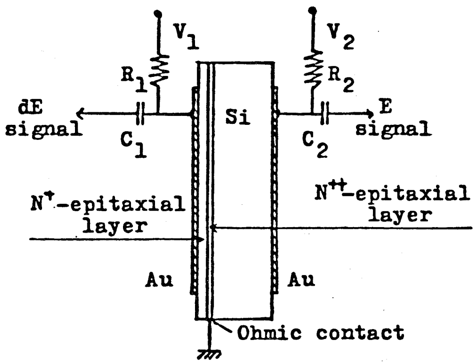


Fig.3. Integrated dE - E silicon detector.

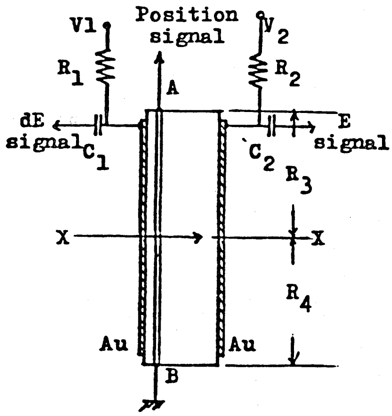


Fig.4. Unification of integrated dE - E detector and position sensitive silicon detector.

## 3. Calculations of N-$N^+$ complex structure

The surface barrier silicon detector consisted of the $N^+$-N complex structure is shown in Fig. 5.

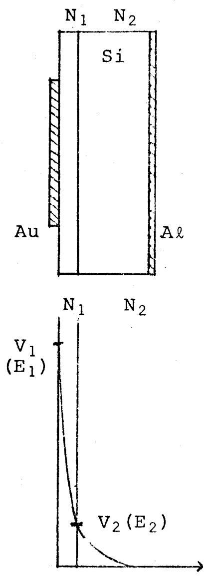


Fig. 5
N-$N^+$ structure

Calculating the Poisson's equation considering the boundary condition of the each region of the detector, analytical relationships of potential and electric fields with the thickness are obtained as follows.

$$\begin{aligned} E_2 &= qN_2l_2/\varepsilon \\ V_2 &= qN_2l_2^2/2\varepsilon \\ E_1 &= q(N_2l_2 + N_1l_1)/\varepsilon \\ V_1 &= q(N_2l_2^2 + N_1l_1^2)/2\varepsilon + qN_2l_1l_2/\varepsilon \end{aligned} \quad \cdots (1)$$

If the impurity concentration $N_1$ of the epitaxial layer $N^+$ is equal to $N_2$, eq. (1) becomes as follows,

$$\begin{aligned} E_{10} &= qN_2(l_1 + l_2)/\varepsilon \\ V_{10} &= qN_2(l_1 + l_2)^2/2\varepsilon \end{aligned} \quad \cdots (2)$$

where $E_{10}$ is the electric field and $V_{10}$ is the potential of this case.

Defining the ratios $\xi$ and $\eta$ as follows,

$$\begin{aligned} \xi &= V_1 / V_{10} \\ \eta &= E_1 / E_{10} \end{aligned} \quad \cdots (3)$$

and substituling these parameters into eq. (1) and (2), the equations

$$\begin{aligned} \xi &= (N_1l_1^2 + N_2l_2^2) + 2N_2l_1l_2 / N_2(l_1 + l_2)^2 \\ \eta &= (N_1l_1 + N_2l_2) / N_2(l_1 + l_2) \end{aligned} \quad \cdots (4)$$

are derived.

Here, defining the ratios $\alpha$ and $\beta$ as follows,

$$\alpha = N_1 / N_2, \qquad \beta = l_1 / l_2 \quad \cdots (5)$$

then equations in (4) become numerical equations of the forms

$$\begin{aligned} \xi &= 1 + (\alpha - 1)\beta^2 / (1 + \beta)^2 \\ \eta &= (1 + \alpha\beta) / (1 + \beta) \end{aligned} \quad \cdots (6)$$

These equations are particulary useful in designing these semiconductor detectors. Results of numerical calculation for $\xi$ and $\eta$ are shown in Fig. 6 and 7.

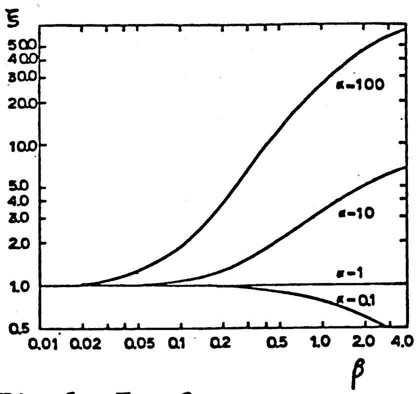


**Fig.6.** ξ −β curves.

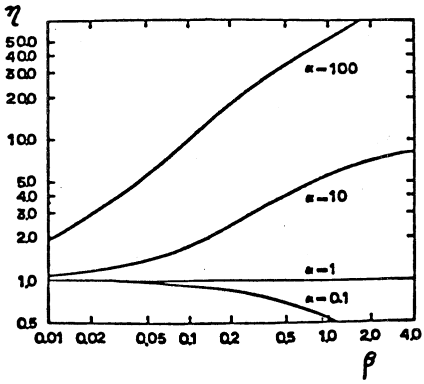


**Fig.7.** η − β curves.

References

1) J.P.Ponpon et al., Nucl. Instr. and Meth. 112 (1973) 465
2) C.J.Maggiore et al., IEEE Trans on NS-24, No.1 (1977) 104
3) S.Osada et al., Nucl. Instr. and Meth. 144 (1977) 353
4) C.R.Gruhn., IEEE Trans on NS-23, No.1 (1976) 145
IEEE Trans on NS-24, No.1 (1977) 93
5) C.R.Gruhn et al., IEEE Trans on NS-24, No.1 (1977) 142