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The MiniCactus CMOS timing sensor development line: towards HV-CMOS monolithic timing sensors with 20 ps resolution

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I. Introduction

The v1 and v2 MiniCACTUS sensors are monolithic CMOS sensors in LF15A technology, designed to investigate the possiblity of tagging time of arrival of Minimum Ionizing Particles with a resolution better than 100 ps. These sensors are a first step towards an ultimate time resolution of 20 ps, needed for future projects like FCC-ee. MiniCactus v1 and v2 feature arrays of diodes without internal amplification, with an analog front-end and discriminator per pixel. A time resolution of 65 ps has been measured on a 0.5 mm² pixel from a 200 µm-thick sensor MiniCactus v1 sensor tested at CERN.

II. MiniCactus Sensors Description

The MiniCACTUS v1 and v2 sensors have the front-end electronics for each pixel at the column level, avoiding large power rails and the associated parasitic capacitance in the active area. The v1 front-end electronics comprises an AC-coupled charge sensitive amplifier, a discriminator and a 4-bit DAC for threshold tuning.

Standard MiniCactus v1 HR wafers have been thinned (100, 200 and 300 µm) and post processed for backside polarization. MiniCactus v1 substrates can be safely biased to at least -300V. All pixels from MiniCactus v1 have been calibrated with 55Fe and 241Am sources. MiniCactus v2 is an improved version of MiniCactus v1, with corrections of couplings between analog and digital electronics, an improved discriminator with programmable hysteresis and twice as many pixels. MiniCactus v2 also features new flavours of analog front-end : an improved CSA, and a VPA inspired from the Altiroc ASIC developed for the ATLAS HGTD. These new front-ends have much faster return to baseline than the original CSA of MiniCactus v1, making them better suited for an environment with high pileup.

III. Test-beam results

MiniCactus v1 sensors with 200 µm and 100 µm thickness, as well as MiniCactus v2 with thicknesses of 200, 175 and 150 µm have been tested with muons at CERN SPS (H4, in parallel with RD51/DRD1). The best timing results so far have been obtained with a 200 µm MiniCactus thick sensor, for a pixel 500 by 1000 microns, with a timing resolution of 65 ps at nominal FE settings and −450 V bias voltage, after time walk effect corrections. First test beam measurements done in June-July 2024 with MiniCactus v2 confirm the shortcomings of MiniCactus v1 have been corrected, and time resolution is comparable for similar high voltage and front-end settings.

IV Future prospects

Time resolution for non amplified sensors is limited by Landau fluctuations, since the charge collection region has to be thick, about 200 microns, to ensure sufficient signal over noise ratio. A way to overcome this difficulty is to add intrinsic amplification to the sensor, produced by a buried PN junction. TCAD simulations performed with Sentaurus have shown the concept to allow for a charge gain of about 10, provided the structure of the pixel edge is carefully optimized to avoid early breakdown. Passive test structures in LF15A technology have been designed to test this idea, and will be available by end of 2024.

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