PROCEEDINGS OF SCIENCE

Edge-TCT Characterisation of TowerJazz CMOS Sensor for the ITK Phase II Upgrade

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The upcoming Phase II upgrade of the Large Hadron Collider (LHC) for the High Luminosity LHC requires the characterisation of new pixel sensors intended to be installed within the ATLAS experiment's inner tracker by 2024. The Edge Transient Current Technique is used to probe prototype TowerJazz Investigator I test structures to study their radiation hardness performance including depletion levels and charge sharing.

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1. Introduction

The CERN ATLAS[1] experiment will upgrade its tracking detector during the Phase-II LHC shutdown to take advantage of the increased luminosity of the HL-LHC, with data-taking expected to start by 2026. The upgraded pixel detector (ITK pixel) will consist of 5 pixel layers and several endcap rings. It will cover an extended $|\eta|$ range, perhaps as far as $|\eta|<4.0$, where η is the pseudo-rapidity $= -\ln(\tan(\theta/2))$, and θ is the angle between a particle and the beam axis.

This paper outlines some of the research being conducted in the characterisation of CMOS pixel sensor prototypes, in order to identify an appropriate design and geometry so as to fulfill the stringent operating requirements of the HL-LHC, including: rapid charge collection (<25 ns), high spatial resolution (10 μm), reduced charge-sharing (<30%), radiation hardness up to 1.5×10^{15} neq/cm^2 fluence (80 Mrad) approximately 30 cm from the interaction point.

The TowerJazz[2] sensor production process is being investigated through a prototype, the investigator chip.

2. TowerJazz Investigator I Prototype Test Chip

The sample under test is an unirradiated TowerJazz Investigator I MAPS (monolithic active pixel sensor), which is a double matrix chip. It includes addressing and output electronics which are located within the central column of the chip between both matrices, as shown in figure 1.

Each matrix is subdivided into 134 mini-matrices, each comprised of a 10 $\times$ 10 array of pixels, the outer-most pixel perimeter of which contains dummy-pixels that cannot be readout. Each mini-matrix varies in pixel size, from 20 to 50 μm, electrode sizes from 1 to 40 μm, as well as geometry variations in the pixel's substructure.

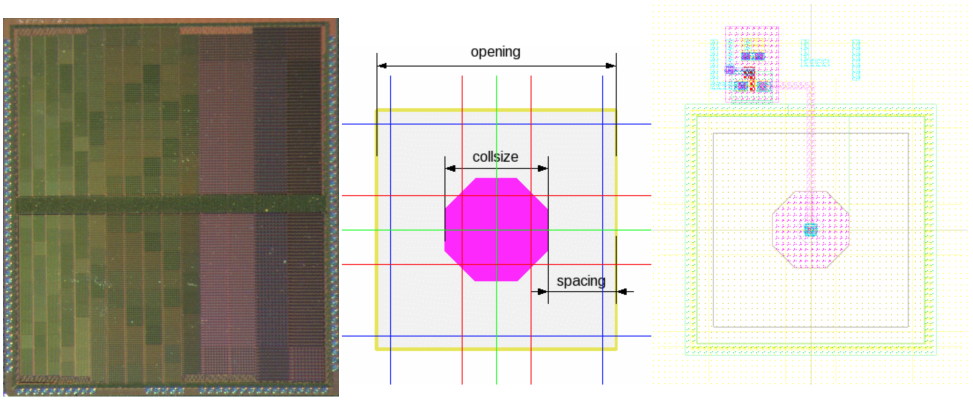


Figure 1: TowerJazz Investigator I test chip (left), with the central horizontal addressing electronics column subdividing the chip into its top and bottom matrices. Vertically arranged columns of mini-matrices of varying pixel sizes are also visible. Diagram of a single pixel geometry (center) with a sketch of its electronic circuitry (right).

The thickness of the sensor comprises of an electrode at that top layer with an n-well right below it. The n-well itself is surrounded by a p-well structure, all of which is only a couple microns thick. An additional deep p-well is also present below the first set of substructures in order to faciliate the full depletion of the particle-sensitive region of the sensor, which in the case of this chip is a 30 μm epitaxial layer.

3. Edge TCT

The Transient Current Technique[4] (TCT) is a method used to probe the response of silicon sensors by firing a focused laser beam, typically of wavelength 1060 nm. The photons' energy deposition within the sensor bulk leads to electron-hole pair creation. The laser beam when fired from the side of a sensor directly into its bulk is referred to as Edge-TCT (E-TCT).

E-TCT can be used for sensor characterisation purposes due to its known trigger timing, known level of energy deposited, as well as its accuracy in terms of the location of electron-hole pair production. This gives rise to the ability to finely scan in two dimensions across the thickness of the sensor to determine its response.

4. Experimental Setup

The E-TCT setup used in these measurements involves a PicoQuant PDL 800-B laser driver, which powers and provides the trigger signal to a PicoQuant LDH-P-C-1060 laser head. This infrared laser beam is subsequently propagated through optic fiber to a Galilean beam expander and focussing lens, in order to provide a focussed beam spot no greater than 10 μm.

The TowerJazz Investigator test chip is itself secured onto a purpose built carrier board using electrically conductive glue, as shown on figure 2, so as to facilitate the connections to powering, resetting (of sensor transistors) and pixel output readout. Biasing is provided via a gold-plated pad under the chip (substrate side) with electrodes on its surface. Connections from the test chip to the board are achieved through ultrasonic wire-bonding.

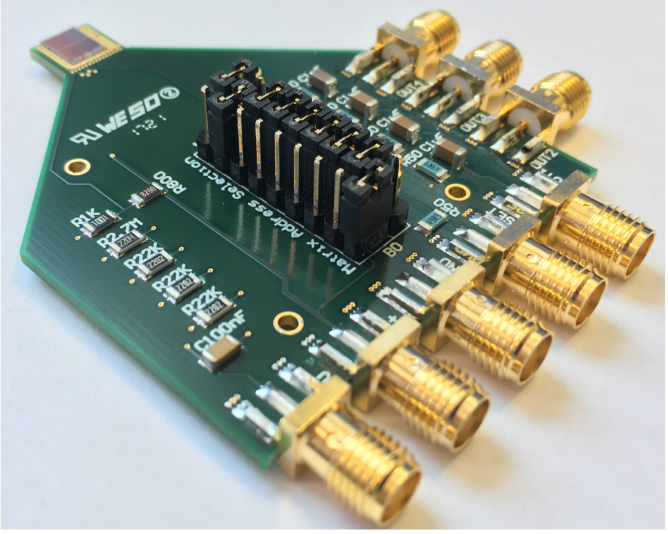


Figure 2: Custom designed TowerJazz Investigator I carrier board for E-TCT measurements.

The target mini-matrix selection is made by 9-bit binary addressing using the corresponding jumpers on the carrier board and the specific pixels whose output is read out are selected directly via wire-bond from the chip.

Each pixel's output is fed into a Cividec 40 dB non-inverting amplifier and is finally routed simultaneously to an oscilloscope for visual assessment as well as a PSI (Paul Sherrer Institute) DRS (Domino Ring System) readout system[5]. A sample output signal[3] from a single pixel is shown on figure 3. The initial rapid signal fall is due to fast moving charge carriers through drift, with a slower subsequent contribution through diffusion as the signal gradually returns to a plateau.

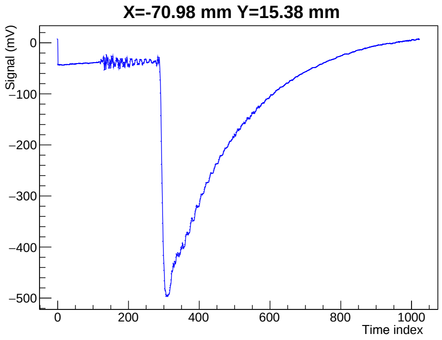


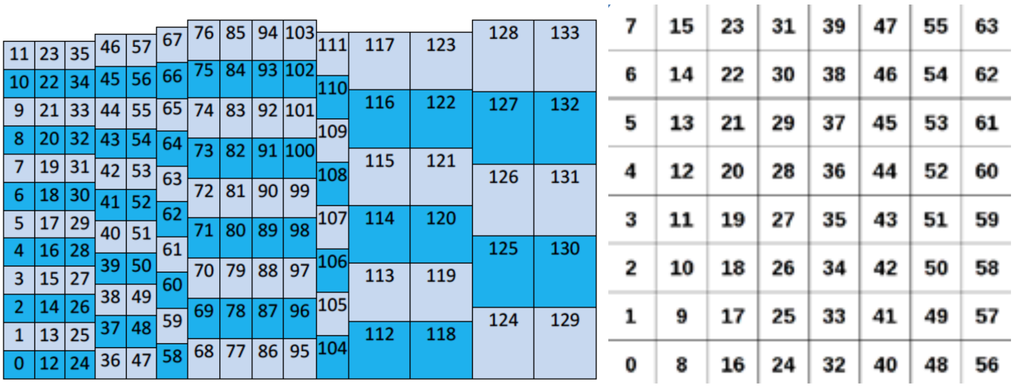
Figure 3: Single pixel sample output, after 40dB amplification.

5. Results

Figure 5 shows a two-dimensional sensor cross section scan for a 50 μm pixel with its corresponding x-axis projection. The cross sectional scan shows the signal in arbitrary charge units, of a 50 μm wide pixel with 30 μm deep epitaxial layer, as expected. This pixel is located on mini-matrix 129 on the investigator chip, the exact location shown on figure 4. The charge collection electrode is located on the left-hand side of the diagram (at 2.12 mm). It can be seen that the epitaxial region shows a greater level of charge collection towards the towards the electrode side. The reason for the non-uniformity of the depletion region throughout the epitaxial layer thickness is still under investigation.

On figure 6, the pixel response to various bias voltages shows a rapid growth of the depletion layer from 0 to -1.5 V and a more gradual growth at higher voltages. This same measurement is being conducted on pixels of different geometries to identify which design can, among other things, reach a fully depleted epitaxial layer at low bias voltages, as a result also reducing power consumption.

Another feature probed by E-TCT is the level of charge sharing between neighbouring pixels, i.e. the amount of charge deposited which drifts towards a neighbouring pixel's electrode in favour of the actual closest electrode at the point of electron-hole pair generation. This can lead to compromised spatial resolution. Figure 7 shows a qualitative assessment of the charge sharing level through the overlapping of the individual pixel signals for a given laser beam position. Charge sharing is measured as fraction of the area underneath the curve outside of the given pixel size. On a 50μm pixel, this was observed to be of the order of approximately 20%.



7	15	23	31	39	47	55	63
6	14	22	30	38	46	54	62
5	13	21	29	37	45	53	61
4	12	20	28	36	44	52	60
3	11	19	27	35	43	51	59
2	10	18	26	34	42	50	58
1	9	17	25	33	41	49	57
0	8	16	24	32	40	48	56

Figure 4: The structure of the Investigator I chip is shown (left) with its subdivisions within mini-matrices (numbered 0 to 133) along with the individual pixel numbering for any given minimatrix (right).

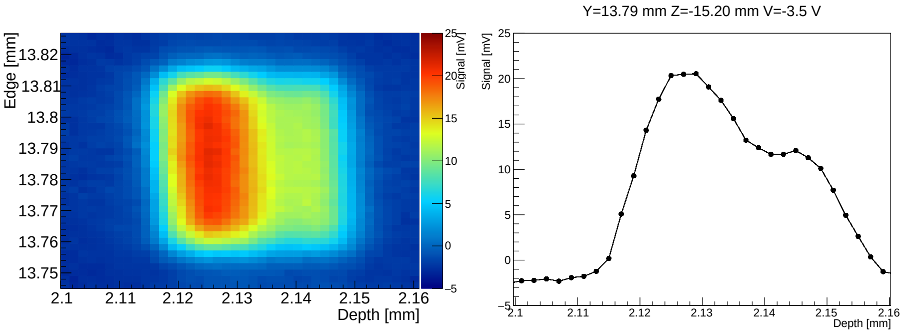


Figure 5: Single 50 μm pixel output, after 40 dB amplification, with a cross-sectional 2D scan (left) and its corresponding x-axis projection (right).

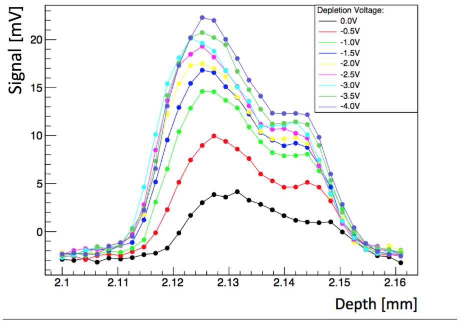


Figure 6: Cross sectional 2D scan of single 50 μm pixel at varying depletion voltages, along with a corresponding x-axis projection.

6. Conclusion

A generic sensor E-TCT characterisation facility has been setup at CERN to investigate prototype pixel sensor features including depletion level, charge sharing, signal response times and the effect of irradiation. One of the effects of radiation damage is the need of higher bias voltage to reach the same depletion depth, which results in greater power consumption over time or reduced

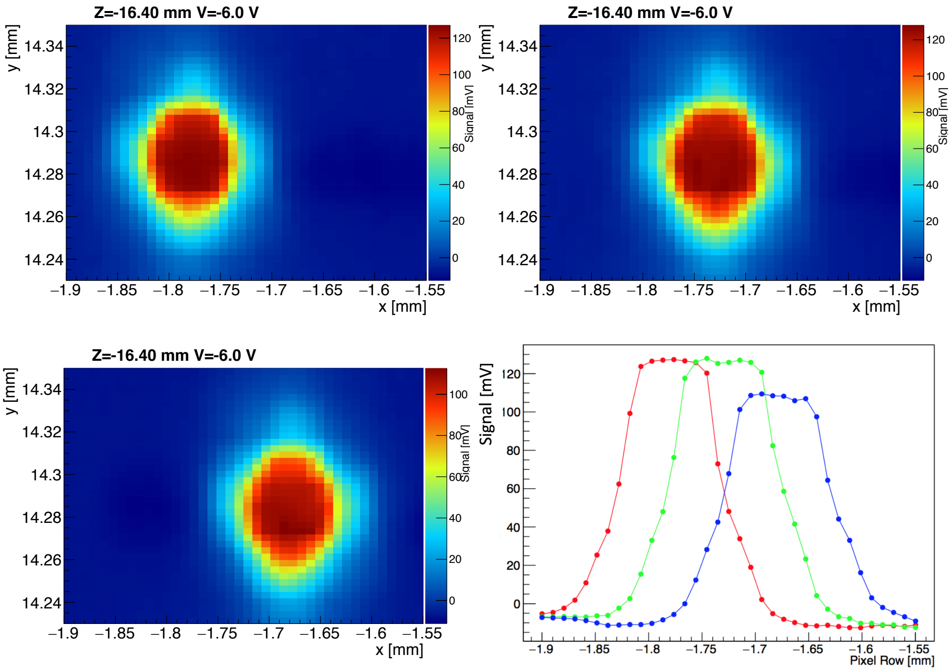


Figure 7: Three separate 2D cross sectional scans of individual pixels with their corresponding x-axis projections showing the level of overlap in signal being produced at each electrode.

efficiency. Irradiated TowerJazz Investigator chips will be studied to quantify these adverse effects in various design geometries. This will include the assessments of bulk damage via neutron irradiation, identifying the level of charge carrier trapping and surface damage via X-ray irradiation.

References

[1] *Expected performance of the ATLAS Inner Tracker at the HL-LHC*, *ATL-PHYS-PUB* 2016 **025**.

[2] H. Pernegger et al., Monolithic pixel development in TowerJazz 180 nm CMOS for the outer pixel layers in the ATLAS experiment, JINST, 13, 01, C01023, 2018.

[3] C. Riegel, *Radiation hardness and timing studies of a monolithic TowerJazz pixel design for the new ATLAS Inner Tracker*, *JINST* **12** 2017.

[4] G. Kramberger et al, *Signal development in irradiated silicon detectors*, *CERN-THESIS* **2001-038** 2001.

[5] S. Ritt, *Development of high speed waveform sampling ASICs*, *In Proc. NSNI* 2010.