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Status of sensor qualification for the PS module with on-chip p_T discrimination for the CMS tracker phase 2 upgrade

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ABSTRACT

The high luminosity upgrade of the LHC is targeted to deliver $3000\,\mathrm{fb}^{-1}$ at a luminosity of $5\times10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. 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 to the L1-trigger. The CMS collaboration has undertaken R&D effort to develop new planar sensors for the pixel-strip (PS) module, which has to withstand $1\times10^{15}\,\mathrm{cm}^{-2}$ 1 MeV neutron equivalent fluence in the innermost layer of the tracker. The module is composed of a strip sensor and a macro pixel sensor with 100 μm × 1.5 mm pixel size. Sensors were characterized in the laboratory and the effects of different process parameters and sensor concepts were studied. This contribution presents a new sensor prototype with n-pixels in p-bulk material in planar technology for the PS module. A new inverted module concept is presented, which has advantages with respect to the baseline concept. Electrical characterization of sensors and SEM-images are presented.

1. Introduction

The current CMS tracker [1] needs a major upgrade, which is developed for an integrated design luminosity of $3000\,\mathrm{fb}^{-1}$ at an instantaneous luminosity of $5\times10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ during the HL-LHC phase [2]. In the legacy tracker system the L1-accept rate is limited to 100 kHz. It will be increased up to 750 kHz in the high luminosity period. For the current sensor technology with p-strips in n-bulk material the increasing full depletion voltage and increasing leakage current of the sensors lead to a situation where the bias voltage and necessary cooling power get close to the limits of the current system. Sensors cannot be depleted, which implies a complete loss of the signal. During HL-LHC the CMS tracker must work at an estimated pile-up of 140 at 25 ns bunch spacing. This has to be addressed at module level. Binary readout of the modules and on chip p_T-discrimination is therefore necessary, in order to include the tracker in the trigger decision and to reduce the data rate.

2. PS module for the CMS phase 2 upgrade

For the upgrade of the tracker two different types of modules are foreseen: The 2S module which contains two silicon strip sensors with 100 μm pitch, and the PS-module [2,3]. The PS-module consists of a pixel and a strip sensor of n in p-bulk technology (Figs. 1 and 2). For testing purposes a smaller prototype sensor was designed and processed. This so-called PS-p light sensor has 6 rows of 38 columns of 100 μm × 1.6 mm pixels and a width to pitch ratio of 0.25. The foreseen readout chip is the Macro Pixel ASIC (MPA) with integrated stub finding logic for p_T-discrimination [4]. A MPA-light demonstrator chip reads out 3 rows of 16 pixels. A total of 6 MPA-light chips are bump-bonded to a PS-p sensor (Fig. 3). The sensors implant width is 125 μm and the pitch is 200 μm at the readout chip boundaries. The n-pixels are directly connected to the chip and a punch-through-protection (PT) structure is implemented to test sensors before bump bonding and ensure the homogeneity of the electrical field in case of accidentally not connected bonds, as well as to protect the chip in case of beam loss scenarios. The PT-structure behaves analog to a transistor in weak inversion and the current from source to drain is dominated by diffusion at the working point. Surface resistivity and p-stop concentration, p-stop width and geometry adjust the current. 200 μm thickness of the active volume was selected and n-in-p technology was chosen as a result of previous studies [5].

3. Prototype sensors and testgroups

Sensors were produced in 4 different flavours (Table 1). Strip

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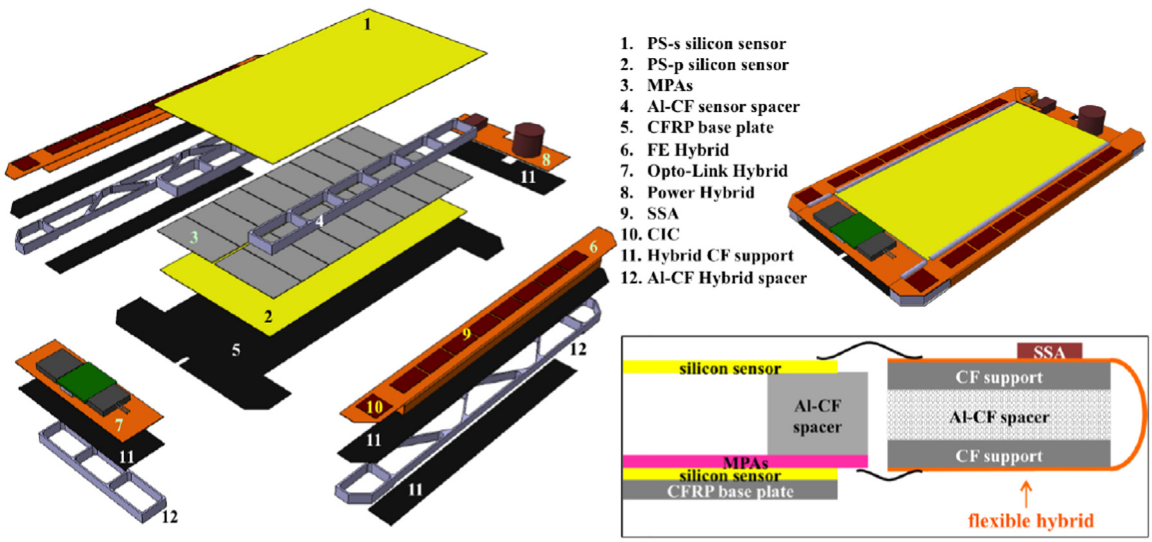

Fig. 1. Exploded view of the PS-module and cross section through the module from technical proposal [2].

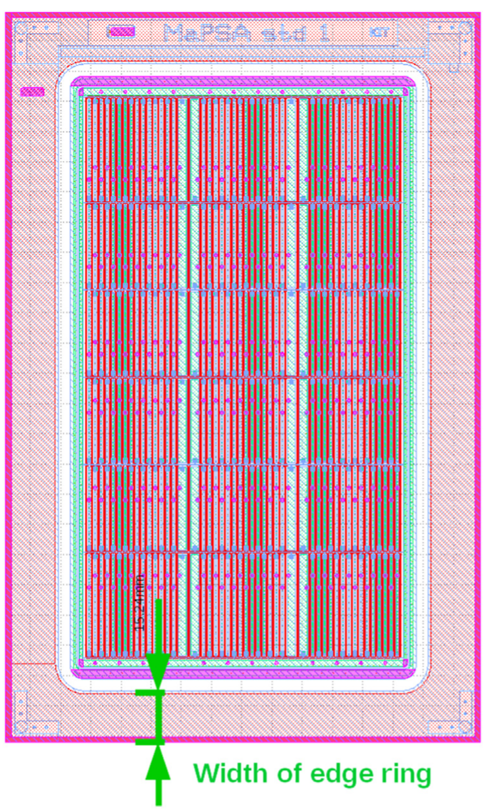

Fig. 2. Standard PS-p sensor layout with indication for the edge ring geometry.

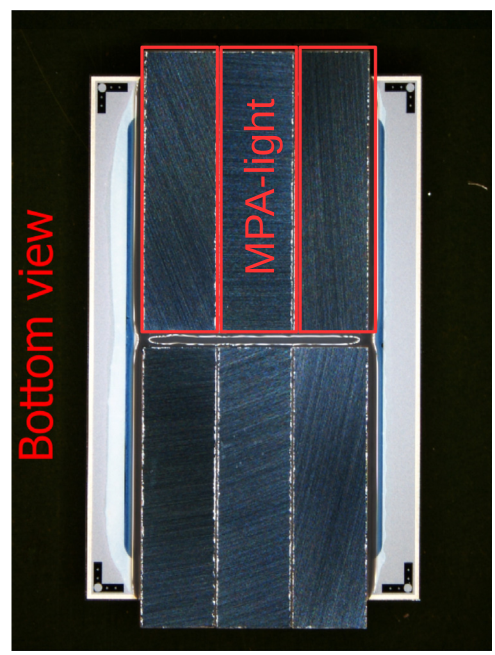

Fig. 3. Bump-bonded PS-p light sensor with 6 MPA-light chips.

isolation was realized with p-stop implants in atoll configuration and for one of the produced variants the p-spray technique was applied. The aim was to study the effects of different p-stop concentrations and depths, and p-spray on sensor parameters, such as single strip current (I_{strip}), interstrip Resistance (R_{int}), punch-through resistance (R_{PT}) and noise. Sensors with three different edge ring widths were produced (Fig. 2). Smaller edge ring width improves the geometric efficiency, but may deteriorate the high voltage stability, increase the dissipated power in the cooling system and increase the probability for microdischarge.

Table 1
Prototype variants with the specified process parameters produced and measured median and standard deviation of V_{dep}.

Variant	Doping conc. (cm^{-3})	Implant depth (μm)	Strip isolation	V_{dep} (V)
1	1×10^{16}	1.5	p-stop	41.7 ± 1.5
2	1×10^{16}	2.5	p-stop	75.5 ± 3.8
3	1×10^{17}	2.5	p-stop	80.6 ± 1.8
4	2×10^{15}	0.5	p-spray	41.8 ± 3.6

4. PS module inverted concept

The PS module inverted concept flips sensor and readout chip in the module (Fig. 4). The advantages are no scattering material between the two sensors, which may have positive effects on the on-chip discrimination logic and better cooling of the chip. The concept avoids to have bump-bonding and wire-bonding on the readout chip, which is not provided by the foundries in the

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