Active edge sensors for the ATLAS upgrade

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Introduction

In view of the LHC upgrade phases towards the High Luminosity LHC (HL-LHC), the ATLAS experiment plans to upgrade the Inner Detector with an all-silicon system.

The n-on-p silicon technology is a promising candidate to achieve a large area instrumented with pixel sensors, since it is radiation hard and cost effectiveness.

We report on the performance of novel n-in-p edgeless planar pixel sensors produced by FBK-CMM, making use of the active trench for the reduction of the dead area at the periphery of the device. The sensor technology, the device simulations of pre- and post-irradiated samples, the electrical characterization of the produced devices will be given. Eventually results on charge collection efficiency with charge particles will be presented.

Motivations

The Large Hadron Collider will turn into a High Luminosity (HL-LHC) after a series of upgrades which are detailed in Figure 1.

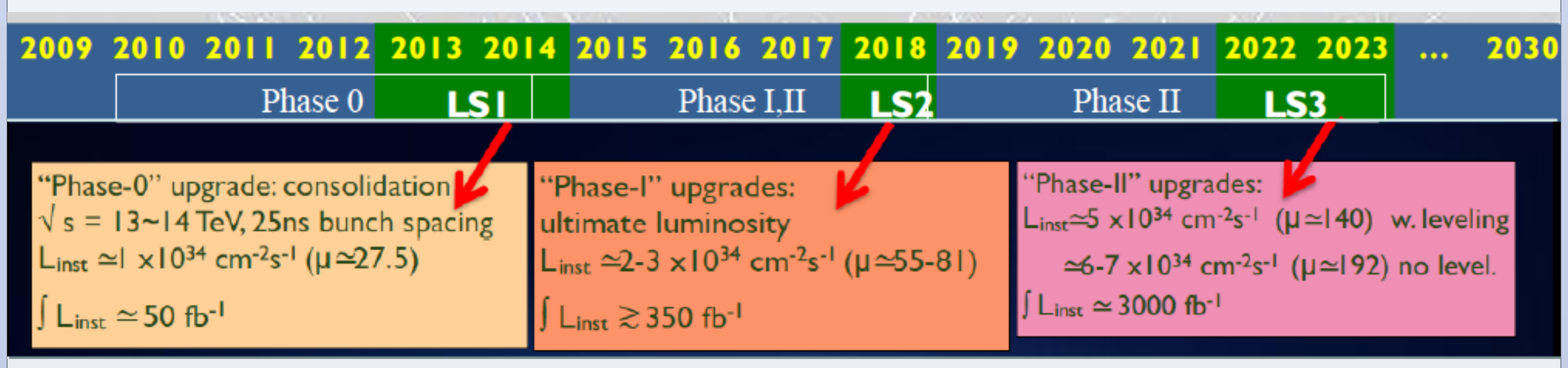

Figure 1. The Large Hadron Collider upgrade plans

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This upgrades pose severe challenges to ATLAS detector. In particular the tracker will have to sustain unprecedented particle rates, radiation doses and fluences. For a pixel layer at 1 cm from the interaction point, a fluence of $\phi = 2 \times 10^{16}$ (1 MeV) n_{eq}/cm^2 is expected after an integrated luminosity of 6000 fb^{-1}. For this the ATLAS collaboration is planning for a new, completely silicon-based tracker for the HL-LHC phase.

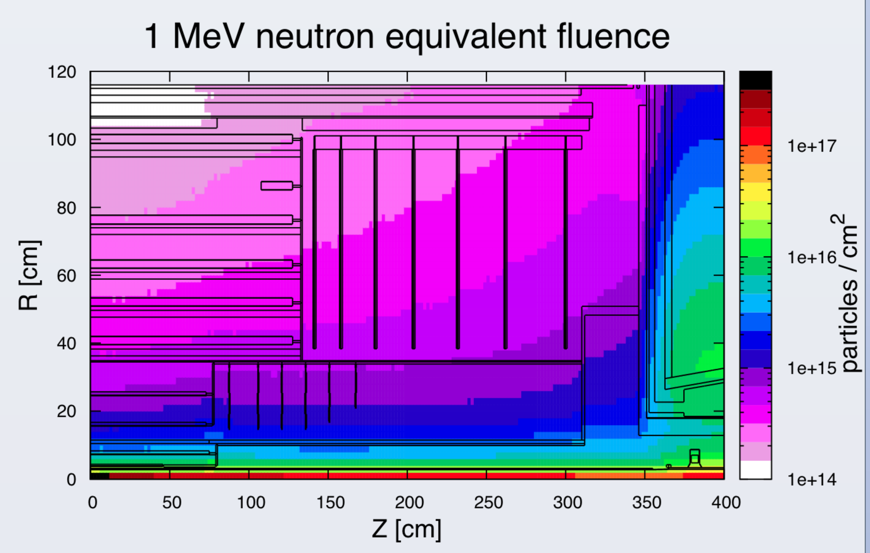

Figure 2. The expected fluences for the ATLAS detector after an integrated luminosity of 6000 fb^{-1}

The new pixel sensors will not only have to sustain the harsher environment, but also have to show high geometrical acceptance without overlapping adjacent modules. Hence the inactive areas of the future pixel sensor have to be reduced significantly. For this reason, efforts were devoted to conceive detectors with reduced dead area.

One way to reduce or even eliminate the insensitive region along the device periphery is offered by the "active edge" technique, in which a deep vertical trench is etched (Deep Reactive Ion Etching, DRIE) along the device periphery throughout the entire wafer thickness, thus performing a damage free cut. See Figure 3 for details. The trench is then heavily doped, extending the ohmic back-contact to the lateral sides of the device: the depletion region can then extend to the edge without causing a large current increase. This is the technology the LPNHE and FBK groups have chosen for planar sensors with reduced inactive zone.

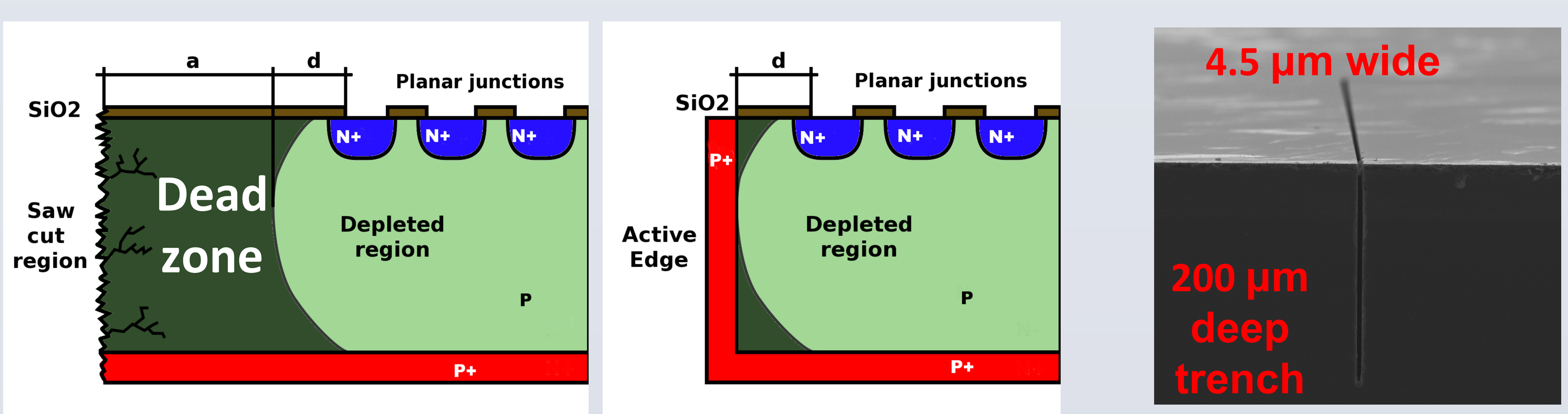

Figure 3. The "active edge" concept.

(Left) A standard planar n-on-p sensor cut away from the wafer with a diamond saw; please note the large dead area. (Middle) Thanks to the DRIE technology the dead area can be greatly reduced. (Right) a detail of the trench

The active edge sensor fabrication at FBK

The sensors are fabricated on 100 mm diameter, high resistivity, p-type, Float Zone (FZ), <100> oriented, 200 µm thick wafers. Both homogeneous ("p-spray") and patterned ("p-stop") implants have been used to insulate the n-type pixels. In Figure 4 a sample wafer from the production. Nine FE-I4 compatible pixel sensors can be accommodated in a 100 mm wafer. The nine FE-I4 sensors differ in the pixel-to-trench distance (100, 200, 300, and 400 µm) and in the number of the guard rings (0, 1, 2, 3, 5, and 10).

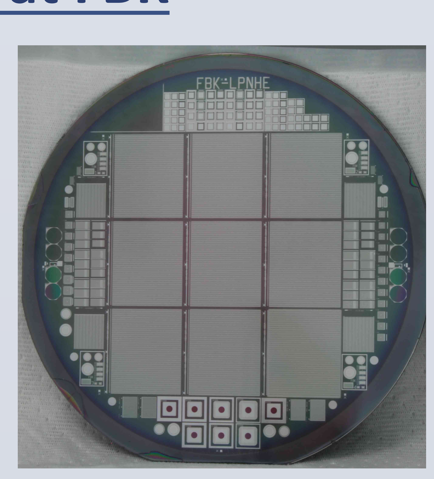

Figure 4. A sample wafer

TCAD simulation of active edge sensors

In order to explore and compare the properties of the design variations considered, numerical simulations were performed with TCAD tools from SILVACO. Several configurations were tested, including various bias voltages and irradiation fluences; observables included breakdown (BD) voltage, electric field distribution and charge collection efficiency (CCE).

In Figure 5 an example from such studies. Several detectors were simulated to study the BD voltage dependence on the number of GRs. As expected, the more the GRs, the larger the BD voltage. CCE was studied with a simulated laser beam which creates charges in an irradiated bulk, at different distances from the edge. The results are reported in Figure 6. It can be seen that already at a bias voltage of 300 V, after a fluence of $\phi = 1 \times 10^{15}$ n_{eq}/cm^2 more than 50% of the original charge, even close to the edge. This sounds very promising for an edgeless sensor to be operated at the HL-LHC.

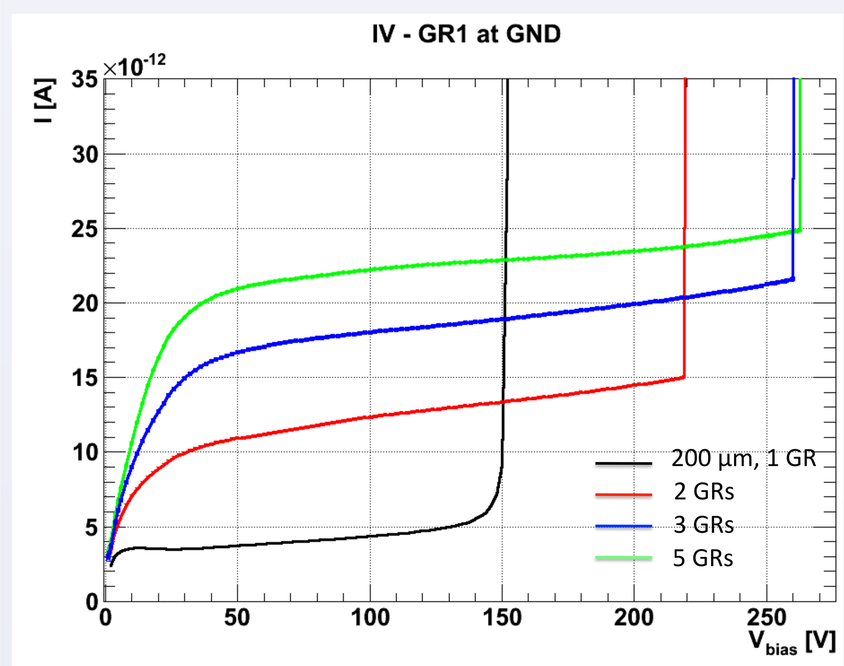

Figure 5. Simulated IV curves for active edge sensors with different number of GRs

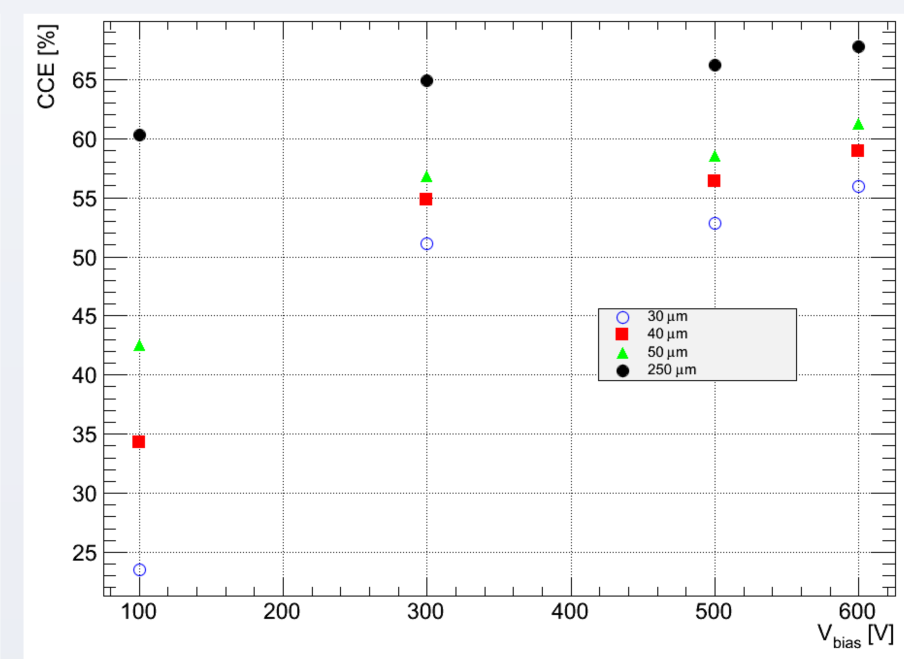

Figure 6. Simulated CCE for an irradiated sensor ($\phi = 1 \times 10^{15}$ n_{eq}/cm^2)

Electrical characterization

The electrical characterization on the received wafers included, among all the measurements, current- and capacitance- voltage. In particular the BD dependence on the number of GRs, on the distance between the first pixels and the trench and on the p-spray dose was studied.

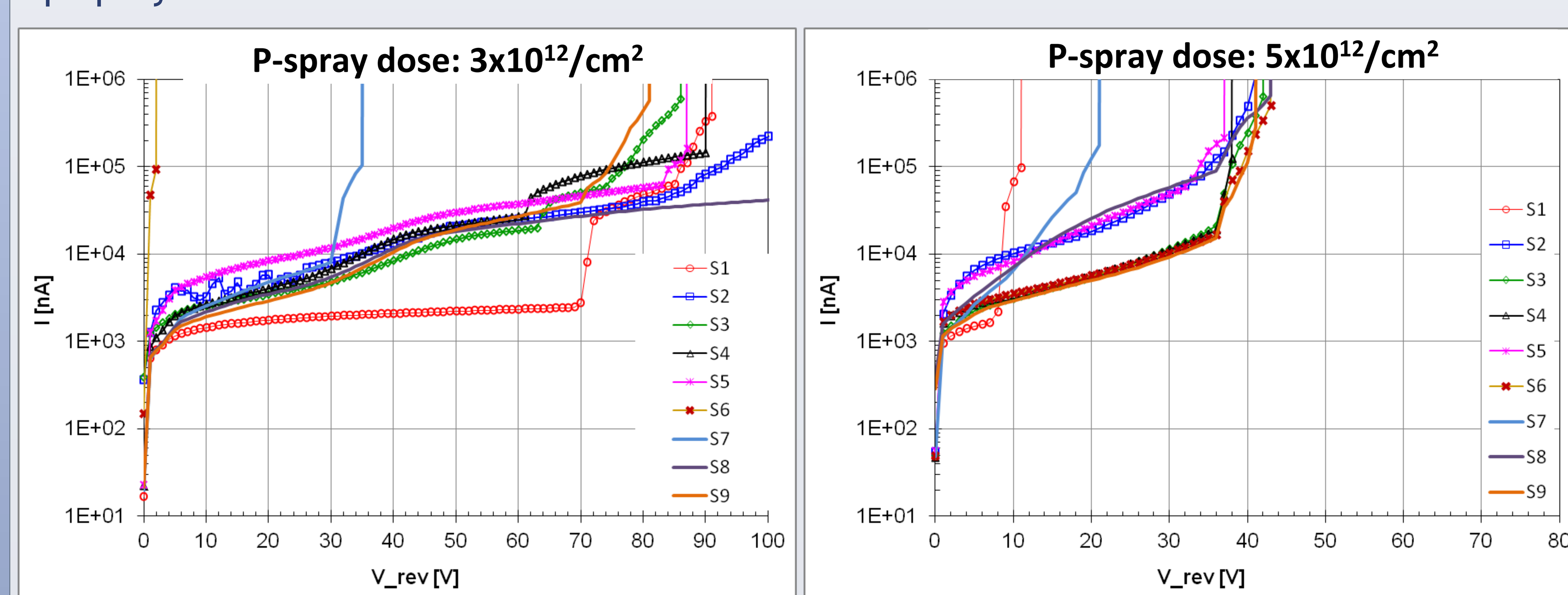

Figure 7. IV curves for active edge sensors for different p-spray doses.

As expected, the higher the p-spray dose the lower the BD voltage. In Figure 8 the CV curves are reported for different frequencies, and for sensors with and without the field plate (a metallic electrode overhang). In the former case the capacitance is almost as double as the latter one, but still at an acceptable level in terms of expected electronic noise.

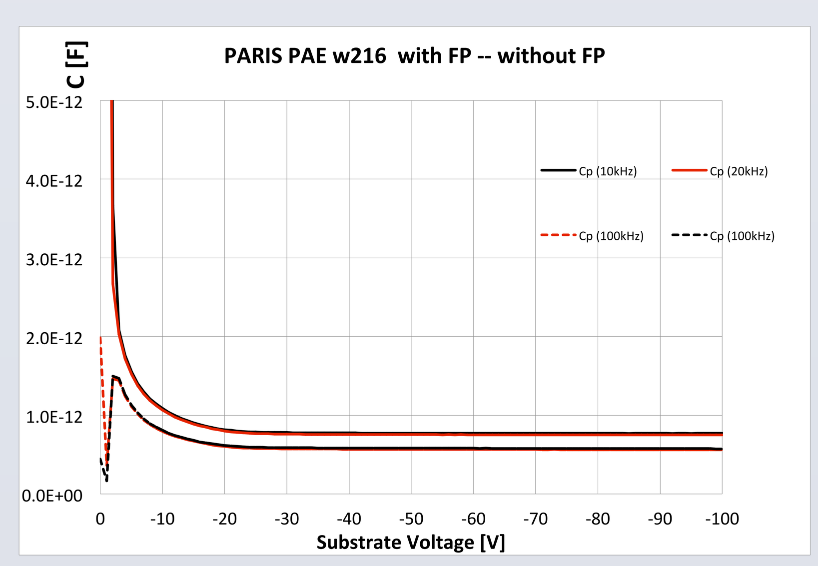

Figure 8. CV curves for active edge sensors, with and without electrode metal overhang

Conclusions and outlook

The active edge technology allows to realize edgeless pixel sensors. FBK and LPNHE are exploring this possibility for the ATLAS pixel detector during the High Luminosity LHC phase. Sensors were produced, based on dedicated full simulation studies. Operation of sensors with only 100 µm wide dead area appears possible. Irradiation campaigns are planned, to test the viability of the technology for the high fluences expected at the HL-LHC. Modules consisting of a FEI4 chip and an active edge sensor are to be built; charge collection efficiency, at the detector's edge, and after irradiation too, will be the ultimate test.

References and contacts

M. Bomben *et al.*, Nucl. Instr. Meth. A 712 (2013) 41-47

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