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Test and extraction methods for the QC parameters of silicon strip sensors for ATLAS upgrade tracker

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ABSTRACT

The Quality Control (QC) of pre-production strip sensors for the Inner Tracker (ITk) of the ATLAS Inner Detector upgrade has finished, and the collaboration has embarked on the QC test programme for production sensors. This programme will last more than 3 years and comprises the evaluation of approximately 22000 sensors. 8 Types of sensors, 2 barrel and 6 endcap, will be measured at many different collaborating institutes. The sustained throughput requirement of the combined QC processes is around 500 sensors per month in total. Measurement protocols have been established and acceptance criteria have been defined in accordance with the terms agreed with the supplier. For effective monitoring of test results, common data file formats have been agreed upon across the collaboration. To enable evaluation of test results produced by many different test setups at the various collaboration institutes, common algorithms have been developed to collate, evaluate, plot and upload measurement data. This allows for objective application of pass/fail criteria and compilation of corresponding yield data. These scripts have been used to process the data of more than 3000 sensors so far, and have been instrumental for identification of faulty sensors and monitoring of QC testing progress.

1. Introduction

Following Run 3, a high luminosity upgrade will be installed on the Large Hadron Collider (HL-LHC). A fully-silicon replacement, the ATLAS Inner Tracker (ITk), is being developed, comprising pixel and strip sensors. The strips portion of the ITk comprises 22000 sensors of 8 types: 2 barrel and 6 endcap [1]. Every sensor needs to be evaluated for quality control (QC), which is performed at various institutes with their own test setups, before they can be integrated into modules that will go into the ATLAS detector. For this, a common framework with common algorithms was developed to objectively assign pass/fail decisions to sensors, interface with the common database, and do reporting.

2. Workflow

Each institute has its own custom setup for performing QC tests. QC tests performed on all sensors are current–voltage (IV), capacitance–voltage (CV), and metrology. Current-stability tests on the sensor as a whole and current–capacitance–resistance (ICR) tests on each individual strip are done on a sample.

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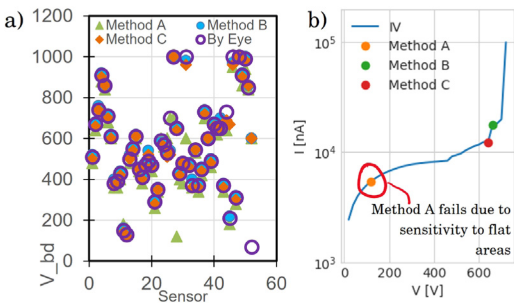

Fig. 1. Comparison of algorithms for determining breakdown voltage (a) to human judgement for several sensors and (b)for a single IV curve. Method A evidently fails, due to its sensitivity to the local slope.

A common set of LabVIEW scripts within the collaboration provide an interface to perform the given test and output a local file in a standard format with the test data. The goal of the QC scripts is to extract and calculate relevant parameters from these local data files and make an automated decision on the sensor.

The ITk database (ITkDB) stores and tracks all information relating to parts of the ITk. The QC scripts interface with this such that QC tests, extracted parameters, and decisions can be automatically uploaded. Additionally, the they are also designed to download raw test data and stored extracted results in order to do batch reporting. With this, results of a wafer can be compared against its batch with interactive plots that can be used to make decisions on accepting a batch or to investigate issues.

3. Treatment of IV tests

Three different algorithms were compared for a set of 52 sensors with diverse features in the IV test in order to identify the more reliable method.

Method A was modified from the definition given in the specifications, which is that $|V_{bd}|$ is the earliest $|V_j| > 100\,\text{V}$ that satisfies $\left(\frac{1}{3}\sum_{k=j-1}^{j+1}\frac{I_{k+1}-I_k}{V_{k+1}-V_k}\right) \div \left(\frac{I_{k+1}-I_k}{V_{k+1}-V_k}\right)_{min} > 5$ [2].

Method B is modified from [3], and has $|V_{bd}|$ as the earliest $|V_{j+1}|$ that satisfies $\frac{I_{j+1}-I_j}{V_{j+1}-V_j} \div \frac{I_{j+1}}{V_{j+1}} > 5$.

Method C is similar to B but with averaging and a running threshold to compensate for the gradually decreasing total derivative, as $\frac{I_{j+1}-I_j}{V_{j+1}-V_j} \div \frac{I_{j+1}+I_j}{V_{j+1}+V_j} > 5.5 + \frac{\min(|V|-500\,\text{V},0\,\text{V})}{100\,\text{V}}$

The comparison is shown in Fig. 1. In general both Methods B and C seem equally reliable. Method C was chosen due to its better expected robustness in cases of soft breakdown.

Fig. 2 shows a screenshot of an interactive plot from the scripts showing various IV curves.

4. Treatment of individual strip ICR tests

The metal readout strips are separated from the strip n^+ implants by a thin oxide, and are therefore capacitively-coupled. These AC-coupled metal strips are probed automatically and individually in order to characterize the RC network on the strip as well as the AC current. These must fall within certain thresholds to pass, with the sensor failing if more than 1% of strips fail, or there are 8 or more consecutive bad strips [2].

Combinations of this information allows the scripts to distinguish between different specific failure modes, such as metal shorts, implant breaks, bias resistor shorts, pinholes, or bias resistor defects, as well as potential measurement or contact issues.

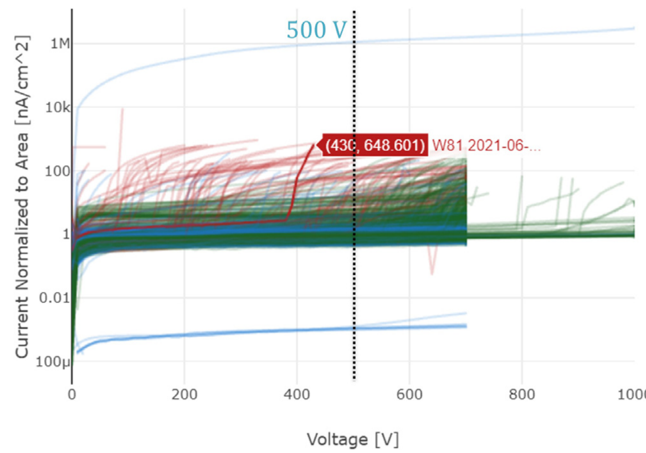

Fig. 2. Screenshot of interactive plot from QC scripts showing latest IV traces from all 3270 tested sensors on the database. Sensor 81, with an early breakdown, is being highlighted by the user. The dashed line at 500 V is the specification before which no breakdown should occur. Green traces represents sensors that pass specifications, red traces those that may not pass specifications, and blue for measurement errors, for example incorrect humidity.

5. Batch reporting

QC approval is done on a batch-by-batch basis. This means that the collaboration reserves the right to reject entire batches, even if they may contain some specification-compliant wafers, if there is reason to believe the batch is unreliable. Therefore, even though the scripts make decisions on individual sensors, reports are produced that show interactive summary plots by batch. This allows humans to visually detect outliers and potential anomalies in properties across the batch not immediately obvious to an algorithm. The reporting tool is also designed to provide a concise table summary per batch in a single interface to help keep track of what tests have been completed on which sensors. Additionally, the scripts provides direct interactive access to both local and database data in Python for studies and investigations.

6. Current status

The QC scripts have proven to be a robust, reliable and intuitive interface for sensor evaluation, reporting and monitoring. Since their introduction, the library has already processed 3000 sensors through preproduction and production in 7 sites in 9 institutes in 5 countries. As we enter production, the scripts are undergoing continuous development to add new features useful to our QC sites.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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