Quality-Control Measurements for the LGAD Silicon Sensors of the ATLAS High Granularity Timing Detector

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The expected increase of the luminosity at the High-Luminosity phase of the LHC (HL-LHC), with instantaneous luminosities up to $\mathcal{L} = 7.5 \cdot 10^{34}$ cm^{-2}s^{-1}, will be a challenge for the performance of the ATLAS detector. The pile-up is expected to increase on average to 200 interactions per bunch crossing, resulting in poorer performance of the currently used reconstruction and trigger algorithms in the end-cap and forward regions of the detector.

To mitigate these pile-up effects, a High Granularity Timing Detector (HGTD) will be integrated in the end-cap regions of ATLAS, between the new Inner Tracker (ITk) and the Liquid Argon (LAr) calorimeter, covering the pseudo-rapidity range of $2.4 < |\eta| < 4.0$. HGTD, which also serves as a luminosity monitor, aims for a single track time resolution for minimally ionizing particles of 30 ps at the beginning of the lifetime, up to 50 ps after the maximum fluence of $2.5 \times 10^{15}\ \frac{\mathrm{neq}}{\mathrm{cm}^2}$. The high precision timing information improves the probability of correct assignment of tracks to the primary vertex.

HGTD consists of four double-sided layers, i.e. two layers on each end-cap. In total, there are 8032 2×4 cm^2 modules, each composed of two silicon sensors bump-bonded with the ASICs and glued on a PCB, adding up to about 6.4 m^2 of silicon. The HGTD sensors are based on the Low Gain Avalanche Detector (LGAD) technology. LGADs are P-in-N diode structures with an extra P-type gain layer, resulting in faster rise time and larger signal-to-noise ratio, allowing therefore for excellent time resolution. Each sensor is a 15×15 array of 1.3×1.3 mm LGAD pads; HGTD will therefore have more than 3.6 million read-out channels.

Currently the sensor pre-production is ongoing. In this process, about 5% of the sensors with the final design are being produced by the chosen vendors and tested before launching the full production. Along with the sensors, an equal amount of Quality Control-Test Structures (QC-TS) is produced, to monitor the quality and uniformity of the sensors and extract wafer-level technology parameters during the production, in a process called Process Quality Control (PQC). Using the QC-TS, bad wafer or issues during the production can be spotted. Furhtermore, acceptance criteria can be defined for an additional selection of good wafers during production and additional parameters can be monitored. The QC-TS consist of many sub-structures including an LGAD, a P-in-N diode and a Metal-Oxide-Semiconductor (MOS) capacitor, while some of the parameters that can be extracted are the break-down voltage, the gain-layer and full depletion voltages, the thickness of the oxide layer and the flat-band voltage.

In parallel with the PQC, the HGTD pre-production sensors, both unirradiated and irradiated, have been tested in a series of test-beam campaigns that have been carried out in the CERN SPS and DESY facilities.

This talk consists of two parts. The first part focuses on the PQC activities with the dedicated probe station setup at CERN, allowing for mass QC-TS testing with minimal manual input. Furthermore, the testing procedure and the parameter extraction methods along with the PQC results and the evaluation of the full HGTD pre-production will be presented.

In the second part, some results of the sensor performace from the last test beam campaigns will be presented for sensors irradiated with different equivalent fluences. Several parameters, that are crucial indicators of the sensor performance, have been studied as a function of the fluence, including the collected charge, the hit efficiency and the time resolution of the sensors.