Quality Assurance of Silicon Microstrip Sensors for the CBM Experiment

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for the CBM Collaboration

(Darmstadt, DPG-2016)

Outline

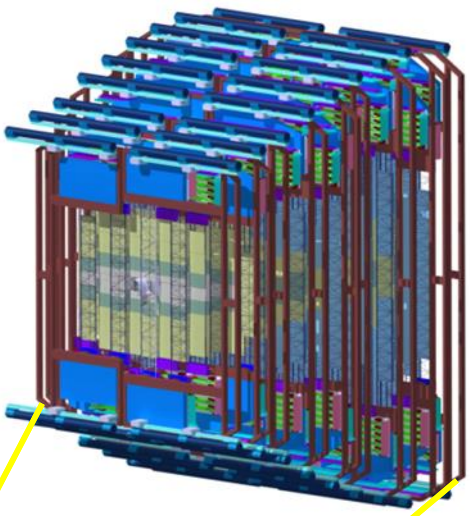
- Sensors for the Silicon Tracking System of CBM
- Strategy for Quality Assurance
- Current status, Results and Experience with sensor prototypes for STS

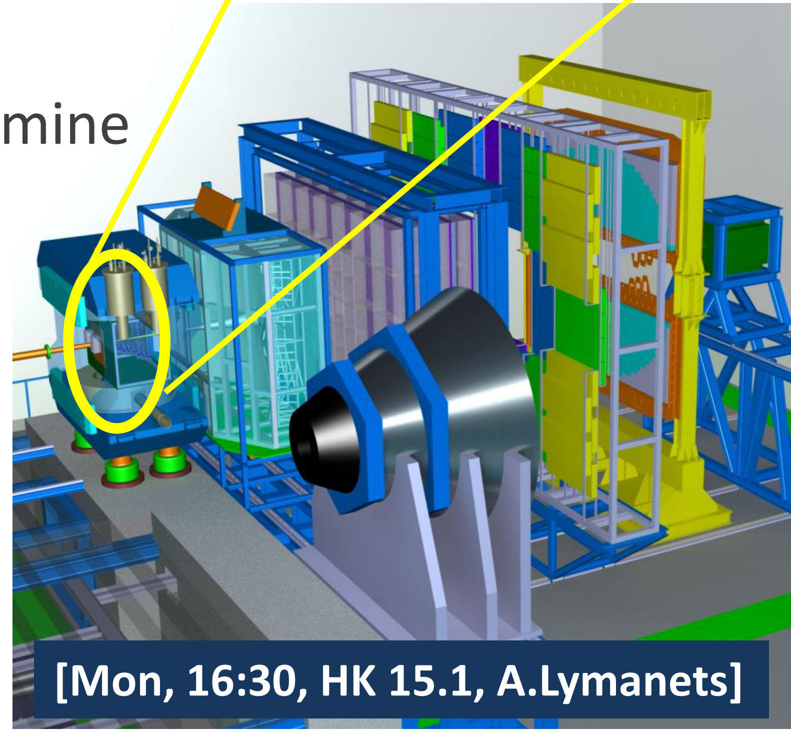
STS and Sensor Characterization

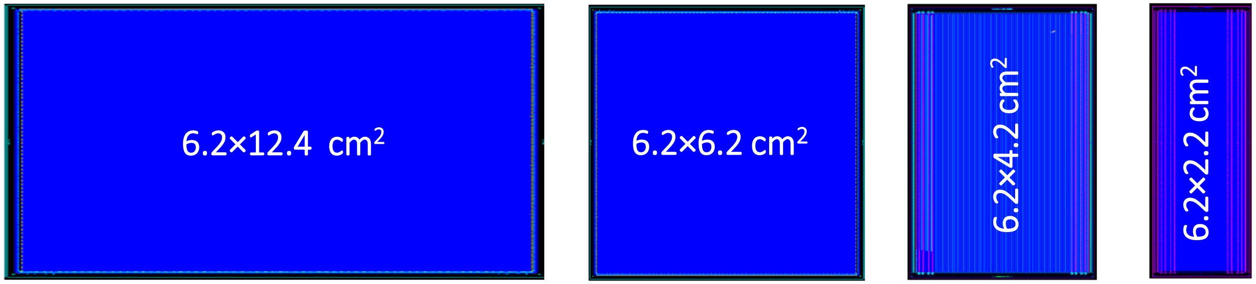
Silicon Tracking System (STS) – part of the CBM detector – 8 detection layers entirely covered by silicon microstrip detectors .

- Total silicon area 4.2 m^2
- CBM Silicon sensors have 2048 strips
- Number of sensors – 1220 double-sided sensors in 3 sizes ≈ **2.5M strips** (1.8M readout channels)

- Efficient Quality Assurance mandatory
- Automated test system is necessary to determine the electrical parameters of each strip.

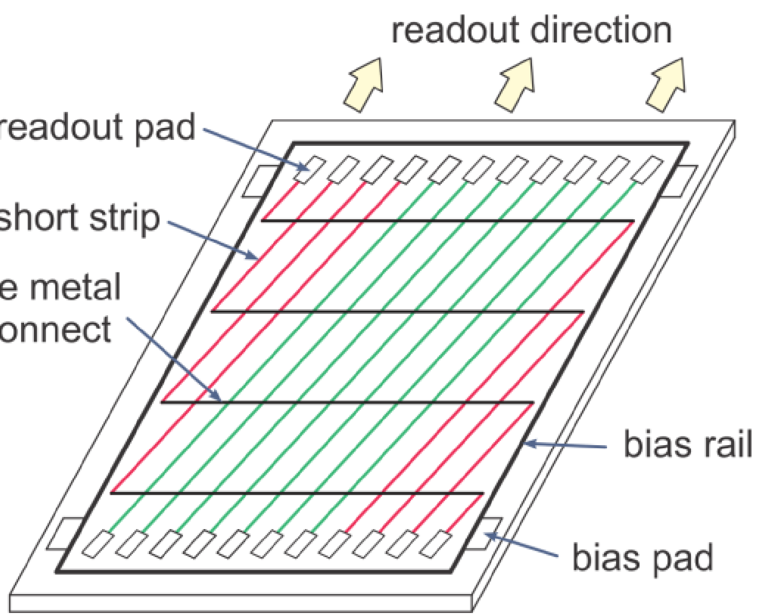






Sensors Design Details

- n-type Si bulk
- thickness 285 µm double-sided
- strip pitch **58 µm, 1024 strips** per side



p-side:

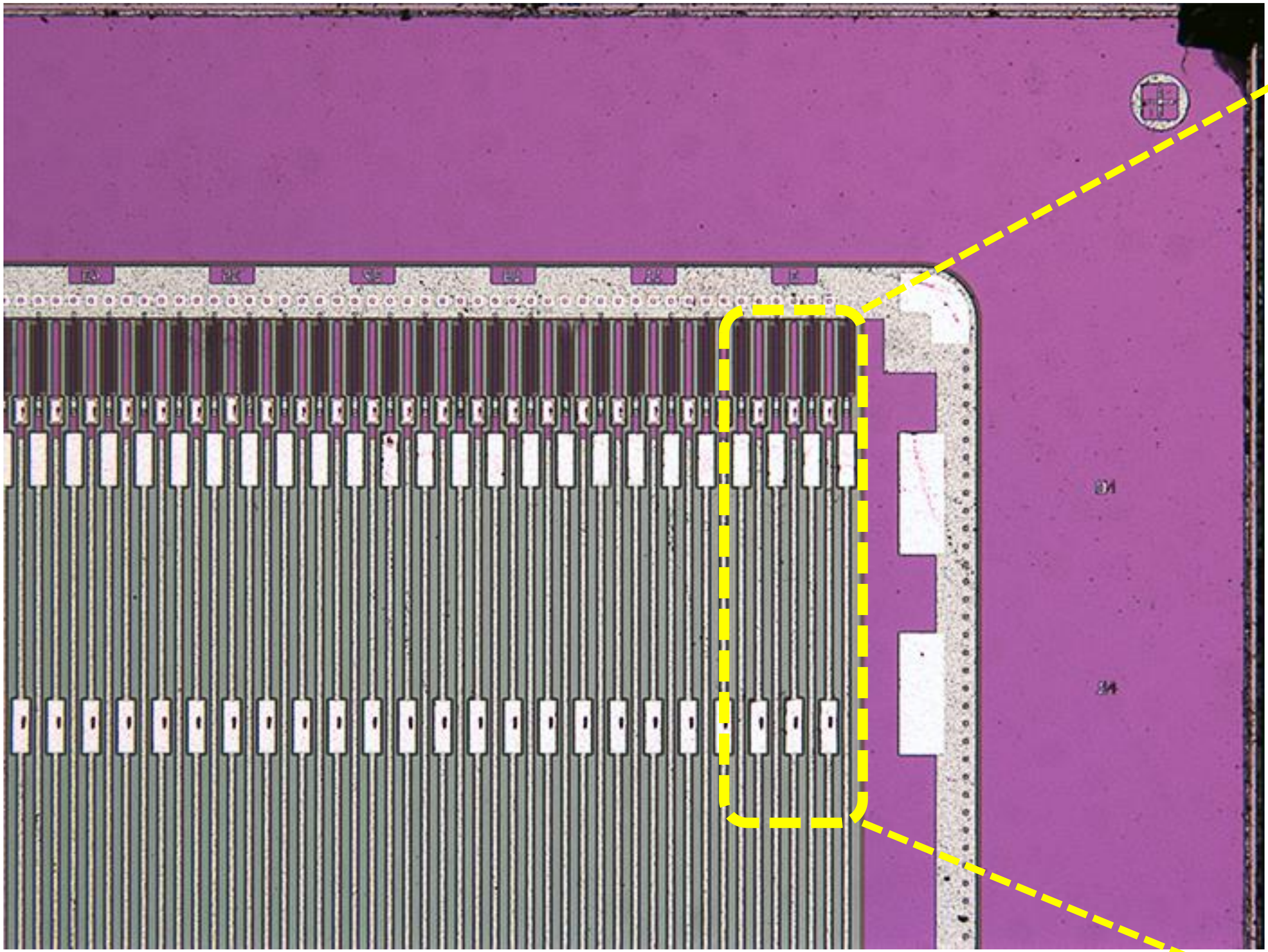
- strips under 7.5 deg angle
- AC coupled strips, read-out via 1st metal layer, AC contact pads at top edge
- inter-strip routing lines between side strips on 2nd metal layer

n-side:

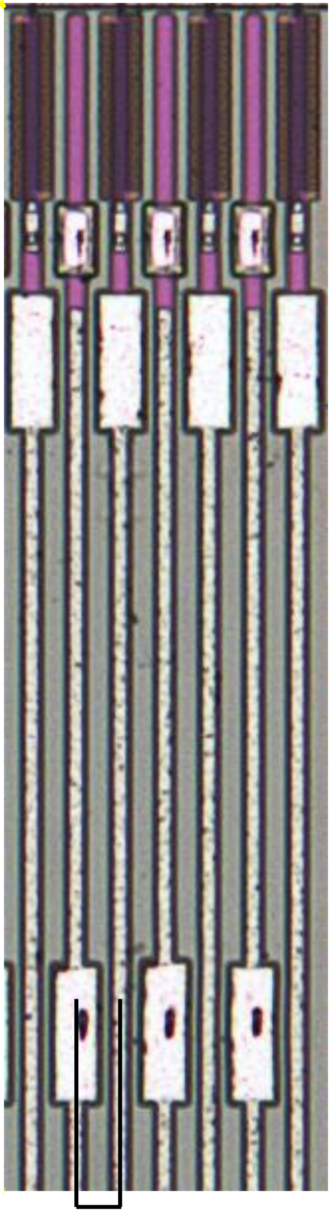
- strips under 0 deg angle
- only 1st metal layer

Wafer thinckness	285 ± 15 µm
Depletion Voltage	< 100 V
Leakage current	< 50 µA @ FVD+20 V
Junction breakdown	> 200 V
Coupling capacitance	> 10 pF/cm
Coupling capacitor breakdown	> 100 V
Interstrip capacitance	< 1 pF/cm
Polysilicon bias resistor	1.5 MOhm ± 20%
Defective strips	< 1% per sensor

CBM Silicon Strip Sensor



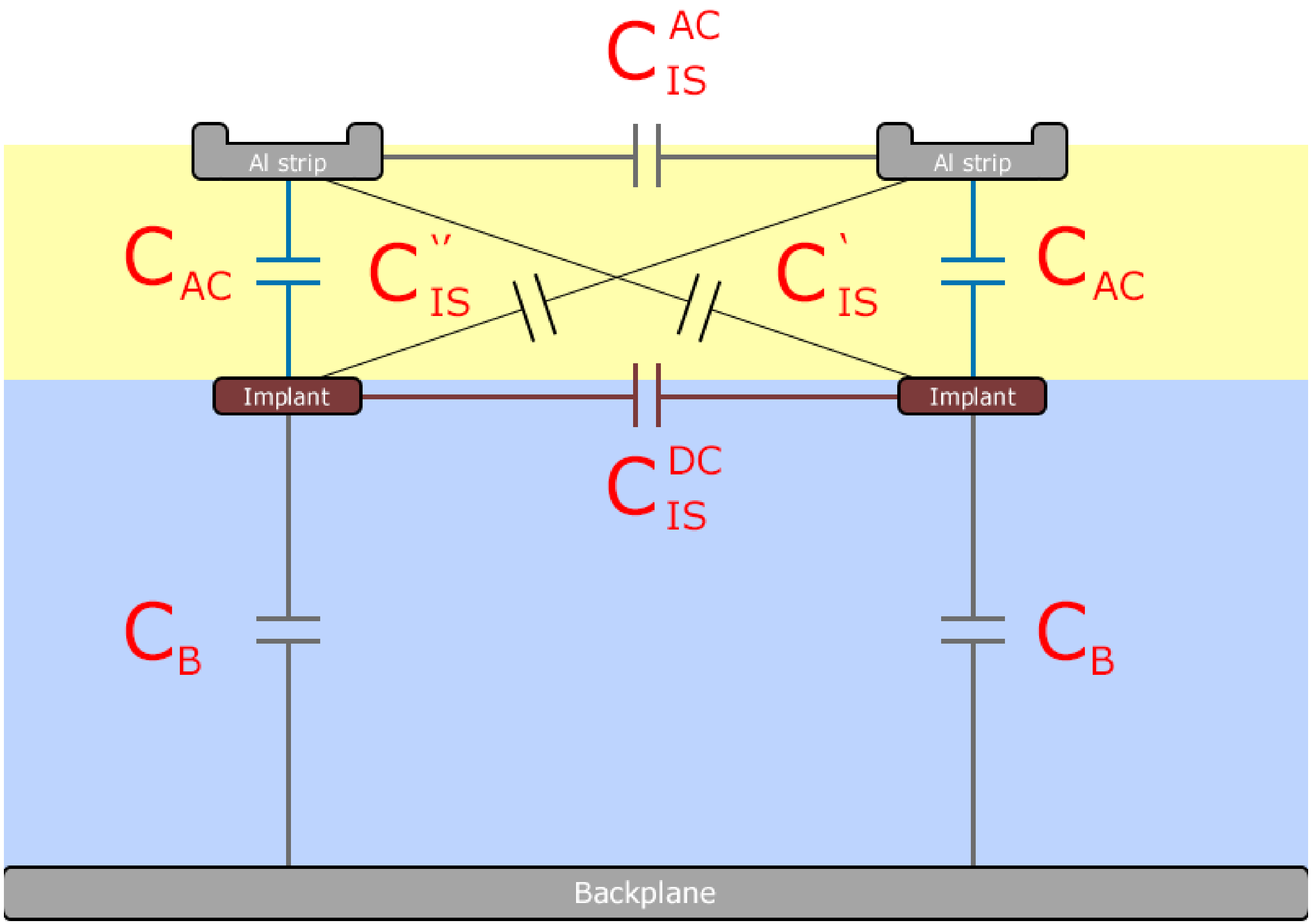
Corner of the CBM microstrip sensor prototype (n-side)



Strip pitch 58 μm

AC Coupled Microstrip Sensor

Sensor model for electrical characterization



- The aim of strip-by-strip measurements is to study strip integrity and uniformity of electrical characteristics over the whole sensor .
- It requires probing 1024 strip pads on each side of the silicon sensor.

STS Sensors Quality Assurance

- **Visual Inspection** **Mon, 15:00, HK 7.4, E. Lavrik**
  - defects are easily detected
  - to do on **all** sensors
- Metrological measurements
  - Flatness, warp, cutting edge
- **Electrical characterization**
  - Basic tests: IV-CV curves
  - Subset test: Strip tests
  - Specific tests
  - Other tests
- Readout characterization
  - With radioactive source
  - With laser Mon, 15:15, HK 7.5, M. Teklishyn

Sensor Test Setup

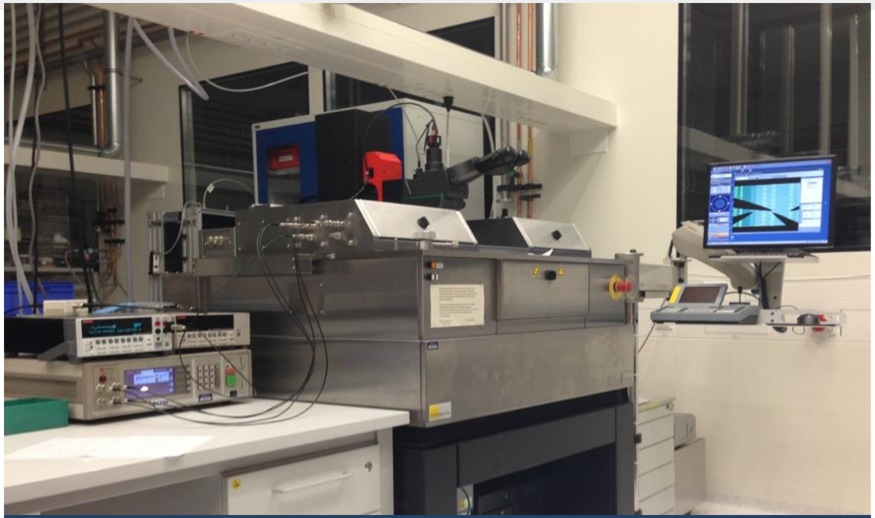
Two solutions:

- Commercial wafer prober (GSI, Darmstadt)
- Custom-built probe station (Uni-Tubingen)

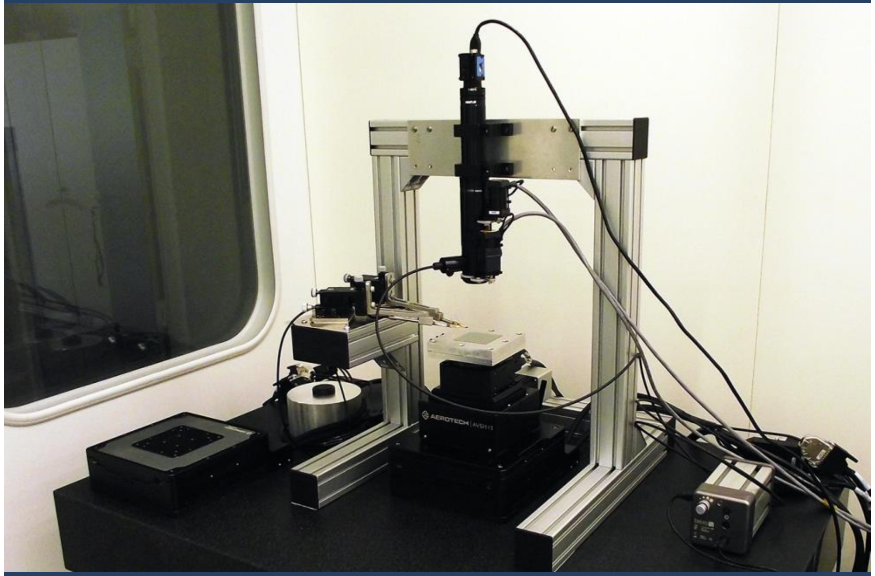
- Light-tight Box, Instruments (voltage source, picoammeter, LCR-meter, switching matrix), Computer
- vacuum chuck carrying the sensor mounted on movable table in X, Y, Z and θ with high precision (~0.4 µm)
- Needles to contact sensor DC (p+ implant) and AC (Metal layer) pads
- Motorized optycal system to allow contact to any pad of the sensor

Advantages of custom built probe station:

- **high accuracy** of positioning and **repeatability** (< 1 µm);
- large travel range of both positioning and optical systems;
- Implementation of features which are really needed (for both hardware and software, e.g. *proper vacuum chuck, auto-alignment of the silicon sensor, repositioning on pads via pattern recognition*, and much more);
- And price.



Commercial wafer prober **Süss PA300PS** (GSI, Darmstadt)



Custom high precision Probe Station (under development, Uni-Tuebingen)

Electrical Characterization

- **Electrical characterization**
  - **Basic tests**: IV-CV curves
    - $I_{leakage}$@FDV, V_{FD}, C_{bulk}, N_{eff};
    - To be done for all sensors;
    - Quality criteria: **I@150 < 50 uA**, I@150 / I@100 < 2, **V_{depl} < 100 V**
  - **Subset test**: Strip tests
    - Pinholes in capacitor dielectric, strip metal and implant shorts and opens, single strip leakage current;
    - on ~**10 % of all sensors;**
    - Strip tests for suspicious candidates during visual inspection;
    - Quality criteria: **< 1% of strips fail**
  - **Specific tests**
    - Coupling capacitance of the readout strip, solysilicon resistance, interstrip capacitance, strip capacitors breakdown voltage;
    - Prototyping stage – for all sensors, production – few strips of ~1-2 sensors/batch

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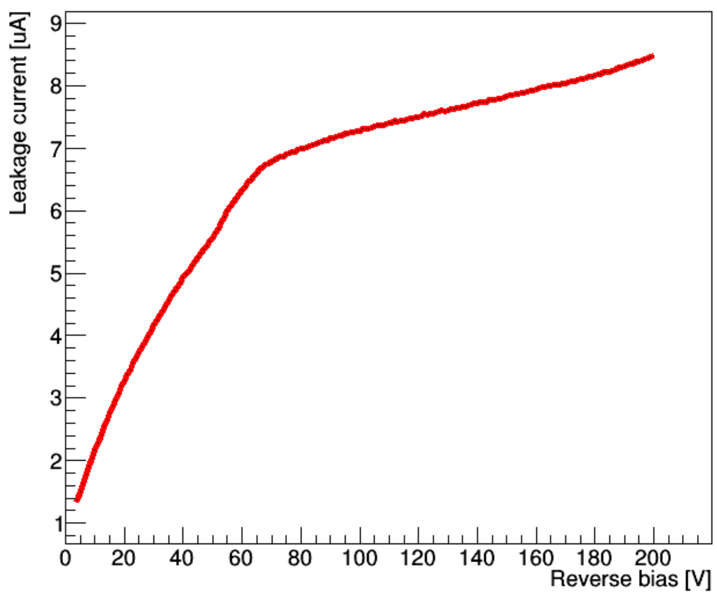
  - **Specific tests**
    - Coupling capacitance of the readout strip, polysilicon resistance, interstrip capacitance, strip capacitors breakdown voltage;
    - Prototyping stage – for all sensors, production – few strips of ~1-2 sensors/batch

Results with Prototype Sensors

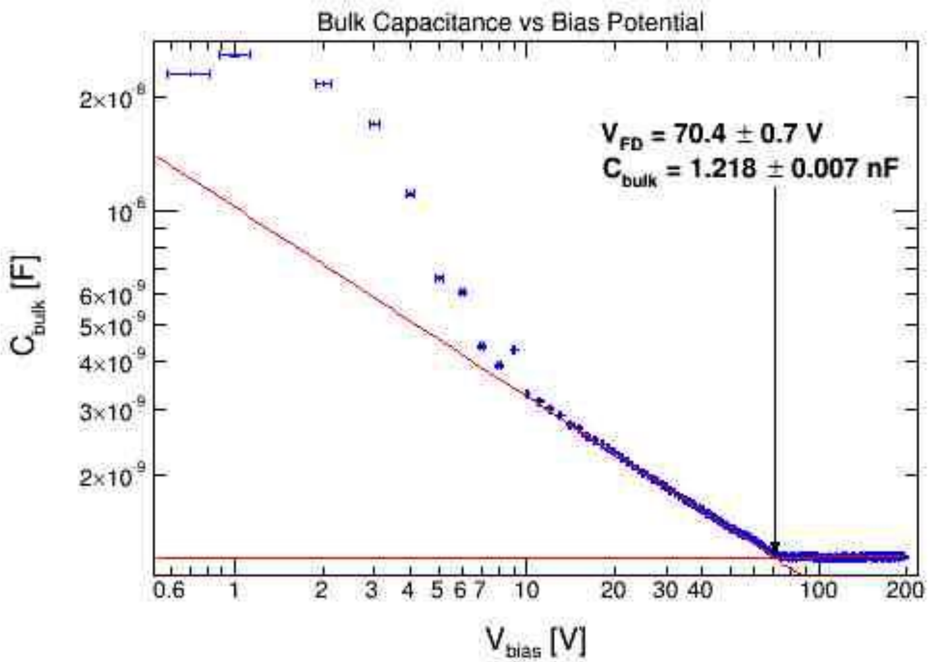
IV – CV Characterization

- 1^{st} and simple estimation of the sensor quality
- Magnitude of leakage current influences the noise performance
- **Leakage current < 10 uA @ 20^0 C, No breakdown up to 200 V**
- **Full depletion is reached at ≈ 70 V**
- **Capacitance saturates at ≈ 1.21 nF**



Leakage current is strongly dependent on temperature

$$I \propto T^2 \cdot \exp\left(\frac{-E_0}{2k_B T}\right)$$

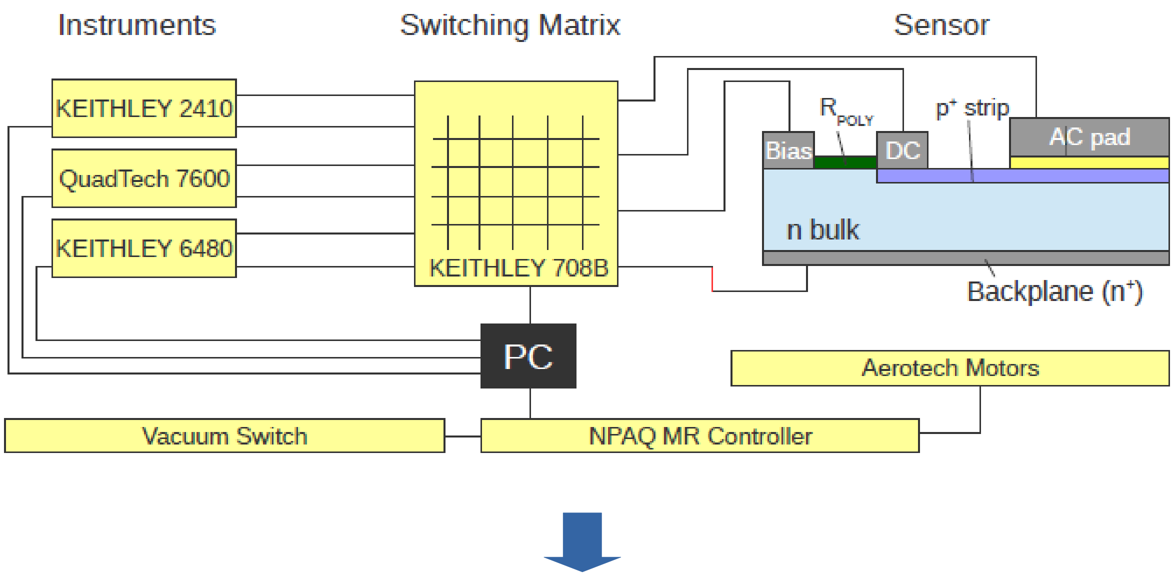


Bulk capacitance measured between backplane and bias ring by LCR meter with $C_S R_S$ function at $1kHz$

Switching Scheme

Instruments (HV source, Amp-Meter, LCR-Meter) on the left are connected via a switching matrix to the needles which contact the sensor to perform different measurements

For each test, the switching matrix has to be reconfigured



- All measurements can be done in a row without manual interaction
- Total measurement time can be strongly reduced

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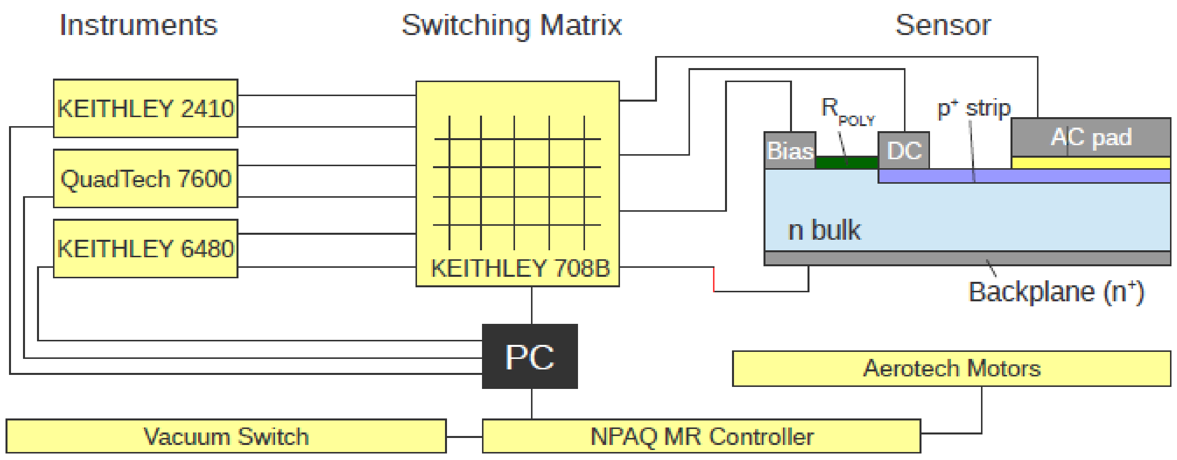


- All measurements can be done in a row without manual interaction
- Total measurement time can be strongly reduced

Strip-by-Strip Characterization

After IV-CV measurements, bias voltage is adjusted to FDV+20V and strip scan is started

4 parameters are acquired for each strip:

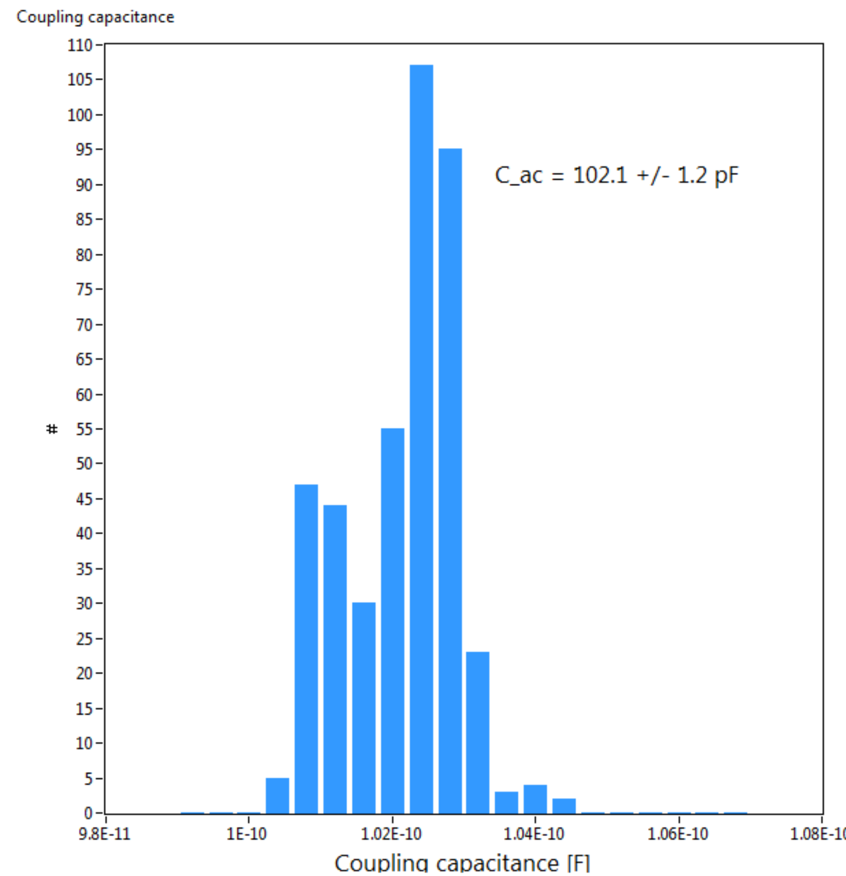
- strip leakage current I_{strip}
- dielectric current I_{diel}
- current between 2 Al strips
- coupling capacitance C_{ac}

Additionally one can measure:

- Polysilicon resistance;
- Interstrip capacitance;
- Total strip capacitance;
- Coupling capacitor breakdown voltage

Results with Prototype Sensors

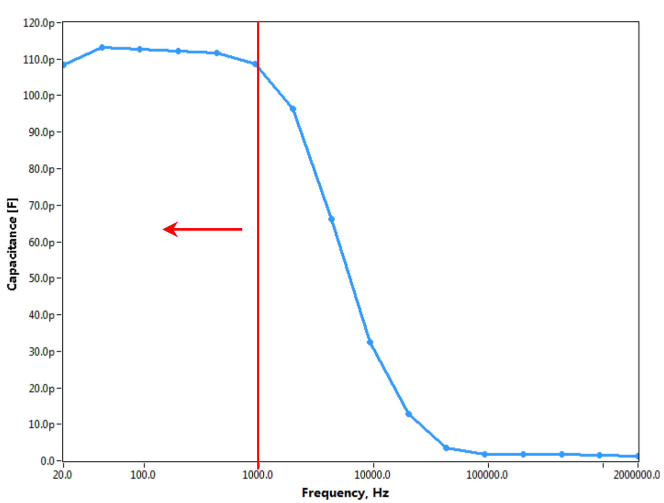
Strip-by-Strip Characterization - C_{ac}



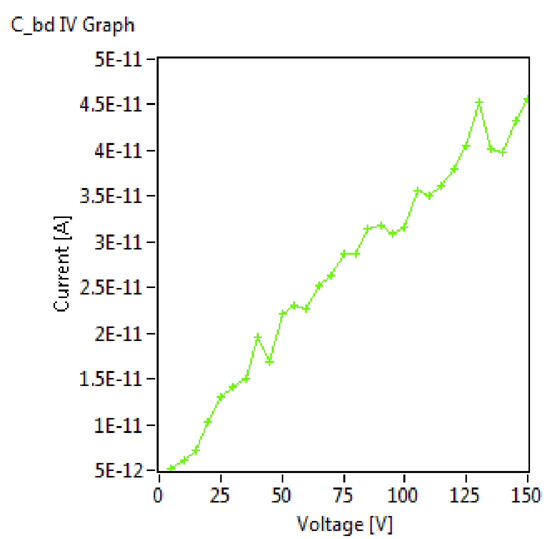
C_{AC} – is a capacitance formed by the strip implant, insulation layer (SiO_2 + Si_3N_4) and the readout aluminum line.

In the strip scan C_{AC} is measured by LCR meter between DC and AC pads, CR in series at 1kHz test frequency.

Frequency dependence of a coupling capacitance of sensors CBM06C6 measured at 90 V.



Breakdown test of coupling capacitors: up to 150 V no breakdown



Measured coupling capacitance for 6.2x6.2 sensors:

$$C_{ac} \approx 17 \text{ pF/cm}$$

CBM specification for coupling capacitance

$$C_{ac} > 10 \text{ pF/cm}$$

Results with Prototype Sensors

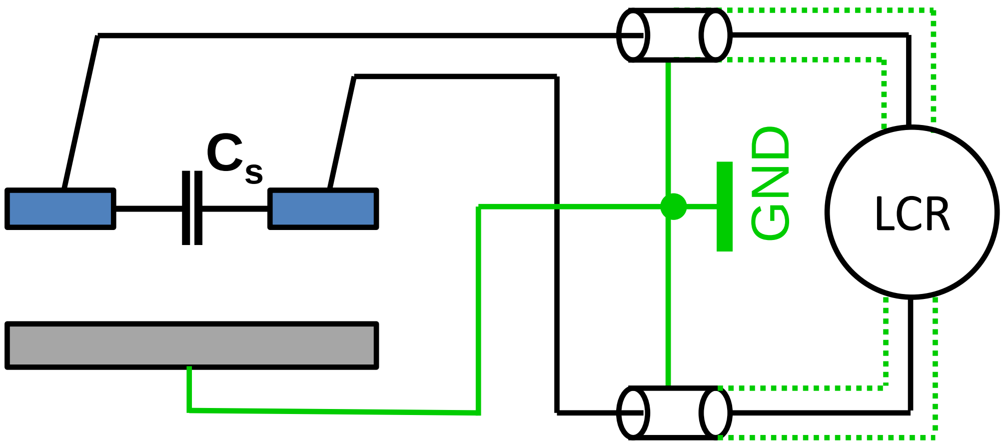
Strip-by-Strip Characterization - C_{int}

C_{int} – main contribution to the input capacitance of the FEE – defines its noise performance

Different methods of C_{int} measurement:

With compensation probes;

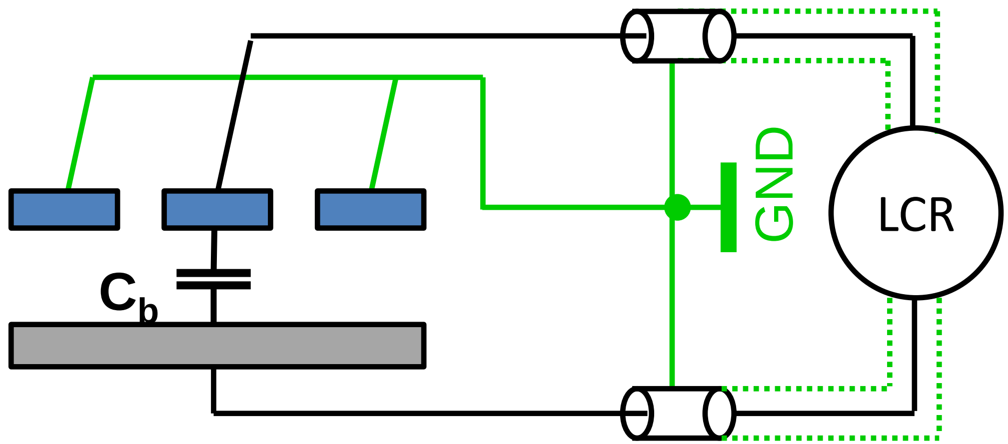
Without compensation probes



Schemes with compensation probes:

C_s = 1.461 ± 0.005 pF/cm

C_b = 0.366 ± 0.007 pF/cm



C_b – single strip backplane cap.; C_s – interstrip cap.

C_{int} has to be significantly smaller than coupling capacitance in order to ensure a good charge collection. Common relation:

$$C_{AC} / C_{int} > 10$$

- *Ok for tested sensors*

Estimation of total strip capacitance:

$C_{tot} = 2C_s + C_b$ = 3.294 ± 0.017 pF/cm

C_{int} measured at *1MHz* test frequency with function *CR in* parallel.

Results with Prototype Sensors

Strip-by-Strip Characterization

Total number of bad strips

Total = sum of I_{strip} , C_{ac}, I_{diel}, I_{metal}

Bad = outside specified cuts

CBM requires **less than 1% of strips that are outside cuts** for at least one of the strip parameters

• Pinholes in capacitor dielectric	$I_{diel} < 1$ nA @ V_{op}
• Strip metal and implant shorts and opens	$0.8\ C_{ac} < C_{ac} < 1.2\ C_{ac}$
• Single strip leakage current	$I_{leak} < 10$ nA @ V_{op}
• Coupling capacitance of the readout strip	$C_{ac} > 10$ pF/cm
• Polysilicon resistance	$R_{poly} = 1.5$ MOhm ± 20%
• Interstrip capacitance	$C_{int} < 1$ pF/cm
• Strip capacitors breakdown voltage	$V_{cbd} > 100$ V

Identified bad channels for CBM06C6w22 (p-side only):

136-I, 136-p, 142-p, 484-s, 485-s, 954-p

Total = 6 strips < 1 %

Summary

- **Quality Assurance program with detailed characterization procedures has been developed for CBM-STS sensor QA.**
- Two probe stations have been set up in GSI DetectorLab (Darmstadt) and University of Tuebingen.
- Prototype sensors for CBM experiment were successfully tested using custom-built probe station – results are in compliance with CBM detectors specifications.
- Custom built probe station allows to inspect required ~10% of the sensors on series production stage.
- Characterization of one double-sided sensor with 1024 strips on every side takes 5-6h.

Results with Prototype Sensors

Strip-by-Strip Characterization

After IV-CV measurements, bias voltage is adjusted to FDV+20V and strip scan is started

4 parameters are acquired for each strip:

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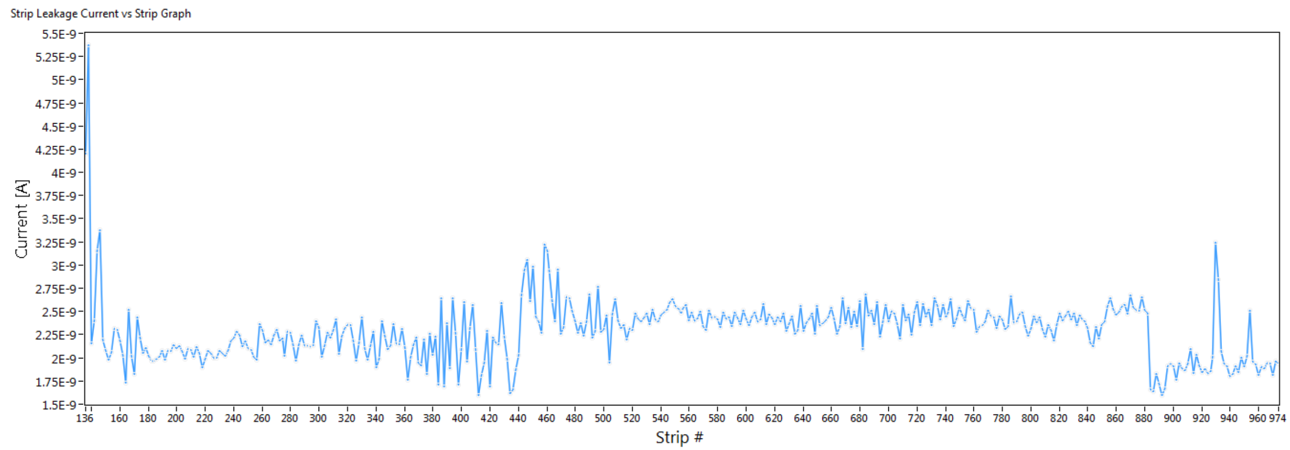
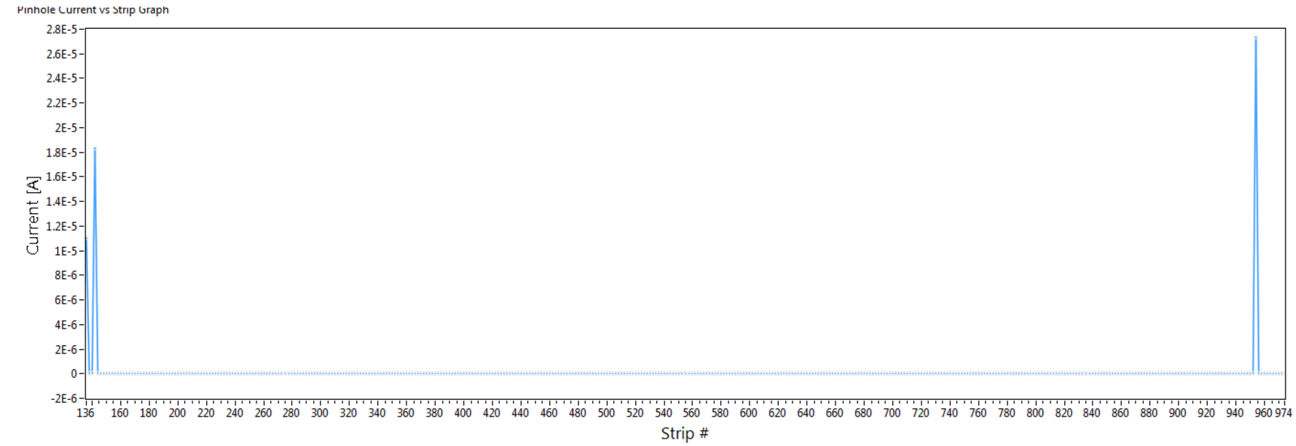
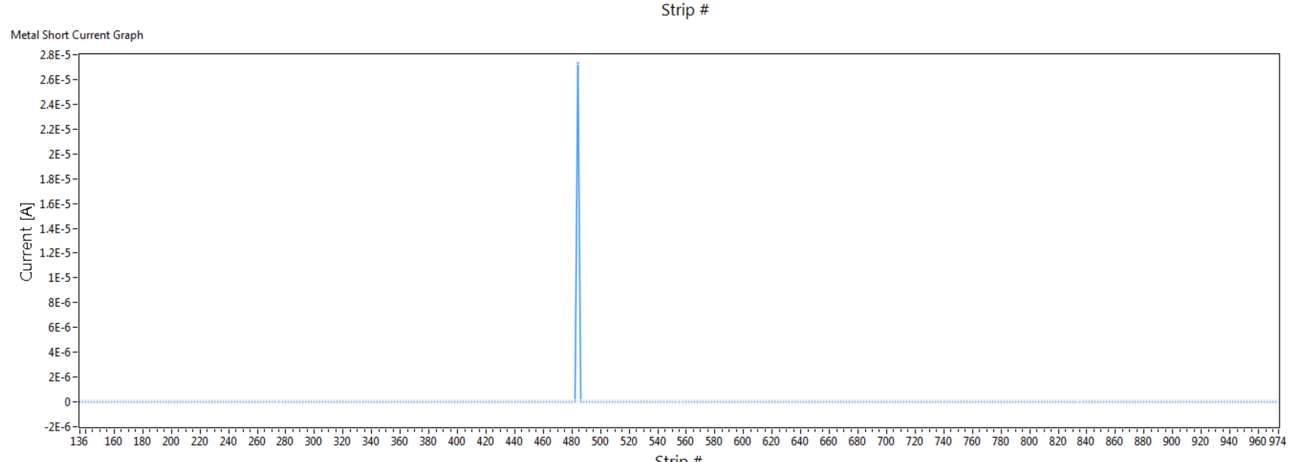
For each test, the switching matrix has to be reconfigured

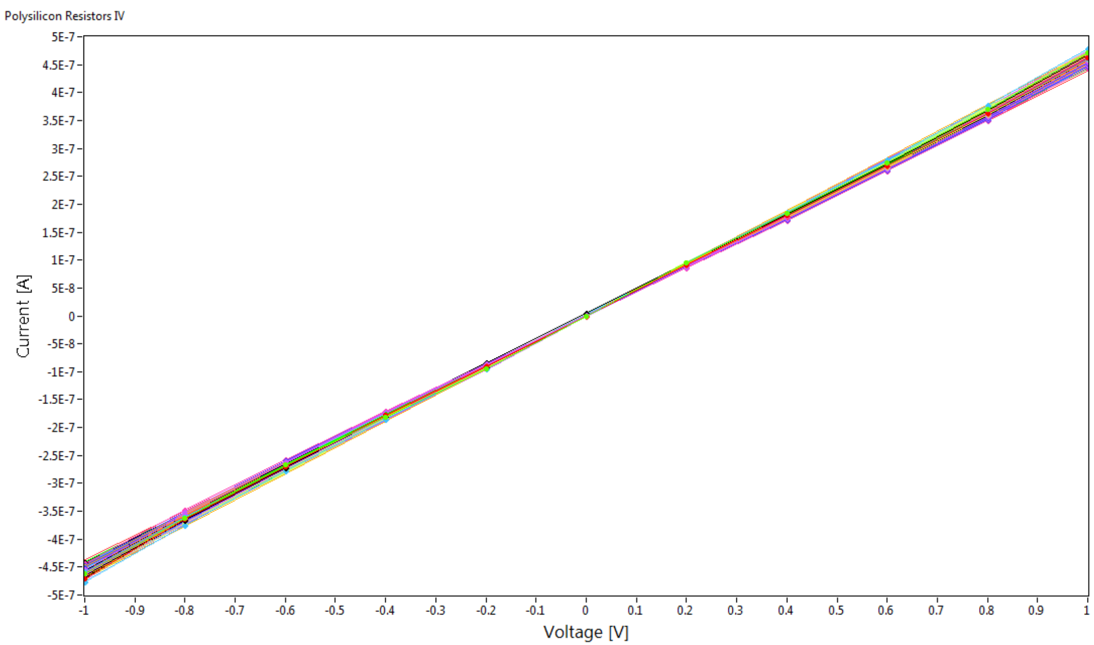






Results with Prototype Sensors

Strip-by-Strip Characterization - R_{poly}

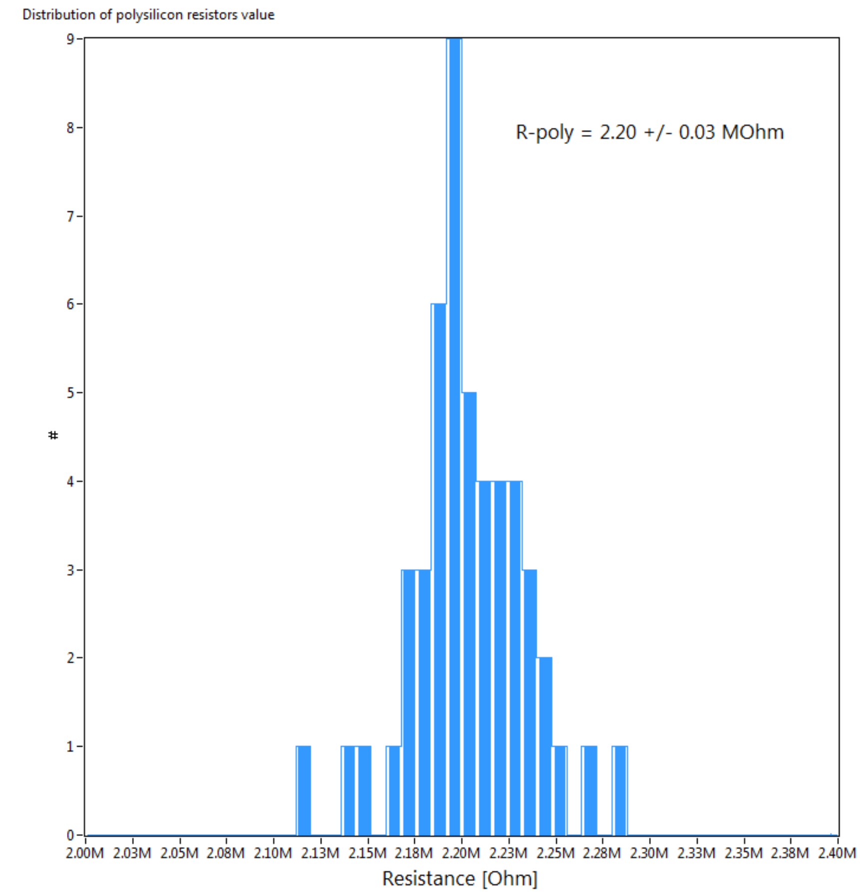


IV scan made by KE V-source/ammeter for voltages (-1.. 1)V applied to DC pad and bias ring.

$$R_{bias} = dU_{appl} / dI$$

Each curve was fitted by a straight line and resistance extracted from the slope.

CBM specification for bias resistors
R_{poly} = 1.5 MOhm ± 20%



Measured resistance:
$R_{poly} \approx$ 2.2 MOhm

Due to sensor specific this value consists of bias resistance and implant resistance connected in series.

Results with Prototype Sensors

Strip-by-Strip Characterization - C_{int}

Schemes without compensation probes:

7 different schemes without compensation probes were used to determine interstrip and total capacitances

S1: C = 2.905 ± 0.004 pF/cm

S2: C = 3.520 ± 0.004 pF/cm

C_{int} measured at *1MHz* test frequency with function *CR in* parallel.