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Monitoring Quality of ATLAS ITk Strip Sensors through Database

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The High-Luminosity LHC upgrade necessitates a complete replacement of the ATLAS Inner Detector with a larger all-silicon tracker. The strip portion of it covers 165 m^2 area, afforded by the strip sensors. Following several prototype iterations and a successful pre-production, a full-scale production started in 2021, to finish in 2025. It will include about 21,000 wafers and a factor of 5 higher throughput than pre-production, with about 500 sensors produced and tested per month. The transition to production stressed the need to evaluate the results from the Quality Control (QC) and Quality Assurance (QA) tests quickly to meet the monthly delivery schedule. The test data come from 15 collaborating institutes, therefore a highly distributed system with standardized interfaces was required. Specialized software layers of QA and QC Python code were developed against the backend of the ITk database (DB) for this purpose. The developments included particularities and special needs of the Strip Sensors community, such as the large variety of different test devices and test types, the necessary test formats, and different workflows at the test sites. Special attention was paid to techniques facilitating the development and user operations, for example creation of "parallel" sets of dummy DB objects for practice purposes, iterative verification of operability, and the automatic upload of test data. The scalability concerns and automation of the data handling were included in the system architecture from the very inception. The full suite of functionalities includes data integrity checks, data processing to extract and evaluate key parameters, cross-test comparisons, and summary reporting for continuous monitoring. We will also describe the lessons learned and the necessary evolution of the system.

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1. Introduction

To prepare for the High-Luminosity LHC era, the ATLAS experiment is working on upgrading Inner Detector. For the reasons of the increased occupancy and radiation damage, the upgrade involves a complete replacement of the tracker with a new system, called the Inner Tracker (ITk) [1]. It will extend the instrumented silicon surface area outward, into the region currently occupied by Transition Radiation Tracker [2] system. This change will increase the strip tracker area from 60 m^2 to 165 m^2. In order to maintain the channel occupancy under 1% and the signal-to-noise ratio over 10, the strip lengths will be reduced compared to the current Semiconductor Tracker [3]. This will result in an increase of the channel count from 6 million to 60 million [1]. The ITk is designed to have a nearly hermetic coverage of the solid angle for incoming charged particles for both barrel and endcap parts, with a minimum silicon area[1]. This necessitated unusual sensor shapes and an increase of the sensor types to the total of 8 variants [5]. This feature enables physics searches for which a reliable track detection is important [6, 7].

In order to cover such a large instrumented area, a large production of about 21,000 wafers is required. It was preceded by a pre-production phase of 1,041 wafers in 2020. This phase included all 8 sensor types designed for production [4]. It was used as a system exercise for verification of designs, testing methodology and throughput by ATLAS sites, as well as the ability of the sites to reliably characterize the sensor performance. The test suite included a set of 10 Quality Control (QC) tests of electrical and mechanical properties of each sensor used in module building as well as 18 Quality Assurance (QA) tests performed on peripheral wafer pieces to verify the technological parameters before and after irradiation. The details of these tests can be found in other publications [8, 9].

Besides these main test results, additional information is recorded in the database (DB) as necessary. Examples are irradiation parameters, details of sensor recovery procedures meant to improve the sensor performance, whether a wafer was set aside as a monitoring piece for warranty reasons, and other special features. This information is recorded either as another test or an object flag in the DB.

The total data size is significant. For a batch of 40 wafers about 556 GB of data is acquired. This volume is dominated by Visual Capture test, which collects high-resolution image scans of the sensor surface. The other tests contribute 16 GB of data volume.

Following the successful completion of pre-production, the production phase started in 2021, to complete in 2025. Its key feature is a high delivery throughput of about 500 wafers a month, a factor of 5 faster than during pre-production, as well as the requirement of an expeditious evaluation of every monthly reception within 4 months. This involves a complete characterization of the wafers from both QA and QC perspectives by 15 institutes involved in their evaluation.

The large volume, distributed nature of the evaluation, and the extensive nature of the tests required usage of a data base (DB) for the test data storage and retrieval, making evaluation summaries, and for tracking locations of the components. For this purpose ATLAS ITk collaboration created a common DB infrastructure. It is a flexible online DB implemented as a cloud-based appli-

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[1] The design for hermeticity has two exceptions: there are gaps between the adjacent sensors in any given layer, and the sensor edge regions are inactive. The gaps are minimized and the sensor layouts use “slim edge” design [4] in order to maximize the active area fraction in each layer.

Table 1: DB interactions by ITk Strip Sensor community.

Work Area	DB Action
Reception	registration + Vendor data upload
Shipment	shipment in DB, shipment reception
QC tests	test results analysis/reporting, upload
QA tests	test results analysis/upload, reporting
Reception approval	QA and QC summaries/reporting, upload
Trends, correlations	DB reporting
Production reporting	DB reporting

cation. It has a user interface and API, which is based on REST[2] API. The DB allows customization of the object types, their properties, tests, and evolution stages for each ITk component. A user interacts with ITk DB either through a browser or via API through Python scripts. The interaction examples include component creation, deletion, listing of available components, upload of a new test to a given stage of the given component, advancement to the next component processing stage, component shipping from one institute and reception by another institute.

The design details of the component types and properties, test type and properties, the stage schema and interaction software are left to the community working on producing the corresponding component. The Strip Sensors community made one of the earliest complete implementations of the component-specific designs in the ITk DB to enable pre-production and production sensor evaluation and distribution. This implementation covers the work performed by the community (Table 1) and the corresponding DB actions[3]. It followed several general guidelines:

- Precise mapping of the component architecture and processes to their real-world usage.
- Enabling of the distributed testing by developing common scripts and verification of their usability at each site.
- Comprehensive coverage of all QA and QC test suites in order to avoid information loss.
- Automation of the DB interaction by Python scripting for every test type.
- Scalability features in the script design, that augmented the functionality of the cloud-based backend.

In this paper we describe the details of the DB design and processing implemented and practiced for the strip sensors and the lessons learned.

2. Database objects

For each wafer, ATLAS received several diced pieces from the manufacturer, Hamamatsu Photonics[4] (HPK):

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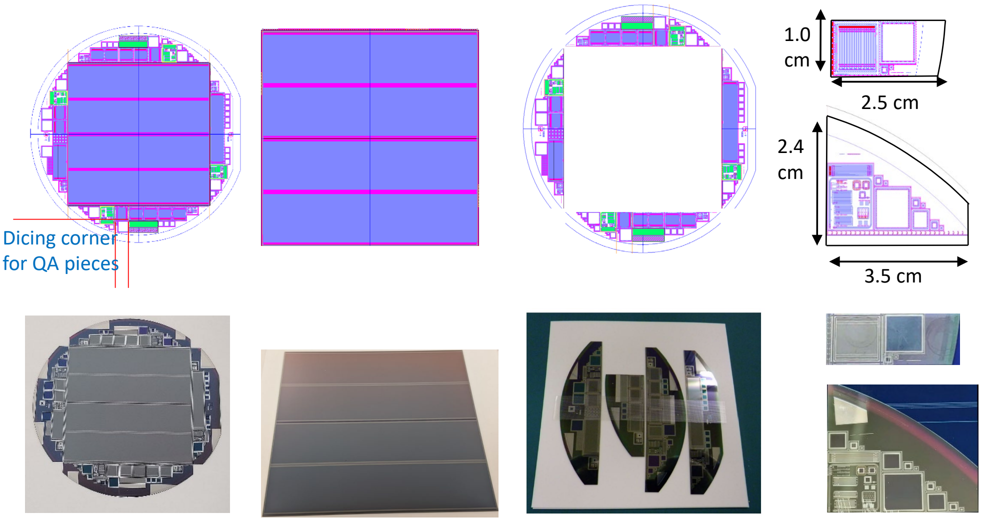
[2] REpresentational State Transfer (REST) is a web architectural style (see https://restfulapi.net/ .)

[3] The relevant Python scripts are stored at https://gitlab.cern.ch/atlas-itk/sw/db/production_database_scripts/-/tree/master/strips/sensors .

[4] https://www.hamamatsu.com/jp/en.html



Wafer (a virtual object) **MAIN** sensor **Halfmoons** Note: a single object in DB **QA pieces:** Mini & MD8, TestChip & MD8

Figure 1: An example of the sensor wafer and its pieces.

MAIN sensor: These are large-area sensors in the center of the wafer. They are distributed to the Sensor QC sites for an evaluation before being used for module construction by Module sites.

Halfmoons: These are peripheral wafer pieces left over after the MAIN sensor is diced out. They contain test devices representative of the MAIN sensor design. The halfmoons follow along with the corresponding MAIN sensor to be used by Sensor QC and Module sites for evaluation.

QA pieces: These are pieces diced out of the halfmoons. They are sent to irradiation facilities and QA sites for evaluation. Unused pieces are left at CERN. Two types of pieces are used. Each of them has a large 8x8 mm^2 diode (MD8) for monitoring bulk depletion and current. One QA type, called "Mini & MD8", also contains a miniature strip sensor for measuring the signal size. Another one, called "TestChip & MD8", has a test chip with several structures for measuring technological parameters [10].

The layout of the wafer and its pieces is shown in Figure 1 for one of the sensor types, along with the pictures of the physical objects. Since each of these objects is subject to different handling and test sequences, they are implemented in the DB as separate objects. This hierarchy schematically is shown in Figure 2. Notably, the halfmoons are physically represented as 4 distinct pieces from a wafer; however, they are implemented in the DB as a single object. This follows the typical scenario of shipping and handling the 4 pieces together. (There is a provision for creating individual test structure objects if the halfmoons are ever diced further.) Even with this mild simplification, we anticipate about 125,000 sensor-related objects to be registered in the DB by the end of the project.

Each DB object has a reference, called a Serial Number (SN). They can, in principle, be created dynamically during the object registration. This can be a convenient feature for many components. In case of the sensors, their lifecycle starts earlier, by fabrication and tests performed at HPK. A summary of these tests is transmitted to ATLAS and entered in the DB at the registration time. Therefore, a common reference is required, and it is useful to originate the SNs at the HPK site.

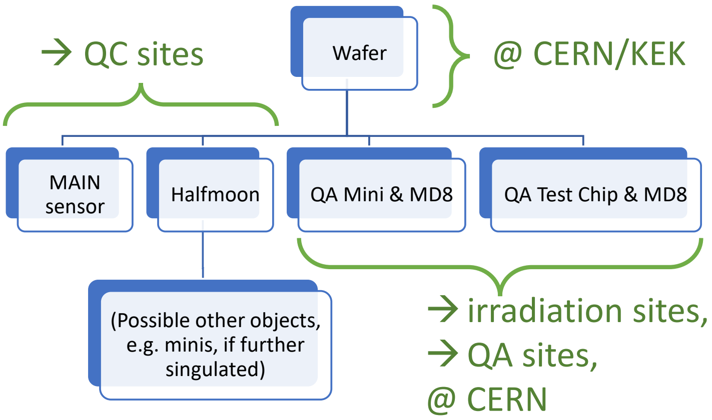


Figure 2: A hierarchy of the wafer and its pieces. All pieces are received at the reception sites, CERN and KEK. This is followed by a distribution of the MAIN sensors and halfmoons to the Sensor QC sites. Some of the QA pieces are sent to irradiation facilities and QA test sites. The rest remains at CERN.

Table 2: Example of SNs for different objects from wafer number *NNNNN* of LS sensor type. In case of other sensor types the mnemonic letter *SL* are replaced by other references: *SS*, *S0*, *S1*, *S2*, *S3*, *S4*, *S5*. For the endcap variants the “SB” letters at the beginning of SN are replaced with “SE”.

Wafer part	SN
Sensor Wafer	20 U SB *SL* 0 **5** *NNNNN*
MAIN sensor	20 U SB *SL* 0 **0** *NNNNN*
Halfmoons	20 U SB *SL* 0 **9** *NNNNN*
"Mini & MD8" QA piece	20 U SB *SL* 0 **1** *NNNNN*
"Test Chip & MD8" QA piece	20 U SB *SL* 0 **7** *NNNNN*

They are subsequently used at the registration as an input. The only minor drawback of this scheme is a possibility of SN address space clashes in case of a previous rogue object registration not conforming to the scheme. This is solved by designated address areas allotted for the sensors and scans of the registered sensors.

The SN scheme for the sensors is fixed and predictive. For a given wafer piece of a certain sensor type and a wafer number, one can easily derive the corresponding SN number (Table 2). Therefore, the different pieces of the same wafer can be easily cross-referenced. This enables a compilation of the QA and QC information related to the same wafer.

It should be noted that, while the different sensor types have different layout geometries (Figure 3), they all feature the same kinds of the wafer pieces and same wafer hierarchy in the DB.

During fabrication time the wafers are produced in groups, called production batches or lots. These sets, of several tens of wafers, have similar properties. This simplifies some of the evaluation tests. For example, only a single pair of QA pieces is typically irradiated for a single batch, making the post-irradiation testing volume feasible. Consequently, one needs to be able to refer to different wafers in the DB that belong to the same batch for the tests cross-reference and to do batch-based summaries. Since the SN scheme did not allow an additional batch reference, secondary

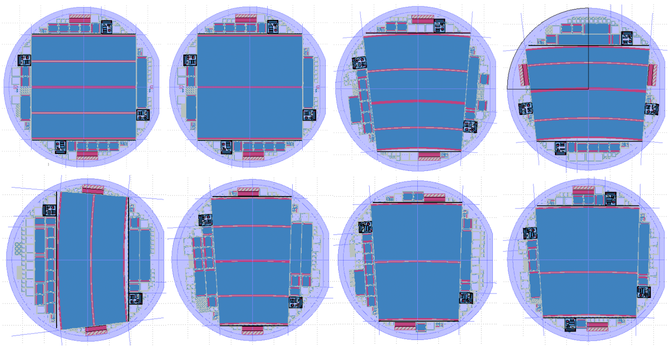


Figure 3: Geometries implemented in 8 sensor types. While the MAIN sensors have a significantly different shapes, the full hierarchy of the wafer pieces is implemented in all wafers.

Table 3: A list of DB references to "real" and "dummy" types of the wafer pieces.

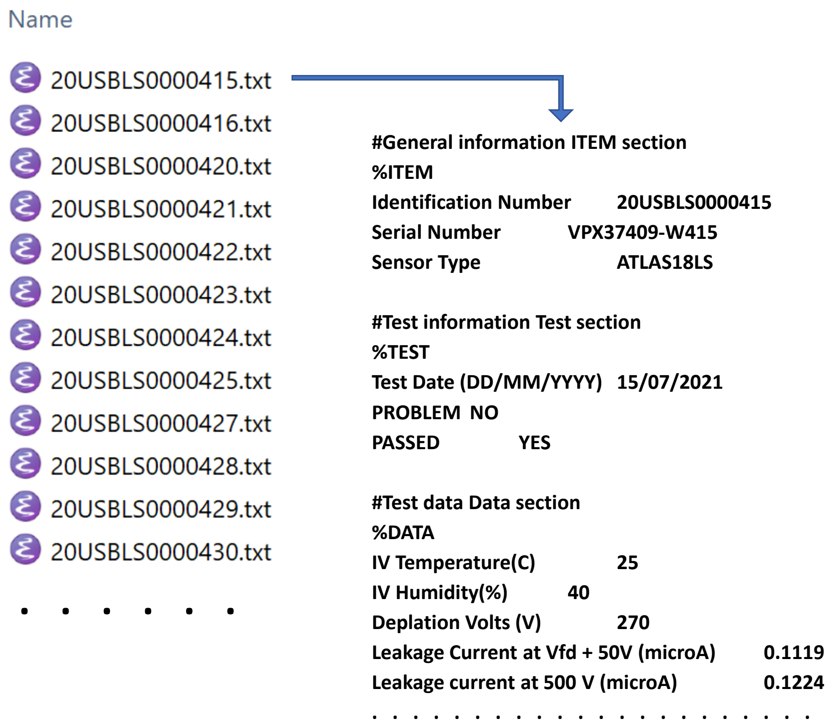
Object type	DB type reference for real sensors	DB type reference for dummy sensors
Wafer	SENSOR_WAFER	SENSOR_W_TEST
MAIN sensor	SENSOR	SENSOR_S_TEST
Halfmoons	SENSOR_HALFMOONS	SENSOR_H_TEST
"Mini & MD8" QA piece	SENSOR_TESTCHIP_MD8	SENSOR_QCHIP_TEST
"Test Chip & MD8" QA piece	SENSOR_MINI_MD8	SENSOR_QAMINI_TEST

(alternative) identifiers were created for each sensor-like object of the form {batch number}-{wafer number}-suffix. These alternative identifiers are also unique and allow DB queries. Additionally, batch objects were created in the DB that contain references to all wafer pieces objects from a given batch. They allow for batch-level properties to be entered, such as the results of the batch evaluation and the evaluation decision.

Invariably a large software development project involves a significant amount of a verification efforts, be that the software writing itself or the viability of the user interactions. In order to facilitate such verifications, a set of "dummy" DB objects were created along with "real" ones (Table 3). The dummy objects have the same exact functionality, tests and lifecycle schema as the objects corresponding to the real sensors. Of course, there is no physical part that matches them. Their SNs have a different address space, and their data entered in the DB do not impact the real sensors. Such objects, that essentially live in a "parallel universe", have shown to be an invaluable tool for development and educational purposes.

3. Sensor Registrations

The lifecycle of the component objects in the DB starts with their registration, when such objects are created. For sensors this step is only performed by the sites that accept the incoming shipments from the vendor, which are CERN and KEK. This organizational scheme matches the object lifecycle within ATLAS, by allowing to track the subsequent shipments to the test and



```
Name

20USBLS0000415.txt
20USBLS0000416.txt
20USBLS0000420.txt
20USBLS0000421.txt
20USBLS0000422.txt
20USBLS0000423.txt
20USBLS0000424.txt
20USBLS0000425.txt
20USBLS0000427.txt
20USBLS0000428.txt
20USBLS0000429.txt
20USBLS0000430.txt
. . . . . .
```

```
#General information ITEM section
%ITEM
Identification Number     20USBLS0000415
Serial Number         VPX37409-W415
Sensor Type               ATLAS18LS

#Test information Test section
%TEST
Test Date (DD/MM/YYYY)   15/07/2021
PROBLEM  NO
PASSED          YES

#Test data Data section
%DATA
IV Temperature(C)         25
IV Humidity(%)        40
Deplation Volts (V)       270
Leakage Current at Vfd + 50V (microA)        0.1119
Leakage current at 500 V (microA)            0.1224
. . . . . . . . . . . . . . . . . . . . . .
```

Figure 4: An illustration of the registration process. The sensor registration script parses a directory with the vendor test data[5](shown on the left with file names in the form "SN.txt"), extracts the serial numbers and parameter values, makes the registration and uploads the data. The files are in ASCII format.

irradiation sites in the DB. Theoretically, there may be the issue of the user interference due to the fixed SN scheme. However, the fact that the number of sites performing the registration is limited helps to avoid this issue.

Due to the large number of sensor-like objects in the DB, the usage of graphical user interfaces (GUIs) for an individual object registration is deemed not practical. Although such tools are frequently seen as attractive by the users, the experience shows that complaints and error rate are unacceptably high for the repetitive manual actions performed in large quantities. Instead, a great deal of automation is achieved by using a command-line Python script. For each delivery of a few hundred wafers, it parses a directory with the vendor data, figures out the SNs, creates the objects in the DB and uploads the vendor test data to each sensor (Figure 4). A full hierarchy of the related wafer parts (Figure 2) is registered for each sensor SN.

The process was tuned before the production phase – the result of the pre-production experience – in two ways:

- Although the text file format used for the vendor data is very portable and easy to create, data glitches are possible. Catching them is much more complicated than for other formats, such as JSON schema[6]. To prevent erroneous data from ending up in the DB, a data integrity

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[5] In the test file content, the word "deplation" is a typo of "depletion". The file structure is kept in its current form after finding this out, to avoid inconsistency in the data processing and side effects from the introducing the change.

[6] https://json-schema.org/

verification step was added in the registration script. This step is performed prior to any DB interactions. The data are parsed in two different ways and the outputs are contrasted. In case of an agreement, the parameter format and expected range are checked. The script is stopped if any issues are found.

- The first observations of the issue above led to the question of fixing the DB information. This was not trivial due to the built-in data protection mechanism where the only site allowed to upload the data is the one where the object is located. In practice this would lead to numerous communications between multiple sites due to the distributed nature of the project. Therefore, an exception was worked in for several people. This limited the number of human interactions and associated communication imperfections.

4. Test Data and Uploads

For the test data acquired on ATLAS side, there was a question of their handling in relation to the test structures in the DB. Although an immediate direct upload to the DB looks attractive, in practice it may require unrealistic expectations of the DB and internet connection uptime. For the tests running for a long time (hours or days) there is an additional concern of data protection. These constraints were addressed by inventing a "local data format" for both QA and QC tests. A simple ASCII format was also used for this purpose. An example for one of the QC tests can be seen in Figure 5. The software for the data acquisition systems was updated to match this format for the output files. Inventing the local data storage step in a common format achieved several objectives:

- A big simplification of the Python scripts that upload the data to the DB. In principle, the test hardware varied significantly between the test sites. However, the scripts typically had to parse a single test file format for a given test.

- Enabling an auxiliary route for data exchanges between the test sites. This was particularly important during initial stages of the QA and QC site qualifications, when the DB interactions were in a relatively early stage of development [8, 9].

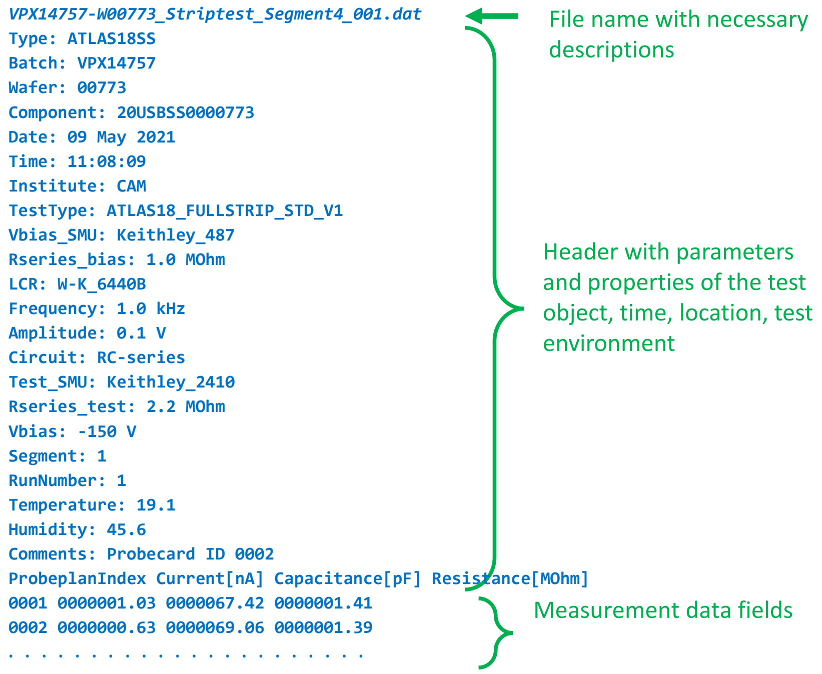
- A valuable backup option in cases of DB outages, forced software updates due to compatibility issues, power outages and unexpected test run terminations.

The local data have to be transmitted to the DB. As usual, it is helpful to implement a "full duplex" communication to ensure feedback for both transmission and data parsing errors, and to derive meaning from the data properties. For the Python scripts, this implied several functionalities:

- Data parsing and analysis performed to derive the parameters of interest from the data set [11].

- The data upload to the DB.

- Data summaries of the data in the DB. While this could be implemented as a completely separate step, it was very useful to have it as a part of the upload. This enabled the immediate comparison between the newly acquired data and the previous records.



```
VPX14757-W00773_Striptest_Segment4_001.dat
Type: ATLAS18SS
Batch: VPX14757
Wafer: 00773
Component: 20USBSS0000773
Date: 09 May 2021
Time: 11:08:09
Institute: CAM
TestType: ATLAS18_FULLSTRIP_STD_V1
Vbias_SMU: Keithley_487
Rseries_bias: 1.0 MOhm
LCR: W-K_6440B
Frequency: 1.0 kHz
Amplitude: 0.1 V
Circuit: RC-series
Test_SMU: Keithley_2410
Rseries_test: 2.2 MOhm
Vbias: -150 V
Segment: 1
RunNumber: 1
Temperature: 19.1
Humidity: 45.6
Comments: Probecard ID 0002
ProbeplanIndex Current[nA] Capacitance[pF] Resistance[MOhm]
0001 0000001.03 0000067.42 0000001.41
0002 0000000.63 0000069.06 0000001.39
. . . . . . . . . . . . . . . . . . . . . .
```

Figure 5: An example of the local data format for one of the QC tests, called Full Strip Test.

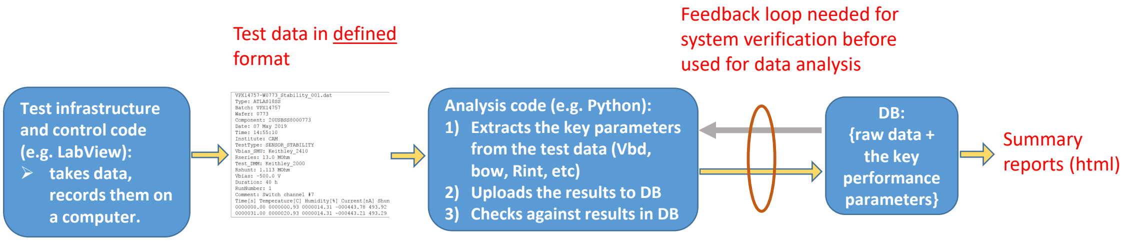
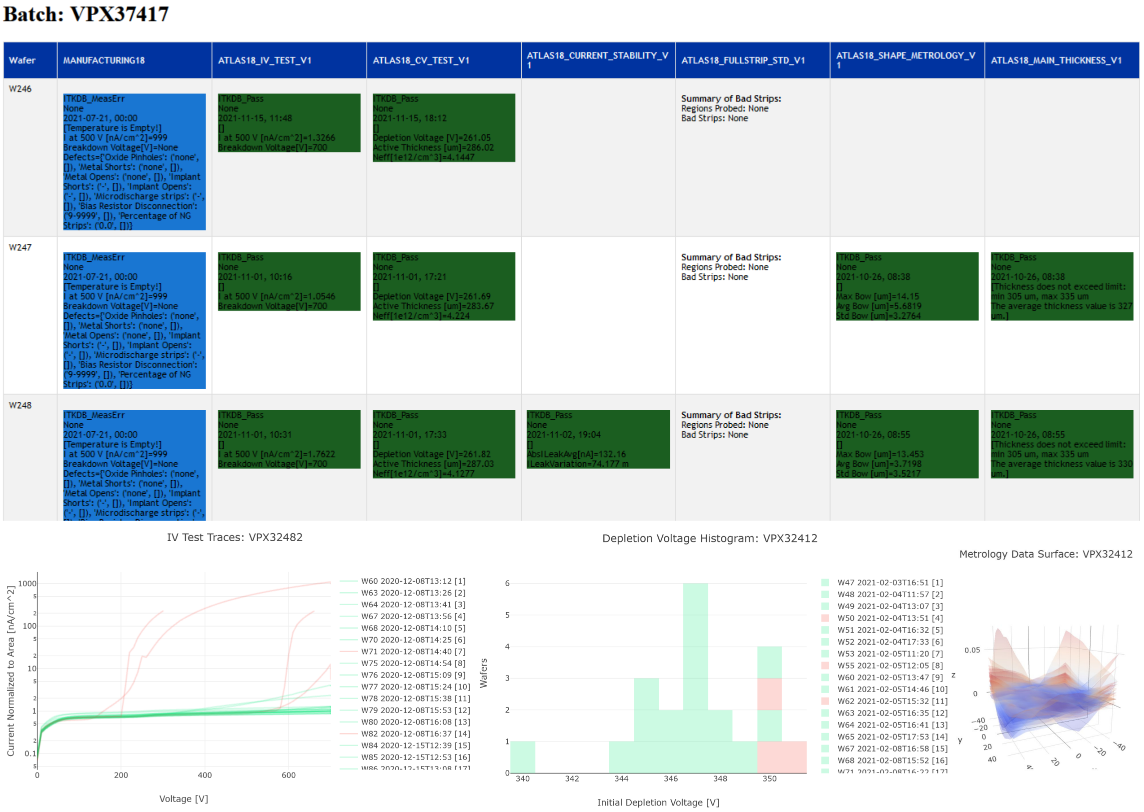


Figure 6: The data flow for Strip sensor tests, from acquisition to the database.

The full data flow is shown in Figure 6. It ends with a custom reporting step. As discussed in Section 2, the sensor fabrication and testing follow the natural granularity of the production batches. Therefore, the QC report data are also batch-based. They show a summary of a set of tests for a batch. The outcome of the tests is color-coded enabling a quick navigation of the test results. The report files also contain a set of plots for the key data and derived parameters (Figure 7). A user can interact with the plots by enabling and disabling the display of individual sensor data and rotating 3D plots. The report files are implemented in the html format enabling cross-platform compatibility.

The QA data processing is substantially similar. Since only a few QA pieces are tested for each batch, the batch-level summary was not required. The QA assessment is also based on an extensive set of tests. The emphasis is put on storing the derived test parameters in the DB. To indicate the data processing quality, a user is given a clear feedback by plots with the data processing outcome (Figure 8). For some of the test types these plots were stored in the DB.



Batch: VPX37417

Wafer	MANUFACTURING18	ATLAS18_IV_TEST_V1	ATLAS18_CV_TEST_V1	ATLAS18_CURRENT_STABILITY_V1	ATLAS18_FULLSTRIP_STD_V1	ATLAS18_SHAPE_METROLOGY_V1	ATLAS18_MAIN_THICKNESS_V1
W246	ITKDB_MeasErr None 2021-07-21, 00:00 [Temperature is Empty!] I at 500 V [nA/cm^2]=999 Breakdown Voltage[V]=None Defects={'Oxide Pinholes': ('none', []), 'Metal Shorts': ('none', []), 'Metal Opens': ('none', []), 'Implant Shorts': ('-', []), 'Implant Opens': ('-', []), 'Microdischarge strips': ('-', []), 'Bias Resistor Disconnection': ('9-9999', []), 'Percentage of NG Strips': ('0.0', [])}	ITKDB_Pass None 2021-11-15, 11:48 [] I at 500 V [nA/cm^2]=1.3266 Breakdown Voltage[V]=700	ITKDB_Pass None 2021-11-15, 18:12 [] Depletion Voltage [V]=261.05 Active Thickness [um]=286.02 Neff[1e12/cm^3]=4.1447		**Summary of Bad Strips:** Regions Probed: None Bad Strips: None		
W247	ITKDB_MeasErr None 2021-07-21, 00:00 [Temperature is Empty!] I at 500 V [nA/cm^2]=999 Breakdown Voltage[V]=None Defects={'Oxide Pinholes': ('none', []), 'Metal Shorts': ('none', []), 'Metal Opens': ('none', []), 'Implant Shorts': ('-', []), 'Implant Opens': ('-', []), 'Microdischarge strips': ('-', []), 'Bias Resistor Disconnection': ('9-9999', []), 'Percentage of NG Strips': ('0.0', [])}	ITKDB_Pass None 2021-11-01, 10:16 [] I at 500 V [nA/cm^2]=1.0546 Breakdown Voltage[V]=700	ITKDB_Pass None 2021-11-01, 17:21 [] Depletion Voltage [V]=261.69 Active Thickness [um]=283.67 Neff[1e12/cm^3]=4.224		**Summary of Bad Strips:** Regions Probed: None Bad Strips: None	ITKDB_Pass None 2021-10-26, 08:38 [] Max Bow [um]=14.15 Avg Bow [um]=5.6819 Std Bow [um]=3.2764	ITKDB_Pass None 2021-10-26, 08:38 [Thickness does not exceed limit: min 305 um, max 335 um The average thickness value is 327 um.]
W248	ITKDB_MeasErr None 2021-07-21, 00:00 [Temperature is Empty!] I at 500 V [nA/cm^2]=999 Breakdown Voltage[V]=None Defects={'Oxide Pinholes': ('none', []), 'Metal Shorts': ('none', []), 'Metal Opens': ('none', []), 'Implant Shorts': ('-', []), 'Implant Opens': ('-', []), 'Microdischarge strips': ('-',	ITKDB_Pass None 2021-11-01, 10:31 [] I at 500 V [nA/cm^2]=1.7622 Breakdown Voltage[V]=700	ITKDB_Pass None 2021-11-01, 17:33 [] Depletion Voltage [V]=261.82 Active Thickness [um]=287.03 Neff[1e12/cm^3]=4.1277	ITKDB_Pass None 2021-11-02, 19:04 [] AbsILeakAvg[nA]=132.16 ILeakVariation=74.177 m	**Summary of Bad Strips:** Regions Probed: None Bad Strips: None	ITKDB_Pass None 2021-10-26, 08:55 [] Max Bow [um]=13.453 Avg Bow [um]=3.7198 Std Bow [um]=3.5217	ITKDB_Pass None 2021-10-26, 08:55 [Thickness does not exceed limit: min 305 um, max 335 um The average thickness value is 330 um.]

Figure 7: An example of a test report for one of the batches. The top portion has a table of sensors and test results. The bottom part shows examples of the summary data for this batch. Only a small subset of the sensors, tests, and summary plots are shown for brevity.

The commissioning of the DB interface scripts across the test sites was done with example data uploaded to the dummy sensor objects. The sites were requested to demonstrate the successful data upload evidence and share the DB references. This practice provided an additional feedback to the script developers.

The batch basis of the script operations was added after the pre-production phase. Initially, when the number of objects and tests in the DB was limited, it was very convenient to query the entire set of the sensors recorded in the DB. However, this progressively limited the data operations as the information amount grew with the project progress. Limiting the DB interactions to a given set of batches allowed us to maintain a nearly constant and acceptable interaction time for the users.

5. Approvals

The lifecycle of the components is reflected in the sequence of their stages in the DB (Figure 9). Notably, all QC tests for the MAIN sensors are uploaded at the single stage called "QC tests", even though a list of test types is significant. This was done intentionally, due to a significant variance in the test sequence for some of the sites. In principle, encoding the different sequences in stages would be possible using the DB functionality of alternative routes between the stages. However, it

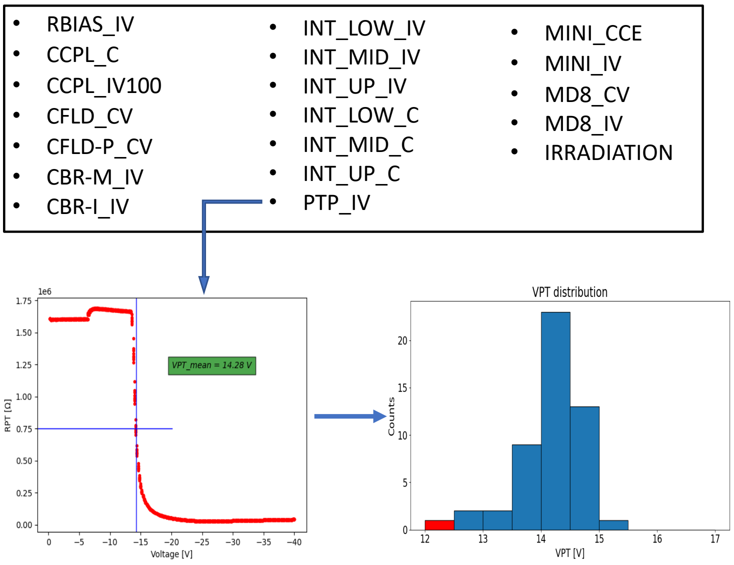


Figure 8: A list of QA test types is shown in the top portion of the figure. The raw data analysis outcome is given in the bottom left plot for one of the tests. The bottom right histogram shows a summary of the derived test parameter for a set of QA pieces.

was anticipated that the sites may need to re-organize their test programs either due to new findings or equipment availability. The complexity management in case of changes was deemed excessive for the more involved stage sequence.

The stage scheme for QA pieces does involve alternative stage sequences. This is due to the real-life variation in their evaluation method. Performing both before- and after-irradiation tests on the same devices would take too long compared to the evaluation time allowed. Therefore the device handling is split in two main ways. Some of the pieces are evaluated without the irradiation exposure, to give an assessment of the initial performance. Others are sent for irradiation and then to the test sites for the post-irradiation studies. The alternative stage scheme captures these possibilities. The pieces with successful test outcome arrive to the final "PASS" stage in both scenarios. To the first order, the outcome of the QA evaluation can be checked by whether the relevant pieces have reached this stage.

After completion of the QC tests, the test sites move the sensors from a batch to the "Blessing" stage, where a review of both QA and QC data is performed by the activity conveners, in collaboration with the test sites. Another batch evaluation software is run, which checks the QC test completeness and outcome. The output is another html file with color-coded QC test results, along with the QA test outcome for this batch as a quintessential input to the evaluation outcome. The software flags questionable test results if they happen, otherwise it pre-assigns the final stage destination for a sensor (Figure 10). These final stages (Figure 9) serve as a classification mechanism for the evaluation outcome. The software decision can be manually adjusted if needed.

At this point of the evaluation process an acceptance report is written and the results are communicated to the vendor. After a mutual agreement on the test results, the sensors are routed to the final stages in the DB identified by the evaluation software. The decision, key parameter

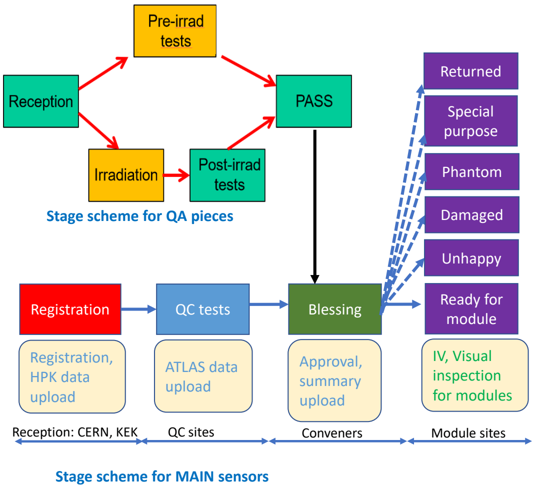


Figure 9: Stage scheme for QA pieces (top) and MAIN sensors (bottom). The test information from the QA pieces, along with the QC data, impact the routing of the MAIN sensors to one of the final stages, which classify the evaluation outcome.

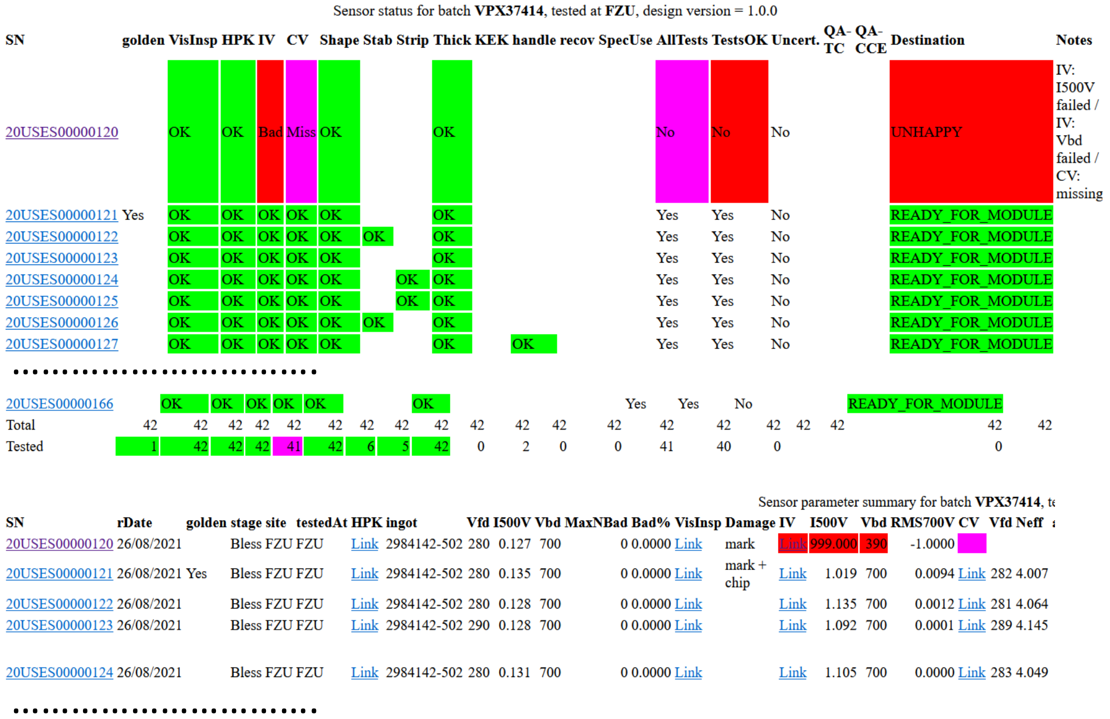
summary, and the references to the evaluation tests are recorded in a special test structure set up in the DB for this purpose. This is done to preserve the record of the evaluation decision in case of a later re-evaluation and other re-checks. All these actions are fully scripted, except for the cases of the manual decision adjustment. They are performed for each delivery at the end of the 4-month evaluation period.

6. Ongoing DB work

Even though the main development of the DB interface was substantially done before evaluating pre-production wafers, continuous maintenance work is anticipated through the duration of the project. The main reasons for this estimate is the significant data size and the software complexity scale. The examples include finding subtle bugs, changes of DB back-end interface, finding a need to develop a new test type, or other actions stemming from an improved understanding of the test data set.

A concrete outstanding development task is storage of the Visual Capture information in DB. Due to the significant data volume, a DB backend development was required. It has recently converged, and the new functionality of storing the large binary files is provided to the ITk. The scripts for the upload and retrieval of the Visual Capture information are currently under development. In the meantime, the data acquired so far have been stored at CERN EOS, a large-scale data storage facility [12].

As the accumulated data size grows, there are more demands for deriving meaningful conclusions from it. Besides the batch-level evaluation, there are details of the statistics, evolution of sensor properties between different batches, performance comparisons between different sensor



Sensor status for batch **VPX37414**, tested at **FZU**, design version = 1.0.0

SN	golden	VisInsp	HPK	IV	CV	Shape	Stab	Strip	Thick	KEK	handle	recov	SpecUse	AllTests	TestsOK	Uncert.	QA-TC	QA-CCE	Destination	Notes
20USES00000120		OK	OK	Bad	Miss	OK			OK					No	No	No			UNHAPPY	IV: I500V failed / IV: Vbd failed / CV: missing
20USES00000121	Yes	OK	OK	OK	OK	OK			OK					Yes	Yes	No			READY_FOR_MODULE	
20USES00000122		OK	OK	OK	OK	OK	OK		OK					Yes	Yes	No			READY_FOR_MODULE	
20USES00000123		OK	OK	OK	OK	OK			OK					Yes	Yes	No			READY_FOR_MODULE	
20USES00000124		OK	OK	OK	OK	OK		OK	OK					Yes	Yes	No			READY_FOR_MODULE	
20USES00000125		OK	OK	OK	OK	OK		OK	OK					Yes	Yes	No			READY_FOR_MODULE	
20USES00000126		OK	OK	OK	OK	OK	OK		OK					Yes	Yes	No			READY_FOR_MODULE	
20USES00000127		OK	OK	OK	OK	OK			OK		OK			Yes	Yes	No			READY_FOR_MODULE	
....																				
20USES00000166		OK	OK	OK	OK	OK			OK					Yes	Yes	No			READY_FOR_MODULE	
Total	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
Tested	1	42	42	42	41	42	6	5	42	0	2	0	0	41	40	0			0	

Sensor parameter summary for batch **VPX37414**, te

SN	rDate	golden	stage	site	testedAt	HPK	ingot	Vfd	I500V	Vbd	MaxNBad	Bad%	VisInsp	Damage	IV	I500V	Vbd	RMS700V	CV	Vfd	Neff
20USES00000120	26/08/2021		Bless	FZU	FZU	Link	2984142-502	280	0.127	700	0	0.0000	Link	mark	Link	999.000	390	-1.0000			
20USES00000121	26/08/2021	Yes	Bless	FZU	FZU	Link	2984142-502	280	0.135	700	0	0.0000	Link	mark + chip	Link	1.019	700	0.0094	Link	282	4.007
20USES00000122	26/08/2021		Bless	FZU	FZU	Link	2984142-502	280	0.128	700	0	0.0000	Link		Link	1.135	700	0.0012	Link	281	4.064
20USES00000123	26/08/2021		Bless	FZU	FZU	Link	2984142-502	290	0.128	700	0	0.0000	Link		Link	1.092	700	0.0001	Link	289	4.145
20USES00000124	26/08/2021		Bless	FZU	FZU	Link	2984142-502	280	0.131	700	0	0.0000	Link		Link	1.105	700	0.0000	Link	283	4.049
....																					

Figure 10: The batch summary reports for the delivery acceptance purposes. The top portion shows color-coded test results for each sensor of the batch, along with the batch-level QA decision and the classification outcome. The bottom portion shows a table of the test parameters. The sensors and the tests are hyper-linked with the web GUI interface of the DB.

types, correlations between the QC and QA data, and so on. Addressing these needs will require additional DB reporting functionalities.

7. Conclusions

The ITk Strip Sensors community has developed a working DB implementation, which is essential for collecting and evaluating data from 15 test sites distributed around the world. The system captures the key features of the different components and the acceptance evaluation cycle. During the development cycle an emphasis was placed on the verification process of the full data lifecycle. This included information upload and retrieval exercises with dummy objects in the DB, iterative practice cycles with the community to ensure that the software suites are usable and adequate, and extensive summary reports. Given the software complexity, continuous work is required on "maintenance" and addressing new requests from the community (e.g. a new test variant or reporting aspect). This DB implementation is scalable and suited to handle large data quantities. It has been used for pre-production and production phases over the last 2.5 years. To-date, over 5600 sensors have been evaluated through the acceptance tests.

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