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STUDY OF THE CHARGE MULTIPLICATION PHENOMENON IS SILICON EPITAXIAL DETECTOR

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1.Introduction

When used as fission fragment detectors or ΔE-detectors in detecting nuclei of intermediate energies, epitaxial silicon detectors allow measuring spectrometric characteristics with a fair degree of accuracy [1,2]. To do this while detecting fission fragments they are to be placed in the spectrometric mode of operation, which is achieved by applying low bias voltage including zero bias. High bias voltage disrupts that mode of operation due to charge multiplication arising [3, 4]. In our work [5] the charge multiplication in epitaxial detectors was investigated from data on the distortion of the one-dimensional energy spectra of fission fragments of ^{252}Cf. The trouble with such a technique is that the charge multiplication for heavy fragments is difficult to study because the multiplication-distorted signals associated with heavy fragments fall in the region of the signals relating to light fragments. To clear up the trouble, a technique was employed that used correlated pairs of fission fragments and two detectors, one of which being a reference detector and the other under investigation. This paper presents the results of investigation of the charge multiplication in the epitaxial detector by the above correlated pair measurement method.

2. Experimental results and discussion

As the source of fission fragments, ^{252}Cf was used, which had been deposited on an alundum base $\simeq$60 μg/cm^2 thick and then covered with nickel carbonyl on both sides. The source intensity by fission fragments was about $\simeq$10^4 fissions/s. The fission fragment source was placed between the detector to be investigated and the reference detector, so that the detector under investigation was irradiated by the fragments that had passed through the base.

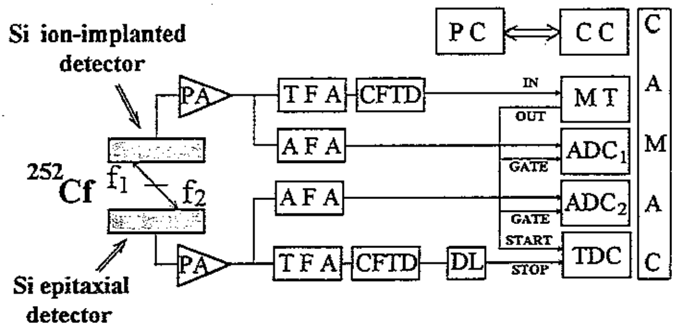

Fig.1. Block diagram of the electronic equipment.

The detector under investigation was made on the basis of a $(n - Si) - (n^{++} - Si)$ epitaxial structure, the epitaxial layer being about 21 mkm thick and of resistivity equal to about 30 Ohm · cm [1]. As the reference detector, an $n - Si$ ion-implanted detector was used. Shown in Fig. 1 is a block diagram of the electronic equipment used. The data were collected event by event, both the amplitudes and the time distribution of the pulses induced by the fragments being registered. The start signal to register an event was generated using the signal from the reference detector. The start signal was applied to the master trigger. Unless the data processing system was processing the preceding event, the master trigger generated gate pulses. The gate pulses let the energy signals be applied to the analog-to-digital converters (ADC). In addition to the gate pulses, the master trigger generated a start signal for the time-to-digital converter (TDC). While performing the off-line analytical treatment, the energy threshold, E, was set $E \geq 10$MeV the time correlation window being 50 ns.

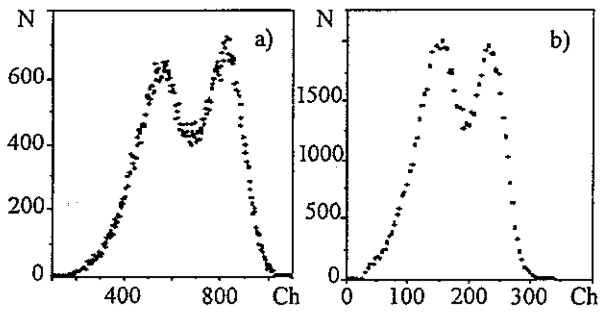

Fig. 2. The energy spectra of the fission fragments of ^{252}Cf.
a) - ion-implanted detector, b) - epitaxial detector

Fig. 2 gives the one-dimensional energy spectra of the fission fragments that were obtained with an ion-implanted detector (Fig. 2a) and an epitaxial detector (Fig. 2b) at bias voltages equal respectively to 100 V and 16 V. Those bias voltages correspond to the multiplication-free mode of operation of both detectors. It is seen from Fig. 2 that the energy distributions of the fragments differ essentially from the standard distributions for ^{252}Cf. For the epitaxial detector, the number of counts at the maximum due to the heavy fission fragments, N_H, is about the same as that at the maximum due to the light fragments, N_L, whereas for the ion-implanted detector the ratio $N_L/N_H \simeq 1.1$. Thus, that the source was essentially thick resulted in the fact that some signals associated with the light fragments were equal in value to the signals associated with the heavy fragments. This makes the investigation of charge multiplication more complicated because the range of a light fragment is longer than that of a heavy fragment, which affects the way the charge multiplication will proceed. But even under those conditions, the experiment performed enabled some qualitative and quantitative regularities

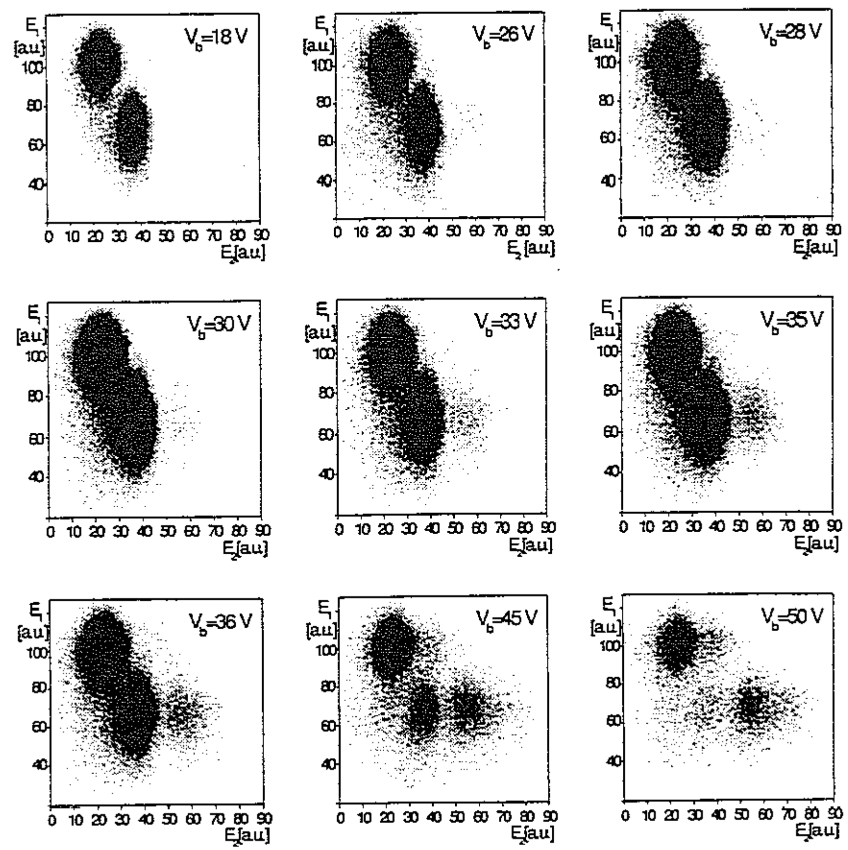

Fig. 3. Two-dimentional amplitude distributions of the fission fragment of ^{252}Cf at various bias voltages V_b

of the charge multiplication in epitaxial detectors to be reliably established.

Presented in Fig. 3 are the two-dimensional amplitude distributions of the correlated fission fragments at various bias voltages V_b across the epitaxial detector and at a constant bias voltage across the ion-implanted detector ($V_b = 100$ V). The X-axis corresponds to the amplidudes of the signals of the epitaxial detector, and Y-axis corresponds to the amplitudes of the signals of the ion-implanted detector. It is seen from Fig. 3 that from the epitaxial detector bias voltages $V_b \simeq 26$ V and $V_b \simeq 35$ V and on, anomalous amplitudes corresponding to the groups of light and heavy fragments appear in the two-dimentional distribution.

Presented in Fig.4 are the amplitude distributions of the pulses due to the light

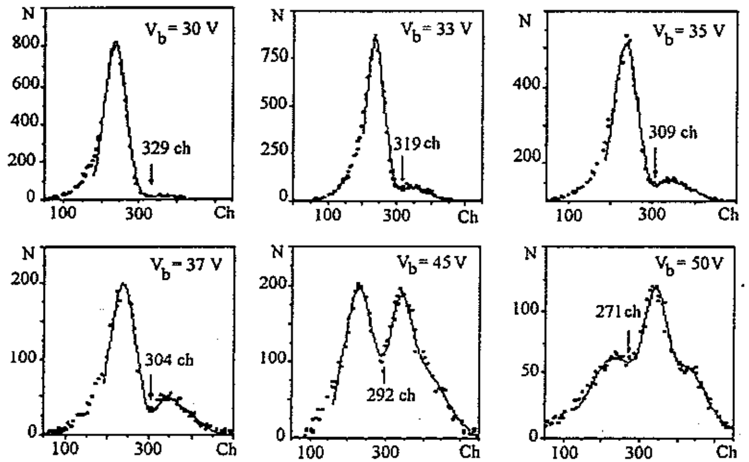

Fig.4. Amplitude distributions of the pulses due to the light fission fragments ^{252}Cf at various bias voltages V_b.

fission fragments at various bias voltages, which shows the dynamics of the charge multiplication for the light fragments. Given next to the arrows are the numbers of the channels that correspond to the minima lying between the peaks of the normal and anomalous signals. It is seen from Fig. 4 that as the bias voltage increases, the minimum concerned shifts to the lesser amplitudes of signals. This testifies that the signals corresponding to the most high-energy fission fragments are the first to be affected by the multiplication. The further increase in the bias voltage brings about charge multiplication for all the light fragments of lesser energy. Moreover, high bias voltage not only results in the peak of the normal signals being distorted substantially by the multiplication but also in the peak being shifted to the lesser amplitudes of signals, which lends support to the above conclusion concerning the way the charge multiplication proceeds.

It is also seen from Fig. 4 that high bias voltage causes a second peak to appear in the distribution of muliplication-distorted signals in the region of high amplitudes. This points to the fact that there is another mode of charge multiplication which we observed both in surface-barrier detectors irradiated with monoenergetic ions [6] and in epitaxial detectors irradiated with fission fragments of ^{252}Cf [5]. Presented in Fig. 5 are the ratios of the number of the multiplication-distorted signals N_{mL} for the light fragments (Fig.5a), N_{mH} for the heavy fragments (Fig.5b) to the total number N of the fission fragments detected by the reference detector as a function of the value $\sqrt{V_b}$, which is proportional to the electric field strenth in the detector. The experimental dependences can be closely approximated by

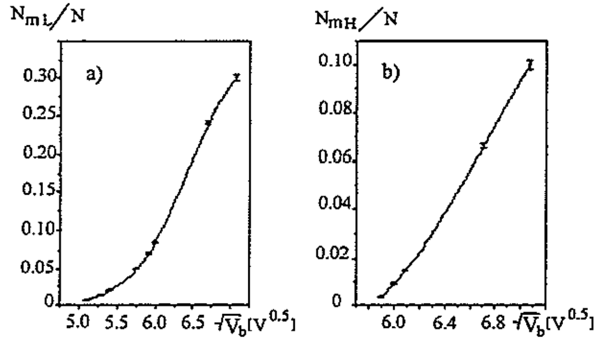

Fig.5. Ratios N_m/N for the light (a) and heavy (b) fission fragments of ^{252}Cf as a function of $\sqrt{V_b}$.

using the probability integral or the error function. This once again confirms the above conclusion that charge multiplication arises as soon as a certain threshod voltage is exceeded, the multiplication-distorted signals correspoding to the most high-energy light fission fragments being first to appear, then, as the voltage increases, the signals corresponding to fragments of lesser energy including heavy fragments get distorted by the charge multiplication.

The dependences shown in Fig. 5 allow the threshold values for the light and heavy fragments, respectively V_{th}^L and V_{th}^H, to be evaluated by extrapolating their initial portion to N_m/N=0. The ratio $\sqrt{V_{th}^H}/\sqrt{V_{th}^L}$, was found from the dependences shown in Fig. 5 to be 1.16±0.05. The qualitative picture of the charge multiplication in the epitaxial detector given by the two-dimensional amplitude spectra of the fission fragments (see Fig. 3) and the one-dimensional amplitude distributions of the light fragments (see Fig. 4) is in agreement with the predictions of the charge multiplication model based on the assumption that the movable current carrier are accumulated near the detector entrance electrode [7]. Moreover, the ratio $\sqrt{V_{th}^H}/\sqrt{V_{th}^L}$ =1.16±0.05 found from the experimental data is in good quantitative agreement with the value F_{th}^H/F_{th}^L = 1.19 calculated in terms of that model. The values F_{th}^H and F_{th}^L are the threshold electric field intensities for heavy and light fission fragments, respectively.

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