The CMS All-Silicon Tracker - Strategies to ensure a high quality and radiation hard Silicon Detector

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Abstract

In December 1999, the CMS collaboration decided to use an all-silicon solution for the tracker. In total the CMS tracker implements 24328 silicon sensors covering an area of 206 m^2. To control a large system of this size and ensure its functionality after 10 years under LHC condition, CMS developed an elaborate design and a detailed quality assurance program.

1 Overall design and radiation hardness precautions

The new CMS layout has four inner barrel (TIB) layers assembled in shells, layers 1&2 are double sided (DS), complemented by two inner endcaps (TIE) each composed of three small disks. The outer barrel (TOB) structure, where the modules are assembled in six concentric layers (layer 1&2 are DS), closes the tracker towards the calorimeter. Two endcaps (TF) ensure a pseudorapidity coverage of $\eta \leq 2.5$. The endcap modules are mounted in 7 rings on 2×9 disks consisting of wedges, each covering 1/16 of 2π. The detectors of ring 1,2,5 are made of double sided modules. A DS module is composed out of two single sided sensors mounted back to back, where one is tilted by an angle of 100 mrad with respect to the detectors that give the phi coordinate. TIB, TIE and the four innermost rings of TF have detectors of 320 μm ("thin"), while TOB and the three outermost rings of the TF have detectors of 500 μm ("thick") ones. The layout is shown in figure 1. All silicon sensors are single-sided with AC-coupled readout and $p+$-strips biased through polysilicon resistors. Pitches range from 80 to 183 μm without any intermediate strips. The substrate is n-type silicon mostly of 6" diameter wafer. The main strategies of CMS to ensure radiation hardness of silicon sensors consist in the reduction of surface damage, delaying the bulk type inversion and using stable

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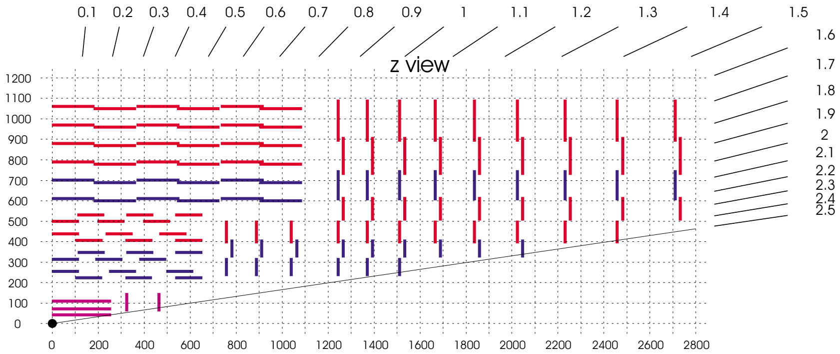

Fig. 1. *The CMS All-Silicon Tracker Layout.*
Cut view of one quarter of the CMS central tracker. Horizontal axis = distance to the IP along beam line, vertical axis = radius (all dimensions in millimeters)

sensors with respect to high voltage. CMS will use ⟨100⟩ with less dangling bonds than standard ⟨111⟩ silicon. This leads to a suppression of surface damage resulting in reduced increase of interstrip capacitance i.e. capacitive noise after irradiation, which is the main noise contribution at working temperature of -10^{o}C. Implementation of a metal overhang over the $p+$ strip (improved field configuration) results in a more stable detector with respect to high bias voltage up to 500V. Using low resistivity silicon delays type inversion point in time resulting in a lower depletion voltage after 10 years of LHC operation. An overview of radiation hardening features implemented in CMS sensors are presented in [1].

2 Procedure

To qualify all testing procedures and capability of the diverse producers, CMS decided to schedule production into 3 steps:

(1) Milestone 200 (M200)
Procurement of 400 sensors / 200 modules (40 TIB, 80 TOB and 80 TF). This provides a first evaluation of the producers process and material and verifies the planned quality assurance procedures.
(2) Pre-series – 5% of full delivery
The company has to prove capability to process sensors at fast pace and adequate quality, before receiving the final order.
(3) Full production within 2.5 years
During full scale production sensors will be tested in samples according to the experience gained in M200 and pre-series.

All construction and quality assurance actions are defined in detail, and regional center managers are responsible for product trace-ability, conformity of actions and database entry. Results of different centers are crosschecked.

3 Sensor & Module Quality Assurance

CMS decided to test the sensor production in samples, but in a quite exhaustive and unique way. After receiving and registrating sensors at CERN, they are shipped to the "Quality Test Centers" (QTC), which are responsible for the overall quality. A certain percentage will be distributed to the "Irradiation Qualification Centers" (IQC) and to the "Process Qualification Centers" (PQC). As part of the acceptance procedures, we will verify the tests done by the producers and carry out additional measurements both on sensors, dedicated test structures (TS) and modules. Figure 2 shows the sensor/module flow. Charge collection efficiency measurements with a source or a laser and noise measurements are forseen on sensors assembled into a module plus bondability and irradiation tests.

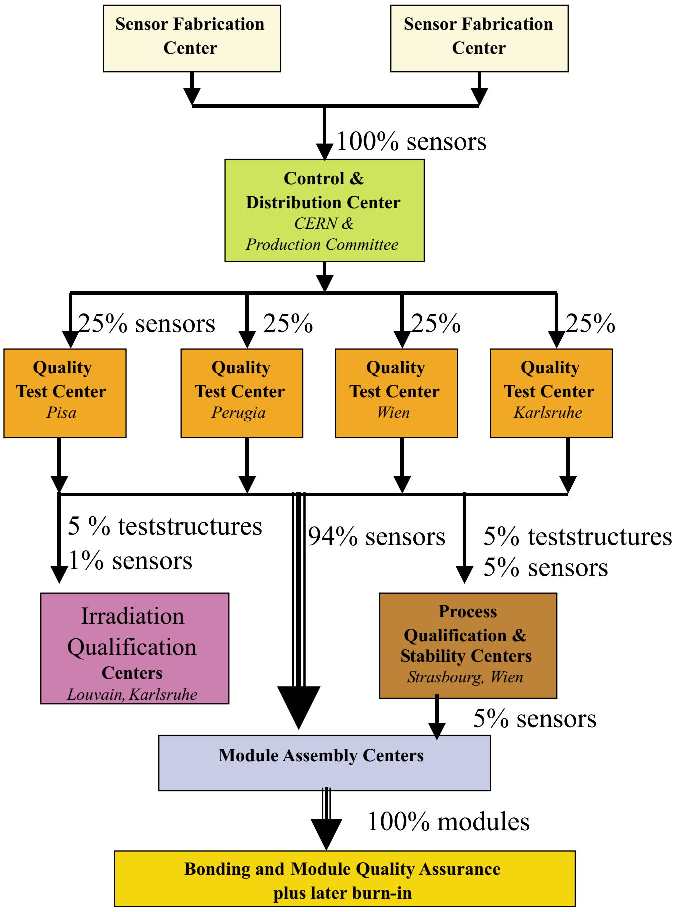

Fig. 2. Logistics of the CMS Quality Assurance and Production.

Quality Test Center

The QTCs *Karlsruhe, Perugia, Pisa, Vienna* check the scribe lines of 100% of sensors under the microscope, while simultaneously measuring the geometrical size. On 5% of sensors additional IV and CV scans up to 550V will be done to verify if breakdown voltage and total current are acceptable and determine the full depletion voltage. On the same sensors QTC will measure all polysilicon resistors R_{poly}, individual DC-leakage currents, the coupling capacities and check for pinholes to monitor the companies output and assure high quality level of sensors. All above mentioned tests will be done on a 100% basis during M200 and the pre-series. In case of non-conform sensors show up during production, all sensors of the corresponding batch will be monitored.

Irradiation Qualification Center

In order to verify the radiation hardness of the full production IQC will submit 1% of sensors and 5% of standard TS to irradiation with the fluence expected for 10 years of LHC[1]. Neutron irradiation will be done in *Louvain* to check for bulk damage, and proton irradiation is planned in *Karlsruhe* to study bulk and additional surface damage produced by ionizing particles. Irradiation will be performed on biased detectors at T=-10^{o}C. Measurements of interstrip resistance, interstrip capacitance, polysilicon resistance are planned before and after irradiation at the operation conditions of CMS (V_{bias}=400V and T=–10^{o}C). Global measurements of IV and CV are foreseen for diodes and full detectors.

Process Qualification Center

To assure homogenous process quality during production, CMS Institutes in *Strasbourg* and *Vienna* check all process-related parameters in detail on 5% of TS. Global measurements consists of IV and CV. Interstrip capacitance, coupling capacitance, interstrip resistance, R_{poly}, sheet resistance of Al and $p+$-implant will be measured on TS, real breakdown voltage of the SiO_2 will be determined. In addition 5% of full size sensors will be submitted to a long term (24h) bias test, and their currents will be monitored (”I-t” test). In total QTC and PQC will measures IV and CV for 10% of sensors.

Module Quality Assurance

There are two steps for module qualification. First the ”Fast Test after Bonding”, which consists of simple readout tests, with noise, pedestal and common mode calculations, plus channel functionality test with either backplane pulsing or light injection, and a short thermal cycling between -10^{o}C and +40^{o}C to identify fragile bonds. And secondly a long-term burn-in test during about 3 days, which encompasses full TF wedges or TIE, TOB structures submitted to extensive thermal cycling with the full readout chain.

References

[1] CMS TDR Addendum, LHCC 2000-016

[1] In 10 years of LHC running the inner layers will receive a fluence of 1.6×10^{14} 1 MeV equivalent neutrons per cm^2, and the outer barrel will be subject to a fluence of 3.5×10^{13} 1 MeV equivalent neutrons per cm^2.