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Results with p-type pixel sensors with different geometries for the HL-LHC

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ABSTRACT

Pixel detectors will be extensively used for the four innermost layers of the upgraded ATLAS experiment at the future High Luminosity LHC (HL-LHC) at CERN. The total area of pixel sensors will be over 5 m². The silicon sensors that will instrument the pixel volume will have to face several technology challenges. They will have to withstand doses up to 2×10^{16} n_{eq} cm⁻², to have a reduced inactive area at the edge of the sensors still being able to hold 1000 V bias voltage and to be relatively low cost considering the large area to be covered. N-side readout on p-type bulk is the most promising technology for satisfying the various requirements. Several sensor types have been produced in the UK, conceived for various readout systems, for studying the properties of n-in-p and n-in-n sensors before and after irradiation with test beam and laboratory measurements. The status of these studies is presented here.

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1. Introduction

While the Large Hadron Collider (LHC) at CERN is continuing to deliver a steadily increasing luminosity to the experiments, plans for an upgraded machine called the High Luminosity-LHC (HL-LHC) are progressing. The upgrade is foreseen to increase the LHC design integrated luminosity by a factor of ten. ATLAS will need to build a new tracker for HL-LHC operation, which needs to be suited to the harsh HL-LHC conditions in terms of particle rates and radiation doses. In order to cope with the increase in pile-up backgrounds at the higher luminosity, an all-silicon sensor detector is being designed. To successfully face the increased radiation dose and occupancy, a new generation of extremely radiation hard silicon detectors has been designed. A minimum of four inner barrel layers, and six endcaps disks on either side, will consist of pixel detectors. These sensors will be bump bonded onto the new radiation hard front end chip, the FE-I4 [1]. This paper will discuss work on new pixel sensors produced by Micron Semiconductor Ltd. [2].

2. Micron wafers

Micron Semiconductor Ltd. has produced two types of sensor wafers: Pixel II and Pixel IV. Pixel II consists of multiple versions of FE-I4 compatible sensors: MPI guard IBL slim edge, MPI guard IBL slim edge ganged, MPI guard IBL ganged, MPI guard IBL and RD50

IBL ganged pixels. Slim edge sensors have 250 μm and the standard have 450 μm from the edge of the last guard ring to the edge of the sensor. Pixel IV had five quad large area sensors (requires four FE-I4 chips) and these are surrounded by single area sensors, including 500 × 25 μm pixel sensors, ganged pixels and slim edge devices.

3. DESY test beam

The DESY test beam consisted of 4 GeV positrons [3]. The tracking was performed by the ACONITE beam telescope (a copy of the EUDET beam telescope [4]). This telescope consists of six equal planes, divided into two groups of three planes each. The Devices Under Test (DUTs) are mounted inbetween these two arms of the telescope (Fig. 1). Only two DUTs were mounted due to the multiple scattering of the 4 GeV beam. The sensitive elements of the telescope planes are Mimosas26 [5] active pixel sensors with a pixel pitch of 18.4 μm. Each plane consists of 1152 × 576 pixels covering an active area of 21.2 × 10.6 mm². The tracking resolution is estimated to be 2 μm [6]. The trigger was provided by four scintillators (two up and two down stream of the telescope), which resulted in an effective sensitive area of 2 × 1 cm². The trigger rate was 1 kHz.

3.1. Devices under test

In total four DUTs were tested in the test beam. All DUTs were readout using the FE-I4 pixel readout chip [1] which had been bump bonded onto the sensors. The FE-I4 has 80 columns × 336 rows of 50 × 250 μm read-out cells. The first DUT was a reference

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Fig. 1. The telescope setup.

Fig. 2. IV scans for the DUTs in the test beam setup. Each measurement interval is 30 min.

one, SCC31, consisting of an n-in-n sensors from CiS [7]. This was a well understood DUT used in previous test beams [8]. The rest were made with Micron sensors, bump bonded onto the FE-I4 chips at IZM [9]. Two of these were n-in-n sensors and the last was an n-in-p sensor. Only the results from one of the n-in-n DUTs will be shown, MSS01.

IV scans were performed with the sensors in the test beam setup, Fig. 2.

The sensor used for MSS01 was not pre-selected before bump bonding and has a consistently higher leakage current than SCC31. But it is still well below the 100 nA per pixel required for upgrade purposes. Pre-selected sensors will provide better IV's in the future.

For the beam tests the DUTs were cooled via a copper tape thermally connecting the backside of the DUTs to the base plate of the thermal enclosure. The base plate was in turn cooled using dry ice (CO_2). Temperatures were recorded, ranging between -45°C and -25°C .

Due to the low energy of the beam, bias and threshold scans were made priority over tilting the sensors in R and Phi. The reference, SCC31, DUT was run at a 3200e threshold and 150 V bias voltage. The Micron DUTs were run at thresholds of 3200e, 1400e, 1200e and 1000e, and bias voltages of: -50 V , 100 V and -150 V , respectively.

4. Test beam results

First the DUTs were returned to a threshold of 3200e and the HV bias was -150 V . The hits maps, from hits in the DUTs that had a matching track in the telescope are shown in Fig. 3.

The efficiency maps for the two DUTs can be seen in Fig. 4. As can be seen, MSS01's efficiency map has a strange regular pattern, consistent throughout the pixel structure. The regularity of this pattern suggests that the issue is coming from the FE side rather than the sensor side. Indeed the FE-I4 is read out in double columns using shift registers. This structure is seen in all efficiency maps

Fig. 3. Hits maps for the DUTs that had a matching track in the telescope.

Fig. 4. Efficiency maps for the DUTs.

Table 1
Efficiencies for MSS01 as a function of threshold and HV (in %).

Threshold	50 V	100 V	150 V	200 V
3200e	95.26	95.87	97.03	–
1400e	–	97.53	97.97	–
1200e	97.53	97.99	98.13	–
1000e	96.96	–	97.57	97.29

Fig. 5. Efficiencies of MSS01 at various thresholds compared to the efficiency of SCC31 (green line). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

maps for MSS01, and it is not seen in the efficiency maps for SCC31. The effect has been found to be HV and threshold independent, with an efficiency drop of about 2–4%. The most likely cause is a miscommunication between the FE-I4 and the readout, where the

low voltage supplied to the FE-I4 is too low. This effect has been seen in previous testbeams and the problem was solved by power cycling the readout [10].

The efficiencies for MSS01 were measured for all the thresholds and HV bias voltages used, and are shown in Table 1. This compares to an efficiency of 97.24% for the SCC31 sensor with a threshold of 3200e and a HV bias of –150 V.

5. Summary and conclusions

As can be seen in Fig. 5, the sensor efficiency has been shown to be very good for the Micron sensor. The overall sensor efficiencies are over 95% even when under depleted. The sensor efficiency can only improve with future test beam data without readout issues causing poor double column efficiency, and the preselection of sensors. The results from the n-in-p sensor are still being processed. MSS01 has now been irradiated and the test beam will be repeated.

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