Proposal for Test Beam Runs at CERN SPS in October (10-18)-November (20-25) 2009
Experiment: ATLAS 3D Silicon pixels

Prepared by Cinzia Da Vià*[1], Philippe Grenier[2] and Ole Røhne[3],
for the 3DATLAS Collaboration.
*Project leader
[1]The University of Manchester,
[2]SLAC National Accelerator Laboratory,
[3]University of Oslo.

8th of September 2009

Introduction

The performance of the B-layer of the ATLAS Pixel Detector will begin to deteriorate after a fluence of 10^{15} cm^{-2} 1 MeV neutron equivalent which it will receive in about 3 years at the LHC design luminosity. The B-layer was originally planned to be replaced during the LHC upgrade Phase 1 in 2013-2014. However, given the technical problems and the time scale of the replacement, the ATLAS collaboration decided to leave the B-layer in the detector and to insert an additional layer, closer the beam pipe, the Insertable B-Layer (IBL). The even higher luminosities of a Super-LHC (Phase 2 Upgrade) will require a new silicon pixel detector, with increased radiation hardness for all other layers as well. Compared with the present detector, it will need to have, (1) a reduced depletion voltage, (2) a reduced capture of charge carriers, (3) increased speed and (4) a smaller charge sharing region to minimize further reduction of signal size. Full-3D active edge and Double Sided 3D sensors, in which the *n* and *p* electrodes are perpendicular to the surface and penetrate through the substrate, offer advantages in all of these qualities [1-2-3]

Detector description

3D silicon sensors use a combination of traditional VLSI and micro-machining technologies. They are presently being processed using two kinds of layouts: the first, shown in Figure 1 (left,) have been proposed by FBK, Trento, Italy and in parallel by CNM, Barcelona Spain. The second, called Full 3D with active edge design, shown in Figure 1 (right), was the original design proposed by S. Parker and C. Kenney. This design is currently being processed within the 3DC Consortium by a collaborative effort of SINTEF, Norway and Stanford, USA. They are all being studied for the ATLAS pixel upgrade by the ATLAS 3D Collaboration [4]. Contrary to the standard planar silicon configuration, in 3D sensors the electrodes are processed inside the bulk of the silicon wafer (fully or partially) instead of being implanted on its surfaces, as can be seen by Figure 1. The consequences of this approach are many fold:

1. Collection distances can be as short as ~50μm while the charge generated by the traversing particle can have much longer track lengths, depending on the application, by varying the thickness of the substrate.

2. Ten times faster response compared to a planar structure due to the short carrier drift distances, higher average field for any given maximum applied field as a consequence of the cylindrical shape of the electrodes, less arrival time spread for all charges, since the particle path from a minimum ionizing particle is parallel to the electrodes.

3. 3D geometry has shown great **flexibility in the use of readout electronics**. Since both electrodes are accessible from the front and back side of the wafer, it is possible to process the readout electrodes to be compatible with both pixel and micro-strip readout chips for both input polarities and on either side of the wafer.

4. Another **crucial feature of 3D sensors is the possibility to minimize its dead area at the edge** to less than a few microns. This is achieved by etching a trench around the detector's physical edge and by diffusing in dopants to make an electrode. The electric field lines, which are parallel to the wafer's surface, can then be properly terminated at the edge electrode. A final dicing etch is then used instead of sawing (as in traditional planar structures) to separate the sensors. The main advantage of this approach is that the dead area, which would otherwise be needed in planar detectors for: (1) guard rings and to (2) keep the bulge of the electric field from possible cracks and edge chips, as well as the conducting edge is here reduced to no more than a few microns. Several prototypes with different dimensions and electrode configurations have been fabricated at the Stanford Nanofabrication Facility (SNF), USA by a collaboration of Manchester, Hawaii, and a Molecular Biology Consortium (MBC) scientist. Active edges were measured in X-rays and high energy particle beams confirming that the sensitivity of the sensors can be extended up to 5±8 μm from the physical edge (active edges require the use of a support wafer and therefore have been successfully fabricated only in the case of full 3D with active edges). During this R&D we plan to study the best design to allow two-side active edges to be fabricated with double sided processing.

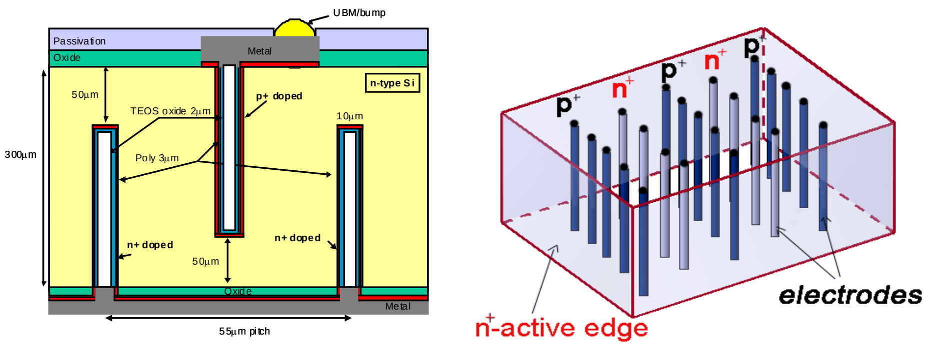

Figure 1. CNM and FBK double side process (left) and full with active edge 3DC (right) sensors. These layouts will be both studied using the EUDET telescope

Recent test beam results

The most recent test beam was carried out at the CERN SPS in May 2009. We tested Full 3D with active edges and double side 3D sensors from FBK-Trento. The main objective of this test beam was the measurement of the Lorentz angle effect in 3D sensors. For this test the setup, composed by 3D devices and a planar sensor, were inserted together with the tracking telescope into the 1.4T B-field 'Morpurgo' magnet in the H8 beam line.

Data analysis is currently on-going. The main preliminary result obtained is reported in Figure 2, where the Time over threshold (TOT) charge of the 3D assemblies at zero and 15 degrees beam incident angles and a sample of the currently installed planar pixel sensors are compared.

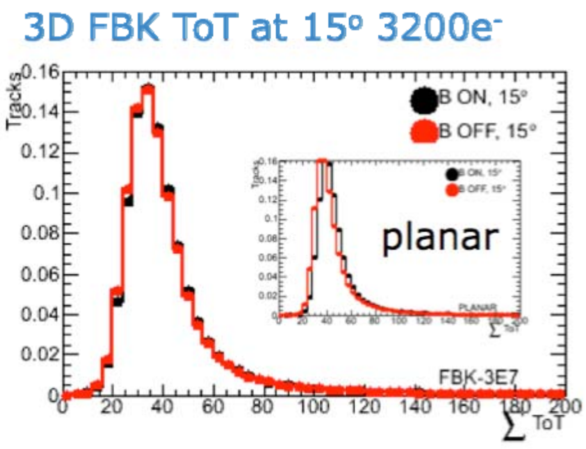

Figure 2. Time over Threshold distribution of an FBK Double Sided 3D assembly inclined at 15 degrees with respect to the incident beam with and without magnetic field. In the insert a planar sensor TOT in the same test conditions.

As can be seen from Figure 2, the Lorentz force does not affect the position of the ToT distribution in 3D sensors. This can be explained by the charge collection mechanism in this type of devices.

Proposed test beam runs with the EUDET telescope

In 3D detectors electrodes occupy a fraction of the sensor active volume. Contrary to expectations, these electrodes are not completely inactive, in fact past x-ray and particle beams have shown that they can respond as much as 60% if minimum ionising particles or X-rays traverse them along their length. Moreover precise measurement of active edges were carried out again in past test beams showing that one could expect to be sensitive within 5-20 microns from the physical edge. All these measurements were affected by the intrinsic resolutions (ranging from 8 to 10 microns) of the telescopes used in the experiments.

By October – November 2009 we will receive the bump-bonded assemblies of the new Full 3D with active edges batch from SINTEF/Stanford and the Double Sided production from CNM Barcelona. These assemblies, together with the FBK Trento, will complete the set of devices being presently considered by the 3D ATLAS Collaboration for the ATLAS pixel upgrade and the IBL.

The use of the EUDET telescope will allow to measure with 2-3 microns precision the 3D response in the electrodes and active edge regions. Moreover a detailed charge sharing measurement with the above precision would give important information on the understanding of the 3D sensor geometries in view of their use as high precision vertex detectors.

ATLAS 3D Contribution to the EUDET Setup

A multicarrier cooling box is presently being designed by mechanical engineers in the ATLAS 3D collaboration (Oslo University and Genova INFN), to be compatible with the EUDET Telescope setup. A card was designed and built by the 3D Genova and SLAC groups to allow multi-chip readout. Both developments will be used during the proposed test beams periods and will be available to the ATLAS pixel EUDET users afterwards.

People and costs

Several institutions are participating to the 3D-Atlas test beams. For this reason we would like to restrict our travel and accommodation support request to students attending the two EUDET test beam periods.

October 10-17:

Kristine Helle, Bergen, Norway

Marcello Borri, Manchester, UK

Isaac Troyano, IFAE Barcelona, Spain

Tomas Slavicek, Technical University, Prague Czech Republic

November 20-25:

Chinghung Li, Manchester, UK

Clara Nellist, Manchester, UK

Erik Davetak, Stony Brook, USA

Marcello Borri, Manchester, UK

References

*[1] S. I. Parker, C. J. Kenney, and J. Segal, "3D--A proposed new architecture for solid-state radiation detectors" Nucl. Instr. and Meth, **A395** (1997) 328-343.*

[2] G. Pellegrini, F. Campabadal, M. Lozano, J.M. Rafí, M. Ullán, R. Bates, C. Fleta, D. Pennicard Double Sided 3D Detector Technologies at CNM-IMB Submitted TNS IEEE 2007.

[3] Double-sided, double-type-column 3-D detectors: Design, fabrication, and technology evaluation. Andrea Zoboli, Gian-Franco Dalla Betta, (INFN, Trento & Trento U.) , Maurizio Boscardin, Claudio Piemonte, Sabina Ronchin, Nicola Zorzi, (Fond. Bruno Kessler, Povo) , Luciano Bosisio, (Trieste U. & INFN, Trieste) . 2006. 10pp. Published in IEEE Trans.Nucl.Sci.53:2775-2784,2006.

*[4] C. Da Vià, Development, Testing and Industrialization of Full-3D Active-Edge and Modified-3D Silicon Radiation Pixel Sensors with Extreme Radiation Hardness .**ATL-PA-MN-0007***