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Evaluation of the bulk and strip characteristics of large area *n*-in-*p* silicon sensors intended for a very high radiation environment

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ABSTRACT

The ATLAS collaboration R&D group "Development of *n*-in-*p* Silico*n* Sensors for very high radiation environment" has developed single-sided *p*-type 9.75 cm × 9.75 cm sensors with an *n*-type readout strips having radiation tolerance against the 10^{15} 1-MeV neutron equivalent (n_{eq})/cm^2 fluence expected in the Super Large Hadron Collider. The compiled results of an evaluation of the bulk and strip parameter characteristics of 19 new non-irradiated sensors manufactured by Hamamatsu Photonics are presented in this paper. It was verified in detail that the sensors comply with the technical specifications required before irradiation. The reverse bias voltage dependence of various parameters, frequency dependence of tested capacitances, and strip scans of more than 23,000 strips as a test of parameter uniformity and strip quality over the whole sensor area have been carried out at Stony Brook University, Cambridge University, University of Geneva, and Academy of Sciences of CR and Charles University in Prague. No openings, shorts, or pinholes were observed on all tested strips, confirming the high quality of sensors made by Hamamatsu Photonics.

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1. Introduction

The upgrade of the Large Hadron Collider (LHC) to 10 times higher luminosity ($10^{35}\ cm^{-2}\ s^{-1}$), the so-called Super-LHC, will require large changes in design and type of sensors of the current ATLAS Inner Detector (ID). As currently planned, the upgraded ID will consist of silicon sensors: pixel detectors and two types of micro-strip detectors with strip lengths of 2.38 and 9 cm [1]. These micro-strip detectors must withstand an anticipated radiation fluence of up to $5–9\times10^{14}$ 1-MeV neutron equivalent $(n_{eq})/cm^2$ [2].

The ATLAS collaboration R&D group "Development of *n*-in-*p* Silicon Sensors for very high radiation environment" has developed ATLAS07 single-sided *p*-type 9.75 cm × 9.75 cm sensors with an *n*-type readout strips having radiation tolerance against a fluence of $10^{15}\ n_{eq}/cm^2$ [3].

The purpose of this paper is to characterize the ATLAS07 full size sensors and verify the sensor performance required by the Technical Specification [4] before irradiation. The evaluation of irradiated sensors using ATLAS07 miniature samples (1 cm × 1 cm) were studied elsewhere: the bulk damage aspects are reported in Ref. [5] and the surface damages in Ref. [6].

2. ATLAS07 large area sensors

The micro-strip silicon sensors studied in this work are ATLAS07 Series I large area sensors [3] fabricated by Hamamatsu Photonics (HPK) using 6 in. (150 mm) process technology [7]. The baseline is *p*-type float zone silicon with crystal orientation ⟨1 0 0⟩ and a thickness of 320 μm. Sensors are single-sided with capacitively coupled readout *n*-type strips biased through poly-silicon resistors. The readout strips have a pitch of 74.5 μm and are electrically isolated by a common and floating *p*-implant ('*p*-stop' isolation) with a doping concentration of 4×10^{12} ions/cm^2. The large area sensor has four segments of strips: Segments 1 and 2 are of axial strips, where the strips are parallel to the edges of the sensor, and Segments 3 and 4 are of stereo strips, where the strips are inclined at an angle of 40 mrad. There are 1280 strips of length 2.38 cm in each segment. Location of four segment areas of the sensor with the strip arrangement and position of DC and AC contact pads is illustrated in Fig. 1. The dead area of the sensor between segments 1 and 2 (3 and 4) and between segments 2 and 3 are 70 and 160 μm broad, respectively.

3. Experimental methods and results

Out of all 30 ATLAS07 Series I large sensors fabricated by HPK, 19 sensors have been measured by the following ATLAS institutes: Academy of Sciences of CR and Charles University in Prague

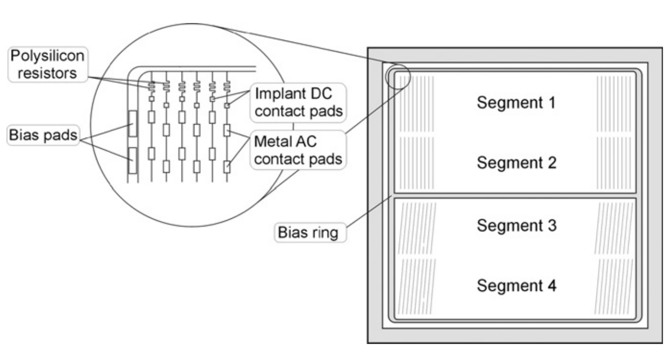

Fig. 1. Location of four segment areas of the ATLAS07 sensor with the strip arrangement and position of DC and AC contact pads (not to scale).

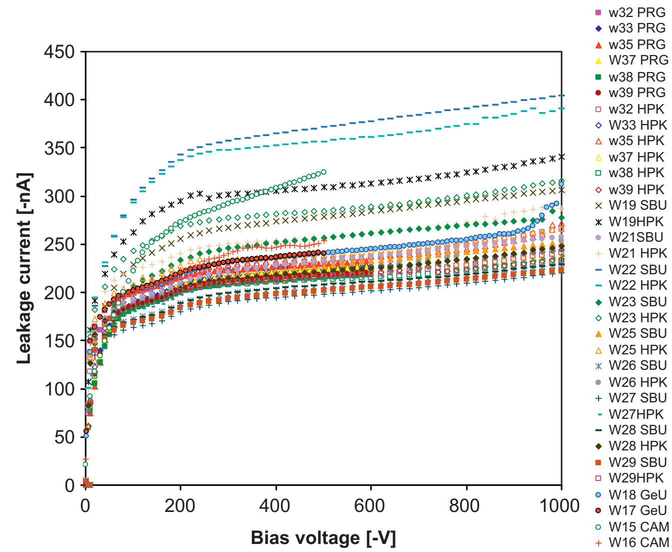

Fig. 2. IV characteristics of large area ATLAS07 Series I sensors normalized to 20 °C.

(sensors W32, W33, W35, W37, W38, W39); Cambridge University (W15, W16); University of Geneva (W17, W18); and Stony Brook University (W19, W21, W22, W23, W25-29).

3.1. Bias voltage and frequency dependence of parameters

3.1.1. Leakage current

The IV characteristics of all 19 tested sensors normalized to 20 °C[1] are shown in Fig. 2. Current was measured with a delay of several seconds (up to 10 s) after setting the reverse bias voltage (V_{bias}). For all tested sensors, the absolute value of the leakage current at 500 V is less than 370 nA. The results are consistent with measurements performed by HPK. The IV characteristics easily comply with the specification [4] that current at 600 V of bias voltage be no greater than 20 μA at 20 °C. Actually, the measured current is more than 50 times lower than this limit.

For most sensors, the IV scan has been measured up to 1000 V. There were no observed onsets of micro-discharges. Sensor W18 had a slow breakdown at ~420 V, but after a short "training," in which the sensor was kept at "breakdown voltage" for a few minutes with current ~10 μA, the breakdown disappeared.

The IV characteristics shown in Fig. 2 were measured before any testing of sensors. The IV scans were repeated after the quality acceptance tests of the sensor (bias voltage scan and strip scan), and the measured leakage current was usually higher by 10–20%.

3.1.2. Bulk capacitance

The bulk capacitance (C_{bulk}) between the backplane and the bias ring as a function of frequency and bias voltage was measured. The frequency dependence measured with function CsRs at 240 V is shown in Fig. 3. One can see that C_{bulk} is constant up to 20 kHz; a frequency of 1 kHz was selected for an estimate of full depletion voltage (FDV).

Plots of the inverse bulk capacitance squared ($1/C^2$) as a function of reverse bias voltage for eight tested sensors are presented in Fig. 4. The full depletion voltages were extracted from the crossing of the linear rise of $1/C^2$ and the saturated plateau.

[1] $I(T_{20})=I(T_M)*(T_{20}/T_M)^2*\exp[-E/2k_B*(1/T_{20}-1/T_M)]$ with E=1.2 eV [8].