Prototype sensors for a module with integrated on-chip logic for the CMS tracker phase-II upgrade

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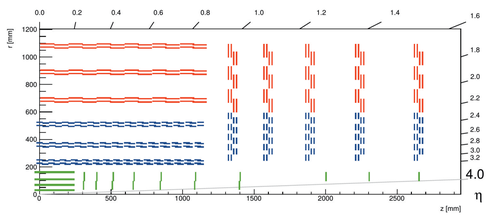
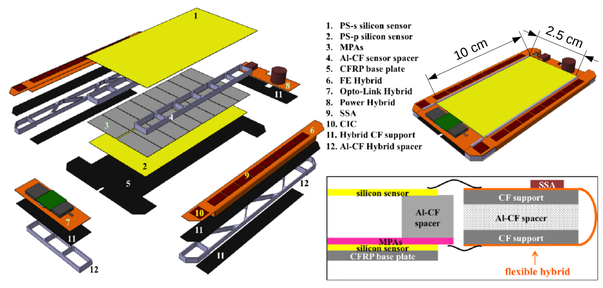
PS module for CMS phase-II upgrade

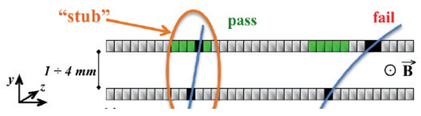
The high luminosity upgrade of the LHC is targeted to deliver 3000 fb^{-1} at a peak luminosity of $5x10^{34}$ $cm^{-2}s^{-1}$. Higher granularity, 140 collisions per bunch crossing and existing bandwidth limitations require a reduction of the amount of data at module level. New modules have binary readout, on-chip p_T discrimination and capabilities to provide track finding data at 40 MHz. Two different module concepts are foreseen, the 2S and the PS module, which consists of a pixel and a strip sensor and has sufficient granularity for the inner part of the outer tracker.
The baseline PS module is composed of a strip sensor and a macro pixel sensor with 100 µm x 1.5 mm pixel pitch, 0.25 width/pitch ratio and n-strips in p-bulk. The MacroPixelASIC (MPA) is bump-bonded to the PS-p sensor and fixed to the AL-CF spacer, which supports the strip sensor mechanically. For the MaPSA light 16x3 pixels in 6 rows are readout by 6 MPA-light ASICs.



Tracker layout: PS modules in blue



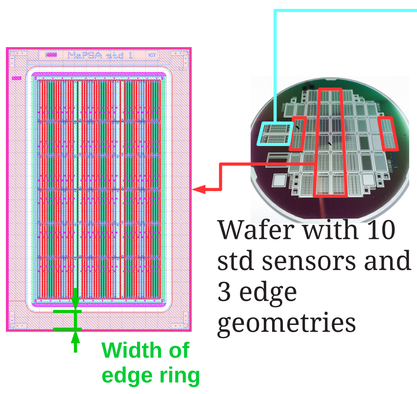
PS-module baseline concept



p_T discrimination at module level

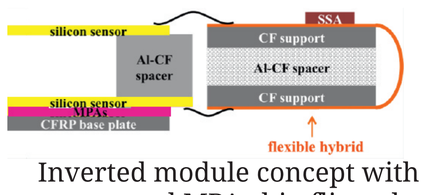
PS-p light sensor prototypes

The aim of the run was to study the effects of p-stop concentration and p-stop implant depth on sensor parameters, to test the new mini inverted PS-pixel concept and different edge ring geometries. The inverted concept flips chip and sensor in the module, which overcomes industry process requirements. An area for routing the LV-power and digital IO of the MPA chip is foreseen on the sensor. Edge ring geometries have impact on the dead detector volume and mass budget. 350 and 500 µm edge ring prototypes with respect to standard 850 µm were produced.



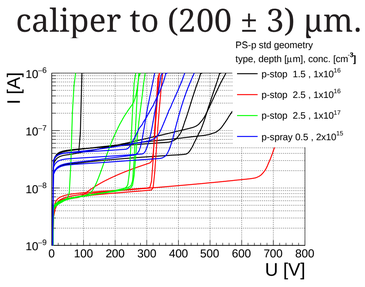
Wafer with 10 std sensors and 3 edge geometries

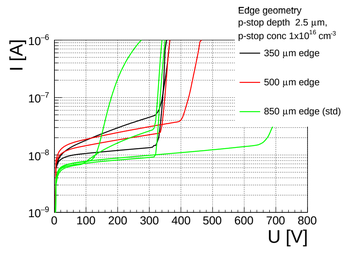
Standard sensor width edge ring and 3x16 strips in 6 rows

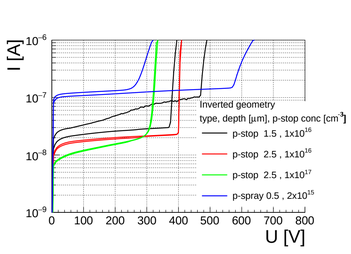


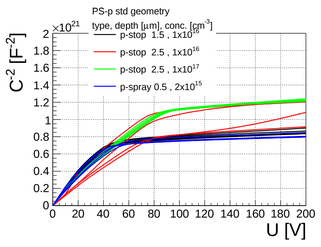
Inverted module concept with sensor and MPA chip flipped

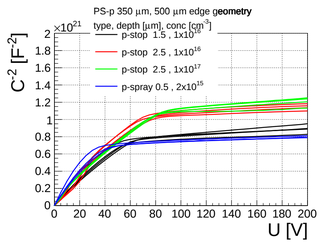
I-V curves for the PS-p sensor prototypes see below. High p-stop concentrations and high implant depth tend to early breakdown, which has been studied in simulations. The impact of the edge ring width on breakdown is not decisive, while the current is increased for smaller edge width. The thickness of the wafers was measured with a micrometer caliper to (200 ± 3) µm.

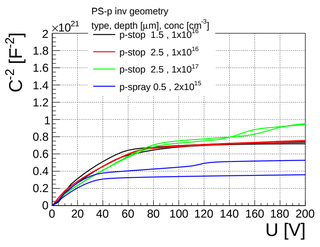








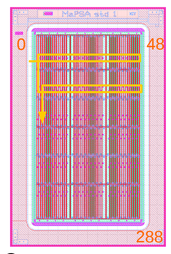




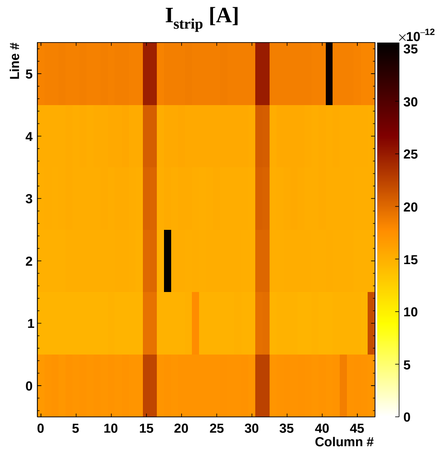
In $1/C^2$-V curves a split in two groups of full depletion voltage was observed for the standard geometry and edge geometry, which needs further studies. The inverted geometry has increased capacitance.

Stripscan results and optical inspection

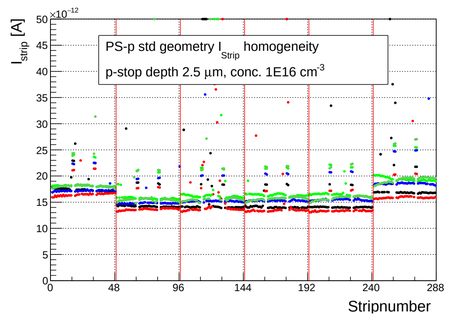
Electrical characterization of the sensors was done in an automated stripscan test setup with x/y stage and micropositioners. I_{Strip} was measured. An analysis for defective strips was performed and inhomogeneities could be mostly tracked down to scratches, found during the optical inspection. Double pitched strips have increased current. Measurements were performed at 130 V bias.



Scan direction and mapping



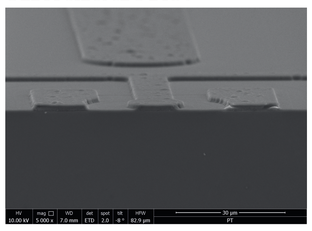
I_{strip} map with higher current for double pitched strips, top and bottom rows.



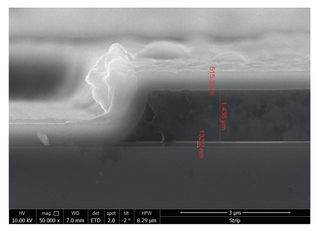
Istrip for five standard sensors with red lines as row indicators

SEM images for determination of material thickness and composition

A sensor was cut, grinded, and polished with diamond 10 nm grain size. Then bufferd HF and HNO_3/HF solution was used to etch the sensor and generate topological contrast and contrast between the doped areas. Scanning electron microscopy images were taken at USTEM in Vienna. Along with this also energy-dispersive X-ray spectroscopy (EDX) analysis was done, revealing the material composition. Pictures were taken at a cut through the metal strip contacts, the punch-through (PT) structures and through the strips. The obtained numbers may be used as input for simulations.



SEM image of a cut through the PT-structure. The bias line is visible in the background.

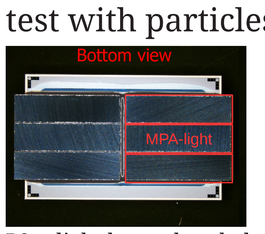


Strip profile

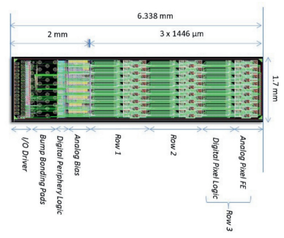
Layer	Thickness [nm]
Strip passivation	515
Strip aluminum	1440
Strip dielectric	132
Backplane aluminum	1520

MaPSA-light test system with particles

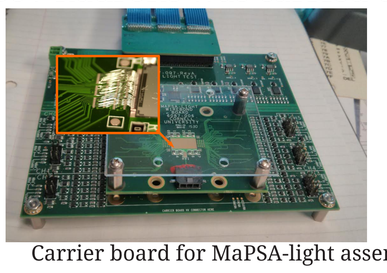
A first test system with the MPA-light chip has been built and studies on the quality of the bump bonds and assembly were done for prototypes from different suppliers, using the increased noise of a connected strip. A test with particles at Fermilab with 120 GeV hadrons was carried out.



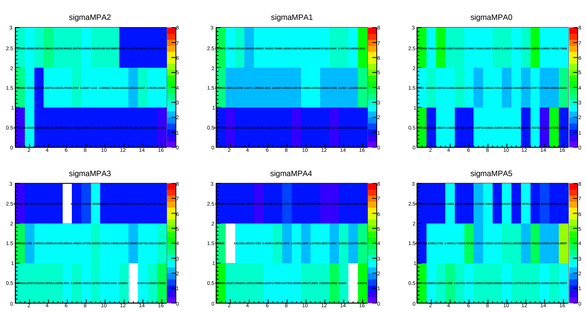
PS-p-light bump-bonded subassembly



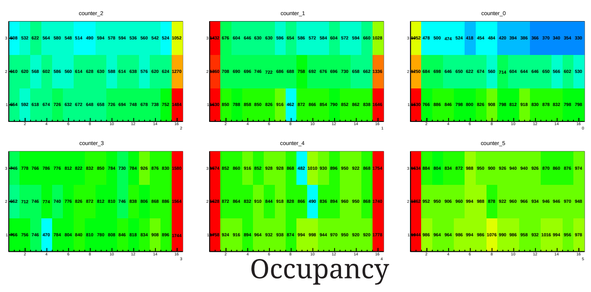
MacroPixelASIC (MPA) chip



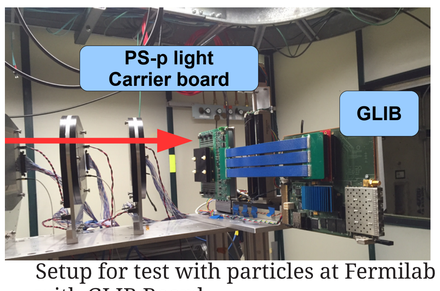
Carrier board for MaPSA-light assembly



Pedestal width for 6 MPA chips.



Occupancy



Setup for test with particles at Fermilab with GLIB Board

The noise plot shows the RMS from the differentiated width of the s-curves with a biased sensor for one assembly. Defective bump bonds have lower noise.
The strips with double strip width show higher occupancy.