Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

13th AGIPD Consortium Meeting

Quality Control and Quality Assurance of the AGIPD Sensors

(for the first delivery of the AGIPD sensors)

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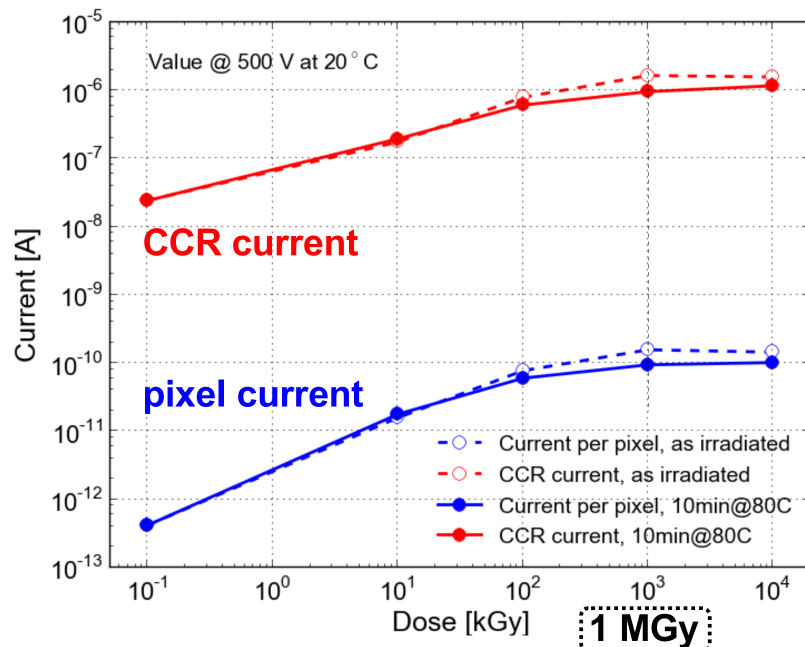
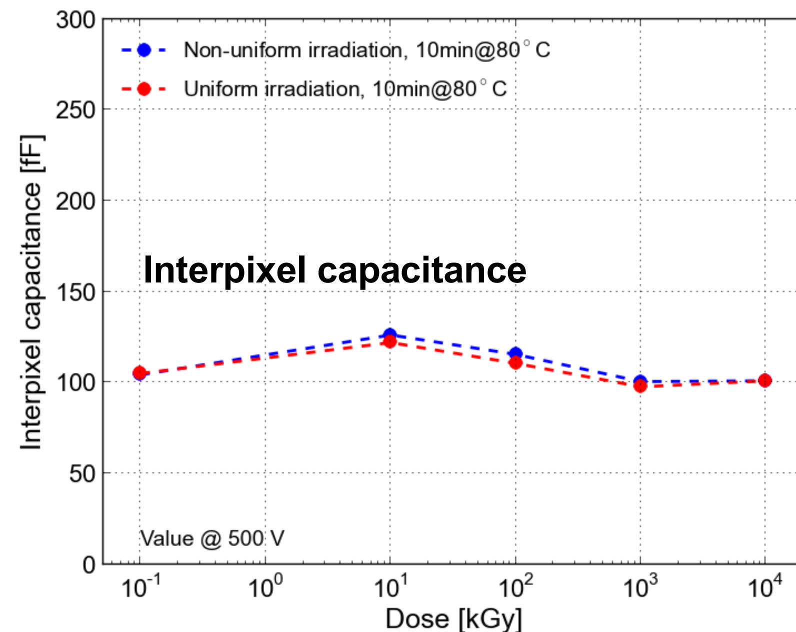
Outline

- Status of the AGIPD sensors → changes since April of 2013
- Summary of measurements at Hamburg
  - Full AGIPD sensors (128x512 pixels)
  - Single-chip sensors (64x64 pixels)
  - Test structures
- Proposed QA procedure
- Summary

Status of the AGIPD sensors

- 20 wafers (2 sensors each) of 1st batch received from Sintef in Feb. 2013
- Production of 2nd batch with 24 wafers to be finalized by Oct. 25, 2013; 2 wafers produced without N_2 annealing for increasing positive charges in the oxide
- 6 wafers fully characterized: 2 cut in Hamburg, 1 shipped to PSI, 3 ready for delivery
- Radiation hardness of the AGIPD sensor proven up to 10 MGy in May 2013:
  - No breakdown observed up to 900 V @ -20°C and 20°C (in dry atmosphere with RH < 5%)
  - Pixel current, CCR current and interpixel capacitance saturate at 1 MGy

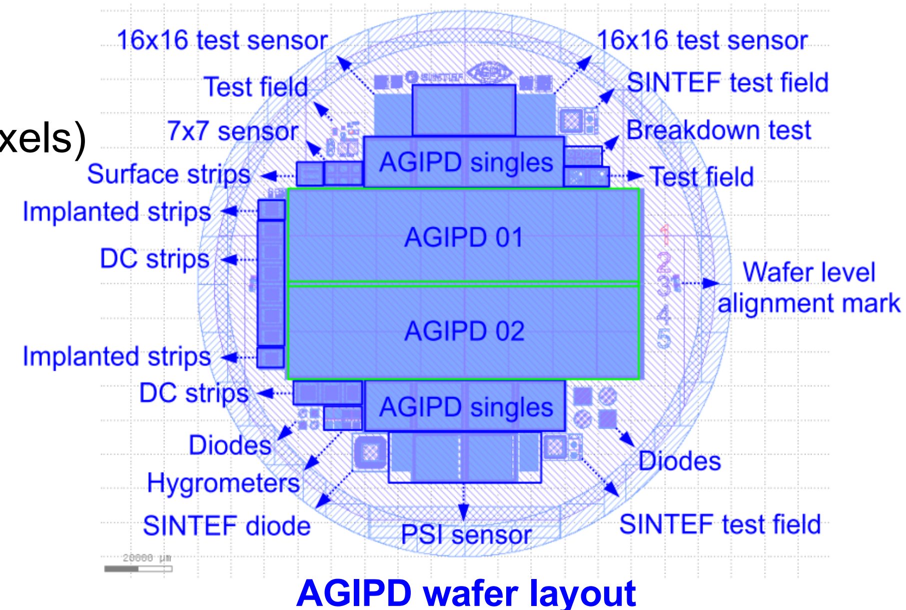




Summary of measurements at HH

- Quality assurance of the full AGIPD sensor (128x512 pixels):
  - Hysteresis $I_{CCR}(V)$ and long-term $I_{CCR}(t)$ in dry air (RH < 5%)
  - $I_{CCR}(V)$ and long-term $I_{CCR}(t)$ in normal atmosphere (RH > 35%)

  → Breakdown voltage & long-term stability
  - $C_{CCR}(V)$ measurement
  - Flatness measurement
  - Visual inspection of pixels and guard-ring structure
- Characterization of the single-chip sensor (64x64 pixels):
  - $I_{CCR}(V)$ & $C_{CCR}(V)$ measurements done for 40 sensors
- Characterization of test structures:
  - $C_{pix}(V)$, $I_{pix}(V)$ & $I_{CCR}(V)$ for mini-sensors (7x7 pixels)
  - $C_{pad}(V)$, $I_{pad}(V)$ & $I_{CCR}(V)$ for diode
  - C(V) for MOS & I(V) for GCD



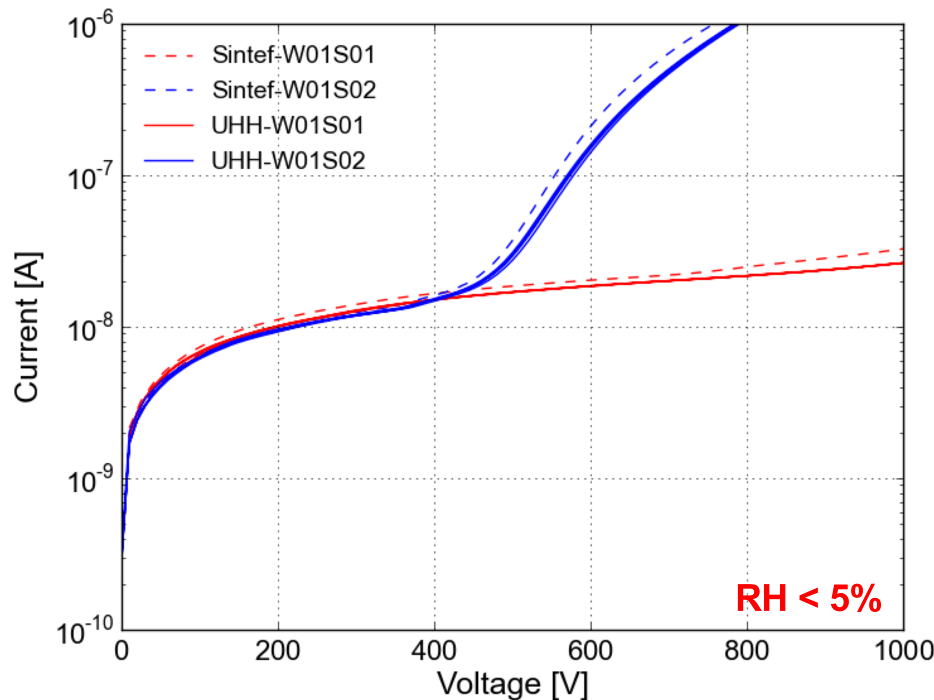
AGIPD wafer layout

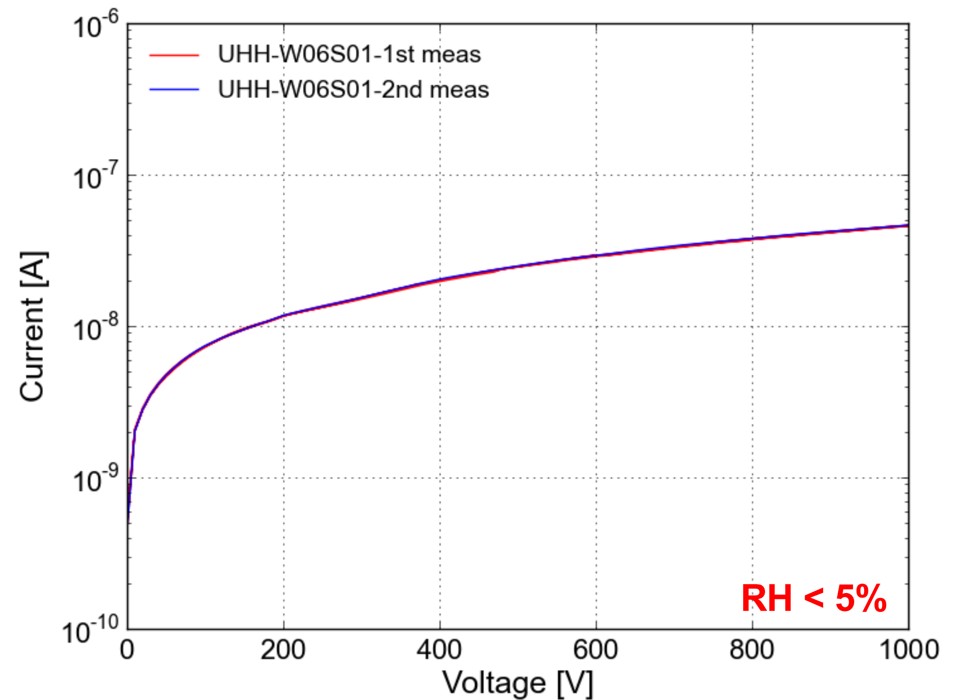
Full AGIPD sensor: I(V) in dry air

- Measurements of 12 AGIPD sensors at HH in dry air with **RH < 5%**:
  - HH reproduces Sintef results
  - No hysteresis effects for non-irradiated sensors
  - Measurements reproducible in dry atmosphere

Yield statistics for overall sensors: Yield = 70%

Cat.1	(before + after annealing) > 900 V	16	40.00%
Cat.2	(750V<before annealing<900V)+(after annealing>900V)	12	30.00%
Cat.3	(before annealing < 750V) + (after annealing > 900V)	2	5.00%
Cat.4	after<900V	10	25.00%
Sum		40	100.00%

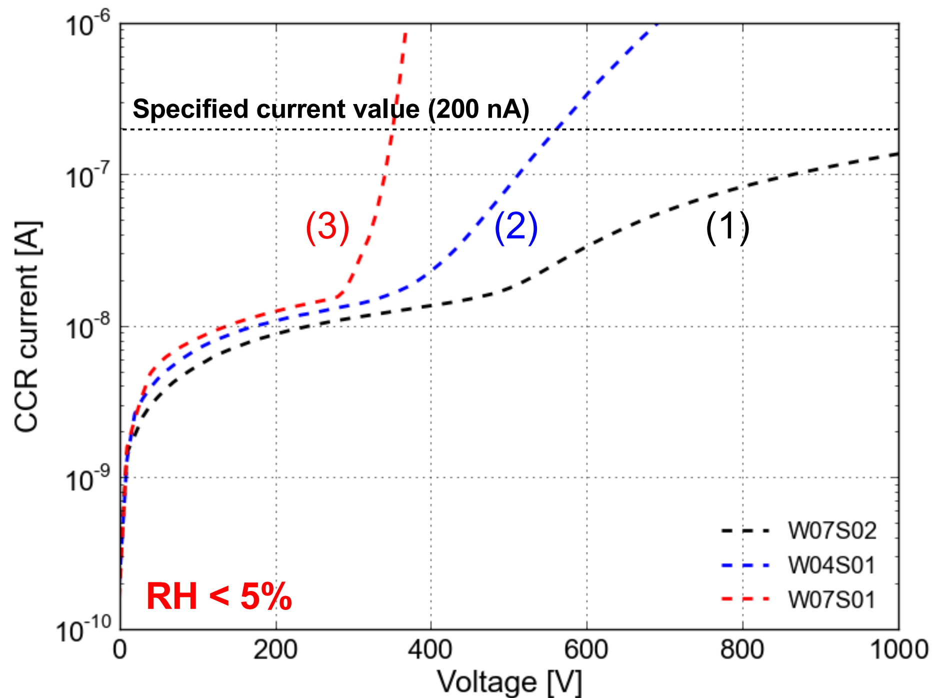


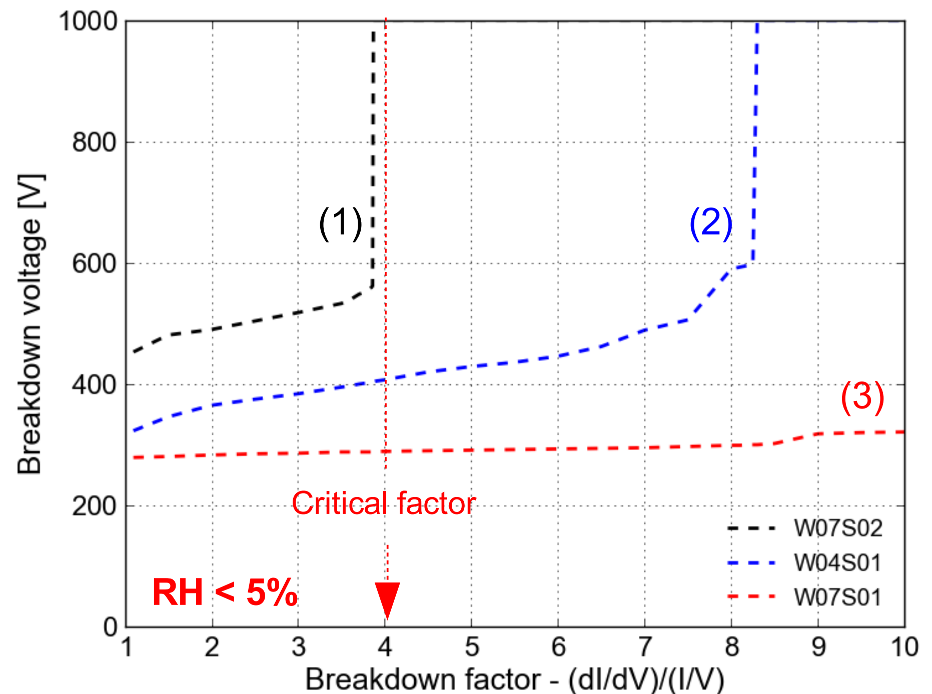


- 10 out of 12 measurements reproduce Sintef results; the other 2 show slightly higher breakdown voltage than Sintef results

Full AGIPD sensor: Breakdown criteria

- Breakdown classification (preliminary) for non-irradiated sensors in dry atmosphere:
  - (1) Soft breakdown with current < 200 nA @ 1000 V (within specification)
  - (2) Soft breakdown with current > 200 nA @ 1000 V (out of specification)
  - (3) Sharp breakdown -> dangerous for sensor operation



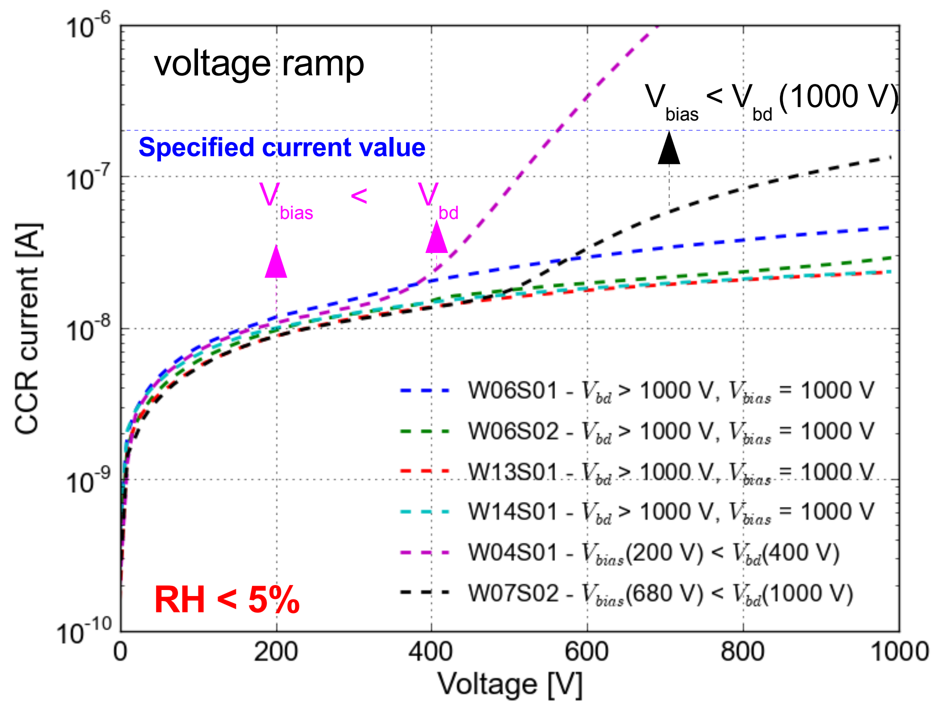


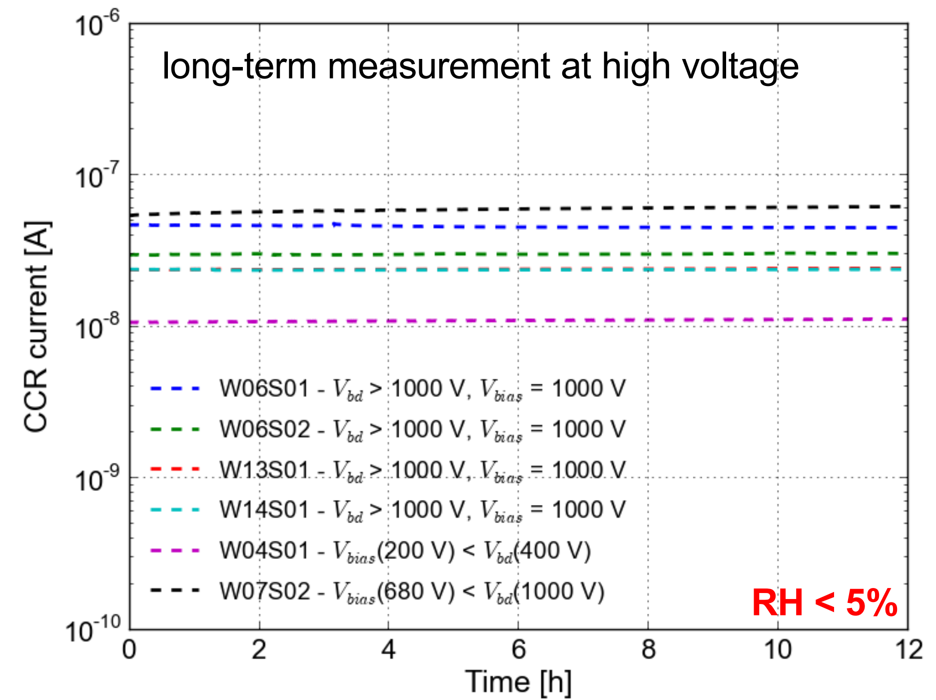
- Breakdown criteria: k = (dI/dV)/(I/V) = 4 (k = 10 used in simulation)
  - k = 4 used to distinguish breakdown-(1) from -(2) and -(3)

Full AGIPD sensor: I(t) in dry air

- Long-term stability in dry air with **RH < 5%**:

  - Voltage ramped to either 1000 V or a voltage smaller than V_{bd}
  - CCR current monitored as function of time over 12 hours



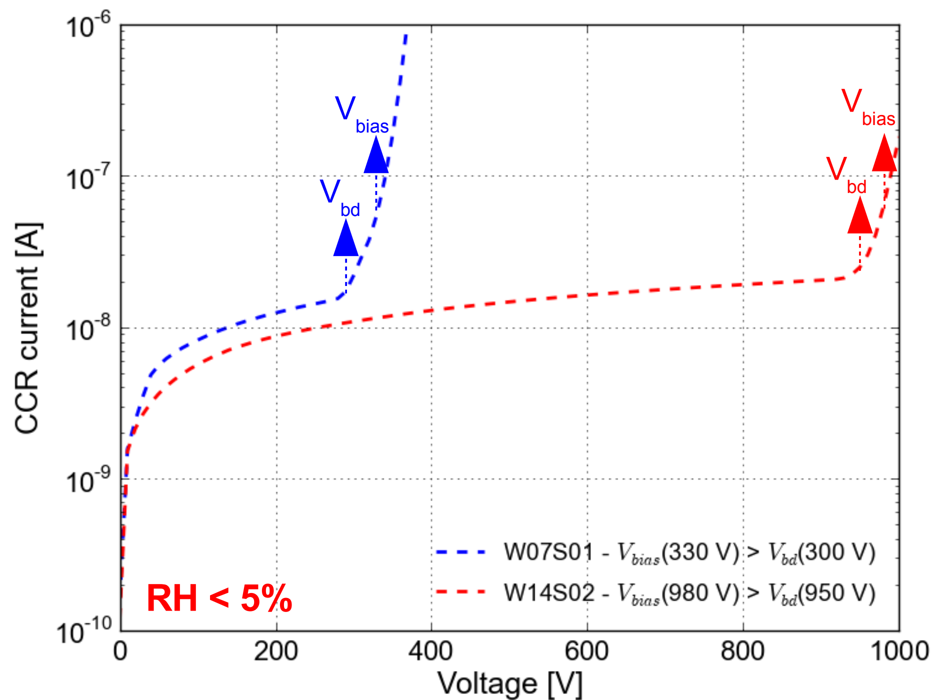


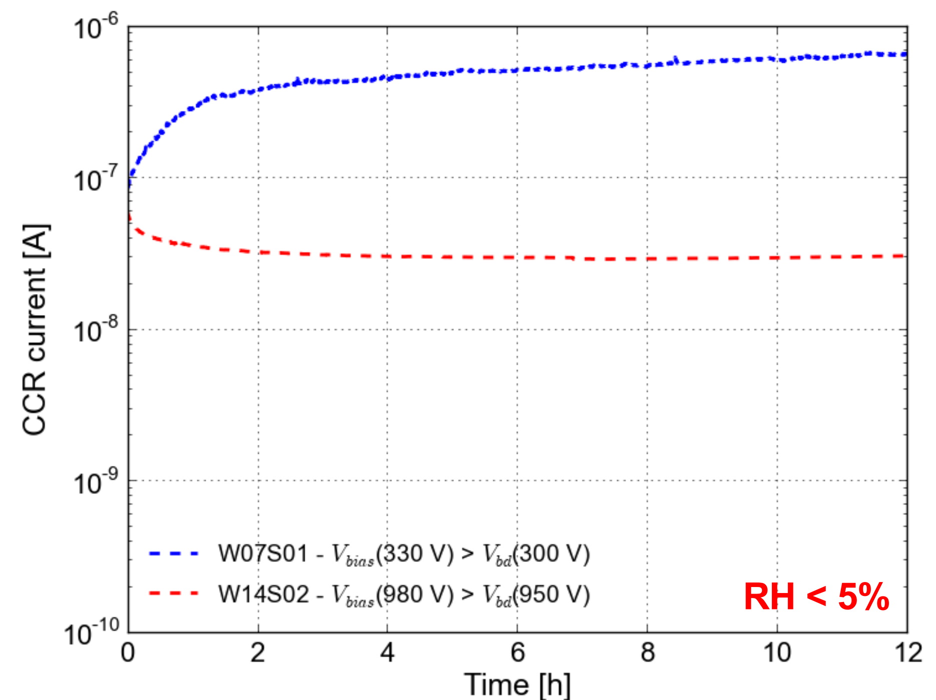
- V_{bd} > 1000 V → I(t) is constant and stable
- V_{bd} < 1000 V & V_{bias} < V_{bd} → I(t) is constant and stable

Full AGIPD sensor: I(t) in dry air

- Long-term stability in dry air with **RH < 5%**:

  - Voltage ramped to a voltage higher than V_{bd}
  - CCR current monitored as function of time over 12 hours

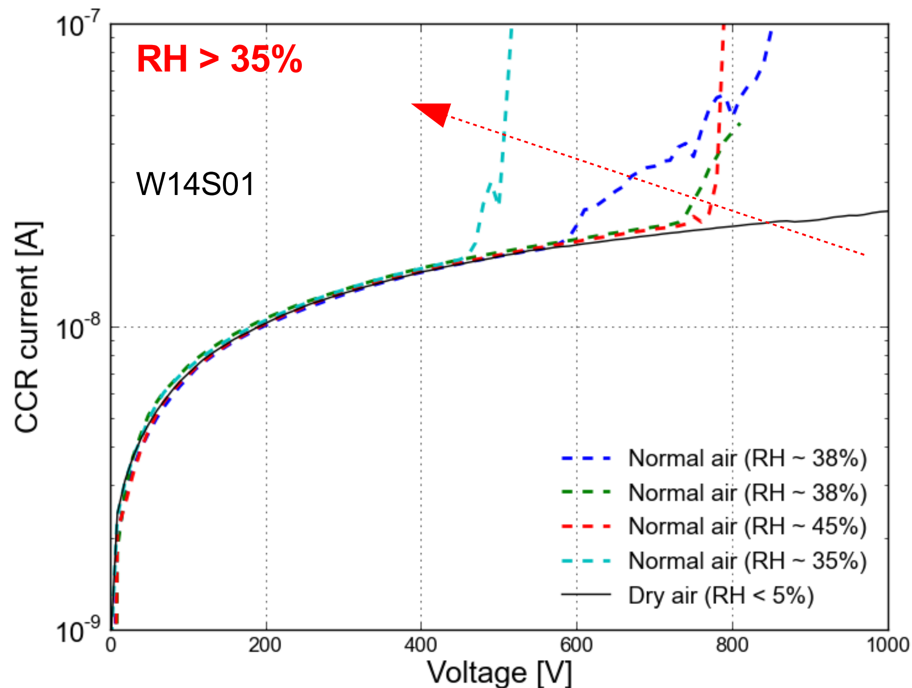


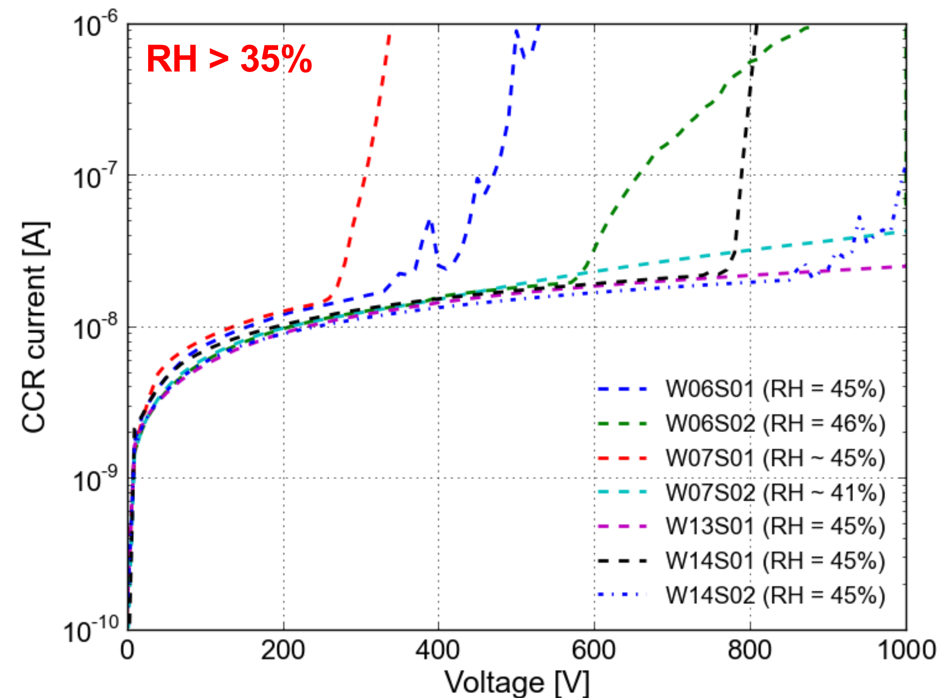


- V_{bd} < 1000 V & V_{bias} > V_{bd} → I(t) changes and its behavior not predictable

Full AGIPD sensor: I(V)&I(t) in normal air

- Measurements in normal air with **RH > 35%**: Be careful!
  - I(V) not reproducible and V_{bd}(RH > 35%) < V_{bd}(RH < 5%) commonly observed (5/7)
    → similar for irradiated sensors





For non-irradiated sensors: Reliable operation only in dry atmosphere

- V_{bd} sensitive to RH and time dependence -> could be related to the quality of insulator, guard-ring geometry and oxide charges -> to be understood

Full AGIPD sensor: I(V)&I(t) in normal air

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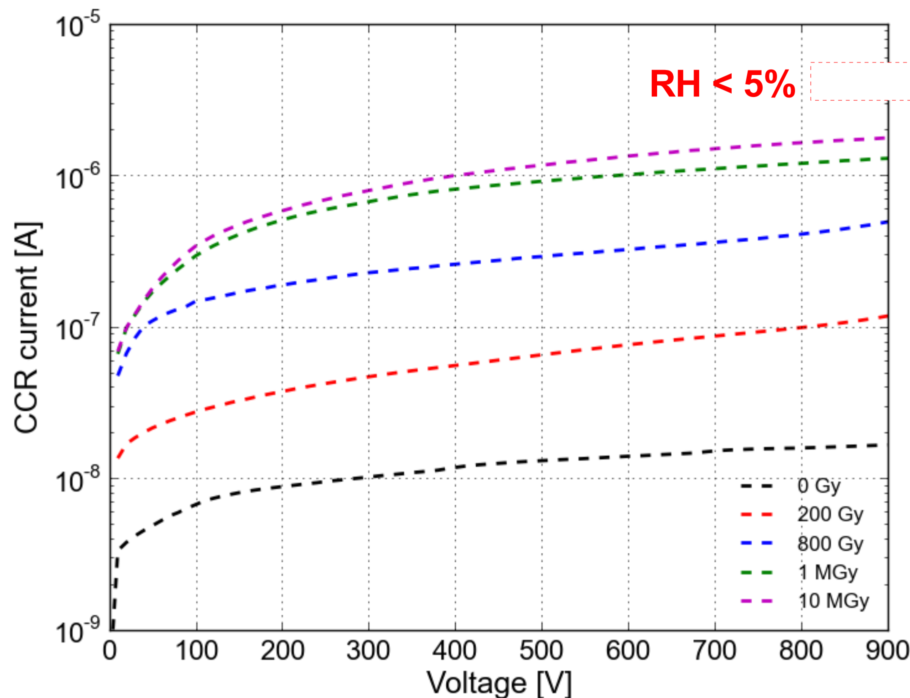
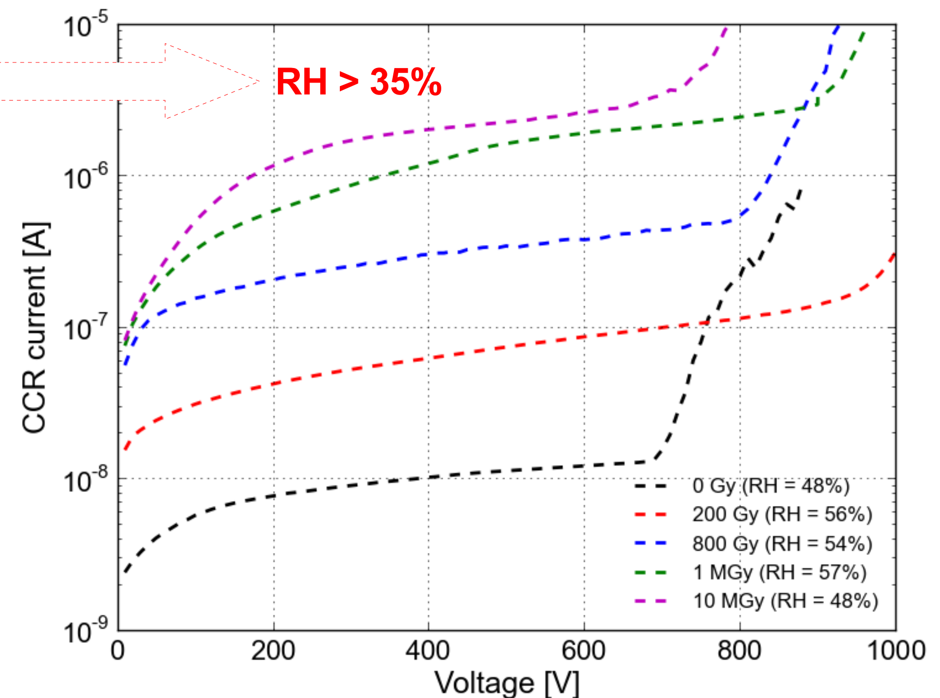




Also for irradiated sensors: Reliable operation only in dry atmosphere

- V_{bd} sensitive to RH and time dependence -> could be related to the quality of insulator, guard-ring geometry and oxide charges -> to be understood

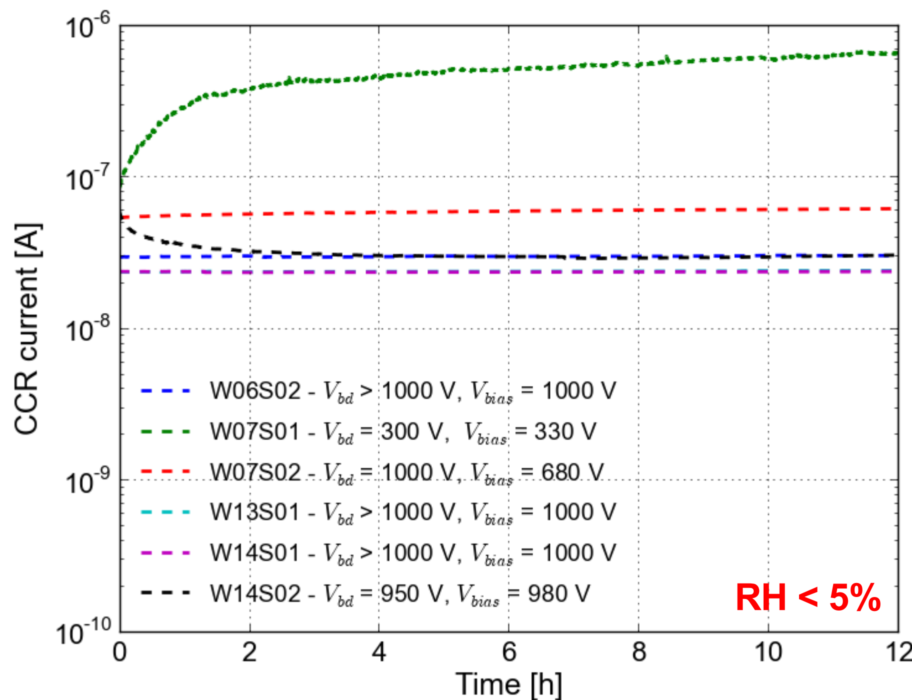
Full AGIPD sensor: I(V)&I(t) in normal air

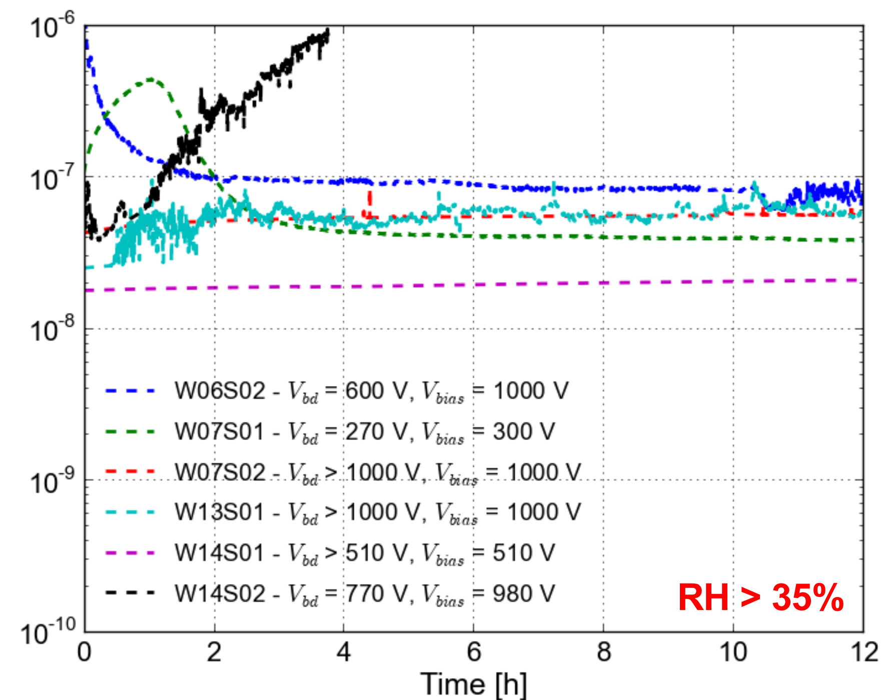
- Measurements in normal air with **RH > 35%**: Be careful!

  - I(V) not reproducible and V_{bd}(RH > 35%) < V_{bd}(RH < 5%) commonly observed (5/7)

    → similar for irradiated sensors

For non-/irradiated sensors: Reliable operation only in dry atmosphere

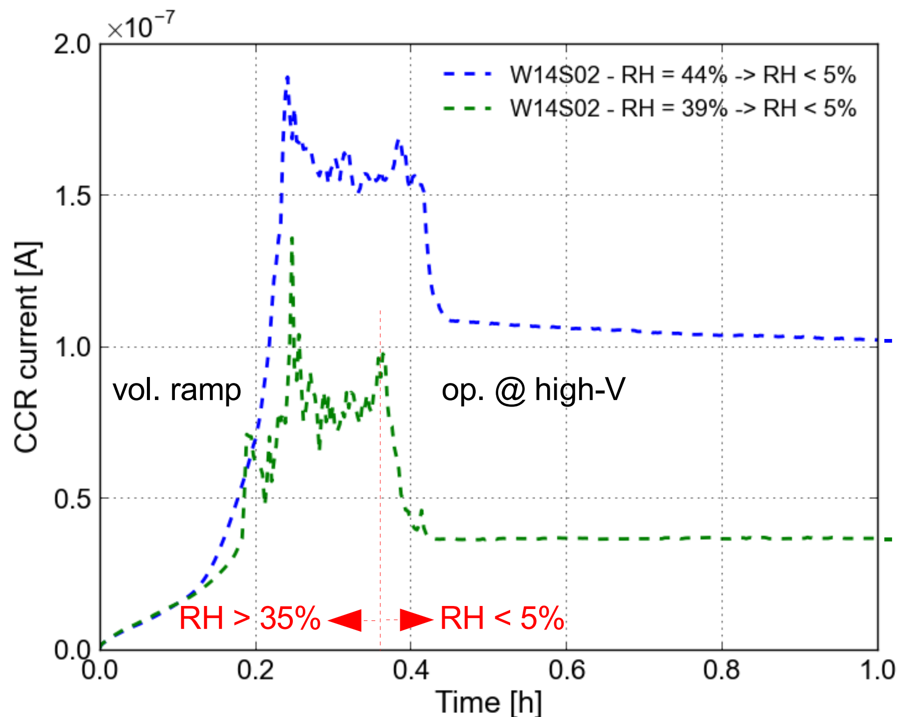


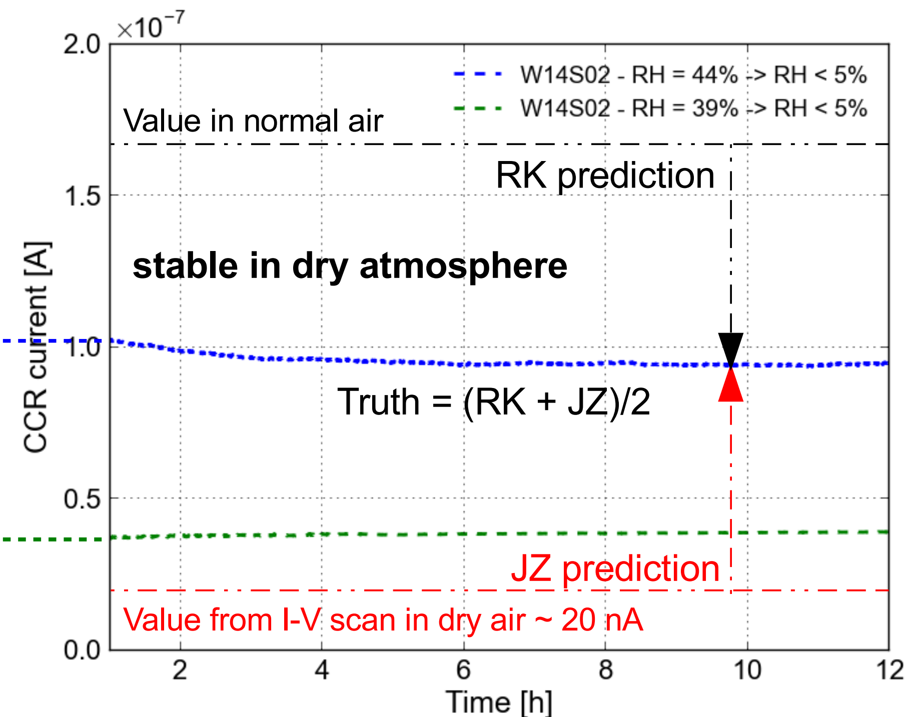


- V_{bd} sensitive to RH and time dependence -> could be related to the quality of insulator, guard-ring geometry and oxide charges -> to be understood

Full AGIPD sensor: I(V)&I(t) in normal air

- Humidity switching experiments:
  - Voltage ramp in normal atmosphere up to a breakdown
  - Stabilize the sensor in normal atmosphere for 10 minutes
  - Switch on dry air flow to reduce the relative humidity down to < 5%

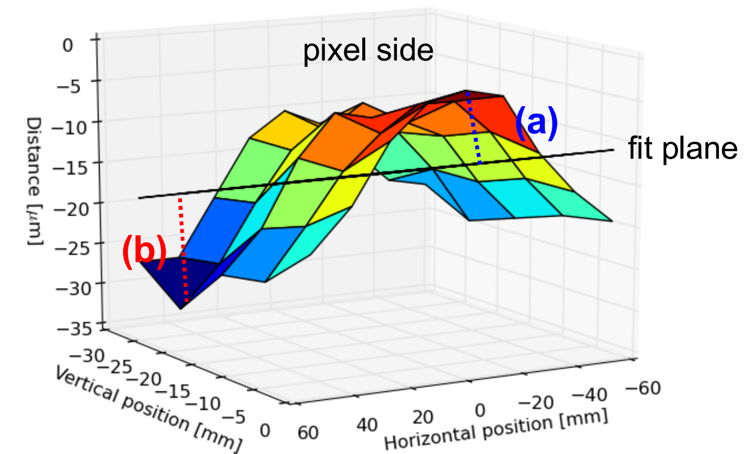


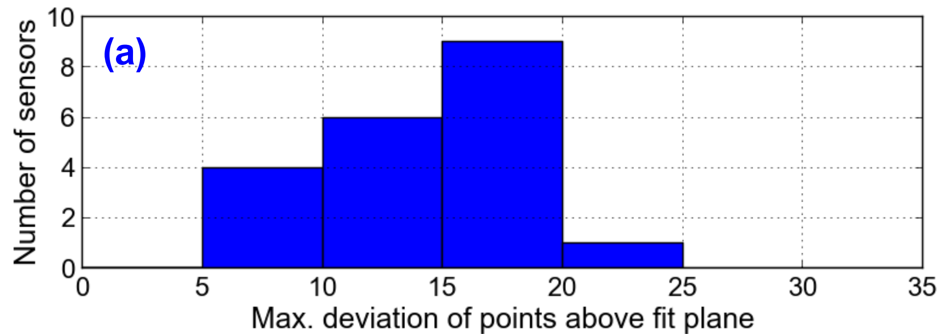


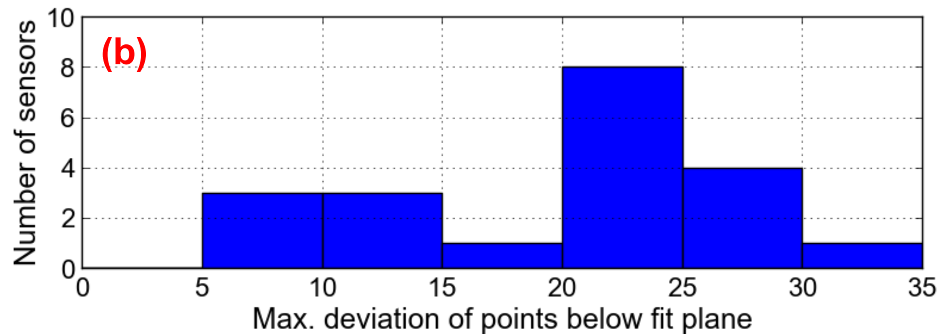
- CCR current decreases and gets stable when dry air on
- **Recovery of sensor from normal air to dry takes a while** (just from observation but no understanding so far)

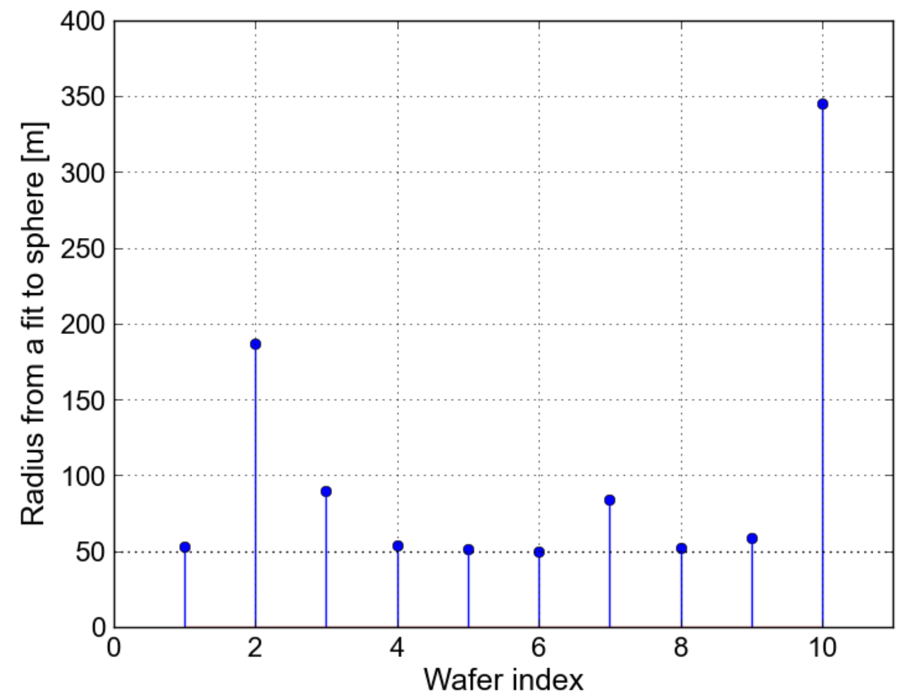
Full AGIPD sensor: Sensor flatness

- Flatness measurements:
  - Done for 10 wafers (20 sensors) for good statistics
  - Fit to a plane for individual sensor: deviation extracted for points above and below the fit plane
  - Slightly higher than specification of 20 µm
  - Radius from a sphere fit for each wafer: ~ 50 m (Needed for force calculation)



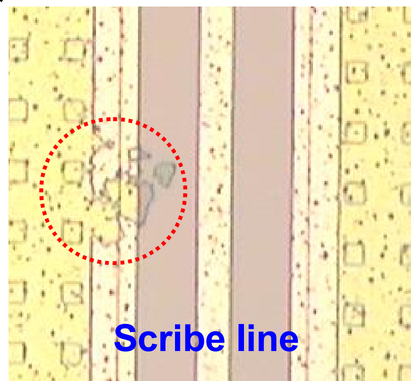




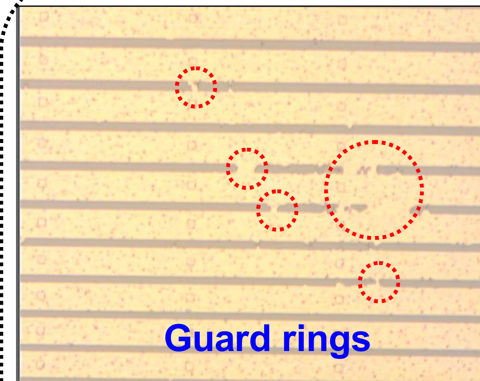


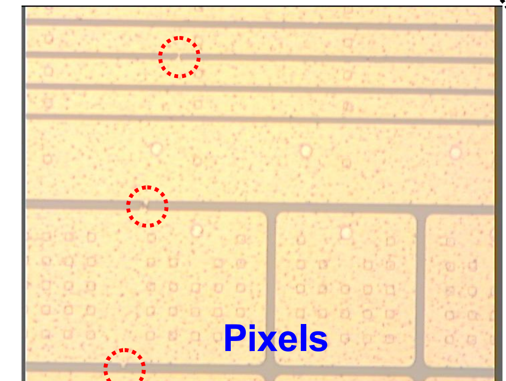
Full AGIPD sensor: Visual inspection

- Visual inspection for pixels and guard-ring structure of each sensor:
  - Problems observed for passivation and metalisation



Problems from passivation layer

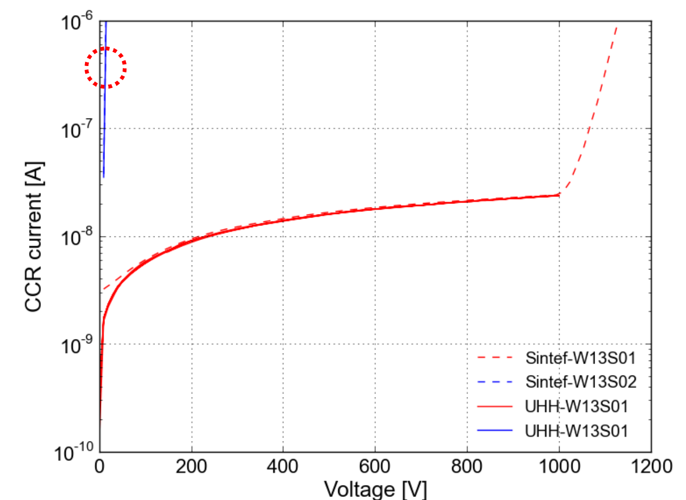




Problems from metal layer

- Judged as bad sensor by Sintef from I-V measurement; actual problems observed through visual inspection at HH
- Information stored (12,000 pictures/sensor)
- Currently the only way to investigate pixel quality

time-consuming (~ 3 h/sensor) but necessary in future measurements



Characterization of single-chip sensors

- I(V) measurements of single-chip sensors (64x64 pixels) in dry air (RH < 5%):
  - 50 single-chip sensors tested:

    Sensor 1-8: Standard AGIPD design of 20 μm pixel gap and 10 μm implant radius

    Sensor 9: 20 μm pixel gap and 20 μm implant radius

    Sensor 10: 40 μm pixel gap and 20 μm implant radius

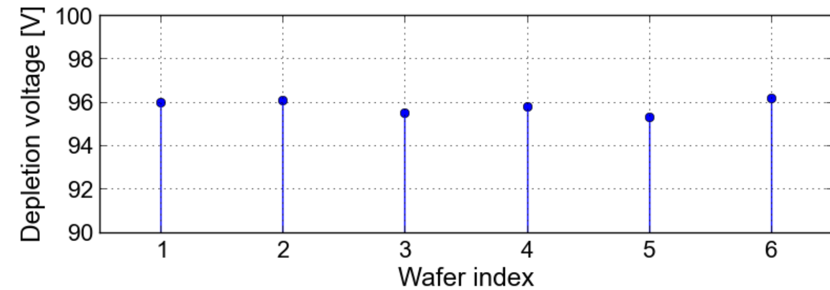
Number of sensor with V_{bd} < 1000 V

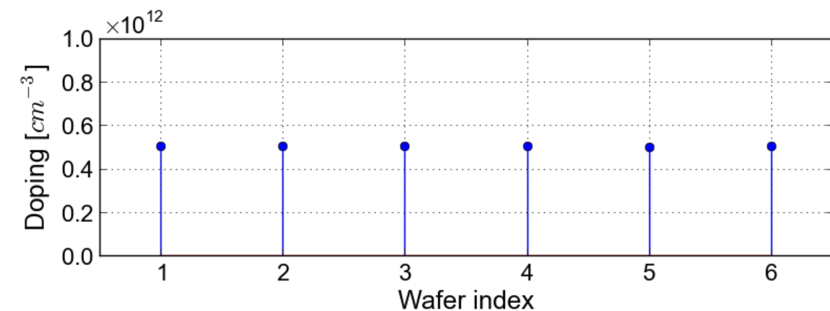
Wafer index	Sensor 1-8 (defects/all)	Sensor 9 (defects/all)	Sensor 10 (defects/all)
1	1/8	0/1	0/1
6	0/8	1/1	1/1
7	0/8	0/1	1/1
13	1/8	0/1	1/1
14	0/8	0/1	0/1
Prop. defects	2/40	1/5	3/5
Yield	95%	80%	40%

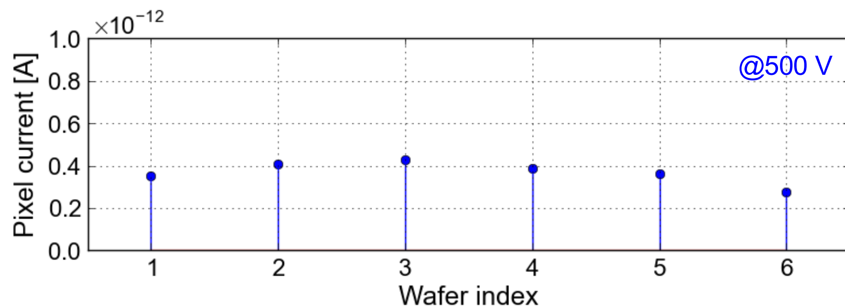
Standard AGIPD design shows a good yield ~ 95%

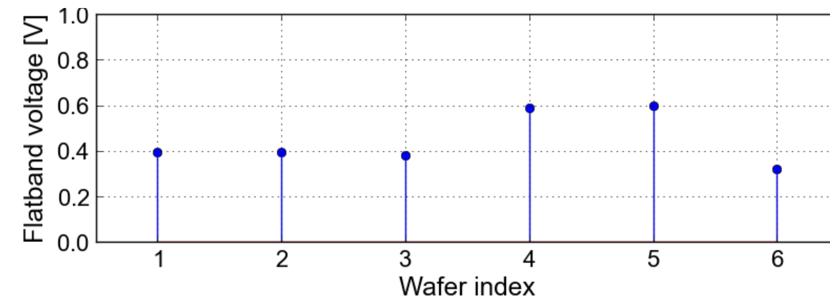
Characterization of test structures

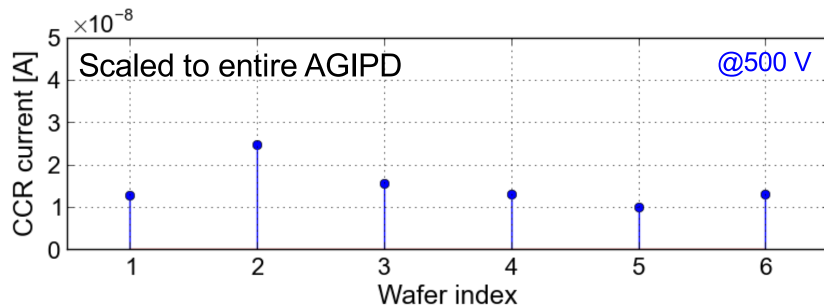
- Characterization of test structures:
  - $C_{pad}(V)$, $I_{pad}(V)$ & $I_{CCR}(V)$ for diode:
    - ⇨ V_{dep} ~ 95 V, N_{eff} ~ 5.1×10^{11} cm^{-3}
  - $C_{pix}(V)$, $I_{pix}(V)$ & $I_{CCR}(V)$ for mini-sensors:
    - ⇨ I_{pixel} ~ 0.4 pA (specification: 3 pA)
    - ⇨ I_{CCR} ~ 15 nA (specification: 200 nA)
  - C(V) for MOS & I(V) for GCD:
    - ⇨ V_{fb} ~ 0.4 V, J_{surf} ~ 2 nA/cm^2

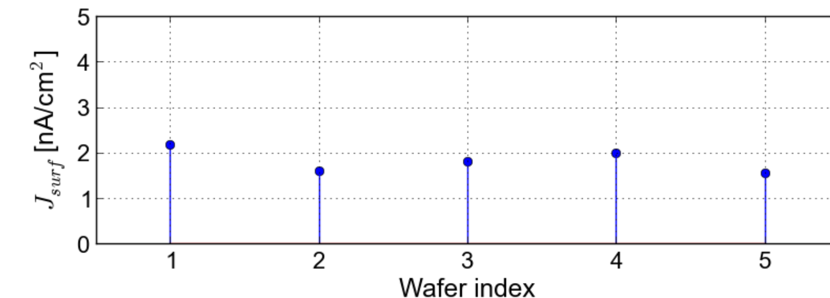












Proposed QA procedure

- Quality assurance of the full AGIPD sensor (128x512 pixels):
  - Hysteresis I_{CCR}(V) and long-term I_{CCR}(t) in dry air (RH < 5%)
  - I_{CCR}(V) and long-term I_{CCR}(t) in normal atmosphere (RH > 35%)
  - C_{CCR}(V) measurement
  - Flatness measurement
  - Visual inspection of pixels and guard-ring structure
- Characterization of the single-chip sensor (64x64 pixels):
  - I_{CCR}(V) & C_{CCR}(V) measurements done for 40 sensors
- Characterization of test structures:
  - C_{pix}(V), I_{pix}(V) & I_{CCR}(V) for mini-sensors (7x7 pixels)
  - C_{pad}(V), I_{pad}(V) & I_{CCR}(V) for diode
  - C(V) for MOS & I(V) for GCD

Time estimate: I_{CCR}(V) - 40 minutes/sensor, long-term I_{CCR}(t) - 13 hours/sensor
Visual inspection - 3 hours/sensor

→ 2 wafers/week

Summary

- **Quality assurance of the full AGIPD sensor (128x512 pixels):**
  - **Electrical measurements:**
    - In dry air (RH < 5%):
      - HH measurements reproduce Sintef results
      - Stable sensor operation in dry atmosphere with $V_{op} < V_{bd}$
    - In normal atmosphere (RH > 35%):
      - V_{bd} commonly smaller than in dry air (RH < 5%)
      - V_{bd} is non-reproducible and also observed for irradiated sensors

      → to be understood
  - **Statistics of flatness obtained: slightly beyond specification**
  - **Visual inspection provides insight to the lithography quality**
  - **3 wafers currently available for delivery**
- **Characterization of the single-chip sensor (64x64 pixels):**
  - **Good yield of 95% for standard AGIPD design**
- **Characterization of test structures: Not too many surprises expected from tests**
- **Radiation hardness of the AGIPD sensor proven up to 10 MGy:**
  - **Pixel current, CCR current and interpixel capacitance saturate at ~ 1 MGy**
  - **All values of electrical properties within specification**
  - **RH sensitive also observed for irradiated sensors**

Open questions/problems

- **Recently the lack of a “DORIS-F4”-type X-ray source is a problem!**
  - Irradiation of AGIPD sensors/chips
  - Sensor breakdown test during irradiation
  - etc.