

Semiconductor Ion-Implanted p-n Junction Neutron Detector

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(Presented by Academy Member George Japaridze)

ABSTRACT. Through successive ion implantation of high-resistance monocrystalline silicon surface n-type (100) with ^{10}B ions of different energy and fluence an ion implanted p-n junction planar diode for neutron detector was designed and manufactured. The inversion p-layer of the diode is concurrently the detector's converter. A portable modular, universal radiation detector (180mm×50mm×30mm) was made on its basis. For management of multicomponent assemblies of the detector system, as well as for statistical analysis of the data and interpretation of the results, the software functions and libraries were developed. Preliminary tests of the detector were carried out by alpha particles (^{241}Am) and neutrons (^{252}Cf). © 2019 Bull. Georg. Natl. Acad. Sci.

Key words: silicon, ion implantation, ^{10}B ions, neutron, detector converter, electronic system, functional prototype

Semiconductor silicon detectors are used in many applications for detection of various types of ionizing radiation and neutrons [1-3].

In semiconductor detectors the fundamental information carriers are electron-hole pairs, which are produced along the path taken by the charged particle (primary or secondary) through the detector. The detection signal is formed by collecting electron-hole pairs. The paper concerns the design and manufacture of a semiconductor ion-implanted neutron detector, where inversion p-

layer of the diode is concurrently the converter of the detector.

Materials and Methods

Starting materials and electronic system of the detector. The starting materials of the detector are the diodes produced by the successive ion implantation of high-resistance monocrystalline n-type (100) silicon surface with ^{10}B ions of different energy and fluence [4]. As a result of model computer calculations by SRIM-2013

(The Stopping and Range of Ions in Matter) and TRIM-2013 (Transport of Ions in Matter) programs [5], a sequential mode of high-fluence ion implantation is selected: energy $E=100-65-40-25-20$ keV, fluences: $\Phi=1\cdot 10^{16}-2.8\cdot 10^{15}-4\cdot 10^{15}-3.3\cdot 10^{15}-3.1\cdot 10^{15}\text{cm}^{-2}$. Fig. 1. represents the results of calculations.

calculations of the parameters of ^{10}B ions interaction with silicon atoms are conducted in the mode “Detailed Calculation with Full Damage Cascades”[5].

According to the main tasks of the project a flowchart of the detector electronic system has been developed (Fig.2).

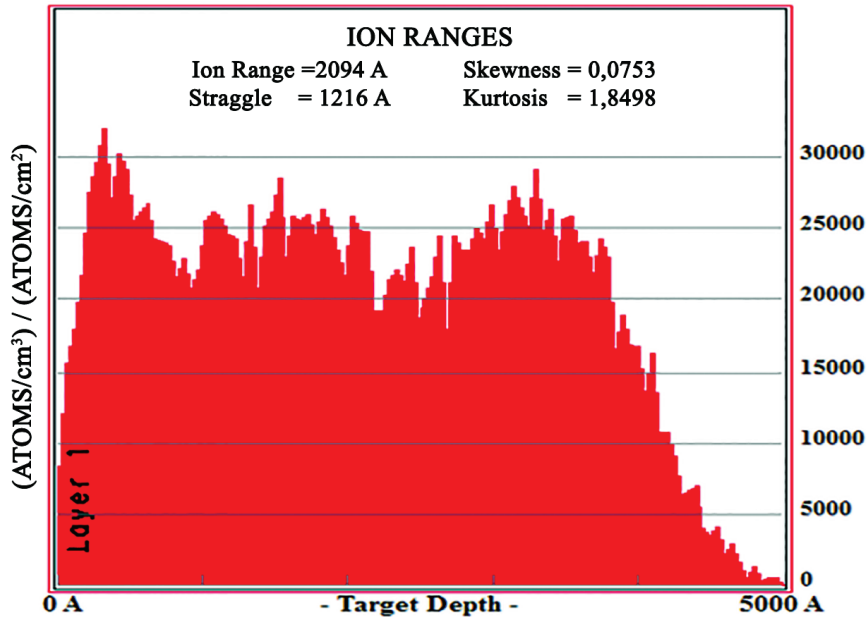


Fig.1. ^{10}B ion distribution in Si as a function of the penetration depth after successive ion implantation (TRIM-2013).

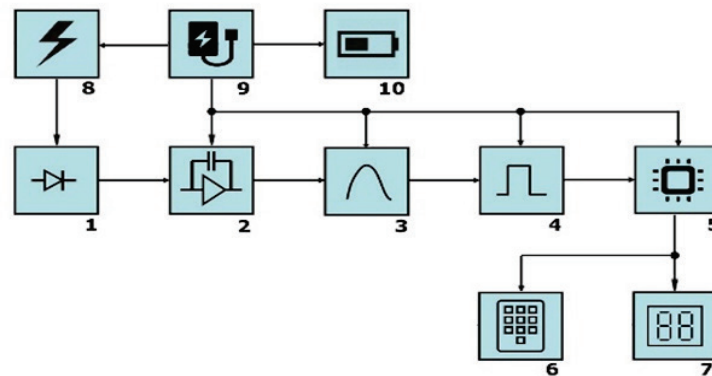


Fig.2. Detector flow chart: 1 – detector; 2 – preamplifier; 3 – shaping amplifier; 4 – comparator; 5 – microprocessor unit; 6 – keyboard; 7 – liquid-crystal display (LCD); 8 – bias generator; 9 – battery-powered PSU; 10 – battery.

Calculated concentration of ^{10}B ions is $2.5\cdot 10^{20}\text{cm}^{-3}$ and is distributed in silicon almost uniformly up to $0.4\ \mu\text{m}$ thick. The

The optimization of all signal processing and the signal-noise level is based on standard and well established procedures [6-9].

The first stage of the electronic system flowchart is the charge sensitive preamplifier, the principal destination of which is the connection with the detector shaping amplifier without degradation of the signal/noise ratio (SNR).

To cope with the pulse grouping problem, the shaping amplifier is used in the analog signal processing chain, at which inlet signal is supplied from the preamplifier and shapes the signal so that a quasi-Gaussian pulse is produced in the inlet. The next element of the analog signal chain is the comparator unit, which compares the signal outgoing from the shaping amplifier with the reference signal. The adjustment of the comparator reference signal will make it possible to adjust the detection limit and filter the detector noise and gamma component of the decay reaction $^{10}\text{B}(n,\alpha)^7\text{Li}$. The microcontroller fulfills full management of each component of the detector system, calculation and processing of pulses, statistical data processing and indication of the results.

Test prototypes of the detector electronic system. To study the preamplifier, a pre-test laboratory prototype of a semiconductor detector was made from the existing read modules. A pre-test laboratory prototype consists of a shielded preamplifier and digital pulse LCD counter. The semiconductor sensor of neutrons is located in a shield. Upon testing by manipulation of the components and their values, the preamplifier parameters and the effective cap methods were selected. As a result, the background and existing gamma radiation has been observed. The detector preliminary testing demonstrated its suitability and the possibilities of its characterization. The main purpose of the second prototype was testing and matching/confrontation of individual components of the system. For testing the analogous part, the pulse generator Г5-78 was used.

Design of the Detector

Using the first and second prototype testing results, a portable detector (180mm×50mm×30mm) of a modular design, consisting of the following four principal modules was developed:

1. The principal microprocessor system board accommodating the basic microprocessor, power and battery charging system, battery charge determining system, low noise bipolar power supply, information input/display systems and the Bluetooth communication module.
2. An analog system board on which hybrid modules of Cremat Inc. pre- and shape amplifiers, a pulse inverter amplifier, a high-speed comparator and the comparator's reference voltage generating digital-analogue converter with a precision reference voltage generator are placed.
3. Semiconduction encapsulated neutrons sensor located on a special printed board.
4. Li-ion battery.

For the purpose of remote measurements the Bluetooth communication module in the detector design is provided. The electronic system has been tested by a CAEN's DT4800 detector emulator. The emulator ensures the generation of test pulses and their supply to the test input of the analog system. The system demonstrated low level of noise, super sensitivity and stability irrespective of the absence of noise shield and close proximity of the modules with the power supply unit.

Testing of the designed prototypes was performed using specially designed laboratory stand equipped with dual digital multichannel analyzer HEXAGON company CAEN S.p.A., a universal radiation dosimeter, and the ^{241}Am and ^{252}Cf nuclear and radiation sources provided by the Nuclear and Radiation Safety Agency (NRSA) and a personal gamma/neutron radiation detector Thermo Scientific PRD ReadEye GN+.

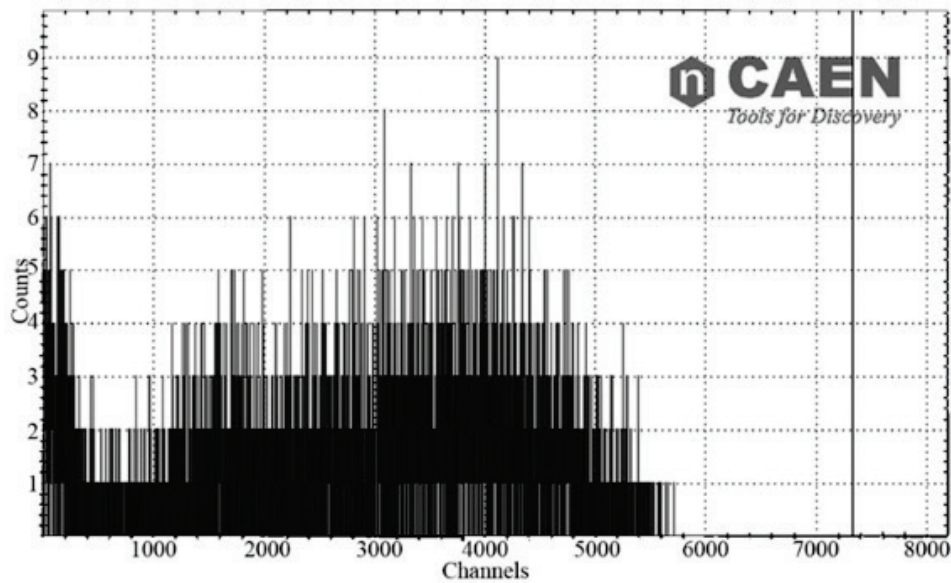


Fig.3. $^{10}\text{B}(n,\alpha)^7\text{Li}$ reaction spectrum.

The results of testing ($^{10}\text{B}(n,\alpha)^7\text{Li}$ reaction) one of the fabricated prototypes of the detector with sources of neutrons (^{252}Cf) are presented in Fig.3. To slow down fast neutrons to the thermal ones, a paraffin moderator 55 mm thick was used.

Poor intelligibility is associated with a lack of statistical data, which is associated with low source intensity. Deviations of the measurement results can be explained by the need to optimize the parameters of the diode.

Conclusion

A universal detector of a modular design was designed and manufactured. The electronic system of the universal radiation detector and its software were developed, manufactured and tested. The created detectors can be used in both nuclear and radiation safety, also in nuclear medicine, nuclear power engineering, radiation monitoring of the environment and other branches of science and technology.

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ფიზიკა

ნახევარგამტარული იონიმპლანტაციური p-n გადასასვლელიანი ნეიტრონების დეტექტორი

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(წარმოდგენილია აკადემიის წევრის გ. ჯაფარიძის მიერ)

მაღალმომიანი მონოკრისტალური n-ტიპის (100) სილიციუმის ზედაპირზე სხვადასხვა ენერჯისა და ფლუენსის ^{10}B იონების თანმიმდევრული იონური იმპლანტაციით შექმნილია იონიმპლანტაციური ნახევარგამტარული p-n გადასასვლელიანი პლანარული დიოდი ნეიტრონების დეტექტორისათვის. დიოდის ინვერსიული p- ფენა ამავდროულად დეტექტორის კონვერტერს წარმოადგენს. მის ბაზაზე შექმნილია პორტატული, მოდულური, უნივერსალური რადიაციული დეტექტორი ზომით (180მმ×50მმ×30მმ). შემუშავებულია პროგრამული ფუნქციები და ბიბლიოთეკები დეტექტორის სისტემის შემადგენელი ბლოკების მართვისათვის, მონაცემთა სტატისტიკური ანალიზისა და შედეგების ინტერპრეტაციისათვის. ჩატარებულია დეტექტორის წინასწარი გამოცდა ^{241}Am (ალფა ნაწილაკები) ^{252}Cf (სწრაფი ნეიტრონები) წყაროებზე.

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