Systematic QA procedures for silicon micro-strip sensors used in CBM

Maksym Teklishyn[1,2]

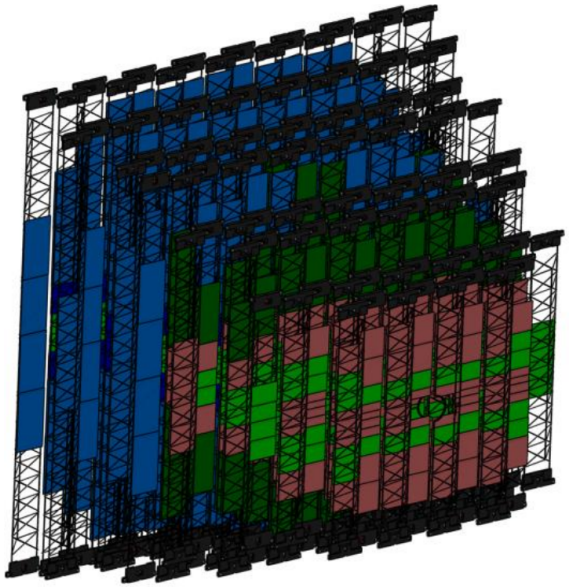
[1]FAIR (Darmstadt), [2]KINR (Kyiv)

Workshop on Perspectives for Joint Science and Academic Training at FAIR and NICA

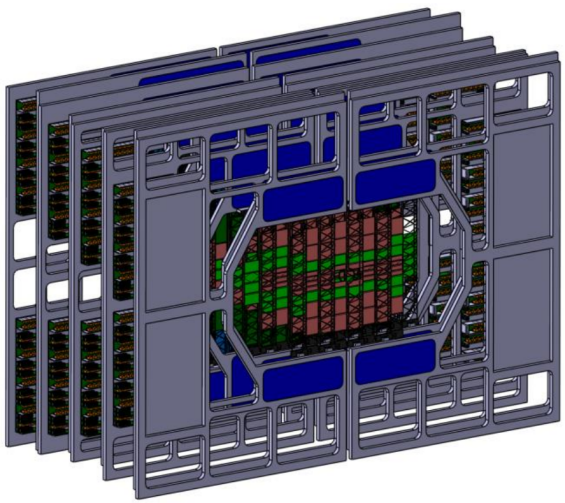
November 16, 2016

Introduction

Silicon Tracking System of CBM



STS carbon ladders

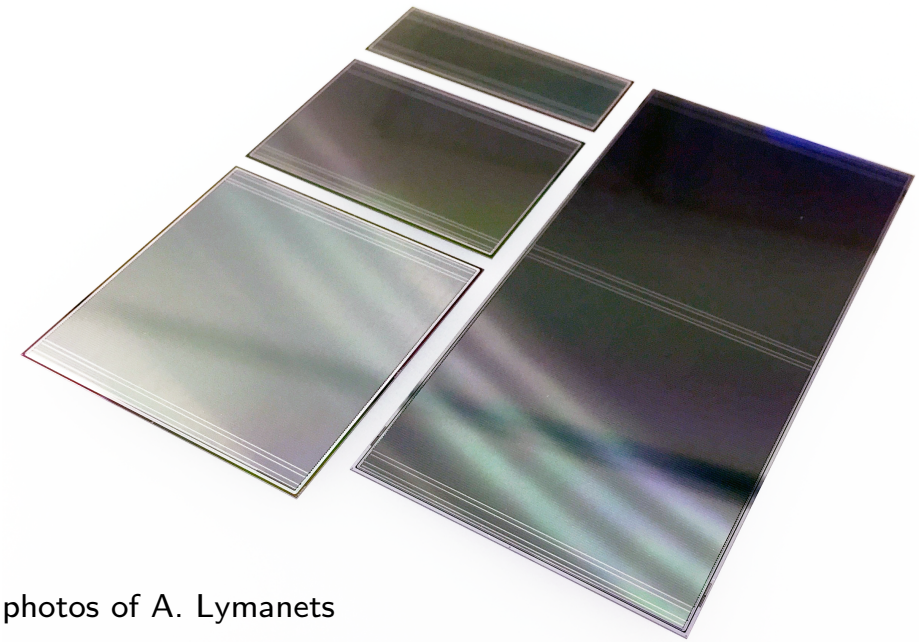


STS units (drawings of O. Vasylyev)

- Core tracking detector of CBM
  - momentum resolution $\Delta p/p \simeq 1.5\%$
  - hit efficiency $\gtrsim 95\%$
- Technical challenges:
  - ultra low material budget ($\simeq 8\%\, X_0$)
    - ★ electronics outside of acceptance
    - ★ connected to sensors with microcables
    - ★ double-sided sensors
  - occupancy up to $10\,\mathrm{MHz/cm^2}$
  - self-triggering electronics
  - hundreds of sensors to be checked:
    - ★ QA procedures are required
- Operational conditions:
  - $1\,\mathrm{T} \times \mathrm{m}$ magnetic field
  - constant temperature of $-5^\circ\,\mathrm{C}$ maintained

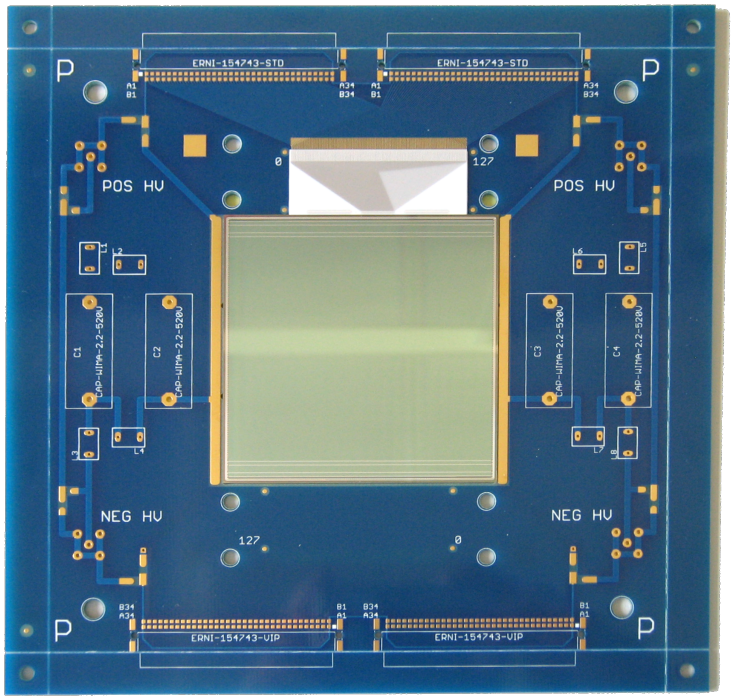
Silicon micro-strip sensors

- Sensor characteristics:
  - n-type silicon
  - double sided, 7.5° strip inclination angle on p-side
  - $300\,\mu\mathrm{m}$ thick, $58\,\mu\mathrm{m}$ pitch
  - required radiation hardness $2 \times 10^{14}\,1\,\mathrm{MeV}\,\mathrm{n_{eq}}/\mathrm{cm}^2$
- Two vendors: CiS, Hamamatsu



photos of A. Lymanets

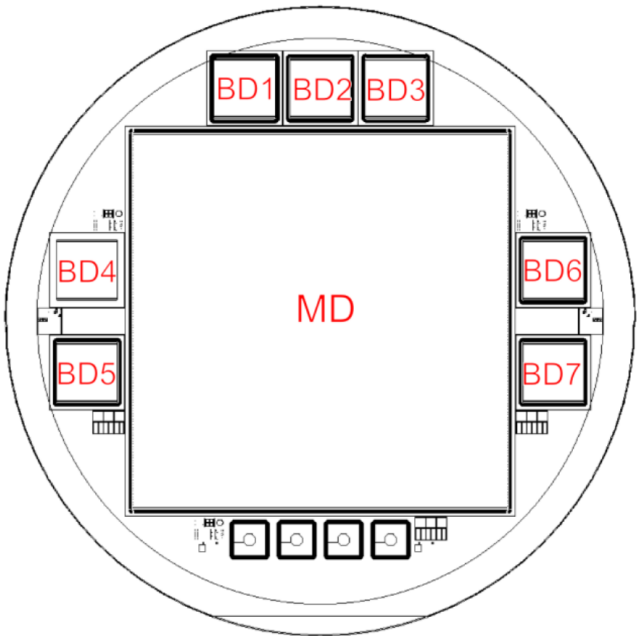
$6.2 \times 6.2\,\mathrm{cm}^2$ microstrip sensor inside the supporting PCB frame



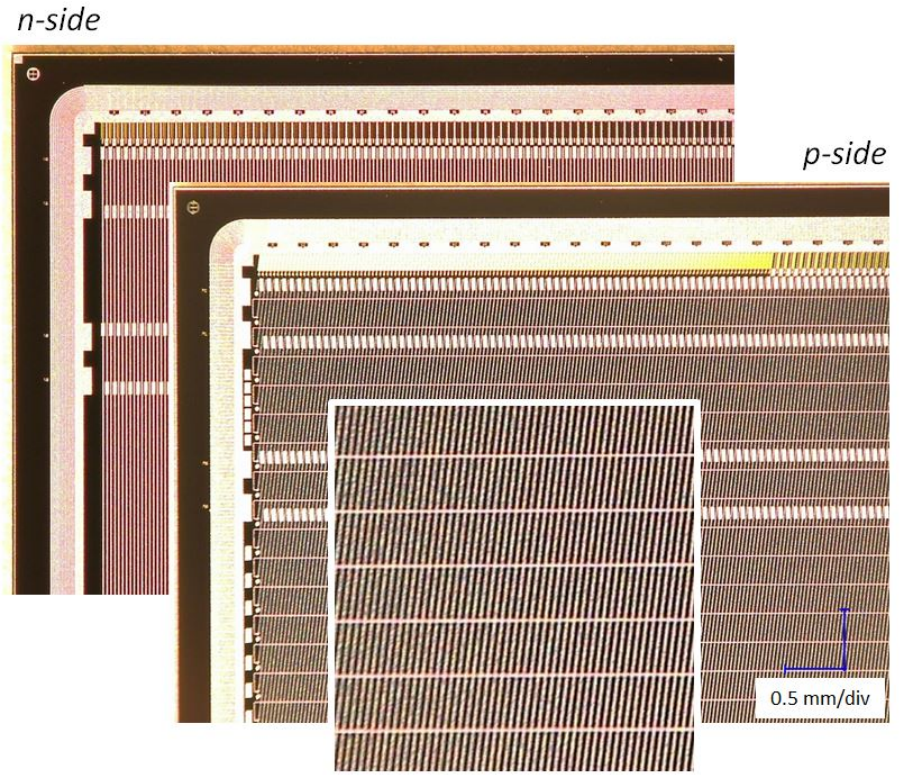
- Various sizes ($\simeq 1000$ in total):
  - $2.2 \times 6.2\,\mathrm{cm}^2$ (tens)
  - $4.2 \times 6.2\,\mathrm{cm}^2$ ($\simeq 300$)
  - $6.2 \times 6.2\,\mathrm{cm}^2$ ($\simeq 300$)
  - $12.4 \times 6.2\,\mathrm{cm}^2$ ($\simeq 300$)

Quality assurance by vendors

- Production procedure (and QA)
  1. wafer etching
  2. electrical tests ($< 400\,\mathrm{V}$ CiS, $< 200\,\mathrm{V}$ Hamamatsu)
     - ★ current-voltage (IV), capacitance-voltage (CV), pin-holes, bad strips...
  3. dicing (laser, diamond)
  4. electrical tests (CiS, optional)



CiS wafer layout for $6.2 \times 6.2\,\mathrm{cm}^2$ sensors



corner view of CiS sensors

- More QA performed by vendors:
  - contra: it costs money
  - pro: it saves our manpower
- Though cross-check is required (can be $\simeq 10\%$)

QA scheme

Pre-production stage: 100% of sensors tested at Quality Assurance Centers

Production stage: 5–10% + suspicious sensors from optical inspection to be tested

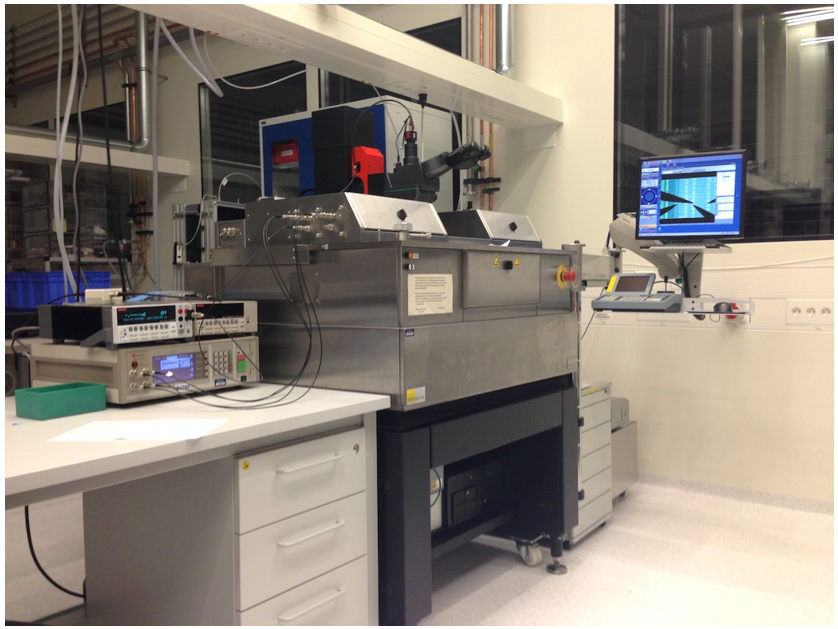
- 1% of sensors to be characterised in-depth (verify QA by vendors)

- QA centres:
  - GSI, Darmstadt
    - ★ electrical tests
    - ★ tests with radiation source (sensor R&D, module tests)
    - ★ tests with infrared laser (sensor R&D, module test)
  - University of Tübingen
    - ★ electrical tests
    - ★ optical inspection
  - JINR, Dubna
    - ★ electrical tests

Butches of sensors to be split between centres during mass production

Electrical tests

GSI probe station



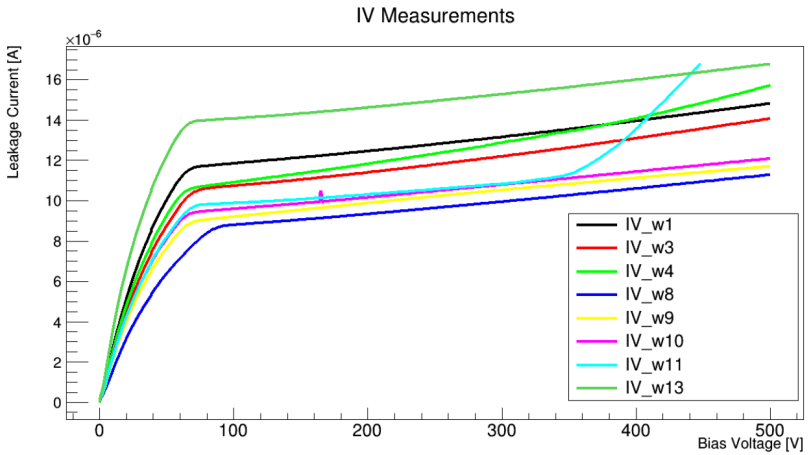
GSI probe station (customised by P. Larionov)

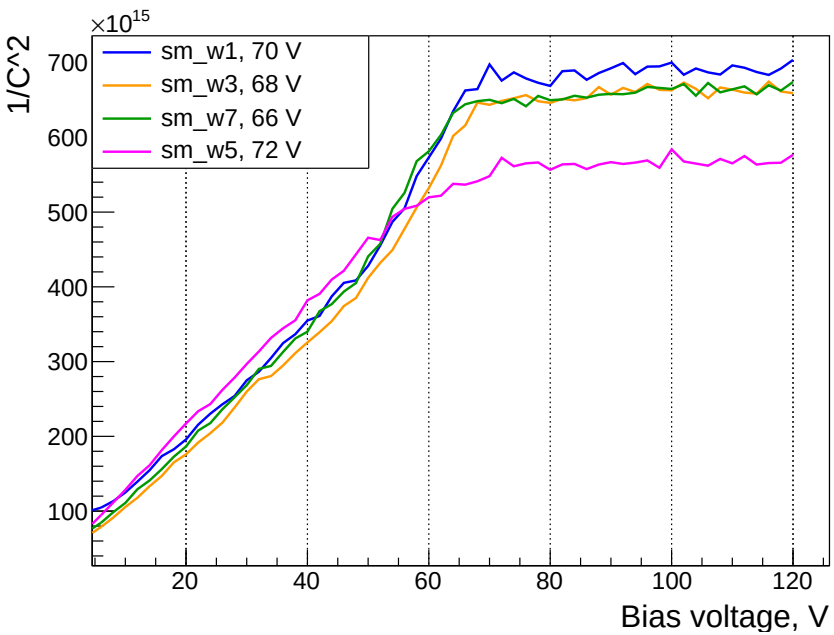
- Süss PA300PS probe station
  - $1\ \mu\mathrm{m}$ movement precision in X-Y-Z directions
  - chuck rotation option (covers $\pm 7.5^\circ$)
  - temperature and humidity control
  - needles with $5\ \mu\mathrm{m}$ tips

- Keithley 2410 SourceMeter $V < \pm 1100\,\mathrm{V}$, $\Delta I = 10\,\mathrm{pA}$
- Keithley 6487 picoammeter/voltage source, $I = 2\,\mathrm{nA} - 20\,\mathrm{mA}$, $V = 505\,\mathrm{V}$
- QuadTech 7600 precision LCR-meter $V_{\mathrm{bias}} = 500\,\mathrm{V}$, $f = (10^{-4} - 2)\,\mathrm{MHz}$, 0.05% accuracy
- Keithley 708B 8×12 switching matrix (up to $1100\,\mathrm{V}$)
- LabView based software:
  - pinhole
  - strip current
  - coupling capacitance

Electrical tests

examples of IV and CV curves from GSI





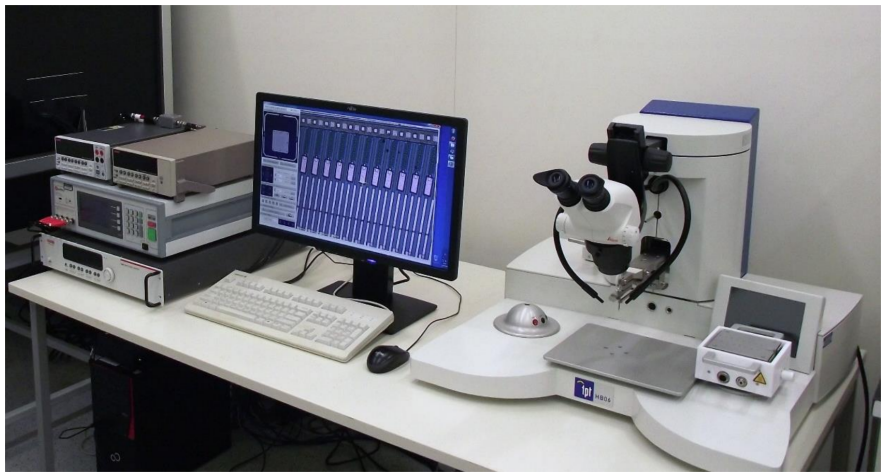
- IV tests of C6 generation, batch 350191
  - kink indicates full depletion
  - cyan line shows break down
  - noise proportional to dark current
- CV tests of CiS sensors
  - saturation of $1/C^2$ indicates full depletion
  - charge collection inversely proportional to the bulk capacitance
- Validation of tests of vendors
- signal$\sim 1/C$, noise$\sim I$

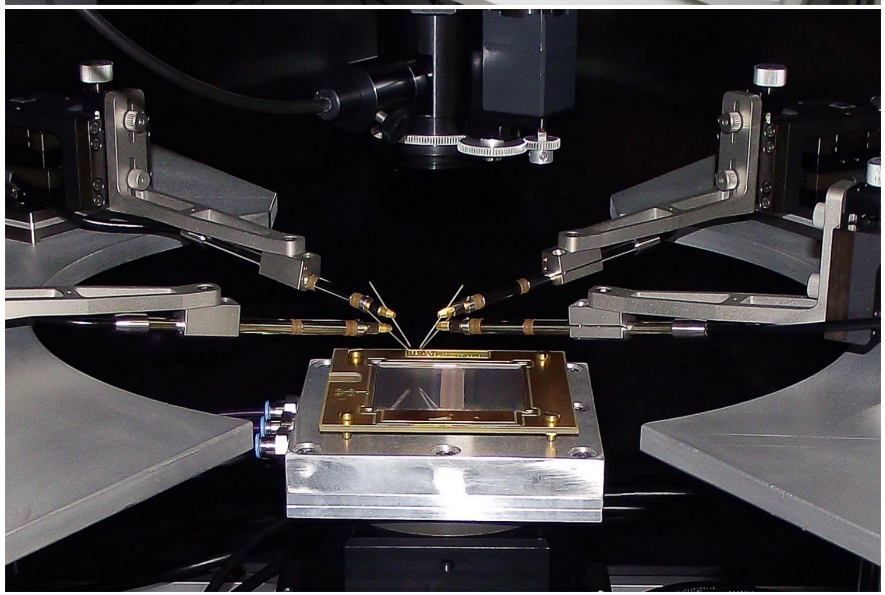
Electrical tests

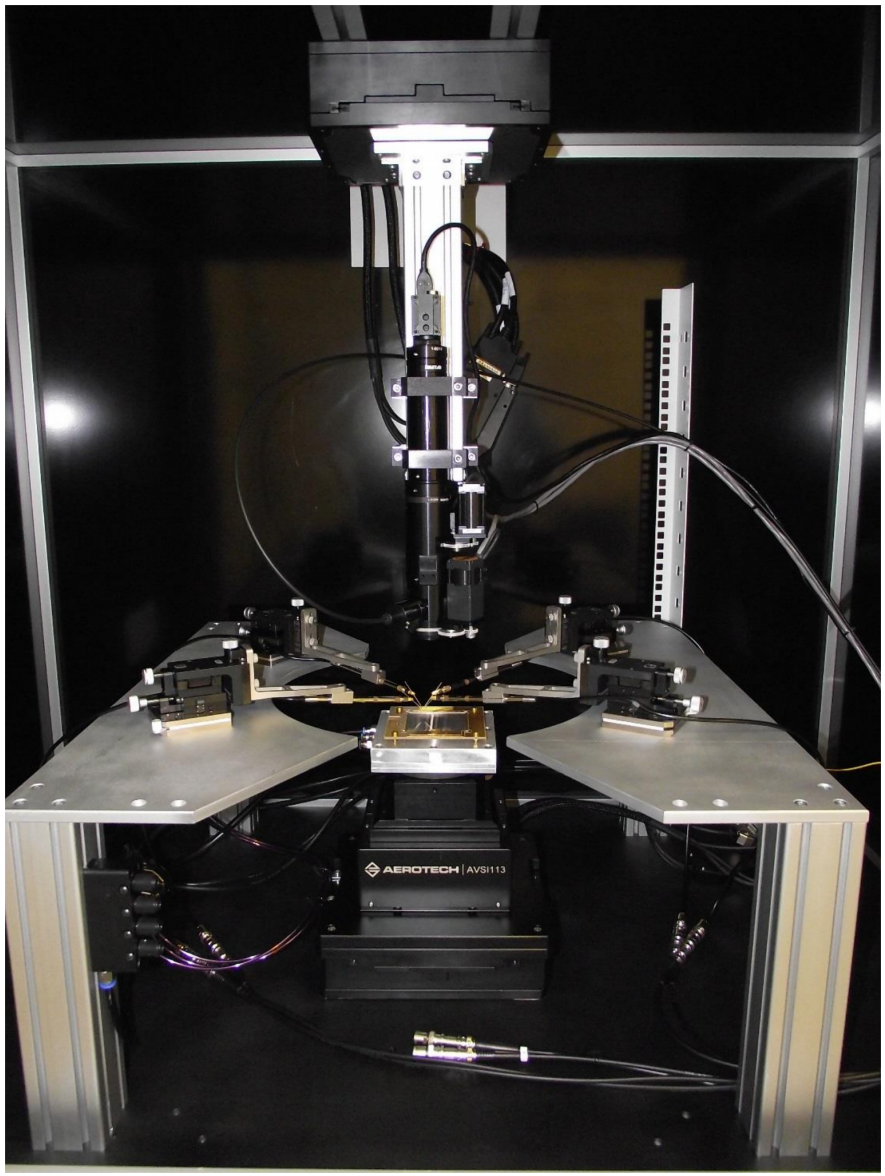
in Tübingen University

Custom made prob station:

photos of Ia. Panasenko

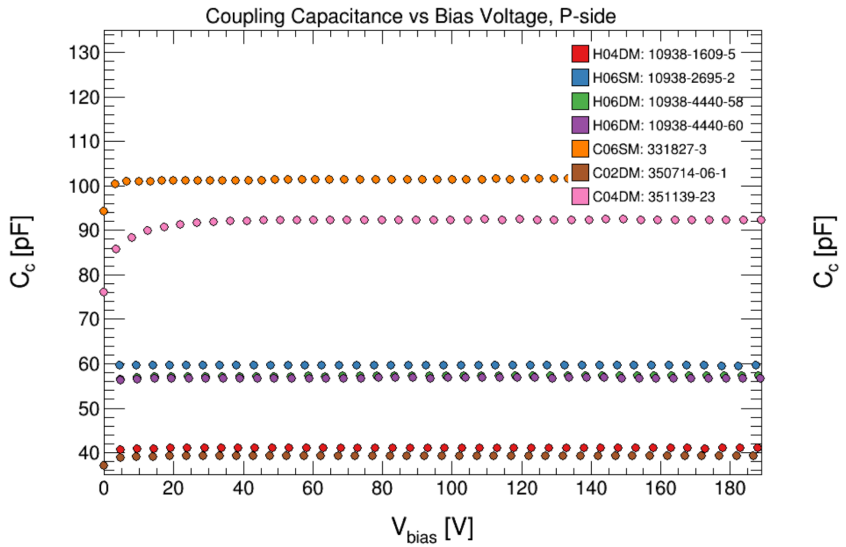


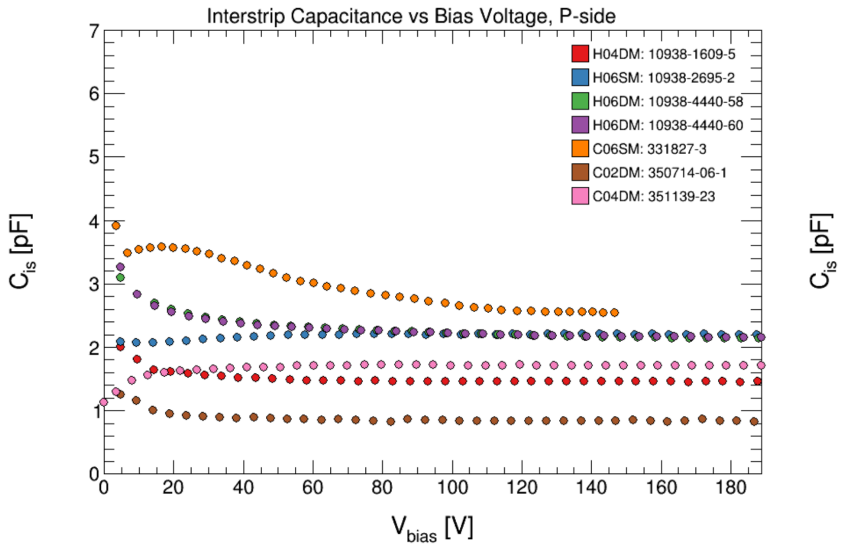


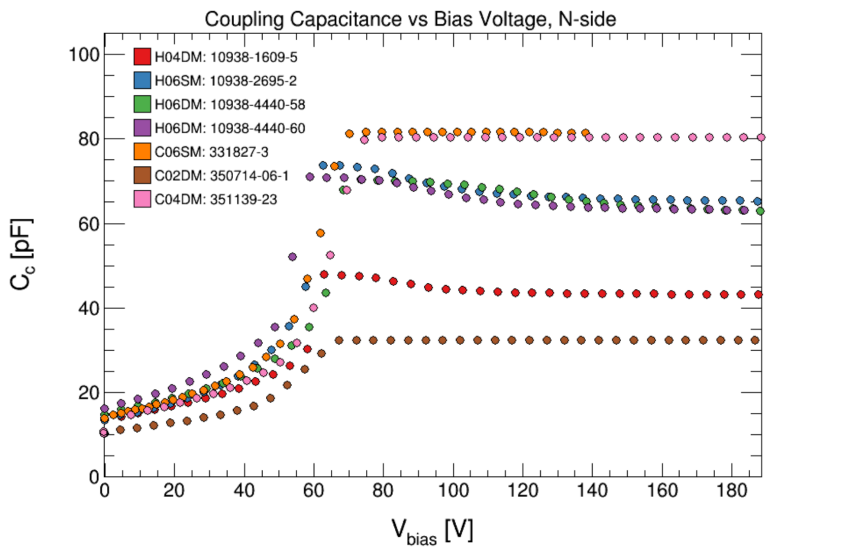


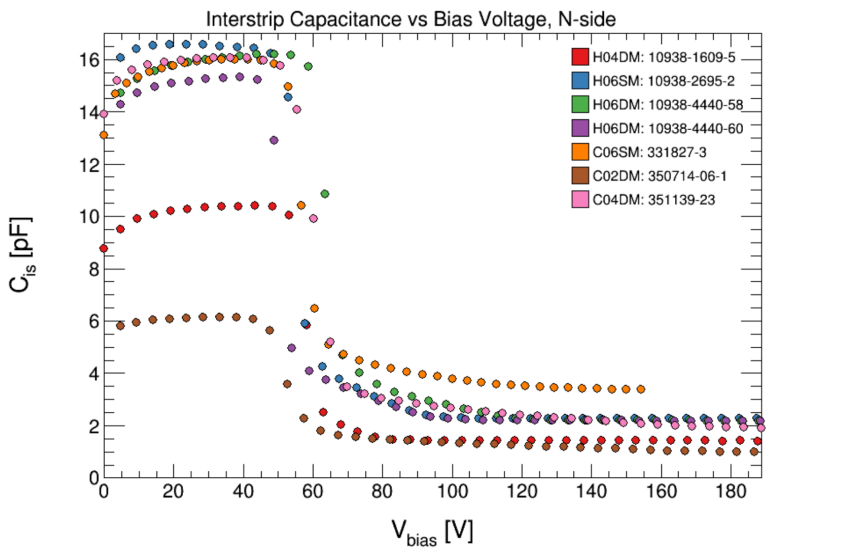
Individual strip tests in Tübingen University

interstrip capacitance vs bias voltage





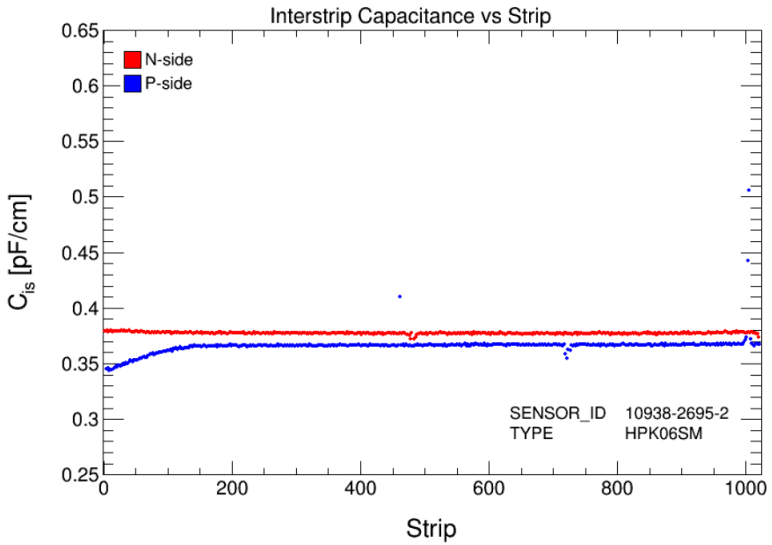


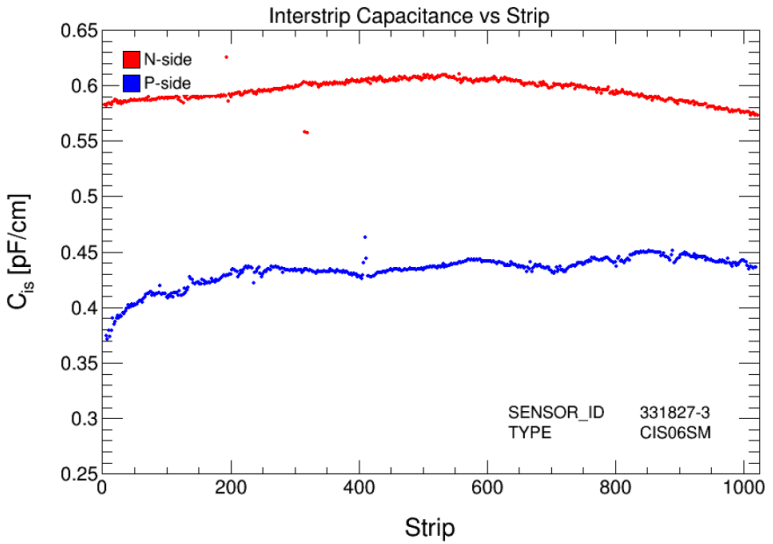


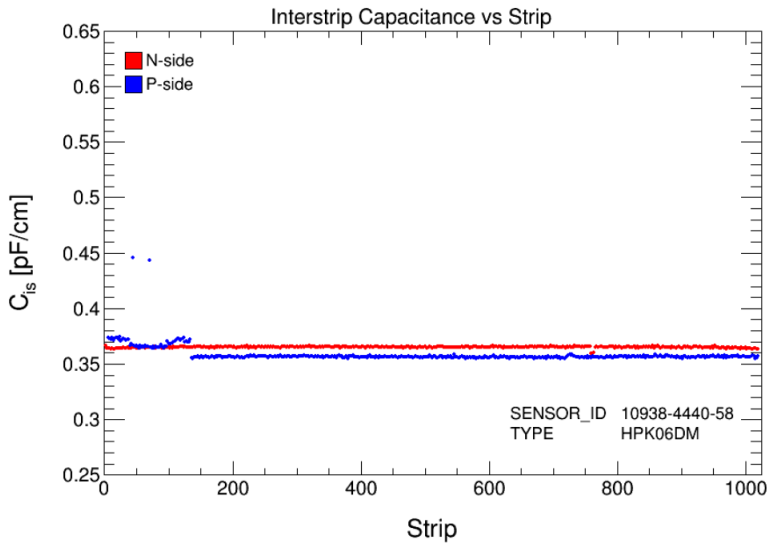
plots of Ia. Panasenko

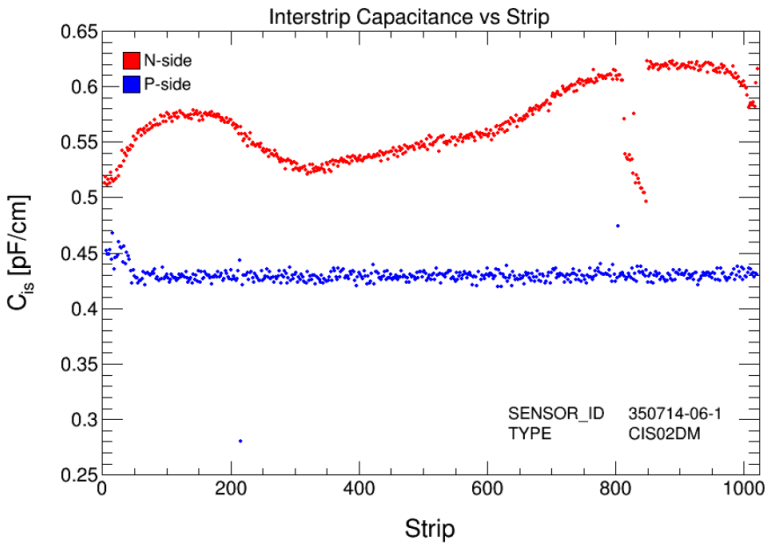
Individual strip tests in Tübingen University

interstrip capacitance per strip





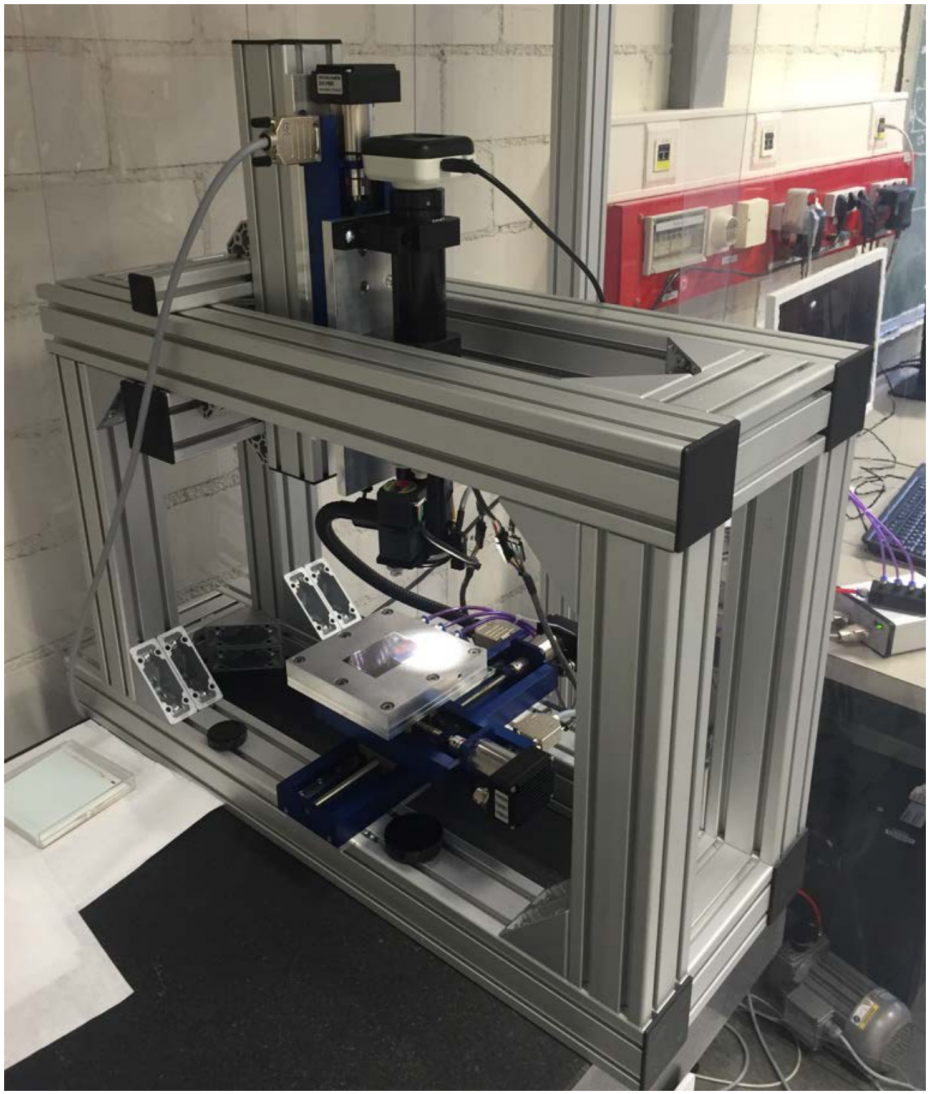




plots of Ia. Panasenko

Optical inspection setup

- Flexible design
  - inspection of different objects (different sensor size/types)
  - micro-cable inspection
- Low hardware dependence, adaptable to almost any hardware
- Configurable QA procedures as plugins
- Report building, storage, viewing and manipulations
- Constant improvement of performance
  - inspection times 1 hour $\rightarrow$ 4 min per sensor side

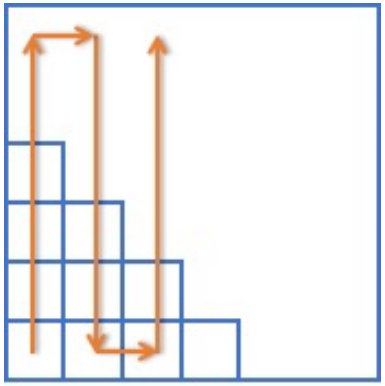


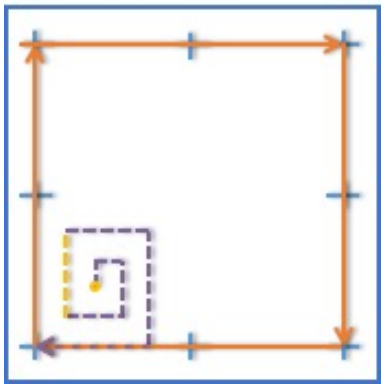
photos and further plots of E. Lavrik

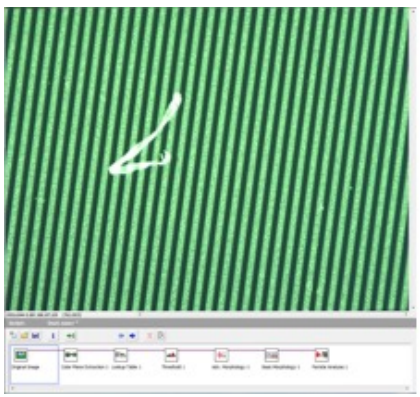
Optical inspection setup

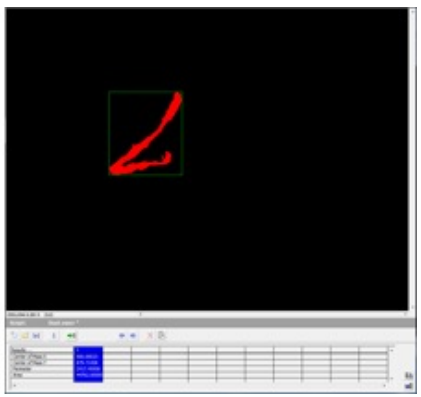
setup capabilities

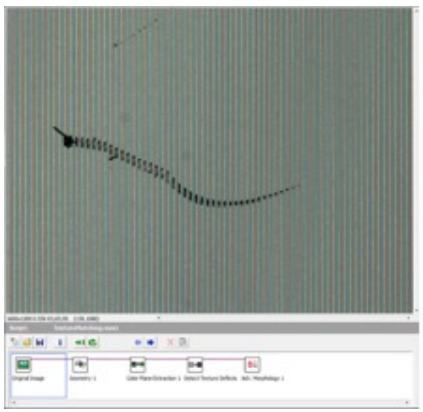
- Possible to detect:
  - dust particles and other foreign objects on the surface
  - scratches
  - single element integrity
    - ★ bias resistors
    - ★ strips
    - ★ pads
    - ★ guard ring
  - sensor edge defects & parallelity
  - possible any deviation from clean pattern (pattern/texture matching)







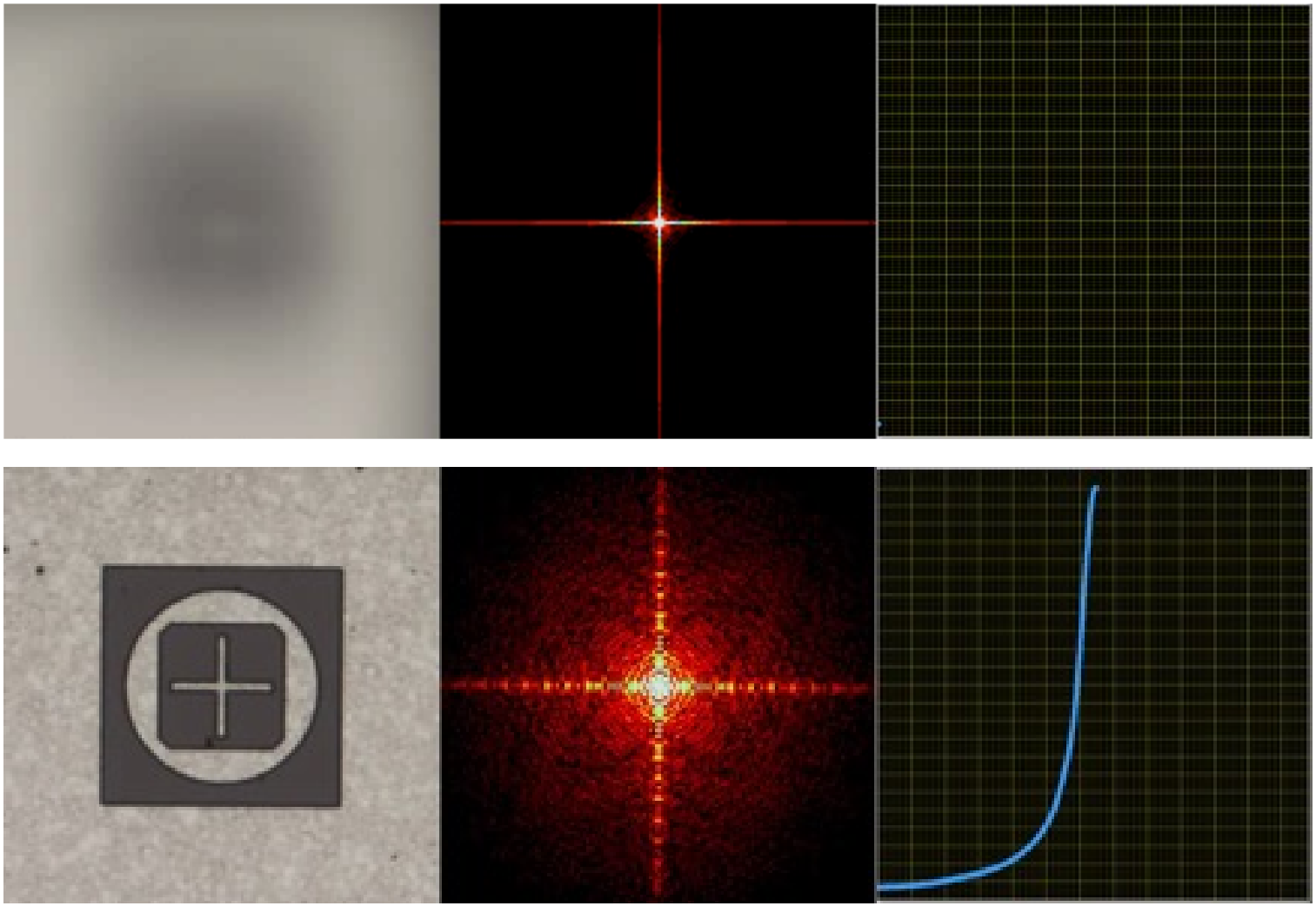




Optical inspection

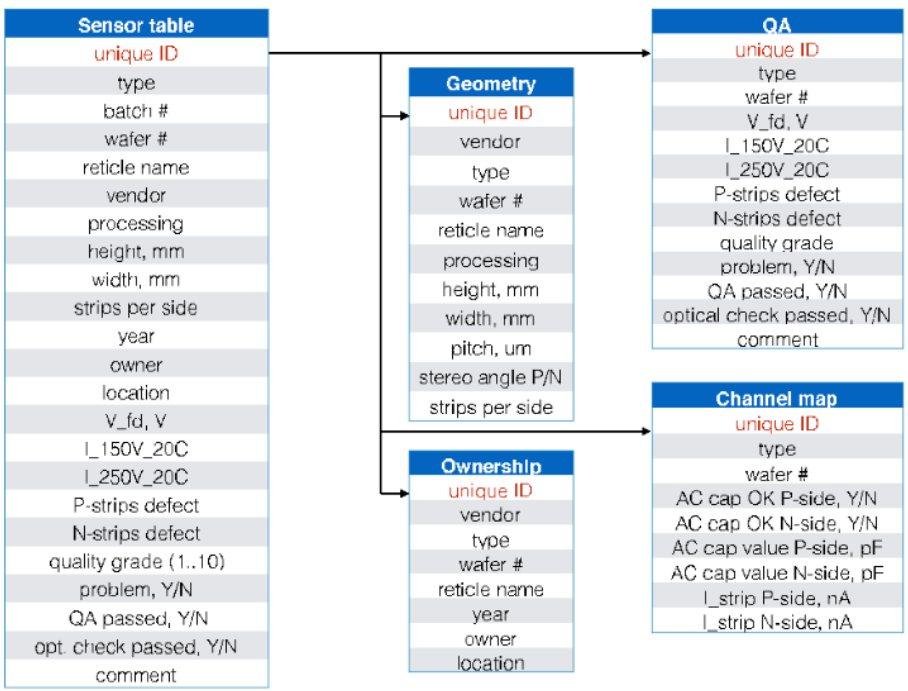
auto-focusing

Source image at different focus values, Fourier transformed image and total amplitude of transformed image ($\simeq 1/3\,\mu\mathrm{m}$ focusing precision):



Database

- Reports formed during analysis to be stored in Database
- Centralised data storage for CBM–FairDB
- 1 full inspection is 12.2 GB per 6×6 sensor (n and p sides)
- Up to 40 TB of images needs to be stored $\rightarrow$ tape storage gStore at GSI
- Database interfaces are currently being developed



picture of D. Bertini

Conclusions

- Three Quality Assurance centres: GSI, Tübingen Univ., JINR
- Quality Assurance procedures to be developed before mass production of sensors
- Cross-check of information, provided by vendors
  - all sensors undergo optical inspection
  - suspicious items and random $1/10$ undergo electrical tests
- Though electrical tests may be harmful: optical inspection preferable
- Database development is in progress
  - QA data to be stored and then easily accessed
- Currently, QA setups helps to perform sensor R&D

Back-up slides

Parameters measured by CiS

The following parameters are checked during quality assurance at CiS:

- current-voltage (IV) and capacitance-voltage ($1/C^2$ vs. V) curve IV up to $250\ V$, if possible up to $400\ V$: while still on wafer and also after dicing.
- Check for depletion voltage $U_{depl} < 90\ V$.
- Check for leakage current $I_{leak} < 50\mu A$ at $U_{depl} = +10V$
- Bulk resistivity (R measurement)
- Strip test, on all strips (p and n sides, pin-holes, shorts to neighbors, interrupts), at 20 V
- Check for leakage current per strip $< 2nA$ (a typical normal performance value),
- On a few strips: strip isolation
- Random sample of Poly-Si resistors (R = 1 MΩ)
- A detailed documentation of the test data is supplied.

Parameters measured by Hamamatsu

At Hamamatsu, the following parameters are checked:

- current-voltage (IV) and capacitance-voltage (CV) curve, up to $200V$
- estimation of the full-depletion voltage
- strip test: all strips (p and n sides, including the corner strips; AC aluminum open, AC aluminum short), at 30 V.
- the double-metal routing lines cannot be tested directly but a fault may show up as an abnormal value of the strip's capacitance.
- check of one sensor per batch for the value of the polysilicon resistor pattern, on p and n-sides; determination of minimum and maximum and average value.

Finally:

- The sensors are shipped diced ("stealth dicing", i.e. using a laser) and packaged in clean room paper envelopes that are tightly arranged in a box.
- A detailed documentation of the test data is supplied.

How to measure