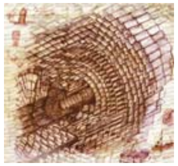
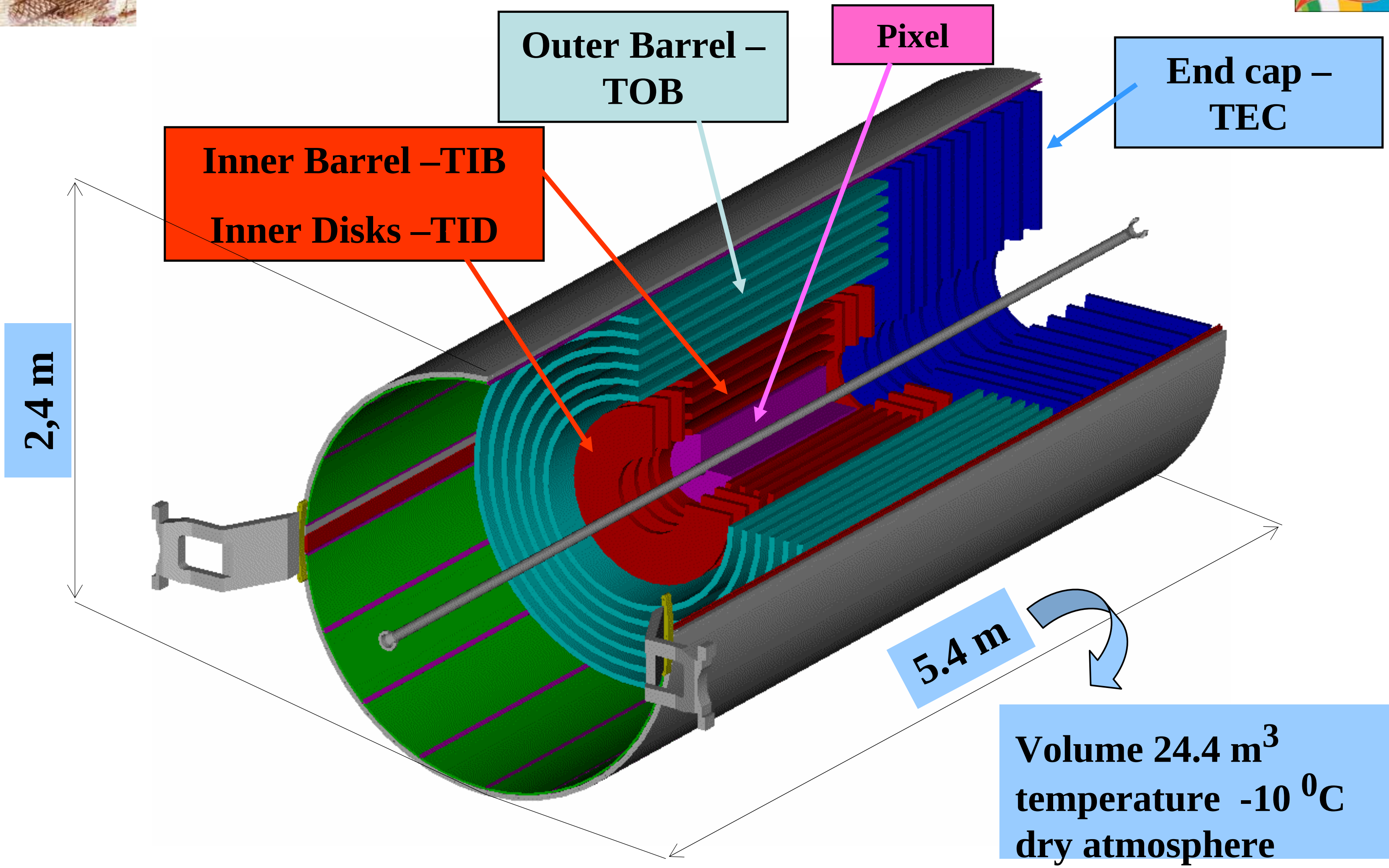
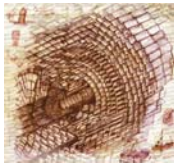


Experience with the Procurement of the Silicon Sensors for the Inner Tracker of CMS

Manfred Krammer
Institute for High Energy Physics
Austrian Academy of Sciences
Vienna, Austria

The CMS Inner Tracker





CMS Tracker: Some Numbers

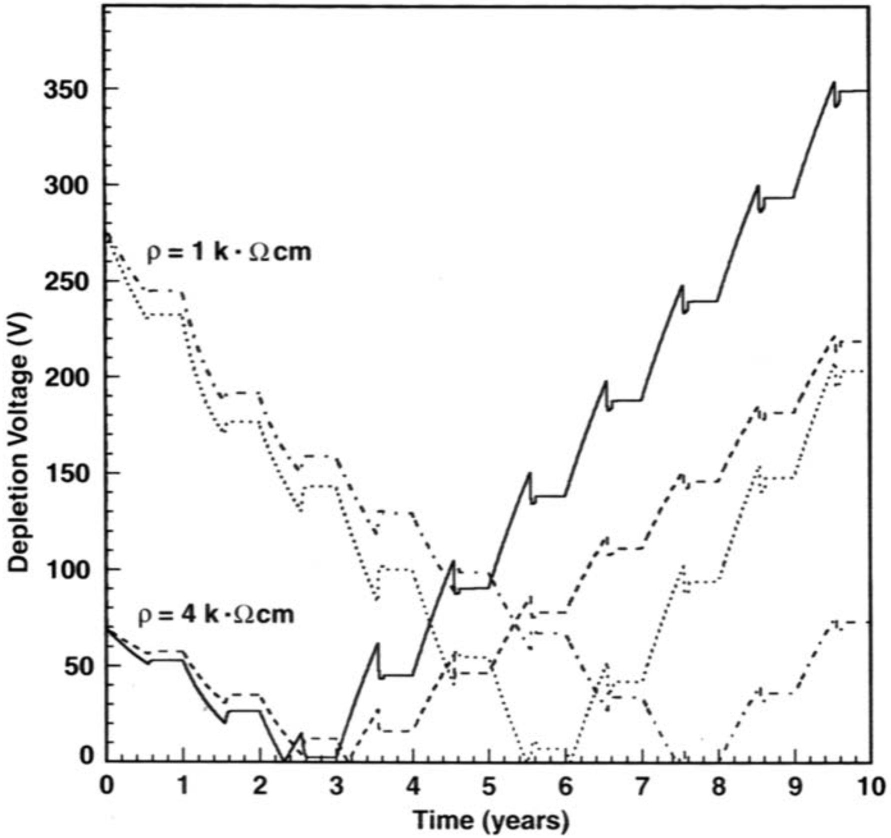
- **210 m^2 of silicon sensors**
- **24,244 single silicon sensors**
- **15,148 modules**
- **9,600,000 strips ≡ electronics channels**
- **75,000 APV chips**
- **25,000,000 Bonds**

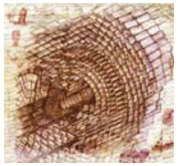
General Design Considerations

- Overall design compatible with mass production
- Sensor area optimised for 6 inch wafer
- Design simple and robust
- Only single sided sensors and single sided process
- Standard Silicon Material (n-type, no oxygenated)

Considerations concerning the Radiation Hardness

Simulated development of the depletion voltage for Silicon sensors with different resistivity:





Considerations concerning the Radiation Hardness cont’

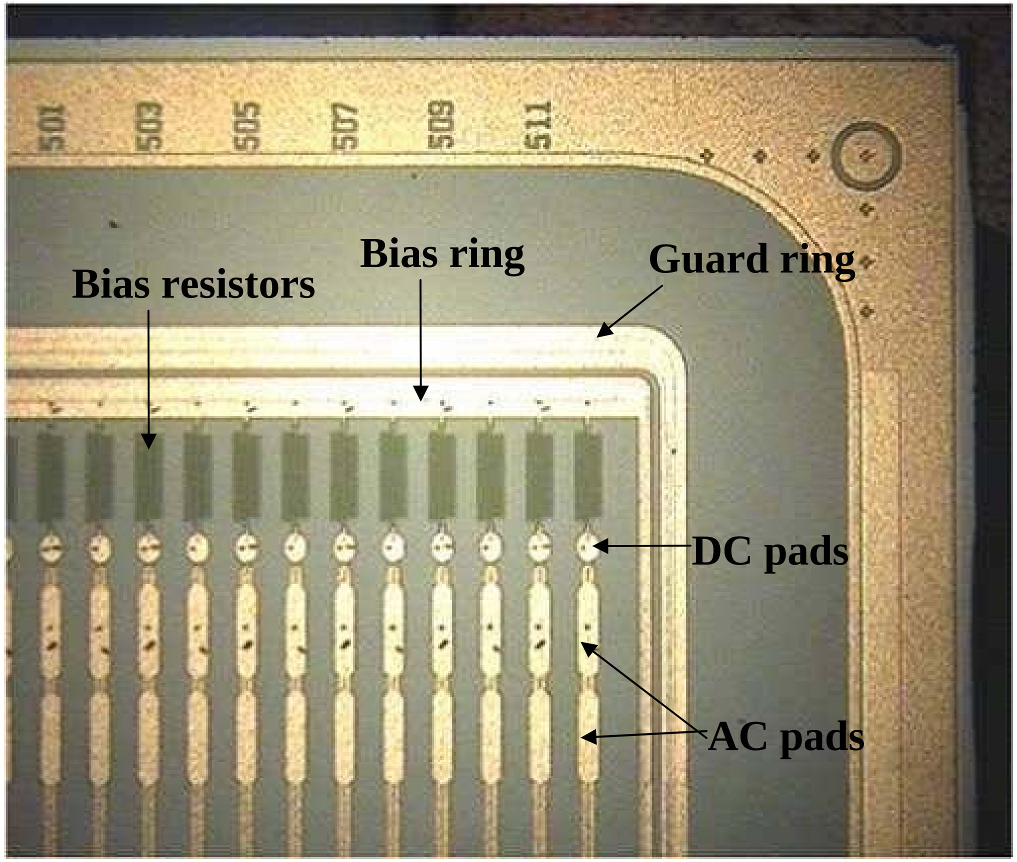
- **Tracker divided into two volumes :**

  Inner part: Fluence up to 1.6 10^{14} n(1 MeV equ.)/cm^2
  Low resistivity (ρ=1.25-3.25 kΩcm) and standard
  “thin” thickness (320 µm).
  →Inversion point later → Operating voltage at start-up and after 10 years about equal.

  Outer part: Fluence up to 3.5 10^{13} n(1 MeV equ.)/cm^2
  High resistivity (ρ=3.5-7.5 kΩcm) and
  “thick” silicon (500 µm).
  → larger signal allows larger detectors (2 sensor modules)

- **Use Silicon with lattice orientation <100>**

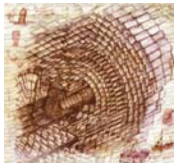
Details of the Sensor Design



Details of the Sensor Design

- p^+ strip implant, pitch from 80 µm to 205 µm , width/pitch=0.25
- Aluminum read-out strips, AC coupled, metal overhang 4 to 8 µm
- Polysilicon Resistors 1.5 MOhm
- p^+ bias ring
- one p^+ guard ring floating
- metal field plates extend beyond implantation of guard ring
- n^+ implant along edges
- distance implant region edge = 2x thickness+110 µm

+ identical set of test structures on every wafer
(equal for every sensor type and company)



15 different Designs needed

Type	IB1	IB2	W1	W1'	W2	W3	W4	W5A	W5B	W6A	W6B	W7A	W7B	OB1	OB2
thick ness	320	320	320	320	320	320	320	500	500	500	500	500	500	500	500
Num ber	1536	1188	288	288	864	880	1008	1440	1440	1008	1008	1440	1440	3360	7056

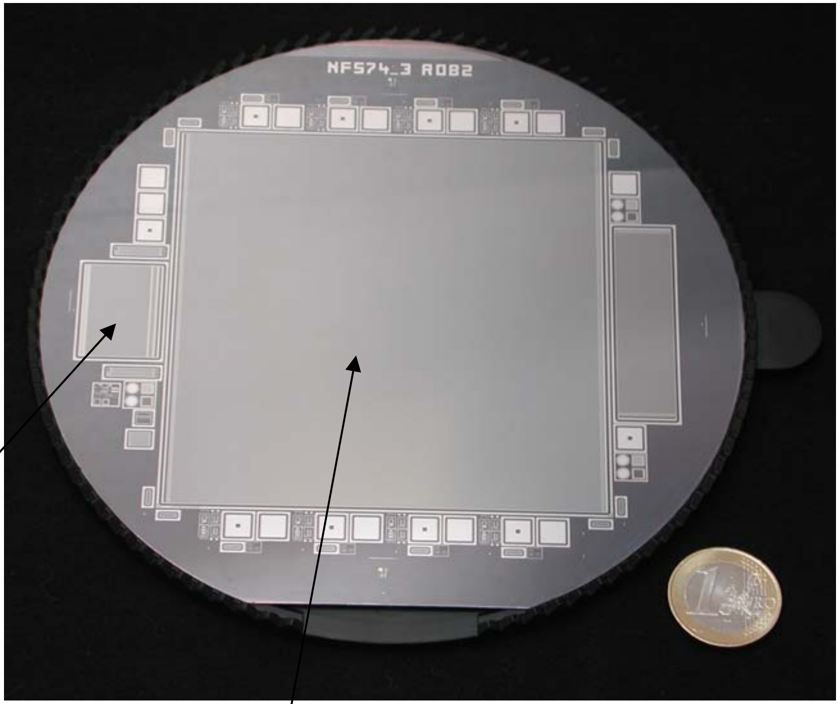
Inner Barrel ← **Wedge type sensors for the forward region** → **Outer barrel**

Total is 24244 single sensors!

Contract awarded to two Companies

Hamamatsu Photonics, Japan:
- All Inner tracker sensors,
- Large part of outer tracker sensors

STMicroelectronics, Italy:
- Part of the outer tracker sensors



Standard test structures

Sensor (OB2)

CMS Sensor Quality Assurance

1. **Detailed test program required from companies**

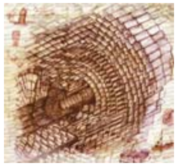
2. **Tests and measurements by the CMS sensor group:**

   Quality Tests on Sensors

   Process Control Tests on Test Structures

   Irradiation Tests (not discussed here)

All results stored in central data base!



Sensor Production and Qualification was completed May 2006

In total 28176 Sensor (25656 HPK, 2520 STM) have been delivered and qualified from the 2 suppliers in the period April 2002 to April 2006 (4 years !).

This number includes sensors used for prototypes and spares.

9198 sensors and **4526** test structures have been tested by the CMS test centers.

➔ Huge data sample available !

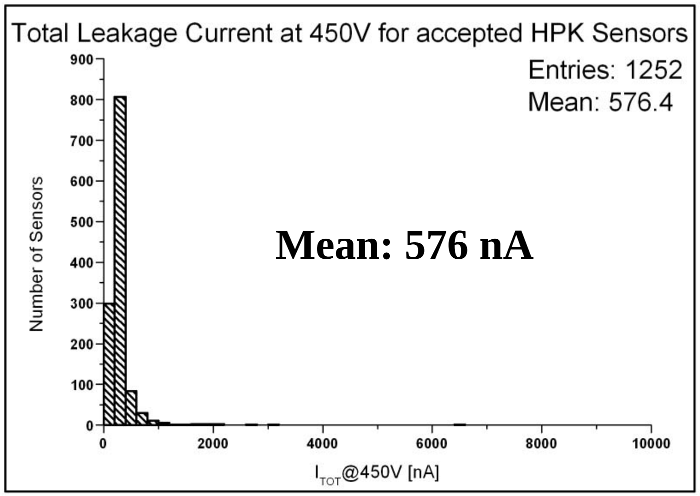
(99% of these Sensors are still ok end of May 2006)

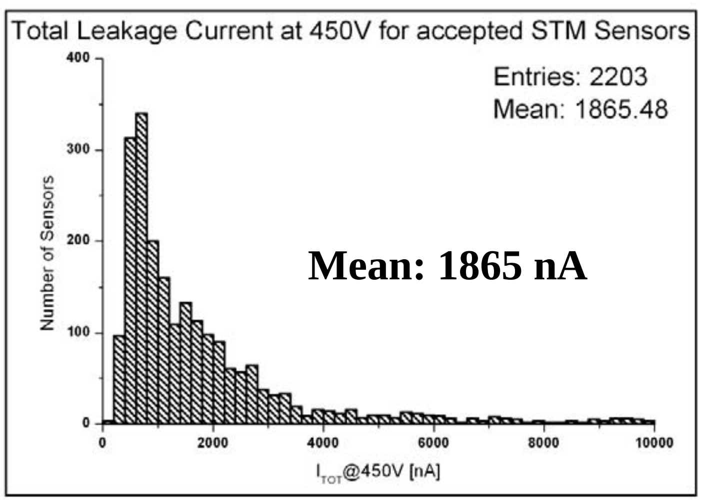
Results from the CMS Sensor Qualification (almost final)

Quality Tests - IV and CV Results

Leakage Current at 450V

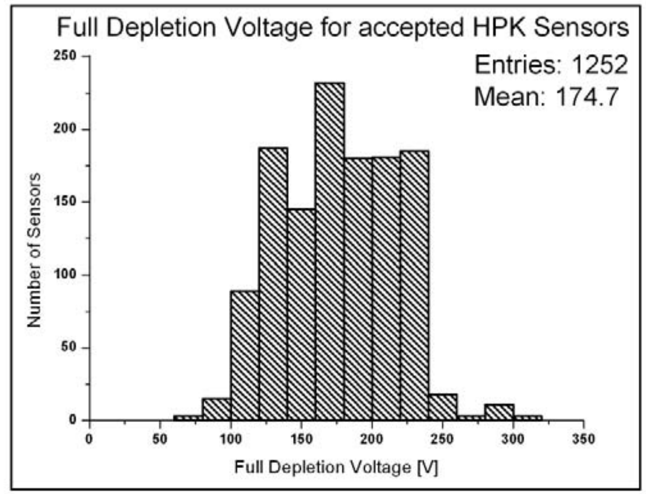
Specification: max 10µA

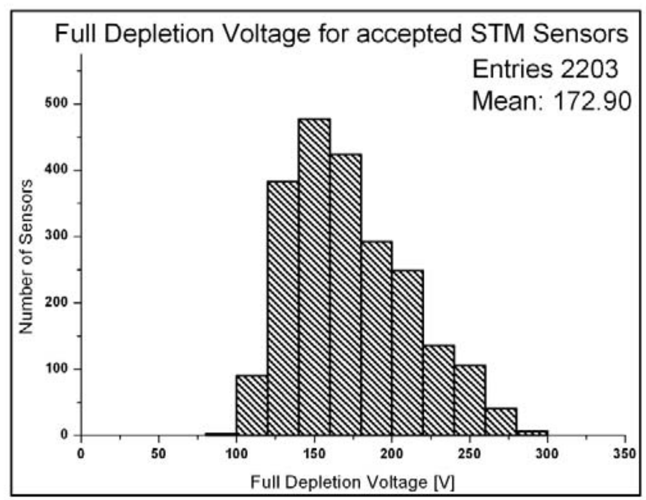




Full Depletion Voltage

Specification: 100 V – 300 V



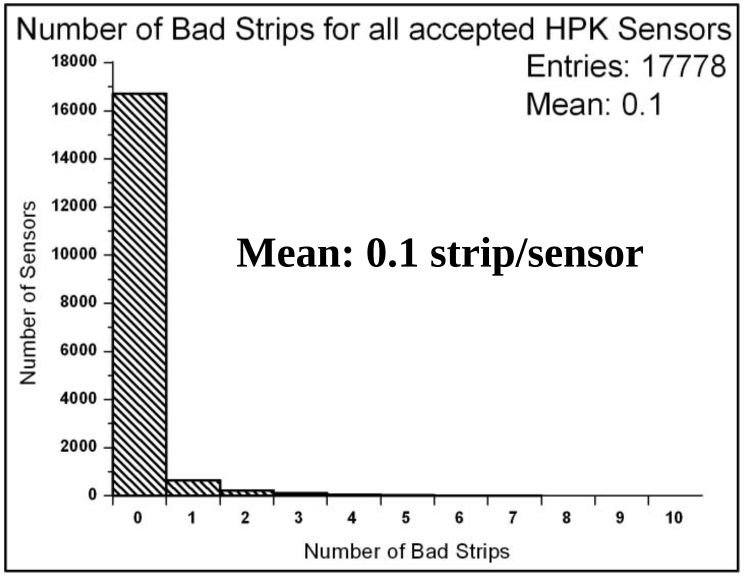


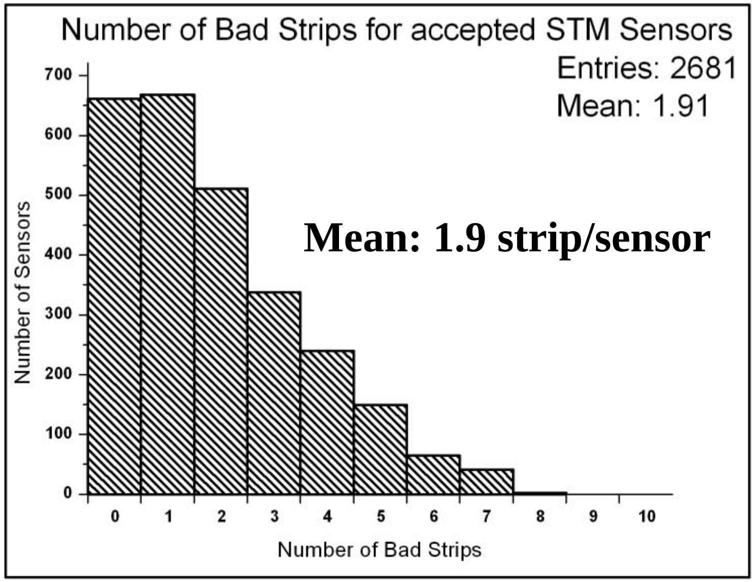
Quality Tests - Result from Strip Scan

Number of bad strips per sensor (pinhole, bad polyresistor, Al short, broken Al, open implant, leaky strip,….)

Number of Bad Strips

Specification: max 1% of 512/768 Channels



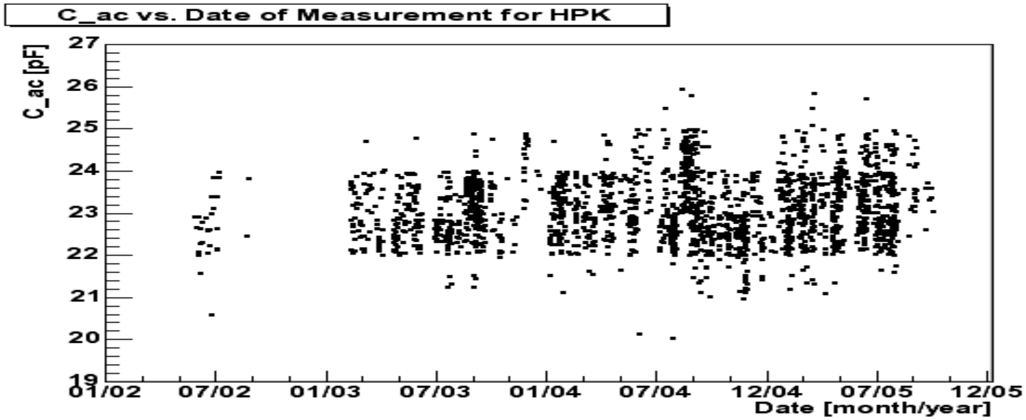


Percentage of bad strips: 0.018% 0.305%

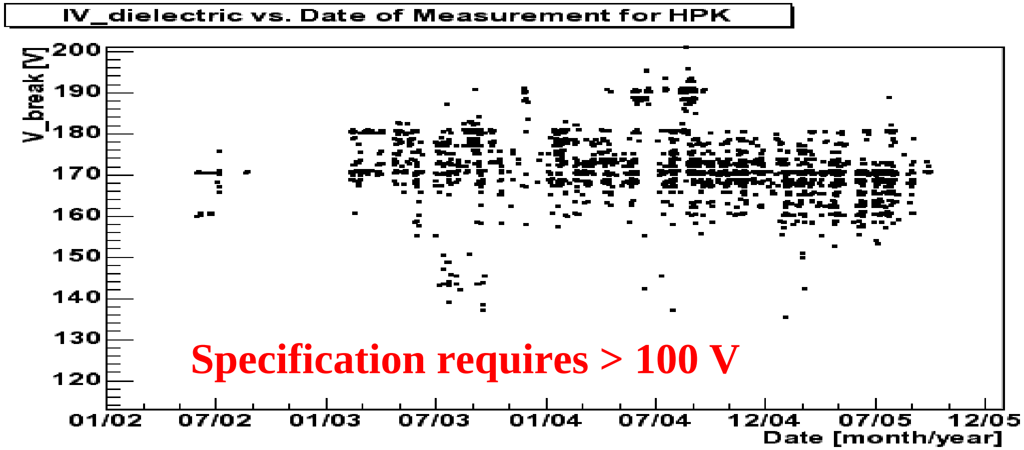
Process Control - Examples

Most parameters are very stable:

Coupling Capacitance:



Dielectric Breakdown Voltage:

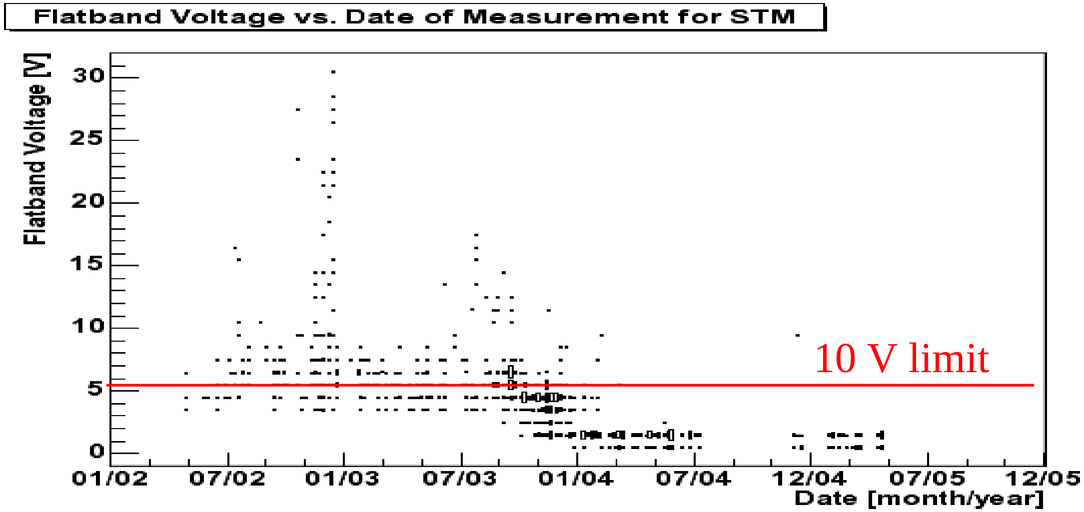


Problems experienced during the sensor production.
(Only some examples of critical problems)

Process Control - Nonconformities

Flatband voltage: Too high for some STM batches.

A consequence of a high flatband voltage is a large increase of the interstrip capacitance after irradiation.

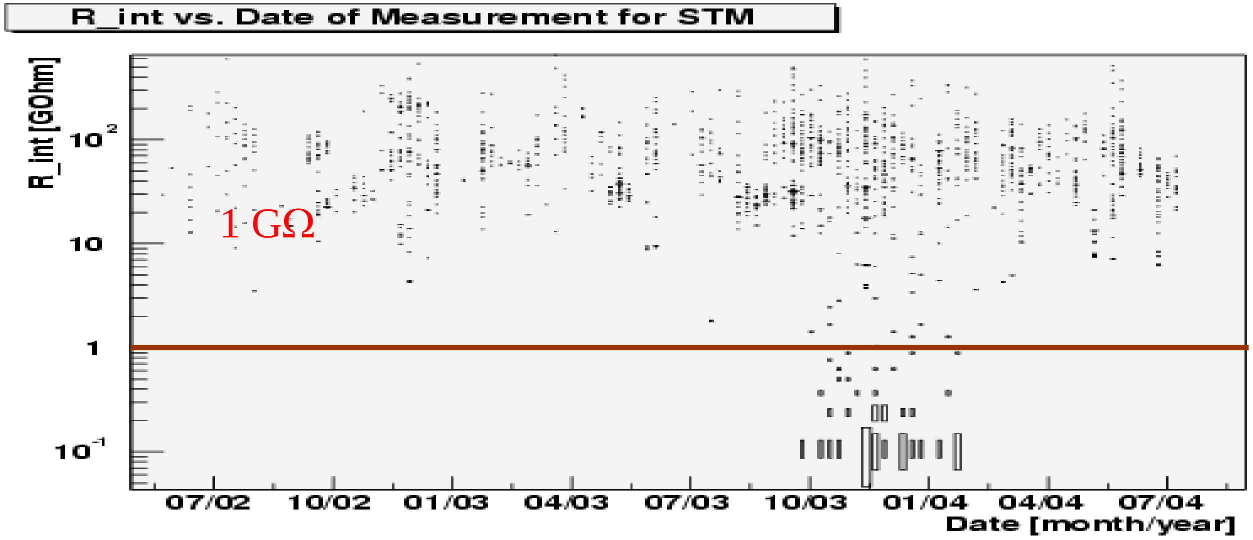


The failure was traced back to a contamination of a single machine in the production line. Level of contamination was not significant for other products in this production line.

Process Control - Nonconformities

Interstrip resistances: **Too low for some STM batches.**

The limit is 1 GΩ to ensure good electrical separation of adjacent strips.



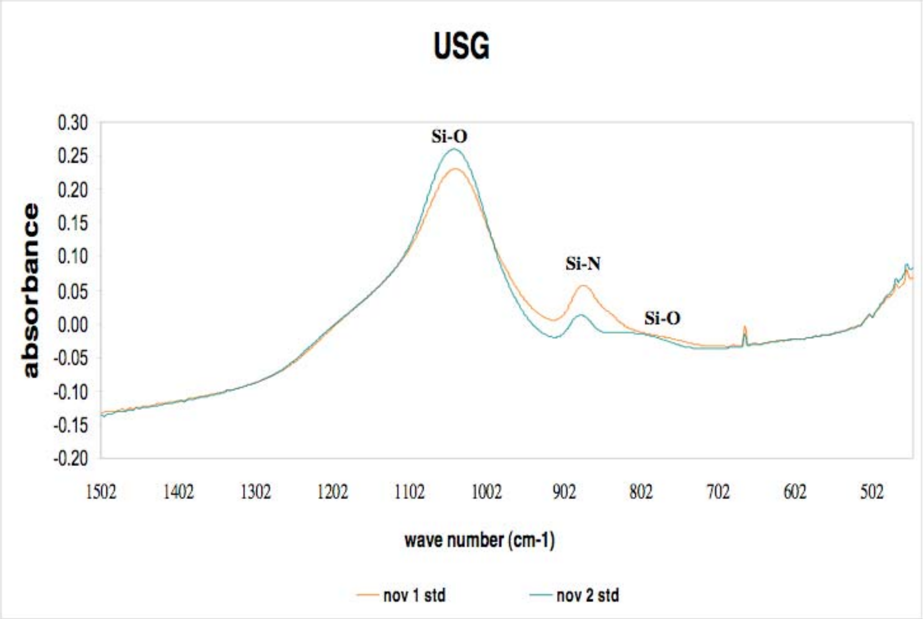
The failure was traced back to a small parameter variation in the production line.

Comment on Production Line Stability

Tiny variations in process parameters can cause significant differences in the electrical parameters.

E.g. Silane gas flow for CVD deposition of undoped silicon oxide in pre metal application.

2 different machines used in production result in different oxide charges.

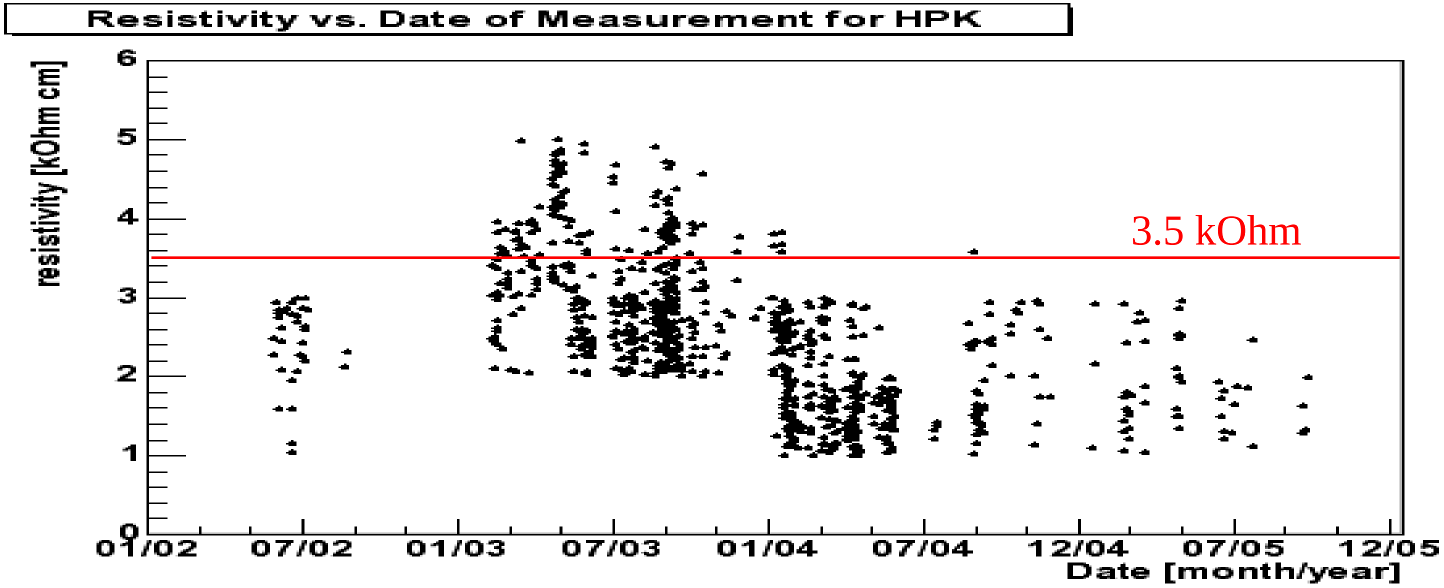


Nov1: Higher SiN peak IR: 1,513 Nov2: Higher SiO peak IR: 1,490

Measurement provided by STM

Process Control - Nonconformities

Wafer material: **Thin sensors (HPK) produced during a certain period on material with too high resistivity.**

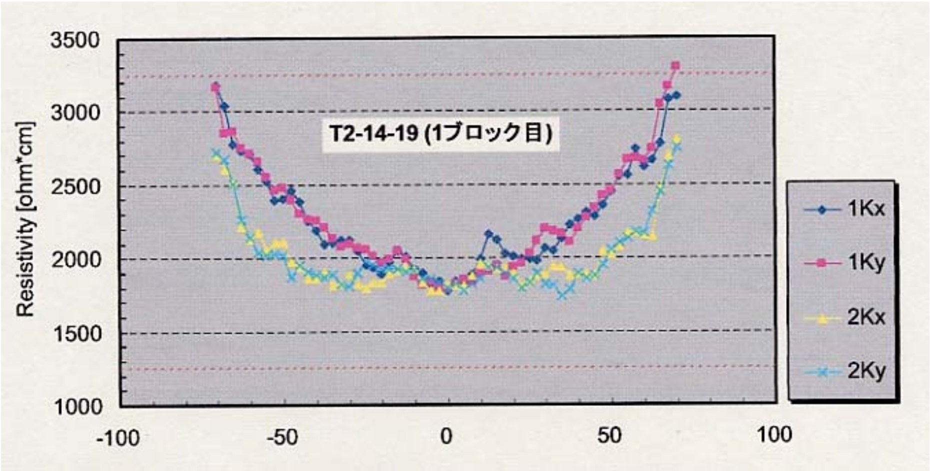


Comments on Wafer Availability and Resistivity

The specification of a small depletion voltage range is problematic for the companies:
- Availability of wafers
- Extrapolation of depletion from ingot measurements
- Variation of resistivity across the wafer

Original specification for the inner layers was a resistivity range of $1.5 < \rho < 3.0$ kOhmcm. This range was enlarged on the request of the company to $1.25 < \rho < 3.25$ kOhmcm

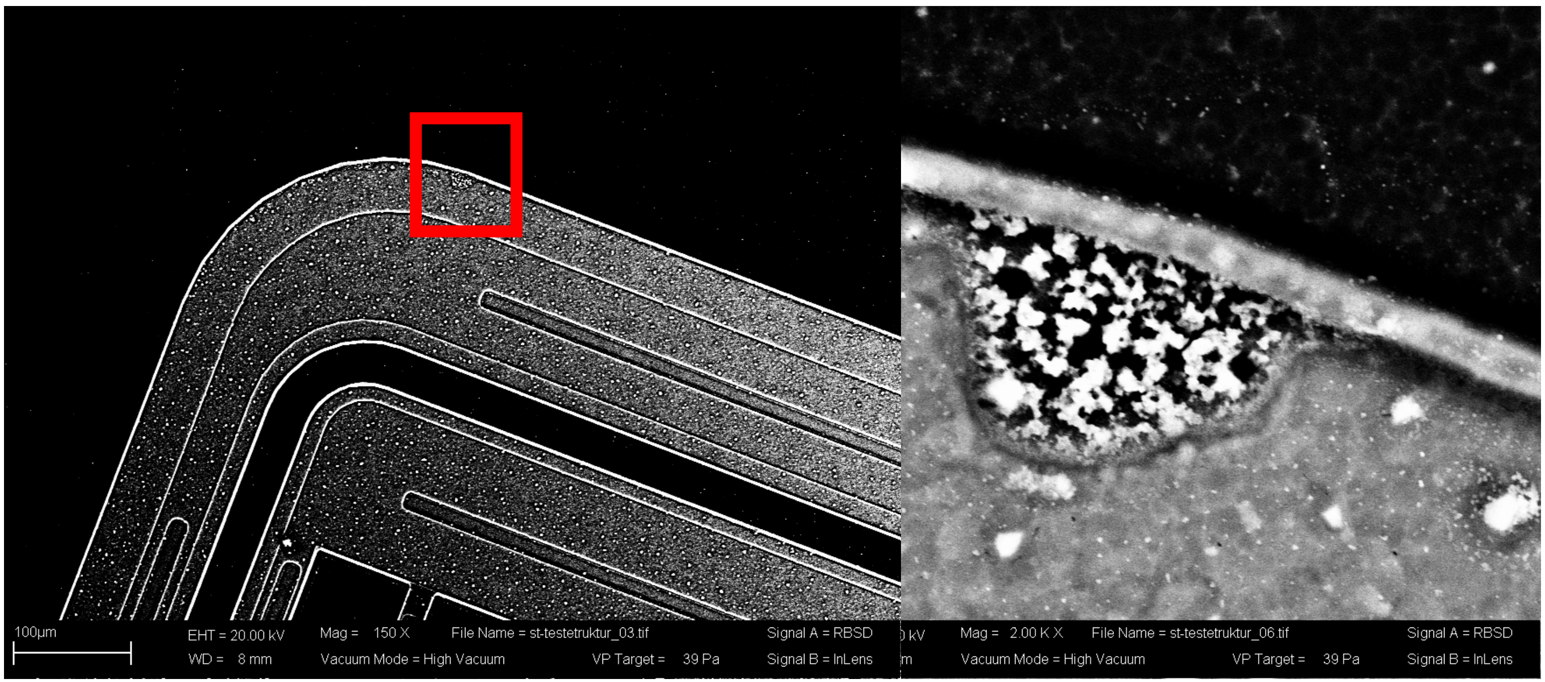
Variation of the resistivity across the wafer:



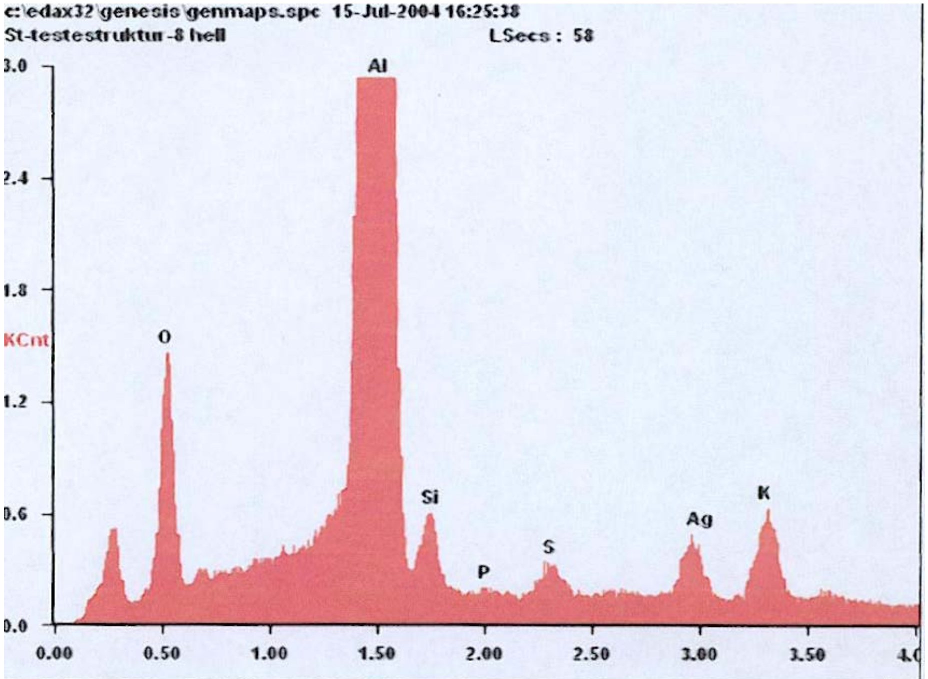
Measurements provided by HPK

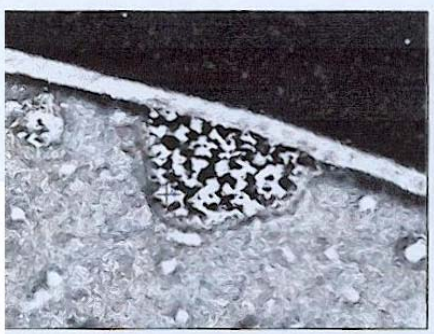
Aluminum Corrosion

Development of stains observed on the Aluminum surfaces of STM sensors. Increase with time only when sensor was under bias and humidity large (>30%r.h.).



Aluminum Corrosion





Element	Wt%	At%
O K	15.64	24.31
AlK	78.20	72.07
SiK	01.88	01.67
P K	00.25	00.20
S K	00.58	00.45
AgL	02.19	00.51
K K	01.26	00.80

Detailed element analysis revealed:

Dots and stains are micro-corrosions of the aluminum surface.

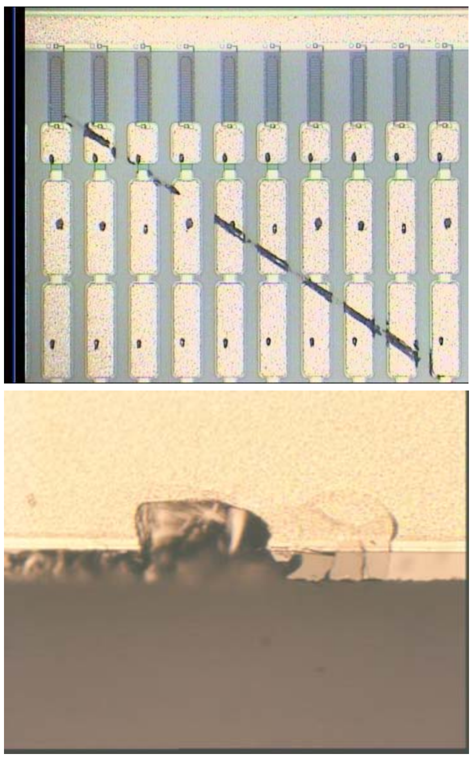
Probable explanation is:
Humidity reacts with Phosphorus (present as a 4% concentration in the passivation oxide) or Potassium and forms an acid (e.g. H_3PO_4).

Measurements provided by Fraunhofer Institute Chemische Technologie

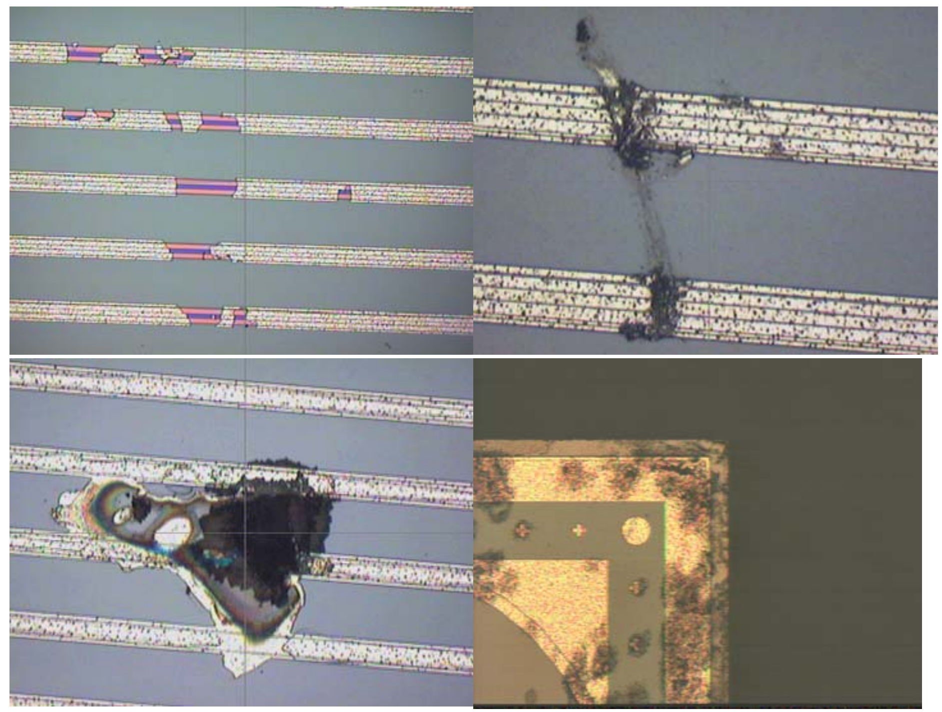
Mechanical Defects

Occasionally problems with mechanical defects. Appears to be difficult to control in large scale production facilities.

HPK:



STM:

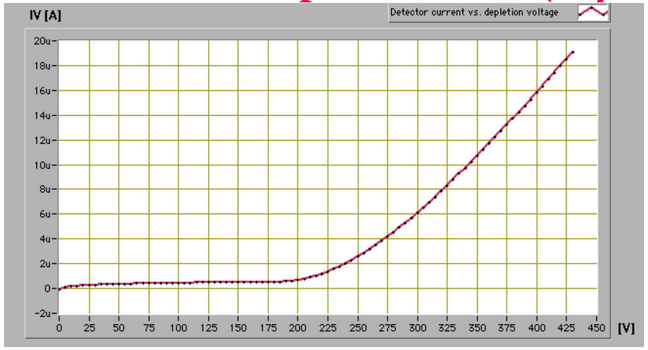


Sensitivity to Mechanical Deformation

Varying current characteristics observed with different vacuum strength (STM Sensors)

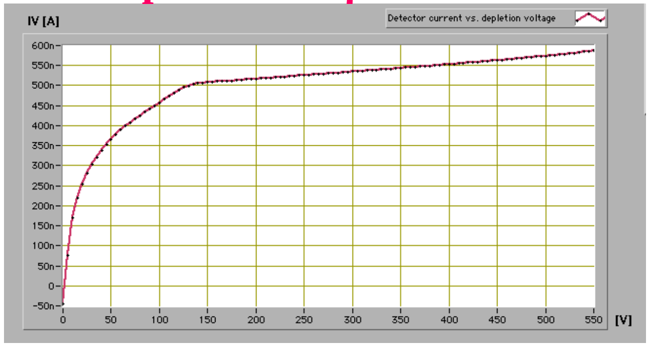
IV in standard setup:

Sensor outside specifications (20µA)

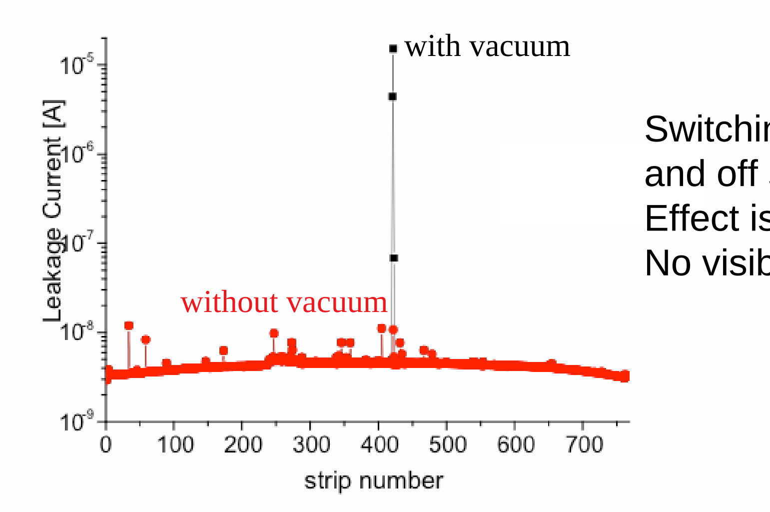


Vacuum switched off:

Sensor perfect 0.5 µA



This is an effect of single strips !

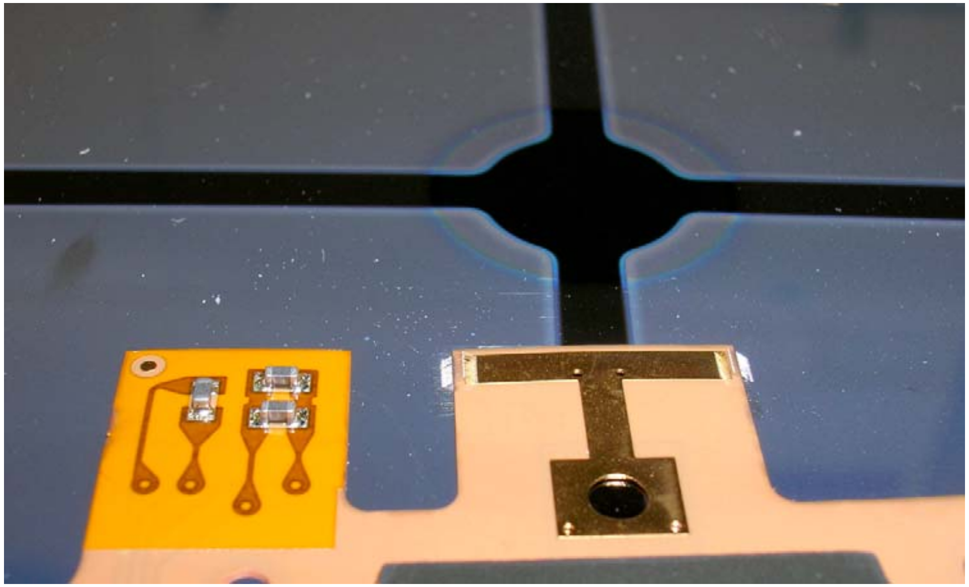


Switching vacuum on and off switches strips.
Effect is reproducible.
No visible defect seen.

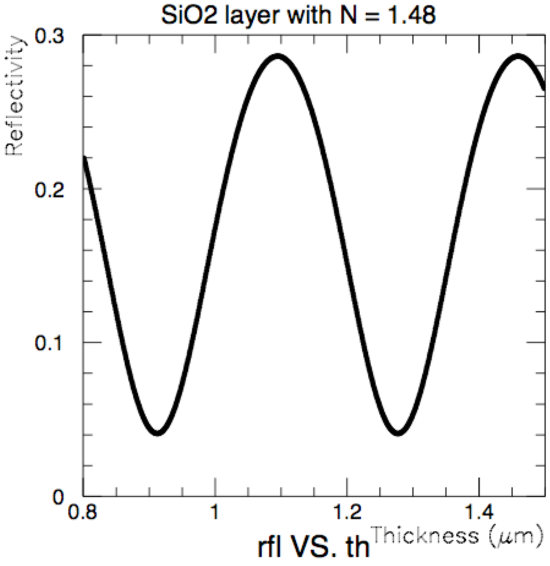
No consequence of this behaviour seen so far in final CMS modules.

Alignment Sensors

The CMS alignment system uses laser beams a la AMS.



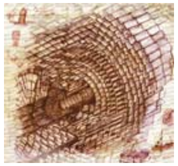
The thickness of the SiO_2 layer between the strips was changed to 1.3 μm for these sensors).



These special sensors are polished on both sides, and have an opening in the aluminum on the backside.
In addition an anti-reflective coating was applied.

Personal comments on HPK

Personal comments on STM



Conclusions for CMS

The delivery of the CMS strip sensors was completed in April 2006.

A very detailed quality assurance programme was developed and implemented by CMS involving 8 institutes.

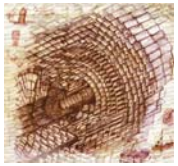
An unpreceded extensive study of the delivered wafers was performed: 16 electrical parameters measured on about 13700 structures.

CMS Process control on test structures was extremely useful

Several problems were identified and eventually solved together with the companies.

The quality of the accepted sensors is excellent and fulfils the requirement of long time operation in CMS.

The overall percentage of good strips in the accepted sensors is 99.94%.



Some Recommendations

Start early discussions with producer

Avoid structures difficult to produce or specification difficult to satisfy.

E.g. Design electronics to work with DC coupled sensors.

Minimum are two producer able to manufacture all types needed.

Contracts must contain provisions for additional orders.

Specifications for the structures and the required tests must be defined in EVERY detail.

Minimise number of different geometries. Rethink if wedge type geometry in the forward region is really the best choice.

Data base to hold all information is crucial.

Design structure of data base early and take it serious.