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A fourfold segmented silicon strip sensor with read-out at the edges

Wim de Boer[a], Alexander Dierlamm[a,*], Frank Hartmann[a], Karl-Heinz Hoffmann[a], Andreas Kornmayer[a], Thomas Müller[a], Andreas Nürnberg[a], Giulio Pellegrini[b], Martin Printz[a], David Quirion[b]

[a] Institut für Experimentelle Kernphysik (IEKP), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
[b] Centro Nacional de Microelectrónica, IMB-CNM-CSIC, Barcelona, Spain

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ABSTRACT

The High-Luminosity LHC upgrade (HL-LHC) is expected to increase the present luminosity by an order of magnitude in the years after 2022. This will necessitate the construction of silicon tracking detectors with a significantly higher radiation hardness and a higher channel granularity to cope with the higher track occupancy. In addition, a contribution from the tracking system to the first trigger stage and a reduction of the material budget would be desirable. The current concept for an upgraded CMS Tracker is based on silicon sensor modules formed of a sandwich of two strip sensors with front-end electronics at the sensor edge. This arrangement allows us to use the displacement of coincident hits in the two stacked sensor planes as a measure of particle momentum. As a consequence it is possible to identify locally particles with low transverse momentum which are not relevant for the Level-1 trigger decision. By applying a momentum cut of 1–2 GeV, the data rate can be reduced by an order of magnitude. This paper introduces a new strip sensor design with a fourfold segmentation along the strips. The inner strips have an offset of half a pitch with respect to the outer strips and are connected to the pre-amplifiers at the edge via routing lines in between the outer strips. The challenge lies in minimizing the induced signals on the routing lines. Several prototypes have been tested and the results are reported. The possible application for the CMS Tracker upgrade is discussed.

1. Introduction

After 2022, it is planned that the LHC will be upgraded to the High-Luminosity LHC (HL-LHC) with a tenfold increase in luminosity (up to $5 \times 10^{34}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$). This increase in luminosity will result in the need for silicon trackers with significantly improved radiation hardness and higher granularity to cope with the increase in track density originating from the increase in “pile-up”, that is multiple interactions per beam crossing. During a single bunch crossing tens to hundreds of collisions may be recorded simultaneously resulting in an overall track multiplicity of several thousands of tracks per trigger (see, for example, the discussion on the new CMS detector tracking system [1]). The first trigger stage (level-1 trigger) processes the data from several sub-detectors (currently not the Tracker) in order to select the most interesting events from LHC proton–proton collisions. The use of the tracking system in the level-1 trigger would be beneficial as a mean to keep the global trigger rate at 100 kHz, even in the high luminosity environment [2,3]. The current CMS Tracker upgrade plan is based on the use of special trigger modules in the outer Tracker region (Fig. 1). The outer Tracker consists of six cylindrical module layers in the central region and six disks in the forward regions, not including the pixel vertex detector. The trigger modules consist of two stacked strip sensors (10 cm × 10 cm) that are connected by wire bonding at the edge to the same front-end ASIC featuring a coincidence logic between the stacked strips. This arrangement allows the identification of high momentum (>1–2 GeV) tracks, for which a large displacement between lower and upper hit position of still up to 8 times the strip pitch depending on the module position in the tracker is expected in the strong magnetic field. Only those hits of high momentum tracks are provided to the level-1 trigger for each event reducing the data rate by one order of magnitude. A sketch of such a module with two strip sensors (the so-called “2S” module) is shown in Fig. 2. We have proposed and prototyped some novel sensors with a new channel routing strategy [4–6]. One of these new sensors is a FOurfold segmented STrip sensor with Edge Readout (FOSTER). The fourfold segmentation of each strip improves the granularity. The routing lines from the inner segments to the edge provide easy connectivity to the front-end electronics at the sensor edge. The challenge lies in minimizing the induced signals on the routing lines in between the strips. As an example, the LHCb VELO sensors should be mentioned, since there signallosses in regions of crossing routing lines have been observed [7]. The differences to our study are that the VELO

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* Corresponding author.
E-mail address: alexander.dierlamm@kit.edu (A. Dierlamm).

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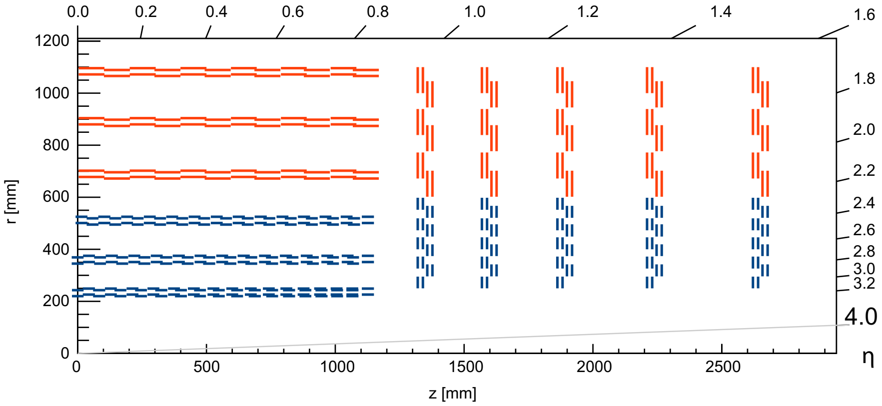

Fig. 1. Baseline layout of the upgraded CMS Tracker for the HL-LHC phase. One-quarter of the detector in the r–z plane is shown. The central layers form cylinders (20 cm $< r <$ 110 cm and $-$115 cm $< z <$ 115 cm) and the forward structures are disks (20 cm $< r <$ 110 cm and 130 cm $< |z| <$ 270 cm). Modules outside a radius of 60 cm consist of two strip sensors (a total of about 8400 2S-modules), while the inner modules consist of one strip and one macro-pixel sensor (a total of about 7100 PS-modules).

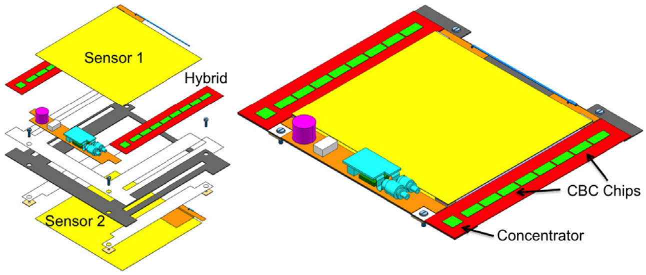

Fig. 2. Drawing of the “2S-module”. On the left side the component parts of the module are shown. On the right side the module is assembled. It consists of two strip sensors with the hybrids at the edges [2].

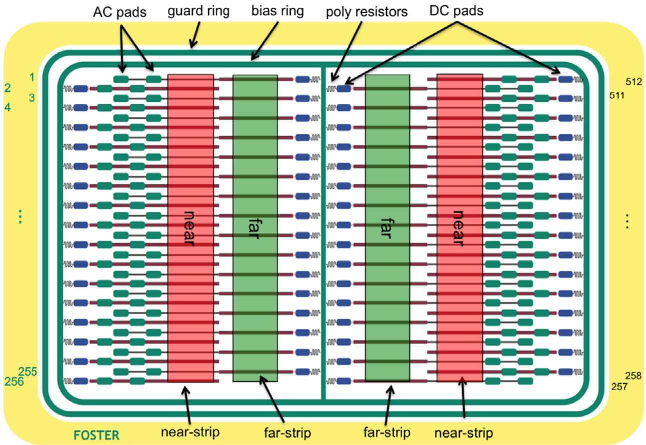

Fig. 3. Schematic view of the FOSTER [5]. The sensor is separated in two halves divided by a central bias line. Each half is divided into two strip regions: the strips near, and far, from the edge. Both far-strips and near-strips are routed to AC pads at the edge, where they can be wire-bonded to the read-out chips.

routing lines are implemented on a second metal layer and that the effects appeared only after accumulation of radiation damage.

In the following, the design, production quality and functionality of this sensor will be discussed for 320 μm float zone silicon in n- and p-bulk material with p- and n-type strips, respectively.

2. Sensor design

The FOSTER prototype is a 35 mm × 15 mm sensor with 4 × 128 strips. The strips have an implant strip length of 7.6 mm (about one-quarter of the sensor length) and a pitch of 100 μm. The AC[1] pads used to connect the strips to the read-out electronics by wire bonds that are all placed at the sensor edge, as shown schematically in Fig. 3. The sensor is separated into two identical halves by an additional central bias line. Each half is divided into two regions called “near” (to the outer edge) and “far” (from the outer edge) with corresponding near-strips and far-strips. The far-strips are connected to the AC pads at the sensor edge via slim aluminum routing lines that run in between the near-strips.

Table 1
Measurement results for the sensor strip parameters at 600 V. There is a distinction between far-strips and near-strips for some sensor characteristics because of the different strip geometry.

Measurement	Position	p-in-n $\bar{x} \pm \sigma_x$	n-in-p $\bar{x} \pm \sigma_x$
Leakage current (pA/cm)	Near	29.7 ± 4.7	52 ± 4
	Far	74 ± 5.2	83.2 ± 5.4
Bias resistor (MΩ)	Near	1.81 ± 0.01	1.73 ± 0.01
	Far	1.86 ± 0.01	1.79 ± 0.03
Inter-strip capacitance (pF/cm)	Near–far	0.57 ± 0.01	0.59 ± 0.02
	Near–near	0.34 ± 0.01	0.39 ± 0.01
	Far–far	0.59 ± 0.01	0.6 ± 0.01
Coupling capacitance (pF/cm/μm)	Near	1.47 ± 0.01	1.51 ± 0.01
	Far	1.5 ± 0.01	1.55 ± 0.02

3. Electrical characterization

Several prototypes of the sensor described above have been produced by Hamamatsu Photonics K.K. (HPK) in Japan. The electrical characterization has been done for two different types of sensors, one with p-strips in an n-type bulk (p-in-n) and the other with n-in-p sensor with p-spray isolation between the n-type strips to interrupt the electron accumulation layer[2] between the strips. The total leakage current is between 3.6 nA/cm^2 and 4.1 nA/cm^2 at 600 V and the full depletion voltages extracted from the C^{-2} versus bias voltage curves yield values

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[1] The metal strips are isolated from the implanted strips by a thin oxide coating, protecting the read-out electronics from the DC currents, which can become quite high after irradiation.

[2] Electrons are attracted by the trapped positive charge at the interface of the silicon and the oxide on top of the sensor.