Characterization of novel square-bordered position-sensitive silicon detectors with a four-corner readout

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We report here about systematic investigation studies performed on silicon position sensitive detectors recently developed in collaboration with Micron Semiconductor Ltd. [1]. The interest in the fabrication of the kind of detectors described in the following was initiated by Micron Semiconductor under contract with the Japan Aerospace Exploration Agency (JAXA) interested to invest in its ongoing GEOTAIL mission observing the magnetosphere of Earth [2]. Measurement of elemental and isotopic composition in the solar energetic particles (SEP) and galactic cosmic rays (GCR) provides important information for understanding the stellar nucleosynthesis, the chemical evolution of the galaxy and the history of the solar system material. In addition, it offers new possibilities for the study of particle acceleration and transport mechanism in the solar/stellar atmosphere and interplanetary/interstellar space. The High Energy Particle Experiment in the GEOTAIL satellite program was constructed to measure the composition of heavy ions in space. A particle telescope not only with a large geometric factor but also with a high mass resolution is required for an isotopic observation of elements from He up to the Fe group nuclei in SEP and GCR. The particle telescope aboard the satellite consists of a stack of Si detectors and uses the well-known ΔE-E algorithm for mass identification. An increase of the geometric factor of the telescope is realized by the use of Si detectors with a large sensitive area combining position-sensitive detectors (PSDs) to the telescope for the determination of particle trajectories. The energy loss in a ΔE-detector varies accordingly with the incident angle of a particle to the plane of the detector. To determine the mass of a particle with high resolution, information concerning the incident angle at which the particle passes through the ΔE-detector is needed to minimize the uncertainty of the path length, hence good position resolutions for the PSDs are demanded.

Using ^{241}Am and ^{228}Th alpha sources as well as various possible beams like — $^{63}Cu^{21+}$ at 40 AMeV, 30 AMeV, 15 AMeV, $^{16}O^{8+}$ at 60 AMeV, 45 AMeV, 30 AMeV, 16 AMeV, 7 AMeV, and $^{4}He^{1+}$ at 25 AMeV, 20 AMeV, 15 AMeV, 7 AMeV — delivered by the K500 cyclotron of Texas A&M University at the SEE LINE of the Radiation Effects Testing Facility, we have examined basic characteristics of the large position-sensitive detectors in terms of their most important operation parameters: position resolution along with position non-linearity determination (the strength of the so-called "pin-cushion" pattern), as well as energy resolution.

The detectors investigated, at least 27 in total, are continuous PSDs of four-corners type with an active area of 62 mm × 62 mm, and of three thicknesses namely 200 μm, 250 μm and 400 μm. The boron-implanted resistive layer on the n-type Si surface serves as the resistive anode for the charge division and forms the p-n junction. There is a phosphorus implantation for the n side. The front (position sensitive) electrode of the PSDs is a square-shaped resistive anode of surface resistance $R_{\square}$, bordered by additional resistive strip lines with a low resistance per unit length, R_L. The width of the strip lines, *w*, is 0.5 mm. Four electrodes, one at each corner of the anode are formed from aluminum contacts. The four signals generated at these contacts are used to determine the position of the incident ion. A fifth signal is taken from the rear face of the detector via an aluminum-evaporated contact (the ohmic contact). This signal provides an independent energy measurement. A collimation plate with a 11×11 matrix of pinholes with diameter of 1 mm and spacing of the pinholes of 5 mm (from center to center) was placed in front of the detectors for non-linearity and position/energy resolution determination.

Exactly 20 years ago, T. Doke *et al.* [3] developed a type of position sensitive silicon detector (PSSD) which provided an excellent two-dimensional position linearity using resistive charge division. They found that, if $R_{\square}$ is larger than $R_L \times L$ (where L is the length of the squared-shaped anode) by a factor of 10 to 15, the resultant deformation of the position pattern was greatly reduced and the non-linearity was found to be less than 2%. Since then, this kind of design rule was used as a standard in large area continuous PSDs fabrication technology.

In our work, we have found a new design rule: with a factor of 2 between the sheet surface resistance and the low resistance strip, we could obtain non-linearity in the position deformation pattern less than 1%. The results of our work are discussed at length in a forthcoming NIM publication [4]. Here we just summarize them in an illustrative manner as per following figures.

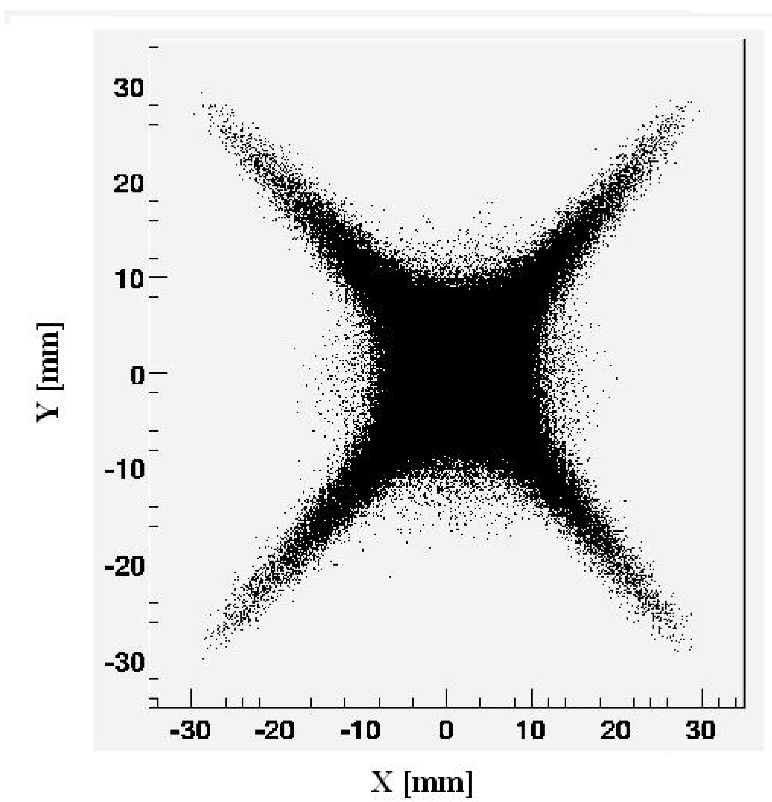

Figure 1. Two-dimensional pattern for PSD without a resistive strip connecting two adjacent corners of the resistive squared-shaped anode: the design rule we started with.

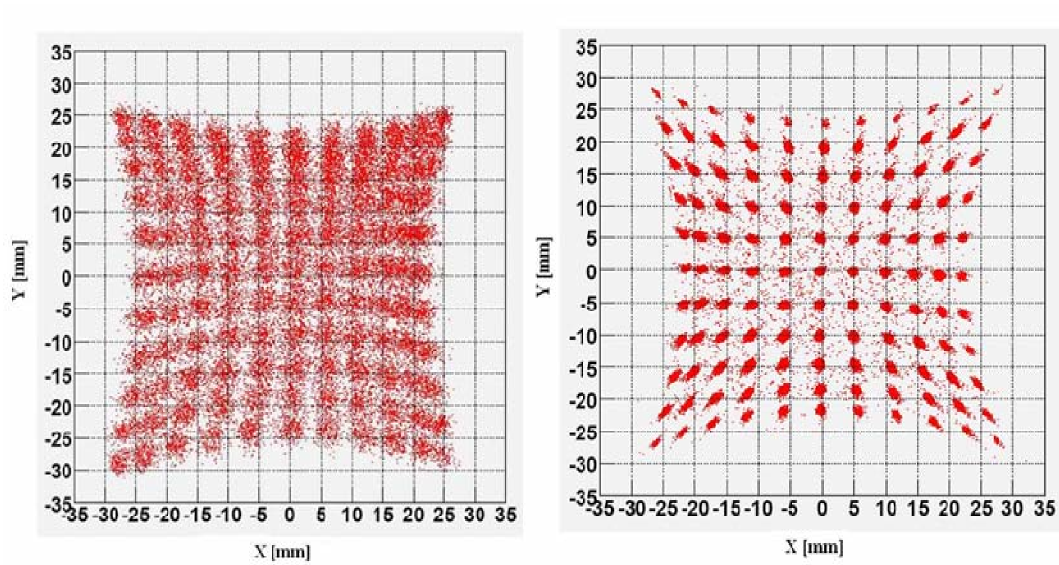

Figure 2. Two-dimensional patterns for PSD with resistive strip connecting two adjacent corners, tested with alpha source (left) and tested with beam (right). In-beam data shows better position resolution due to larger energy loss deposed in the detector.

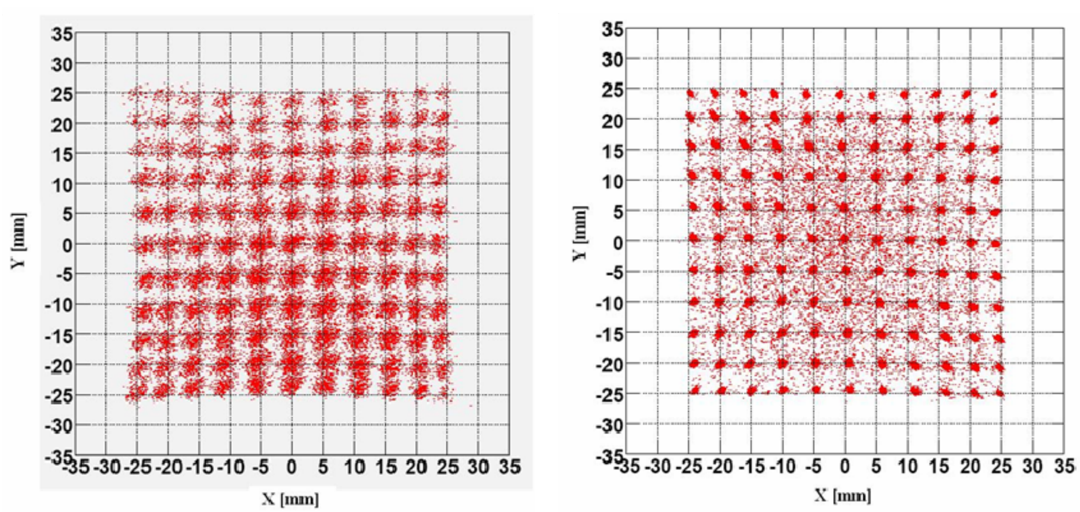

Figure 3. Two-dimensional patterns for PSD with resistive strip connecting adjacent corners, tested with alpha source (left) and tested with beam (right). Here we applied the design rule with a ratio of 2 between anode sheet resistance and the resistance of the resistive strip, unlike Figure 2 for which a ratio of 0.23 was used in the design.

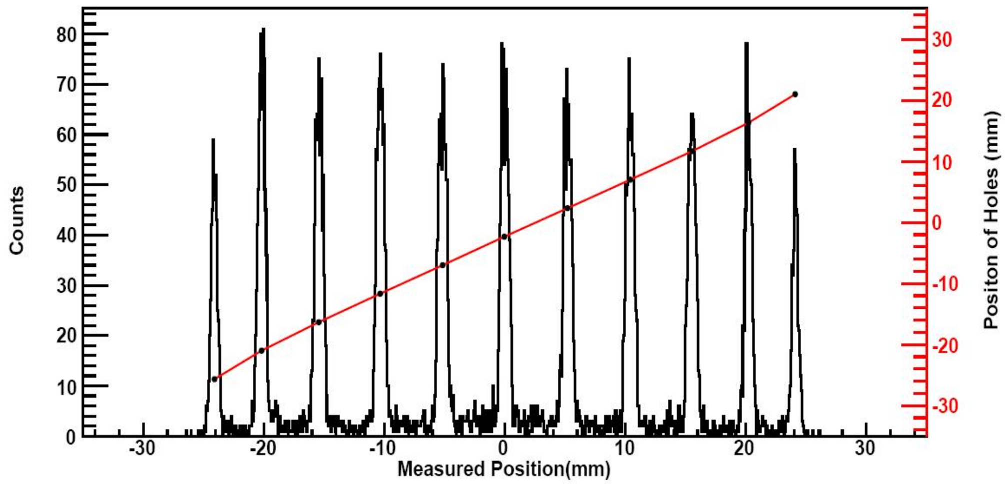

Figure 5. Non-linearity of less than 1% determined along the X position of PSD manufactured with the new design rule and tested with beam using the collimating plate with a matrix of 11 × 11 pinholes. The red line is to guide the eyes with respect to variation of the non-linearity along the central row on the collimating plate on the detector X position. In this case a position resolution of 0.69 (7) mm (FWHM) was measured.

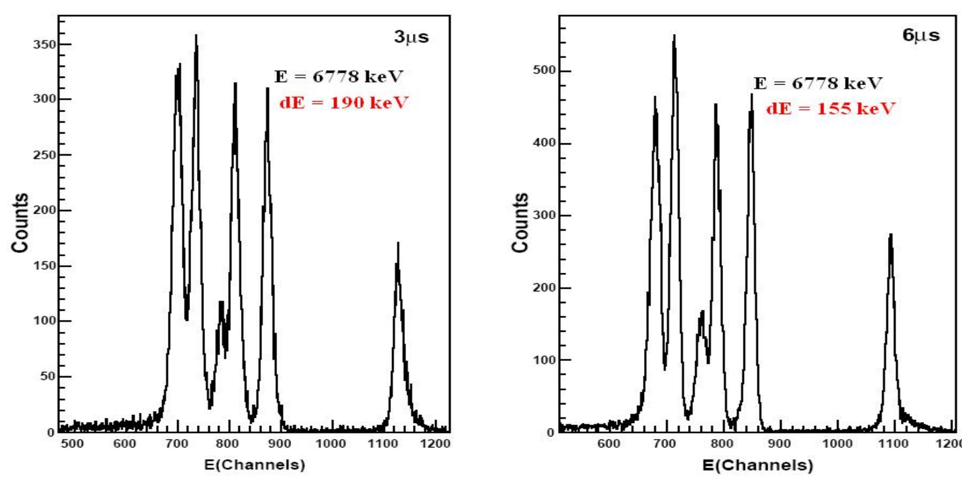

Figure 4. Energy resolution (dE/E) measured with ^{228}Th source measured for 3 μs (left) shaping time as being of 3% (FWHM) and for 6 μs (right) shaping time as being of 2% (FWHM).

[1] www.micronsemiconductor.co.uk

[2] H. Matsumoto *et al.*, Jpn. J. App. Phys. **44**, 6870 (2005).

[3] T. Doke *et al.*, Nucl. Instrum. Methods Phys. Res. **A261**, 605 (1987).

[4] A. Banu *et al.* (to be published).