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Edgeless & Slim-Edge Detectors for RD50

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The planned HL-LHC (High Luminosity LHC) is being designed to maximise the physics potential through a sizable increase in the luminosity, totalling $1x10^{34}cm^{-2}s^{-1}$ after 10 years operation. A consequence of this increased luminosity is the expected radiation damage at $3000fb^{-1}$, making the tracking detectors required to withstand hadron equivalences to over $1x10^{16}$ 1 MeV neutrons per cm^2

Within the RD50 Collaboration, a massive R&D program is underway to develop silicon sensors with sufficient radiation tolerance. One area of interest within the coloration is the study of reduced edge or “edgeless” sensors. Such devices allow for the reduction of dead area when such sensors are arranged in a tiled format for applications ranging from particle physics to synchrotron and free electron laser (FEL) facilities and medical imaging.

In this paper are details of several edgeless detector technologies investigated via the RD50 project. They include measurements of Slim Edge, SCP and Active Edge devices for investigation of leakage currents, S/N levels, as well as details of post irradiation performance.

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[1] Speaker

1. Introduction

Standard silicon detectors have a relatively large insensitive region around their active area. This dead region due to presence of multiple guard rings and the clearance for the dicing street of the sensors can extend to more than a few millimetres, depending on the detector application and therefore operational requirements. In a silicon sensor the diced surface contains a high density of lattice defects. A significant fraction of these are electrically active. Such a surface could then lead to a significant reverse current in the device.

The guard rings present around the active detector area produce an effective screening of the electric field in the active area from the region adjacent to the chip cut, isolating the active area from the detector edge, thereby reducing the leakage current on the nearby strips or pixels. To remove inactive regions around each sensor reduced edge or “edgeless” sensors are required.

Such sensor designs in conjunction with through-silicon vias (TSV) [1] would also result in a reduction in radiation length, making edgeless sensors a promising option for the particle physics community. Such sensors utilize one of a number of methods to reduce the number of guard rings and their pitch so to increase the active area of tiled detectors.

1.1 RD50

The proposed luminosity upgrade of the Large Hadron Collider (HL –LHC) will present several technological challenges to the particle physics community. The CERN RD50 project has been established to explore detector material and designs that have the potential to withstand the expected fluencies and associated radiation damage at the HL-LHC. One of the more active areas of research in the RD50 collaboration is the study of reduced edge detectors as a radiation hard technology The following sections will now surmise the ongoing work on this technology.

2. Edgeless Detectors

For edgeless detectors to be a viable candidate for use in particle physics applications, they must be shown to be operating with low leakage currents, high S/N levels and additionally be operational after irradiation. The following sections details some of the detector technologies investigated by the RD50 project which are thought to be potentially suitable for such an application.

2.1 Scribe – Cleave & Passivate (SCP)

The scribe-cleave & passivate (SCP) technique aims to create a highly resistive cut edge to eliminate leakage currents via the edge of the device. The detectors are first scribed with a laser close to the active area. The silicon is cleaved along the scribed edge, which leaves the surface with low defect density & therefore high resistivity. Surface passivation follows to make the sidewall highly resistive [2]. As a result guard rings are not required.

This process is limited to creating a highly resistive edge only along a crystal plane. Therefore the sensor must be produced in a silicon wafer of an appropriate crystal [1 0 0] structure. However, once produced the SCP is a post-processing technique and therefore not limited to a particular sensor vendor.

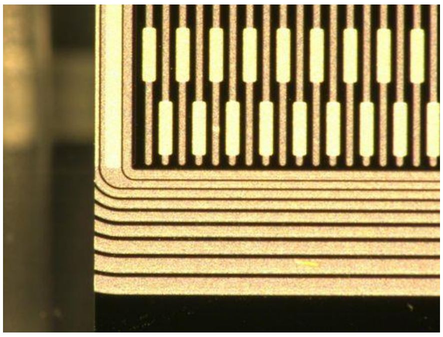

Fig 1: An SCP detector showing a cleaved edge on the left hand side. The inner ring is the bias rail, with the remaining outer rings the guard rings [3]

2.2 Results with SCP Devices

Recently there have been many studies on the fabrication and testing of SCP devices. These include results of source tests of P-type and N-type strip sensors for CCE collection pre irradiation [4], post irradiation [5], as well as measuring with Laser TCT scans [6] and micro-focussed X-rays [3]. One of the device performance criteria for SCP detectors is the collection efficiency near the edge. Several studies have been performed to study this behaviour,

Recent results by G. Pellegrini et al [7] testing 3D double sided detectors using SCP technology showed that the performance of the detectors tested was not affected by the cleaving process. In this study 3D silicon sensors were fabricated using the SCP technology, reducing the distance from the guard ring to the physical edge of the sensor to 100μm.

The detectors were then bump bonded to an FEI-3 readout chip. An example of the pixel hits distribution obtained with ^{90}Sr source can be seen in fig 2. In these tests no reduction of the charge collection efficiency can be identified at the edge of the devices.

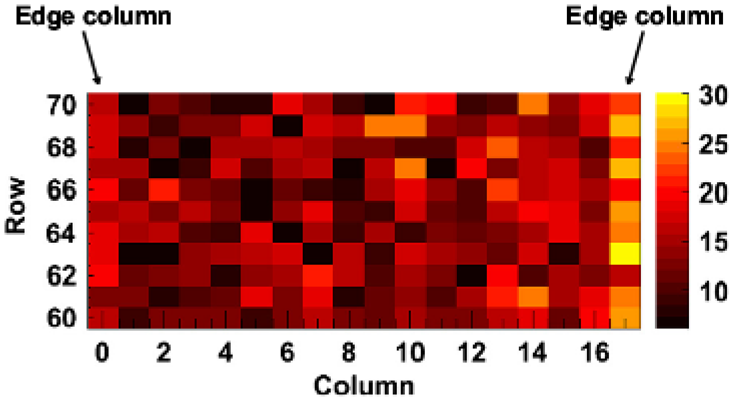

Fig 2 Pixels hit distribution with a ^{90}Sr Source. The right hand scale shows the number of hits [7]

Tests utilising a micro focussed 15 keV X-ray beam (2.5µm FWHM) [3] also showed there was no significant degradation in charge collection for the edge strips in an n-type SCP strip sensor. Strips sensors with and without cleaved edges were scanned with the beam, and readout with the AliBaVa system. In Fig [3] we can see the mean signal size with and ADC cut of 40 for both (left) standard edge and (right) cleaved edge strip sensors with a pitch of 74.5µm.

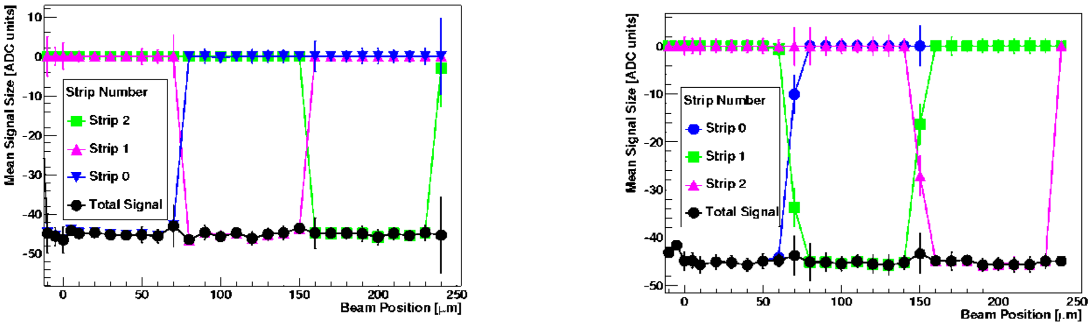

Fig 3: Mean Signal size with a ADC cut of 40 for scans of the strip detector with a) full guard ring structures and b) SCP edge [33]

Recently, transient current technique (TCT) measurements with a focussed laser have been performed on both pre and post irradiated SCP devices [6]. Scans were made across the standard and SCP edge of the detectors (Fig 4). Results show that the application of the SCP edge does not affect its charge collection properties, even after irradiation levels of 1.5x10^{15} 1 MeV neutrons per cm^2.

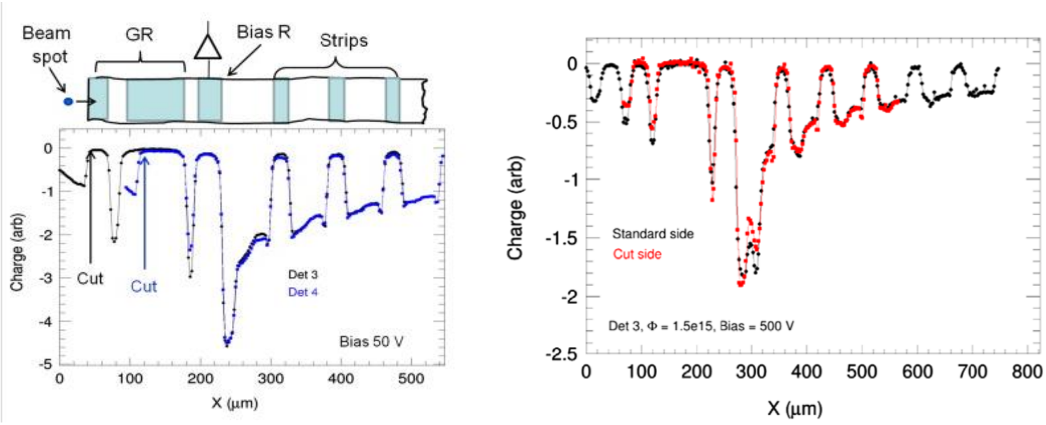

Fig 4 Comparison of charge measured in IR laser scans across (a) Un-irradiated SCP detector and (b) standard and SCP edge of irradiated detector [5]

Such results suggest that sensors utilising a SCP edge successfully reduce the detector dead area without sacrificing the detector's performance, even after hadron irradiation.

2.3 Active / Slim Edges

Active edge sensors aim to turn the physical cut edge of the sensor into a junction and therefore allow the depletion of the silicon all the way to the physical edge. The sensors sidewalls are cut using dry etch techniques to eliminate the microscopic damage associated with the sawing. The sidewalls of the cut edges are then doped to compensate for the high level of defects at the sidewall, and passivated with a thermal oxide layer [2].

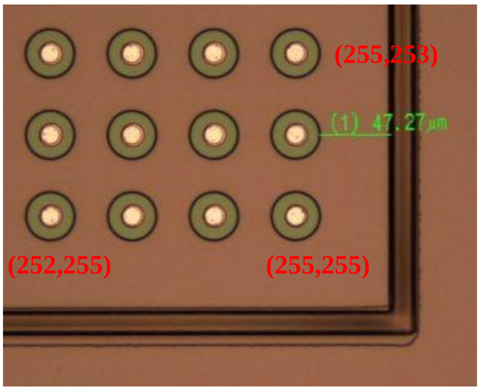

Fig 5 Active edge pixel showing less than 50µm from the edge pixel to the sensor edge, with pixel co-ordinates. [3]

Slim edges devices reduce the dead area by reducing the number of guard rings used in tandem with the reduction of the distance from the outer guard ring to the cut edge. Further reductions can be made in a double sided process by placing the guard rings on the back surface such that they overlap the edge pixels/strips on the front side [8].

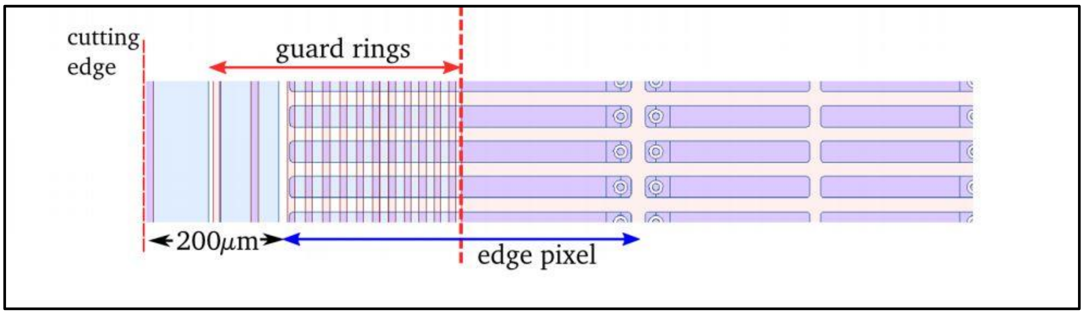

Fig 6: Example of slim edge devices proposed for the IBL, where edge pixels on the sensor surface overlap the guard rings structures on the back. [8]

Many slim edge devices utilize active edge technology to allow for the reduction of the distance from the outer guard ring to the cut edge.

2.4 Results with Active /Slim Edge Devices

Recent results have been shown by A Terzo et al. [9] with active/slim edge devices interconnected to both ATLAS FE-I3 and FE-I4 devices.

Hit efficiencies for 100μm thin sensors with 50μm active edge designs were studied using particle testbeams experiments at DESY (4GeV electrons) and CERN (140GeV pions) using the EUDET telescope [9]. In Fig 7 we see the hit efficiencies for the sensor edge.

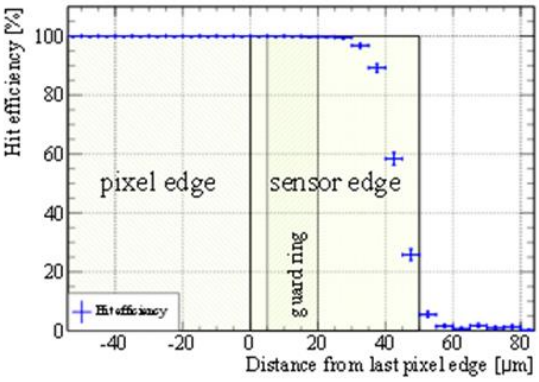

Fig 7: Hit efficiencies for an FE-I3 module with a 100μm thin sensor with 50μm active edge designs [9]

No significant degradation of charge collection is observed for such active edge designs.

Similarly to the SCP devices, a micro focussed X-ray beam was also used to study the behaviour of active edge devices [10]. 100μm thick n-in-p sensors were flip chip bonded to Timepix2 readout ASICS, with pixel to edge stances ranging from 50 to 100 μm. A scan across a single edge pixel was performed under varying bias conditions and full charge collection was seen at ~30V. (Fig 8)

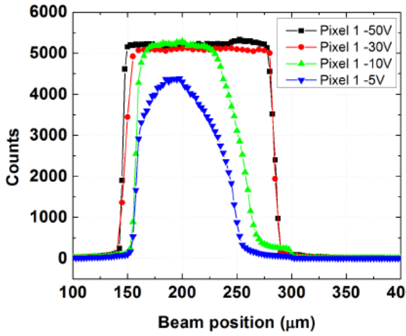

Fig 8: Scan over an edge pixel of a 100μm thick active edge pixel sensor flip chip bonded to a Timepix2 ASIC under varying bias conditions. [10]

A more detailed raster scan was then performed over the corner of the device, covering both the edge pixels and the dead region (Fig 9).

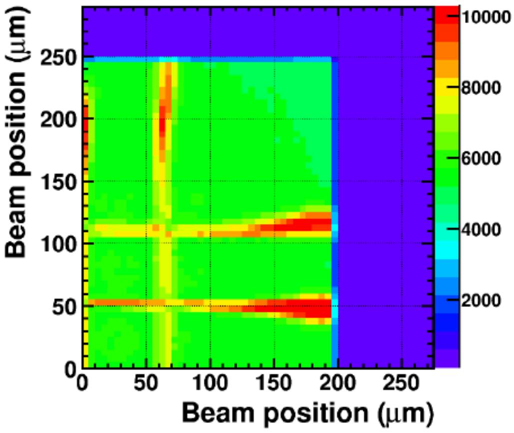

Fig 9: Scan over an edge pixel of a 100μm thick active edge pixel sensor flip chip bonded to a timepx2 ASIC under varying bias conditions. [10]

3. Conclusions

In this paper, an outline of the current work of the RD50 collaboration into reduced edge/edgeless sensors has been shown. A range of tests have been performed on SCP strip and pixel sensors, including testbeams, radiation source tests focussed x-rays, and TCT measurements.

All indicate unirradiated SCP devices perform well in regards to charge collection for near to edge strips/pixels. Additionally, such devices after irradiation to levels of $1.5x10^{15}$ 1 MeV neutrons per cm^2 also show promising results for such devices.

Similarly Active Edge devices have been shown to exhibit no reduction in charge collection for edge pixels. Preliminary results with irradiated devices also show no degradation in performance for those pixels close to the active edge.

Further tests for both SCP and Active Edge devices will continue centring on irradiated sensors and varying sensor flavours (n-on-n, p-on-n) for comparisons.

References

[1] C. Kenney, J. Segal, E. Westbrook, S. Parker, J. Hasi, et al., ‘Active-edge planar radiation sensors’, Nucl. Instrum. Meth. A 565 (2006) 272B.

[2] V. Fadeyev et al, ‘Scribe-cleave-passivate (SCP) slim edge technology for silicon sensors’, Nucl. Instr. Meth. A 731 (2013) 260

[3] A. Blue et al ‘Characterization of edgeless technologies for pixelated and strip silicon detectors with a micro-focused X-ray beam, JINST 8 P01018 (2013)

[4] M. Christopherson et al, ‘Scribing-Cleaving-Passivation for High Energy Physics Silicon Sensors’ PoS Vertex2012 (2013) 020

[5] V. Fadeyev et al, ‘Update on scribe–cleave–passivate (SCP) slim edge technology for silicon sensors: Automated processing and radiation resistance Nucl. Instrum. Meth. A 765 (2014) pp 59-63.

[6] I. Mandic et al, ‘TCT measurements with slim edge strip detectors’, Nucl. Instrum. Meth. A 751 (2014) pp 41-47

[7] G. Pellegrini et al ‘Recent results on 3D double sided detectors with slim edges’, Nucl. Instrum. Meth. A 731 (2013) pp 198-200

[8] S Altenheiner *et al*, ‘Planar slim-edge pixel sensors for the ATLAS upgrades’ *JINST* **7** C02051 (2012)

[9] S. Terzo et al, ‘Thin n-in-p planar pixel sensors and active edge sensors for the ATLAS upgrade at HL-LHC’ arXiv:1409.8579

[10] D. Manesuki et al ‘Edge pixel response studies of edgeless silicon sensor technology for pixelated imaging detectors’. JINST 10 P03018 (2015)

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