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Particle pulse shape discrimination on a silicon surface barrier detector irradiated with 14 MeV neutrons ☆

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ABSTRACT

Based on two kinds of zero-crossing electronic setups, the particle pulse shape discrimination (PSD) test of a silicon surface barrier (SSB) detector, which was irradiated with 14 MeV neutrons from a d–T reaction, was performed. Good separation between alphas and protons has been achieved. Discrimination thresholds were estimated to be about 3 MeV. The result is comparable with the previous reports, as well as the dynamic range of the two methods discussed in this paper. This work is helpful to use SSB detectors for measuring mixed charged particles spectra induced by neutrons or charged particles.

1. Introduction

Particle identification performs an importance role in nuclear radiation detections. Especially in a mixed radiation field, one often need to identify a certain kind of radiation from the others (e.g. separate neutrons from n/γ mixed radiation field, separate a certain kind of charged particles from the others in nuclear reaction experiments, and so on). Generally, particle identification of a silicon surface barrier (SSB) detector is obtained by using either a TOF technique [1,2] in which a pulsed beam (or a start signal pick off system) and appropriate flight path are needed, or $\Delta E - E$ method [3], whose discrimination threshold is determined by the thickness of ΔE detector, above these limit their applicability.

It is well known that different charge particles make different density of plasma in SSB detector due to their different stopping power, and the total charge collection time reflects the rise time of output signals. Pausch and his colleagues [4–6] have employed the zero-crossing method which has been also widely used in the separation of neutrons and gamma rays in scintillation detectors [7,8] to identify incoming charged particles injected from the rear-side of a (n-type) 4π Si-detector array.

To improve the self-particle identification capability for single SSB detector, and to investigate the difference between particles produced inside of the detector and ones injected from the outside, we performed PSD tests on a SSB detector with two electronic setups of zero-crossing technique. In this work, the different charged particles (alphas and protons) were generated via (n,α) and (n, p) reactions induced by irradiation of the detector with 14 MeV neutrons, which were produced by d–T reaction on the Cockroft–Walton Accelerator at the China Institute of Atomic Energy (CIAE) [9].

2. Experimental details

A totally depleted SSB detector used in this experiment was manufactured by the Ortec Company. The effective area of the detector is 450 mm^2 and the thickness is 500 μm. The detector has a resistivity of 7.8 kΩ cm and full depletion voltage Ud of +125 V, respectively. Fig. 1 shows the schematic diagram of the experiment. The SSB detector was placed in a 14 MeV neutron beam. Then, alphas and protons were produced by the Si(n,α) and Si(n, p) reactions. The output signals from the detector were firstly preamplified by a preamplifier (ORTEC-142B). Then the time signals were modulated by a timing filter amplifier (ORTEC-474) because of their low amplitude. The start time of the signal was identified with a constant fraction discriminator (CFD, ORTEC-935), while the energy signal was amplified by a shaping amplifier (ORTEC-572) with a shaping time of 1 μs, whose unipolar output was used to measure the particle energy (Pulse Height), while bipolar output was used for pulse shape analysis. The zero-crossing time was picked off with a timing single-channel analyzer (ORTEC-551). The time between the start and the zero-crossing of the signal

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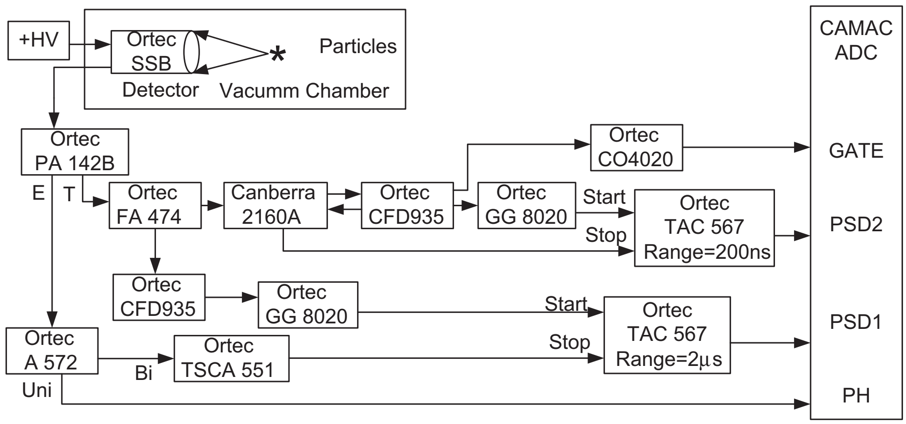

Fig. 1. The experimental setup. CFD (Constant Fraction Discriminator); TSCA (Timing Single-Channel Analyzer); TAC (Time-to-Amplitude Converter); ADC (Analog-to-Digital Converter).

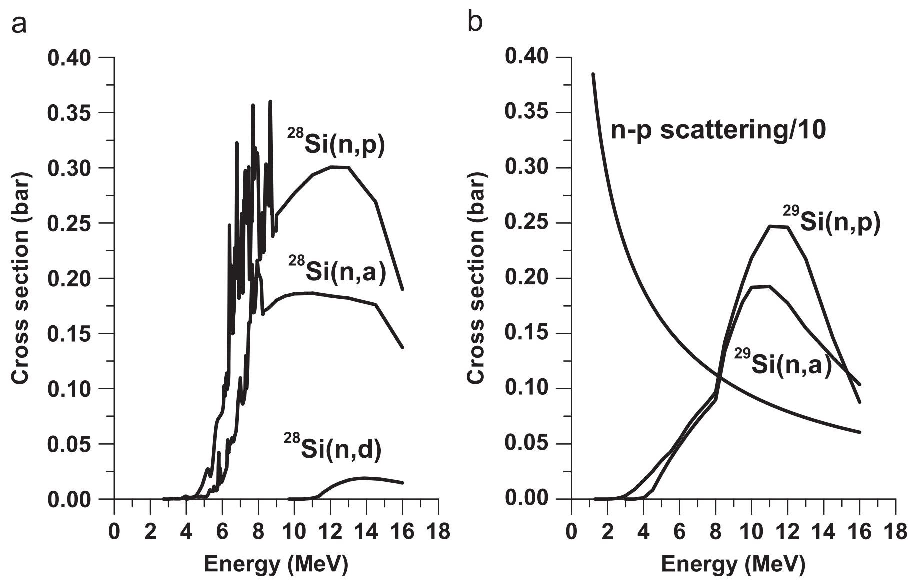

Fig. 2. The corresponding cross-sectional data from ENDF/B-VII.0 [10]. (a) Neutron induced reactions on ^{28}Si; (b) neutron induced reactions on ^{29}Si and n–p scattering (divided by a factor of 10).

served as one of the PSD methods in this work, the other PSD method was realized by analyzing the T output from the 142B with a pulse shape discriminator module (ComTec-2160A), which consists of two successive differentiation circuits to identify the zero-crossing time. Gate and delay generators (ORTEC-GG8020 and CO4020) were used to optimize the time intervals for the time-to-amplitude converter (TAC, ORTEC-567) and to gate the CAMAC ADC for AD conversion. Therefore, the two methods can be performed simultaneously, allowing the particles to be identified in the two-dimensional plot of zero-crossing time versus pulse height.

The main experimental procedure can be described as follows: Step 1. The signal outputs from the detector were carefully tested with a ^{239}Pu alpha source. An operating bias of +80 V was chosen because the energy and time output amplitudes were stable, and the signal/noise ratio was fine. Step 2. Energy calibration of the detection system was performed in a vacuum chamber, where, a thick Th isotope source ($\sim$1 mg/cm^2) was used. It was a complex alpha emitter and deposited on a base of Tantalum. Step 3. The SSB detector was irradiated with 14 MeV neutrons, which were generated by the d–T reaction on the Cockroft–Walton Accelerator at CIAE with E_d=300 keV. It was a practical way to generate alphas and protons inside the detector by neutron induced reactions on Si. The thresholds of the ^{28}Si(n, p), ^{29}Si(n, p), ^{28}Si(n,α), and ^{29}Si(n,α) reactions are 3.999, 2.998, 2.749, and 0.035 MeV, respectively. Fig. 2 shows the corresponding reaction cross-sections [10]. In addition, a thin polyethylene $(CH2)_n$ foil was placed in front of the detector to enhance the proton yield from n–p scattering. Finally, the experiment test was stopped as soon as the counts reached an acceptable statistical accuracy to reduce the neutron damage to the detector.

3. Result and discussion

After calibration, the locations of the alpha particles in the two-dimensional plots (Fig. 3), as well as the linear relationship between the energy and the ADC channel (E=0.0099 × CH−0.042 (MeV)), were obtained.

The results of the PSD tests are shown in Fig. 4. The zero-crossing time were obtained by two independent electronics. PSD2 method analyzed the fast (ns magnitude) time signals, while PSD1 method analyzed the integrated energy signals with a shaping time of μs magnitude and its electronics were suitable for the input signals