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NUCLEAR EXPERIMENTAL TECHNIQUES

Special Features of Formation of High-Performance Semiconductor Detectors Based on αSi–Si(Li) Heterostructures

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Abstract—A production technology of nuclear radiation detectors based on αSi–Si(Li) heterostructures is considered. It is shown that these detectors are more efficient as compared to traditional *p–n* structures due to a thin near-surface (“dead”) layer.

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The progress of the nuclear spectroscopy technique is substantially specified by the creation of nuclear radiation semiconductor detectors (SCDs) [1, 2], in particular, silicon detectors based on Si(Li) *p–i–n* structures having relatively small sizes (with a sensitive-surface diameter $d < 50$ mm and thickness $W =$ 1.5–2 mm) [3–5]. However, up-to-date requirements imposed on these detectors lead to the necessity of increasing their sizes up to $d >$ 50–100 mm and $W >$ 2 mm. In this case, physical, technological, and structural decisions should take the properties of the initial large-size crystal into account in an attempt to meet optimum electrical, radiometric, and spectrometric characteristics of the detectors [6–9].

In this study, special features of the production technology of the high-performance nuclear radiation semiconductor detectors having large sizes ($d >$ 50 mm and $W =$ 1.5–4 mm) and based on αSi-Si(Li) amorphous silicon–silicon heterostructures are considered.
1 A special feature of this heterostructure is a high and sharp (relative to the diffusion Si(Li) *p–n* junction) potential barrier of the heterocontact. This is important for ensuring in SCDs a thin entrance window (“dead layer”) and optimum electrophysical and spectrometric characteristics.

The αSi-Si(Li) heterostructures were formed on *p*-type single-crystal silicon wafers with a 50-mm diameter and thickness of ≥2 mm. The specific resistance of the initial crystal varied in the range ρ = 1000–5000 $\Omega \cdot$ cm, when the lifetime of nonequilibrium current carriers $\tau \geq$ 300 μs. After a number of mechano–chemical treatments of crystals, the lithium ion diffusion was carried out in vacuum at a depth of ~300 μm at a temperature of 450°C. The diffusion depth was monitored by the sphere–section method.

After etching with a polishing etch in an HF:HNO_3:CH_3COOH mixture of acids and in aniline etch, the reverse currents of the samples were ≤10 μA. Further, the lithium-ion drift process was performed first at T = 70–80°C and voltage U = 100–400 V and then at T = 60°C and U = 200 V. The additional low-temperature drift process contributed to equalizing the degree of compensation over the entire crystal volume.

After completion of all lithium-ion drift processes, the diffusion region was completely ground away, and α-Si (the layer thickness was ~500 Å) was sputtered on this surface from the completely removed *i*-region (lithium-compensated silicon). Gold and aluminum coatings were used to obtain ohmic metallic contacts: (i) the aluminum coating on the sensitive surface of the structure with an α-Si layer (on which ionizing

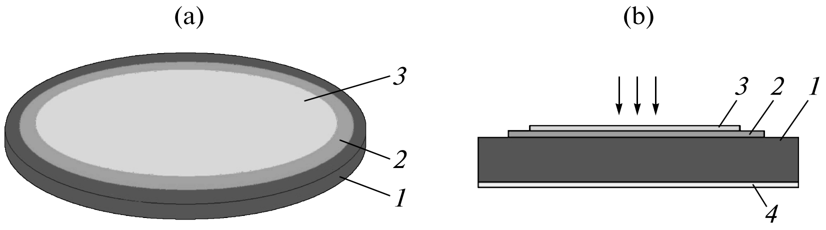
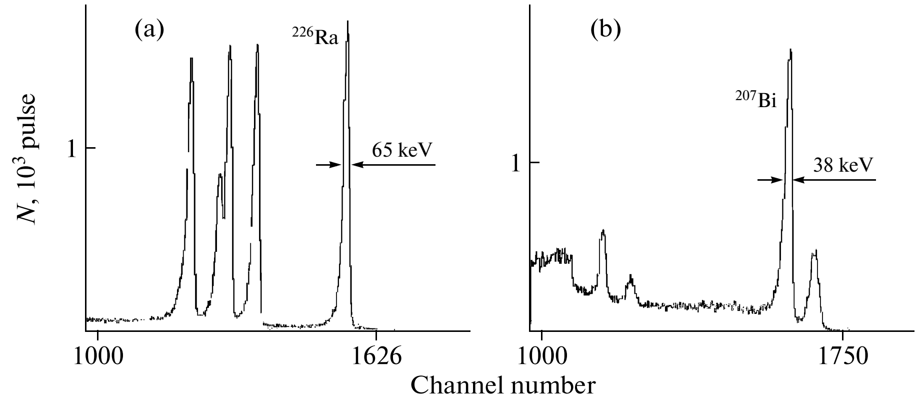


Fig. 1. Design of the αSi–Si(Li)-based detector: (a) detector, view from above; (b) general appearance of the detector; (*1*) single-crystal silicon, compensated by the lithium-ion drift method; (*2*) amorphous layer; (*3*) aluminum contact; and (*4*) gold contact.



1 **Fig. 2.** Energy spectra of the αSi-Si(Li): **a** heterostructure: (a) for ^{226}Ra particles (E_α = 7.65 MeV); and (b) for ^{207}Bi particles (E_β = 1 MeV).

radiation falls) and (ii) the gold coating on the opposite side (Fig. 1).

The detectors obtained by this procedure had the following parameters. When the reverse bias voltage $U_{\rm rev}$ ~ 20–300 V, the dark current was equal to ~0.5–1.2 μA, the capacitance value was ~40–200 pF, and the energy noise $E_{\rm ns}$ ~ 25–60 keV.

The energy resolution was measured using sources of ^{226}Ra α particles and ^{207}Bi β particles. The amplitude spectra were recorded using a standard spectrometric section. Figure 2 shows the energy spectra of the detector for ^{226}Ra α particles (E_α = 7.65 MeV) – R_α = 65 keV and for ^{207}Bi β particles (internal-conversion electrons) (E_β = 1 MeV) – R_β = 38 keV. As it can be seen from the energy spectra, for the SCD based on αSi-Si(Li) heterostructures in the case of α particles, the influence of the thickness of the amorphous silicon layer on the energy spectrum formation is insignificant, since the absorption depth of α particles is very small (0.25 μm). In the case of β particles, the influence of the thickness of the amorphous silicon layer is not also great, but, in this case, the influence of the degree of compensation of the thickness of the sensitive silicon region on the formation of the β-particle energy spectrum shows itself, since the absorption depth of β particles reaches 2 mm. As a result, the SCD energy resolution for α particles is $R_\alpha < 1\%$ and for β particles $R_\beta \geq 1\%$ and is determined by the half-width of the particle energy spectrum.

The obtained results showed that the nuclear radiation detectors based on αSi-Si(Li) heterostructures are more efficient by 0.5–1.5% in respect to electrical (current, capacitive), radiometric (noise, dead layer thickness), and spectrometric (energy resolution, amplitude spectrum formation) characteristics as compared to traditional Si(Li) *p–i–n* detectors.

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SPELL: 1. heterostructure