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New test and analysis of position-sensitive-silicon-detector *

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Abstract We have tested and analyzed the properties of two-dimensional Position-Sensitive-silicon-Detector (PSD) with new integrated preamplifiers. The test demonstrates that the best position resolution for 5.5 MeV α particles is 1.7 mm (FWHM), and the best energy resolution is 2.1%, which are notably better than the previously reported results. A scaling formula is introduced to make the absolute position calibration.

Key words position sensitive, position distortion, particle telescope, charge division method

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1 Introduction

Position sensitive telescope for charged particle detection is of special importance in the scattering and reaction experiment with radioactive nuclear beam. Position-Sensitive-silicon-Detectors (PSD) or silicon strip detectors are often used as the first one or two layers in the telescope. In general strip detector has better position resolution and can accept higher counting rates, but it gives very large number of output channels, each of which must be followed by preamplifier and other main electronics. In contrast PSD, based on the so called charge division method, has only four position signal outputs and one energy signal output, at the cost of a little worse position resolution[1—3] and lower counting rate. Radioactive nuclear beam has in general low intensity and therefore the detection counting rate is relatively small. In this case application of PSD has its inherent advantages such as simple setup, much less related electronics channels and low cost.

In China, in the past few years PSD has been used previously by several groups using the traditional isolated pre-amplifier[4—7]. Along with the increased complexity of the experiment more compact electronics is urgently required. The first step is to use the integrated pre-amplifiers which are normally placed close to the detector where the space for experimental setup is generally very limited. This integration may introduce some unexpected problems such as cross talk and heat noise, etc., and affect the position and energy resolution. Therefore careful test must be done before the application of PSD to real physics experiment.

In this article we report the test results of five PSDs linked to integrated pre-amplifiers which were made in our laboratory.

2 The experiment

The tested PSD is an ion implantation type silicon detector (S5379-02) produced by Hamamatsu Photonics. Its sensitive area is 45 mm×45 mm, with a thickness of (325±15) μm. The Boron ions are implanted into the n type silicon base material to form the anode of the photodiode with a large surface resistance (typical resistance per unit square 20 kΩ). Additional low resistance line (typical resistance 2 kΩ) was made around the sensitive square area in order to transmit the signal to the four corners, where the position signals are read out. The total energy signal is read from the cathode which is a gold layer covering the back surface of the base silicon wafer. The full depletion voltage is 80 V (maximum 100 V) with

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a typical dark current of 30—100 nA and a detector capacity of 780 pF.

Linked to the PSD are the new integrated preamplifiers which are made by AD series chips together with 2SK152 Field Effect Tubes (FET). One box hosts eight channel preamplifiers built on 4 small electrical circuit boards. As shown in Fig. 1, the signal to noise ratio, tested by using 5.5 MeV α particles, is increased from 100 mV/15 mV≈7 for the previously designed single channel A250 preamplifier[7] to 190 mV/10 mV=19 for the newly designed integrated preamplifier, due to the better treatment of the circuit distribution and shielding. Also the cooling circuit is built on the box so that the whole box could be placed inside a vacuum chamber to have much better anti-interference performance.

For the test experiment, ORTEC-572 unit is the main amplifier for the total energy channel whereas 4066 unit is used for the position signal amplification. In addition, CF8000 unit (octal Constant Fraction discriminator) and GG8000 unit (Gate Generator) are used to provide the trigger and gate signals. The data are acquired by the CAMAC system with CC7700 controller.

In the test experiment ^{241}Am radioactive source was used, which provides α particles at 5.486 MeV (85.2%) and at 5.443 MeV (12.8%). The best energy resolution of 2.1% at 5.5 MeV was obtained when a shaping time of 6 μs was used for 572 amplifiers. For comparison we note that the previously reported energy resolution is 2.4% for the same PSD but with the single channel A250 preamplifier[7].

If A, B, C, D denote four position signals taken from the four corners of PSD, the position of the penetrating particle can be determined by:

Method 1[1, 2]:

$$\frac{X}{L} = g_x \frac{(C+D)-(A+B)}{A+B+C+D}, \quad \frac{Y}{L} = g_y \frac{(B+C)-(A+D)}{A+B+C+D}, \tag{1}$$

where g is a size calibration factor which might be obtained from the adjustment of the spectrum size to the real detector size.

Method 2[4]:

$$\frac{X}{L} = w_x \frac{(C+D)-(A+B)}{E}, \quad \frac{Y}{L} = w_y \frac{(B+C)-(A+D)}{E}, \tag{2}$$

where E is the total energy, and w the size calibration factor. We use these two methods to analyze the position resolution.

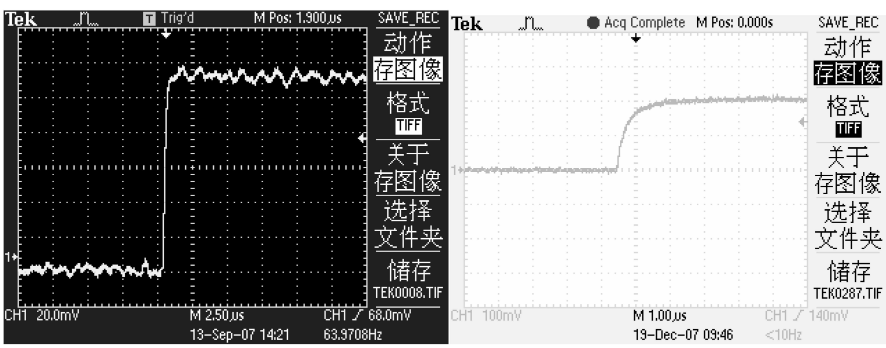

Fig. 1. Signal taken from the A250 preamplifier (left, time 2.5 μs/unit, amplitude 20.0 mV/unit), and from the new integrated preamplifier (right, time 1.0 μs/unit, amplitude 100mV/unit).

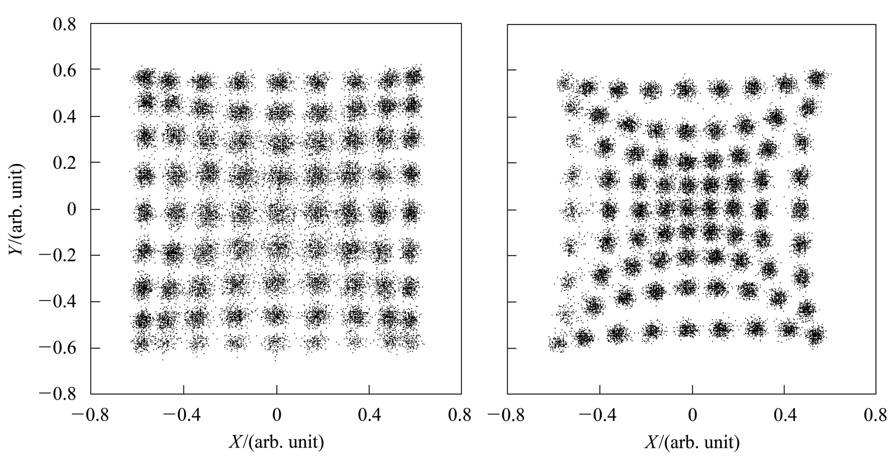

Fig. 2. PSD position spectra obtained with Method 1(left) and 2(right), corresponding to a mask with 9×9 holes. The horizontal and vertical axes present X and Y relative coordinates, respectively.

A collimation mask with 9×9 holes was installed 5 mm in front of the PSD, with distance between the centers of two adjacent holes being 5 mm and the diameter of the hole 0.5 mm. ^{241}Am radioactive source was placed 20 cm away from the collimation mask. Fig. 2 (left and right) shows the experimental position spectra obtained with Method 1 and Method 2, respectively. The average position resolution is 1.7 mm (FWHM) with Method 1 and 2.0 mm (FWHM) with Method 2. Both spectra show some distortion at the edge area compared with the real hole distribution on the mask. The reason of the distortion is analyzed and could be restored by applying the scaling formula, as described below.

3 Analysis for distortion and scaling formula

The reason for the distortion of PSD position spectrum has been explained previously[7], but only in an analytical way. The calculation shows that the time needed for a output channel to collect the charge spreading on the detector surface is related to the position of the particle traveling across the PSD. For instance, for a particle traveling near a corner, the charge collection (at a 99% level) time at this corner is about 0.1 μs whereas the time is as large as 1.5 μs for the counter side signal output.

We may describe the distortion quantitatively based on the formulas presented in Ref. [1]. The charge amplitude for four corners (symbolized by P_1, P_2, P_3 and P_4) and that for the total energy (symbolized by E) as a function of time (t) and position (X,Y) are given as:

$$Q_{P_1}(t;X,Y) = \frac{4Q_0}{\pi^2}\sum_{m,n=1}^{\infty}\frac{1}{m\cdot n}\sin\frac{m\pi X}{L}\times \sin\frac{n\pi Y}{L}(1-e^{-t/\tau_{mn}}),$$

$$Q_{P_2}(t;X,Y) = -\frac{4Q_0}{\pi^2}\sum_{m,n=1}^{\infty}\frac{(-1)^n}{m\cdot n}\sin\frac{m\pi X}{L}\times \sin\frac{n\pi Y}{L}(1-e^{-t/\tau_{mn}}),$$

$$Q_{P_3}(t;X,Y) = \frac{4Q_0}{\pi^2}\sum_{m,n=1}^{\infty}\frac{(-1)^{m+n}}{m\cdot n}\sin\frac{m\pi X}{L}\times \sin\frac{n\pi Y}{L}(1-e^{-t/\tau_{mn}}),$$

$$Q_{P_4}(t;X,Y) = -\frac{4Q_0}{\pi^2}\sum_{m,n=1}^{\infty}\frac{(-1)^m}{m\cdot n}\sin\frac{m\pi X}{L}\times \sin\frac{n\pi Y}{L}(1-e^{-t/\tau_{mn}}),$$

$$Q_E(t;X,Y) = \frac{4Q_0}{\pi^2}\sum_{m,n=1}^{\infty}\frac{1-(-1)^m-(-1)^n+(-1)^{m+n}}{m\cdot n}\times \sin\frac{m\pi X}{L}\sin\frac{n\pi Y}{L}(1-e^{-t/\tau_{mn}}).$$

where $\tau_{mn}=RC(m^2+n^2)^{-1}/\pi^{-2}$. The typical signal decay time for PSD is RC/π^{-2}=1.58 μs. We assume T the charge collection time of the whole electronics system and P the relative time $P=T/(1.58\ \mu s)$. Fig. 3 and 4 show the calculated position spectra with Method 2 and 1, respectively, by applying various cuts on the charge collection time. With Method 2 (Fig. 3), the distortion is resulted only from the incomplete charge collection from the four corners, which appear as numerators in Formula 2, while the total energy E, which appears as denominator, is almost uniform for any position. In contrast, with Method 1 (Fig. 4), the incomplete collection of charge affects both the numerator and denominator, and

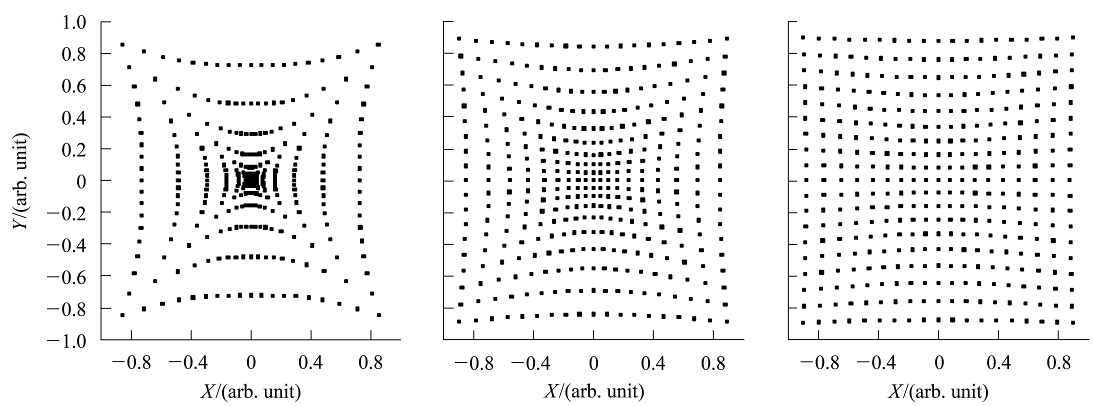

Fig. 3. The calculated position spectra with Method 2 for different charge collection time (from left to right P=0.1, 0.3, 0.5). The horizontal and vertical axes present X and Y coordinates, respectively.

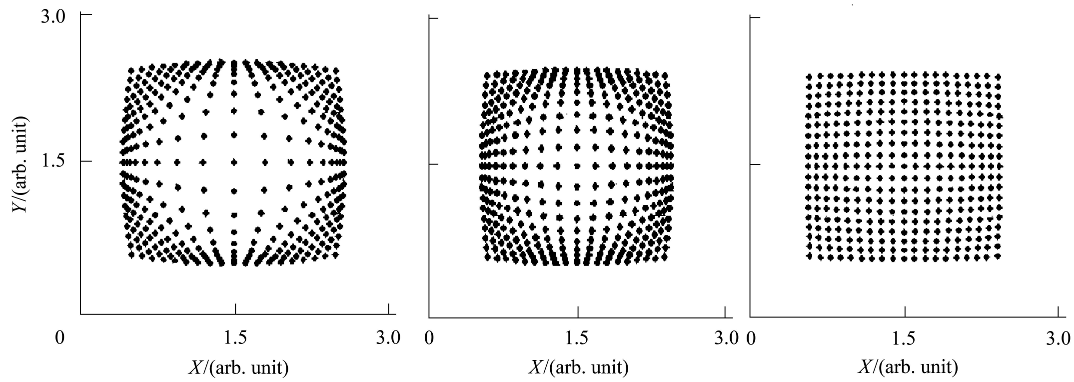

Fig. 4. The calculated position spectra with Method 1 for different charge collection time (from left to right P=0.3, 0.5, 1.2). The horizontal and vertical axes present X and Y coordinates, respectively.

result in a reversed distortion. In reality the distortion may be caused by more complicate reasons such as preamplifier timing characteristics and the band width match between the preamplifier and the main amplifier. Therefore the observed distortion may be different from the above simple analysis especially for spectrum with Method 1, as shown in Fig. 2 (left picture).

Another correction which needs to be dealt with is the so called "absolute area" correction[7], namely the factors g or w in Formula (1) or (2) respectively. This factor can be obtained by converting the observed relative coordinate spectrum to the corresponding real size of the detector area.

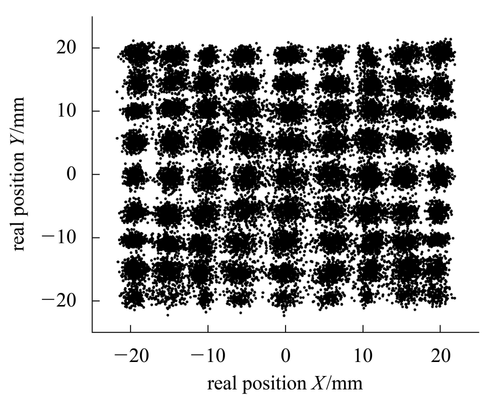

Fig. 5. The PSD position spectrum after applying the scaling formula as described in the text.

We now define a scaling formula which takes into account both the distortion correction as well as the absolute size correction. If (X,Y) is a position directly measured based on Method 1, and (X^0,Y^0) is the corrected position, we find:

$$X^0 = 22.5\times 1.53\cdot\left(X - 0.4XY^2\cdot \mathrm{e}^{-\left(\frac{|X|-0.4}{0.12}\right)^2}\right) \quad (3)$$

and the same for Y^0 (just exchange X and Y in Eq. (3)). After applying this formula onto every event plotted in the left picture of Fig. 2, we get Fig. 5 in which all the coordinates now correspond to the real position. This scaling formula can then be applied to physics experiment detection without the mask. The similar method could also be applied to position spectrum taken with Method 2.

4 Application and conclusion

PSD together with the new integrated preamplifier were tested and a position resolution of less than 2 mm was obtained which is better than the previously reported result of 2.3 mm. The distortion of the position spectrum is theoretically analyzed by applying different charge collection time to the charge propagation formula. A simple scaling method is proposed to restore the position spectrum to its real distribution.

Si-CsI telescope has been one of the most reliable systems for charged particle detection. Two physics experiments of our group, aiming at the cluster structure of ^{16}C and proton halo structure of ^{17}Ne, were recently completed at the Radioactive Ion Beam Line in Lanzhou (RIBLL). Eight sets of these kind telescopes, together with the new integrated pre-amplifier, were successfully used in both experiments and generated good data which are actually under physics analysis.

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