Metallization of the EMCM 3 & 4 wafers

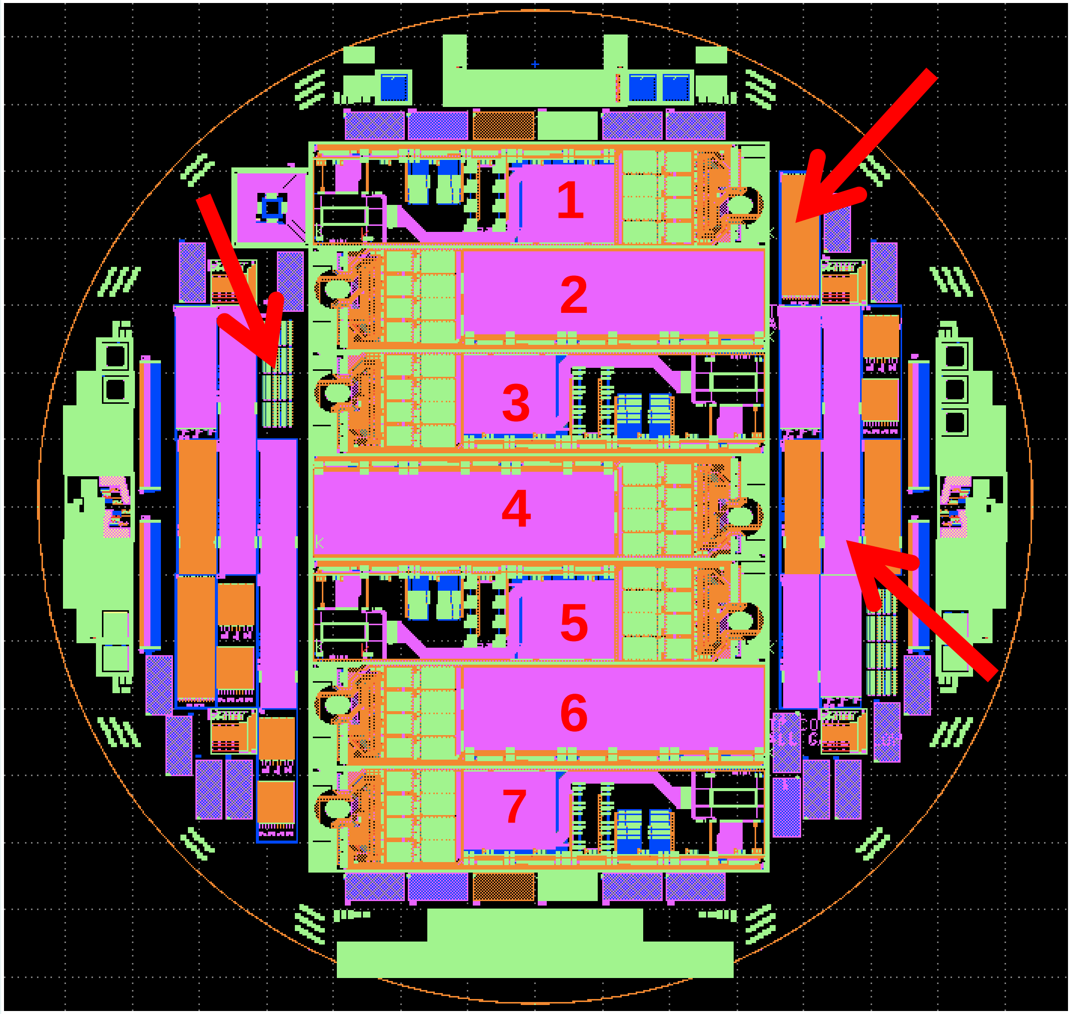
7th International Belle II VXD Workshop
18th International Workshop on DEPFET Detectors and Applications

Daniel Klose
for the HLL team

Outline

- EMCM wafer
- Metallization
- Defects
- Test structures, test strategies and results
- Summary and conclusion

EMCM wafer layout

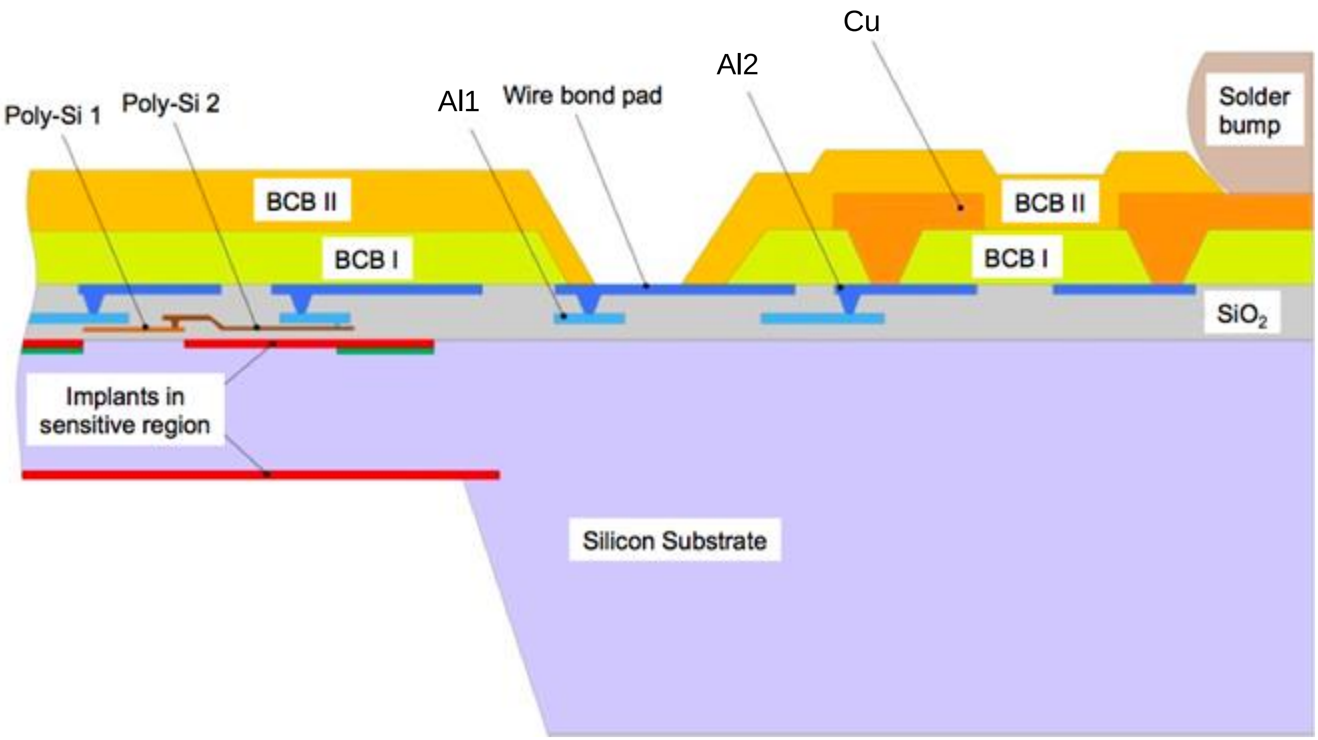


1. **EMCM 3/4 CH1**: EMCM w/o diff. clock
2. **1**: PXD9-like
3. **EMCM 3/4 CH2**: EMCM w/o diff. clock
4. **2**: PXD9-like
5. **EMCM 3/4 CH3**: EMCM w diff.clock
6. **3**: PXD9-like
7. **EMCM 3/4 CH4**: EMCM w diff. clock

Plus:

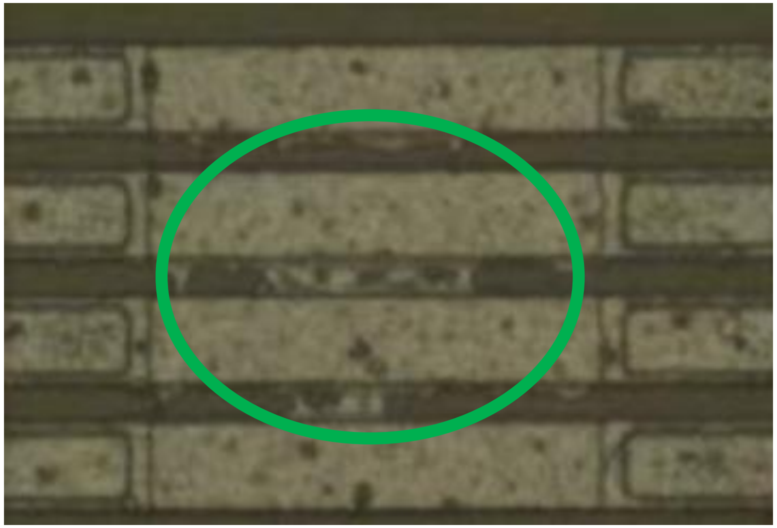
- 5 contact chain structures
- 10 comb structures
- 2 Kelvin structures

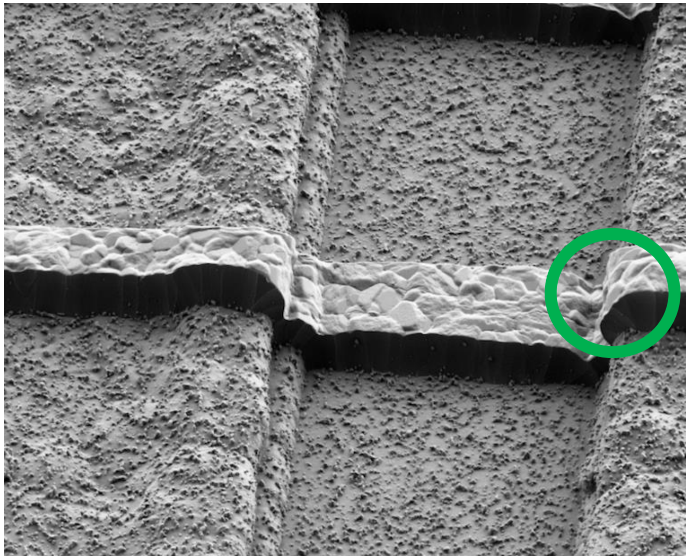
Metallization

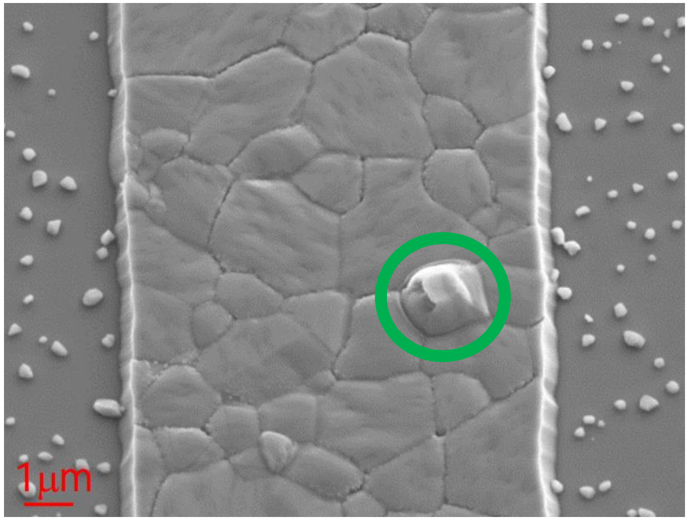


- Metallization done layer by layer with alternating of dielectric and routing material (Al1, Al2 and Cu)
- SiO_2 & BCB (BenzoCycloButene) as dielectrics between the layers
- Connection between the layers done per vias/ contacts
- Poly1 & Poly2 not present on EMCM

Defects



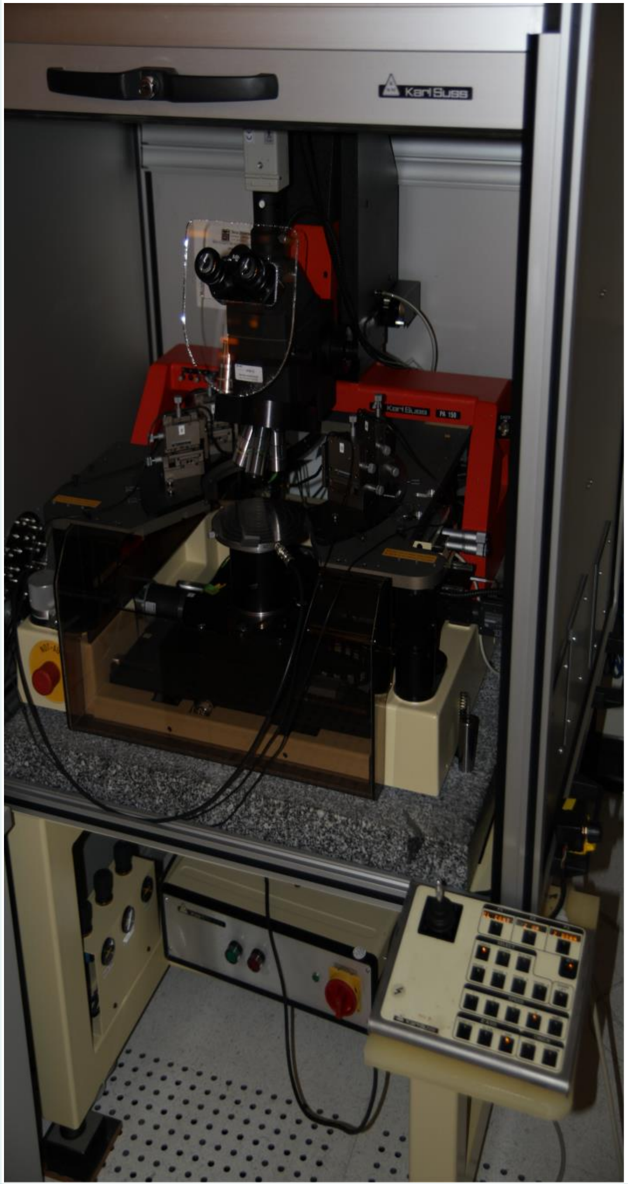


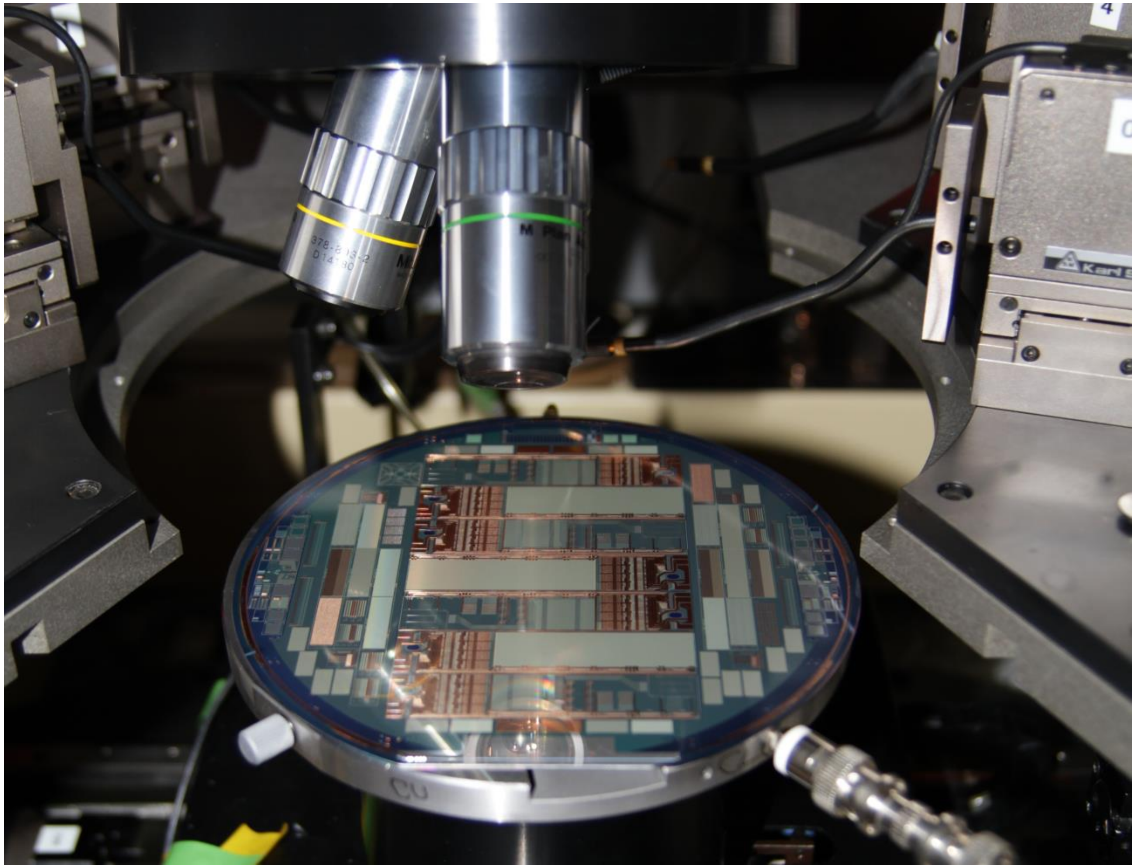


- Lateral shorts (Stringers)
- Discontinuities (Topographie)

- Hillocks
- Etching of contacts might lead to missing contacts
- Breakdown of the dielectric

Experimental setup





- Left: semiautomatic probe station PA 150, with Keithley 4200 and up to 4 out of 6 SMUs (Source Measurement Unit)
- Right: wafer with EMCM modules and test structures to verify different aspects of the processing steps

EMCM 3 & 4 production

EMCM	Wafer no.	Type	ILD thickness type
EMCM3	17	Standard	A
EMCM3	18	Standard	A
EMCM4	24	SOI	A
EMCM4	25	Standard	A
EMCM4	26	Standard	A
EMCM4	27	Standard	A
EMCM4	28	Standard	A
EMCM3	29	Standard	B
EMCM3	30	Standard	B
EMCM3	31	Standard	C
EMCM3	32	Standard	C

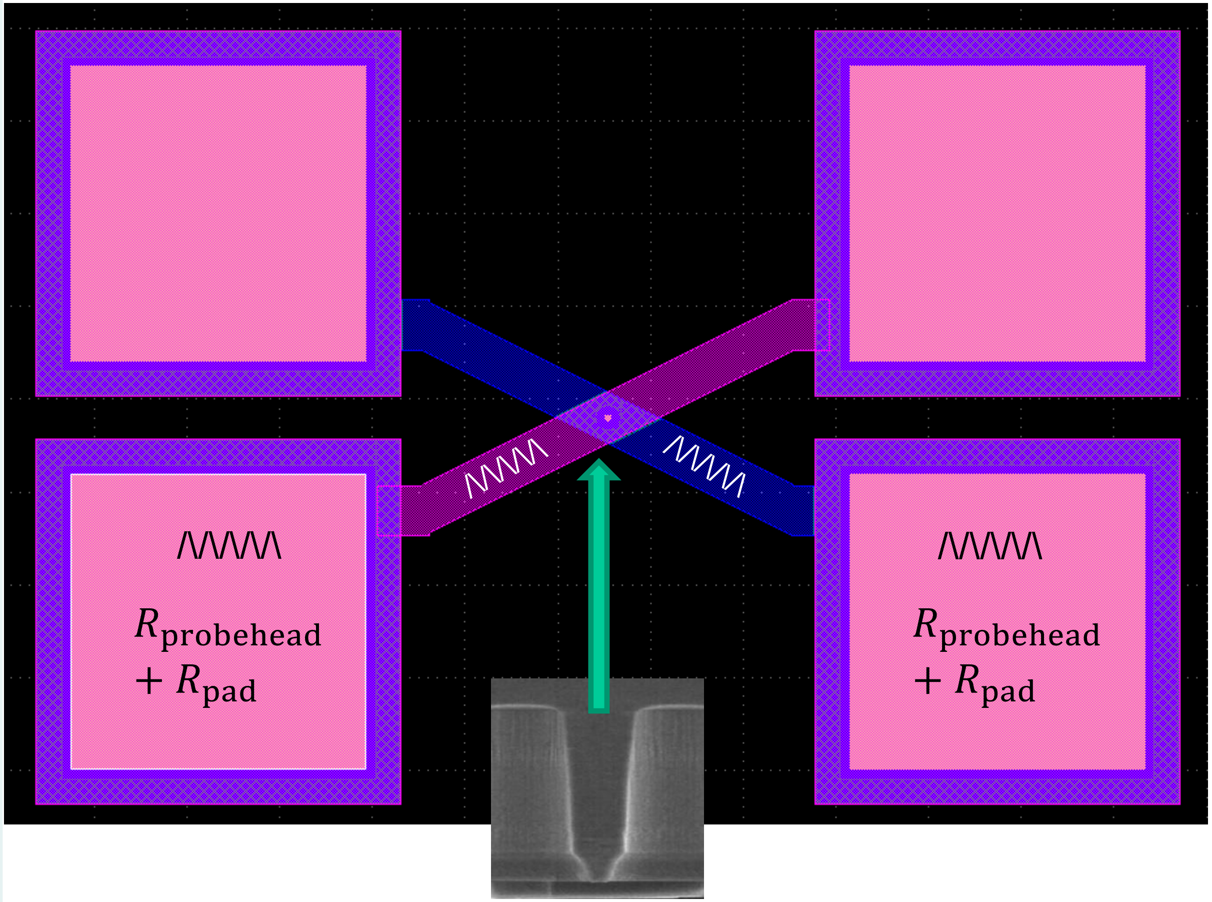
- All EMCM 3 & 4 wafers have the same layout

- ILD (inter layer dielectric) thicknesses/ types: A < B < C
  type A chosen for PXD9 production

- 6 EMCM3 wafers
- 5 EMCM4 wafers

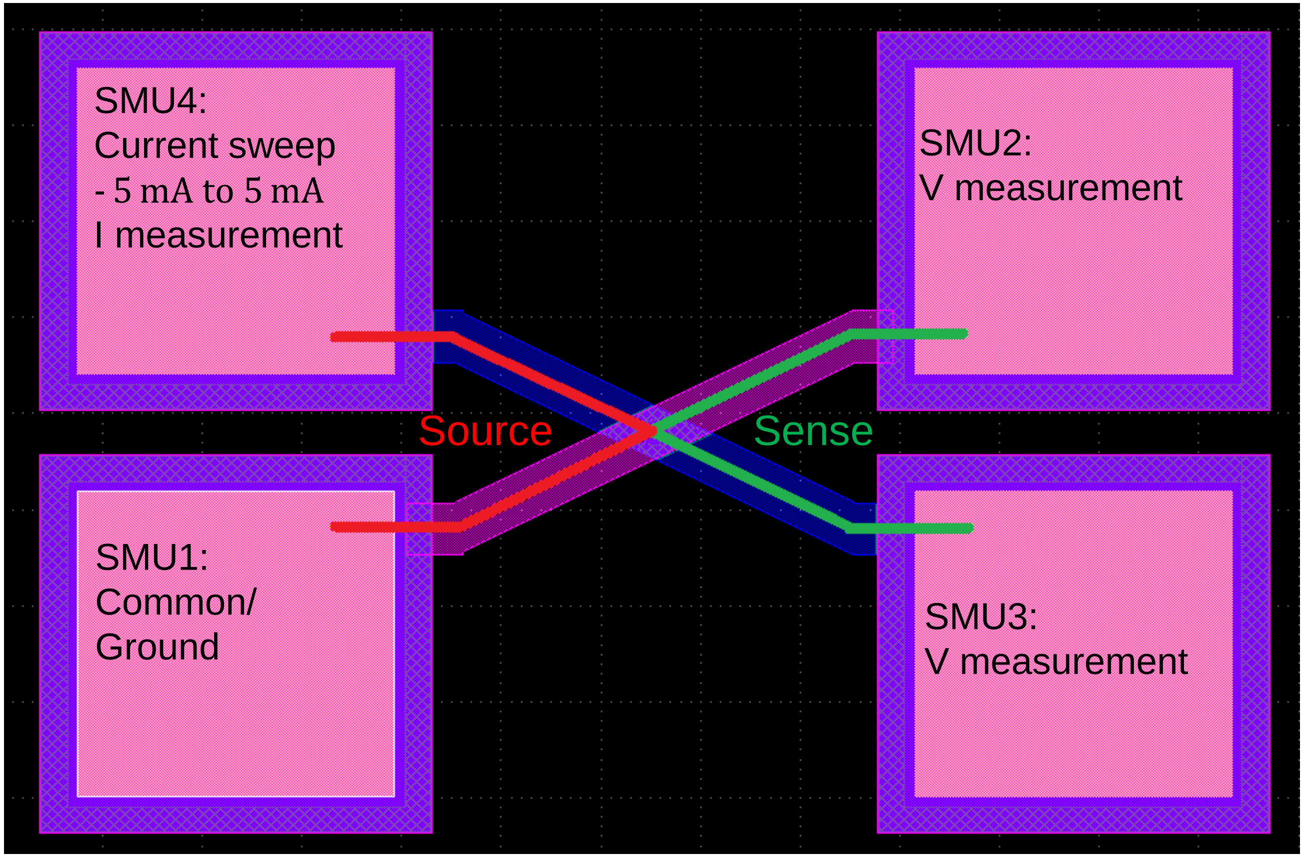
- Total number of contacts in one PXD9 module ≈ 264000

Kelvin structures – normal resistance test



- Purpose of the Kelvin structure: Precision measurements of the resistance of different contact sizes
- Kelvin measurement = Four wire measurement!
- Left:
  - One contact in a Kelvin structure
  - The resistance of all the elements sums up >> contact resistance

Kelvin structures – Four wire measurement



SMU4:
Current sweep
- 5 mA to 5 mA
I measurement

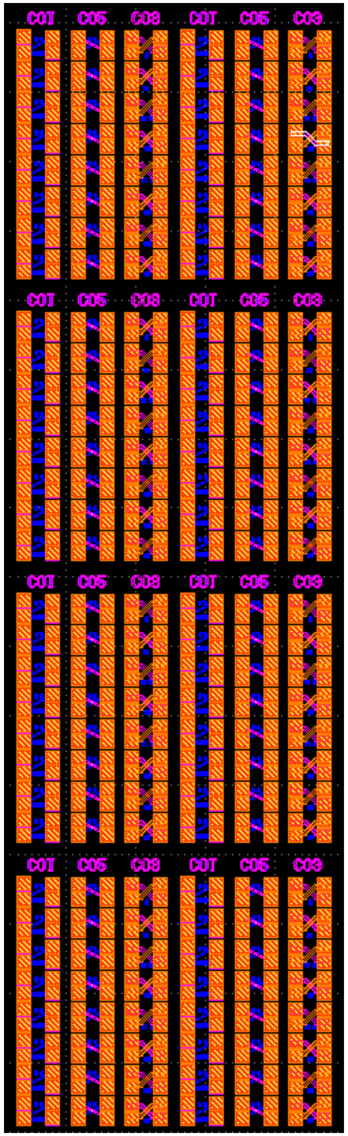
SMU2:
V measurement

Source

Sense

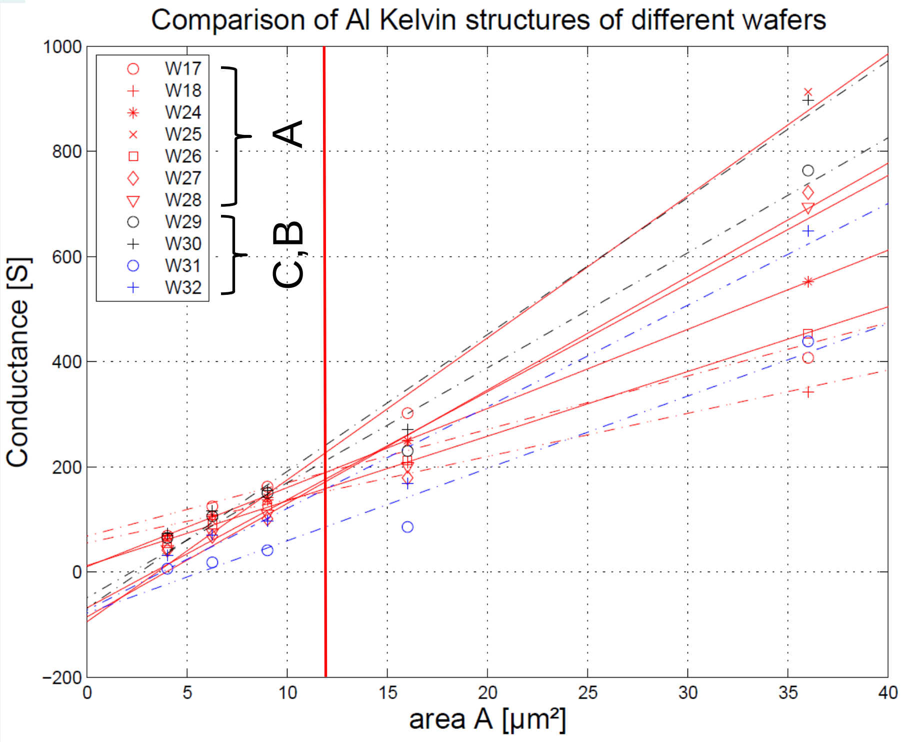
SMU1:
Common/
Ground

SMU3:
V measurement

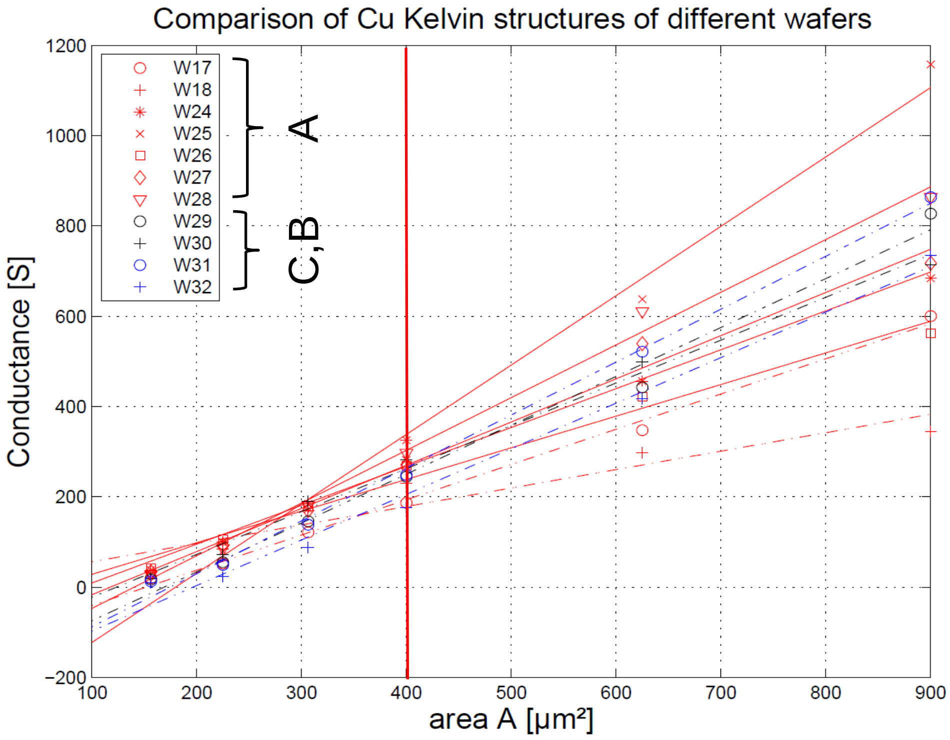


- Red: Source line delivers the current
- Green: Sense line measures the voltage. Just a small current in the sense line
  - ➢ Low voltage drop at the contact
  - ➢ Just the resistance of the contact is measured
- Right: array of Kelvin structures

Results Kelvin structures



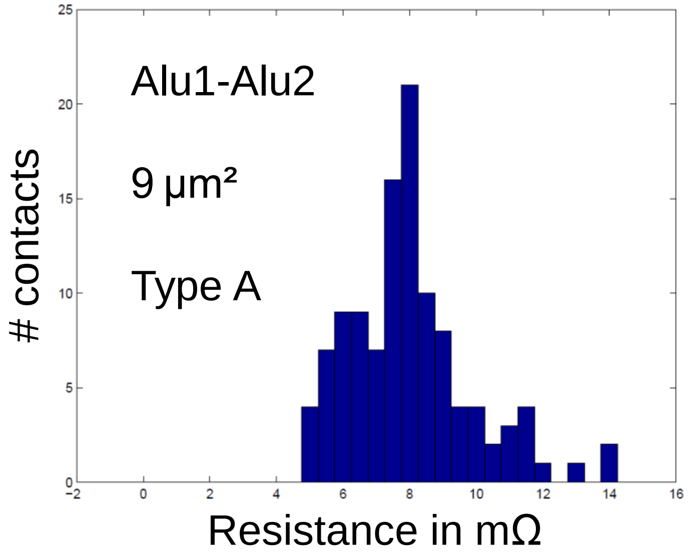
Comparison of Al Kelvin structures of different wafers

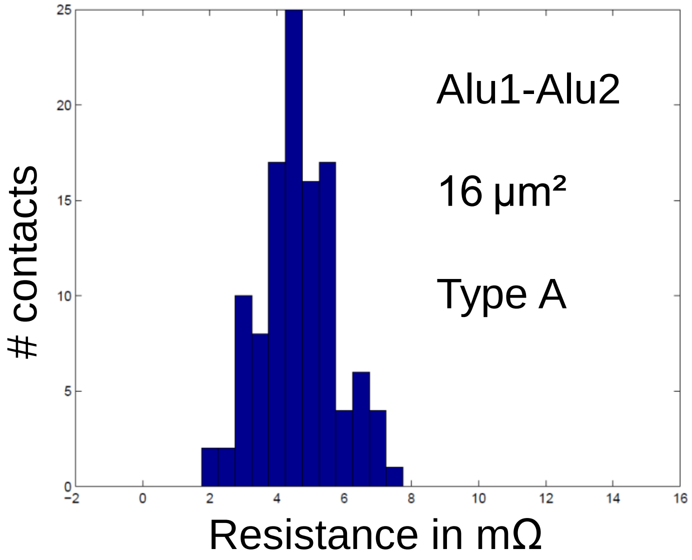


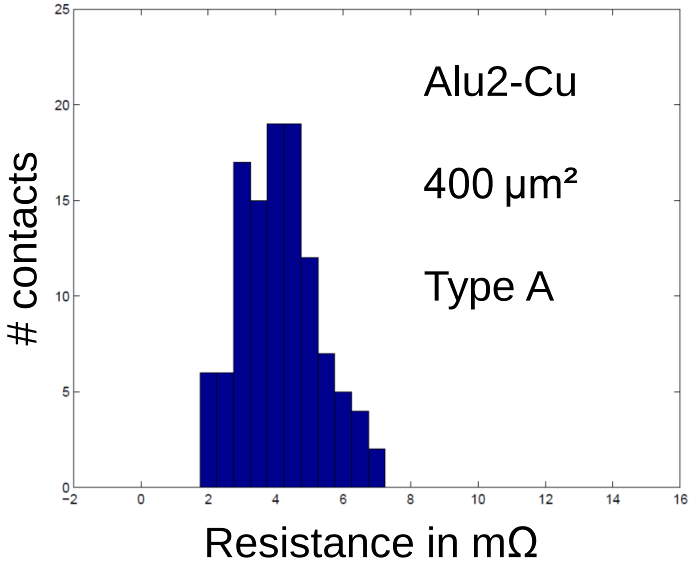
Comparison of Cu Kelvin structures of different wafers

- Mean value of the conductance per wafer ∝ area of the contact
- Red bar: chosen contact size for PXD9
- Different technologies don't seem to have a huge impact on these structures
  - Dash dotted lines belong to the EMCM3 wafers with different technologies
  - Solid lines refer to EMCM4 wafers with the same technology

Results Kelvin structures

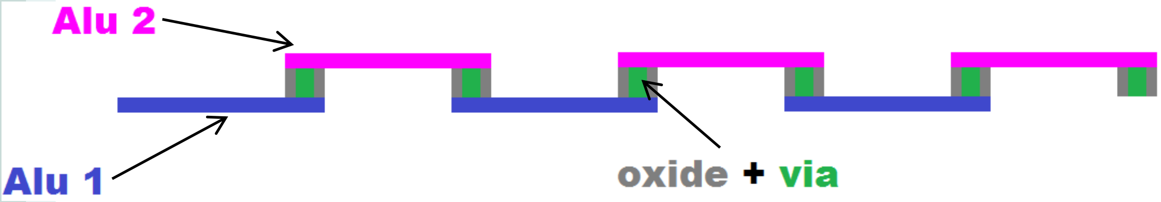


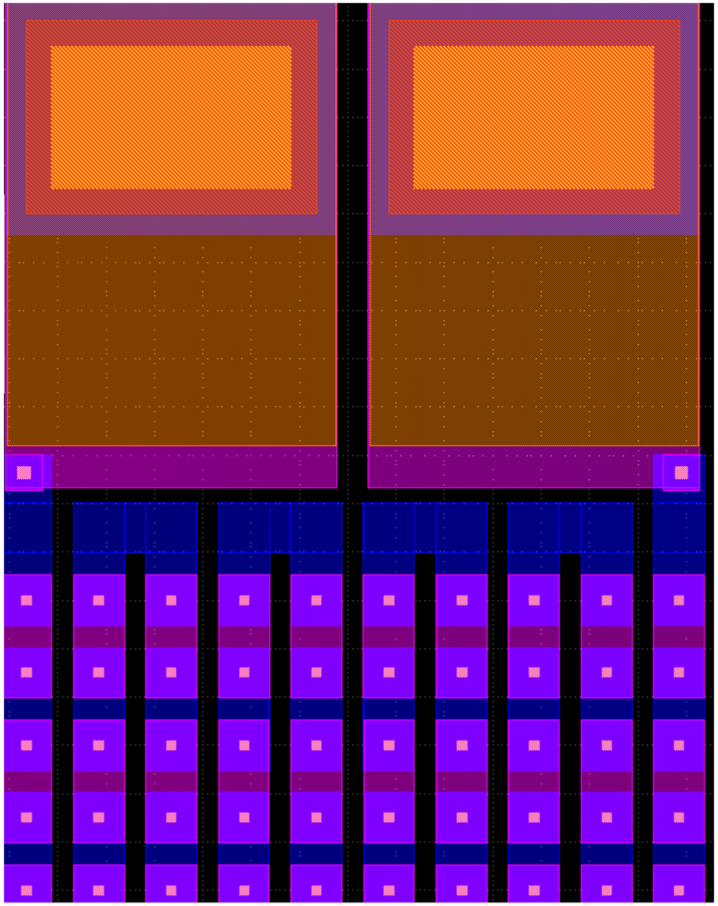




- Resistance in the desired range of just a few mΩ
- All contacts are closed for the chosen contact sizes = yield of 100%
- 112 contacts of same size measured on the 7 type A wafers

COntact CHain (COCH) structure

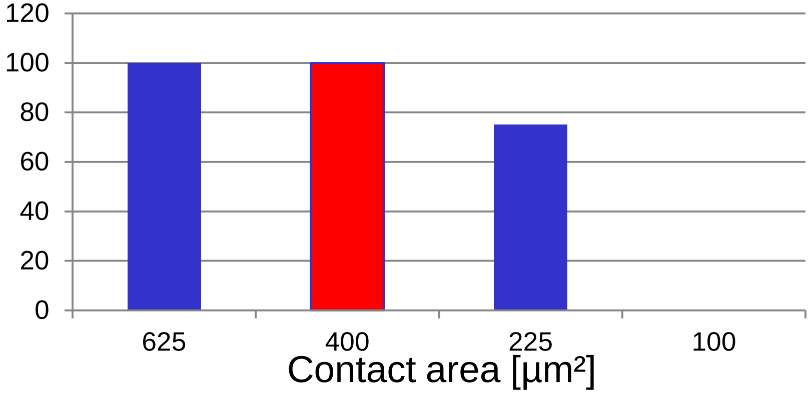




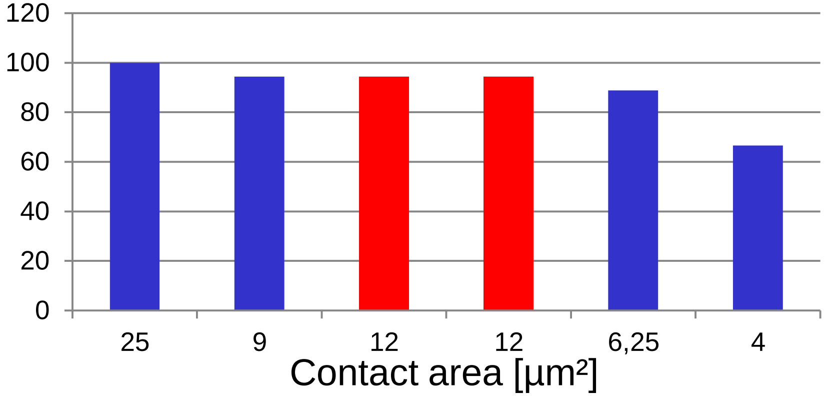
- Purpose of the COCH structure:
  - Testing the reliability of the contact sizes with good statistics: 1500 contacts (Al2-Cu) or 3500 contacts (Al1-Al2)
  - This gives information on the quality of the processing

Yield of the COCH structure

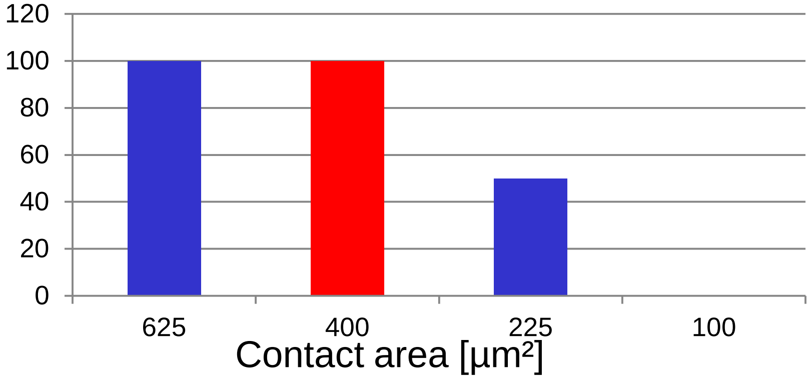
Yield EMCM3 Al2-Cu, type A



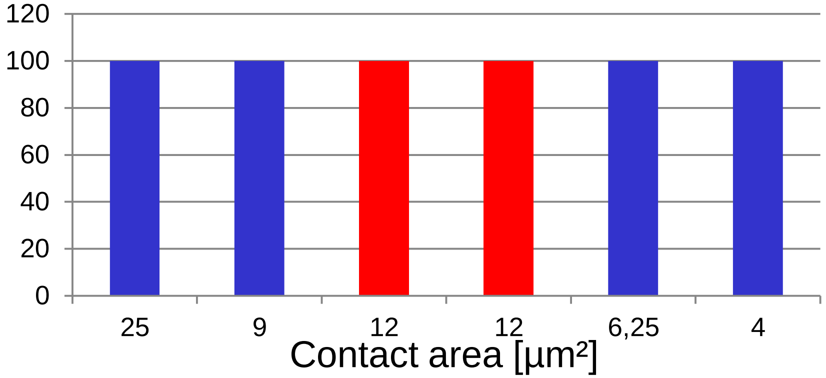
Yield EMCM3 Al1-Al2, type A



Yield EMCM4 Al2-Cu

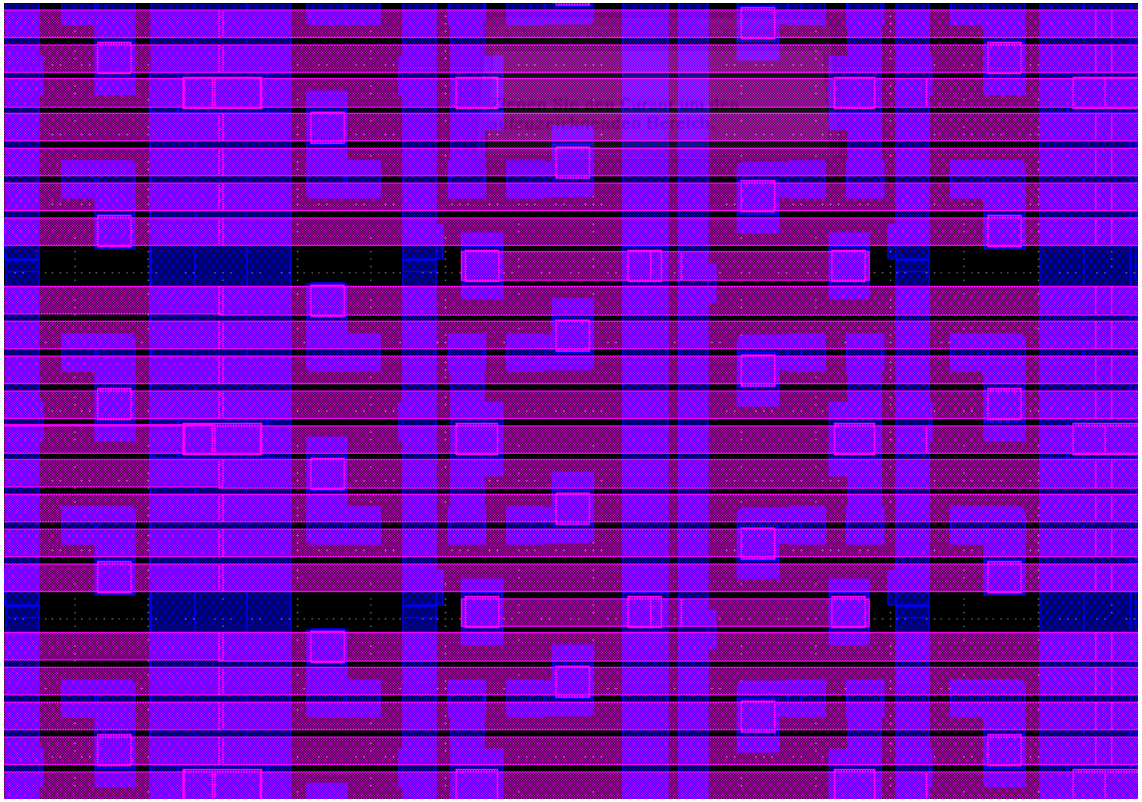


Yield EMCM4 Al1-Al2



- Red bars: The chosen contact sizes 400 µm² (Al2-Cu) and 12 µm² (Al1-Al2) are safe for PXD9 also in the COCH structure
- $\mathrm{Rel}_{\mathrm{al1-al2\_contacts}} \approx$ 1.16 (Al1-Al2) (EMCM3), $\mathrm{Rel}_{\mathrm{al1-al2\_contacts}} \approx$ 1.00 (Al1-Al2) (EMCM4)
- Threshold for broken chain: 1 kΩ

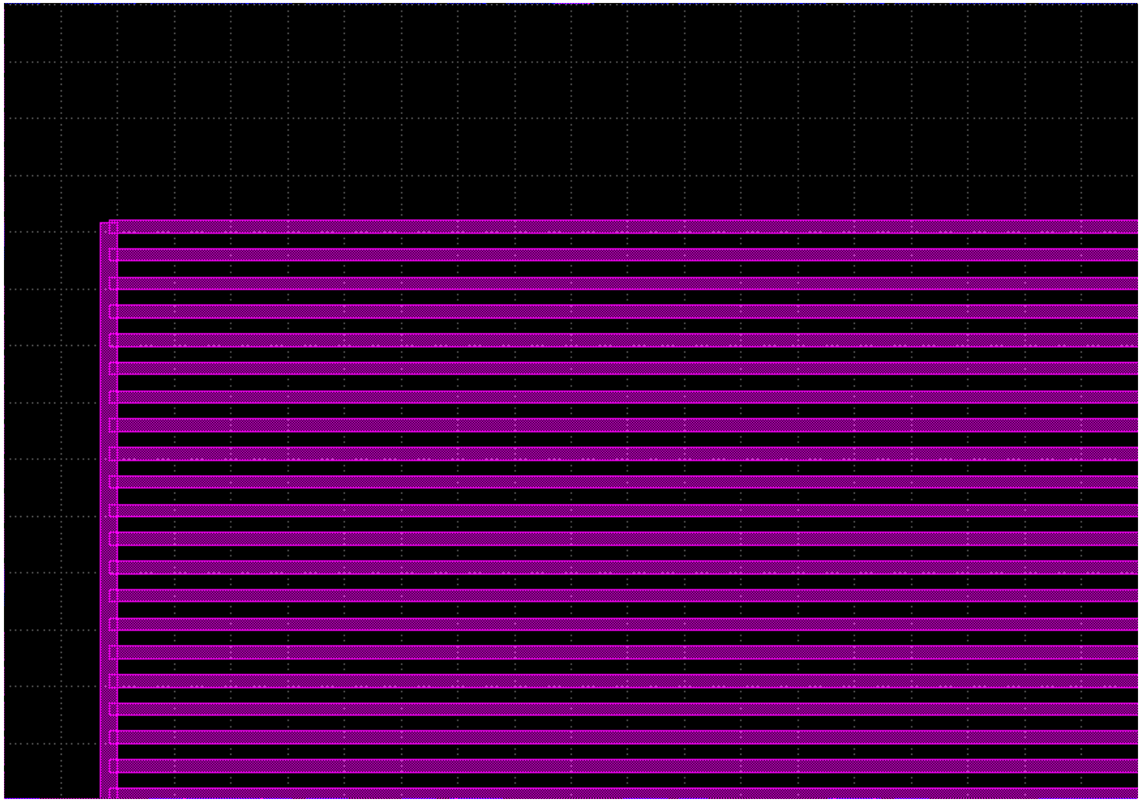
Comb structure



- Test structure for:
  - Lateral shorts/ stringers
  - Breakdown of the dielectric

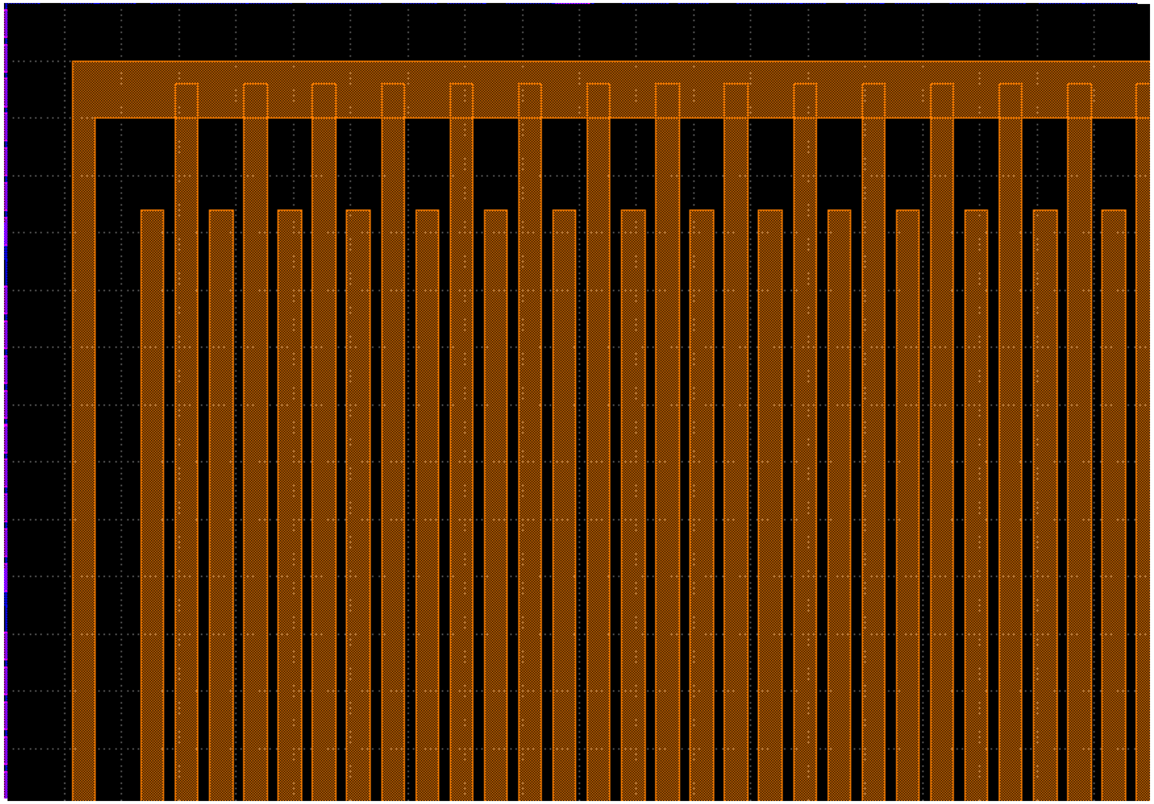
)

Comb structure



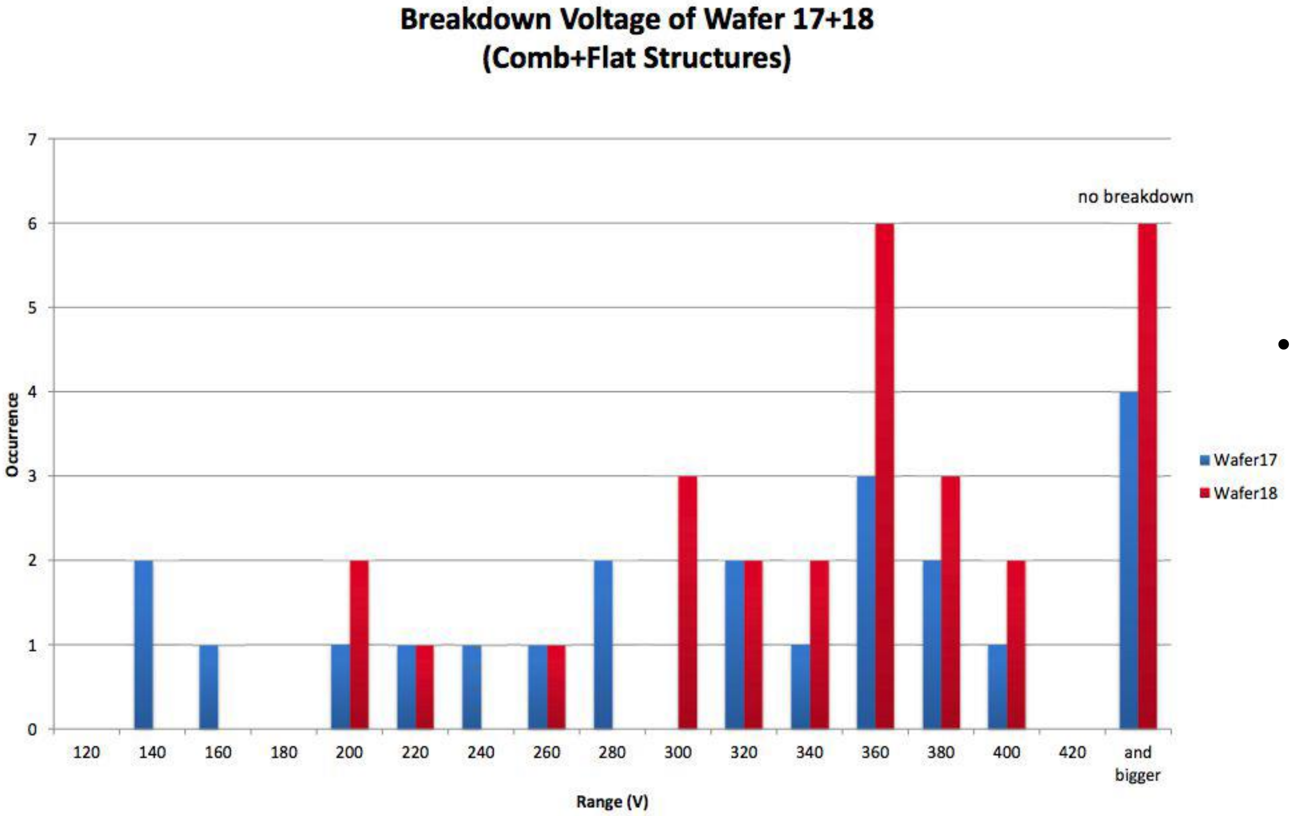
- Test structure for:
  - Lateral shorts/ stringers
  - Breakdown of the dielectric
- Variations in:
  - Layer thickness
  - Gap between lines
- Minimal gap size for PXD9 Al2: 3 µm
- Results:
  - All the tested structures/ wafers stated stable results

Comb structure



- Test structure for:
  - Lateral shorts/ stringers
  - Breakdown of the dielectric
- Variations in:
  - Layer thickness
  - Gap between lines
- Minimal gap size for PXD9 Al2: 3 µm
- Results:
  - All the tested structures/ wafers stated stable results

Breakdown structures


Breakdown Voltage of Wafer 17+18 (Comb+Flat Structures)

- Two different typologies:
  - ➢ Unstructured Al1
  - ➢ Structured Al1
- Used to determine the strength of the inter-metal dielectric for structures with ‘extreme’ designs (no stress relief)
- Breakdown structures and Comb structures tested up to +420 V → very robust technology as max voltage applied for PXD9 normal function is less than 50 V

Summary and conclusion

- Different aspects of the metallization for the later PXD9 wafers were tested
- From the results of the Kelvin and COCH structures it can be stated that the chosen contact sizes are reliable (yield = 100%) and therefore safe for use for the PXD9 wafers
- A combination of the measurements on Kelvin, COCH and Comb structures stated that the chosen technology and design exclude the most common defects