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Electrical and spectroscopic characterization of 7-cell Si-drift detectors

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Abstract

Ten detector modules based on monolithic 7-cell Si-drift detectors with integrated junction field effect transistors (JFETs) are currently under production. The modules' hexagonal shape with a wrench size of 16 mm allows very small distances to the samples and a compact multi-module arrangement. The sensors have active areas of ~50 mm^2 and a thickness of 450 μm. A proper spectroscopy operation of all modules was obtained by five common supply voltages and a 6th voltage which must be individually adopted. Detector capacitances varied from 83 to 145 fF, where statistical spreading caused by device mismatch amounts to 0.4%. On-chip scattering of the JFET's transconductance and source potential in a source-follower configuration are around 1%. Their spreading caused by process variations and device mismatch remain below 8%. Typical spectral resolution and non-linearity is about 300 eV and below 1% between 4.5 and 18 keV, respectively. After irradiation with a total dose of ~2 Mrad the resolution decreases by ~40%. By shielding the cell borders and JFETs from direct irradiation with usage of a Zr mask, a spectral peak-to-valley ratio of ~1000 was achieved.

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Keywords: Silicon drift detector; X-ray spectroscopy; Junction field effect transistor; Electrical performance; Spectroscopic performance; Radiation tolerance

1. Introduction

Experiments with synchrotron radiation, which detect X-ray fluorescence like absorption spectroscopy, standing waves, or fluorescence tomography demand for energy-resolving detectors. For good detection efficiency, it is necessary that these devices are able to observe simultaneously the radiation emitted into a large angular range. With present and future high-brilliance synchrotron radiation sources it is also important that the detectors can cope with high local count rates. At present, this kind of experiments is done using detectors with single-element sensors or voluminous hybrid sensors having a few small-sized sensitive elements, which thus only register a small fraction of the totally emitted radiation. Sensitive sensors are for example especially designed Si-drift diodes (SDDs) [1]. The SDD operates in the room temperature range, whereas conventional Si(Li) or Ge detectors requires cooling with liquid nitrogen. Recently, square arrangements of 77 and 19 hexagonally shaped drift diodes have been developed to increase the detection area and integral count rate, and thereby the detection efficiency [2,3]. The basic idea of our module concept is to extend the hexagonal single-cell shape to a hexagonal array of seven cells and also a hexagonal module shape. The 7-cell SDD module is of much smaller size than present commercially available instruments and has already shown its mega-count rate capability at room temperature [4]. Its compactness allows very short distances to the specimen. These modules have perpendicular sidewalls and can be combined in a flexible way to larger arrangements in accordance with the experimental requirements and with the space available in a specific experiment. For many applications it is also advantageous to reach larger spectral peak-to-background ratios. The identification of origins of events with partial charge collection was already a topic for single-cell [5] and 7-cell SDDs [6]. Applying spatially resolved spectroscopic measurements to sensors of the new 7-cell SDD family utilized in Ref. [4] we identified the regions where the

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charge collection is incomplete. In Ref. [7] we reported already on a mask-based approach to reduce this effect.

The objective of this paper is the presentation of the electrical and spectroscopic performance of a small number of sensor modules taking advantage of the mask approach for the 7-cell SDDs with an active area of up to $50\,mm^2$. In Section 2, the setup of the module's sensor part is presented and methods for its electrical and spectroscopic characterization are summarized. Section 3 explains in detail the procedures for the extraction of the most important small-signal parameters and presents the results. In particular, sensor-, junction field effect transistor (JFET)- and interconnection-related parameters will be determined and analysed. Finally, the improvements of the spectral behaviour are described.

2. Setup and experiments

Fig. 1 shows a photograph of the sensor part of the 7-cell SDD modules. The sensor (PNSensor GmbH, Germany) is placed with its downward oriented entrance window on a lower step (~300 μm deep) of a 3-D structured base frame (Hightec MC, Switzerland). AlN wafers of 635 μm thickness and a Cu-based metallization in thin-film technique were chosen as base material and interconnection layers for the double-sided carrier, respectively. Conventional wire-bond technique (AlSi 1%, 25-μm diameter) was used to connect the output and biasing pads of the sensor to the pad row at the right-hand side of the frame. The sensor needs to be contacted also on the side facing the entrance window (Fig. 1 bottom). Here, the wire loops are located

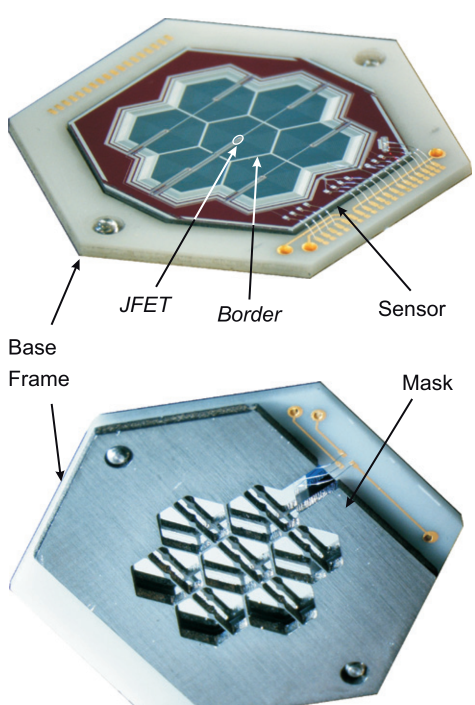

Fig. 1. Photograph of the base frame with 7-cell SDD on top side and mask on back side.

between the side walls of a small channel at the right-hand side of the mask mounted onto the base frame's back side. Through-hole vias are used to bring all lines to the top surface. Zr plates of 450-μm thickness (Goodfellow GmbH, Germany) were chosen as base material of the mask. Zr is ideally suited for photon absorption between 2.5 keV (highest L emission line) and 18 keV (K-edge), which is also the main spectral operation range of the 450-μm thick SDD sensor. The straps and bridge-like structures of the mask cover the cell borders and JFETs, respectively. The charge collection is incomplete if photons hit either the cell borders or the JFETs which leads always to larger spectral background level at the low-energy side of a spectral line [7]. The mask structure shown in Fig. 1 was produced using laser-cutting technique (Nutech GmbH, Germany). The precise alignment of the mask with respect to the sensor and of the sensor with respect to the base frame was achieved by using a manual flip-chip die bonder (Finetech GmbH, Germany). The dual-component adhesive H70E-175 (Polytec GmbH, Germany) was chosen for gluing procedures. Two holes in the corners of the base frame and mask (cf. Fig. 1) allows a screw connection to further housing parts (not shown).

The SDD principle is based on the idea of sideward depletion, where a n^--doped substrate is fully depleted by a small sized ohmic n^+-contact (anode) positively biased with respect to a surrounding planar p^+-electrode on the substrate's top side and planar p^+-diode contact on the substrate's back side [1]. By subdividing the pn junction on the top side into 21 concentric hexagonal-shaped electrodes and supplying a suitable voltage gradient on such a ring system, a nearly radial symmetrical lateral field is generated, forcing signal electrons radially inwards to the n^+-ring anode. The p^+-rings are biased by means of an integrated resistive voltage divider, which reduces the external biasing connections only to the innermost (R#1) and the outermost ring (R#X), where the outermost ring is a honeycomb-like structure and common for all cells (cf. Fig. 1 top). In this way, a small anode is defined, whose charge-collecting capacitance C_{anode} is independent of the sensitive cell area of $\sim 7\,mm^2$. The anode is directly connected to the gate (G) of the on-sensor integrated JFET, keeping the total node capacitance $C_{det} = C_{anode} + C_{GD}$ as low as ~110 fF (cf. Section 3.2), where C_{GD} is the gate-drain capacitance of the JFET. On the back side the p^+-region is subdivided into two subregions. The first subregion consists of seven hexagonal-shaped large contacts (cell size) which are connected to each other (contact BC). The second subregion is a honeycomb-like structure at the cell boundaries like R#X on the top side. BC can be slightly positive biased with respect to boundary contact BC*, forcing signal electrons inwards to the main cell area. In this way, split events will also be suppressed "electronically".

The n-channel JFETs are separated from the n^--bulk by a deep p-implantation. This inner guard (IG) contact is negatively biased with respect to the surrounding bulk