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The influence of inhomogeneities of materials on spectrometric characteristics of silicon detectors

This work deals with influence of inhomogeneities of initial materials, for manufacturing Si(Li) detectors, on detector's spectrometric characteristics. It is shown the results of investigation of structural features of Si(Li) detectors. The results of the research, of diffusion and drift of lithium ions into silicon, grown by Chohralski method and floating zone melting method, were described. It was shown that insufficient compensation of detector's sensitive area is due to existence of local inhomogeneities in initial crystal volume, and also with imperfection of contacts of p-i-n structure. Moreover, it was described the current- voltage and farad- voltage characteristics of Si(Li) detectors. Also, the energy spectra of detector structure on the β-particles ^{207}Bi (E_β = 1 MeV) R_β = 38 keV and α-particles ^{226}Ra (E_α = 7.65 MeV) Ra = 65 keV was illustrated. It was experimentally approved that the results from low ohm p-Si crystal, grown by Chohralski method, have advantages to manufacture of big size Si(Li) p-i-n detectors, with low value of reverse current and high exploitation characteristic.

Key words: silicon, lithium ion drift, p-i-n structures, Si(Li) detector.

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Кремнийлі детекторлардың спектрометрлік сипаттамаларына материалдың біртексіздігінің әсері

Бұл жұмыста кремнийлі детекторлардың спектрометрлік сипаттамаларына материалдың біртексіздігінің әсері қарастырылған. Si(Li) p-i-n детекторларының құрылымдық ерекшеліктері қарастырылған. Чохральский және тигельсіз зоналы балқыту әдісімен өсірілген кремнийдегі литий иондарының диффузиясы және дрейфінің зерттеу нәтижелері көрсетілген. Детекторлардың сезгіш аймағындағы жеткіліксіз компенсациялар негізгі материал көлемінде локалды біртексіздікке және де p-i-n құрылымдағы контактілердің жетілдірмегеніне байланысты. Si(Li) детекторларының вольт-амперлік және вольт-фарадтық сипаттамалары алынды. β-бөлшек ^{207}Bi (E=1 МэВ) R_β=38 кэВ және α-бөлшектері ^{226}Ra (E_α=7,65 МэВ) R_α=65 кэВ бойынша детекторлық құрылымның энергетикалық спектрлері алынды. Тәжірибе нәтижесіне қарап Чохральский әдісімен алынған кремнийден алынған аз кері ток және жоғары эксплуатациялық сипаттамаларға ие үлкен өлшемді Si(Li) p-i-n детекторларын дайындау артықшылығын көрсетілген.

Түйін сөздер: Кремний, литий ионы дрейфі, p-i-n құрылымы, Si(Li) детектор.

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Влияние неоднородности материала на спектрометрические характеристики кремниевых детекторов

В работе рассматривается влияние неоднородности материала на спектрометрические характеристики кремниевых детекторов. Рассмотрены структурные особенности Si(Li) p-i-n детекторов. Описаны результаты исследования диффузии и дрейфа ионов лития в кремний, выращенный по методу Чохральского и безтигельной зонной плавкий. Показано что, недостаточная компенсация чувствительной области детекторов обуславливается наличием локальных неоднородностей в объеме исходного материала, а также несовершенством контактов p-i-n структур. Описаны вольт – амперные и вольт-фарадные характеристики Si(Li) детекторов. Получены энергетические спектры детекторных структур по β-частицам ^{207}Bi (E=1 МэВ) R_β=38 кэВ и по α-частицами ^{226}Ra (E_α=7,65 МэВ) R_α=65 кэВ.Экспериментально показано, что результаты из низкоомного p-Si выращенного методом Чохральского имеют преимущества при использований для изготовления Si(Li) p-i-n детекторов больших размеров, малыми обратными токами и высокими эксплутационными характеристиками.

Ключевые слова: кремний, дрейф ионов лития, p-i-n структура, Si(Li) детектор.

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THE INFLUENCE OF INHOMOGENEITIES OF MATERIALS ON SPECTROMETRIC CHARACTERISTICS OF SILICON DETECTORS

Introduction

The solution of many problems of modern science and technology and all experimental nuclear physics requires improvement of existing instruments for the nuclear radiation detection [1]. For the detector structures imposed very strict requirements related to their current, charge, capacitive, spectrometry, time characteristics, as well as the sameness of identification of the ionizing radiation, regardless of their falling into any precise large-area of detector.

The studies of semiconductor nuclear-radiation detectors are aimed at deepening ideas about the properties and capabilities of semiconductor materials. The successful solution of these problems depends on the correct understanding of the relationship between the electrical characteristics of semiconductor radiation detectors on the properties of the original semiconductor material. Usually the relationship between the properties of the original material and the semiconductor device is viewed from the point of view of a certain concentration of different point imperfections of the crystal lattice.

In this direction it is represented a number of interesting physical featuresof bulk crystals [2]. Thus, for example, introduced by the use of this approach, the concept of «large-scale trap» due to fluctuation of the local concentration of atoms as the main lattice and various impurity atoms (electrically active and inactive) in the bulk crystal. It is shown the nature of «large-scale trap» and technological reasons for their occurrence. It is determined the physical mechanisms of their influence on the kinetic processes in the bulk of the crystal.

In [3-4] are considered characteristics of complexes and multiply charged centers of nickel manganese atoms in the strongly compensated silicon. The importance of this research is to establish the facts of the presence in certain local areas of significant non-homogeneous distribution of impurities in them. The study of physical processes in such areas can reveal the physical processes causing new fundamental functional principles. Therefore, in semiconductor physics, they can cause a wide interest among theorists and experimentalists [5].

Material and methods

For the manufacturing the detector dislocation-free silicon single crystal p-type was taken asa initial material, 100 mm diameter, having a resistivity $\rho = 10 \div 12$ Ohm • sm and lifetime $\tau \geq 50$ ms grown in an argon atmosphere by the Chohralski method. The oxygen concentration is equal to No=2 • 10^{17} sm^{-3}. Also, it was used the silicon produced by floating melting zone, with resistivity $\rho = 1000 \div 5000$ Om.sm and lifetime $\tau \geq 500$ microseconds. After a certain chemical-technological operations the diffusion of lithium were held on one sideof silicon wafers in a vacuum at a temperature$T = (450)$ ^{0}C to a depth of 320-350 μm. After that, to compensate for the entire thickness of the plate the drift of lithium ions on the entire plate thickness was carried out. The process drift was conducted in two stages: the main, at $T = (80 \div 100)$ ^{0}C and reverse bias voltage 80-120 V and additional stage is smoothing, with an increase in the reverse bias to the 300V ~ at the same temperatures. The gold and aluminum coating were used to obtain the ohmic metal contacts [6].

Results and discussion

Important characteristics of Si (Li) p-i-n detectors of radiation depends on the nature of the distribution of lithium in the diffusion region, as a drift in the process determines the distribution of conductivity in the i-region and the quality of the n^+i-junction. During the diffusion process the lithium deposited on the numerous irregularities, this lead lithiumto go to inactive state. At the same time as more violation of the crystal lattice as more lithium becomes inactive. This explains the decrease in the concentration of electrically active surface regions of lithium plates. Here we can only note that in a low-resistance of p-Si samples with high oxygen content coordinate dependence of concentration of lithium ions in the depth of the diffusion region may be different from the well-known relationship

$$N_x = N_0 erfc\left(\frac{x}{2\sqrt{Dt}}\right),$$

where $N_x$and N_0– surface concentration of lithium at the depth x, respectively, t – diffusion time, D=23*10^{-4}exp(15200/kT) sm^2/s – lithium diffusion coefficient in silicon.

The amount of current flowing in the reverse bias Si (Li) p-i-n structure is the most important electrophysical parameter that determines the level of current noise of semiconductor detectors.

According to the analysis, the volume of reverse current component of Si (Li) *p-i-n*-structures is almost completely determined only by generational current in compensated *i*-region and does not depend on the specific resistance of the starting material. Consequently, the value component of the reverse current of our detectors should be equal $I_{rev} = IS$ = 3,4 mA. This value is used as a criterion by which to assess whether a substantial contribution to the total current makes the surface component.

As it can be seen from the experimental curves (see. Figure 1), the reverse current of detectors from low resistive silicon obtained by Chohralski method (ρ = 10 ohm. sm) is in agreement with the calculated value in the saturation region taken with high accuracy. This indicates the absence of surface currents, and hence the stability of radiometric characteristics in a wide range of working fields.

The reverse currents of detectors from high resistant floating zone siliconhave quite a different character (ρ = 4 kOm.sm). In this case, the measured values greatly exceed the inverse critical currents (I_{rev} = 3.4 mA) in almost the entire range of the reverse bias (at 10 V). This indicates the formation of an inversion layer on the surface of these detectors. The width and conductivity of the inversion layer, as known, determined by the original semiconductor resistivity and the surface band bending.

Volt – farad characteristics of Si (Li) *p-i-n* detectors are shown in Figure 2. The best characteristics are observed in detectors grown by Chohralski method.

Insufficient compensation of sensitive area of detectors due to the presence of local inhomogeneities in the amount of starting material, and the imperfection of contacts of *p-i-n* structures. Using special "soft" modes of lithium ions drift, as well as the replacement of chemically-precipitated aluminum back contact on the sprayed layer of aluminum, with an additional leveling drift reduces the magnitude of the bias voltage,under this condition it achieves the necessary thickness of the sensitive area.

From the analysis it is clearly seen the advantages of using a low-resistance *p*-Si grown by the Chohralski method for the manufacture of Si (Li) *p-i-n* detectors of large size, with small reverse currents and high performance characteristics.

One of the main operating parameters of semiconductor detectors of nuclear radiation is the energy equivalent of noise level E_n. This parameter determines the radiometric capability of detector, energy resolution and detection efficiency. The energy equivalent noise level values are measured in two ways: a spectrometric and a method of direct measurements.

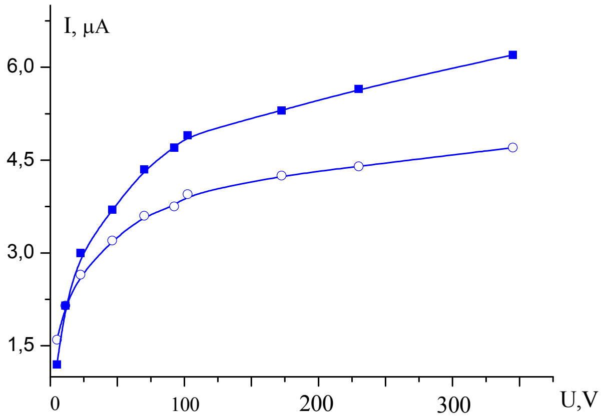


Figure 1 – CVC of Si (Li) p-i-n detectors made of low-resistive p-Si, grown by Chohralski method – ○ -; and high-resistive silicon obtained by floating zone melting – ■ –

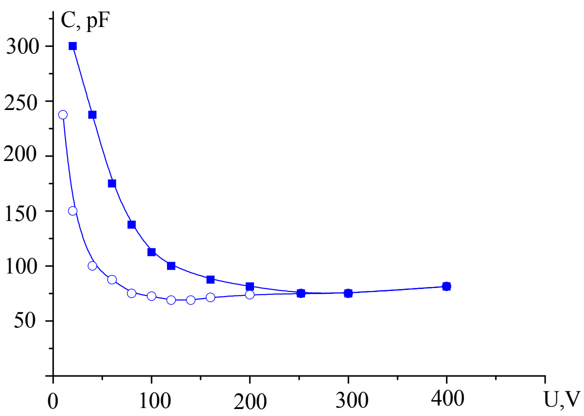
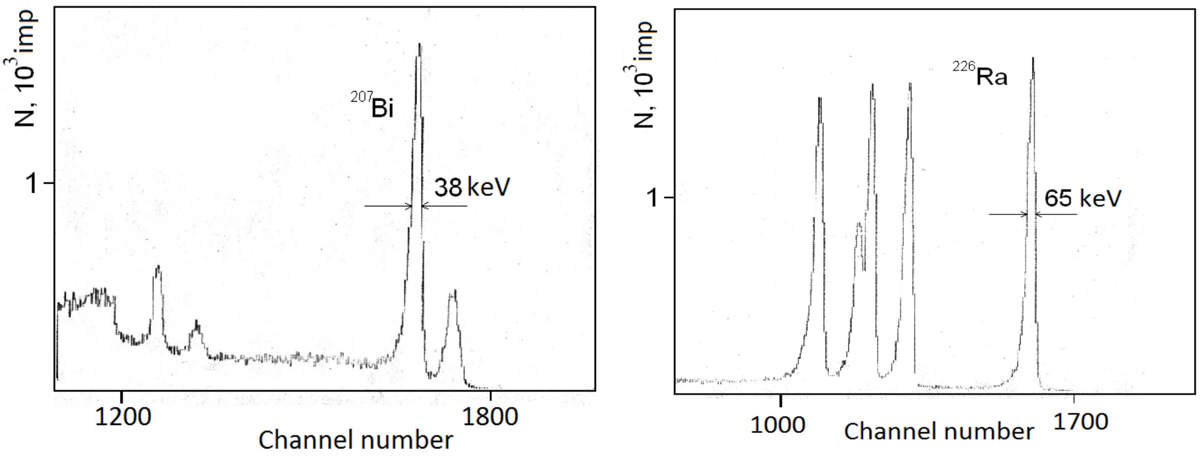


Figure 2 – VFC of Si (Li) p-i-n detectors made of p-Si, grown by Chohralski method – ○ – and floating zone melting – ■ -

By using these samples it was studied the spectrometric characteristics of detectors at room temperature. The energy resolution was measured by using a source of α^{207}Bi particles and β^{226}Ra particles. Registration of amplitude of spectra was carried out using a conventional spectrometer path.

Figure 3 a, b shows the energy spectra of detector structure on the β-particles ^{207}Bi (E_β = 1 MeV) R_β = 38 keV and α-particles ^{226}Ra (E_α = 7.65 MeV) Ra = 65 keV.



а) *б)*

a) β-particles 207Bi (E_β~1 1 MeV); b) 226Ra α-particles (Eα=7.65 MeV).

Figure 3 – The energy spectra of the detector structure

Conclusion

As we conclude, the drift and diffusion of lithium ions in silicon grown by the Chohralski method, with high content and inhomogeneous distribution of impurities, has significant features associated with the formation of the dipole structures in the field of in homogeneities of concentration of acceptor impurity. After completing the process of drift the lithium in the compensated region can not provide sufficient high resistivity, this due to the presence of local inhomogeneitiesin distribution of the acceptor impurity, and thermally generated carriers.

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