Si(Li) detector with ultra-thin entrance window on the diffusive lithium side

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Abstract. Present work reports the results of activities intended to reach thin Si(Li) detector entrance window on the diffusive lithium layer side. It was established that the new n-contact represented by a heterostructure of unalloyed amorphous n-type silicon a-Si:H allows one to achieve the entrance window thickness 3 – 4 orders of magnitude smaller than the lithium-side entrance window of standard Si(Li) detectors. The films of amorphous silicon were synthesized with MASD (magnetron assisted silane decomposition) method in mixture of SiH4 (25%) and Ar (75%) gases. Lithium layer surface resistivity and silicon target type (n- or p-) affection on electrical properties of Si(Li) detector contact produced were studied. The investigation performed led to a technology of Si(Li) detector production with thickness of the entrance window on the diffusive lithium layer side below 0.1 µm.

1. Introduction
A Si(Li) semiconductor detector (SCD) constitutes a principal element of the multilayered semiconductor spectrometers (SCD-telescopes) employed for the registration of the high-energy charged particles. The spectrometric properties of such detectors are predominantly determined by the thickness of their entrance window, through which the particle has to traverse before it can deposit its energy within the sensitive volume of the detector. In case of the standard Si(Li) detector, the main contribution to the total thickness of the entrance window is made by diffuse lithium layer that usually have a thickness of 300 – 400 µm. Therefore, it becomes necessary to minimize the thickness of the dead lithium layer if one is going to perform high precision energy measurements and particle identification via the SCD-telescopes.

Usually, the minimization is achieved by grinding off the excessive lithium and production of the new n-contact on the final sample. The new n-contact should provide low reverse currents, lack of noise and satisfactory spectrometric properties. Such a contact can be obtained either by performing additional low-gradient lithium diffusion [1], or by sputtering of a thin layer of undoped amorphous silicon (a-Si:H) [2, 3]. The best results were achieved with magnetron sputtering of amorphous silicon films inside the argon atmosphere with 17% hydrogen admixture [4].

The thickness of the dead layer was determined via the measurement of the energy loss of the registered α-particles. With the temperature of 249° K and offset voltage of 1170 V the
thickness proved to be less than 5.3 $\mu$m. In case of the entrance window being located on the p-contact side (Pd, Au) the same parameter usually lies within the range of 0.1 – 0.2 $\mu$m. Thus, the development of a technique that allows one to produce the entrance window of the similar thickness on the side of n-contact is of great interest.

The present paper reports the results of experimental production of the thin entrance window on the side of diffused lithium layer. The new n-contact is basically a heterostructure consisting of the undoped amorphous silicon (a-Si:H), synthetically produced by the magnetron assisted silane decomposition inside the gaseous mixture of SiH$_4$ (25)% and Ar (75)%, and crystalline silicon of the n-type conductivity. The aluminum is used to produce resistance contact to the amorphous silicon.

2. Experiment

The monocrystalline silicon of the p-type conductivity was used as a source material for Si(Li) detector production. The source silicon material had been grown via the float zone melting technique and had the volume resistivity of $1.5 - 4$ k$\Omega$-cm and the mean carrier lifetime of $800 - 1000$ $\mu$s. The plates with (111) surface orientation had area of 150 mm$^2$ or 230 mm$^2$ and 2 – 3 mm thickness. In order to remove the layer compromised by the grinding the plates were etched in mixture of HF:HNO$_3$ (1:8) and thoroughly rinsed by deionized water. The diffusion was carried out for 10 – 15 minutes at the temperature of 370° – 380° C.

Consequently, the detector workpiece was cut out in a mushroom-like shape (Fig. 1), and additional etching in HF:HNO$_3$ (1:8) mixture was performed. The surface contact layers were produced via the vacuum sputtering of Al for the n-contact, and Pd for the p-contact. The lithium drifting was performed at the temperature of 100 – 110° C, voltage of 300 – 500 V and current not exceeding 5 mA. Then, in order to achieve the region with uniform compensation, the so called “cold” drifting was performed at 70° C and voltage of 700 V to equalize lithium distribution. After the completion of “cold” drifting the produced p-i-n structure was cleared of the excessive lithium by grinding.

The surface resistance of the remaining lithium layer was measured via the four-point probe method. After the additional HF:HNO$_3$ (1:8) etching, the new n-contact was produced from undoped amorphous silicon (a:Si-H) and covered with Al. The amorphous silicon films of 300 – 500 $A$° were deposited via the magnetron assisted silane decomposition technique inside
Figure 2. $\alpha$-spectra form the mixed source $^{239}\text{Pu}$ (5.15 MeV) + $^{238}\text{Pu}$ (5.5 MeV) + $^{233}\text{U}$ (4.8 MeV): (1) - irradiation from Li contact side, (2) - Pd contact side. The spectra were calibrated according to $\alpha$-peak positions, hence the energy loss inside the dead layer is not taken into account.

3. Results
The best results were obtained with n-type conductivity silicon target sputtering with resistance of 5 $\Omega$·cm. One should note that the amorphous film of thickness 200 – 500 A° had almost no effect on the spectrometric properties of the produced Si(Li) detectors and high-impedance amorphocrystalline structures.

The energy spectra of $\alpha$-particles from the mixed source Pu-U source obtained via a-Si:H/Si(Li) detector are given in Fig. 2. The measurements were carried out at room temperature and voltage of 600 V. The detector had 2 mm thickness of the sensitive region, Li contact area of 135 mm$^2$ and Pd contact area of 200 mm$^2$. The surface resistance after the grinding of the excessive lithium was 6 k$\Omega$·cm.

The energy spectra of the $^{207}\text{Bi}$ source obtained via the same detector at liquid nitrogen temperature and with bias voltage of 300 V are given in Fig. 3. The entrance window thickness...
Figure 3. Low-energy part of $^{207}$Bi spectrum, measured at liquid nitrogen temperature: (1) - irradiation from Li side, (2) - from Pd contact side. The inset shows total spectrum of the source.

of the Si(Li) detector was determined by measurement of $^{207}$Bi Auger electron energy loss for different bias voltages. The amount of energy loss was calculated by comparison of Auger KL1-L2 and KL1-L3 peak positions to characteristic X-ray peaks. The obtained results were validated with results of Monte-Carlo simulation implemented in GEANT4 framework.

The thickness of the entrance window on the diffuse layer side is comparable to the corresponding thickness on the Pd side, as can be seen from Fig. 2, 3. The determined values of the dead layer thickness lay within $0.12 - 0.15 \mu m$. The achieved result may be explained by well performed passivation of the amorphous-crystalline silicon interface and also by the presence of built-in field that appears due to the doping gradient of the crystalline silicon on the n-contact side.

4. Conclusions
The developed technological modes of the n-contact production for Si(Li) detectors allow one to obtain the thickness values of the entrance window on the corresponding side not exceeding $0.15 \mu m$. Further investigations are needed in order to understand the influence of the diffusion modes and lithium drifting on the resulting thickness of the entrance window.

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