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Detailed studies of full-size ATLAS12 sensors

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ABSTRACT

The "ATLAS ITk Strip Sensor Collaboration" R&D group has developed a second iteration of single-sided n^+-in-p type micro-strip sensors for use in the tracker upgrade of the ATLAS experiment at the High-Luminosity (HL) LHC. The full size sensors measure approximately $97 \times 97\ mm^2$ and are designed for tolerance against the $1.1 \times 10^{15}\ n_{eq}/cm^2$ fluence expected at the HL-LHC. Each sensor has 4 columns of 1280 individual 23.9 mm long channels, arranged at 74.5 μm pitch. Four batches comprising 120 sensors produced by Hamamatsu Photonics were evaluated for their mechanical, and electrical bulk and strip characteristics. Optical microscopy measurements were performed to obtain the sensor surface profile. Leakage current and bulk capacitance properties were measured for each individual sensor. For sample strips across the sensor batches, the inter-strip capacitance and resistance as well as properties of the punch-through protection structure were measured. A multi-channel probecard was used to measure leakage current, coupling capacitance and bias resistance for each individual channel of 100 sensors in three batches. The compiled results for 120 unirradiated sensors are presented in this paper, including summary results for almost 500,000 strips probed. Results on the reverse bias voltage dependence of various parameters and frequency dependence of tested capacitances are included for validation of the experimental methods used. Comparing results with specified values, almost all sensors fall well within specification.

1. Introduction

The foreseen upgrade of the Large Hadron Collider (LHC) to the High-Luminosity LHC (HL-LHC) is scheduled to deliver collisions in 2022 [1]. To achieve a total cross-section of $3000\ fb^{-1}$, the instantaneous luminosity of the HL-LHC is expected to reach $5 \times 10^{34}\ cm^{-2}\ s^{-1}$ at a centre of mass energy of 14 TeV. The increase in particle fluence necessitates an upgrade of the ATLAS inner detector: an all-silicon new inner tracker (ITk) [2] is proposed to replace the current SemiConductor Tracker (SCT) and Transition Radiation Tracker (TRT). The ITk layout as presented in the Letter of Intent [3] assumes silicon microstrip detectors to be used for 7 endcap disks, and 5 barrel layers. From simulations verified by experiments, the highest particle fluence in the barrel short strip layer is expected to be $5.3 \times 10^{14}\ n_{eq}/cm^2$ [4]. Including a safety factor of 2, candidate ITk sensors will have to be radiation hard up to levels of $1.1 \times 10^{15}\ n_{eq}/cm^2$. The goal of the ITk Strip Sensor collaboration is to develop a silicon microstrip sensor that is suitable for use in the new ITk. Results of detailed studies of properties of full-size sensor prototypes are presented in this paper, whereas studies of radiation damage of $1 \times 1\ cm^2$ miniature sensors are reported in [5,6].

2. ATLAS12 large area sensors

The ATLAS12 sensors are the second iteration of sensors designed for the Upgrade ITk, superseding the ATLAS07 types [7]. To cope with the effects of radiation damage during the sensor lifetime, operation in partial depleted mode is foreseen towards the end of the detector lifetime. The sensor will need specially designed structures between the strips to guarantee strip isolation during its lifetime and mitigate radiation-induced surface damage whilst retaining a low inter-strip capacitance. A single-sided n^+-in-p sensor offers a trade-off between the above requirements and cost [8]. 120 full-size prototype sensors were manufactured by Hamamatsu Photonics [9] on a 6 in. wafer process using p-type float zone silicon. Sensors were delivered in 4 batches: VPX12318, VPX12518, and VPX12519, of 33, 32 and 35 sensors respectively were shipped to the UK, and VPX14757 containing 20 sensors was delivered to the US.

The largest square sensor that can be cut from the wafer measures $97.5 \times 97.5\ mm^2$. This geometry is denoted "Outer Cut". Sensors with 462 μm reduced edge metal all around, denoted "Inner Cut", were made available as well to allow for smaller inactive regions in the final detector layout. The sensor strip implants are arranged in 4 columns of 1282 implants each, with the top and bottom implant of each column serving as field shaping strips. The resulting strip pitch is 74.5 μm and the strip length is 23.9 mm. All strips are connected to the bias rail by poly-silicon resistors implanted in the sensor. For biasing the central two columns, a bias rail runs through the centre of the sensor. Top metal layer strips are AC-coupled to the strip implants, which have p-stop traces running in between along the full length for strip isolation. The top metal layer is passivated, with openings for probing and wirebonding. Fig. 1 contains a photograph showing the sensor details.

3. ATLAS12A mechanical properties

The sensor mechanical specifications state the following:

- nominal thickness: 310 ± 20 μm;
- thickness variation: ± 10 μm across the sensor. This means some thickness variation is allowed between sensors, but not across a sensor;
- sensor flatness when unstressed: < 200 μm;
- outer cut dimensions: $97540 \pm 25\ \mu m^2$;
- inner cut dimensions: $95,692 \pm 25\ \mu m^2$; and
- no cracks or chips at the dicing line to extend further inwards than 50 μm.

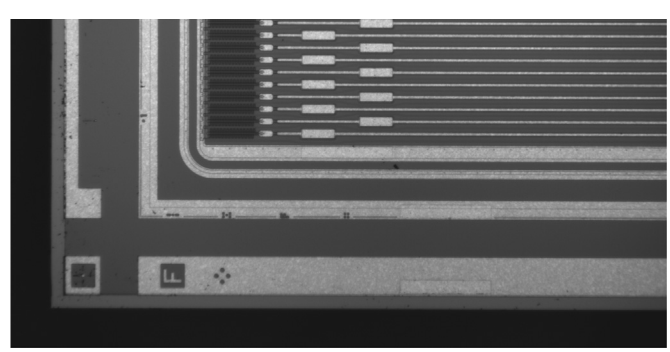

Fig. 1. Picture of the corner of an Outer Cut ATLAS12 sensor, illustrating the layout of the bias rail, guard ring, strip top metal and bias resistors. The dicing streets intended for the Inner Cut sensors are clearly visible.