INFLUENCE OF THE SURFACE ELECTRONIC PROCESSES ON THE SPECTROMETRIC CHARACTERISTICS OF SILICON DETECTORS

G.P. Gaidar, S.V. Berdnichenko, V.G. Vorobyov, V.I. Kochkin,
V.F. Lastovetskiy, P.G. Litovchenko
Institute for Nuclear Research of National Academy of Sciences of Ukraine, Kiev, Ukraine
E-mail: gaydar@kinr.kiev.ua

In this paper the features of influence of the surface electron processes on the formation of silicon surface-barrier detector structures were founded, the regimes of chemical treatments of the surface for Si crystals were established with using of different combinations of etchants for the accelerated creation of surface-barrier structures with stable parameters, the slow regimes of etching were developed for making the detectors of plane-parallel geometry. On the basis of experimental studies concerning the improvement of the formation processes of qualitative surface-barrier structures, the fabrication technique of the silicon spectrometric detectors was optimized; the prototypes were manufactured and their characteristics were identified.

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INTRODUCTION

Semiconductor detectors occupy an important place among devices of nuclear spectrometry and are used to study the spectral composition, intensity, spatial and angular distribution of ionizing particles [1]. Silicon is the most attractive material for producing detectors due to the developed silicon technology and the ability to create not only the dosimetric and radiometric but also the spectrometric detectors. Semiconductor detectors on the basis of silicon are used for the detection of charged particles and γ-rays with the energy of $\leq$ 100 keV.

The semiconductor detectors are divided into surface-barrier Au-Si, diffusion with (*p-n*)- and (*n-p*)-junctions, respectively, and drift-diffusion of *p-i-n*-type depending on the parameters and the manufacturing technology. A significant advantage of the surface-barrier detectors, manufactured on the basis of silicon (as opposed to the detectors on the basis of germanium), is their ability to operate at room temperature without any special cooling.

The rapid development of fabrication industry of semiconductor detectors led to the appearance of large quantity of the nuclear radiation counters and spectrometers designed to solve the concrete problems in the various fields of the fundamental and applied research of the modern physics. Detectors are used in the nuclear physics, at study of cosmic space, in biophysics, geophysics, medicine and other fields of science and technology, which use the radioactive radiation [2, 3]. Semiconductor detectors have important qualities, such as high energy resolution, linearity of characteristics over a wide range of energies for different particles, small time of pulse rise, insensitivity to the magnetic fields, compactness, mechanical strength, the ability to operate at low temperatures, etc. Today the semiconductor detectors provide the best accuracy in determining of the particle coordinates in the large detection systems, capable of operating at very high magnetic fields, and in the fairly hard radiation conditions, which is especially important for the large-scale experiments to study rarest processes (in particular, the experiments on *American Tevatron Collider*) and the experiments at the *Large Hadron Collider*.

Among the wide class of the nuclear radiation detectors on semiconductor crystals the silicon-lithium detectors [Si(Li)-detectors] with the thickness of sensitive area from 2 to 7 mm occupy a special place. These detectors are the basic spectrometric elements at the registration of the long-range charged particles with the energy of ~ 100 MeV [4–6]. Such detectors are the structure with *p-i-n*-junction formed by diffusion of lithium in the semiconductor silicon plate of *p*-type conductivity. Lithium is the shallow impurity which is used to produce the highly compensated *i*-areas of silicon nuclear radiation detectors. Meanwhile, the compensation was carried out by the electric drift of lithium from thin surface layer. In this layer the preliminary introduction of lithium was carried out at 500…600 ^{o}C during about 5 min with a sharp further cooling, while the drift of lithium was carried out at 65…100 ^{o}C. The literature data concerning the diffusion coefficient of lithium are characterized by the straggling of several orders not only in silicon, but also in other semiconductors. This fact is explained by the effective interaction of lithium (under the diffusion in the interstitials) with background impurities and defects, which are introduced during the growth, as well as during the thermal and other material treatment [7].

Thus, the development of semiconductor nuclear radiation detectors with high energy resolution and position resolution, with signal linearity over a wide range of energies for different types of particles are closely connected with the properties of the initial crystal, in particular, with the presence of the impurity inhomogeneities in its bulk. In addition, when creating detectors we should take into account a set not only physical, but also technological, and design features. These features connected with manifestation of the effects caused by the interconnection of the parameters of initial crystals with the manufacturing technology of the effective nuclear radiation detectors on their basis, as well as with characteristics of the obtained detectors. Therefore, it is necessary not only deeply understand physics of the phenomena that occur on the surface and in the bulk of silicon crystals, but also to be able to purposely control the complex technological processes (diffusion, drift, chemical and mechanical treatments).

Finally, the detector structures (such as *p-n* or *p-i-n*) must have optimal noise, capacitive, current characteristics that provide the effective radiometric parameters (energy resolution, qualitative amplitude signals, high sensitivity, thin input "windows" – "dead layers" etc.).

In view of the above, the aim of this research was definition of the physical nature of basic processes in structures with the surface potential barrier on the high-resistance silicon to optimize the manufacturing technology of high-quality test samples of nuclear radiation detectors with stable characteristics for nuclear-physics experiments.

1. FEATURES OF PHYSICAL PROCESSES OF THE FORMATION OF SURFACE-BARRIER STRUCTURES

The surface-barrier structures are an integral part of the many types of semiconductor detectors. In semiconductor spectrometer the measured energy range are determined by the thickness of the sensitive layer, which depends on the type of detector. Since the entire sensitive volume must be available for the charged particles, and the width of the "dead layer" should be minimal, *p-n* (or *n-p*)-junction must be created near the surface of the crystal. This can be done in two main ways. 1). Surface diffusion of substance with added impurity of one type deep into the crystal, which has a low impurity concentration of another type. 2). Formation of an artificial surface barrier by using the chemical properties of the surface in pure *n*-silicon.

Detectors with diffusion junctions can be obtained by the diffusion of phosphorus from gaseous or solid state into the *p*-type silicon crystals. In the latter case P_2O_5 are applied directly on the silicon surface, and then placed in a furnace. The depth of penetration of impurities can be controlled by the duration of the diffusion process and the temperature at which this process occurs.

It can be done similarly, if the *p*-type covering should be applied on the *n*-type material, which serves as the main body of the detector. However, in this case, instead of having to create a surface layer of *p*-type by thermal diffusion of the chemical contaminations, it is more reasonable to use the chemical properties of *n*-Si surface. The surface layer of *n*-Si is easily oxidized, and behaves as electron acceptor (*p*-layer). The electrical contact with the surface layer (the inversion area) is performed by the layer of metal (usually, gold), which is applied to the semiconductor surface by sputtering in a vacuum. Nonoperating ("dead layer") of the gold film on the surface is very thin and makes up about 3^{-6} cm. In the contact of metal and real surface of silicon (metal-semiconductor) the surface-barrier structures form the working *p-n*-junction, which creates a sensitive volume of the detector under reverse voltage. In such detectors the thickness of sensitive area can be varied by changing of reverse bias voltage that allows carrying out the separation of charged particles for paths and ionization density.

Since the temperature regime of manufacturing of the surface-barrier rectifying contact and the noninjecting rear contact does not exceed of 100 ^{o}C, it allows to save the value of the lifetime of minority charge carriers (τ) and create the detectors with high energy resolution (*R*).

It should be noted that the modern detectors with implanted *p-n*-junctions are heat treated at temperatures ~ 800 °C to anneal the radiation defects that leads to the reduction of the lifetime of minority charge carriers and the deterioration of the energy resolution, including the expense of considerable thickness of the input "window".

The physical processes, which control the characteristics of surface barriers, are quite complex. At present, it becomes increasingly clear that the surface states are the dominant controlling factor of rectifying characteristics, rather than the difference in the work functions from the metal and semiconductor. The type (donor and acceptor), the concentration and the energy position of the fast and slow surface states determines the potential of semiconductor free surface and the surface, which is directly under the metal electrode.

Properties of the chemically etched Si surfaces in different environments have largely studied already, but the results of the experiments are very different. For example, it can be extracted the following regularities for the etched silicon surfaces in the mixture of nitric (HNO_3) and hydrofluoric (HF) acid:

1) immediately after etching the surface is unstable, but the stability increases when exposed to air;

2) in the neutral environment (vacuum) the surface will be of weak *n*-type for *n*-type material;

3) the environment with a high electron affinity [*Note*. The electron affinity is the energy that is needed in order to take away an electron from the single negatively charged ion, eV/atom; the similar energy released when an electron is captured by the neutral atom or molecule], such as oxygen or ozone (O_3), creates the shift of the surface potential to the *p*-type surface, while the ammonia, water vapor, HF vapor creates the shift to the *n*-type surface;

4) the surface properties can be modified by chemical treatment.

In early work with surface-barrier detectors it has been found that the Au-Si surface barriers reveal the aging effects that are sensitive to hostile environments, and often exhibit the deterioration of properties after exposure to high vacuum. But it is also known that the special chemical treatments give the good diodes (stable in vacuum) without a long aging.

In Ref. [8] the role of the magnitude of metal work function in the surface-barrier detectors was investigated. The absence of definite connection between the metal work function and the degree of rectification was found as a result of carried out experiments. In fact, if the aging occurs during long-continued time, all studied metals, including with the very low work function, create the good diodes. However, the lowest reverse currents, the minimal aging time and the best energy resolution were obtained only with metals such as Au, Cr, Pt. The work function of these metals is greater than of silicon. According to the authors, the electric field that arises from the difference in the work functions, is the best for electronegative or electropositive impurities and promote the adsorption or decelerate of it. In this case, the electric field promotes the adsorption of oxygen on the surface of the detector. Therefore, the aging time of diodes with Pt-, Cr-, and Au-contacts are a few days, compared to the several months for metals with the lower work function than in Si.

The surface states are controlled by the chemical treatment of the surface and by the environment. In Ref. [9] shown that the layer is formed immediately after etching on the semiconductor surface. The thickness of this layer depends on the chemical, which was used in order to "quench" of the etch reaction. This layer was much more at "quench" by deionized water (the film thickness of ~ 100…200 Å), than at surplus of nitric acid HNO_3 with further washing in deionized water (the film thickness of ~ 10…20 Å). It is believed that this film is the form of silicon hydride or elemental silicon, but is not oxide. Such film can be a place of localization of the fast surface states.

In Ref. [10] the classification of factors that control the properties of the surface rectifying barriers is presented in order of importance: 1) the surface treatment; 2) the adsorbed gases; 3) the difference in work functions. The theoretical model of the semiconductor-metal contact (which takes into account the presence of two intermediate layers, inner and outer surface states) was also presented.

The surface-barrier detectors that have a thin input "window" are used for registration and spectrometry of charged low-energy particles (< 1 MeV) with small path. The input "window" of detector is determined by the thickness of the surface layer, which is intersected by the charged particle before it reaches the sensitive layer (the space-charge region). The dependence of capacitance and thickness of sensitive layer on the reverse-bias voltage value, and a limited magnitude of sensitive layer (up to 2…3 mm), which depends on the resistivity of the initial material, are the disadvantages of detectors with thin input "window". Si(Li)-detectors are used to measure the spectra of the particles of higher energies.

2. OPTIMIZATION OF PROCESSES OF THE FORMATION OF SURFACE-BARRIER STRUCTURES WITH STABLE CHARACTERISTICS

The surface-barrier detectors of total absorption energy of charged particles (*E*-detectors) with a wide range of the thicknesses of sensitive area and the detectors of the specific energy losses (dE/dx-detectors) are used for nuclear radiation spectrometry. The thickness of sensitive area of dE/dx-detectors is much lesser than path of the identifiable particles.

The thin silicon detectors, the ionization chambers and the proportional counters can be used as dE/dx-detectors; silicon detectors or detectors on the basis of high purity germanium (*HP Ge*) can be used as *E*-detectors.

The method of manufacture of dE/dx-detectors must satisfy a number of conditions. The main condition is the obtaining of the high plane-parallel plates of crystals, since the fluctuations of particle energy losses due to the nonuniformity of thickness should be smaller than the statistical fluctuations of the charge, which is released by the particle in the thin detector. With decreasing of detector thickness the technological complexities are increased (even negligible changes in the thickness can lead to straggling in the energy losses of the flying particles), since the thin silicon plates is very brittle, that complicates their processing and using in the experiment. The thin silicon plates are manufactured by using precision grinding and etching.

Furthermore, at full depletion of the detector volume (at the increasing of reverse bias on detector) when the space-charge region extends to the rear contact (which must necessarily be noninjecting) the detector must have a low noise level. The detector of specific energy losses should also have the thin input and output "windows", because the uncontrolled losses of charge take place in these "windows".

The detector of specific energy losses should have the high resolution, which can be obtained under the condition of high electric field strength in detector.

The basic parameters of dE/dx-detectors, such as the level of reverse currents, the quality of the surface barrier, the thickness of the input "windows", and, finally, the energy resolution, are directly related to the properties of the initial semiconductor material and the electronic state of its surface. Therefore, to create the qualitative and reliable detectors with the required parameters we must study the bulk and surface properties of the initial silicon crystals.

Therefore, in this paper to identify the suitability of silicon for the production of detectors, the following parameters were investigated: the gradient of resistivity along the ingot diameter, the lifetime of minority charge carriers, and the concentration distribution of dislocations. We also studied the influence of different regimes of etching on the quality of surface-barrier junctions and the magnitude of the input "windows" of detectors. At forming the surface-barrier structure the state of semiconductor surface was monitored using the measurement techniques of the combined effect of field and the contact potential difference. It is allowed to determine the magnitude of bending of energy bands on the silicon surface at the different chemical treatments, the kinetics of the surface potential φ_k and its homogeneity.

It was experimentally found that for producing of detectors with the thickness of sensitive area of $W \leq 100$ μm the band-purified single silicon crystal of *n*-type conductivity with resistivity of $\rho \approx 1…2$ kΩ·cm and lifetime of the minority charge carriers of > 500 μs is most appropriate. Plates of silicon should have a homogeneous electrophysical parameters along the diameter (the spreading of ρ and τ should be < 30 %), and to be the structurally perfect (without dislocation and defect clusters). In order to avoid the phenomenon of ion channeling in the direction of the main crystallographic axis of the crystal [111], cutting of samples from the silicon ingot was carried out at the angle of 8^o to this direction.

The surface-barrier technology was used under the development of detectors. At such technology (in contrast to the diffuse and planar technologies) the silicon plates were not affected by the high temperature treatment, which, as a rule, leads to a considerable reduction of the lifetime of minority charge carriers and the deterioration of the energy resolution of detectors.

The carried out studies have shown that the magnitude of surface potential varies with the lapse of time after the chemical treatment of silicon and reaches in certain surrounding atmosphere the stationary value in the depending on the etching rate and the type of substance, which was used in the “quenching” of the etching reaction. It is found that at the end of the etching reaction with using of nitric acid (HNO_3), instead of H_2O, the oxidation rate decreased significantly, and on the real Si surface formed more thin oxide (~ 20 Å).

The opportunity to accelerate the stabilization of surface processes by applying to the Au-Si contact the reverse voltage of ~ 0.6 V (i.e. the order of magnitude of the potential barrier height) was found as a result of the carried out experiments. Thus, the electric field in the metal-semiconductor contact, without substantial affecting on the equilibrium height of the barrier, will accelerate the drift of the oxygen ions through the gold film to the semiconductor surface, which results in a more rapid formation of surface-barrier junction.

Fig. 1 shows the influence of the environment (vacuum (I), moist oxygen (II)) on the level of reverse currents of the freshly manufactured surface-barrier Au-*n*-Si structures.

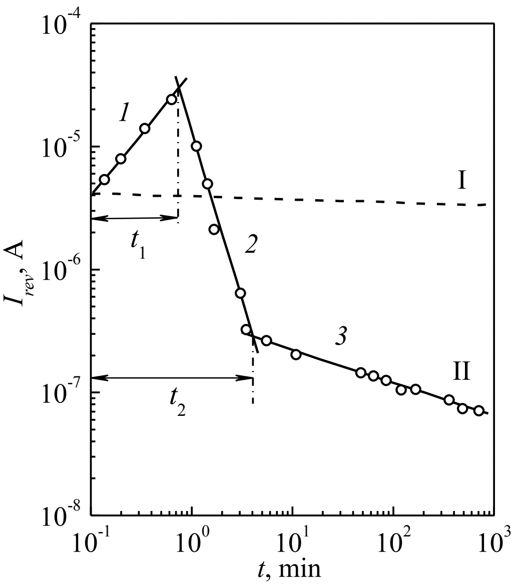

Fig. 1. Kinetics of changes of the reverse current I_{rev} of the surface-barrier Au-n-Si diode (ρ = 2 kΩ·cm, U = 50 V) in the different atmospheres: I – vacuum; II – moist oxygen. In the different parts of curve II the rate of surface recombination s, cm/s is: 1 – 1; 2 – 2.4; 3 – 0.23

It was established experimentally that if immediately after the deposition of gold on the silicon surface the environment of dry oxygen was created, then the barrier is not formed and the detector has a high reverse current (see Fig. 1, curve I). When starting of the moist oxygen the current at the beginning increases slightly with a small time constant t_1, and then gradually decreases (see Fig. 1, curve II). Probably, t_1 corresponds to the time that required for the diffusion process of oxygen through the metal layer to the semiconductor surface. Oxygen can be adsorbed in the form of O_2, i. e. the oxygen molecule captures an electron. The mechanism of $H_2O \rightarrow (H_2O)^+ + e^-$, $O_2 + e^- \rightarrow O_2^-$ is possible as well. Thus, the experiment showed that the most optimal formation of the high-quality and stable surface-barrier *p*-*n*-junctions occurs at the aging of structures in the atmosphere of moist oxygen.

It was revealed that in the surface-barrier detectors, in which the space-charge region *W* extends through the entire thickness of the crystal, the heterogeneity of surface charge leads to the considerable inhomogeneity of *W* that substantially impairs the energy resolution of detectors.

It was proved experimentally that at the low etching rate (~ 5 μm/min) and the ensuring of the conditions of equal access of etchant to the entire surface of the crystal, the homogeneous surface with high uniformity of the surface potential ($\Delta\varphi_k$ ~ 15 mV) can be obtained that allows to produce the high-quality detectors.

As noted, one of the important requirements to *dE*/*dx*-detectors is the plane-parallel plates for each of them to provide the same energy losses of charged particles, which cross of detectors through the area of input “windows”. To achieve this aim the etchant must satisfy the following requirements: a) to create on the plate surface such charge (in magnitude and sign), which would corresponds to the formation of the surface barrier; b) has uniform rate of etching on the area of plate with minimal surface relief.

For the plane-parallel etching of crystals the plant with two movements of the crystal has been developed: the rotation of the cup with etchant, inclined at the angle of ~ 30°, with a rate of 60 revolutions per minute, and the rotation of the crystal in etchant on the special basis. Meanwhile, the same access of etchant to all points of the crystal is achieved, that ensures a uniform rate of etching over the entire area of plates.

Before etching the plate is plane-parallel planished (by the powders with a gradual decrease in grain size from M20 to M7), and then thoroughly washed in the organic solvents and the high-resistance water (~ 3…5 MΩ). A number of etchants on the basis of the superpurity concentrated acids [hydrofluoric (HF), nitric (HNO_3) and acetic (CH_3COOH)], combined in the different proportions, was used. The surface relief after etching was checked on profilometer with the recording on a recorder chart. The radius of curvature of the diamond probe was 10 μm. The smallest surface relief (~ 0.5 μm) was observed at treatment by the etchant of $1HF : 20HNO_3 : 1CH_3COOH$, whereas the other used etchants resulted in appearance of the strong relief of surface (~ 5…15 μm). Therefore, from the viewpoint of a plane-parallel, these etchants were unsatisfactory.

To create detectors with thickness of sensing area $W \geq 200$ μm the rapid etchants (with the etching rate of ~ 20 μm/min) were applied. The freshly etched silicon surface was slightly depleted with significant inhomogeneity of φ_k, as shown by measurements of the surface potential. The required value of $\varphi_к$ and the inversion at the surface are reached in two days after aging of plates on air. Based on these results, the formation of a potential barrier in the metal-semiconductor contact (by thermal deposition of gold) was carried out after aging the plates during the indicated time taking into account the kinetics of surface potential φ_k.

The etchants with small etching rate ~ 3.5 μm/min (the composition of etchants was selected on the basis of HF, HNO_3, and CH_3COOH) were used for chemical polishing of the crystals to produce thin detectors with $W \leq 100$ μm. It was determined that under these conditions the value of the surface potential φ_k in two hours after treatment will have a stable value, which is corresponded to the weak inversion of conductivity for the high-resistance silicon.

In addition, at manufacturing of detectors with $W \leq 100$ μm the sequential etching technology was used at the beginning from the rear side of plate and then from the front side of crystal to a certain depth (50 and 150 μm, respectively). To ensure the noninjecting rear contact, the thickness of the etching layer was fitted as follows: the reached value of the surface recombination rate (s) should correspond to the optimal value of the effective lifetime of minority charge carriers (τ_{ef}). It should be noted that in the finished detector the effective carrier lifetime connect with the surface recombination rate by the expression of $\frac{1}{\tau_{ef}} = \frac{1}{\tau_0} + \frac{2s}{w}$, where τ_0 is the lifetime of minority charge carriers in the crystal bulk, w is the thickness of the plate. The measurement results of τ_{ef} in thin plates by the method described in Ref. [11] gave the value for τ_{ef} about 500 μs.

The carried out studies allow to establish the possibility of forming the noninjecting rear contact of detectors by means of the thermal deposition of Ge and Al thin layers on the rear side of the crystal, which has a certain value of the surface recombination rate. After the chemical polishing of crystals, through a certain time, the germanium (~ 50 $\mu g \cdot cm^{-2}$) and aluminum (~ 30 $\mu g \cdot cm^{-2}$) layers were sequentially deposited to the rear surface by the method of thermal evaporation. Germanium with p-type conductivity and resistivity of ~ 3 Ω·cm was used. The germanium layer was applied under high vacuum (about 10^{-6} Torr) at evaporation rate of about 1 Å/s. At lower vacuum and smaller evaporation rates the germanium layer is saturated by oxygen atoms (up to ~ 1%), that resulting in the undesirable change in conditions on the crystal surface. The proposed technological regime allows to obtain the α-Ge amorphous layer and to create a neutral surface of Si crystal (the condition of flat energy bands on the surface).

Thus, the evaporation on the rear side of the Ge and Al layers allows creating detectors capable of operating at reverse bias, which in 2…3 times exceeds the full depletion voltage of detector. Increasing of the electric field strength in dE/dx-detectors is necessary at using them in the experiments with charged particles with the high atomic numbers of Z, when the high density of ionization in the track is created.

Measurement of the current-voltage characteristics allowed us to estimate the range of working biases of detectors, the value of the breakdown voltage, the level of reverse currents, which contribute to the noises of detectors.

After evaporation of Ge and Al and the aging of plates in air for 2 days the gold layer (about 70 $\mu g \cdot cm^2$) was deposited on the working surface to form the surface-barrier structure.

The carried out analysis of configuration of the space-charge region in the surface-barrier structures on the high-resistance semiconductors has shown that such structures are not pure Schottky diodes. Therefore it is necessary to take into account the presence near the surface the area of inversion conductivity of the minority charge carriers. In this inversion area with high carrier concentration the electric field strength is much lower than in the space-charge region. Therefore, in the inversion layer the electron-hole pairs, generated by the charged particle, recombine before reaching the sensitive area of detector. Under these conditions, at the presence of input "window", the main spectrometric characteristic of detector (a linear dependence of the amplitude of useful signal of detector on the energy of nuclear particles) is distorted.

3. MAIN CHARACTERISTICS OF THE MANUFACTURED TEST SAMPLES OF SURFACE-BARRIER DETECTORS

The results of carried out research of the electron processes on the silicon surface became the basis for the development of the advanced manufacturing technology of high-quality and stable surface-barrier detectors based on silicon plates.

The batch of detectors with thickness of sensitive area $W = 200$ μm and working area $S = 3.5$ cm^2 (Fig. 2,a) was made on the basis of Si plates with resistivity $\rho = 1.5…2$ kΩ·cm and lifetimes of the minority carriers $\tau \sim 1000$ μs. The batch of detectors with thickness of sensitive area $W = 100$ μm and working area $S = 1.5$ cm^2 (see Fig. 2,b) was made on the basis of Si plates with resistivity $\rho = 4$ kΩ·cm and lifetimes of the minority carriers $\tau \sim 1000$ μs.

Let us consider the main characteristics of a typical surface-barrier detector. Fig. 3 shows current-voltage characteristics of such detector under direct and reverse voltage. Fig. 4 shows the capacitance-voltage dependence, and Fig. 5 shows the dependence of $1/C^2 = f(V)$.

The measuring of capacitance-voltage characteristics showed that the detectors have a sharp p-n-junction, it is evident from the region of the linear dependence of $1/C^2 = f(V)$. Capacitance-voltage characteristics show that the total depletion of the detector occurs when a reverse voltage of ~ 60 V.

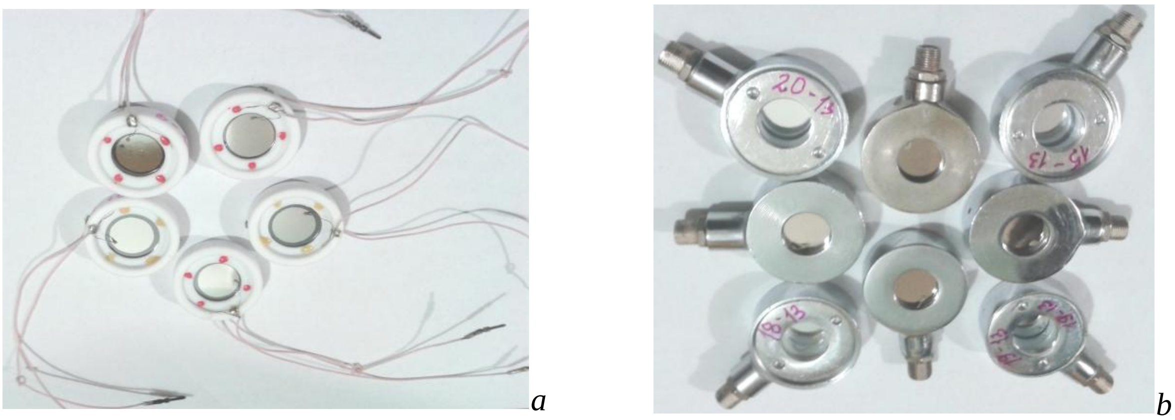
a *b*

Fig. 2. General view of the surface-barrier detectors manufactured on the basis of Si plates:
a – ρ = 1.5…2 kΩ·cm, W = 200 μm; b – ρ = 4 kΩ·cm, W = 100 μm

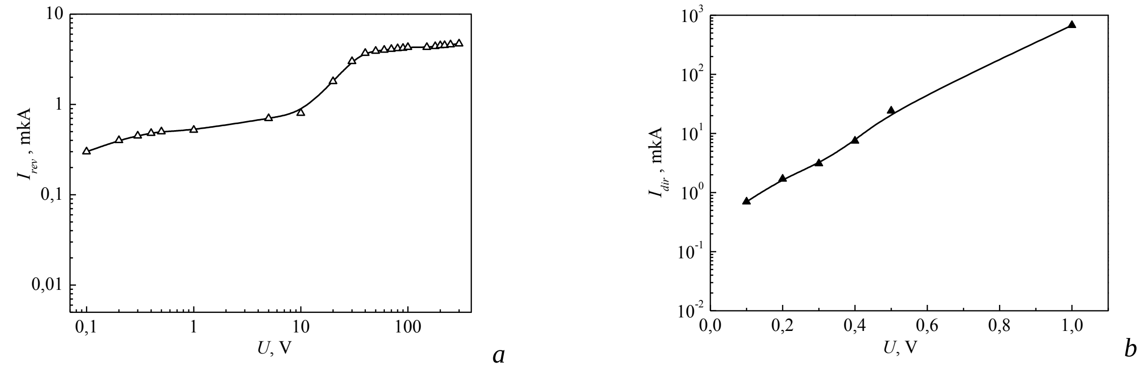

Fig. 3. For the surface-barrier detector based on n-Si plates, dependences on the bias voltage:
a – the reverse current I_{rev}; b – the direct current I_{dir}

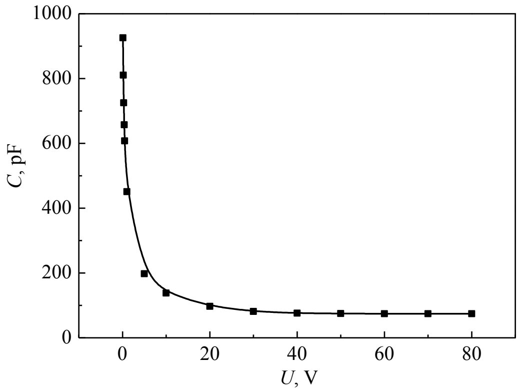

Fig. 4. Capacity-voltage dependence C = f (U)
of the surface-barrier detector (at S = 1 cm^2)

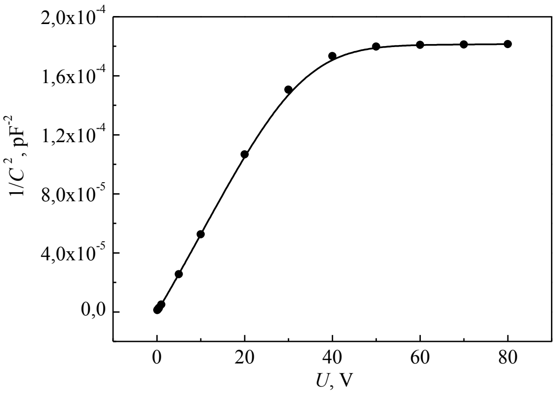

Fig. 5. Dependence 1/C^2 = f (U)
of the surface-barrier detector

The current-voltage characteristics shows that the detector should work under the maximal reverse voltage of ~300 V, while the electric field strength in the detector is $2 \cdot 10^4$ V/cm. At such electric field strength the spectrometry of heavy charged particles is feasible. The heavy charged particles cause under absorption the high density of the electron-hole pairs.

Fig. 6 shows the typical α-particle spectra of three-component source (^{233}U, ^{237}Pu, ^{241}Am) for the surface-barrier detector with thickness of sensitive area W = 200 μm.

Spectrometric characteristics of surface-barrier detectors with thickness of sensitive area W = 100 μm were determined under irradiate by three-component source from the anterior and the rear sides of the crystal (Fig. 7). The achieved energy resolution of such detectors R was less than 70 keV. The values of the energy resolution coincided after irradiation of detector from both sides. This fact defines sameness of the input and output “windows”.

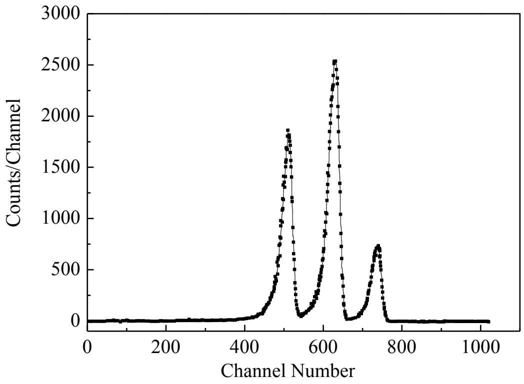

Fig. 6. The α-particle spectra of three-component source (^{233}U, ^{237}Pu, ^{241}Am) of the surface-barrier detector with the thickness of sensitive area W = 200 μm when the reverse bias voltage U = 250 V and current I = 0.65 μA

CONCLUSIONS

1. A complex research of the surface and bulk properties of the initial silicon in order to solve the problem of the creating of spectrometric semiconductor detectors with predetermined parameters was carried out.

2. The methods of chemical treatment of the Si surface by means of choice of the composition of etchants on the basis of high-purity acids of HF, HNO_3, and CH_3COOH were developed for plane-parallel etching of silicon crystals.

3. The method of accelerated formation of surface-barrier structures through applying a reverse voltage at the stage of the forming of potential barrier in the Au-Si contact was proposed.

4. It was found that after the deposition of gold on the silicon surface the optimal formation of qualitative and stable surface-barrier *p-n*-junctions occurs with aging of structures in an atmosphere of the moist oxygen.

5. According to the optimized surface-barrier technology on the basis of Si plates with resistivity $\rho = 1.5...2$ kΩ·cm and lifetimes of the minority charge carriers $\tau \sim 1000$ μs, the detectors with thickness of sensitive area $W = 200$ μm and with working area $S = 3.5$ cm^2 were manufactured, as well as on the basis of Si plates ($\rho = 4$ kΩ·cm, $\tau \sim 1000$ μs) the detectors with $W = 100$ μm and $S = 1.5$ cm^2 were produced for using in the nuclear physics experiments.

6. The main electrophysical parameters of the surface-barrier nuclear radiation detectors and their spectrometric characteristics were determined.

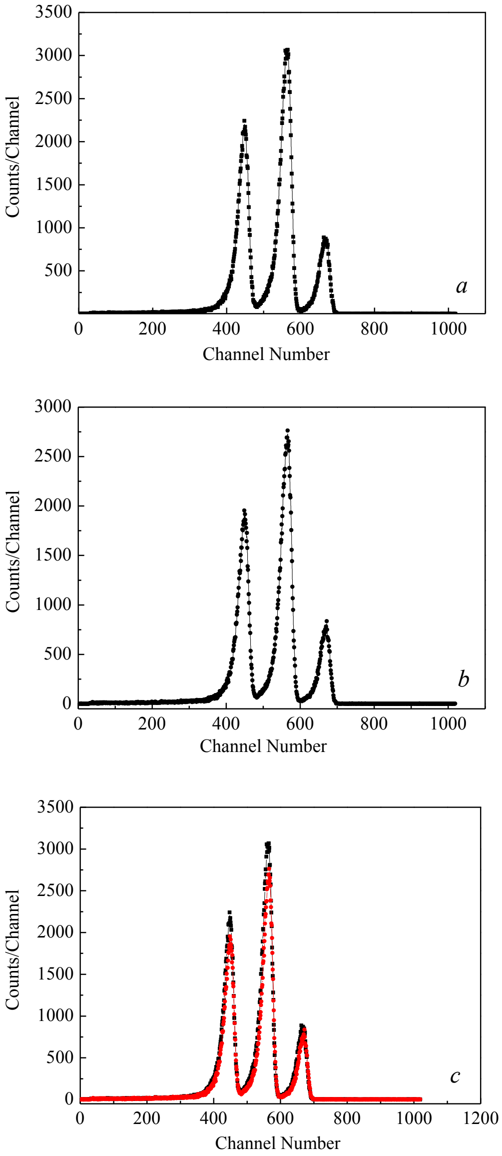

Fig. 7. The α-particle spectra of three-component source (^{233}U, ^{237}Pu, ^{241}Am), obtained by the surface-barrier detector with W = 100 μm when irradiated this detector from the side of: a – input "window" (working side); b – output "window" (rear contact); c – combined (both) spectra

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ВЛИЯНИЕ ПОВЕРХНОСТНЫХ ЭЛЕКТРОННЫХ ПРОЦЕССОВ НА СПЕКТРОМЕТРИЧЕСКИЕ ХАРАКТЕРИСТИКИ КРЕМНИЕВЫХ ДЕТЕКТОРОВ

Г.П. Гайдар, С.В. Бердниченко, В.Г. Воробьев, В.И. Кочкин, В.Ф. Ластовецкий, П.Г. Литовченко

Выявлены особенности влияния поверхностных электронных процессов на формирование кремниевых поверхностно-барьерных детекторных структур; установлены режимы химических обработок поверхности Si-кристаллов с использованием различных составов травителей для ускоренного создания поверхностно-барьерных структур со стабильными параметрами; разработаны медленные режимы травления для изготовления детекторов плоскопараллельной геометрии. На основе проведенных экспериментальных исследований по совершенствованию процессов формирования качественных поверхностно-барьерных структур оптимизирована технология изготовления кремниевых спектрометрических детекторов, изготовлены опытные образцы и определены их характеристики.

ВПЛИВ ПОВЕРХНЕВИХ ЕЛЕКТРОННИХ ПРОЦЕСІВ НА СПЕКТРОМЕТРИЧНІ ХАРАКТЕРИСТИКИ КРЕМНІЄВИХ ДЕТЕКТОРІВ

Г.П. Гайдар, С.В. Бердниченко, В.Г. Воробйов, В.І. Кочкін, В.Ф. Ластовецький, П.Г. Литовченко

Виявлено особливості впливу поверхневих електронних процесів на формування кремнієвих поверхнево-бар’єрних детекторних структур; встановлено режими хімічних обробок поверхні Si-кристалів з використанням різних складів травників для прискореного створення поверхнево-бар’єрних структур зі стабільними параметрами; розроблено повільні режими травлення для виготовлення детекторів плоско-паралельної геометрії. На основі проведених експериментальних досліджень щодо вдосконалення процесів формування якісних поверхнево-бар’єрних структур оптимізовано технологію виготовлення кремнієвих спектрометричних детекторів, виготовлено дослідні зразки та визначено їх характеристики.