R. A. Muminov, S. A. Radzhapov, Y. Q. Toshmurodov, B. S. Radzhapov, Coordinate-sensitive detectors of ionizing radiation on the basis of the Si (Li) $p-i-n$ large-dimension structures, *Comp. nanotechnol.*, 2017, Issue 3, 29–32

4.2. COORDINATE-SENSITIVE DETECTORS OF IONIZING RADIATION ON THE BASIS OF THE Si (Li) p-i-n LARGE-DIMENSION STRUCTURES

Muminov Ramizulla Abdullaevich, doctor of sciences, academic, Physical-technical Institute SPA «Physics-Sun», Academy of Sciences of Uzbekistan, e-mail: detector@uzsci.net

Radzhapov Sali Ashirovich, doctor of sciences, Physical-technical Institute, SPA «Physics-Sun» Academy of Sciences of Uzbekistan, e-mail: detector@uzsci.net

Toshmurodov Yorkin Kaxramonovich, PhD student, Physical-technical Institute, SPA «Physics-Sun» Academy of Sciences of Uzbekistan, e-mail: detector@uzsci.net

Radzhapov Begjan Salievich, PhD student, Physical-technical Institute, SPA «Physics-Sun» Academy of Sciences of Uzbekistan, e-mail: detector@uzsci.net

Abstract: The results of development and optimization of the production technology of large- size semiconductor position-sensitive X-ray detectors, based on Si(Li)-p-i-n structures have been reported. The authors investigated the electro-physical and radiometric characteristics of large-size semiconductor detectors.

Index terms: semiconductor position-sensitive detector, current-voltage, the capacitance-voltage, noise-voltage spectrometric characteristics.

КООРДИНАТНО-ЧУВСТВИТЕЛЬНЫЕ ДЕТЕКТОРЫ ИОНИЗИРУЮЩЕГО ИЗЛУЧЕНИЯ НА ОСНОВЕ Si(Li) p-i-n СТРУКТУР БОЛЬШИХ РАЗМЕРОВ

Муминов Рамизулла Абдуллаевич, д-р физ.-мат. наук, академик, Физико-технический институт НПО «Физика-Солнце» АН РУз, e-mail: detector@uzsci.net

Раджапов Сали Аширович, д-р физ.-мат. наук, Физико-технический институт НПО «Физика-Солнце» АН РУз, e-mail: detector@uzsci.net

Тошмуродов Ёркин Кахрамонович, аспирант, Физико-технический институт НПО «Физика-Солнце» АН РУз, e-mail: detector@uzsci.net

Раджапов Бегжан Солиевич, аспирант, Физико-технический институт НПО «Физика-Солнце» АН РУз, e-mail: detector@uzsci.net

Аннотация: В данной работе представлена оптимизация технологии изготовления полупроводниковых координатно-чувствительных детекторов рентгеновского излучения большого размера на основе Si(Li) p-i-n – структуры и исследованы электрофизические и радиометрические характеристики.

Ключевые слова: полупроводниковый координатно-чувствительный детектор, вольтамперные, вольтфарадные, вольтшумовые и спектрометрические характеристики.

Semiconductor coordinate-sensitive detectors of ionizing radiation that determine simultaneously the energy and coordinate of incoming particles play a special role in the precision nuclear spectrometry. They may also find application in medicine, particularly in medical tomography.

Production of semiconductor detectors of nuclear radiation for medical purposes, i.e. for tomographic systems requires precise physical processes and conditions. Meanwhile, such systems use low-energy X-rays to generate electron-hole pairs in semiconductor detector sensitive area. Energy (Eg) varies in the range of <200-300 eV. Such energy represents the highest possible values and practically reflects largely confined performance of a large array of detectors based on semiconductors. In order to meet the above conditions related to extending the energy resolution of detectors it is necessary to create certain physical conditions to ensure the highest possible collection of charge carriers generated in the result of the loss of photon energy of X-rays. In addition, these conditions must ensure stable performance at any point of sensitive area of the detector and the detector itself must be a coordinate-sensitive one.

This paper reports physical and technological steps in the process of manufacturing of large-size Si (Li) detectors of nuclear radiation (Ø≥60 mm, W = 4 mm). A new technique of lithium ions drift while the sample being exposed to the impulse electric field, is shortly applied for the formation of Si (Li) structures [4-7].

To obtain Si (Li) p-i-n structures we used wafers (diameter ~60 mm and thickness of 4-5 mm) of commercial p-type silicon with a resistivity of $\rho = 1 \div 5$ kΩ, lifetime of carriers $\tau \geq 500$ microseconds and the oxygen concentration $N_{O_2} \sim 10^{16}$sm^3 cut. Diffusion of lithium was done on one of side of the wafers in vacuum (~10^{-5} m of mercury column) at temperature $T_{diff} = 480^0$C onto depth of $520 \div 550$ microns for about 1.5 minute, whereas the similar process was carried out in the other side of the wafer.

Results of scientific-technological data.

Summarizing the above mentioned we have developed a technological route for the Fig.1. development of radiation detectors of large size, in particular:

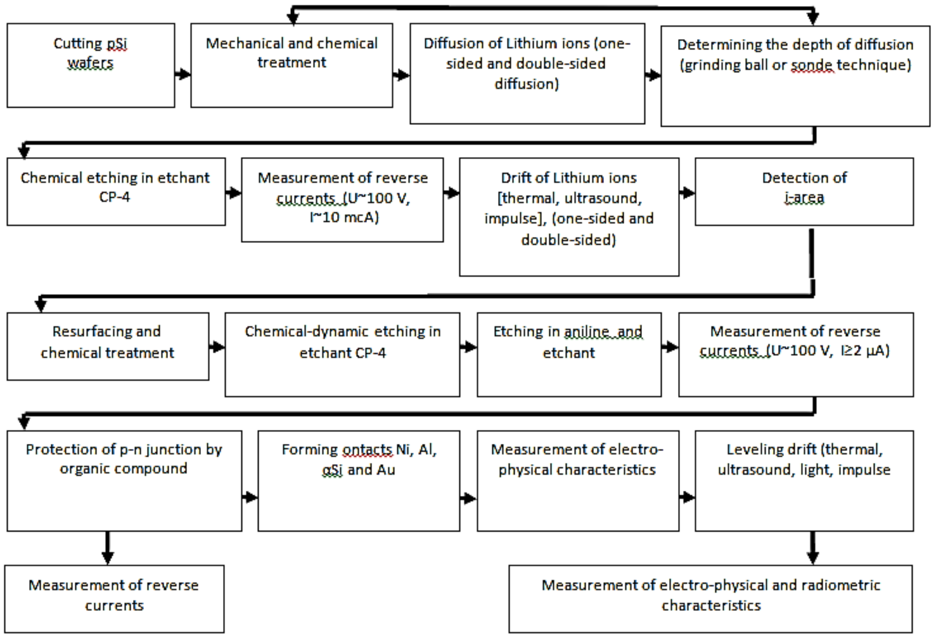


Fig. 1. Technological route of the development of Si (Li) detectors.

1. Dynamic rotational methods of etching of silicon wafers up to 110 mm developed to ensure their flatness and parallel to ± 1 ÷ 2%.

2. Methods for lithium diffusion on monocrystalline silicon wafers of large size developed that provide a sharp drop in the distribution of their concentration after a certain pre-set depth of penetration is reached.

3. Multi-stage drift process of lithium ions onto silicon wafers with diameters up to 110 mm to ensure high uniformity of compensation of sensitive area of the detector developed.

4. Scientifically-based methods of acoustically stimulated processes to optimize the performance of lithium-silicon radiation detectors with a large area of the sensitive area have been developed.

5. Highly efficient silicon lithium detectors each with an area of not less than 60 cm^2 with the following parameters: $U_{reverse}$ ≈ 50-200V, dark current I_{dark} ≈ 1 ÷ 4 mA, the capacitance C = 200 ÷ 1000 nF, detection efficiency 30 ÷ 35%, noise factor En ≈ 30 ÷ 50 keV, energy resolution as per ЭВК ^{207}Bi, R_{β}=40÷90 keV, have been manufactured.

Following the chemical-technological operations, both sides of the wafer got T-shaped n^+-p-n^+ structure. Further, a process of drift of lithium ions in a strictly rectangular impulse electric field at temperature T = 80-85ºC was conducted in n^+-p-n^+ structures. Duration of the amplitude of the pulse was 7 seconds, the value of the amplitude of the pulse was 500 Volts, and pulse period was 14 seconds, whereas the duration of the front of increase and decay of the pulse did not exceed 2÷3 microseconds. Temperature mode and the electric field impulse were controlled by a special electronic unit.

Comparative performance characteristics of the Si (Li) detectors obtained by applying conventional technique and the one proposed by us are shown in Table 1.1.

Table 1.1

Comparative parameters of detectors

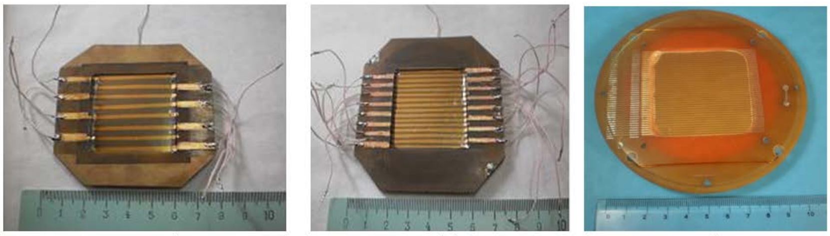
Parameter	The proposed technique	Conventional technique
Duration, compensation, hour	~250	~360÷400
Diameter of sensitive areas, mm	60	60
Thickness of sensitive areas, mm	4	4
The highest and lowest operating voltage, V	100÷600	250÷600
Background current, microampere	1,2÷1,8	1,8÷2,0
Capacity, pF	150÷220	130÷250
Energy equivalent of noise, keV	22÷25	30÷35
Energy resolution: keV		
for α-particles of ^{238}Pu with energy E_{α}=5,5 MeV	48÷60	62÷70
for β-particles of ^{207}Bi with E_{β}=1 MeV	35÷38	40÷42

We have proposed and further conducted a study of the impact of impulse electric field on the aligning drift (AD) of lithium ions.

«AD» in impulse electric field ensures that negative effects of drift stemming from traditional techniques (high temperature and high voltage values of the electric field) are virtually eliminated. This in turn brings forward the possibility to develop high quality Si (Li) p-i-n detectors in the shortest possible time-span with extended operating area surface [8].

Following the study and respective technological activities, we have been able to develop the technology for manufacturing semiconductor coordinate-sensitive detectors (SC-SD) based on large-size Si (Li) p-i-n detectors with 8, 16 and 32 stripes (Fig.2. a, b, c) for X-ray and tomography.

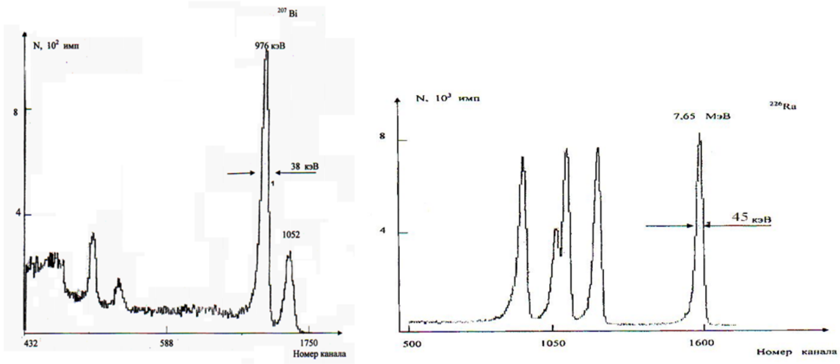
Fig. 2 illustrates the general view of semiconductor coordinate-sensitive detectors (SC-SD) – 8 (SC-SD) – 16 (SC-SD) – 32 [2].



a) b) c)

Fig. 2. General view of the semiconductor coordinate-sensitive detectors based on Si (Li) p-i-n structures.

a) (SC-SD) – 8 b) (SC-SD) – 16 c) SC-SD) – 32



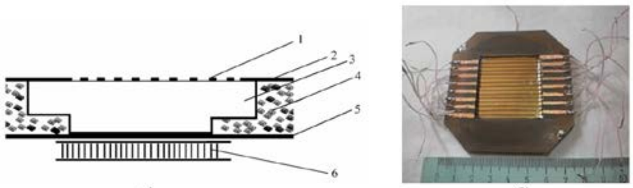
a) b)

Fig.3. Energy spectra of Si(Li) p-i-n detector (Ø=60mm W_i=4 mm).

a) for β-particles of ^{207}Bi (E_β~1 MeV); b) for α-particles of ^{226}Ra (E_α=7,65 MeV).

The developed SC-SD at temperature T = 300 K and operating voltage $U_{обр}$ = (200-600) have the dark current of I = 1,5-4,5 microampere, the capacitance C = 150 pF, and the noise $E_ш$=22-28 keV. The energy resolution as per ^{226} Ra_α= 33-46keV. On Fig.2 (1 element) at operating voltage of $U_{обр}$= 300V has dark current value I = 0,2 – 0,6 microampere, the capacitance of C = 40 pF, and noise E_n = 9-12 keV. The energy resolution as per ^{226} Ra_α= 14-18 keV with energy E_α = 7.65 MeV account (0.2-0.4)%.

On Fig. 4 semiconductor coordinate-sensitive detectors based on Si (Li) p-i-n structures of large size with thermally-cooled device are shown.



a) б)

Fig. 4 semiconductor coordinate-sensitive detectors based on Si (Li) p-i-n structures of large size with thermally-cooled device:

a) SC-SD; 1 – stripes of Au (contacts), 2 –insulator from special material ghetenaks, 3 – Si(Li) p-i-n structures, 4 – compound EKLB – 10, 5 – metallic layer, 6 – thermal-cooling device (Pelletier module),

b) general view of SC-SD – 16

The developed SC-SD-16 (16 elements) at temperature T = 240K and operating voltage $U_{обр}$= = (100-800)V have dark current I = 50-80 nA, the capacitance C = 220 pF, and noise E_n= 0.8-1 keV. Energy resolution as per ^{241}Am R= 2,3-2,6 кэВ (1 element); with operating voltage $U_{обр}$ = 200V has dark current I = 2-4 nA, the capacitance C = 50 pF, and noise E_n= 0.3-0.5 keV. The energy resolution for ^{241}Am R = 1,1-1,3. [7].

The current-voltage characteristics. On Fig. 5 the dependence of the leakage current on the voltage for stripes with minimum and a maximum value of I_{leak} 8-line detector with a T-shaped section. In the interval between these two curves the average median curve of I_{rev} for all 8 lines is shown. The area of one strip is 40 × 1,5 mm^2. The dispersion of values of I_{rev} across all lines is insignificant which is symbolic of uniform chemical treatment of all stripes. However, absolute values of I_{leak} are large. These types of detectors had separating sections' width of ~550 microns and subsequent etching at such groove width allowed to completely remove more drastic deformations induced as the result of such etching. Therefore, the current-voltage characteristics of all stripes are characterized by generation component of the leakage current. By increasing the width of strip up to 800 microns, we have witnessed dramatic improvement of the current-voltage characteristics (Fig. 4, curve 4 with an extended plateau up to 200 V). In the case of strips stretched along the width of the wafer for the same area, we got 16 lines, size 40 × 1,5 mm^2, each. The leakage currents of such detectors would decrease (Fig. 5 b). Meanwhile, I_{leak} variation would increase from strip to strip.

Planar detectors size 50 × 1,5 × 4 mm^3 were divided into 8 or 16 strips, 400 mm wide each. The value of leakage current for strip line S_n= 50 × 1,5 mm^2 or S_n= 55 × 1,5 mm^2 equals to 5.3 microampere at U = 100 B. Spread of values of I_{leak} across the strips in this case was 5% (Fig. 5, curve 1). Since it is necessary to obtain elements of discrete detectors, i.e. in our case strips with the identical values of I_{leak}, the planar technology for manufacturing detectors is applicable. The spread of values of I_{leak} across strips for detectors with a T-shaped cross-section is also negligible (curve 3, Fig .5). However, absolute values of I_{leak} are large.

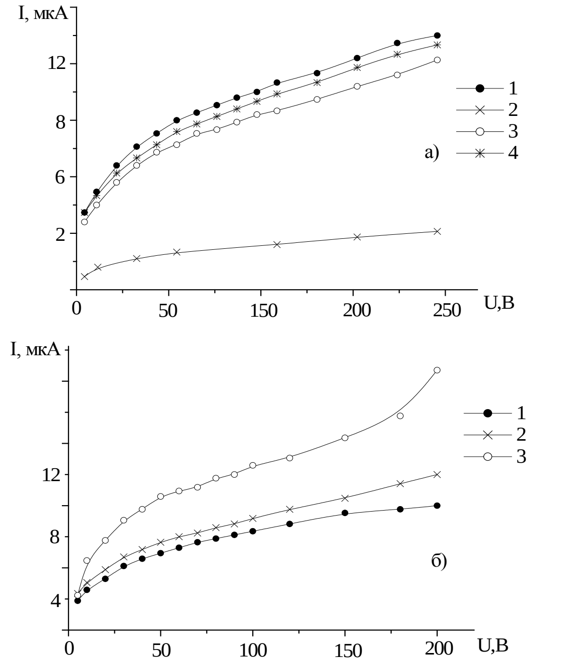


Fig.5. Leakage currents of multi-stripped discrete SC-SD:

а) 8- strip for: 1 strip with highest values of I_{leak}; 2 – strips with the dividing grooves width of 400 microns; 3 strips with the lowest possible values of I_{leak}; 4 the average median values of I_{leak} of all strip lines.

б) 16- strip for: 1 strip with highest possible values of I_{leak}; 2 the average median values of I_{leak} of all strip lines; 3 strips with the lowest possible values of I_{leak}.

Volt-capacitance characteristics. Volt-capacitance characteristic of strips of all types of the studied detectors evidence satisfactory level of compensation achieved in the process of drift of lithium ions by using new impulse technique. Curves c = f (U), (Figure 6) come on plateau already at a reverse bias of 20 ÷ 25 V, that is symbolic of a fairly sharp n-p junction and a small length of overcompensation area near the n-contact of the Si (Li) p-i-n structure.

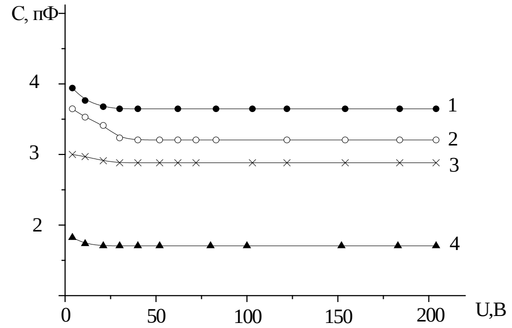


Fig.6. Electrical capacitance as a function of bias voltage for:

1 and 2-strips with highest and lowest values of 8-strip detector,

3 and 4-strip with lowest and highest values of 16-strip detector

Volt-noise characteristic. On Figure 6 the average quadrate value of the power noise as a function of the bias voltage is presented for detectors with different width of separation grooves. When the width of the groove is ~150 microns, noise increases consonant to the increase of the reverse bias voltage (Curve 1), which is associated with the generation component in the leakage current for this type of strip detectors. For detectors with width of the groove ~800 microns the dependence E_n=f(U) is nearly constant and noises do not grow up to the values U = 100V.

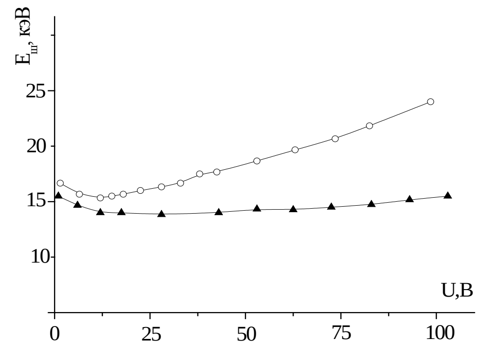


Fig.7. the average quadrate value of the power noise as a function of the bias voltage for:

--▲—discrete SC-SD (groove width 450 microns),

--o—8 strip rectangular SC-CD with polished windows.

Thus, following the study and respective technological activities, we have been able to develop and optimize the technology for manufacturing semiconductor coordinate-sensitive detectors (SC-SD) based on large-size Si (Li) p-i-n structures. Besides, we have been able to optimize the required process conditions, determine diffusion modes and drift of lithium ions, studied electrical and radiometric characteristics of the SC-SD manufactured at room temperature and thermal cooling devices (Pelletier module).

We have developed and designed SC-SD-8, SC-SD-16 and SC-SD-32 of large size (50x50x4) mm with thermal cooling unit that will improve electrical and radiometric characteristics of the detecting unit of tomography systems.

Список литературы:

1. Akimov Yu.K. Silicon radiation detectors. // NET. – 2007. – V1. – pg. 5-34.

2. Muminov R.A., Radzhapov S.A., Toshmurodov Yo.K., Bekbaev S., Kurmantaev A., Saymbetov A.K. Development and production of position-sensitive detectors of large // 8th International scientific conference «Recent advances in fundamental physics and physical education», Almaty, Kazakhstan 9 – October 11, 2013 pp. 186-187.

3. Muminov R.A., Radzhapov S.A., Toshmurodov Yo.K., Risalieva Sh., Bekbaev S. Semiconductor position-sensitive detectors larger с thermo device // 9th International Conference on Nuclear and Radiation Physics 24-27 September 2013, Almaty, Kazakhstan. str.114-115.

4. R.A. Muminov, S.A. Radzhapov and N.A. Sagyndykov A low-background β-ray spectrometer with composite detecting modules // Instruments and Experimental Techiques.- New York , Vol. 48, №. 1, 2005, pp. 41-42.

5. R.A. Muminov, S.A. Radzhapov, N.A. Sagyndykov and K.M. Nurbaev Salient feartures of the fabrication of Si(Li) detectors with a large-volume working region // Atomic Energy. – New York, Vol. 98, №. 1, 2005, pp. 69-71.

6. S.A. Radzhapov A Versatile Spectrometer Based on a Large-Volume Si(Li) p-i-n Structure // Instruments and Experimental Techiques.- New York, 2007, Vol. 50, No. 4, pp. 452-454.

7. R.A. Muminov, S.A. Radzhapov, and A.K. Saimbetov Developing Si(Li) Nuclear Radiation Detectors by Pulsed Electeic Field Treatment //Technical Physics Letters.- New York, 2009, Vol. 35, №. 8, pp. 768-769.

8. Patent RUz № IAP 04073 Muminov R.A., Radzhapov S.A., Pindyurin Y.S., Saymbetov A.K. // Method for manufacturing a Si (Li) pin Structure. 2012.