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DEVELOPMENT OF SILICON STRIP DETECTORS WITH ORTHOGONAL FIELD

The development of semiconductor strip detectors with orthogonal field with high energy and position resolution, linearity of the signal over a wide energy range for various types of particles, is closely linked with the technology of manufacturing the detection modules and semiconductor properties of the original crystal. In this paper we consider the physical and technological features of manufacturing of Si (Li) strip detectors with orthogonal field with a large sensitive area. The manufactured detectors have following electro-physical and radiometric characteristics: under working voltage U = (50-600)V shows the I ~ (0,1÷0,5) μA reversed current, capacitance is C = 25 pF, noise E = (12÷35) keV, energy resolution $R_{в}$ = 18 keV from the source of ^{207}Bi ($E_{в}$ = 1MeV) and $R\alpha$ = 46 keV from the source of ^{238}Pu ($E_{\alpha} \approx$ 5,5MeV). Investigation of the impact of irregularities on characteristics of strip detectors, as well as their role in the phenomena of charge transport in a condition of orthogonal field.

Key words: *p-i-n* stucture, detector, Si(Li) strip detector.

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Ортогональды өріспен кремний негізінде жолақты детекторларды дайындау

Жоғары энергия мен орынға ие ортогональды өрісті шалаөткізгіш жолақты детекторларды жасау, түрлі типті бөлшектер үшін энергиялары кең аралықтағы сигналдың сызықтығы, анықтау модульдерді дайындау технологиясы және бастапқы кристаллдың шалаөткізгіштік қасиеттеріне тығыз байланысты. Бұл жұмыста үлкен сезгіш аумаққа ие Si(Li) негізінде жолақты детекторларды алудың физикалық және технологиялық ерекшеліктері қарастырылған. Алынған детектордың электрофизикалық және радиометрикалық параметрлері: U = (50-600)В аралығында кернеу берілгенде оның шекті параметрлері қараңғылық ток I~(0,1÷0,5) мкА, сиымдылық C=25 пФ, шуылы E = (12÷35) кэВ. Детектордың *в*-бөлшек ^{207}Bi (E=1 МэВ) $R_{в}$=18 кэВ және α-бөлшектері ^{226}Ra (E_{α}=7,65 МэВ) R_{α}=46 кэВ бойынша энергетикалық спектрлері алынды. Жолақты детекторлардың сипаттамаларына біртексіздіктің әсеріде зерттелді және ортогональ өріс уақтында заряд тасымалдаушылардың әсерінің ролі зерттелді.

Түйін сөздер: *p-i-n* құрылымы, детектор, Si(Li) жолақты детектор.

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Разработка кремниевых стриповых детекторов с ортогональным полем

Разработка полупроводниковых полосковых детекторов с ортогональным полем с высокой энергией и положением, линейность сигнала в широком диапазоне энергий для различных типов частиц тесно связана с технологией изготовления модулей обнаружения и полупроводниковых свойств исходного кристалла. В работе рассматриваются физико-технологические особенности изготовления Si(Li) стриповых детекторов с ортогональном полем с большой чувствительной областью. Электрофизические и радиометрические параметры изготовленной детекторов при рабочем напряжении $U = (50\text{-}600)$В находятся в пределах значения темнового тока $I \sim (0,1 \div 0,5)$ мкА, емкость $C = (20 \div 200)$пФ, шумы $E = (12 \div 35)$ кэВ. Энергетические разрешения $R_в = 18$кэВ по ЭВК ^{207}Bi ($E_в = 1$МэВ) и $R_\alpha = 46$ кэВ по ^{238}Pu ($E_\alpha \approx 5,5$МэВ), соответственно. Исследовано влияние неоднородностей на характеристики стриповых детекторов, а также их роль в явлениях переноса носителей заряда в условиях ортогонального поля.

Ключевые слова: *p-i-n* структура, детектор, Si(Li) стрип детектор.

Introduction

The solution of many problems of modern science and technology, especially experimental nuclear physics, requires the creation of new, and improvement of existing devices for registration of nuclear radiation. In recent years, it is becoming more widely to use semiconductor detectors (SCD) based on silicon, germanium, and compound semiconductor type compounds as A^3B^5 and A^2B^6 [1-3]. Among the broad class of nuclear radiation detectors based on semiconductor crystals the silicon-lithium detectors occupy a special place [4-6].

The development of semiconductor strip detectors with orthogonal field with high energy and position resolution, linearity of the signal over a wide energy range for various types of particles, is closely linked with the technology of manufacturing the detection modules and semiconductor properties of the original crystal. In this paper we consider physical and technological features of manufacturing of Si (Li) strip detectors with orthogonal field and with a large sensitive area.

The disadvantages of existing semiconductor strip detectors are not high position resolution, as well as the impossibility of combining the thin entrance window with a sufficient thickness of the sensitive area. Processing methods of creating resistive layers and modes are not enough covered in the technical literature. The identity of the elements of discrete strip detectors with orthogonal field and characteristics of resistive layers of continuous strip detectors caused by the initial parameters of the semiconductor, in particular, coordinate the distribution of in homogeneities in the volume, and nature. During the spectrometric processes heterogeneity manifested in the form of large-scale traps, but their nature and coordinate distribution in the track remain undiagnosed. The obtained correlation of the effective dimensions of in homogeneities and their spectrometric characteristics of the detectors is not investigated on the working conditions of detectors with orthogonal field.

Investigation of various defects in semiconductors and having the ability to control their concentrations carry fundamental importance in the development of high quality semiconductor strip detectors with orthogonal field and with large amounts of sensitive area, as these characteristics ultimately determine the coordinate and computing spectrometric characteristics of these devices.

Material and methods

Si (Li) p-i-n structure was made by us on the basis of single-crystal silicon wafer of p-type with initial parameters: the resistivity $\rho = 5000\Omega$.cm, the lifetime of the charge carriers $\tau = 300$ µs. After some chemical-technological operations on plates the diffusion of lithium to one of its sides were carried out in vacuum at a temperature $T = 450^0$C at a depth of 300 µm. After that, to compensate for the entire thickness of the plate, the drift of lithium ions in the entire thickness of the plate was carried out. The process of drift conducted at a temperature $T = 80 \div 100^0$C, the reverse bias voltage 60-300V for obtaining the compensated *i*-region. The thickness of the *i*-region is 6 mm. After the process of drift, the plate cut rectangular shape, then the diffusion (n+) region erupted with wire saw with diameter of $(100 \div 300)$ µm. As a result of extended operation, a groove with depth $(0.4 \div 0.6)$ mm and a width of 200 µm at a distance of $(0.4 \div 1)$ mm apart was obtained. Then a number of chemical-engineering operations were held. By using a mask, Al and Au contacts were deposited on each strip.

Results and discussion

For large size SCD particular importance is the flatness of the *p-n* junction overall area of its sensitive surface, and the depth of the p-n barrier forming by diffusion method. This is due to the fact that on the one side the thickness of the diffusion region should be sufficiently thin (the "dead layer"), i.e. layer on which the energy loss of the charged particles in this layer do not contribute to the energy spectrum of the amplitude and on the other side the thickness should be enough thick to provide an effective *p-n* barrier. In order to ensure effective conditions for the formation of p-n barrier and one of the important radiometric parameters (of the "dead layer") of SCD–based on Si (Li) p-i-n structures, we carried out a study on the selection of the optimum thickness of the diffusion region after the end of the drift of lithium ions to the desired (set) thickness of Si (Li) p-i-n structure. On the lithium side, a layer with thickness of 120 microns was removed. The remaining layer of lithium determines the resistance of the diffusion layer from the detector parameters and conditions of diffusion. The calculated values were in good agreement with the measured values. Lithium side was probed with collimated source. It is shown that the lithium layer is homogeneous. Consequentially, there are analytical dependences of noise for signals that determine the energy and position of a particle from the parameters of the detector, the temperature resistance of the diffusion layer and constant of forming a continuous chain [3]:

$$\delta(E) = 7{,}2915 \times 10^{19} C \times \times \left[\frac{kTRe}{\tau}\left(1 + \frac{R}{48R_e}\right)\right]^{1/2} \frac{eV}{C}, \quad (1)$$

$$\delta(p) = 7{,}2915 \times 10^{19} \times \times \left[\frac{3kT\tau}{R}\left(1 + \frac{R_e}{R} + \frac{C^2 R_e R}{192\tau^2}\right)\right]^{1/2} \frac{eV}{C}, \quad (2)$$

where C is the capacitance of the detector – 25 pF, R – resistance of the resistive layer, R_e – equivalent noise resistance of the FET 200 Ohm, τ – time of the forming a chain – 0.25 μs, k –Boltzmann's constant, T is the temperature – 300 K. After substituting the values of the equation it can be rewritten as keV:

$$\delta(p) = 128{,}5 \left[\frac{1}{R}\left(1 + \frac{0{,}2}{R}\right)\right]^{1/2}, \quad (3)$$

$$\delta(E) = 3{,}5 \left[1 + \frac{R}{9{,}6}\right]^{1/2}, \quad (4)$$

where R is expressed in kilo Ohms. The contribution of the leakage current in the noise energy signal, at room temperature in the case of single differentiation-double integration pulse shaping, can be written as keV:

$$\delta(I) = 3{,}44[I\tau]^{1/2}, \quad (5)$$

where I – leakage current. The total noise of the energy signal from (4) and (5)

$$\delta(IE) = [\delta^2(E) + \delta^2(I)]^{1/2} \quad (6)$$

can be written from (6)

$$\delta(P) = \frac{\delta(P) \times L}{E}, \quad (7)$$

where L is the length between the contacts of the lithium layer, E – energy of particles.

In the manufacture of silicon strip detectors and we have measured the electrical characteristics of the spectrometer. Obtained by the proposed method detectors have the following typical parameters: a reverse bias voltage U_{rev} ~ 20 ÷ 200, dark current I ~ 0,1÷0,5 μA, the capacitance C ~ 25 pF, the noise energy E_n ~ 12-35 keV.

In most cases, the two types of measurements is the most significant: determination of the energy of the particles and their flow measurement. Sometimes it is necessary to register a group of particles of low intensity in the presence of a large number of other particles with very similar energies.

The energy resolution is measured by using a source of α^{226}Ra particles and β particles ^{207}Bi. Registration of amplitude spectra was carried out using a conventional spectrometer path. The energy resolution of detectors for α-particles is ^{226}Ra (E_α = 7,65MeV) R_α = 46 keV (Fig.2.) and for β-particles from the source of ^{207}Bi (E_β ~ 1 MeV) R_β ~ 18 keV (Fig.1 .) taken at T = 300 ° K.

Studies have shown that the shape and energy resolution for α and β particles are not significantly different from the area of the entrance and side window detectors.

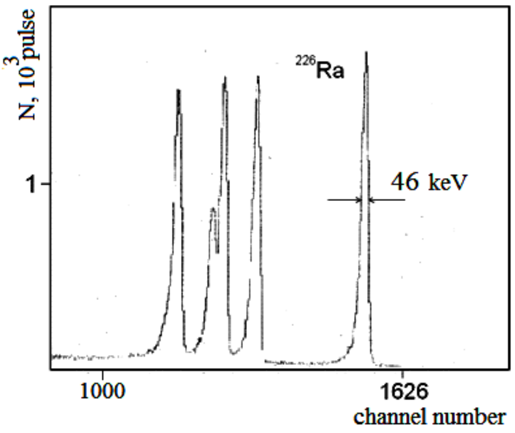

Figure 1 – The energy resolution of the detector or α-particles ^{226}Ra (E_α = 7,65MeV).

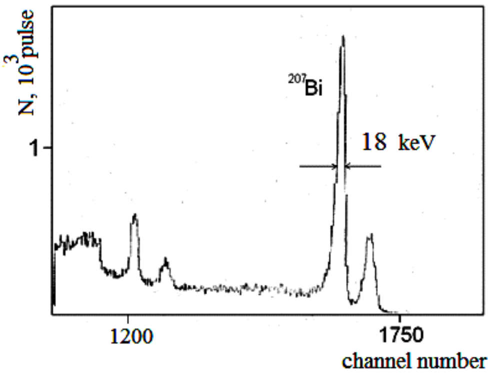

Figure 2 – The energy resolution of the detector for β-particles ^{207}Bi ($E_\beta \sim 1$ MeV)

Manufacturing process of Si (Li) strip detectors with large working area from the large-diameter silicon has their own characteristics. This is due to impurity in homogeneities, formation of dipole structures in places, acceptor impurity clusters and inhomogeneous distribution of the resistive layer in the large size silicon surface. All of these factors significantly alter the processes of diffusion and drift of lithium ions, and the choice of the resistive layer. However, it is necessary to solve a number of issues of technological and physical nature. These issues relate to the characteristics of the low-temperature diffusion of lithium to obtain a uniform resistive layer and also for the processes of diffusion and drift of lithium ions in large size silicon, optimizing the electrical and radiometric characteristics of each band and structures, and for matching electronics.

Conclusion

Consequently, research has shown that the detectors that was developed by us, can operate effectively with both perpendicular and parallel fall of the particles relative to electric field, and can be successfully applied to the detection of long charged particles.

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