Spatial characterization of monolithic multi-element Silicon-Drift-Detectors for X-ray spectroscopic applications

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Spatially resolved spectroscopic measurements with a 10 and 20 μm pencil beam have been performed on a monolithic 7-element Silicon-Drift-Detector (SDD). Detailed studies are shown of the modification of the spectroscopic response at pixel edges and pixel centre. The results give quantitative insight into the local SDD performance. A simple model predicts global properties (e.g. peak-to-background ratio) of larger SDD arrays, like the 61-element detector currently under development.

1. Introduction

In the last few years efforts have been made in designing and fabricating of a new type of semiconductor X-ray detector: the Silicon Drift Detector (SDD) with integrated field effect transistor (FET). These detectors can be used for high countrate spectroscopic applications [1,2].

At present time monolithic 61-element SDDs are being developed in a joint European project [3]. They have hexagonally shaped independent pixels, each of an active area of 5 mm^2. Each pixel will have high countrate properties at good energy resolution (<350 eV) [2] resulting in a total countrate in the order of 10^7 cps per 61-element SDD. First JFETs will be integrated on the detector chip. Signal processing (amplification, peak detection) will be performed in front-end chips which will drive flash ADCs. Data will be transferred optically to multi-channel-analyser (MCA) modules [4,5]. Thirty-two 61-element SDDs are intended to be arranged in a hemisphere like geometry (“bucky ball” with average radius of 4.3 cm [5]).

In this publication we present results from spatially resolved measurements of a monolithic 7-element SDD with a similar design as the one of the 61-element SDD. The focus of the experiments lies on the quantitative understanding of the local spectroscopic performance of multi-element SDDs. Regions of incomplete charge collection and dead areas at pixel borders/edges and within the pixels are investigated, as well as crosstalk between adjacent pixels, and homogeneity of the spectroscopic response of the pixels.

The data allow a detailed understanding of the detector behaviour under homogeneous illumination and extrapolation to the 61-element SDD.

Due to its performance the SDD can be applied, e.g., to time dependent fluorescence X-ray absorption spectroscopy of low concentrated samples which are inaccessible by transmission XAFS [6].

2. Experiment

Experiments were carried out at the bending magnet beamline X1 at Hamburger Synchrotron-strahlungslabor (HASYLAB). A fixed photon energy of $E = 10$ keV was chosen using a Si(1 1 1) double crystal monochromator. The outgoing photon flux was monitored by an ionization chamber and stabilized via a monochromator feedback system. The beamsize at the detector was defined by 10 and 20 μm pinholes in a 100 μm thick Au foil. The pinholes were mounted on two goniometers and a x–y-translation stage for adjusting purposes. Behind them ($\leqslant 10$ mm), the detector was mounted on a second x–y-stage to be scanned across the pencil beam. The SDD-chip was mounted in a metal housing together with seven independent amplifier and shaper channels ($\tau = 280$ ns) built at HASYLAB. Spectra were recorded by CAMAC ADC/MCA-modules (Le-Croy 3512/3588). Total countrates were in the order of 8–10 kcps and the sample time per MCA-spectrum was 60 s. Prior to experiment the beamsize was verified by use of a high resolution CCD-camera (Photonic Science, model *XIOS*).

3. Results and discussion

Results from a scan across the border between two adjacent pixels and from a scan across a pixel centre are shown in Figs. 1 and 2 (pinhole 10 μm), respectively. Here TC is the total number of counts in the range of 1–12 keV. P/B is the peak-to-background-ratio with $P :=$(integral intensity of 10 keV-peak) and B:=(integral background intensity in the range of 1–10 keV, without the Si-escape line). An area of 40–50 μm width between

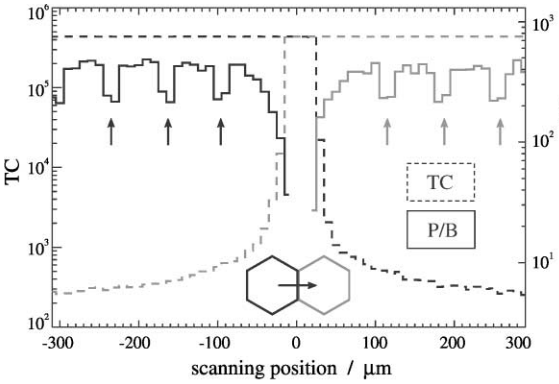

Fig. 1. TC and P/B across the edge between two adjacent pixels. Note, that the two hexagons plotted are not scaled to the x-axis.

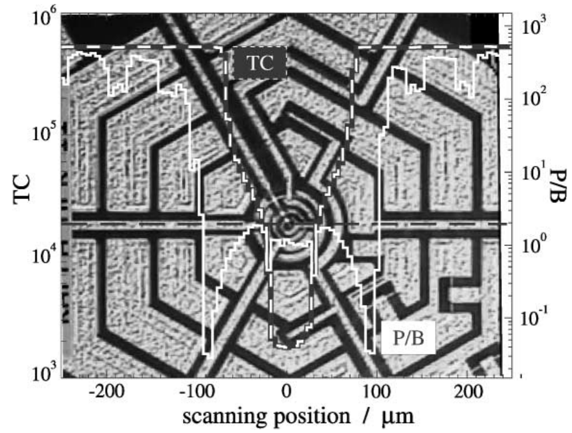

Fig. 2. TC and P/B for a scan across the centre of one pixel. Underlying is a photograph of the corresponding region of the SDD-chip. Scan path marked by the horizontal black dashed line.

the two pixels exists where charge clouds are split and produce the same TC in both pixels. In a ca. 90 μm wide region P/B is decreased. Here, the MCA spectra get increasingly distorted (peak shifts, increase of background). Quantitatively the same behaviour can be seen when investigating the outer detector edges. This leads to the conclusion that inner and outer pixel borders behave the same.

In Fig. 1 periodic decreases of P/B by a factor of two can be observed (see arrows). Such dips are also visible in Fig. 2. This behaviour of P/B coincides with the 18 p^+-ring structures ([2]) on the one side of the SDD-chip. The experimentally observed decrease in P/B can be modelled by a change of the depth of the active SDD volume from 280 to 278 μm.

Fig. 2 shows a scan through the centre of one pixel. In a 150 μm wide region TC decreases and a central dead area (50 μm) exists where nearly no counts are detected. In this area the FET surrounded by its guard ring is located. P/B is found to be affected in a region of 230 μm width. The region of charge losses and decrease of TC is found to be matching with the area within the centermost p^+ implant ring.

These quantitative results allow to predict the spectroscopic performance of monolithic multi-element SDDs of a given number of pixels and geometry under integral illumination. In the simplest model we assume that the total pixel area can be divided into undistorted and heavily distorted area and that heavily distorted area (edges, center) only contributes to the background. Table 1 summarizes the relative areas of critical charge losses and the derived P/B-values for integral illumination under this rather crude assumption. Also the highest P/B of the investigated 7-element detector under local illumination is given: 420 (first line, see also Fig. 1). If no radiation mask is applied to the detector, 7.8% of the active pixel area generate heavily distorted spectra (edges ED and center CE) and P/B is found to be largely decreased (second line of Table 1). Since outer and inner edges behave the same, this result is valid for any number of pixels. It is in very good agreement with the measured $P/B = 11.2$ of the 7-element detector under integral illumination. Covering the outer edges by a radiation mask (45 μm width) improves P/B for the single element SDD by a factor of 17 (third line), but it becomes less important for higher pixels numbers. Thus, performance improvement of large SDD arrays will mainly be achieved by covering all pixel edges, also inner ones, by a radiation mask.

In addition to the results discussed above the cross-talk ratio (CT) between two adjacent pixels was investigated. CT was defined as the number of counts detected in one pixel divided by the sum of counts seen in both pixels when illuminating one of the pixels. For both pinholes used it was found that $\mathrm{CT} \leqslant 2 \times 10^{-3}$ in a lateral distance of 50 μm from the border between two pixels and $\mathrm{CT} \leqslant 8 \times 10^{-4}$ in a distance of 150 μm.

The energy resolution of the 10 keV-line has been evaluated from the locally measured data. No significant inhomogeneities in the area of undistorted spectra of a pixel could be observed.

Table 1

Undistorted (UN) and heavily distorted ((ED), edges (CE), centre) pixel areas of multi-element SDDs, as derived from local spectroscopic measurements on the 7-element SDD. NPIX: number of pixels; mask: outer edges covered by a radiation mask; P/B, derived from given areas

NPIX	UN (%)	ED (%)	CE (%)	P/B
1 (Local illum.)	100	—	—	420
1, 7, ... (No mask)	92.2	7.3	0.5	11.9
1 (Mask)	99.5	—	0.5	199
7 (Mask)	96.2	3.3	0.5	25.3
61 (Mask)	93.2	6.3	0.5	13.7

4. Conclusions

Spatially resolved measurements with 10 and 20 μm pencil beam have been carried out on a monolithic 7-element SDD. At pixel edges and pixel centre the spectroscopic response was shown to be modified. The results give detailed quantitative insight into the local SDD performance and allow to predict the global performance of SDD arrays. It was summarized how the P/B ratio (and generally the detector response) can be improved by covering the edges of each pixel by a radiation mask. Covering inner edges becomes increasingly important for larger SDD arrays.

The results may trigger the direction of further development of multi-element SDDs. Present and future applications in high resolution, high countrate X-ray spectroscopy (e.g. fluorescence XAFS on highly diluted systems, X-ray holography) will benefit.

References

[1] E. Gatti, P. Rehak, Nucl. Instr. and Methods, A 225 (1984) 608.
[2] P. Lechner et al., Nucl. Instr. and Methods, A 377 (1996) 346.
[3] EC Contract no. ERBFMGECT980106.
[4] M. Reinecke, K. Hansen, Nucl. Instr. and Meth. A 465 (2001) 606–617.
[5] K. Hansen, L. Tröger, IEEE Trans. Nucl. Sci. 47 (2000) 2748.
[6] P. Kappen et al., J. Catal. 198 (1) (2001) 56.