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Investigation of Characteristics of Semiconductor Detectors of a-C/n-Si Heterostructure and p-n Junctions by Means of Registration of Charged Particles

K.S. Ohanyan

Yerevan State University, Armenia
e-mail: kohanyan@ysu.am

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1. Introduction

Today different types of particle registration as well as semiconductor detectors have obtained wide application in basic and applied investigations of high energy and nuclear physics. The provide accurate measurements of fluxes of particle energies and ionizing radiation.

Still it is necessary to create new types of detectors, to develop existing ones and to improve their working characteristics in order to extend the application field of detectors and to reach higher accuracy of measurements. Besides the matters of simplification of detector production technologies are of special importance. Semiconductor detectors with a-C/n-Si heterostructure and frame electrode on frontal surface of silicon monocrystal base of p-n junction were prepared in the framework of this ideology.

Studies of the energy characteristics of the above mentioned detectors are presented in this paper in order to reveal the possibilities of their usage in alpha spectrometric measurements. ^{238}Pu+ ^{239}Pu+ ^{233}U and ^{226}Ra reference alpha radioactive isotopes by OSAI standards have been used as sources of radioactive fluxes in the measurements [1,2].

2. The structure of the semiconductor detector with frame electrode on frontal surface

Today semiconductor detectors prepared by traditional technology are used for registration of charged particles [3,4]. That is the opposite surfaces of detectors prepared from silicon or other semiconductor materials are covered by a metal film which includes its sensitive volume to registration of particles. This kind of approach allows to minimize the time of free charge accumulation created in the detectors volume by ionizing rays on electrodes due to which the speed action (quick response) of the detector is enhanced. But the metal film on the input surface of the detector is an additional material medium on the way of charged particles penetrating the sensitive range (region) of the detector where the particles lose some or negligible part of their energy.

A test has been performed by us to discard the technology of full metal coverage of the input surface of the detector. A semiconductor detector with p-n junction has been studied (p-n junction was realized by Bore diffusion in the depth of 3-4 μm) which is a flat film of 350 μm prepared from silicon monocrystal. The back surface of the detector is fully covered by a thin nickel layer and a nickel layer like a light-gage wire with a surface of 2x2 mm^2 by a rectangular parameter length is set on the frontal surface which functions as a frame electrode. There is a SiO_2 thin layer of 20-50 Å thickness on the frontal surface restricted by a metal frame. The metal film of back surface and the frame of frontal surface serve as electrodes for application of magnetic field to the detector as well as for obtaining registration signals of particles from them.

3. Structure of semiconductor detector with a-C/n-Si heterostructures

a-C/n-Si semiconductor structures are also of interest in views of registration of charged particles and ionizing rays in general. They are widely applied in functional electronics. But the potential of their application as particle detectors is not completely studied.

Few studies have been conducted which show that this kind of structures may be used in experimental methods of registration of ionizing rays [5,6]. Such investigations were also conducted in this work by using a-C n-Si heterostructure. It is a flat (substrate) of 350 μm thickness prepared from silicon monocrystal on which a clear amorphous carbon film (a-C) of ~100 nm thickness is set by the pulsed-laser deposition method. A Schottky barrier is formed in the heterojunction region of semiconductor monocrystal and amorphous carbon due to which the heterojunction obtains property of p-n junction.

a-C layer and low-resistant metal contact are produced in a single technological cycle in the switch the laser Q mode (the radiation wavelength – 1.06 μm, the duration of pulsed laser evaporation – 30 ns, fluence in radiation area of targets ~10^9W/cm^2). The formation of the low-resistant contacts (Ag on a-C and In on n-Si) was performed without any additional processing. The characteristics of produced contacts are the thickness uniformity and good adhesion. Like in the case of silicon with p-n junction a silver layer like a light-gage wire with a surface of 2x2 mm^2 by a rectangular parameter length is set on the frontal surface which functions as a frame electrode. The resistance value of a-C film ($\rho_{a\text{-}C}$=1.43x10^6 Ohm cm) was also estimated having regard the geometrical dimensions of the heterostructure.

Electrical properties of a-C/n-Si heterostructure were defined on the basis of measurements conducted at room temperature and the dark CVC (current voltage characteristic) of a-C/n-Si heterastructure (J is current density, A/cm^2) was extracted in the range of 0.2 V < U < 0.45 V inverse biases (the polarity is + on n-type silicon) which is in satisfactory conformity with the law of current density $J = J_0 \exp(eU/nkT)$ with the ideality factor n = 2; 4. The "dark" CVC is shown in Fig. 1.

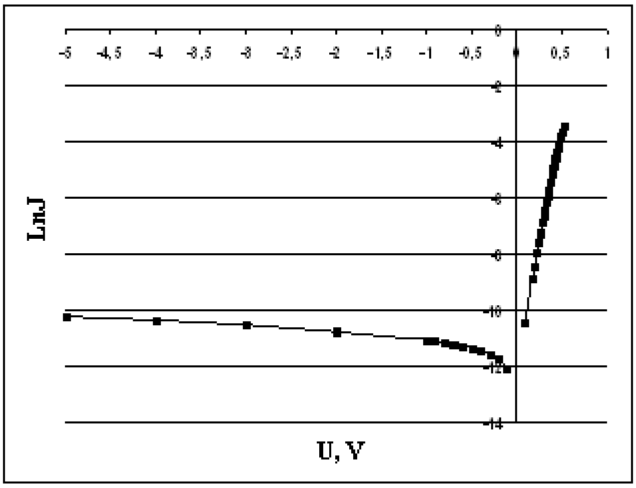

Fig. 1. The "dark" CVC of a-C/n-Si heterastructure.

4. Description of the experimental facility

An experimental facility was assembled for investigation of the energy characteristics of semiconductors with a-C/n-Si structure and frame electrode on the frontal surface of silicon monocrystal base of p-n junction used as particle detectors. The flow diagram of the facility is shown in Fig. 2. It is composed of registration unit, preamplifier, amplifier, amplitude analyzer and accumulation unit of information obtained during the measurements.

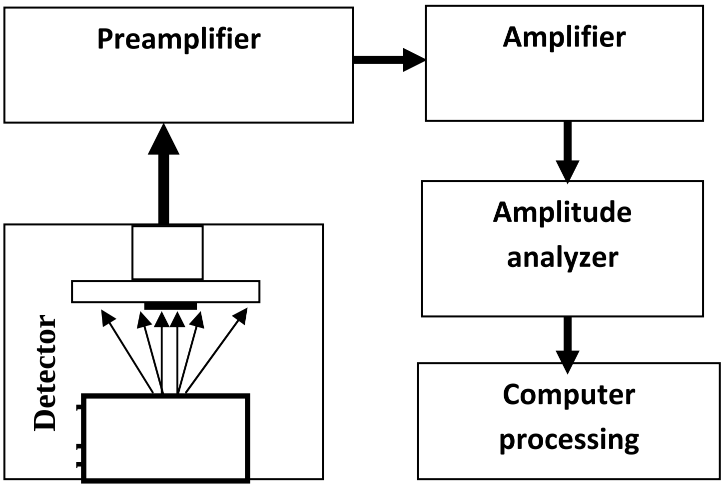

Fig. 2. The flow diagram of the experimental facility.

A socket contact connected to the entry of the preamplifier where the detector under investigation is positioned and a movable pedestal for installation of a radioactive radiating source are coaxially situated in opposite positions in the chamber with metallic walls and 600 cm^3 volume of registration unit. A movable pedestal allows to change the distance between the detector and the surface of the radioactive source consequently the path length of alpha particles in the air within the range from 0.5 cm to 6 cm.

A beam mechanical collimator is placed between the detector and movable pedestal in order to minimize the influence conditioned by the beam divergence (the path length of alpha particles) in measurements of energy values of alpha particles (Fig.2), which allows to minimize the divergence angle. Indeed, the alpha particle which is delivered from radioactive source and reaches the detector at angle φ to its surface normal then it passes

$$W = W_0 \frac{1}{\cos\varphi} \tag{1}$$

way through the air layer of W_0 thickness existing between the radioactive source and the detector. This in turn leads to the dispersion of energy values of particles entering the detector [7, 8]. The highest dispersion value for energy of particles entering the detector at the surface normal is observed in the case of maximum value $\varphi_{\max}$ of beam divergence value and is determined by the following expression:

$$\delta E_{\varphi\max} = (W - W_0)\frac{dE}{dx} = W_0\left(\frac{1}{\cos\varphi_{\max}} - 1\right)\frac{dE}{dx}\ , \tag{2}$$

where dE/dx is the specific losses of ionization in material medium. The permissible value of the widest divergence angle φ_{max} and the linear dimensions of collimator are determined by condition $\delta E_{\varphi max} << \Delta E_{ck}$, where E_{ck} is the half width of alpha spectrum in the case of ideal collimation (parallel beam of alpha particles falling on the detector surface at angle $\varphi_{max} = 0$). Based on this criterion and having regard the quite long time necessary for obtaining the sufficient amount of statistical data an iron collimator with 1mm, 2mm and 3mm diameter, 1cm thickness and 1.5x1.5 cm^2 surface was used in measurements, placed at the distance of 1mm from the detector surface.

5. Results of measurements and the processing of the spectrum

^{238}Pu+^{239}Pu+^{233}U and ^{226}Ra alpha radioactive reference isotopes by OSAI standard which deliver alpha particles with kinetic energy limited in the 4.5-7.6 MeV range were used as sources of radiation fluxes in order to examine energy characteristics of the detector [3]. As result of measurements the distribution of signals of pulses delivered to the enter of the analyzer was shown on the screen which is localized in the range of channels of small and large numbers (Fig. 4).

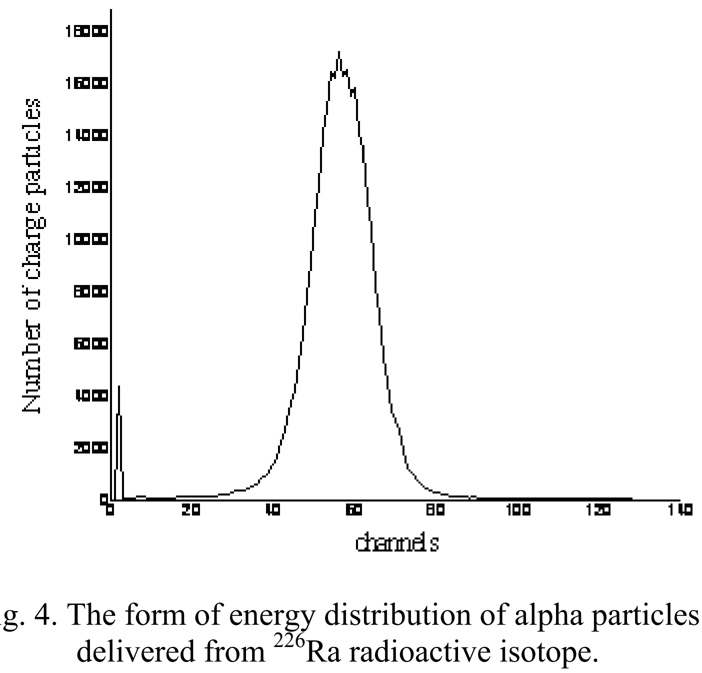

Fig. 4. The form of energy distribution of alpha particles delivered from ^{226}Ra radioactive isotope.

The distributions of signals localized in the channels of small number are the result of noise signals formed in the detector and successive electronic circuit diagram (the maximum value of the signals of noise amplitude is estimated which according to the conducted measurements doesn't exceed the energy equivalent to 250 keV).

The second distribution is localized in the channels of mid range of analyzer. It is conditioned by registration of alpha particles in the detector. The lower limit of energy distribution range is often larger than the upper limit of the value of noise signals, which serves as a basis for the detector in the whole range of energy distribution of alpha particles (3 MeV< E <9 MeV) to be used to conduct energetic measurements in the background of viewed noise signals. This distribution range is informative for the energy spectrum of alpha particles. It is enlarged resulting from superposition of alpha particles spectra with different energies (Fig. 4.). The exposition time of measurements' duration is chosen so that the registration number of alpha particles is quite large and in each superposed spectrum their distribution is Gaussian.

The energy spectra obtained from alpha particles were processed by means of ORIGIN program as a result of which the energies of radionuclides were identified. The background inputs are taken into account in the restoration process of the spectra, besides an extrapolation was performed based on the background data of low and high energy ranges out of information spectrum. Graph of restored alpha spectra is shown in Fig. 5a and 5b.

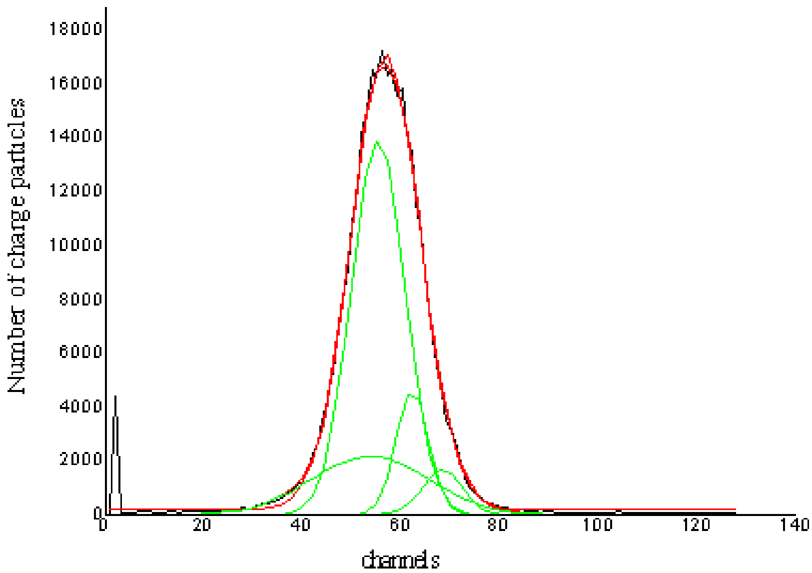

Fig. 5a. The forms of restored alpha spectra obtained by means of frame detector. Energy distribution of alpha particles delivered from ^{226}Ra radioactive isotope.

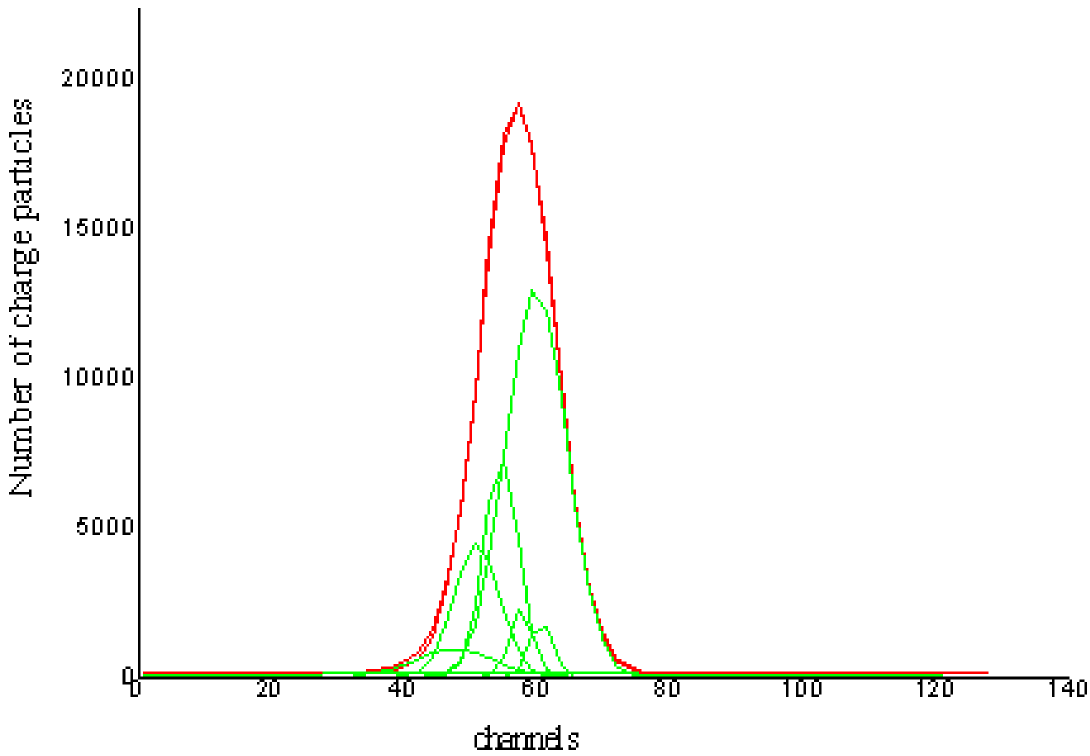

Fig. 5b. The restored forms of the alpha spectra obtained by means of the detector with a-C/n-Si heterostructure. Energy distribution of alpha particles delivered from $^{238}Pu+^{239}Pu+^{233}U$ radioactive isotope.

It is easy to see that the measurements conducted by the detectors of frame and a-C/n-Si heterostructure are sufficient for identification of alpha spectra (the resolution of the detector is 0.8%). The linear characteristics of the detector are studied as well. It shows linearity in the whole energy range of alpha particle fluxes.

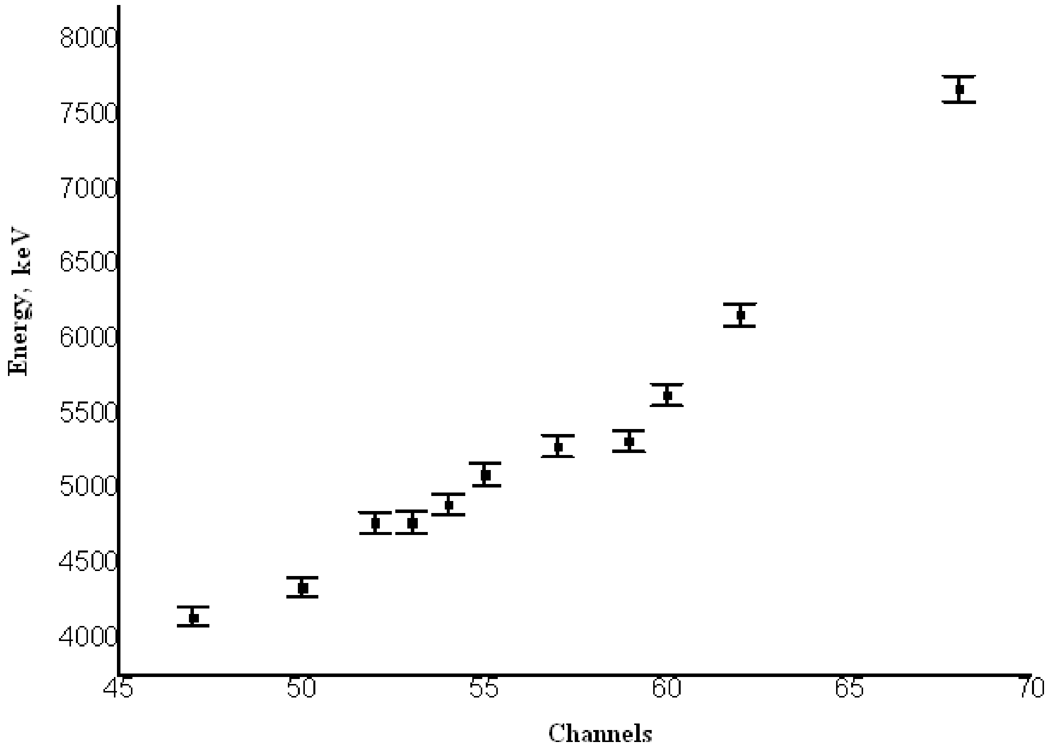

Fig. 6. Linear characteristic of detectors.

6. Conclusion

Performed studies show that frame electrode semiconductor and a-C/n-Si heterostructure detectors have good energy resolution (0.8%) and linearity. Accordingly detectors of this structure can be used in alpha spectrometric measurements. It is necessary to note that alpha radioactive radionuclides are clearly identified without creating vacuum medium between the detector and radioactive source which is of special importance for express analysis of alpha radioactive radionuclide pollution.

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