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THICK Si(Li) COAXIAL DETECTORS FOR REGISTRATION OF INTERMEDIATE ENERGY HEAVY IONS

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Попеко Л. А. и др. E7-2007-5

Толстые Si(Li) коаксиальные детекторы для регистрации тяжелых ионов промежуточных энергий

Изготовлены толстые Si(Li) коаксиальные детекторы для регистрации длиннопробежных сильноионизирующих продуктов ядерных реакций с высоким разрешением. Показано, что эффективность собирания заряда и разрешение сильно зависят от температуры охлаждения и величины приложенного напряжения. Тестовые эксперименты показали, что коаксиальные детекторы в состоянии регистрировать тяжелые ионы промежуточных энергий с разрешением 0,5–0,7 %. Потери энергии во входном окне не превышают 100 кэВ.

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Thick Si(Li) Coaxial Detectors for Registration of Intermediate Energy Heavy Ions

Thick coaxial Si(Li) detectors are fabricated to register long-range high-ionizing reaction products with high resolution. It is shown that charge collection efficiency and resolution strongly depend on cooling temperature and magnitude of voltage applied. The test experiments have shown that coaxial detectors are capable of registering the intermediate energy heavy ions with 0.5–0.7 % resolution. The energy losses in entrance window of the detector are less than 100 keV.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

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INTRODUCTION

It is known that in nucleus–nucleus collisions with energies higher than Coulomb barrier the high multiplicity particles in wide range of A and Z numbers are realized. Moreover, the reaction products are produced with large angular and momentum dispersions. Reconstruction of so complicated processes is in need of applying the 4π informative and high sensitive detecting complex to measure the multitude of kinematics parameters with good accuracy and unambiguous identification of A and Z fragments. Registration of long-range particles which are produced in nucleus–nucleus collisions under the intermediate and high energies is also a significant problem. The ranges of such particles reach several tens of cm (for example Si matter). At present, to register long-range fragments in correlation experiments CsI detector walls, which provide an energy resolution order 1 %, are mainly used. There are some problems to use CsI detectors in vacuum (especially in ultra-high vacuum).

The objectives of the given work were: to carry out evaluation of available detector systems and techniques which would be used for detection of high-ionizing particles in a wide energy region (from several MeV/u up to 100 MeV/u) with high-energy resolution (order 10^{-3}), to distinguish projectile-like fragments from the non-reacting ion beam, expected to be very close to magnetic rigidity, and also to have 100 % detector efficiency and reliable (Z, A) identification power.

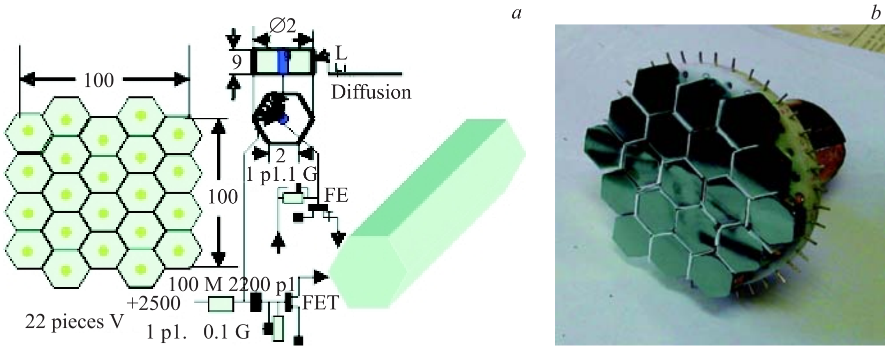

Fig. 1. Schematic overview of a coaxial Si detector: *a*) technology of manufacture and testing; *b*) view of detector wall from 22 hexagonal pieces

The Si-detector type was chosen as the most available and satisfying the above-indicated requirements. An advantage of the silicon thick detectors in comparison with HPGe is the low atomic number which is responsible for the suppression of the gamma-ray background through Compton scattering. We use sufficiently low-cost industrially produced high-resistant silicon (1000–2500 Ω cm). The coaxial-type lithium drift technology was applied. In contrast to planar technology it uses a radial electric field to move Li drift front on the radius to the center in the direction of higher electric field (Fig. 1, a). As far as compensation the mean rate of Li drift front increases considerably and it permits one to produce 10–12 mm J-transition within 7–10 days. The length of sensitive volume for particles penetrating in crystal cylinder through the face plate is limited only by the length of starting crystal and can be up to 200 mm.

1. THICK Si(Li) DETECTORS OF COAXIAL TYPE

The detectors [1, 2] have the following dimensions: 28–30 mm in diameter, 9 mm of length (100 mm was also made), the drift thickness is 12 mm, the sensitive volume is up to 90 %. Insensitive parts of the detector are: a diffusion lithium layer 0.3 mm thick situated on the crystal surface and the central core. The lithium layer and the p-type core form n^- and p^+ of a diode, respectively. The main steps of the production process are: lapping, etching and washing of the crystal; applying the lithium on a side surface of the crystal and lithium diffusion; lithium drift in radial electric field at a temperature of 140°C for 250 h for a thickness of 12 mm; clean etching and test measurements.

2. ENERGY AND EFFICIENCY CALIBRATIONS

The energy and efficiency calibrations are done by the measurement of the electric capacity as a function of the voltage applied and the counting rate of a ^{60}Co and ^{137}Cs source with known activity. Detectors with an energy resolution better than 5 keV and an efficiency of more than 90 % are considered as ready to use [3]. Our experience is that detectors stored at room temperature for 15 years show a stability of the Si(Li)-detector parameters within 3 %. The calibration spectrum of one of the silicon detectors is shown in Fig. 2.

For comparison, a HPGe spectrum is also presented. It can be seen that the total counting rate defined mainly by Compton scattering coincides for both detectors. The peaks of total absorption differ more than one order of magnitude that is proportional to the fifth power of the ratio of the atomic numbers. It confirms the advantage of the silicon multi-detector wall over germanium for the suppression of the gamma-ray background at the sacrifice of the multi-scattering

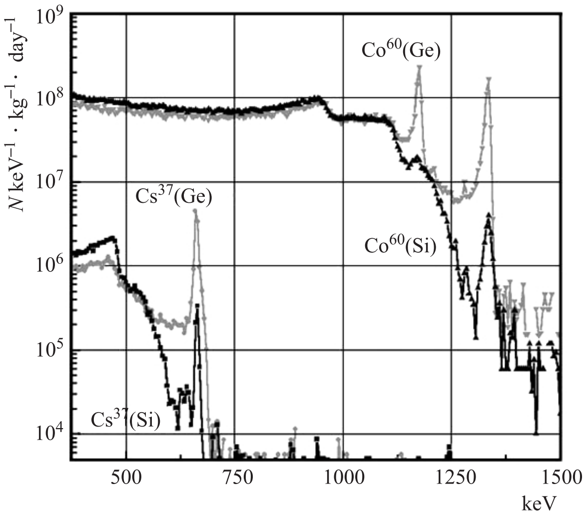

Fig. 2. Test measurement of Si(Li) detectors (dark line). The same spectrum for a HPGe detector (gray line) is presented for comparison

process. The value of the gamma-ray background suppression depends on the size of the multi-detector wall, the «dead» material inside and the lower energy registration threshold. The Si(Li) detectors were installed in a matrix which consists of a Teflon holder and clean copper inner shielding (Fig. 1, *b*).

3. TEMPERATURE AND VOLTAGE CHARACTERISTICS

In Fig. 3 alpha spectrum from ^{238}Pu is presented for room and nitrogen temperature under the same voltage. From Fig. 3 it is seen that alpha spectrum under room temperature is asymmetric with very low intensity energy tail caused by charge losses. Lowering of detector temperature improves the charge collection considerably. It is known that heavy ions generate plasma in track in which essential charge is lost due to recombination processes. In our case, alpha particles generate electron-hole pairs near surface due to short range and screening of external field in track by plasma drives to diffusion of carriers to detector surface. Magnitude of losses is determined by rate of surface recombination, by mobility of carriers in track and by external electric field on the detector surface.

Spectrum of alpha particles under nitrogen temperature depending on voltage is presented in Fig. 4. From Fig. 4 one can see that with the increase of voltage maximum is shifted to higher energy and the intensity of low energy «tail» is decreasing noticeably. It points to the improvement of charge collection efficiency.

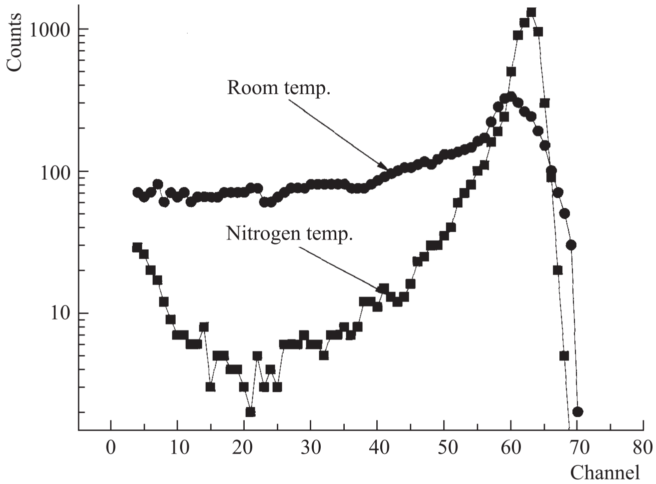

Fig. 3. Pu-238 alpha spectrum ($E = 5.5$ MeV) for room and nitrogen temperature

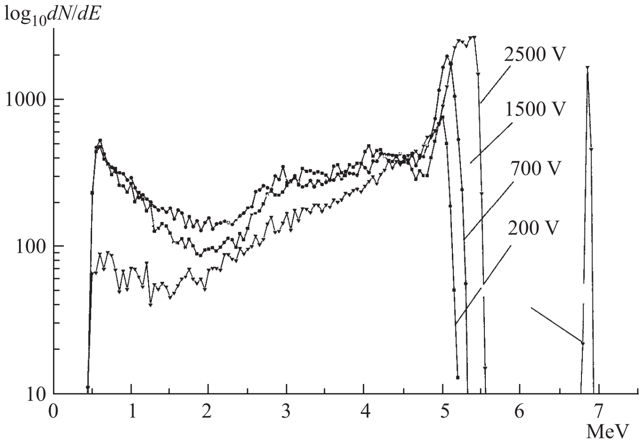

Fig. 4. Alpha spectrum of ^{238}Pu versus magnitute of voltage

In Fig. 5 we show an efficiency of collection for different region of spectrum depending on magnitude of voltage. From Fig. 5 it is seen that saturation of the collection intensity for total spectrum is reached under 1500 voltage. However, «peak» efficiency reaches 100% only under 5000 voltage.

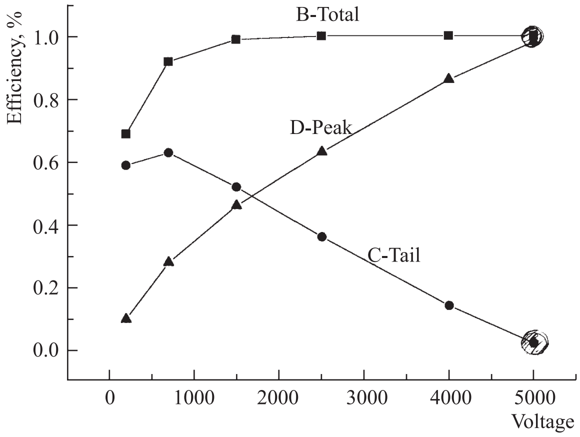

Fig. 5. Efficiency of charge collection versus magnitude of voltage: B) efficiency of total charge collection; C) efficiency of collection for low-energy spectrum «tail»; D) efficiency of collection for «peak» spectrum

4. RESULTS OF HEAVY-ION FRAGMENT TESTING

Using fragment-separator COMBAS (Dubna, Russia) one has separated monochromatic radioactive beams ^{6}He and $^{7-9}$ Li with 10^{-3} resolution in order to measure energy resolution of coaxial detectors [4]. In Fig. 6, *a*, energy spectrums of monochromatic ^{6}He and $^{7-9}$Li particles are presented. From Fig. 6, *a*, it is seen that ^{6}He and $^{7-9}$Li spectrums in energy interval from 150 to 300 MeV have symmetric gauss shapes with energy resolution in the range from 0.5 to 0.7 %.

CONCLUSION

Thick totally depleted Si(Li) coaxial detectors made of HR industrial Si were fabricated and investigated under different temperature and voltage treatment conditions. Detection of monochromatic radioactive beams ^{6}He and $^{7-9}$Li with energy from 150 to 300 MeV has shown that Si(Li) coaxial detectors provide for energy resolution in the range from 0.5 to 0.7 %.

Results of measurements show that coaxial detectors are able to register the intermediate energy heavy ions with better resolution if the energy losses in entrance window of detector are less than 100 keV.

We have prepared telescope from detectors composed of ΔE coaxial detector (0.2 mm) and E coaxial detector (10 and 100 mm) to continue study of detector performance (resolution, efficiency et al.) and identification power for registration

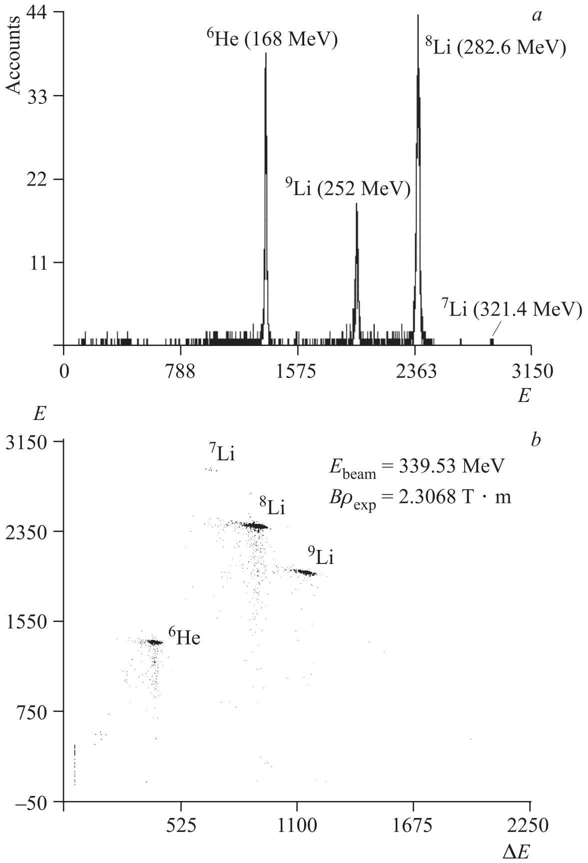

Fig. 6. Identification plot of ^{6}He and $^{7-9}$Li isotopes. Horizontal axis — ΔE (planar Si 1.5 mm), vertical axis — 9 mm coaxial Si detector: *a*) spectrums of monochromatic ^{6}He and $^{7-9}$Li isotopes; *b*) demonstration of an identification power of detector telescope composed of ΔE (Si 1.5 mm) and E (9 mm) coaxial detector

of more complex isotopic spectrums. The detector telescope from ΔE detector and thick totally depleted Si(Li) coaxial detectors can be also efficiently used to register e^- and e^+ particles from β-decay of stopping radioactive nuclei in depth telescope.

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