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Double Sided Drift Method Reduces the Effect of Crystals' Inhomogeneity to Si(Li) Detector's Electro-Pysicsal Characteristics

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This work is devoted to find an optimal mode of double-sided drift of lithium ions into monocrystalline silicon in order to obtain large sized Si(Li) p-i-n structured detectors of X-ray radiation. As it was shown in the work the proposed method of obtaining large sized Si(Li) p-i-n structured detectors helps to reduse the effect of impurity inhomogeneities in the initial silicon crystal to detectors' electro-physical characteristics.

Keywords:- *Si(Li) Detectors; Double Sided Drift; Drift of Li ions; Large Sized Detectors.*

I. INTRODUCTION

A feature of soft γ and χ is considered to be radiation with E <120 keV. The allocation of this range is due to the peculiarities of registration and spectrometry of low-energy quantum radiation. Previously, the study of the spectral composition in this area was carried out by energy dispersion spectrometers – proportional and scintillation counters and devices with wave dispersion- spectra in which its reflection from a crystal is used to decompose radiation by wavelengths [1].

Spectrometers with proportional counters have a high efficiency in the range of 20-30 keV. Their resolution has almost reached the theoretically possible limit due to the statistical nature of the formation of charge carriers and is 1 keV for quanta with energy of 8 keV.

The use of a scintillation detector in spectrometry ensures high efficiency of radiation detection up to 120 keV.

However, as a result of the multi-stage process of converting the energy absorbed in the scintillator into an electric pulse, the energy resolution of the scintillation spectrometer is extremely wide and amounts to 3-4 keV for quanta with energy of 8 keV.

In the early 60s, a way was outlined to create a γ and χ radiation spectrometer with high resolution and recording efficiency [2] based on a semiconductor material. The combination of high registration efficiency with high energy resolution in this device is due to the high specific density of the detector material and the low energy required for the formation of a pair of charge carriers. If it is necessary to expend ~30 eV energy on the formation of a pair of charge carriers (ions) in a proportional counter for the formation of one photoelectron in the scintillation counter ~ 300 eV, then in the semiconductor detectors, energy of ~ 3 eV is spent on the formation of an electron-hole pair. This circumstance turned out to be decisive in the fact that a semiconductor detector is the main element in creating a spectrometer of soft X-ray and gamma radiation.

II. CHARACTERISTICS OF THE SEMICONDUCTOR MATERIAL.

The process of formation of a pair of charge carriers in the semiconductor detector during the absorption of X-ray radiation is similar to the formation of an electron-hole pair in a gas ionization chamber. In the absence of radiation, the direct current through the detector should be minimal so that its fluctuations do not affect the magnitude of the pulse caused by the radiation quantum. This means that the charge carriers should have a sufficiently large mobility and lifetime in the detector material, and the number of free carriers should be small.

These conditions are met by silicon p-i-n detectors manufactured by lithium drifting technology, which in essence is an inversely biased p-i-n diode with an i-region.

Like any semiconductor diode, the semiconductor detector has a reverse current, which consists mainly of a diffusion current, as well as a surface leakage current. In addition, the crystal lattice of the material contains impurities and defects introduced in a controlled and uncontrolled way. Many of them are traps of charge carriers, which reduce the effective lifetime of the latter.

Unlike scintillation counters, the semiconductor detector does not have an internal amplification mechanism and therefore the signal at its output is extremely small, which is why the electrical noise of the amplified path degrades the resolution of the spectrometer, especially at low quantum energies.

In addition, the semiconductor detector itself is a source of noise caused by fluctuations in the current flowing in its circuit. In lithium drifting detectors, the main components of the current are the generation current due to the generation of pairs in the sensitive volume of the detector under the influence of thermal vibrations of the lattice, and the surface leakage current, depending on the size of the detector surface, its structure of the applied voltage, etc. Poor quality of the semiconductor detector material, the presence of macro defects and the accumulation of inhomogeneities also increase the fluctuations of the leakage current and charge collection time and degrade resolution.

The influence of these factors on the resolution of the semiconductor detector and operational characteristics are discussed below.

The manufacturing technology of Si (Li)-p-i-n electromagnetic radiation detectors (E=100-300 keV) with a thin input window is determined by the requirement of manufacturing highly sensitive detectors that retain their characteristics for a long time.

III. DEFECTS OF DETECTOR SILICON

The source material for our study of detectors is a special Si going to their manufacture. It is necessary to dwell in detail on the parameters, defects in the structure and composition of the source material, since they are responsible for the shape of the spectral line, and ultimately for the energy resolution of the detector.

The use of silicon as a starting material for the semiconductor detector is primarily due to the ability to work at room temperatures and low sensitivity to the γ–background. The relatively large band gap in Si makes it possible to drastically reduce reverse currents in electron-hole junctions. The concentration of intrinsic charge carriers in Si at room temperature < 10^{10} cm-3, which corresponds to a resistivity of about 230 kOhm·cm. To obtain silicon of intrinsic conductivity, it is necessary to reduce the content of electrically active impurities to a concentration of 10^{10} cm-3.

In the currently available most pure silicon samples, the impurity content is two orders of magnitude higher than its own conductivity, and the lifetime of non-basic charge carriers reaches several milliseconds. It should be noted that no matter how silicon single crystals are obtained, they always have some defects in structure and composition. The conditional classification of defects in their size and physical nature, given in [3], is given in the table. According to the table, the following main types of structural and composition defects can be distinguished in Si: microdefects (empty spaces in the lattice nodes, nodes displaced from the equilibrium position, the presence of chemically foreign atoms in the nodes, etc.). macro defects (alien phase. cracks, shifts, gross violations of uniformity in the distribution of impurities, etc.), and defects of intermediate sizes (layering in the distribution of alloying impurities, Herring statically distributed inhomogeneities, which are much larger in size than the characteristic lengths in a semiconductor, but much smaller than the size of the sample itself [4]).

Consider the impurity inhomogeneity in Si, which is the most important indicator of the quality of a semiconductor material. The reasons causing the appearance of impurity bands can be divided into two main groups [5]: 1) the course of the crystallization process itself, regardless of external influences, and 2) the behavior of the crystallization front, set by the thermal asymmetry of the stretching system and temperature fluctuations in the melt. So, depending on the growing conditions, significant fluctuations in the nature and magnitude of the impurity inhomogeneity can be expected, with the strongest fluctuations of the crystallization front associated with rotation having the main influence. As measurements [6] have shown, the distance between the bands not associated with the rotation of the ingot or crucible is statistically distributed near the value characteristic of these growing conditions, which is reproduced within 10% in all areas of the ingot. This characteristic distance decreases more sharply at first and then more slowly as the pulling speed increases between the strips.

For ingots grown without rotation, the distance between the strips does not depend on the growth rate and the type of impurity and varies from 0.04 to 0.06 mm. In addition to the impurity heterogeneity, the properties of silicon are significantly affected by the accumulation of vacancies (vacancy clusters). The features of cluster distribution in Si single crystals obtained by various methods were studied in [7]. At the same time, the specificity of etching pits caused by clusters is a flat bottom, and their geometry is determined by the crystallographic orientation of the plane under study. There are four types of cluster distribution: uniform, spiral ring, ring and striped. As it turned out, the concentration of clusters is sensitive to the method of obtaining Si single crystals, so in single crystals obtained by the method of floating zone method, the concentration of clusters was 10^{-4} - 10^{-6} cm^{-3}, and in the crystal obtained by the Czokhralski method 3 – $5*10^{10}$ cm^{-3} [7].

In addition, it was found [7] that the nature of the dopant with a concentration of $5 \cdot 10^{17}$ cm^{-3} has little effect on the pattern of cluster distribution. Since vacancy clusters usually appear in the cross-section of the ingot in the form of spiral formations, they are also called swirl defects.

Currently, by analogy with vacancy clusters, there are two types of defects in Si, forming a swirl pattern: 1) large pits -A-defects and 2) local - B- defects. Electron microscopy made it possible to establish the microscopic nature of the swirl defects. As studies have shown, A-defect is a dislocation loop or a cluster of dislocation loops. According to [7], in pure Si, quarrelsome loops are formed when embedded silicon atoms combine, which at temperatures close to melting temperatures are in equilibrium with the lattice. As for type B defects, their exact nature of formation is still unknown. The accumulation of these defects, under certain conditions, transforms into defects of type A. The latter are formed at a certain critical value of the growth rate.

Thus, the presence of various kinds of inhomogeneities in the Si source material requires a more detailed study not only of their physical nature, but also of the possibility of monitoring and controlling the concentration of these inhomogeneities, since they ultimately determine the main counting-spectrometric characteristics of the semiconductor detector.

Here are the main features of the manufacturing process of Si(Li) detectors: 1) the choice of the configuration of the T-shaped plates [8] makes it possible to obtain a thin entrance window of the detector, and at the same time enclose the surface of the p-i-n junction in a sealed housing; 2) the design dimensions of the T-shaped plate are selected taking into account the physical processes occurring in the n, p and i regions; 3) the width of the p-type ring and its height are selected depending on the detector design and the quality of the initial Si; 4) the height of the p-ring h should be minimal, because the larger h, the larger the surface of the negative collecting electrode of the detector and the greater the value of the field strength along the perimeter of the i-region differs from the homogeneous field in the center of the sensitive area. The requirement of mechanical strength limits the h value from below [8]. In case of the need for long-term storage and operation of detectors, it should be borne in mind the high mobility of lithium even at room temperature.

To avoid the detrimental effects on the spectrometric characteristics of a large detector of the above defects in the crystal and various complex formations, our group proposed the method of double sided diffusion and drift of lithium ions into a silicon single crystal [8, 9]. Previously, we published a paper on the optimal mode of double sided diffusion of lithium atoms into a silicon single crystal [8, 9]. As the experiment showed, the process of double sided diffusion and drift of lithium ions reduces the time for manufacturing detectors by up to four times, and helps to avoid problems with defects in the crystal. In this paper, we want to talk about the optimal mode of lithium ion drift into a silicon single crystal for fabricating large Si(Li) detectors.

One of the final processes for making a detector is the drift process. Also, perhaps the drift process is the most important and longest part of the process. Therefore, finding the optimal drift mode is a very important part in the manufacture of detectors.

IV. METHODOLOGY

As is known, the following factors are the most important for the manufacture of radiation detectors: 1) the choice of the initial crystal; 2) ensuring plane parallelism of the surface of the original crystal with the help of technological processing of the crystal; 3) the process of carrying out the diffusion of lithium atoms into a silicon crystal; 4) carrying out the drift of lithium ions into a silicon single crystal.

Previously, in [8, 9], we described in detail the double-sided technology for manufacturing a Si(Li) p-i-n structured detector of large dimensions. In this paper, we will focus on finding the optimal regime for the double sided drift of lithium ions.

In the current work as an initial crystal, it was taken dislocation-free p-type monocrystalline silicon grown by Czochralski method. The crystal has the following characteristics: its initial diameter was 100 mm, a resistivity - 10-12 Ohm*cm and a lifetime more than 50 μs. The silicon mono crystal grown Czochralski method has a high degree of LiO complex formation, and this generally has a bad effect on the stability of the detection spectrum of the detectors. Application of

V. RESULTS.

Below we present the results of an experiment. Our results show that the optimal regime for the double sided drift process is: temperature T = 90 – 120 ° C and the voltage U = (150 – 600) V. By choosing the optimum values of the reverse bias voltage and the drift temperature, it is possible to achieve the maximum degree of compensation, which is characterized by the volume charge in intrinsic region (i-region) of the p-i-n structures. Figure 1 shows the experimental I- V characteristics of large sized Si(Li) detectors during the drift process in 100 – 400 hours period of time.

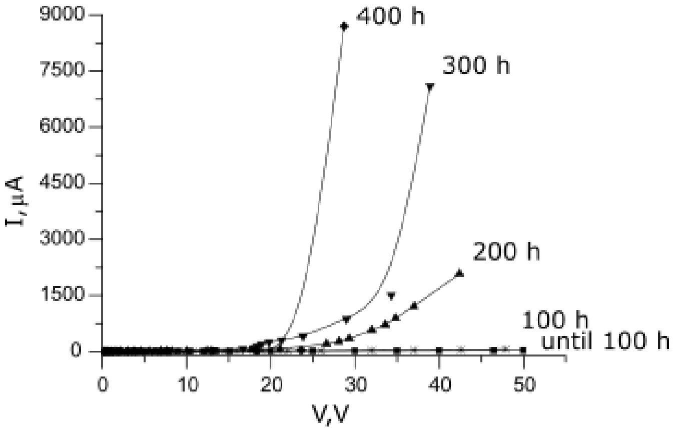

Fig. 1:- I- V characteristics of large sized Si(Li) detectors during the drift process in 100 – 400 hours period of time.

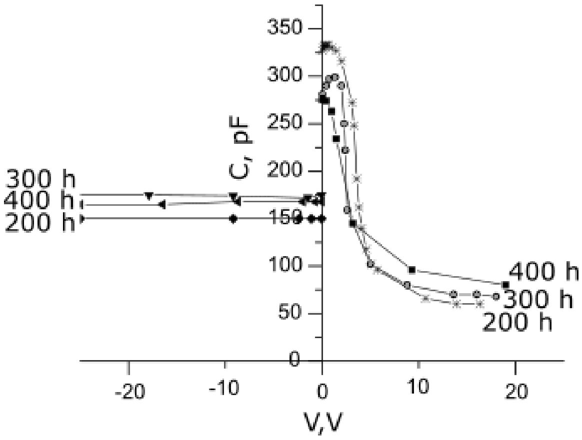

Fig. 2:- C-V characteristic large sized Si(Li) detectors during the drift process in 100 – 400 hours period of time, at a frequency f=1 MHz

The mono crystal grown by Czochralski has a high degree of LiO complex formation, and this generally has a negative effect on the stability of the detection of the detectors. Despite this, from the I- V and C – V characteristics (Fig. 1; Fig. 2) of large sized Si(Li) detectors during the drift process it can be seen that the value of inverse current and capacitance of the detector is much low than that of detectors obtained by the traditional method [10]. This proves that under the optimal mode of drift of lithium ions into a single crystal of silicon, the detectors have a better spectral characteristic, i.e., the method of double-sided diffusion and drift reduces the effect of various complex formations in the body of the crystal to the electro- physical characteristics of the crystal.

VI. CONCLUSION

The findings of this paper may be useful to developers of Si(Li) radiation detectors of large size. Because obtaining Si(Li) p-i-n structures with a large area is associated with a certain complexity. As one of the solutions of these problems we offer here new technology of obtaining these detectors and provide optimal regimes of it.

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