ISSN 0020-4412, Instruments and Experimental Techniques, 2014, Vol. 57, No. 5, pp. 564–565. © Pleiades Publishing, Ltd., 2014.
Original Russian Text © R.A. Muminov, S.A. Radzhapov, Yo.K. Toshmuradov, Sh. Risalieva, S. Bekbaev, A. Kurmantaev, 2014, published in Pribory i Tekhnika Eksperimenta, 2014, No. 5, pp. 53–54.

NUCLEAR EXPERIMENTAL TECHNIQUES

Development and Optimization of the Production Technology of Large-Size Position-Sensitive Detectors

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Received December 4, 2013

Abstract—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 and intended for tomographic and environmental problems, are described. The detectors with a 50 × 50 × 2-mm-size sensitive area with 8, 16, and 32 strips were produced. With a voltage of 100–500 V, the energy resolution is 50 and 75–80 keV for electrons with an energy of 1 MeV and for α particles with an energy of 7.65 MeV, respectively, when the dark current is 0.5–1 μA, the capacitance value is 300 pF, and noise is 40 keV.

DOI: 10.1134/S0020441214040083

Semiconductor nuclear-radiation detectors, allowing one to simultaneously determine the energies and locations of particle impacts have lately become irreplaceable in studies of scattering processes on solid targets when determining the angular distributions of nuclear particles.

Position-sensitive detectors (PSDs) are being intensely developed for space, medical, and biological studies and for studies in atomic physics too. They have large advantages over other detectors of similar application, namely, the high energy and position resolutions; signal linearity in a wide energy range for particles of different types; insensitivity to magnetic fields; and stability, small overall dimensions, and arriving-data processing simplicity.

This work presents the results of our performed development and optimization of the production technology of semiconductor nuclear-radiation PSDs, based on Si(Li)-*p*–*i*–*n* large-size X-ray detectors for tomographic and ecological problems.

The production of such detectors requires precision physical processes and conditions. They are specified by the fact that low-energy X-ray beams are applied in these systems for generation of electron–hole pairs in the sensitive region of a semiconductor detector. The energy resolution in them should be $E_g <$ 200–300 eV, being almost limiting for many detectors based on semiconductor crystals. To meet the requirements for the energy resolution, it is necessary to create physical conditions and mechanisms for ensuring the maximum collections of charge carriers, generated due to X-ray quantum energy losses. In this case, these conditions should ensure the same result at any point of the sensitive region of the detector and the detector itself should be position-sensitive.

To solve these problems, it is required to correlate properties of the initial semiconductor crystal (conductance, homogeneity, imperfection, etc.) and conditions for providing high-efficient *p*–*n* or *p*–*i*–*n* semiconductor structures with large sensitive region volumes and thin input windows ("dead layer") on the frontal side of the structure.

The creation of Si(Li)-*p*–*i*–*n* structures with a sensitive-region diameter of ~100–120 mm and a thickness >1.5 mm is a technologically complex problem. In particular, it is necessary to create a sufficiently extended, uniformly lithium-compensated sensitive region. To obtain the specified characteristics of the large-size PSDs, such parameters as the temperature, diffusion annealing time, voltage values, and drift-conduction method, are important. The diffusion and lithium ion drift modes are selected in accordance with those proposed in [1, 2].

The lithium diffusion was performed in vacuum to a depth of ~500 μm at the temperature t = 500°C. After the diffusion, steps were etched on the plate to obtain a *T*-shaped form. After etching by the polishing etchant in an $HF : HNO_3 : CH_3COOH$ (1 : 3 : 1) acid mixture and in the aniline etchant, the initial samples had reverse currents $I \leq 10$ μA. Then, the lithium ion drift was carried out in samples on the specially designed and produced drift plant. The drift mode was performed with the temperature T_{dr} = 60–90°C and a bias voltage of 50–600 V.

Upon the completion of formation of the Si(Li)-*p*–*i*–*n* structure, the whole crystal was subjected to

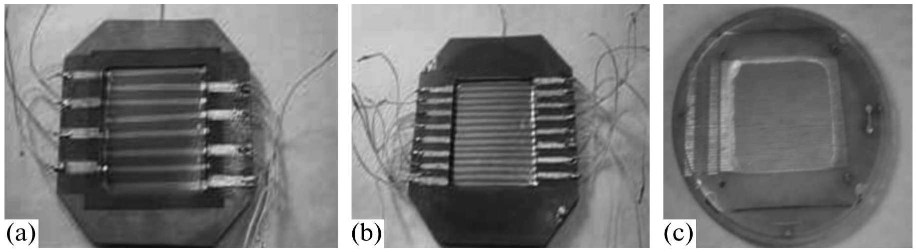

Fig. 1. General appearance of the semiconductor position-sensitive detectors based on Si(Li)-*p*–*i*–*n* structures with (a) 8, (b) 16, and (c) 32 strips.

chemical–technological treatment to ensure the minimum reverse currents. The PSDs were made of finished Si(Li)-*p*–*i*–*n* structures with a sensitive-region diameter of 60 mm and a thickness of 2 mm. Then, Al contacts (1000 Å) were deposited on the rear underside of the plate by the vacuum deposition method under a pressure of 5×10^{-5} Torr, and Au (~200 Å) contacts were deposited on the frontal surface using special masks with strips. After that, the ready-made detectors were placed into the housing. The detectors had rectangular shapes with the $50 \times 50 \times 2$-mm size sensitive region. Three position-sensitive structure versions with 8, 16, and 32 strips (see Fig. 1) were designed.

With the working voltage U_{rev} = 100–500 V, the produced PSDs with 16 strips have the dark current I = 0.5–1 μA, capacitance value C = 300 pF, noise E_{ns} = 40 keV, energy resolutions for internal-conversion electrons ^{207}Bi (E_β = 1 MeV) R_β = 50 keV and for α particles ^{226} Ra (E_α = 7.65 MeV) R_α = 75–80 keV. For one element (band) and the working voltage U_{rev} = 300 V, the dark current I = 0.1–0.3 μA, the capacitance value C = 40 pF, noise E_{ns} = 9–12 keV, the energy resolution for ^{226}Ra with the energy E_α = 7.65 MeV is 0.2–0.4% (12–14 keV).

Thus, as a result of the performed studies and technological works we designed the production method of large-size semiconductor PSDs based on Si(Li)-*p*–*i*–*n* structures with 8, 16, and 32 strips.

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Translated by N. Pakhomova