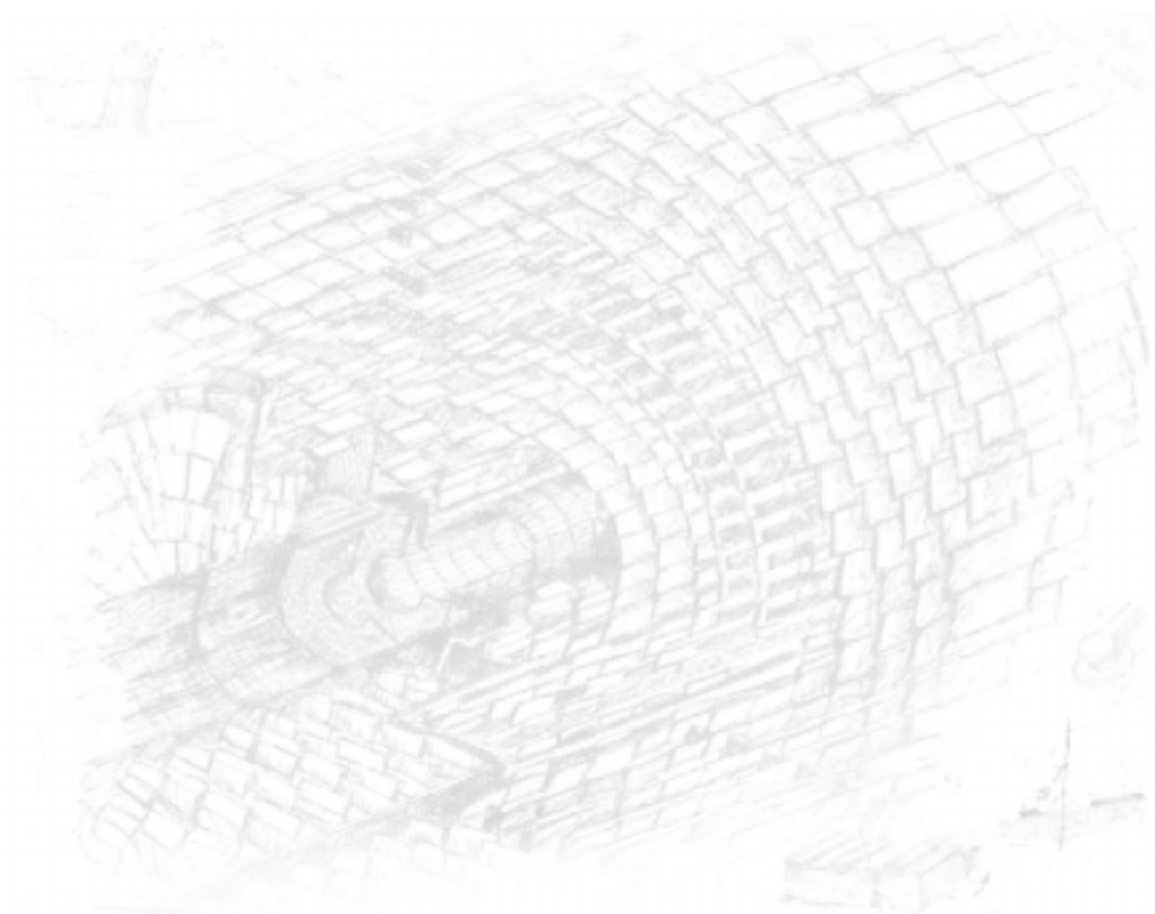


Specifications for the Quality Control & Assurance of the CMS Silicon Sensors



*Version 5
04/06/00*

By the CMS Tracker Sensor Working Group

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1. Introduction

Over the last few years a lot of progress has been made in understanding the operation of silicon sensors in the harsh environment of LHC. The design and technology of the CMS silicon sensors is the outcome of a considerable R&D effort on the part of CMS institutes, in close collaboration with industry. The CMS silicon sensor design appears well suited for running our system up to 10 years at LHC.

The advances made in the technology, together with the industrialization of the fabrication process, have resulted in a considerable cost reduction of the devices, thus opening the possibility for a more extensive use of Silicon Sensors than previously envisaged.

We are now ready to move from the R&D phase to a pre-production phase for the challenging construction of about 230 m² Silicon Strip Tracker (SST). This is the largest silicon-based system ever designed for High Energy Physics attention has to be devoted to the production, acceptance tests and the overall organization of the activities involved.

This document describes the procedures and the organization of the silicon sensors Quality Control. In particular this includes:

- Organization and management for the production.
- Testing procedures and acceptance criteria.
- Testing setups.
- Documentation and database.
- Management of non-conformities.
- Packaging and handling.
- Schedule.

Particular emphasis has been given to the Quality Control and Assurance procedures that, based on our R&D experience, will provide the best criteria (compatibly with our budget and schedule) for testing and monitoring the production of the sensors.

This large production may be carried out by different vendors. It will last about 2.5 years and the quality assurance will be the task of several institutes. It is thus important to assure that the sensor production is both homogeneous and stable over the entire production run and the quality tests are consistently carried out in the various institutes. As will be discussed in the following chapters, our general strategy will be:

- Selected companies will fabricate sensors following our Technical Specifications. They will test the whole production and deliver sensors complying with our acceptance criteria.

- As part of the acceptance procedures, we will verify the tests done by the producer and carry out additional measurements both on sensors and test structures.
- During the pre-production we will fully test all sensors. If these meet our requirements we will test only on a sample basis during the production.
- We will carry out extensive measurements on samples of test structures to monitor the process stability over the entire production.
- We will perform sample irradiation tests on sensors and test structures, to monitor the process radiation hardness over the entire production
- Sensors will be accepted provided they pass the tests carried out by the collaboration.
- The companies will be responsible to ensure that no unauthorized changes in the design, processing or packaging will occur during the whole production. Any subcontractor used by the companies must also understand its obligation in this respect.
- The companies must operate within a Quality Assurance Program satisfying the requirements of ISO 9000 or equivalent national standard.
- The centers responsible for testing will perform quality tests and apply acceptance criteria strictly following the Quality Control Specifications.
- To assure consistency of tests among different centers during the whole period of construction, they will undergo a calibration testing procedure before and occasionally during the production.
- The centers will keep track of possible non-conformities during the whole delivery to keep under control all the potential sources of problems and request appropriate action to the companies.

2. Sensor Production Network and Activity Plan during production

Given the large number of sensors to be produced and the various checks to be performed, the production may be distributed among different companies and tests will be carried out in several test centers (CERN, Louvain, Karlsruhe, Perugia, Pisa, Strasbourg and Wien). All the above mentioned centers have availability (or plan for immediate upgrading) of:

- Clean Room with temperature and humidity control.
- Automatic probe stations and the relative semiconductor instruments for testing.
- Trained technicians and physicists for the whole period of production.

Under the responsibility of an already defined local coordinator for sensor activities, each center will be able to undertake his share of responsibility. In addition it is imperative to centrally coordinate the production. A Production Committee is foreseen to manage the whole process.

It is important to design a Production Network, to define clearly the functions and the responsibilities of each center, to define the organizational interfaces between them in order to guarantee a smooth flow of production with the annexed information. In Fig. 2.1 we describe the Production Network. The functions and the responsibilities of each center are summarized below and detailed in the following chapters.

- **Sensor Fabrication Centers (SFC):**
(*Companies*)

Responsible for sensor fabrication, testing and delivery following our Technical Design, Quality Control Specifications, Terms and Conditions of the Contract.

- Design the sensor masks and submit them to the Production Committee for approval.
- Procure the silicon substrates.
- Process the wafers.
- Cut the wafers.
- Test the whole sensor production and deliver sensors that satisfy our acceptance criteria.
- Provide electronic documentation of test results.
- Pack and deliver the sensors in due time to the Control and Distribution Center.

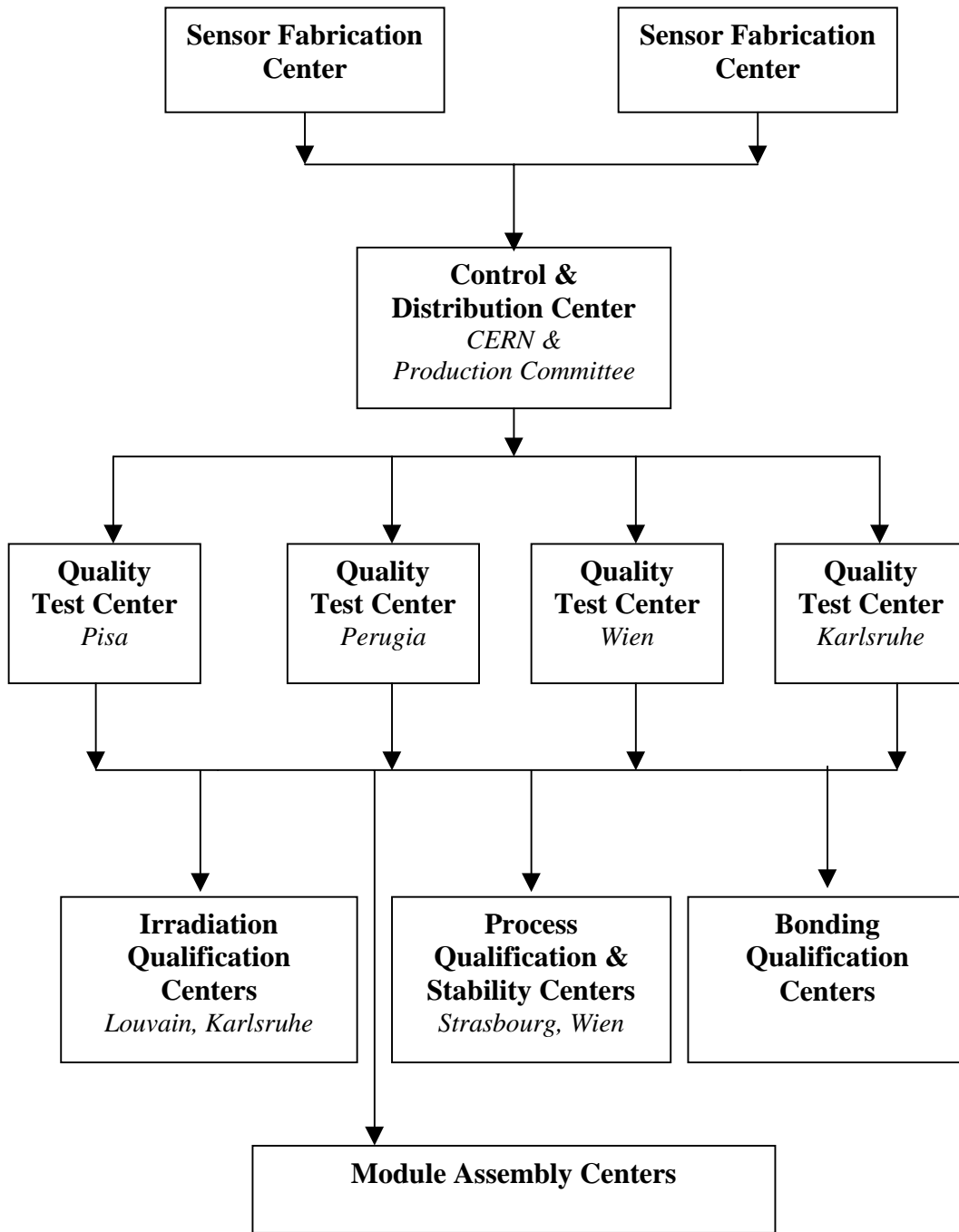


Fig 2.1: Proposed Sensor Production Network

- **Control and Distribution Center (CDC)**
(*CERN, Sensor Production Committee*)

Responsible for reception, distribution and monitoring of the sensor production. This center has a double functionality: one concerns the logistics and the second the control of the production.

Logistics aspect of CDC (*CERN*):

- Receives sensors from producers.
- Crosschecks the producer electronic documentation and inserts it into the DB.
- Distributes sensors to the Quality Test Centers

Monitoring of the production by CDC (*Sensor Production Committee*)

- Writes Specifications.
- Advises on the technical aspects of sensor procurement.
- Keeps contact with companies.
- Monitors centrally the flow of production.
- Keeps record of non-conformities and takes action if needed.
- Makes sure the schedule is followed.

- **Quality Test Centers (QTC):**
(*Karlsruhe, Perugia, Pisa, Wien*)

Responsible for the Acceptance Tests of the sensors.

- Receive and register sensors and test structures from the CDC.
- Optically inspect the sensors.
- Perform quality acceptance tests.
- Communicate to the CDC the test-results.
- Insert test results into the DB.
- Pack, register, select and distribute a fraction of sensors and test structures to Process and Irradiation Qualification Centers and part of structures to Bonding Centers.
- Ship accepted sensors to Module Assembly Centers.

- **Process Qualification Centers (PQC):**
(*Strasbourg, Wien*)

Responsible for the Process Stability Qualification of the sensors

- Receive and register samples of sensors and test structures from the QTC.
- Perform process acceptance tests.
- Perform stability tests (current vs time) on sensors.
- Certify and monitor the stability of sensor processing.
- Inserts results into the DB.
- Communicate to the CDC and the QTC the test-results.

- Irradiation Qualification Centers (IQC):

(Louvain, Karlsruhe)

Responsible for the Radiation Hardness Qualification of the sensors.

- Receive and register samples of sensors and test structures from the QTC.
- Perform tests on sensors and test structures before irradiation
- Irradiate sensors and test structures.
- Perform post-irradiation tests.
- Certify and monitor the stability of radiation hardness of sensor processing.
- Insert results into the DB.
- Communicate to the CDC and QTC the test-results.

- Bonding Qualification Centers (BQC)

(Bonding Centers)

Responsible for the bonding of detectors.

- Receive and register test structures from the QTC.
- Perform bonding tests on the structures.
- Insert results into the DB.
- Communicate to the CDC and QTC the test-results.

- Module Assembly Centers (MAC):

(Assembly Centers)

Responsible for the Mechanical Assembly of the detectors.

- Receive and register accepted sensors from the QTC.
- Assemble the sensors together with the front-end electronics in detectors.

The tests on sensors assembled in modules will be described in another document.

3. Overview of Sensors Design and Specifications

The sensor design and process for the SST are compatible with the most common 4", 5" and 6" technologies and with large production volumes in the limited time available for sensor production. An efficient use of the wafer surface as active area of the devices is made, to reduce the detector cost per unit area. The sensors are single sided devices and require a minimal number of processing steps, also resulting in a cost reduction.

General sensors design considerations are:

- a) Selection of substrates of good quality is needed to avoid excessive radial resistivity variations and local mechanical defects.
- b) Double-sided polishing will assure higher process yield and will keep surface effects under control.
- c) Carefully controlled dose and doping profile and the use of metal overhang will limit the occurrence of critical fields at the junction edge.
- d) Good ohmic contact is needed to avoid charge injection from the back contact.
- e) Edge stabilization will avoid high fields in the area damaged by the cutting procedure.
- f) Multi-guard structures between the detector active area and the n^+ edge implant may be used to distribute the voltage drop on the junction side over a larger region, enhancing the breakdown performances of the device.
- g) The strip width over pitch ratio is determined as a compromise between achieving a low strip capacitance and ensuring safety in terms of field gradients close to the implants.

This chapter contains a description of sensor design and specification. The "Technical Specification of CMS Silicon Strip Sensors" are included as an Appendix.

3.1 General sensor characteristics

The technology is a derivation of the standard planar process usually employed in the IC industry. The implants and the following thermal diffusion are tuned in order to obtain junctions deep and smooth, enhancing breakdown and noise features. The overall thermal budget of the fabrication process is chosen as low as possible, as this is an important source of dark current.

3.1.1 Substrate specifications

The sensor material is n-type silicon, phosphorus doped with <100> crystal orientation. For sensors produced from <100> crystals, irradiation leaves unchanged the inter-strip capacitance and, as a consequence, the strips noise. The resistivity is matched to the expected radiation. The high purity, as well as the excellent uniformity in doping concentration, requires the use of silicon grown with the Float-Zone technique.

The substrate thickness and resistivity are different for the inner and the outer tracker. A thickness of 320 μm and a resistivity of 2-4 $\text{k}\Omega/\text{cm}$ are chosen for the inner layers as a compromise between signal-to-noise and depletion voltage after irradiation. The outer layers are instrumented with 500 μm thick wafers with a resistivity larger than 4 $\text{k}\Omega/\text{cm}$. These values of thickness also assure good mechanical properties and thus good production yield. The precision required in thickness and bending allows little spread in depletion voltage throughout the wafer and ease of testing and assembly. The low resistivity chosen for the inner layers improves the radiation hardness by shifting the fluence at which the type inversion takes place toward higher values. The use of oxygen diffused sensors is possible for the layers closest to the beam line to improve the performance after type inversion.

The large amount of sensors needed for the CMS SST requires the use of wafers from many different ingots. It is important to know which wafers belong to a given ingot. By correlating measured properties of sensors with the corresponding ingot number the quality of the material can be monitored effectively. As an example wafer producers provide to the companies resistivity profile measurements. These measurements map the radial wafer resistivity and, by wafer sampling inside an ingot, the longitudinal resistivity profile for the ingot. Companies selected for sensors production must provide these measurements in paper and electronic format as well as a suitable wafer-ingot link.

3.1.2 Implant specifications

A p+ implantation is performed on the front side in order to define the strip-shaped diodes. Geometrical dimensions are defined by means of the photo-lithographic precision attainable with these technologies, which is of the order of 1 μm .

A ratio of strip width to pitch of $w/p = 0.25$ is chosen as a compromise between a low total strip capacitance and stable detector operation at high voltage. Each strip has metal overhang in order to enhance the breakdown performance.

A structure of multiple p+ guard-rings is used in all detectors around the active area. The innermost ring is used to bias the implants through arrays of poly-silicon resistors. A second ring is designed to prevent the flowing of leakage current external to the active area in the bias ring. A multi guard option is foreseen in order to prevent breakdown caused by high voltage drop between the detector edge and the guard-ring.

On the back-side an n+ implantation is necessary in order to allow good ohmic contact between the bulk and the metal contact. Moreover, the presence of this highly doped n+ layer acts as a barrier for minority carriers coming from the depleted bulk and for majority carriers injected from the metal contacts, keeping the overall leakage current, and thus the shot noise, very low.

An n+ implant is required on the front side along the edges of the devices in order to prevent the space charge region from reaching the cutting edge, thus protecting the active area from injection of charges originated in this heavily damaged region.

A passivation layer protects the front side from accidental scratches and reduces considerably the influence of ambient conditions (like humidity) or other pollutants (like alkaline metals) on the detector performance. The passivation both simplifies the handling and enhances the stability in time of the electrical performance.

The sensor strips are AC coupled and poly-silicon biased. Arrays of integrated capacitors are produced on the sensor by using a multi-layer of thin dielectrics. An arrangement of grown and deposited oxides and nitrides is chosen, with high density, low trapped charge and homogeneous coverage. This configuration minimizes the number of pinholes, while allowing high enough specific capacitance to guarantee efficient charge collection. Quality control of the oxides and nitrides is needed to minimize both the interface states and the inter-strip coupling, assuring stability of electrical performances in time. The thickness of all metal electrodes is chosen as high as possible to reduce the total series resistance of the read-out strips.

The choice of poly-silicon as the biasing technique is mainly due to its established radiation resistance, and relies on the capability of producers in defining the resistance value by means of controlled doping by implantation or diffusion. The chosen value of the resistors is sufficiently high to guarantee low noise, and still low enough to avoid undesirable voltage drops between the strips and the bias ring. The polyresistors design allows the use of saturated poly-silicon specific resistance improving uniformity and stability of the resistance.

Analysis of possible processing problems requires knowledge of which wafers belong to a given processing batch and ingot. This correlation allows also effective batch quality monitoring through sample testing (see chapter 6).

3.2 Sensor design

Several different sensor designs are needed for the Silicon Strip Tracker. All designs share several characteristics. The distance of the active area (situated inside the inner edge of the bias line) from the cutting edge is 1140 μm along the strip direction, and 1000 μm orthogonal to the strip direction for 320 μm thick sensors. These dimensions are and 1500 μm x 1350 μm respectively for 500 μm thick sensors.

Two rows of pads are used at the edge of the strips on each side of the sensors to allow for micro-bonding. Bonding pads are long enough to allow repair in case of failures during micro-bonding. A row of test pads is used to contact each implant for testing purposes. The p+ strips are connected to the bias ring with a poly-resistor (see fig. 3.1). In the empty area between the guard structure and the n-well close to the corners, a series of reference marks is foreseen for positioning and mechanical survey purposes. Every second strip is numbered.

For each wafer the surface not occupied by the sensor is used for several test structures designed to monitor the stability of the technology and the main critical characteristics of the device.

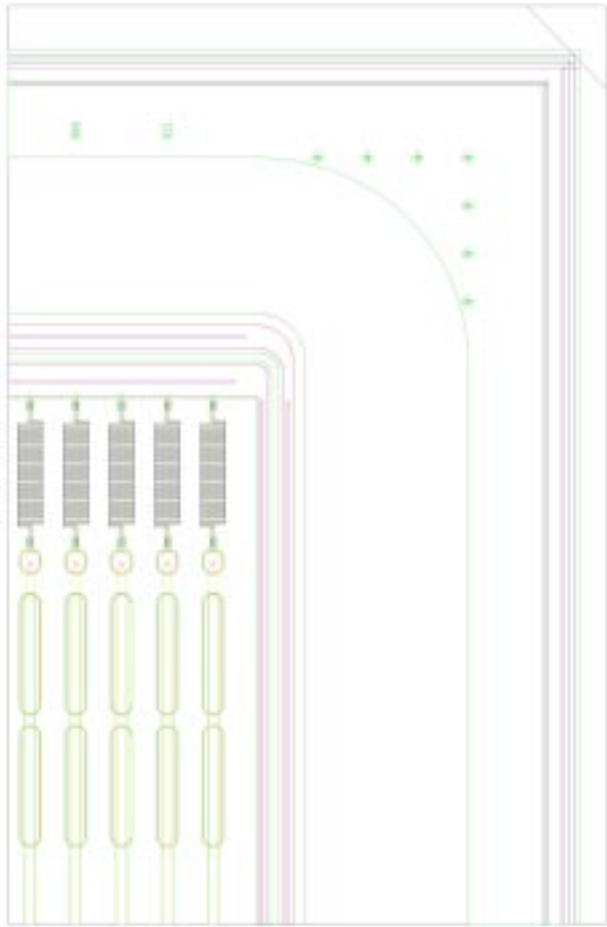


Fig. 3.1 A sensor corner: are visible strips metal layer, polyresistors, the bias ring and external guard-ring. The design is for a sensor with 183 μm pitch without multi-guard structure

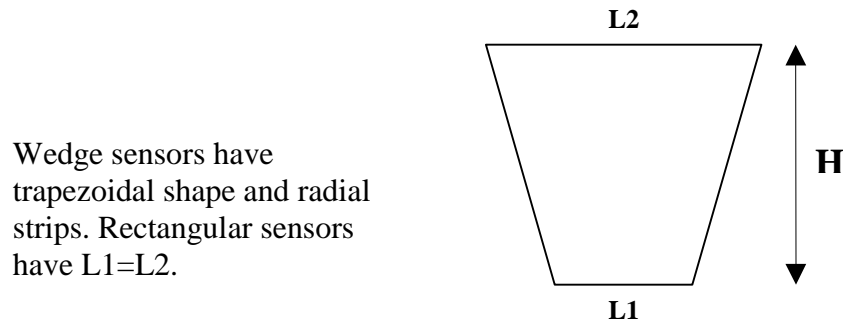
3.3 Masks design

All thick sensors are produced from 6" thick wafers. For thin sensors three options exist, corresponding to the choice of either 6", 5" or 4" wafers. In general one sensor is produced per wafer. In the 5" option a subset of the sensors are such that two are produced from a single wafer.

Depending on detector and wafer size, detectors consist of either one or two daisy-chained sensors. The detectors of the Outer Barrel (OB) consist of two identical thick rectangular sensors. Those of the three outermost rings (W5, W6 and W7) of the End-cap consist of two trapezoidal thick sensors. Using 6" wafers all other detectors consist of a single thin sensor. Using 5" or 4" wafers all other detectors consist of two thin sensors with the exception of the innermost ring of the End-cap (W1) in 4" and the two innermost ring (W1 and W2) in 5".

Two Inner Barrel (IB) layers and three OB layers are equipped with "double-sided" modules made of single sided detectors back to back in a stereo configuration. Three rings out of seven (W1, W2 and W5) in the End-cap are also equipped with "double-sided" modules.

Tables 3.1 to 3.4 give the basic geometric parameters of the sensors in the three options.



Type	L1	L2	H	Pitch	strips	multiplicity
OB1	96.4	96.4	94.5	122	768	5520
OB2	96.4	96.4	94.5	183	512	6336
W5a	99.0	112.4	84.0	126-143	768	1440
W5b	112.4	123.0	66.1	143-156	768	1440
W6a	86.1	97.5	99.0	163-185	512	1008
W6b	97.5	107.6	87.8	186-205	512	1008
W7a	74.1	82.9	109.8	140-156	512	1440
W7b	82.9	90.9	98.8	157-172	512	1440

Table 3.1- Sensors from 6" wafer 500 ± 20 μm thickness: physical dimensions (mm), pitches (μm), number of strips and multiplicity (not including spares)

Type	L1	L2	H	Pitch	strips	multiplicity
IB1_6	63.4	63.4	119.2	80	768	1584
IB2_6	63.4	63.4	119.2	120	512	1224
W1_6	64.1	88.1	89.5	81-112	768	576
W2_6	88.2	112.4	90.3	113-143	768	864
W3_6	65.0	83.2	112.8	124-158	512	880
W4_6	59.9	73.4	117.4	113-139	512	1008

Table 3.2 - Sensors from 6" wafer 320 ± 20 μm thickness: physical dimensions (mm), pitches (μm), number of strips and multiplicity (not including spares)

Type	L1	L2	H	Pitch	strips	multiplicity
IB1a_5	63.4	63.4	79.4	80	768	1584
IB1b_5(*)	63.4	63.4	39.7	80	768	792
IB2a_5	63.4	63.4	79.4	120	512	1224
IB2b_5(*)	63.4	63.4	39.7	120	512	612
W1_5	64.1	86.7	84.2	81-110	768	576
W2a_5	65.3	82.5	85.5	83-104	768	576
W2b_5	65.3	82.5	85.5	124-157	512	576
W3a_5	78.6	93.3	73.4	100-119	768	704
W3b_5(*)	93.3	99.7	31.9	119-127	768	704
W4a_5	58.1	68.8	93.5	110-130	512	1008
W4b_5(*)	68.8	73.5	40.4	130-139	512	1008

Table 3.3- Sensors from 5" wafer 320 ± 20 μm thickness: physical dimensions (mm), pitches (μm), number of strips and multiplicity (not including spares).

(*) The design contains two identical sensors with the given dimensions.

Type	L1	L2	H	Pitch	strips	multiplicity
IB1_4	63.4	63.4	59.5	80	768	3168
IB2_4	63.4	63.4	59.5	120	512	2448
W1_4	48.8	63.0	70.5	92-119	512	768
W2a_4	62.9	74.6	58.1	80- 95	768	576
W2b_4	74.6	83.3	43.2	95-106	768	576
W2c_4	62.9	74.6	58.1	119-141	512	576
W2d_4	74.6	83.3	43.2	141-158	512	576
W3a_4	53.5	62.7	68.8	101-118	512	1056
W3b_4	62.7	69.3	49.1	118-131	512	1056
W4a_4	59.6	66.9	64.0	113-127	512	1008
W4b_4	66.9	73.4	56.3	127-139	512	1008

Table 3.4 - Sensors from 4" wafer 320 ± 20 μm thickness: physical dimensions (mm), pitches (μm), number of strips and multiplicity (not including spares)

In the OB there are 5928 detectors, 11856 sensors and 2 masks. In the three outermost ring of the End-Cap there are 3888 detectors, 7776 sensors and 6 masks. The number of detectors, wafers, sensors and masks for the three options for the thin detectors are given in Table 3.5

	detectors	wafers	sensors	masks
Inner Barrel				
6"	2808	2808	2808	2
5"	2808	4212	5616	4
4"	2808	5616	5616	2
W1-W4				
6"	3328	3328	3328	4
5"	3440	4926	5152	7
4"	3984	7200	7200	9

Table 3.5. Number of detectors, wafers, sensors and masks for the three options for the thin detectors.

4 Tests and acceptance requirement to be fulfilled by companies

The CMS Collaboration will accept sensors delivered by the suppliers and qualified as good according to the results of two series of tests:

- tests performed by the supplier;
- tests performed by the CMS collaboration before and after the exposure to irradiation.

Suppliers will process sensors, test the whole production and deliver sensors which satisfy the acceptance criteria. The following list of measurements is envisaged to characterize and qualify a sensor. Each measurement must be performed on all sensors. The measurement results must be documented and provided in electronic format. Each measurement scheme must be agreed between CMS and suppliers.

We classify the tests in three different categories:

1. Tests to be performed on each sensor before and after dicing, aiming to qualify the global quality;
2. Test to be performed on strip-by-strip basis for each sensor, to point at defective strips;
3. Tests to be performed on dedicated test structures, for each batch, to monitor the process quality.

For each category CMS indicates acceptance criteria.

4.1 Test for each sensor

- Measurement of the leakage current as a function of the reverse bias (IV curve). This measurement must be performed at room temperature (20 ± 1 °C) and $RH < 35\%$, up to 1000 V or at the measuring instrument compliance of 1 mA. It should be performed also after dicing.
- Measurement of the capacitance between the backplane and the guard-ring at 1 kHz frequency as function of the reverse bias up to 600 V (CV curve). Determination of the depletion voltage from this curve.
- Optical inspection after dicing.
- On a subset of wafers (1% per ingot) we require the determination of the average substrate thickness and the deviation from flatness in the active area.

4.2 Tests for each strip

- measurement of the strip leakage current at a reverse bias voltage of 500V for sensors showing a leakage current that exceeds 500 nA at 500 V
- measurement of the coupling capacitance (C_{ac}) at 1 KHz
- identification of the strips with the following defects:
 - discontinuities along the metal line

- shorts of the metal line among neighboring strips
- pinholes through the dielectric layer between the metal strip and the implant
- measurement of the poly-silicon resistors value (R_{poly})
- measurement of the current through the coupling dielectric at voltage of 120 V across it.

4.3 Tests on test structures (10% for each batch):

- measurement of the sheet and implant resistance
- measurement of coupling capacitance breakdown voltage
- measurement of the inter-strip resistance per unit length (R_{int})
- measurement of the inter-strip capacitance per unit length (C_{int}) : the coupling capacitance of each strip to the two neighboring -one on each side- at 1 MHz frequency and at depletion voltage.

4.4 Acceptance Criteria

The Suppliers will deliver sensors meeting the following acceptance criteria. CMS will accept the sensors if they also meet the acceptance criteria of the tests performed by CMS.

Tests on sensors

Before or after dicing:

- Depletion voltage $V_{dep} < 250$ V
- Sensor thickness within ± 20 μm , sagitta < 30 μm
- Number of defective strips $< 1\%$. A strip is considered inside specifications if:
 - $I_{strip\ leak} < 0.5$ μA at 500 V
 - Coupling capacitance > 1.2 pF/cm per μm of implanted strip width
 - I dielectric leakage < 1 nA at 120 V
 - Poly resistors value 1.5 ± 0.5 $\text{M}\Omega$
 - No metal breaks or shorts to neighbors
 - No implant breaks or shorts to neighbors

After dicing:

- V breakdown > 500 V
- $I(500\text{V}) < 100$ nA/cm² at 21 °C, 35 % humidity
- optical inspection: no damage on the cut line region and visible damage on the junction side or on the backplane.

Tests on test structures

- Implant strips : < 200 $\text{K}\Omega/\text{cm}$ (400 Ω/square)
- Metal strips : Aluminum 18 $\text{m}\Omega/\text{square}$, (thickness ≈ 1.5 μm)

- $R_{int} > 1 \text{ G}\Omega$
- C_{int} within 0.2 pF/cm from the parameterization

Parameterization of the interstrip capacitance

The interstrip capacitance is parameterized by the formula:

$$C_{int} = a + b \frac{w + 23 \mu m}{pitch}$$

where w is the strip width in micron, $pitch$ is expressed in micron and $a = 0.1$ (0.3), $b = 1.6$ (1.4) for thin (thick) sensors.

- The following table 4.1 summarises the electrical tests of the sensors and the acceptance criteria.

Tests on sensors made by companies		
Tests on sensors		Acceptance criteria
Global tests		$V_{\text{breakdown}} > 500 \text{ V}$
IV	Before dicing	Leakage current @ 500 V, $I(500\text{V}) < 100 \text{ nA/cm}^2$ at 21 °C
	After dicing	$I(500\text{V}) < 100 \text{ nA/cm}^2$ at 21 °C
CV		Depletion voltage $100 < V_{\text{dep}} < 250$
Strip by strip measurements	IV	$I_{\text{strip leak}} < 0.5 \mu\text{A @ } 500 \text{ V}$
	CV	Coupling capacitance $> 1.2\text{--}1.3 \text{ pF/cm}$ per μm of implanted strip width
	Scans:	$I_{\text{dielectric leakage}} < 1\text{nA @ } 120 \text{ V}$
	Poly	Polyresistors value $1.5 \pm 0.5 \text{ M}\Omega$
	Strip	No pin hole No metal breaks or shorts to neighbors No implant breaks or shorts to neighbors
Tests on test structures made by company		
Tests		Acceptance criteria
Implant resistance Metal strip resistance inter-strip resistance inter-strip capacitance per unit length at 1 MHz frequency and reverse bias voltage of 500 V		<ul style="list-style-type: none"> - $< 200 \text{ K}\Omega/\text{cm}$ ($400 \Omega/\text{square}$) - $18 \text{ m}\Omega/\text{square}$, (thickness $\approx 1.5 \mu\text{m}$) - $R_{\text{int}} > 1 \text{ G}\Omega$ - C_{int} within 0.2 pF/cm from the parameterization

Table 4.1

5. Control and Distribution Center Activity

The distributed organization for the Quality Control of the sensors has to be centrally coordinated. The sensors produced in the fabrication centers are delivered to one central place (CERN) from where they are dispatched to the different test centers.

Explicitly, the role of this center is:

- Reception of sensors from fabrication centers.
- Check the conformity of the companies test results, and insert the documentation into the DB.
- Distribute the sensors to the different test centers.

Since these operations do not imply to expose the sensors to the environment, a classified clean room is not needed.

A Sensor Production Committee is foreseen to monitor the flow of sensors from the fabrication centers to the modules assembly centers. Its main functions are:

- Interact with the companies to monitor their production schedule, to give them feedback in case of non-conformities, to ask or provide any general information that might be useful for the fabrication.
- Monitor the activities of the Quality, Process and Irradiation Centers and make sure that the system runs smoothly and the schedule is followed.
- Decide the provisional acceptance of sensors.
- Manage any non-conformity detected by the different testing centers, and formulate and apply strategies for dealing with them.

6. Acceptance Tests performed by the Quality Test Centers

The Quality Test Centers (QTC) are responsible for the acceptance tests of the sensors from the pre-series and the production. There are four QTCs: Karlsruhe, Perugia, Pisa and Wien. Sensors are received from the Central Distribution Center (CDC), registered, inspected, tested and, upon acceptance, distributed to the Module Assembly Centers.

During pre-series 100% of sensors are evaluated and tested for acceptance. In this phase 5% of sensors and 20% of test structures will be sent to PQC and IQC for qualification.

During production 5% (+ suspicious) of sensors will be tested by QTC and only 1% of sensors and 4% of test structures will be sent to PQC and IQC for qualification.

6.1 Registration and Optical Inspection

Sensors received from the CDC are identified and registered, packaging is surveyed for damage and finally all sensors undergo an optical inspection under microscope. Both cut and surface quality will be verified.

The needed equipment consists of a x-y stage computer-controlled system equipped with a microscope, a CCD camera and a monitor. The stage system loaded with the sensor moves along the interesting regions. Acceptance is based on observation watching the structures on a large screen. Estimated time needed for this test is about 10 minutes.

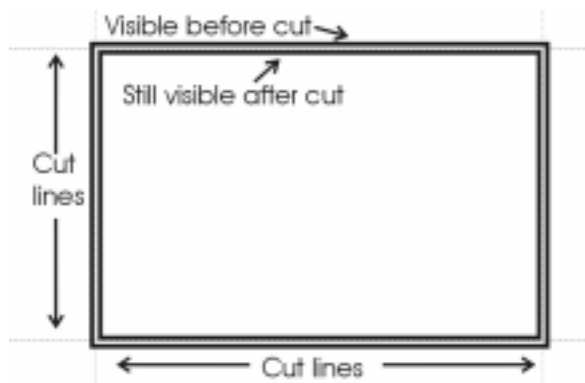


Figure 6.1

Looking at the reference rings defining the cutting lines, geometry and size can be checked. A visible intact inner ring with a complete missing outer ring indicates an accepted cut. See figure 6.1. The movement of the computer-controlled stages gives further assurance of the geometrical size, by moving a crosshair from one edge to the other, and simultaneously reading the distance of the movement. The cutting tolerance is $\pm 20\mu\text{m}$.

6.2 Electrical Quality Test procedures and Acceptance Criteria

Sensor acceptance is based on global and strip-by-strip tests.

- Global tests: IV and CV curves are studied.
 - IV: Measuring the total leakage current from 0 – 600V reverse bias between bias ring and backplane with a defined stepping of 2V/s requires 5 minutes. Measuring up to 600V explores a range of 100V above the minimum specified value of V_{break} . The setup must be able to limit total current to $\sim 30 \mu\text{A}$.
 - CV: The CV measurement is performed to measure the depletion voltage and to study the breakdown performance. Measuring the total capacitance between bias ring and backplane from 0 – 500V reverse bias with a 2V/s stepping requires 5 minutes. The capacitance is measured in the range 1-10 kHz
- The strip-by-strip tests are performed to identify strip defects, to compare them with the vendor information and to monitor the homogeneity of the sensor. All these tests are done with the sensor at $V_{\text{bias}} = 500\text{V}$.
 - Pinholes: We check all the AC pads for pinholes by measuring the current to ground on the AC pad at 500 V bias. A current above 1nA indicates a pinhole (I_{diel}). Pinholes can be identified also by a capacitance measurement with a quasi-static device.
 - Coupling Capacitance: Measuring all coupling capacitances (CC) of one sensor gives us confidence about the resulting homogeneity in charge collection. Additionally this measurement probes for pinholes, shorts and breaks. During full production this test will only be done on a fraction of strips.
 - Strip Leakage Current, Polyresistor values and Inter-strip resistance: Probing of the DC pads for current and voltage identifies leaky strips, low or high polyresistors (R_{poly}) and gives a lower limit on the inter-strip resistance ($R_{\text{interstrip}}$). Polyresistor values are determined by measuring the voltage drop (V_{poly}) over the resistor, with $V_{\text{bias}} = 500\text{V}$ supplied, and the leakage current (I_{leak}) through the diode by bypassing the resistor with an ampere meter. R_{poly} is then calculated by: $R_{\text{poly}} = V_{\text{poly}} / I_{\text{leak}}$. The acceptance criteria are strip leakage current: $I_{\text{leak}} < 500\text{nA}$ per strip and $R_{\text{poly}} = 1.5 \pm 0.5\text{M}\Omega$ at $V_{\text{bias}} = 500\text{V}$; the fraction of resistors outside this values must be less than 1%. During full production this test will only be done on samples.

At least one sensor per batch will be tested for coupling capacitance, strip leakage current and polyresistors. Assuming a testing time of about 10s per strip for all strip-by-strip measurements in total, we expect about 85 minutes for 512 strips. The following table summarises the electrical tests of the sensors and the acceptance criteria.

Tests on sensors made by the Quality Test Centers		
	Test	Acceptance criteria
Global	IV	$I_{\text{tot}} < 100\text{nA}/\text{cm}^2$ at $V_{\text{bias}} = 500\text{V}$ $V_{\text{break}} > 500\text{V}$
	CV	$100\text{ V} < V_{\text{dep}} < 250\text{ V}$
Strip- by strip	Pinhole measurement	Current through AC pad: $I_{\text{diel}} < 1\text{nA}$
	PolyResistance (*)	$1.5 \pm 0.5\text{M}\Omega$
	Strip Leakage Current (*)	$I_{\text{leak}} < 500\text{nA}$
	Coupling Capacitance (*)	$1.2\text{--}1.3\text{ pF}/\text{cm}$ per μm of impl. strip width
	Total Defect strips	$\leq 1\%$
	(*) Tested on a fraction of strips during production	

Table 6.1

It is recommended to measure all parameters in the same scan (CC, R_{poly} and I_{leak}) by applying needles to DC and AC pad simultaneously (either by probe card or by individual needles) and switching between different measurement setups.

The maximum number of defect strips accepted per sensor is 1% including pinholes / shorts / breaks / leaky strips. All tests are performed at room temperature (21°C) and humidity $35 \pm 5\%$.

6.3 Test set up description

There are two different kinds of setups, both able to measure all required parameters.

Setup 1 (Perugia / Pisa)	Setup 2 (Karlsruhe / Wien)
Automated probe station with several different probe cards and automated wafer loader.	Automated probe station with flexible needle setup.
Probe card for DC and AC pads	Individual needles on DC and AC pads
Voltage supply (600V - 1mA or better)	
IV meter (electrometer)	
(Quasistatic) CV meter, LCR	
Switching device	
Chuck for 6" sensors	
Microscope for inspection	
CCD + monitor for visual inspection. All instruments computer controlled.	

Table 6.2

7. Process Stability Tests performed by Process Qualification Centers

The process quality and stability is the responsibility of the companies. However all the critical parameters, especially the compliance with the technical specifications as given Chapter 4 are monitored by us.

The goals of our process quality tests are:

- To ensure constant quality throughout the production.
- To discover problems as early as possible.

The process qualification centers, which receive the sensors and test-structures from the quality test center, are responsible of:

- Perform process acceptance tests.
- Perform stability tests (current vs time).
- Qualify, certify and monitor the process stability of the producers.
- Insert results into the database.
- Alert the central distribution and quality test centers of non-conformities.

In order to measure the relevant process parameters, test-structures are implemented on all wafers. In addition some measurements are also performed on sensors (i.e. Current vs time measurements).

All tests are done at room temperature, since the handling is simpler and safer. Therefore the test criteria are defined by extrapolating the specifications from -10°C to room temperature if applicable.

On all wafers of the pre-series we perform the tests listed in Chapter 7.1. These results allow to judge the quality of the sensors delivered by the companies and to crosscheck the data they provide. During the production only a few percent of the wafers from a batch will be tested on a random basis. This should be sufficient to ensure constant quality since the process parameters do not vary from wafer to wafer but from batch to batch.

7.1 Test-structures

On each wafer there are four half moons outside the sensor area. We will use two half moons with specially designed small structures, including a mini-sensor, for the process qualification and the irradiation tests. The test-structures on a half moon are organized in sets. In principle there may be more than one set on a single half moon. All the test-structures are arranged such that the contact/bonding-pads are in one line and all measurements can be done at the same time with one probe card. Thus the

probe card and the layout for the irradiation support are simplified. A common ground-line for all structures is foreseen.

We will perform the following measurements on the test structures:

- CV curve: Measurement of the capacitance at 1-10 kHz to determine the depletion voltage. Therefore we scan from 0-1000 V in steps of 2V/s.
- IV curve: Measurement of the current through the bias and/or guard-ring vs. voltage. This allows to verify the breakdown stability of the sensor. The scan is done from 0-1000 V (or breakdown) in steps of 2V/s. The IV and CV measurements will be done in the same voltage ramp.
- C_{int} : Measurement of the Inter-strip Capacitance. The applied voltage V should be about 1.5 times the depletion voltage V_{dep} ($V = 1.5V_{depl}$). The measurement is performed at 1 MHz. C_{int} is parameterized as a function of width (w) and pitch (p): $C_{int} = 0.1 + 1.6*(w+20 \mu m)/p$ pF/cm for thin sensors and $C_{int} = 0.3 + 1.4*(w+20 \mu m)/p$ pF/cm for thick sensor.
- R_{int} : Measurement of the Inter-strip Resistance.
- R_{poly} : Measurement of the Polysilicon Resistors.
- R_{al} : Measurement of the resistivity of the metal (Al) lines
- R_{p+} : Sheet resistance of p^+ implant
- C_{ac} : Measurement of the coupling capacitance.
- I_{Die} and $V_{break(ac)}$: Check if dielectric holds the required voltage. Measure the current I_{Die} at 100 V, afterwards increase the voltage until the dielectric breaks. Record the breakdown voltage $V_{break(ac)}$. The measurement of the breakdown voltage is a destructive test.

The mini sensor, with the same pitch as the full size sensor, will be used to perform IV and CV scans, and, if needed, any other measurement that can be done on the full size sensor.

A summary of the measurements that will be performed and the acceptance criteria is shown in Table 7.1.

Measurements	Acceptance criteria
CV	$100 \text{ V} < V_{\text{dep}} < 250 \text{ V}$ depends on resistivity
IV	Breakdown voltage $> 500 \text{ V}$, Total leakage current $\leq 100 \text{ nA/cm}^2$ @ 500 V at 21°C
C_{int}	C_{int} in 10% from the parametrization
R_{int}	$R_{\text{int}} > 1 \text{ G}\Omega$
R_{poly} $R_{\text{p+}}$ R_{al}	$R_{\text{poly}} = 1.5 \pm 0.5 \text{ M}\Omega$; less than 1% may be outside the range $R_{\text{p+}} < 200 \text{ k}\Omega/\text{cm}$ $R_{\text{al}} \leq 18 \text{ m}\Omega/\text{square}$
C_{ac} $V_{\text{break of } C_{\text{ac}}}$ I_{Die}	$C_{\text{ac}} > 1.2 \text{ pF/cm}$ per μm of implanted strip width. $V_{\text{break(ac)}} > 120\text{V}$ $I_{\text{Die}} < 1 \text{ nA}$ at 120 V

Table 7.1: A summary of the measurements performed and the acceptance criteria.

We estimate a total of about 1 hour for a complete characterization of all parameters of the structures on one half-moon.

7.2 Test Set-up Description for Test-structures

For the standard tests the half-moon is connected via a probe card to the switching matrix, for the irradiation test a special support is designed on which the sensor is glued and wire bonded.

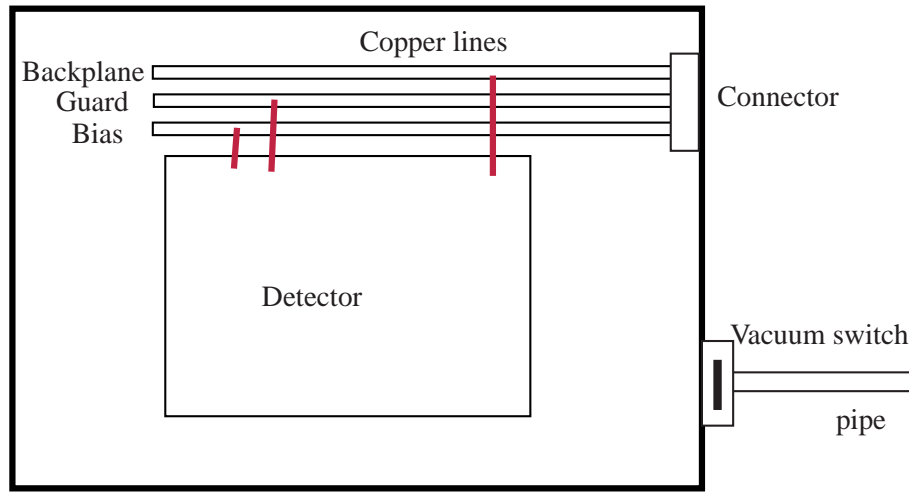
The switching matrix is connected to a Source Measure Unit (High Voltage) e.g. Keithley 237 (or Power Supply plus Ohmmeter, computer controlled) and a Precision C Meter (1 MHz) e.g. HP 4285A. The source meter will be set with a hardware compliance of $50 \mu\text{A}$. The matrix switches between the two measurement units and the contacts on the test-structure. Thus the measurements can be done sequentially without any manual intervention.

7.3 Current Stability Test (I-t Longtime Measurement)

Sometimes it may happen, due to process problems, that the sensor current is not stable in time. Detection of such a problem requires that a sensor is kept at high voltage for several hours. In order to perform this test we will build a dedicated set-up for monitoring sensor current over a period of 24 hours at 500 V . We have foreseen a scenario in which the I-t test could be done on all real sensors, if that should be necessary. A special I-t test station has been designed that allows us to make this test on a large number of sensors at the same time.

The sensors are connected by wire bonds to the mounting support. To allow the monitoring of several sensors in parallel, up to 10 sensors will be connected through a switching matrix to a source measure unit. All sensors are held by vacuum.

The acceptance criteria will be a stable leakage currents over a period of ≥ 20 hours, never exceeding a total leakage current of $100 \text{ nA/cm}^2 @ 500 \text{ V}$ at 21°C .



Vacuum jig (rubber on top)

Light tight Box for 10 detectors

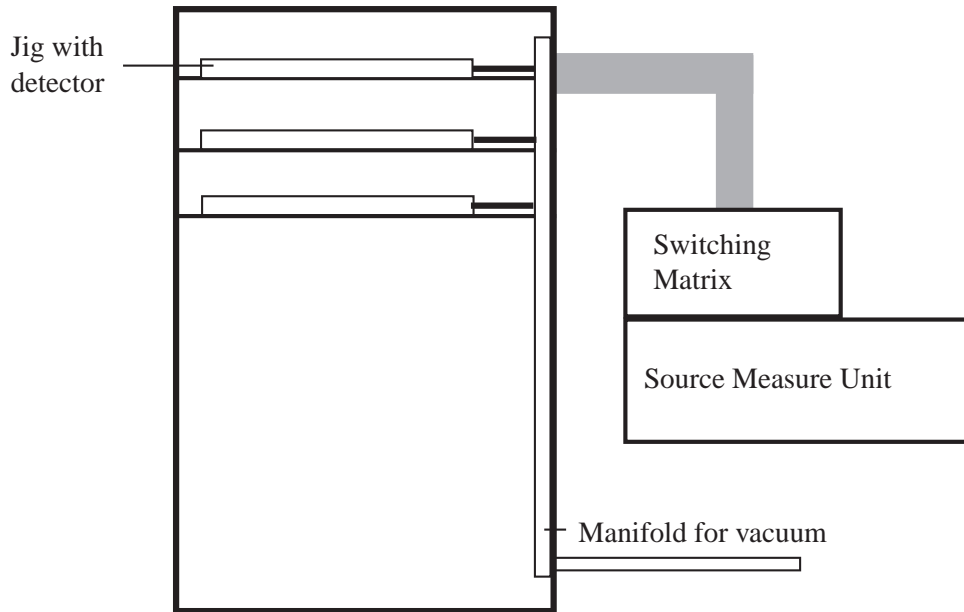


Figure 7.1: Set-up for longtime I_t -measurements

Assuming 200 working days per year and 2.5 years of testing, one I-t setup can test 10000 sensors. In a scenario where we need to test all 30000 sensors, we will need, with some safety margin, 4 I-t set-up.

8. Irradiation Tests performed by Irradiation Qualification Centers

After irradiation there is a degradation of sensor characteristics and performance. R&D studies have shown that radiation hardness can be improved by adequate design, substrate and processing. We will provide to producers a design and indications for substrate and processing that should ensure an operability of detectors for, at least, ten years in the LHC environment. Nevertheless, we want to qualify the radiation hardness of production lines and to keep under control the quality of the substrates used.

In 10 years of LHC running the first layers of the SST inner barrel will be subject to a fluence of 1.6×10^{14} 1 MeV equivalent neutrons per cm^2 and the first layer of the outer barrel will be subject to a fluence of 3.5×10^{13} 1 MeV equivalent neutrons per cm^2 . Sensors will be irradiated at the fluence expected for 10 years of LHC taking into account a safety factor of 1.5 due to uncertainties in the computed fluxes.

The Irradiation Qualification Centers (IQC) are responsible for the radiation hardness qualification of the sensors during the pre-series and the whole production. They receive and register sensors from the Quality Test Centers, perform tests before irradiation, irradiate sensors, perform tests after irradiation and insert results into the DB. The IQC certify the radiation hardness of sensors and, in case of non-conformity with the acceptance criteria, alert the Central Distribution Center.

Irradiation tests will be performed mainly on test structures, but also on few full-size sensors. During pre-series 20% of structures and 5% of full-size sensors will be irradiated and tested. If these tests will be satisfactory, during production those percentages will be decreased to 4% and 1% respectively.

There will be two IQC, Louvain and Karlsruhe, which will use the irradiation facility located in Louvain. In addition, the possible use of the irradiation facility in Karlsruhe is being investigated.

8.1 Irradiation facility set-up and procedures for Irradiation

8.1.1. Description of the set-up

The cyclotron of Louvain accelerates proton (up to 90 MeV) and deuteron (up to 50 MeV) beams. They are used in dedicated experimental areas to produce secondary neutron beams.

A 50 MeV – 10 μA deuteron beam produces a high-flux wide-band spectrum of neutrons via the (d,n) reaction on a thick ^9Be target (Figure 8.1). Sheets of polyethylene, cadmium and lead (20 mm thick total) are placed immediately downstream the target and filter out the low-energy neutrons. They also decrease the

relative charged particle contamination to about $3 \cdot 10^{-4}$. The ratio gamma/neutron is about 5 %. (Figure 8.2).

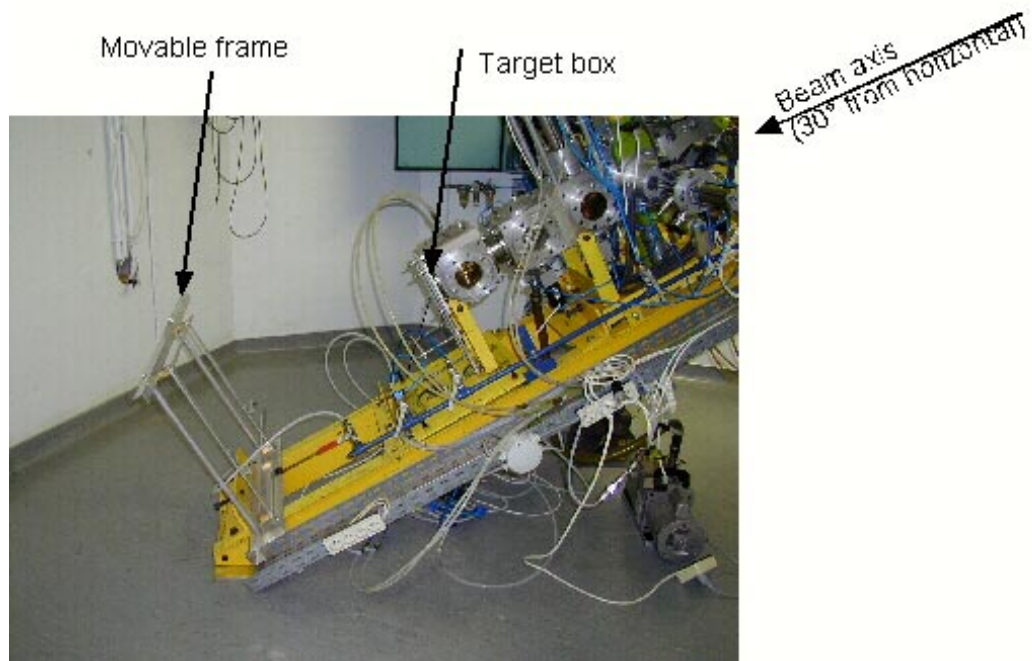


Figure 8.1: High flux neutron irradiation beam line

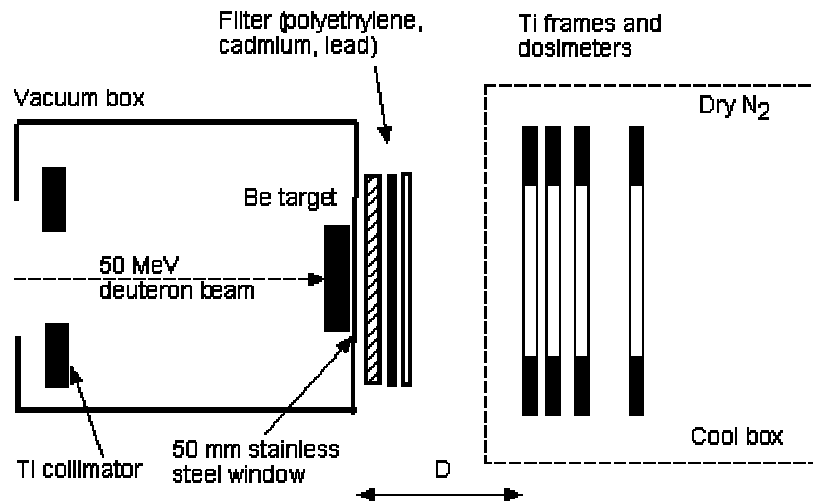


Figure 8.2: Sketch of the neutron production setup.

The average neutron energy is 20 MeV and the neutron yield is about $6.7 \cdot 10^{11} \text{ n } \mu\text{C}^{-1} \text{ sr}^{-1}$. The absolute neutron flux and the energy spectrum have been estimated from the activation of several metallic foils through reactions of known cross-sections

(Figure 8.3). The absolute dose rate has been measured using a calibrated ionization chamber mounted according to the ICRU-45 protocol.

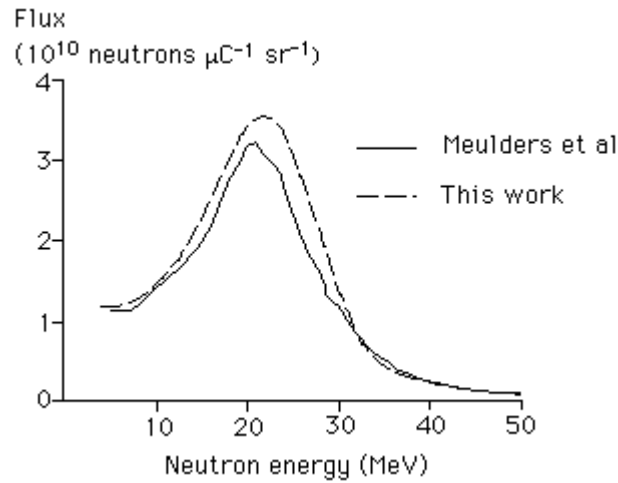


Figure 8.3: The neutron energy spectrum (dashed curve) deduced after unfolding the activation measurements. The continuous line show previous data obtained by Meulders et al. (1975).

Samples can be brought very near to the target: at this position the beam spot has a diameter of 20 mm. The samples to be irradiated are fixed on thin G10 “forks” at the center of a Titanium frame. This minimizes the activation of materials in the vicinity of the neutron beam. Several Ti frames are then stacked in a cooled box, itself attached to a movable structure located at a variable distance from the neutron production target. The integration of the electric charge accumulated on the target monitors the fluence. In addition, RPL and Alanine dosimeters are attached in front and behind the stack. (Figure 8.4).

The distance of the stack to the target depends on the transverse size of the samples and is adjusted to reach a more or less uniform neutron flux. For small size samples (2 cm diameter) the dose rate at 9 cm from the production target is such that a fluence equivalent to 10 years of LHC operation can be reached in 23 minutes at the highest intensity of the deuteron beam.

As previously mentioned, we are investigating the use of the proton irradiation facility at Karlsruhe (FZK). The isochronous cyclotron at FZK is able to produce intense (up to 30 μA) extracted proton beam at 26 MeV. It is equipped with a raster scanning system, which allows uniform irradiation of large surfaces (15*15 cm²), therefore it can be used for irradiation of both full sensors and test structures, several of them being put in a stack. It is foreseen that this facility, as a complementary to the Louvain one, will serve mostly for irradiating full sensors to study simultaneously surface and bulk damage effects. The access to the facility is relatively easy and flexible, beamtime can be reserved on a short notice. A cool-box (down to -10 C with dry air ventilation) is available, biasing system could be provided if necessary.

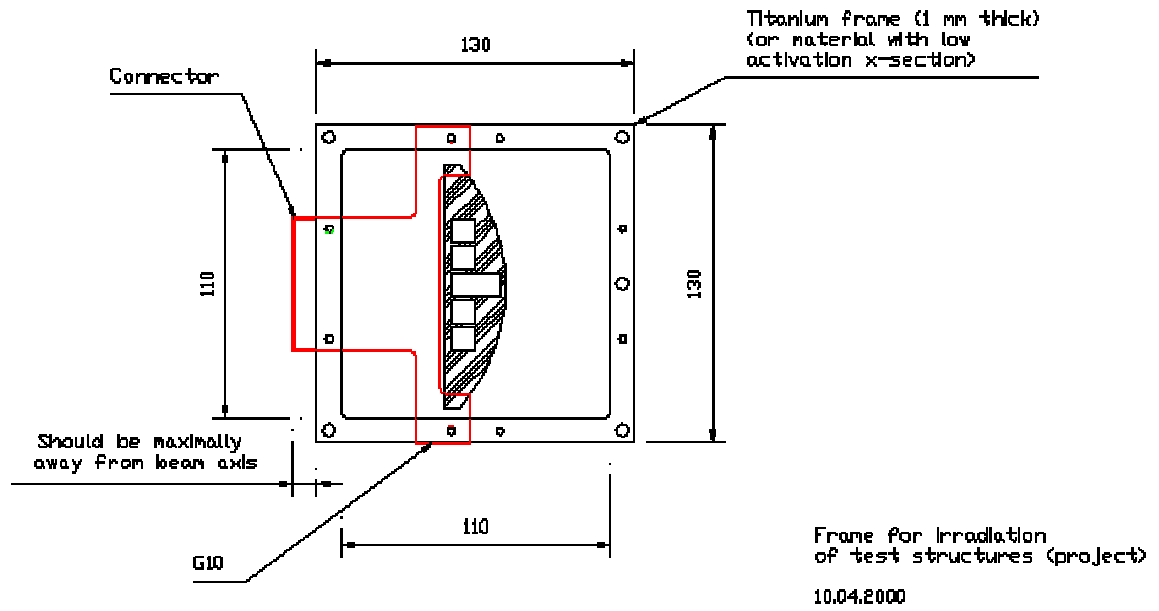


Figure 8.4: Titanium frame and G10 support “fork” to irradiate silicon test structures.

8.1.2. Procedures for irradiations

- The access to the irradiation facilities of Louvain is submitted to the public presentation of a proposal in front of the Program Advisory Committee (PAC). The PAC meets twice a year. A planning meeting is held every 3 months to share the available accelerator time among the accepted projects according to the demands (<http://www.cyc.ucl.ac.be>).
- The physical access to the irradiation area is restricted to personnel having a valid medical certificate (valid 6 months) certifying that they are allowed to work in a controlled radiation area.
- Physicists have to bring the dosimeters (RPL and alanine) needed to evaluate the doses given to their equipment.

8.2 Testing procedures before and after irradiation and acceptance criteria

Tests are performed on full-size sensors (IV, CV, C_{int}) and on dedicated structures (CV on diodes; C_{int} , R_{int} , and R_{poly}), both before and after the irradiation. After irradiation all devices undergo an annealing procedure of 80 minutes at 60 °C. From the point of view of depletion voltage, that procedure is roughly equivalent to 10-15 days of annealing at room temperature (the duration of “beneficial” annealing). Except for that period, irradiated devices are stored at low temperature (-10 °C). The measurements will be performed at low temperature by means of a thermal chuck.

Except for the use of this chuck, the procedures for tests are the same described in the two previous chapters:

- Tests on structures: CV on diodes, C_{int} , R_{int} , R_{poly} ,
 - CV on diodes: see par 7.1. After irradiation we check for $V_{dep} < 250$ V, in order to ensure an adequate over-depletion and an operating voltage < 500 V.
 - C_{int} : see par. 7.1. After irradiation the inter-strip capacitance should remain unchanged and, anyway, the acceptance criteria is set on the total strip capacitance: $C_{tot} < 1.2$ pF/cm.
 - R_{int} : see par. 7.1. After irradiation the inter-strip resistance is hardly degraded; the acceptance value is $R_{int} > 20$ M Ω .
 - R_{poly} : see par. 7.1. Polysilicon resistors should not be affected by irradiation. The acceptance value is the same as before irradiation: $R_{poly} = 1.5 \pm 0.5$ M Ω .

- Tests on full-size sensors: IV, CV, C_{int} .
 - IV: see par. 6.2. After irradiation the current increase (ΔI) is described by the α parameter: $\Delta I/V = \alpha\phi$ (where V is the active volume and ϕ the fluence). The value expected with our annealing procedure, referred to a temperature of 21 °C, is: $\alpha \sim (3.5\div 4.5)\times 10^{-17}$ A/cm. A value of $V_{break} > 500$ V is required also after irradiation.
 - CV: see par. 6.2. Check of V_{dep} on full-size sensors and measure the back-plane capacitance. After irradiation C_{back} should remain unchanged.
 - C_{int} : see par. 7.1. After irradiation the inter-strip capacitance should remain unchanged and, anyway, the acceptance criteria is set on the total strip capacitance: $C_{tot} < 1.2$ pF/cm.

The following table 8.1 summarises the electrical tests of the sensors and the acceptance criteria after irradiation.

Tests on sensors made by the Irradiation Qualification Centers		
	Test	Acceptance criteria
Structures	CV on diodes	$V_{dep} < 250$ V
	C_{int}	$C_{tot} < 1.2$ pF/cm
	R_{int}	> 20 M Ω
	R_{poly}	1.5 ± 0.5 M Ω
Full-size	IV	$\alpha \sim 3.5-4.5\times 10^{-17}$ A/cm $V_{break} > 500$ V
	CV	$V_{dep} < 300$; $C_{back} < \text{as before irradiation} + 10\%$
	C_{int}	$C_{tot} < 1.2$ pF/cm

8.3 Test set-up description

The set-up for IQC is:

- Probe-station with single needles or dedicated probe-card.
- Thermal chuck for 6" sensors
- Voltage supply (600 V, 10 mA or better)
- IV meter
- CV meter
- Switching device
- Freezer (-10 °C)
- Oven

All instruments are computer controlled.

9. Handling, packaging and shipping

The large number of tests to be performed as well as the fact that the sensor qualification sites are geographically distributed will imply considerable handling and movement of the sensors and test structures. The handling, packaging and shipping are therefore important steps in the overall sensor production and must have well defined and safe guidelines.

9.1 Handling and storage

There are a number of options for how to safely handle the sensors. The general rule is to avoid direct human contact with the sensor and to have the sensor surfaces come in contact only with clean, and whenever possible, soft surfaces so as to avoid scratches, stresses and the pick up of undesirable substances. We will have to investigate with the sensor producers to see in what sort of packaging the sensors will be delivered. We will request something that is both safe and provides easy access to the sensor. It would be desirable to have the sensor container that is delivered become the container that can hold and protect the sensor for all the testing steps, right up until the mounting on the module. Unfortunately, the need to contact the back plane for biasing the sensor makes this scheme unlikely. Therefore it is likely that the sensor will have to be transferred to a different container at the quality test centers (QTC). Nevertheless, it is planned that the amount of subsequent handling of the sensors be minimized in order to avoid damage to the device. The following general guidelines will be formalized in order to achieve this:

- If possible, sensors will go into unique boxes/trays and remain there for all testing procedures. After transfer and between tests, boxes should be closed (or trays should go into enclosed protected storage areas).
- Pick-up tools used to transfer sensors should be either vacuum pens with soft, clean anti-static suction pads or soft plastic fork-like manipulators for lifting up sensor from the back side. Manipulation should not be by hand, even when gloves are used for protection. Care should be taken such that sensor can not be dropped long distances onto hard surfaces (e.g. if vacuum is lost to vacuum pen).
- Handling of sensors should only take place in a clean room environment of class 100.000 or better. Masks and gloves should be worn by workers handling or testing sensors.
- Storage of sensors should take place in a similarly clean environment. In addition the atmosphere should be dry (less than 40% RH), at approximately 21° C, and of inert gas (argon or nitrogen) where possible. Note that a large inert gas storage volume may require special safety precautions in adjacent work areas such as oxygen meters.

9.2 Packaging

The box or tray used for the testing steps at the QTC can be used to contain the sensor for shipping if it holds the sensor securely and can avoid damaging forces from being applied to the sensor in the case of shocks from transport (dropping). It remains to be seen if a box/tray design can achieve this requirement. If not, then the sensor must be transferred to an appropriate shipping container. The packaging of the sensor must meet the following criteria:

- Anti-static surfaces (this needs further investigation as to what materials are OK)
- Shock-proof (sensor should survive dropping of shipping container from 2 meters onto floor)
- Simple (inexpensive) and easy to open
- Nearly hermetic closure of containers (e.g. plastic boxes with lids taped shut)
- Can allow multiple sensor storage in single volume if safety criteria are met
- Packing of sensor containers should use larger volume cardboard box with adequate stuffing materials to absorb shocks and collision damage
- No packaging should change during production

9.3 Shipping

The packaging mentioned above must also meet the shipping criteria of the commercial transporter if such is used. The original shipping packaging (from the manufacturer) may be reused for this purpose if it meets all requirements. In addition, the following issues should be addressed to assure safe transport:

- Safe handling of sensor transport boxes should be assured. Boxes should be marked as fragile and proper assurances of careful handling by commercial transporter should be made if such transport is used.
- If private transport of collaboration institutes is used, similar assurances of handling should be made with written guidelines furnished with the transport boxes. Clear marking of contents, sender and destination should appear on boxes.
- Safe, trusted private transport by members of the project is favored over commercial transport when possible.
- Goods should be insured when risk of damage or loss is possible. This will not recover the sensors but would allow financial compensation in case of accident. Guidelines for this issue will need to be defined.
- In the case of non-conformity of sensors, it may be that sensors will need shipment back to the manufacturer. The handling of this case will need an agreement of procedure with the sender, with the manufacturer, and with the Control and Distribution Center.
- The shipment of test structures should follow the same procedures as for the sensors.

10. Requirements for critical and risky activities

There are a number of activities that are more critical or risk-prone that may require special procedures or particular attention. Listed below are those we feel are in this category with a short explanation.

- Transport - especially commercial transport
- Packaging - if this requires direct handling of sensor
- Handling - moving sensor to and from test equipment
- Probing - both with probe cards and micropositioner needles
- Bonding and bond removal - if bonding is used for the long term leakage current test

The actions to take in the case of transport, packaging and handling were mentioned in the previous section. For the case of probing, if a probe card is used, it should be equipped with edge sensors which detect needle contact. These sensors should be used to prevent overdriving the probe card into the sensor. In the case of micropositioner needles, special care must be taken such that needle touchdown can be viewed directly and good control of needle movement is required. In addition, design of the inspections stations, test stations and probing equipment must take into account safety of the sensors. This implies protection of the silicon surfaces against any accidental contact. In the case that sensors must be bonded for testing, the usual precautions for bonding must be taken. This implies that the bonding machine has been recently tested with a similar substrate (aluminum on silicon) and the machines parameters are optimized and the bond quality checked. In the case of bond removal, care must be taken to avoid damage during this procedure. Special protective devices may be advisable for this manual step.

In addition, the following safety measures should be taken to avoid accidental damage to sensors and test structures:

- Appropriate cleaning of all surfaces coming in contact with sensors – this includes pick-up tools, carrier box or tray, test jigs, vacuum chucks, probe needles.
- Installation of equipment to prevent any static discharge to sensors – this includes anti-static mats, wristbands and storage boxes; any surfaces which are likely to come in contact with the sensors must be appropriately grounded or isolated. One should avoid use of static inducing equipment (e.g. synthetic chair covers).
- Any possibility of deposition of chemicals onto the sensor surface should be prevented. This implies that the areas where sensors are openly exposed to the atmosphere should not be in proximity to glue curing, soldering or other similar activities that release chemical vapors or expelled substances.
- Electrical sensor test equipment must have appropriate over-current and over-voltage protection, preferably in hardware.
- Sensors under high voltage testing must be assured of a dark environment since light leaks could lead to loss of depletion and unexpected large voltage differences in sensitive areas of the sensor.

11. Non-Conformities classification

We intend to classify as non conform a test result of a sensors or a test structure that fails to pass our own tests according to the established acceptance criteria. There could be three different categories of non-conformity:

1. Non Conformity identified during Sensor qualification (NCD)
2. Non Conformity identified during Process qualification (NCP).
3. Non Conformity identified during Irradiation qualification (NCI).

It will be very useful to keep track of eventual non conformities along the various phases of testing. In order to achieve this, we simply have assigned to all the possible causes of failure an identification number, which will be stored into the DB and annotated into the checklists as well. At that point, we will have a powerful tool to track and analyze the possible sources of non conformities and promptly react giving feedback to the company to take care of the problem. We would like to point out again that the companies will deliver only fully tested sensors and thus we will not expect major problems during production.

The following tables summarize a classification for non-conformities on sensors identified by the Quality Test Centers (Tab. 11.1), the Process Qualification Centers (Tab. 11.2) and the Irradiation Qualification Centers (Tab. 11.3).

NCD1	Optical inspection failed
NCD2	Total current exceeding
NCD3	Breakdown voltage lower
NCD4	Depletion voltage out of range
NCD5	Percentage leaky strip exceeding
NCD6	Percentage polyresistors out of range exceeding
NCD7	Percentage coupling capa. out of range exceeding
NCD8	Percentage pin-holes exceeding
NCD9	Percentage of shorted strips exceeding
NCD10	Percentage total strips defecting exceeding

Table 11.1: Type of non-conformities on sensors detected by QTC

NCP1	Total sensor current unstable in time
NCP2	Depletion voltage on TS out of range
NCP3	Total current on TS out of range
NCP4	Breakdown voltage on TS out of range
NCP5	Inter-strip capacitance on TS out of range
NCP6	Inter-strip resistance on TS out of range
NCP7	Polyresistance on TS out of range
NCP8	Aluminum resistivity on TS out of range
NCP9	Implant resistance on TS out of range
NCP10	Coupling capac. Value on TS out of range
NCP11	Coupling capac. Breakd. on TS out of range

Table 11.2: Type of non-conformities detected by PQC

NCI1	Depletion Voltage on sensor after irradiation, out of range
NCI2	Total current on sensor after irradiation, exceeding
NCI3	Breakdown voltage on sensor after irradiation, lower
NCI4	Strip capacitance on sensor after irradiation, out of range
NCI5	Depletion voltage on TS after irradiation, out of range
NCI6	Strip capacitance on TS after irradiation, out of range
NCI7	Inter-strip resistance on TS after irradiation, out of range
NCI8	Polyresistance on TS after irradiation, out of range

Table 11.3: Type of non-conformities detected by the IQC

It is planned that the contract and the delivery of the sensors will proceed in two different phases:

- The first is the pre-series (5% of the total) in which 100% of sensors will be tested by us.
- The second phase is the massive production, in which (based on the previous experience) we will test sensors in sample.

The main aim of full testing during the pre-series is to qualify the production line of each company and, eventually, to identify potential non conformities not detected by the company's quality control. This first phase will provide us a very valuable information concerning the reliability of the manufacturers. After this step is completed, there will be an evaluation of the different sources (if any) of problems. In case some non conformities would be identified, their distribution, their eventual correlation with respect to the time of processing and even to the ingot number, will be a very useful information to provide to the company. Based on these information we will request an appropriate recovery action. In the very unlikely case of severe problems we reserve the right to cancel the entire contract with that company.

Once a manufacturer has successfully passed the first phase, it will be responsible to make sure that no changes will occur during the subsequent massive production. The experience accumulated by the test centers during this first stage will be used to identify potential problems during the production. During this second phase sensors and structures will be tested on a sample basis to monitor the stability of the process. Identification of NCP and NCI cause a warning for further investigation on different test structure (belonging to the same batch) and on the sensor belonging to the same wafer and may result in rejection of sensors. Of course, NCD causes the rejection of the sensor but also a further investigation on other sensors and structures belonging to the same batch.

12.1 Check list by Quality Test Centers

Wafer ID:		Name (tester):			
Date:	Temperature:	Humidity:			
				OK?	NCDid
Global test					
Optical inspection					1
Size					
Cut lines					
Coloring					
Observed defect					
I @ 500 V	Value:				2
V _{break}	Value:				3
V _{dep}	Value:				4
Strip by strip test					
	Mean value	RMS	# out of spec.		
I _{strip} @ 500 V					5
Poly-resistors					6
Coupling capacitance					7
Pinholes					8
Shorted strips					9
Total defected strips					10
<i>Everything OK?</i>					
<i>Database written?</i>					
<i>Remarks:</i>					

12.2 Check list by process qualification centers

<i>Wafer ID:</i>		<i>Name (tester):</i>	
<i>Date:</i>	<i>Temperature:</i>	<i>Humidity:</i>	
	Value	OK?	NCPid
<i>Full size</i>			
Max current in 24 hours (@ 500V)			1
<i>Test structures</i>			
Depletion Voltage			2
IV curve: Total current @500 V			3
IV curve: Total current @500 V			3
Bias current @500 V			3
Guard current @500V			3
Breakdown voltage			4
Inter-strip Capacitance			5
Inter-strip Resistance			6
Poly-silicon Resistors			7
Metal layer resistance			8
Sheet resistance			9
Coupling Capacitance			10
Coupling Dielectricum Breakdown Voltage			11
<i>Everything OK?</i>			
<i>Database written?</i>			
<i>Remarks:</i>			

12.4 Check list by irradiation qualification centers

<i>Wafer ID:</i>		<i>Name (tester):</i>		
Irradiation				
<i>Date:</i>		<i>Fluence:</i>		<i>Annealing done?:</i>
Test				
<i>Date:</i>		<i>Temperature:</i>		<i>Humidity:</i>
	Before irradiation	After irradiation	OK?	NCId
<i>Full-size</i>				
V_{dep}				1
I @ 500 V		$\alpha =$		2
V_{break}				3
C_{back}				
C_{int}				
C_{strip}				4
Structures				
V_{dep} (diode 1)				5
V_{dep} (diode 2)				5
V_{dep} (diode 3)				5
C_{int} (structure 1)				6
C_{int} (structure 2)				6
C_{int} (structure 3)				6
R_{int} (structure 1)				7
R_{int} (structure 2)				7
R_{int} (structure 3)				7
R_{poly} (structure 1)				8
R_{poly} (structure 2)				8
R_{poly} (structure 3)				8
<i>Everything OK?</i>				
<i>Database written?</i>				
<i>Remarks:</i>				

13. Database

Close to 30000 sensors will be produced during CMS tracker construction phase. All of them will be tested several times in several places. To store test results and keep track of conditions of shipping one can not use any longer paper-based carrier of information. Instead, an electronic database is a solution that is taken by the CMS tracker collaboration. Database itself is just a collection of related data, therefore in reality one uses a Data Base Management System (database plus tools) and applications which allows final user to communicate with a database and perform all needed operations like smart data insertion and retrieve, control functions and etc. There are a lot of Database Systems on the market. The final solution about concrete system to be used will be made in a nearest future. Here, we describe basic organization principles and features of a database system we want to have.

From a chain of quality tests described above one can conclude that a database will contain three main types of information: results of sensor tests, results of process quality control measurements and results of radiation hardness study. A detailed description of parameter sets that should be stored in the database has been done in previous sections. Let us consider, as an example, a sensor part of the database.

As it is mentioned above, sensors will be tested and shipped several times. All actions performed on sensors will be documented and stored in the database. Main reasons to store test results and shipping information are the following:

1. Find a source of any *problem* that may be discovered during the final quality control.
2. Couple two sensors (where it is needed) with *similar characteristics* assembling a module.
3. Set an *operational regime*, e.g. a bias voltage, of a module based on measured characteristics of sensor(s).

Sensors will be produced by selected Sensor Fabrication Centers where information about material properties (Chapter 3) and detailed test results (Chapter 4) will be collected. Each sensor will get a unique identification number (ID) which will contain following information: SFC ID, ingot ID, type, batch ID and serial number in a batch. In such a way we establish relations between individual sensor and a file(s) that collects common information of certain type (e.g., material properties of sensors produced from the same ingot) for a group of sensors.

Together with sensors, information collected at SFC will arrive to Control & Distribution Center where it will be checked and inserted in the database.

Then, sensors will be sent to the Quality Test Centers where they will be tested again (Chapter 6) and information will be stored in the database. The activity workflow at QTC is shown on Figure 13.1. Each box represents certain activity, result of which is inserted in the database. For example, '**R_poly**' means that a scan of polysilicon resistors will be performed and a vector of measured values will be stored in the database. '**I_strip**' means a measurement of a leakage current of each strip at fixed bias voltage (500V), the result of this test will be saved in the database as a vector of measured currents and a list of strips with a current higher than 500nA (Section 6.2). Vertical orientation of boxes on Figure 13.1 means that tests/measurement are performed consecutively while horizontal

orientation means that operations can be done in arbitrary order. Solid border boxes show obligatory tests and optional tests are represented by dashed-border boxes.

Finally, qualified sensors will be shipped to the Module Assembly Centers where they will be coupled with hybrids and put on carbon frames.

Since tests will be performed at different QTCs, PQC and IQCs, the database will be distributed among them with one central repository that will be very likely at CDC. At all centers tests will be performed by different instruments, which will be interfaced with database system to insert measurement information online directly in it. Instruments may be operated by not qualified in computing personal, hence, friendly graphical user interfaces, online documentation and operative expert support are mandatory. The information will be inserted and retrieved in parallel by many different users and applications. That is why fast parallel queries processing, access control and powerful administrative tools are important.

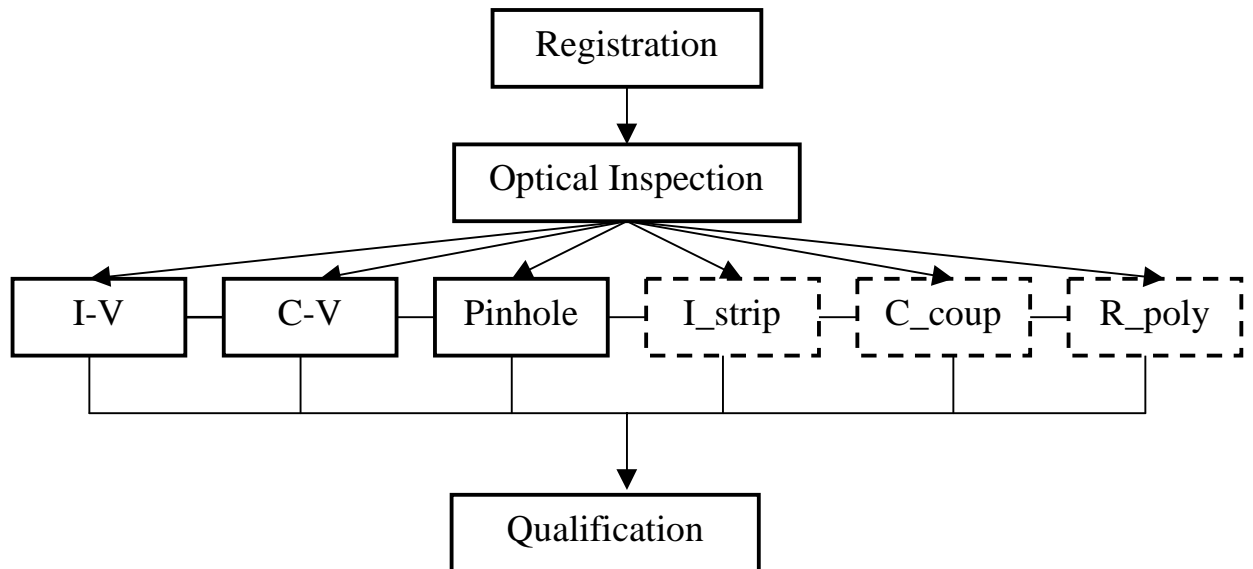


Figure 13.1: Activity workflow at QTC during production phase for a 5% sample of sensors.

To estimate disk space needed to store results of various tests and measurements discussed in this document, we make some assumptions. First, we consider only dependencies (e.g., C-V, I-V measurements or coupling capacitor measurements versus strip number) but not a single number measurement (e.g., depletion or breakdown voltage) or 3D views and pictures. Second, all dependencies are two dimensional and taken with fixed length of 1000 for each dimension (here we introduce some safety factor, as the maximum dimension will be equal to the maximum number of strips that is 768). Third, we conservatively assume that each measurement at Quality Centers can be repeated at least three times and we will keep all results in the database. An information that comes from SFC will have the largest size of 2 GB. QTCs, PQC and IQCs provide about 300 MB each. Thus, the total size of the database will be about 3GB.

14. Schedule

The schedule for the sensor testing centers is shown in fig 14.1. The preparation of the centers has already started and will be commissioned with the sensors of the Milestone 200 near the end of 2000. The QA of the sensors procured with the tender will start in the 3rd Quarter of 2001 with the final qualification of the 1st 5% of the production.

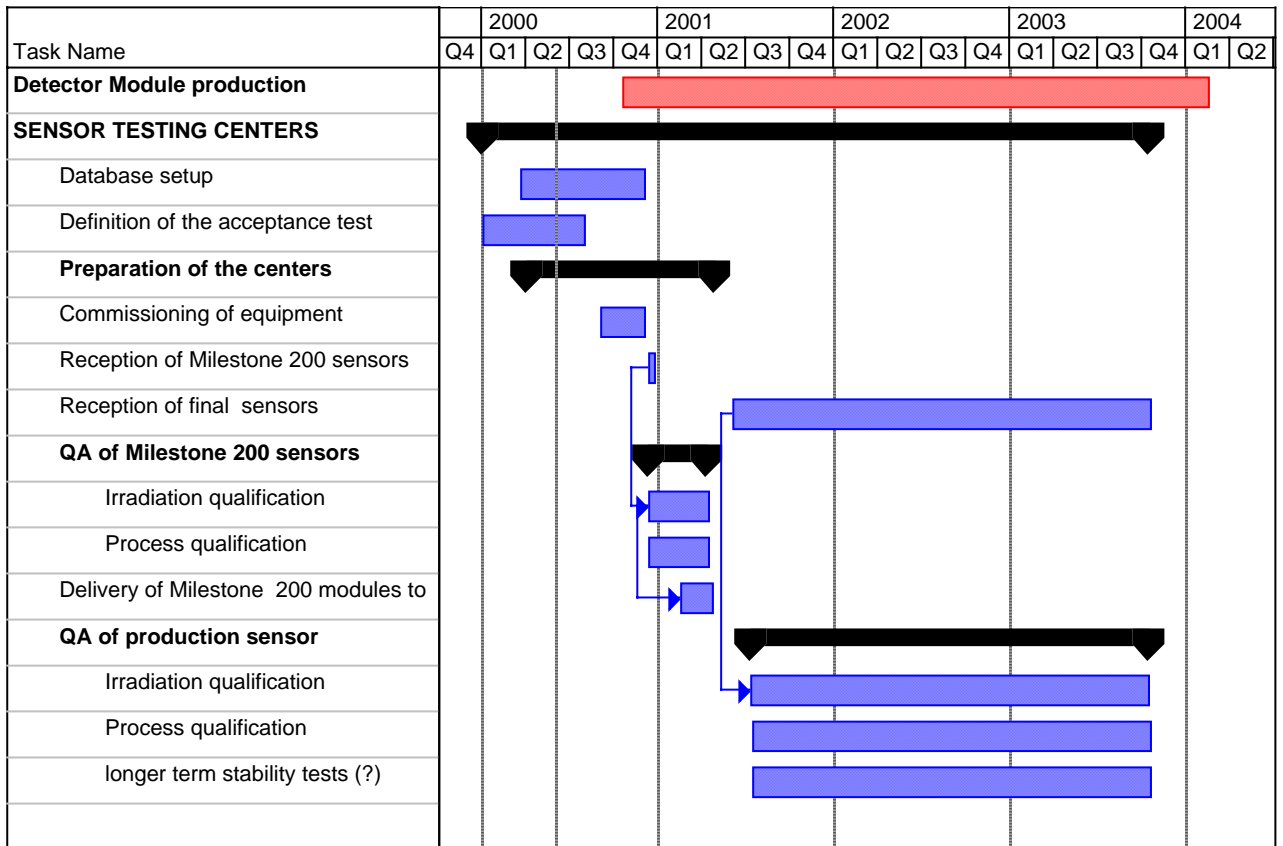


Figure 14.1. Schedule of the Sensor Testing Centers

