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A high energy resolution 4cm-wide double-sided silicon strip detector

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Abstract

Double-sided silicon strip detectors (DSSD) with an energy resolution of 1-2 keV (FWHM) are attractive devices for future hard X-ray and soft Gamma-ray applications. For example, they are well suited as scatterer detectors for semiconductor Compton telescopes working in the sub-MeV to MeV band, as well as imaging spectrometers in the hard X-ray band. In this paper, the performance of newly developed 4 cm-wide DSSDs is presented.This DSSD has an active area of 38.4 mm times 38.4 mm, with a thickness of 300 μm. The stip pitch is 400 μm. The detector shows an average energy resolution of 1.5 keV (FWHM) for 59.5 keV gamma-rays,operated at -20°C with a bias of 100 V. A 22 keV hard X-ray image is also obtained with 400 μm resolution.

Keywords: DSSD; hard X-ray imaging spectroscopy;
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1. Introduction

Double-sided silicon strip detectors (DSSDs) are a popular technology as a position sensitive detector based on semiconductor materials (see e.g. [1] and references therein). They can cover a large area using relatively small number of read-out channels with a positional resolution as good as ~100 μm and timing resolution of ~100 ns. However, obtaining a high energy resolution, as good as 1-2 keV, together with large area at the same time is not easy.

We are developing a DSSD technology with special emphasis on the energy resolution. Based on the results from several test devices, we developed a 2.56 cm wide DSSD [2][3]. Combined with VA32TA low noise analog VLSI (manufactured by Ideas ASA, Norway), the 2.56 cm DSSD system has shown an energy resolution of 1.26 keV in full width at half maximum (FWHM) for 59.5 keV gamma-ray line emission. At the same time, it has a position resolution of 400 μm, enabling us to obtain hard X-ray imaging spectroscopy on a photon-by-photon basis [4].

Our research is aiming at exploring the univerese in the energy band from ~10 keV to the MeV range. As presented elsewhere (e.g. [5][6]), a semiconductor Compton telescope (SCT) is one of the key technologies to explore this energy band. With superior energy and position resolution, SCT can trace the photon Compton scattering very precisely. Improved accuracy leads to better angular resolution, and hence higher sensitivity. We are proposing a SCT based on Si and CdTe devices [5][7][8][9][10]. In our project, DSSD is the key device to be used as a scatterer detector.Therefore, a larger volume and higher energy resolution with sufficient positional resolution is required for our DSSDs.

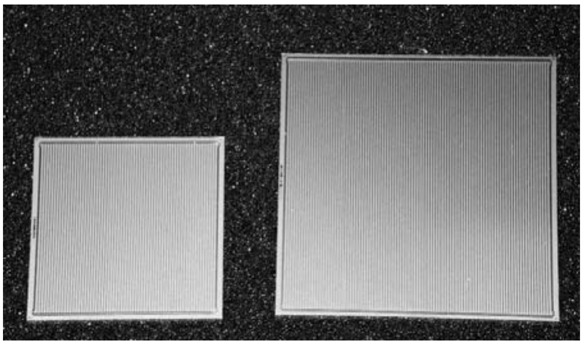

Figure 1. Photo of the 4 cm DSSD (right) compared with the 2.56 cm DSSD (left).

In this paper, we present the results from our newest device, a 4 cm-wide DSSD. The detector is based on the 2.56 cm DSSD technology.The design and basic performance is presented in section 2, and the imaging and spectroscopy properties are shown in section 3 and 4, respectively. A brief summary and current status of our DSSD project is described in the last section.

Table 1: Specification of the 4cm-wide DSSD.

Active area	38.4 x 38.4 mm^2
Detector Thickness	300 μm
Strip pitch	400 μm
Strip cap	100 μm
Number of strips per side	96
Full depletion voltage	~ 80 V
Strip capacitance	10 pF

2. The 4 cm DSSD design

The basic parameters of the 4 cm DSSD is summarized in table 1. It is a 38.4 mm x 38.4 mm large detector with 300 μm thickness and with 400 μm positional resolution. The detector is fabricated using the same technologies as those used for the 2.56 cm DSSD [2], manufactured by Hamamatsu Photonics, Japan. Basically, it simply increases the detector area by a factor of 2.25 (see Fig.1). The p-side is the junction side with 96 strip electrodes and n-side is the ohmic side with also 96 strips orthogonally oriented. The DSSD does not employ an integrated AC capacitor, so the detector bias is applied through the strip electrodes.

Total strip capacitance is measured to be 10 pF per strip. The inter-strip capacitance is 5 pF and the body is 5 pF. These measurements are held at room temperature with a bias of 100 V.The ratio of the total strip capacitance between this device and the

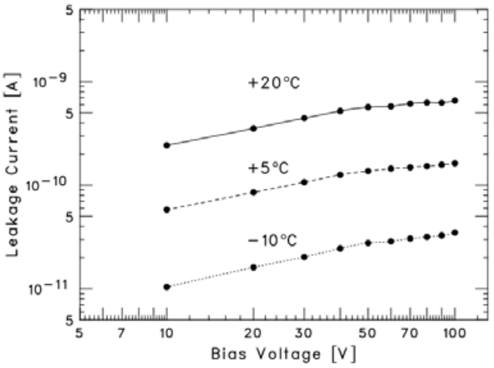

Figure 2. Leakage current of the 4 cm DSSD measured with various temperature.

2.56 cm DSSD is ~ 1.6, in good agreement with the geometric area ratio of 1.5. The I-V curve of the detector is presented in Fig.2. The leakage current at 20^{o}C is measured to be 660 pA per strip at a bias of 100V, while that in -10^{o}C is 35 pA per strip.

3. Detector set up and the gamma-ray image

The 4 cm DSSD is mounted on a structure made of aluminum ceramic, and read out with specially designed low noise analog VLSI, VA32TA.The VA32TA has an input of 32 channels and can be used in both positive and negative input charge. Six chips in total are used in the system. The p-strips are directly connected to the VLSI inputs while n-strips are connected via RC-bias chips from which a positive bias is applied to the DSSD. A RC chip is made of 32 sets of polysilicon bias registers of 5 GΩ and coupling capacitances of 50 pF. The VLSIs are mounted on the front-end-cards we commonly use for the studies of DSSDs and CdTe detectors (see e.g.[7]).

By using the 2-dimensional information from the p-side and the n-side, we demonstrate the imaging capability of the DSSD. In Fig.3, a 22 keV line image of a brass mask is presented. The image was obtained in 24 hours, with a read out rate of about ~5 Hz. The operation temperature was 5^{o}C and the bias was 100V. Although five channels are disabled due to high noise, a 400 μm resolution 38.4 mm wide image is clearly obtained. Note that this image is created by selecting the gamma-rays within the energy band from 15 to 30 keV.

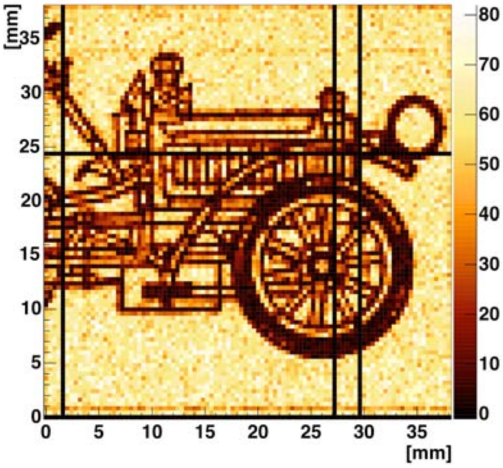

Figure 3. ^{109}Cd 22 keV line X-ray image of a 0.4 mm thick brass maks with a shape a classic car.

4. Spectral performance

Spectral performance is the key of this device.We cooled the detector down to -20^{o}C and irradiated gamma-rays from an ^{241}Am source. In Fig.4 we present the summed spectra of 89 channels out of 96 p-strips. An energy resolution of 1.5 keV (FWHM) at 59.5 keV is obtained. The bias voltage was set at 110 V, and the peaking time of the shaping amplifier was set at 4 μs. Events with only one channel exceeding 8.0 keV in 96 channels are selected in the analysis.

As already reported[4], the 2.56 cm DSSD has an energy resolution of 1.26 keV (FWHM) at the same condition. Assuming that the read out noise is caused by the detector capacitance, simply scaling this result by the strip size gives $1.26 \times \sqrt{1.5} = 1.54$ keV. This value is generally consistent with our results. On the other hand, we can estimate the expected energy resolution of the 4 cm DSSD from the noise performance of the VA32TA chip itself. Following Tajima et al. (2004)[4], the noise component can be calculated as follows: pre-amplifier noise of 1.0 keV at input capacitance of 10 pF, shot noise of 0.2 keV at leakage current of ~15 pA, thermal noise from bias register of 0.2 keV at 5 GΩ, and Poisson noise of 0.4 keV at 60 keV input. The total noise thus expected is

1.1 keV (FWHM). Therefore, an unknown noise source is still hidden in this setup.

By analyzing the data strip by strip, we find that the resolution ranges from 1.0 to 2.0 keV, peaking at 1.4 keV. Among them, 8 strips show energy resolution better than 1.2 keV. This fact suggests that at least in these channels, the currently measured noise performance reaches or is very near to the inherent maximum of the detector system.We will continue improving the performance to obtain a better resolution as a whole.

5. Conclusions and future projects

A 4 cm-wide DSSD system with an energy resolution of 1.5 keV (FWHM) at 59.5 keV is demonstrated. The detector has an active area of 14.7 cm^2, with a thickness of 300 μm. This corresponds to a volume of 0.4 cm^2. It also has a positional resolution of 400 μm. Because the trigger part of the VA32TA LSI has a shaping time of 300 ns, a timing resolution of <500 ns can be obtained in principle as well.

Although the properties of 4 cm DSSDs are sufficient to be used as scatterer detectors in a SCT, we need more volume. Our goal is to collect a volume of ~300 cm^3 in total to obtain an effective area of ~30 cm^2 as a Compton camera.

Development of technologies to stack the DSSDs is on-going. We have a 6 stories 2.56 cm DSSDs stacked system with 7 mm pitch[1], and testing a 8 stories system with 2 mm pitch. We are also verifying the new analog VLSI VA64TA series and demonstrating the new read-out system with floating ground eliminating bias chips. These results will be presented soon.

On the DSSD technology itself, we have a plan for a larger device, a 51.2 x 51.2 mm^2 DSSD with a thickness of 500 μm and a strip pitch of 400 μm. With this design, we can obtain ~3 times larger volume (1.25 cm^3) with almost unchanged strip capacitance (~13 pF). Before jumping into a new detector, however, we are currently manufacturing several 4 cm DSSD systems to verify its total performance. Because the 4 cm DSSDs are already working as a large-area photon-counting hard X-ray imager with high energy resolution, some will be used as a prototype for inspection and/or medical use.

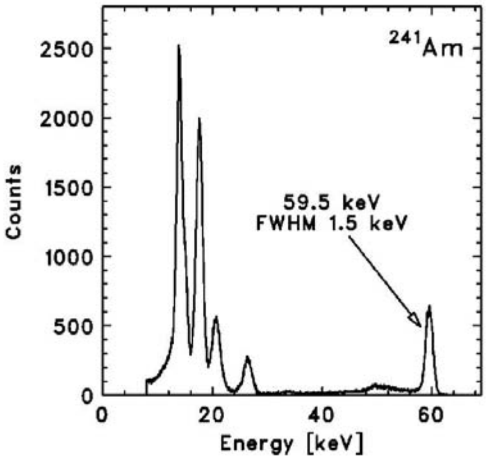

Figure 4. Sum of the ^{241}Am spectra obtained from 89 channels of the p-side strips. Data were obtained at -20°C with a bias of 110 V. Peaking time of the VA32TAs was set at 4 μs.

Acknowledgments

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