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**ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫНЫҢ**

# БАЯНДАМАЛАРЫ

# ДОКЛАДЫ

**НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК**
**РЕСПУБЛИКИ КАЗАХСТАН**

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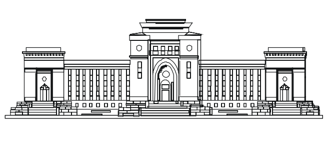

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# PHYSICAL FEATURES OF FORMATION OF SILICON p-i-n DETECTOR STRUCTURES

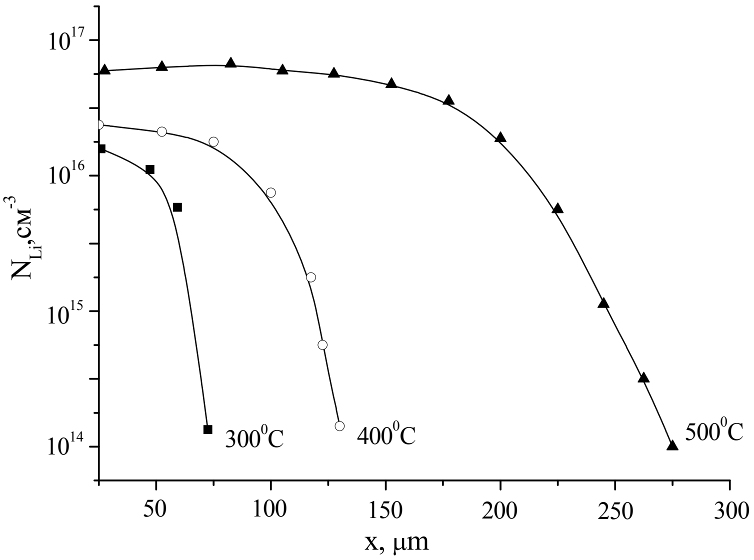
**Abstract.** This paper presents the results of studies of the physical processes of diffusion and drift of lithium ions to form a silicon detector p-i-n structures of large volumes. It is illustrated the dependence of the diffusion profile of lithium in silicon. The theoretical expression for the thickness compensated field depending on the temperature-time mode drift was derived. It is considered the method of formation of p-i-n structures based on silicon.

**Key words:** silicon detectors, silicon detectors of large size, semiconductor detectors of p-i-n structure, coordinate sensitive detectors, strip detectors of radioactive radiation.

It is well known, that the development of semiconductor materials discovered opportunities of development of semiconductor detectors of nuclear radiation for various purposes. Among the nuclear radiation detectors, based on semiconductor crystals, special place occupy a silicon-lithium detectors [1-3]. Additionally, registration of various types of radiation (ionizing) continues to be a special challenge of modern science and technology development, thus their practical application. Among them, a special place occupied by the development of semiconductor detectors (SCD) of nuclear radiation with high energy and position resolution, linearity of the signal over a wide energy range for various types of ionizing particles [4-5]. The development of semiconductor devices, microelectronics is based on the introduction to the volume of the semiconductor crystal impurity atoms to a predetermined depth, and the desired concentration.

The successful solution of the task of building of high-performance Si (Li) detectors of nuclear radiation of large areas and the extent of sensitive area depends on a proper understanding of the properties of the original crystal of large diameter, and their physical connection to the performance of the detector. This requires a better understanding of the properties of the original crystal and establish their role in the formation of high-performance detector structures such as p-n, p-i-n junctions. A widespread method of administration (doping) of an impurity atom in the crystal volume, based on the diffusion process, etc, on the surface of the semiconductor chip must create a "reservoir" alloyed impurity atom and subsequently to conduct diffusion and drift at certain high temperatures.

For diffusion processes of the SCD of large size (> 50 mm W> 2 mm), we have optimized the process conditions and temperature regimes of the process of diffusion. The diffusion of lithium is carried out under vacuum. Diffusion of lithium, heated at 300 - 500 0C silicon platinum, carried in the vacuum chamber at a pressure of $10^{-5}$ Torr. It is should be noted, that these conditions and modes determined according to the type of SCD with respect to their surface dimensions of the sensitive area and length (thickness). Diffusion temperature is selected depending on the resistance of the initial material, on condition that the lithium surface concentration has to be much greater than the initial concentration of acceptor in the silicon Na, etc. $N_{Li} >> N_A$ (on the order of two or more), because the surface concentration defines from the marginal solubility, depending on the temperature.




The diffusion profile of lithium in silicon grown
by floating zone melting method at T = 500 ° C; T = 400 ° C; and T = 300 ° C for t = 60 sec.

Tolerance of temperature during the diffusion is determined by the relation:

$$1-\frac{N_A}{N_S}=erf\,\frac{d}{2\sqrt{Dt}}$$

where Ns – surface concentration; d – depth of diffusion; D – diffusion coefficient; t – diffusion time.

When the selection of the diffusion it is must to be considered what diffusion parameters (diffusion depth d, the surface concentration Ns) must be obtained. For obtaining a large surface concentration, a higher temperature is required. In the Figure 1. diffusion profile in silicon samples obtained by means of floating zone melting is presented. The diffusion of lithium is conducted under vacuum (≈$10^{-5}$ mm. Hg) at T = 500 º C T = 400 $^0$C and T = 300 ° C for t = 60 sec. Considering the high rate of diffusion of lithium ions at m d≤100, it is very difficult to ensure reproducibility of the diffusion at high temperatures. Therefore, the diffusion mode is selected for each type of SCD device.

The method of Compensation of semiconductor by impurity ions, was first proposed by Pell [6]. Despite the seeming simplicity of the method of the drift (to the reverse shifted field n + -p junction, the lithium ions is drowned from the reservoir in a concentration of $N_{Li}≈N_A$), getting well compensated field of large volume is quite challenging. This is mainly due to factors such as: the effect of thermally generated free charge carriers, the presence of local inhomogeneities in the distribution of the concentration of acceptors in silicon source, capture drifting lithium ions for various traps and the formation of complexes with oxygen. Therefore, mobility, hence, the lithium diffusion coefficient D obtained in silicon abnormally large, i.e. $10^7$ times higher than that in conventional elements that provide the donor levels in silicon. However, the lithium diffusion coefficient depends on the concentration of oxygen in silicon, as diffusing in the crystal lattice, lithium compounds with oxygen in the form of a complex $LiO_2$ and can easily move on only after the thermal decomposition of compounds. This complicates the drift, since the oxygen content in the silicon reaches $10^{18}$ cm$^3$. Therefore, for the manufacture of semiconductor detectors, usually uses silicon with a minimum concentration of oxygen ($10^{15}$–$10^{16}$ cm$^{-3}$).

An important parameter, to be controlled, in the process of the drift is compensated depth of field W. If we assume that W> $W_0$, where $W_0$ - initial thickness of the p- n junction after the diffusion, and the temperature T and drift voltage $V_{др}$ applied to the sample are unchanged, then in terms of compensating flow of lithium ions carried in unit time is $\rho\mu_T E_x$. It creates the compensation, so the speed of movement of lithium ions $v_x=\mu_T E_x$ will determine by the change in the thickness of the junction.

$$\frac{dW}{dt} = \mu_T \frac{V_{\partial p}}{W}$$

From this

$$W_2^2 - W_1^2 = 2\mu_T V_{\partial p}\left(t_2 - t_1\right)$$

By this way the expression for the thickness of the compensated region, depending on the temperature and time drift mode was obtained:

$$\Delta W = \sqrt{2\mu_{Li} V_{\partial p} \Delta t}$$

So, the depth compensation is independent from the distant resistivity of the initial silicon.

The drift of lithium ions was carried out on specially designed and manufactured drift unit. The voltage was applied to each crystal independently, and directly, controlled during the drift. Temperature range of lithium drift (essential for detectors with a predetermined value of "output window"), which allows to calculate the "blurring" of the concentration profile of lithium in silicon during the drift and select the optimum temperature at which the blur profile and thus increasing in the thickness of "exit window" is minimal. In connection with this drift mode is selected as follows: the temperature – $T_{др}$=70-100°C, a bias voltage 100-400 V, depending on the magnitude of leakage current on each chip (Table). In this way, it is creates the conditions of high temperature and high electric field of the p-n junction, and the lithium ions are moved to the p-region, compensating the space charge acceptor which leads to a redistribution of the electric field. As the result it is creates equal concentrations of lithium ions and acceptors, therefore, the electric field in this region is reduced. As the applied external voltage remains constant, the lithium ions continue to penetrate in the p-region.

Table 1

| t, $^0$C | 70 | 70 | 75 | 80 | 90 | 100 | 100 | 100 | 90 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|
| U, B | 100 | 100 | 200 | 200 | 300 | 300 | 400 | 400 | 200 | 200 |
| t, h | 25 | 50 | 50 | 75 | 75 | 100 | 100 | 200 | 200 | 250 |

By this way, the results of studies on the role of oxygen content in the bulk of silicon is very important for detectors on the larger crystals with high performance, in particular: the thermal spraying, the surface layer of diffusing material needed heating of the silicon wafer to a certain temperature; compensation process sensitive area by SCD drift of lithium ions should be carried out stepwise by changing the offset voltage drift over time.

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## КРЕМНИЙЛІ p-i-n ДЕТЕКТОРЛЫҚ ҚҰРЫЛЫМДАРДЫҢ ҚАЛЫПТАСУЫНЫҢ ФИЗИКАЛЫҚ ЕРЕКШЕЛІКТЕРІ

**Аннотация.** Жұмыста литий иондарының диффузия және дрейф құбылыстарының p-i-n құрылымды, үлкен өлшемді кремний литийлі детекторлардың қалыптасуының физикалық қасиеттерінің зертеу нәтижелері көрсетілген. Литийдің кремнийге диффузиялық профилінің тәуелділігі алынған. Жасалу және қалыптасу технологиялары қарастырылған. Теориялық түрде компенсацияланатын ауданың қалыңдығының дрейфтің температура-уақыттық режиміне тәуелділік формуласы қарастырылған. Кремнийдің негізінде p-i-n детекторлардың қалыптасу методикасы қарастырылған.

**Түйін сөздер:** кремнийлі детекторлар, үлкен өлшемді кремнийлі детекторлар, p-i-n құрылымды кремнийлі детекторлар, координатты сезгіз детекторлар, радиациялық сулеленулің жолақ детекторлары.

**А. К. Саймбетов, Н. М. Джапашов, Н. К. Сисенов, Н. Б. Куттыбай,
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## ФИЗИЧЕСКИЕ ОСОБЕННОСТИ ФОРМИРОВАНИЯ КРЕМНИЕВЫХ p-i-n ДЕТЕКТОРНЫХ СТРУКТУР

**Аннотация.** В работе представлены результаты исследований физических процессов диффузии и дрейфа ионов лития для формирования кремниевых детекторных p-i-n структур больших объёмов. Получены зависимости диффузионного профиля лития в кремнии. Теоретический выведена выражение для толщины компенсируемой области в зависимости от температурно-временного режима дрейфа. Рассмотрена методика формирования p-i-n структур на основе кремния.

**Ключевые слова:** кремниевые детекторы, кремниевые детекторы больших размеров, кремниевые детекторы p-i-n структуры, координатно-чувствительные детекторы, стриповые детекторы радиационного излучения.

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