

## Review

of official reviewer for a doctoral thesis of Japashov Nursultan on the topic "Development of high-sensitive detection system based on large-sized silicon lithium structures", submitted for the degree of Doctor of Philosophy (PhD) in the specialty "D071900 - Radio engineering electronics and telecommunications"

### 1. The relevance of the research topic and its connection with general scientific and national programs (the requirements of practice and the development of science and technology).

In the dissertation of Japashov Nursultan, a study of highly sensitive detection systems based on silicon-lithium structures with an sensitive area diameter more than 110 mm is considered. A silicon lithium detector with p-i-n structure and readout electronics for these detectors were chosen as the objects of study. The paper proposes a new double-sided method of diffusion and drift of lithium particles into monocrystalline silicon to create highly sensitive Si (Li) p-i-n structured detectors. As initial materials for these detectors were chosen silicon crystal - p-type, obtained by the float-zone method, with diameter 110 mm, thickness 8-10 mm, resistivity  $\rho = 1000 \div 10000 \text{ Ohm} \cdot \text{cm}$  and with life time  $\tau \geq 500 \text{ } \mu\text{s}$  was used and silicon of p-type grown in an argon atmosphere by the Czochralski process, with diameter 110 mm, a high resistivity of  $\rho = 10 \div 12 \text{ Ohm.cm}$  and with a lifetime of  $\tau \geq 50 \text{ } \mu\text{s}$ .

Furthermore, it was created readout electronics for these detectors. More precisely, a special charge-sensitive preamplifier with low noise and low delay times was developed. After that, the rest of the reading electronics was developed, which includes a counter and an AVR microcontroller with access to a personal computer for monitoring radiation.

Silicon detector systems are well developed at the present time, but an increase their efficiency and accuracy in detecting ionized radiation is still an urgent research issue. There are several problems that prevent to obtain a high-precision of radiation detection instrument. They are mainly related to the size of the sensitive area of the detectors.

One of the long and energy-intensive processes in the technology of manufacturing Si (Li) p-i-n nuclear radiation detectors is the formation of the i-region by diffusion and drift of lithium ions. So, to create a sensitive area of the detector with a thickness of more than 4 mm, months of painstaking work are required. In addition, providing a large sensitive surface of semiconductor detectors in combination with high energy resolution is still a rather difficult task. This is primarily due to a special requirement for the technology of growing semiconductor materials for semiconductor detectors. The most developed industrial detector materials of silicon of large diameters contain significant inhomogeneities in the distribution of electro-physical parameters over the volume of the crystal. The local and impurity bands present in the sensitive volume of semiconductor detectors significantly impair its radiometric characteristics.

Consequently, the requirements of a large sensitive surface and high energy expansion are mutually exclusive.

To shorten manufacturing time and avoid inhomogeneities in the fabrication of Si (Li) p-i-n nuclear radiation detectors, we propose a double sided diffusion method for lithium ions, which precedes a further double sided drift, which is the next stage after double sided diffusion in the development of the detector. The fabrication of the Si (Li) p-i-n structure by means of double sided technology helps to shorten the manufacturing time of the detector and optimizes the physical parameters of the detector. The double sided technology of manufacturing p-i-n structure has a number of advantages, this - with the double sided formation of the p-i-n structure, the manufacturing time is reduced by several times, the structure becomes more homogeneous and etc. Because while penetration of lithium ions in silicon, lithium ions are distributed from the surface side of the crystal into the depth, while the deeper the distribution, the greater the non-uniformity appear in the crystal. Accordingly, with the double sided technology, the ion penetration length is halved and this noticeably reduces the manifestations of the non-uniform distribution of lithium ions in mono-crystalline silicon.

Also, for the successful operation of detection systems, it is very important to construct suitable electronics, since detection of signals using silicon band detectors is complex. This is due to the following characteristics of the detectors: small multichannel signals, pending intelligent electronics for signal detection (high gain and noise suppression), leakage current (DC).

## **2. Scientific results in the framework of the requirements for dissertations (paragraphs 2, 5, 6 of the "Rules for the award of scientific degrees").**

In the dissertation of Japashov N., there are below listed, new scientific results:

1 The regimes of diffusion of lithium atoms in a silicon single crystal were detected by experimental testing. This regime is well fit for manufacturing of a detector with a sensitive area greater than  $110 \text{ mm}^2$  and a thickness of 4 mm.

2 Experimentally it was determined the technological regimes of double-sided drift of lithium ions into monocrysalline silicon, including a synchronous step change in temperature and reverse bias voltage leading to a reduction in the drift path of penetration of lithium ions and to a more homogeneous detector structure, thereby reducing the FWHM of the energy spectra of the detector for beta particles by 5 keV and for alpha particles at 7 keV.

3 Theoretical assumptions and experimental provisions showed that the technology of double-sided drift reduces the manufacturing time of the Si (Li) p-i-n structure by 4 times.

4 The developed charge-sensitive preamplifier for a Si (Li) p-i-n structured detector showed a low noise level; for detectors with an output capacitance of 300 pF, the mean square deviation of the noise current is 45 nA and the minimum delay time is up to 8 ns. Also, it is established that the preamplifier is fully compatible with other, alternative, silicon detectors with an output capacitance from 10 to 1300 pF.

**3. The degree of validity and reliability of each scientific result (scientific provision), conclusions of the applicant, formulated in the thesis.**

The validity and reliability of scientific results are confirmed by the large amount of own research of the author, performed using a complex of physical and technological methods of analysis, the logical interrelation of the experimental results and their consistency with generally accepted scientific principles.

The validity of the conclusion, that the optimal diffusion regime of lithium for obtaining large-diameter detectors is confirmed by the obtained electro-physical characteristics measured by special technology and equipment.

The validity of the conclusion that the method of conducting a double -sided drift of lithium ions into a monocrystalline silicon is carried out by a simultaneous stepwise increase in temperature is confirmed by the obtained current-voltage, capacitance-voltage characteristics, in the experimental data it is shown clear explanation of this process.

The validity of the conclusion that the technology of double-sided drift of lithium ions into a monocrystalline silicon improves spectrometric characteristics, increases the efficiency of the detecting system and shortens the detector manufacturing time, is confirmed by the improved spectrometric characteristics of the detecting system. It is clearly seen from the output spectra of detector, that FWHM of the energy spectra of the detector is reduced for beta particles by 5 keV and for alpha particles at 7 keV.

The validity of the conclusion that the developed charge-sensitive preamplifier for silicon detectors has a high speed, low sensitivity to the input capacitance, which ensures its stability due to low-noise amplifiers with a noise level not exceeding  $0.45 \text{ nV} / \text{Hz}^{1/2}$ , as well as matching the impedance of the connected line and the input of the amplifier, is confirmed by the results of the measuring instruments.

The conclusions brought in the dissertation are justified, logically follow from the content of the work and are the result of the generalization of a large amount of experimental data.

**4. The degree of novelty of each scientific result (scientific provision), conclusions of the applicant, formulated in the thesis.**

The results of theoretical and experimental research presented in the dissertation are new.

1 It was found that the optimal regime for lithium diffusion into large-diameter silicon ( $\geq 110 \text{ mm}$ ) with a thickness of the sensitive region  $W \geq 4 \text{ mm}$  is at a temperature  $T = (450 \pm 20) ^\circ\text{C}$ ,  $t = 3 \text{ min}$ ,  $h_{\text{Li}} = (300 \pm 10) \mu\text{m}$ .

2 The method of conducting a double sided drift of lithium ions into a silicon monocrystal is performed by a synchronous stepwise increase in temperature from  $55 ^\circ\text{C}$  to  $100 ^\circ\text{C}$  and a reverse bias voltage from  $70 \text{ V}$  to  $200 \text{ V}$ .

3 The technology of double-sided drift of lithium ions into a silicon monocrystal improves spectrometric characteristics, increases the efficiency of the detection system and reduces the time to manufacture the detector.

4 The developed charge-sensitive preamps for silicon detectors have high speed (delay time no more than 5 ns), low sensitivity to the input capacitance, which ensures, as a result, a low-noise amplifier with a level of  $0.43 \text{ nV/Hz}^{1/2}$  and its stability, and the possibility of matching the impedance of the connected line and the input of the amplifier.

#### **5. Evaluation of the internal unity of the results.**

The results of the dissertation have an internal unity, since all sections are aimed to solve the problem of studying the structural, electrical and hardware implementation of the detecting systems and detector structures with the subsequent optimization of the technological conditions of their production and use for manufacturing for industrial purposes.

#### **6. The focus of the results obtained by the applicant on the solution of the relevant actual, theoretical or applied problem.**

The new scientific results obtained by the applicant and presented in the dissertation are aimed at solving an important applied problem: spectrometric devices, based on Si (Li) p-i-n structured detectors with a sensitive surface diameter of more than 110 mm and a thickness of sensitive area more than 4 mm, intended for X-ray detection.

#### **7. Confirmation of sufficient completeness of publications of the main provisions, results and the conclusion of the dissertation.**

According to the materials of the dissertational work, 11 publications were published. From which 8 are articles, 2 in an international scientific publication, having citations in Thomson Reuters database (ISI Web of Knowledge, Thomson Reuters), which is also included in the Scopus database, 6 articles in scientific publications recommended by the Committee on the Control of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, 1 report at an abroad international conference and 2 reports at local international conference.

#### **8. Disadvantages on the content and design of the thesis.**

1 The technology of manufacturing of individual parts of the spectrometric system was well described, but the description about the technology of assembling the spectrometric system is poor. For example in pages 59 and 60 diagrams of the electronic parts of the spectrometry system is detailed described, but it would be nice to add a more extensive explanation of current circuits here.

2 On page 61, figure 2.9 shows the spectrum, obtained from the detector on a computer monitor, but the description of software is not enough.

3 On page 84, an SPM image of the Si (Li) p-i-n structure is shown, but again, no detailed description of these images is given. It is necessary to bring reasonable conclusions associated with this image. It would be better to make a qualitative analysis of the surface structure.

4 The author in his work uses the AVR microcontroller to process the output signals of the detector, but does not talk about other existing microcontrollers. It is necessary to express all the advantages and disadvantages of the AVR microcontroller and justify why this particular microcontroller is better suited for this kind of signal processing.

**9. Compliance of the dissertation with the requirements of section 2 of the «Rules for the award of scientific degrees».**

The dissertation "Development of high- sensitive detection system based on large- sized silicon lithium structures", meets the requirements of section 2 of the "Rules for the award of scientific degrees" to dissertations.

Protected scientific position can be qualified as a solution to an important applied technical problem.

The combination of new scientifically based theoretical and experimental results are an important achievement in the development of electronic devices.

Based on the above, I am confident to say that the applicant, Japashov N., deserves to be awarded the degree of Doctor of Philosophy in the specialty 6D071900 - Radio Engineering, Electronics and Telecommunications.

Official reviewer  
doctor of physico- mathematical  
sciences, professor



Umarov F.F.