Design and simulations for the detector based on DSSSD*

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Abstract The present paper describes the design and simulation results of a position-sensitive charged particle detector based on the Double Sided Silicon Strip Detector (DSSSD). Also, the characteristics of the DSSSD and its testing result were are discussed. With the application of the DSSSD, the position-sensitive charged particle detector can not only give particle flux and energy spectra information and identify different types of charged particles, but also measure the location and angle of incident particles. As the detector can make multi-parameter measurements of charged particles, it is widely used in space detection and exploration missions, such as charged particle detection related to earthquakes, space environment monitoring and solar activity inspection.

Key words DSSSD, identification of charged particle, Monte Carlo simulation

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1 Introduction

The space environment contains phenomena that are potentially hazardous to humans and technological systems. The interaction of space particles with spacecraft materials and electronics components is complex to describe and difficult to simulate with ground-based test facilities. It is also not possible to fully specify the space radiation environment for a given mission because of unknowns in mapping it and in the processes that generate it. The space environment also changes with time, often in unpredictable and undiscovered ways, making it a challenge to completely assess the hazards in any orbit. The description of the space environment requires new terminology for both the hazards and the places where they occur.

In addition, an existing theory model and some observational results shows that high-energy charged particle flux, energy spectrum and projection angle etc. in ionosphere space will change significantly before the occurrence of an earthquake [1–5].

Therefore, the detector performance as a function of particle identification, energy spectra and input angle measurement can provide plenty of detailed charged particle data in space, so as to support space inspection or earthquake prediction work. To this purpose, a specific position-sensitive charged particle detector has been designed and is going to be constructed. The detector shown in Fig. 1 consists of two silicon strips and a scintillator, while the associated electronics are essentially composed of low-noise preamplifiers, shaping circuits and discrete-component amplifiers.

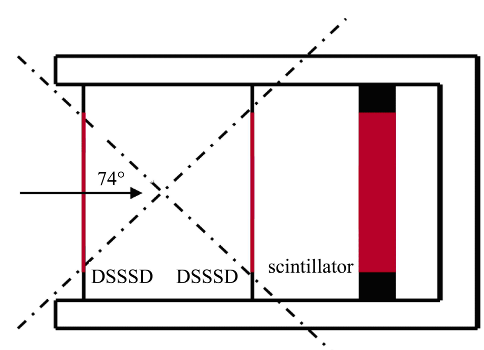

Fig. 1. The structure of the position-sensitive charged particle detector.

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In this paper we present the design and simulation results for the DSSSD-based position-sensitive charged particle detector, its construction details its performance and its testing results.

2 Structure of detector system

To fulfill the requirements of the space environment or seismic exploration detection, the structure of a position sensitive charge particle detector is as follows. As shown in Fig. 1, the front part has a ΔE-E construction, which consists of two 50 mm×50 mm DSSSDs. Both of them can give the two-dimensional position information of incident particles. Thus we can get the angles of incident particles. The ΔE-E technique was used to identify the sorts of particles and to measure their low energy spectra. The second part includes a scintillator calorimeter, which is used to measure the higher energy spectra of charged particles.

The precision of position measurement mainly depends on the strip spacing and the method of readout. As long as only digital information is used and the effects arising from the track inclination and charge diffusion during collection can be neglected, the measurement precision (root-mean-square deviation from the true coordinate) is given by

$$\sigma_x^2 = \frac{1}{P}\int_{-P/2}^{P/2} x^2 \mathrm{d}x = P^2/12.$$

Thus,

$$\sigma_x = P/\sqrt{12},$$

where P is the pitch value of the strip detector, which is the distance between the centers of two adjacent strips [6].

3 Double sided silicon strip detector

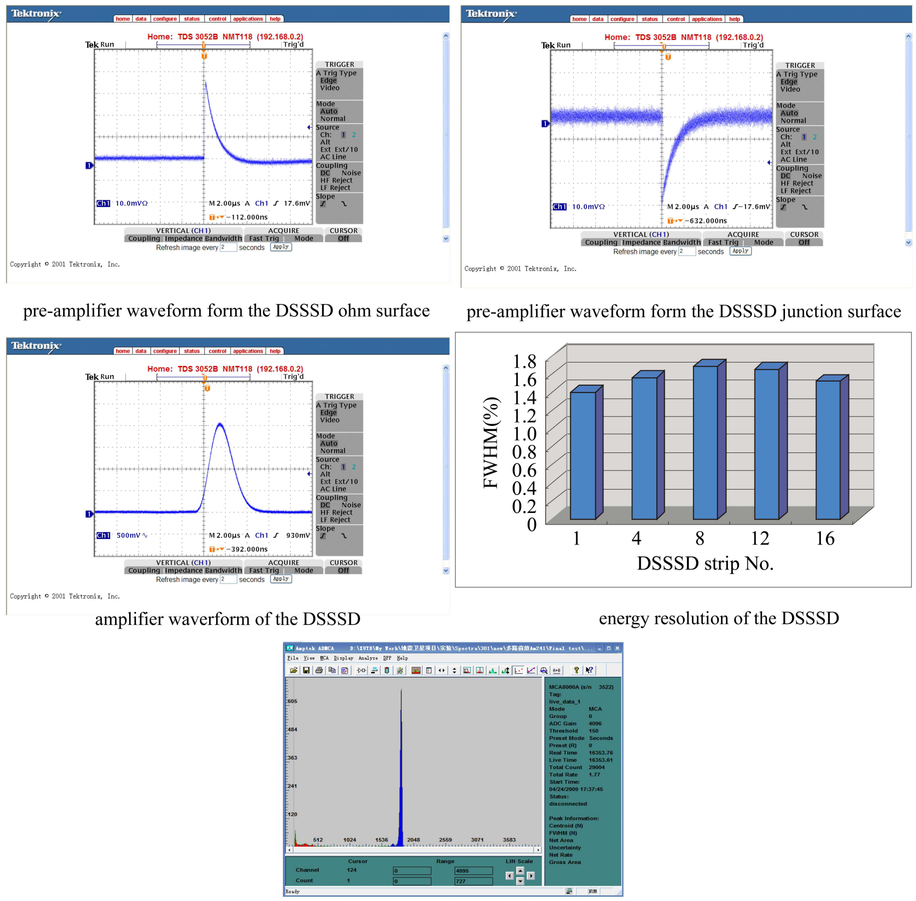
The DSSSDs used in the position-sensitive charged-particle detector are a kind of new silicon semiconductor detector. They have the properties of high position resolution, high energy resolution, wide linear range, fast response time, small size, etc. They offer excellent capabilities for the detection, identification and characterization of radioactive isotopes. These detectors provide enhanced capabilities over the existing systems and have direct applicability in the areas of decontamination and decommissioning (D&D), nuclear materials, spent nuclear fuel (SNF) and mixed waste, as well as for basic laboratory nuclear physics and gamma ray astrophysics. The DSSSD is made by segmenting the contacts of a planar silicon detector. By using ion implantation, or lithography technology, a series of narrow-band electrodes perpendicular to each other were formed on the upper and lower surfaces of silicon. Each strip can be used as an independent silicon detector. The two-dimensional information is gained by segmenting orthogonally on each side of the detector. One dimension is determined by which strip is collecting the electrons and the other dimension by the strip collecting the holes. The energy measurements are obtained from the signal amplitude of either the electron or the hole carrier [7].

Radiation is measured by means of the number of charge carriers set free in the detector, which is arranged between two electrodes. Ionizing radiation produces free electrons and holes. The number of electron-hole pairs is proportional to the energy transmitted by the radiation to the semiconductor. As a result, a number of electrons are transferred from the valence band to the conduction band, and an equal number of holes are created in the valence band. Under the influence of an electric field, the electrons and holes travel to the electrodes, where they result in a pulse that can be measured in an outer circuit. The holes travel in the opposite direction and can also be measured. As the amount of energy required to create an electron-hole pair is known, and is independent of the energy of the incident radiation, measuring the number of electron-hole pairs allows the energy of the incident radiation to be found.

The DSSSDs used in the position-sensitive charged particle detector are of the so-called MICRON design W. This has 16 strips, 50 mm long and 3 mm wide separated by 0.1 mm, on the front face of a 64 μm thick n-type silicon wafer, and 16 orthogonal strips of the same dimensions on the back face. Each front strip consists of a 400 nm thick region of the silicon wafer heavily doped by implantation of acceptor impurities to form a p^+ type material. This p^+ type layer, together with an evaporated layer of 200 nm aluminum, acts as an electrical contact. The back strips are made similarly by implanting donor elements. A penetrating particle induces charge signals in the closest front and back strips, caused by the mobility of ionized electrons and holes, respectively.

If sufficient voltage is applied, the edge effects (of charge-sharing between neighboring strips) are negligible, thus each particle gives rise to a signal from exactly one front strip and one back strip. This tells us which of the 256 pixels of 3 mm×3 mm area, the cross-over regions between front and back strips, was hit. If two or more particles, emitted simultaneously, are detected by the same DSSSD, one should find the right correspondence between the front and back strips by comparing their energy signals. This procedure is also an efficient filter against electronic noise.

A simple test set-up was used for the test of the DSSSD. A multi-channel charge-sensitive pre-amplifier was developed for the DSSSD. The results of the test are shown in Fig. 2. As a result, the DSSSD has an energy resolution of 1.6% (for ^{241}Am in 5.486 MeV α particles), and its position resolution is better than 0.9 mm.



pre-amplifier waveform form the DSSSD ohm surface

pre-amplifier waveform form the DSSSD junction surface

amplifier waverform of the DSSSD

energy resolution of the DSSSD

Fig. 2. Testing results for the DSSSD.

4 Simulation and results

The Geant4 program was used for detector simulation. This article will introduce the simulation results for the position-sensitive charged particle detector so as to achieve the optimized structure and parameters.

Geant4 is a free software package composed of tools which can be used to accurately simulate the passage of particles through matter. All aspects of the simulation process have been included in the toolkit. At the heart of Geant4 is an abundant set of physics models to handle the interactions of particles with matter across a very wide energy range. Data and expertise have been drawn from many sources around the world and, in this respect, Geant4 acts as a repository that incorporates a large part of all that is known about particle interactions [8, 9].

4.1 Simulation of the energy deposition

The ΔE-E method was used for the energy spectra measurement of charged particles and particle identification, and simultaneous measurement of particle flux. The ionization energy loss rate of the particles in materials can be approximately described by the Bethe-Bloch formula,

$$-\frac{\Delta E}{\Delta x}=\frac{4\pi z^2e^4NZ}{M_{\rm e}v^2}\left[\ln\frac{2M_{\rm e}U^{-2}}{I(1-\beta^2)}-\beta^2-\left(\delta+\frac{c}{z}\right)\right].$$

The formula can be simplified to:

$$\Delta E\cdot E\propto MZ^2\Delta x.$$

By measuring the particle energy loss ΔE in the front Si detector and E in the end detector when particles pass through the detector system, considering their relation with particle mass and charge, we can distinguish different sorts of particles from each other.

Figure 3 shows the Geant4 simulation of electrons and protons at different energies in the ΔE-E detectors (DSSSD thickness is 150 μm and 300 μm, respectively) in the group of energy deposition. The results show a good ability of the detector to identify different types of charged particles. The relation between incident energy and deposit energy of electrons and protons in each layer of the detector and their total energy are shown in Fig. 4. With it, we can construct the original energy spectra through the measured energy spectra.

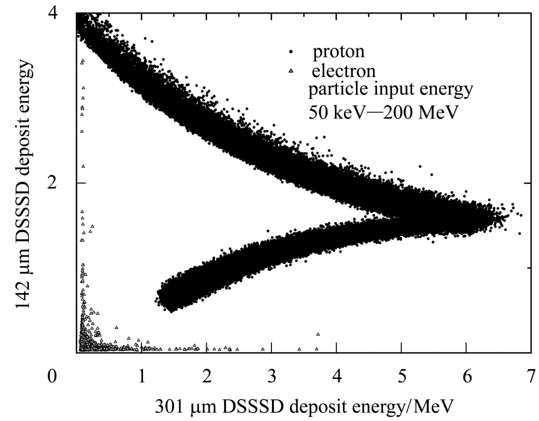


Fig. 3. Energy deposition of different energies of electrons and protons in the ΔE-E Si detectors.

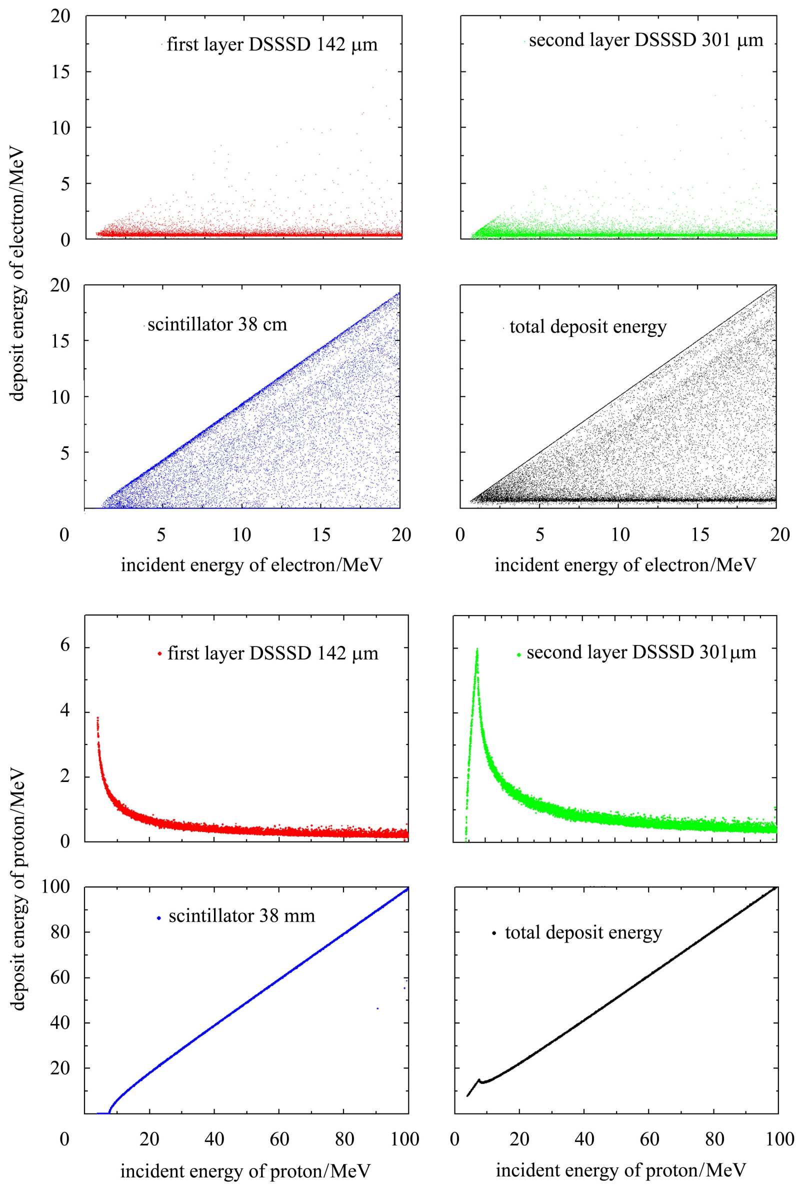


Fig. 4. The deposit energy vs. incident energy of electrons and protons in each layer of the detector and the total energy.

The results show that the position-sensitive charged particle detector with the current design parameters can effectively identify different particles and make specific energy spectrum measurements for charged particles.

4.2 Simulation of the incident particle position

By using the double-layer DSSSD, it's possible to determine the incident particle position and make angle measurements.

As mentioned above, the position resolution of the strip detector can be given by

$$\sigma_x = P/\sqrt{12}.$$

The angular resolution of the position-sensitive detector is

$$\sigma\theta^2 = \frac{\sigma_{x1}^2+\sigma_{x2}^2+\sigma_{\mathrm{s}}^2}{z^2}.$$

Among them, σ_{x1}, σ_{x2} are the first and second detector position resolution, respectively. σ_{s} is the positional deviation of electrons caused by its scattering when electrons pass through the first DSSSD, and Z is the distance between the two DSSSDs. The simulation results show that for protons and α particles, the position deviation caused by scattering with the 150 μm thick DSSSD is very small. But a larger deviation in position was found when electrons passed through the first piece of the DSSSD because of the scattering (Fig. 5). In order to achieve the best detector performance, thorough considerations of the DSSSD thickness, spacing, the incident particle energy and other factors are needed.

Figure 6 shows the simulation results for the detector pitch angles under conditions of different DSSSD thicknesses with different spaces between them. The results show that the angular resolution of the detector can reach 4° for electrons with incident energy larger than 1.7 MeV by using a 60 μm thick DSSSD as the ΔE detector; and for electrons with incident energy larger than 3.0 MeV, the angular resolution of the detector can reach 4° by using a 150 μm thick DSSSD as the ΔE detector.

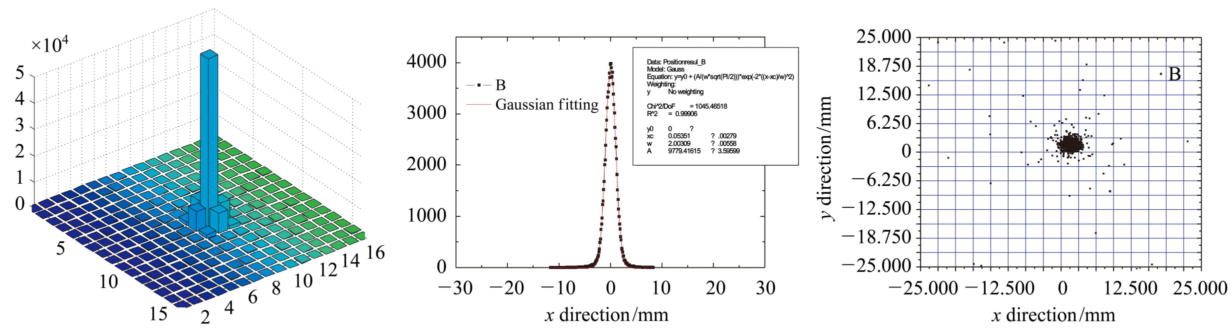


Fig. 5. Incident electron in the detector's position resolution simulation results.

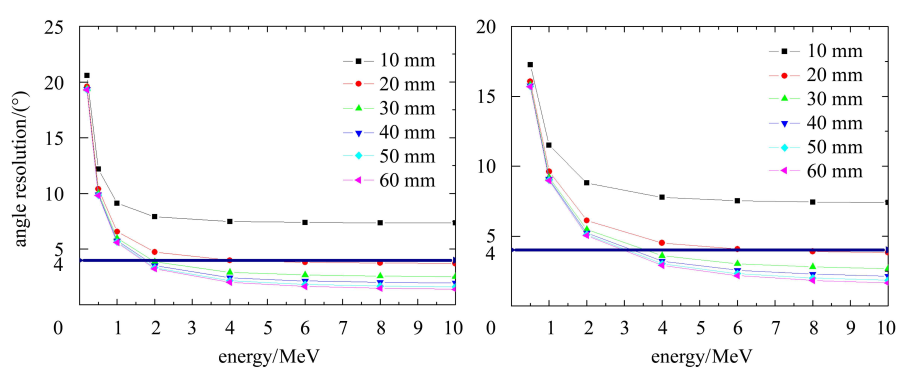


Fig. 6. The calculated results for the detector angle resolution under different conditions (thickness on the left is 60 μm, and on the right is 150 μm).

5 Summary

A position-sensitive charged particle detector based on DSSSD was simulated for energy spectra, incident angle measurement and charged particle identification. The characters of the new DSSSD were discussed and its testing result was shown. The results show that this detector with the current design parameters can effectively identify different particles and make energy spectra and angular measurement for charged particles.

As the detector can make multi-parameter measurements of charged particles, it has wide application fields in space detection and exploration missions, such as charged particle detection related to earthquakes, space environment monitoring and solar activity monitoring.

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