Status of Sensors:

Measurements on the AGIPD Sensors

(from 1st batch to 2nd batch)

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Current status

- **2 deliveries from Sintef**
  - 1st batch with 20 wafers (2 sensors/wafer) received in Feb. 2013
  - Radiation hardness for 1st batch proven up to 100 MGy → saturation observed at ~ 1 MGy
  - 5 wafers from 1st batch packaged and sent to PSI for bump bonding by Dec. 2013, residual test structures after UBM and Indium deposition processes received in Hamburg
  - 2nd batch with 25 wafers received in Nov. 2013 (2 wafers with additional wet oxidation), 2 wafers cut for sensor quality test and verification of radiation hardness
  - Sensor/Wafer quality investigated for 1st and 2nd batch and compared to specification

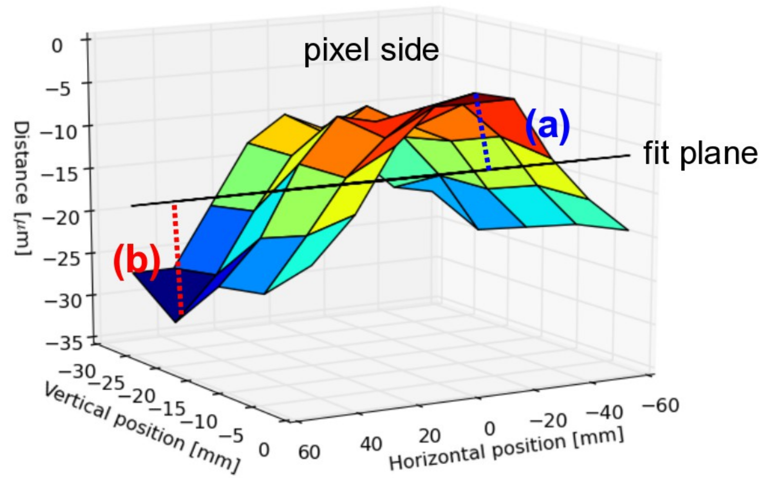
Specifications

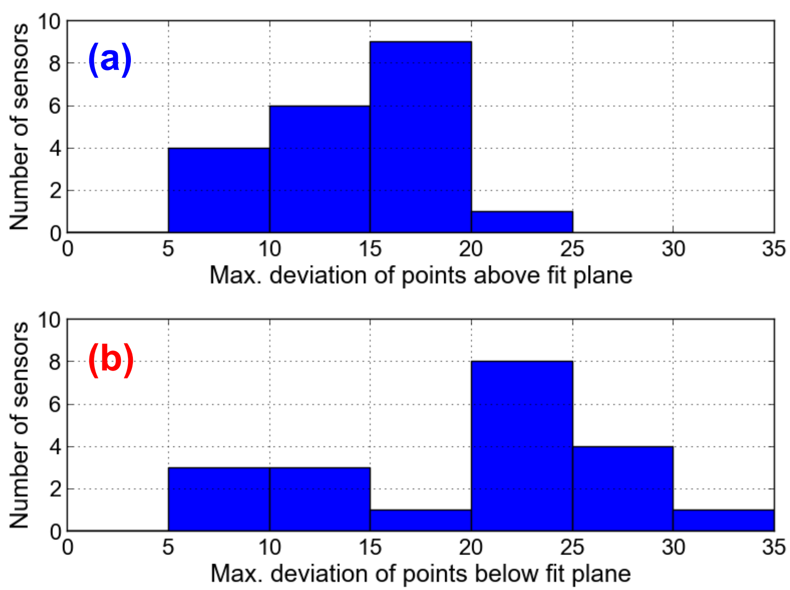
Parameter	Value	Comments
mechanical		
dimensions (distance between centres of scribe lines)	107,650±5 µm x 28,050±5 µm	
mechanical thickness	500±20 µm	mounting tolerances, X-ray conv. efficiency
flatness (sensors after cutting)	< 20 µm	bump bonding, *value to be discussed*
distance pixel edge to cut edge	1200 µm	dead space for science
electrical@20°C [vacuum and air(<25% humidity); 0 to 1 GGy X-ray dose]		
n doping	3-8 kΩ·cm	depletion voltage, sideway depletion at edges
dead layer n^+-side	< 0.5 µm Al < 1 µm n^+Si	minimize, but no compromise on breakdown; *values to be discussed*
doping non-uniformity	< 10%	distortions in charge collection
pixel dimensions	200 x 200 µm	see sensor design
nominal operating voltage	500 V	
breakdown voltage	> 900 V	Sensor should operate stably at > 900 V high voltage option for high photon densities; mounting, pulse shape, dead space at edges; *details of guard-ring design to be discussed*
pad layout		bump bonding, capacitance; see sensor design
coupling type@500V	DC	
inter-pixel capacitance@500V	500 fF	noise, cross-talk
total dark current sensor@500V	50 µA	power
max. dark current/pixel@500V	50 nA	noise, operation of read-out ASIC
max. dark current CCR@500V	20 µA	
passivation		irradiation, environmental effects *to be discussed*
electrical@20°C [vacuum and air(<25% humidity); unirradiated]		
dark current sensor@500V	200 nA	quality Si-bulk and technology
max. dark curr./pixel@500V	20 nA	quality Si-bulk and technology
max. dark curr. CCR@500V	200 nA	quality Si-bulk and technology

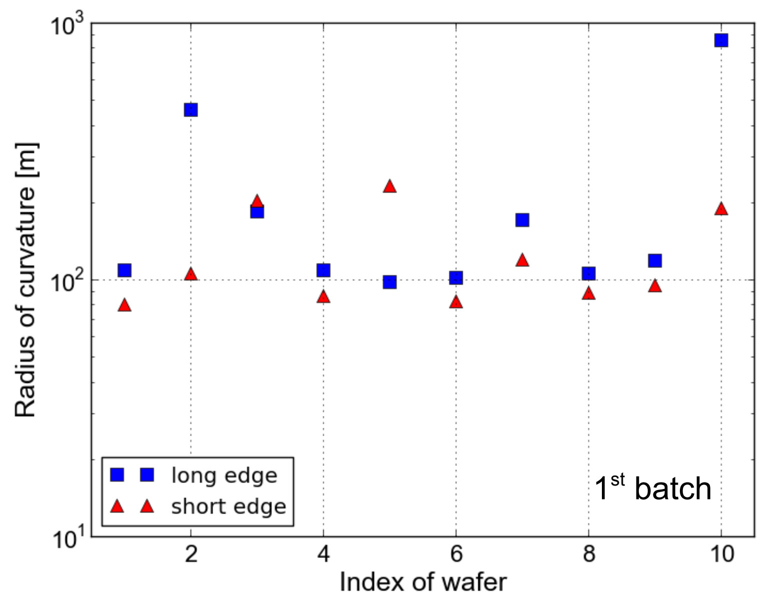
Sensor flatness

- Flatness measurements:
  - Fit to a plane for individual sensor: deviation slightly higher than specification of 20 µm
  - Radius of curvature: ~ 100 m
  - Max. force on a bond pad (0.01 – 0.1 mN) << force needed for bonding (6 mN/bond) and de-bonding (2 mN/bond), thus not a problem!

  No problem found so far during bump bonding!

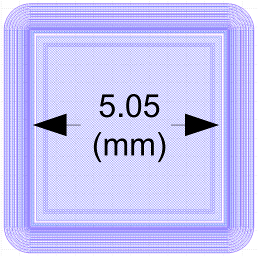


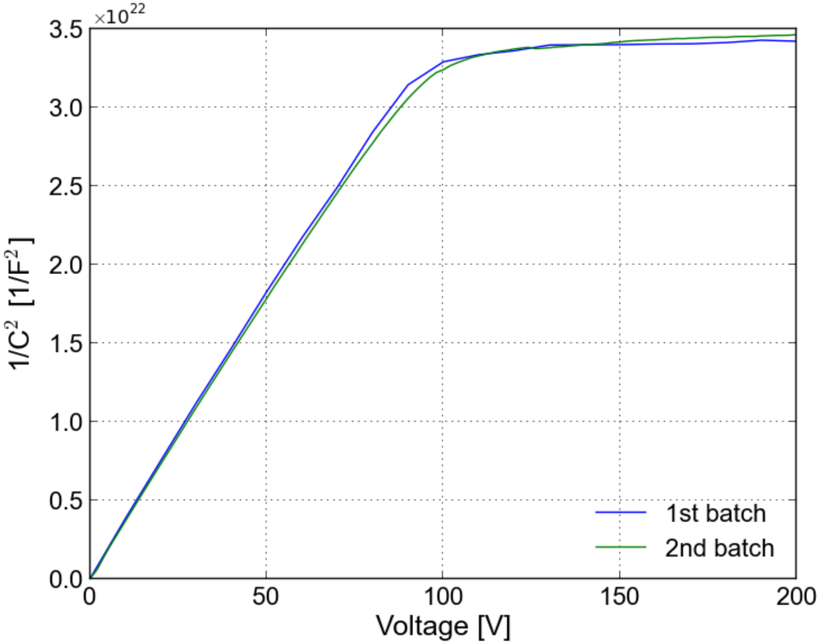


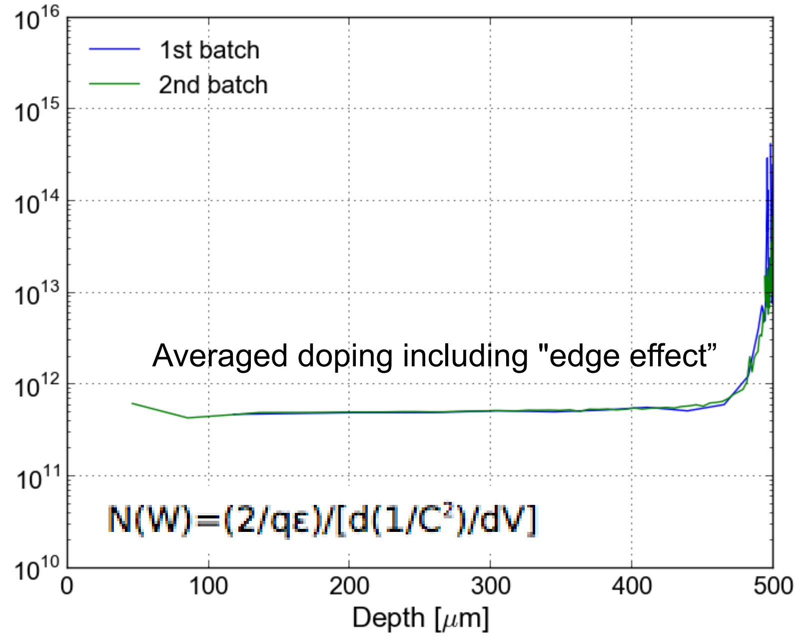


Doping concentration

- Doping, resistivity and its uniformity:
  - Direct determination from C-V measurement on diode
  - Doping/Resistivity calculated from depletion voltage, profile from $1/C^2(V)$





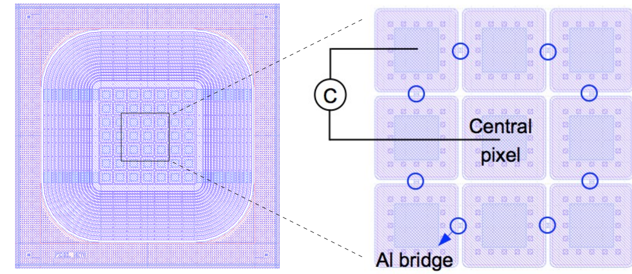


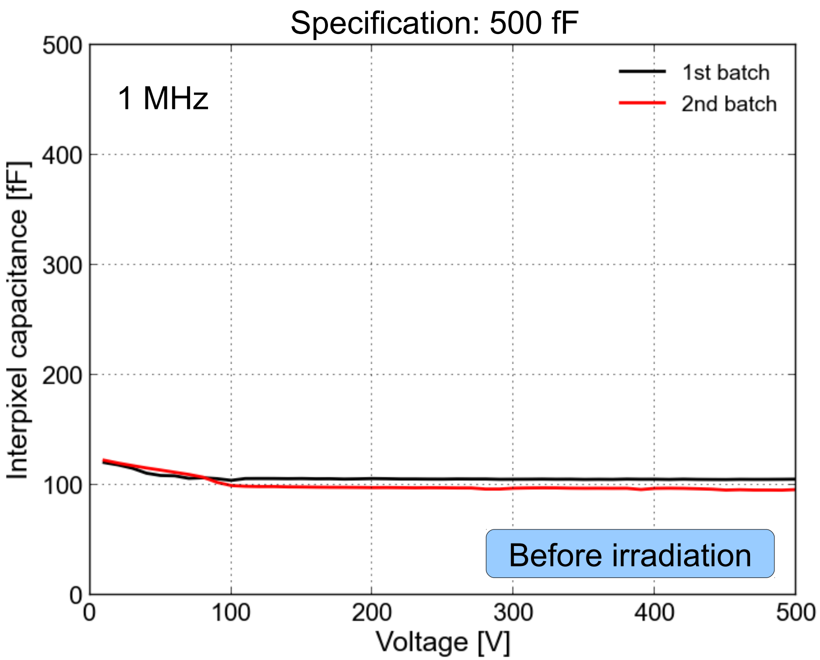
– 1^{st} batch: V_{dep} ~ 95 V → N_d ~ 5.3×10^{11} cm^{-3} & ρ ~ 7.9 kΩ·cm
– 2^{nd} batch: V_{dep} ~ 105 V → N_d ~ 6.0×10^{11} cm^{-3} & ρ ~ 7.0 kΩ·cm → slight increase

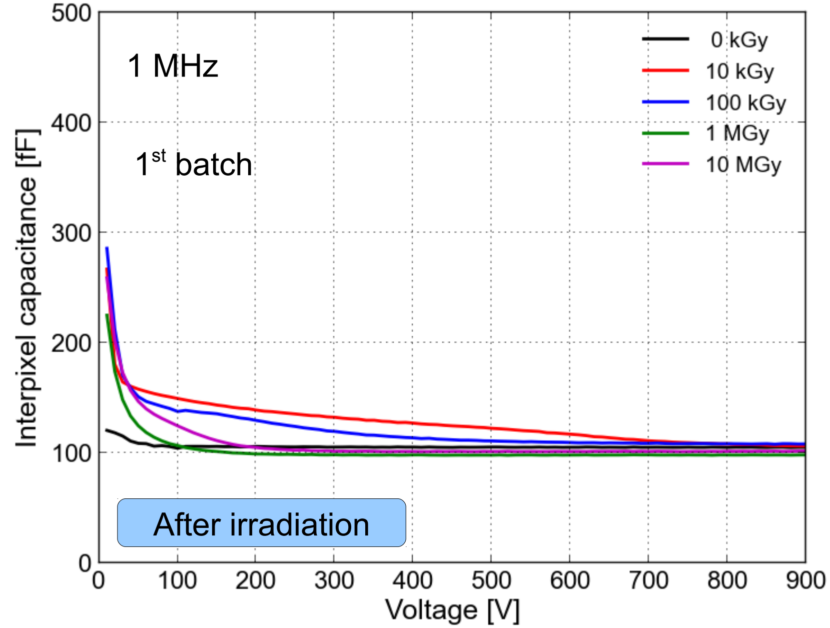
Within specification!

Interpixel capacitance

- Interpixel capacitance C_{int}:
  - Determined from test sensor with 7x7 pixels
  - Measurements done before and after irradiation







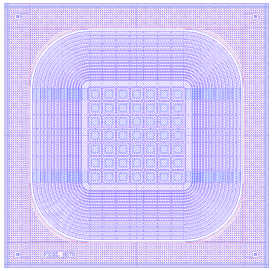
- C_{int} decreases with bias voltage and saturates before V_{dep}
- 1st batch: C_{int}@500 V ~ 102 fF; 2nd batch: C_{int}@500V ~ 98 fF

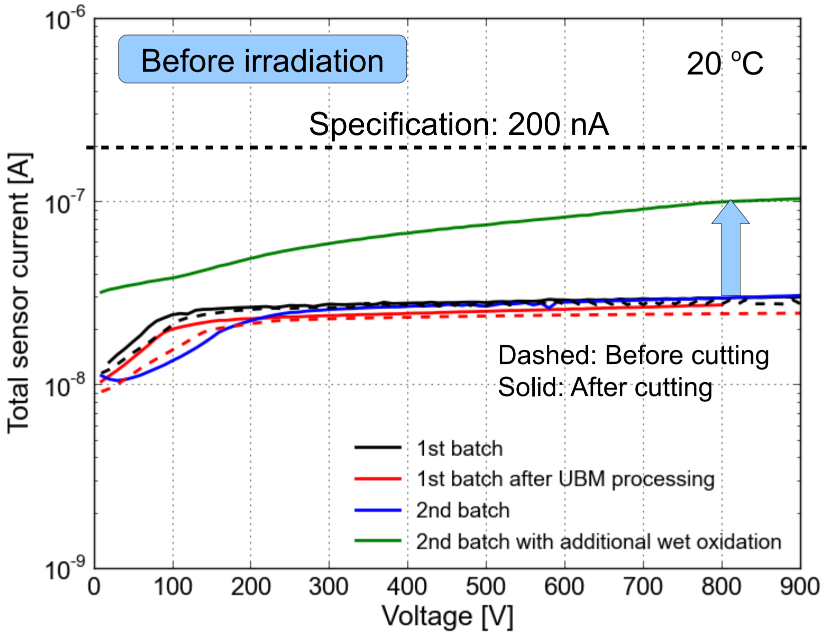
Within specification!

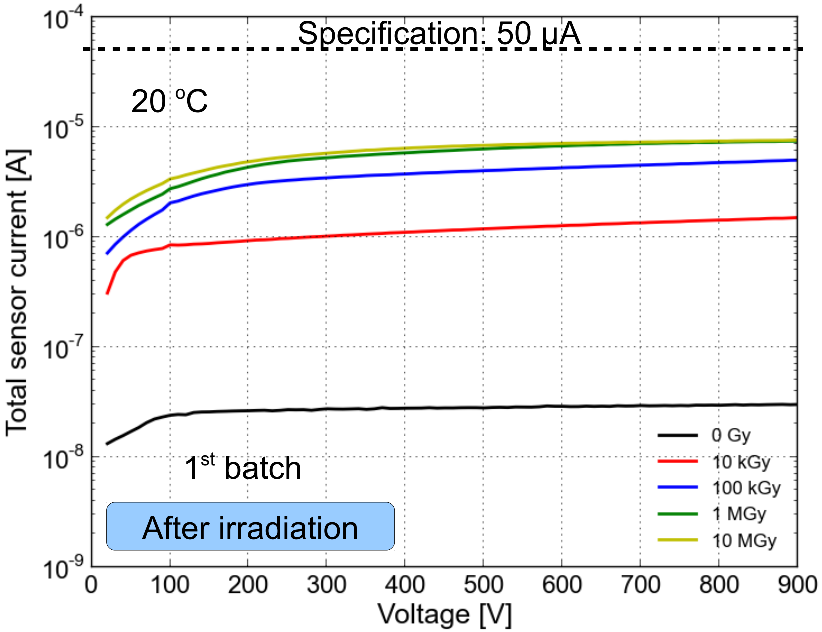
- No significant change of C_{int} after irradiation

Sensor current

- Total current of AGIPD sensor:
  - Determined from test sensor with 7x7 pixels → scaled to AGIPD sensor
  - Measurements done before and after irradiation





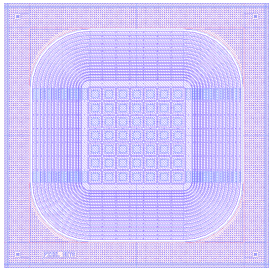


– Before irradiation: Sensor current ~ 25 nA@500 V, minor difference w/wo cutting

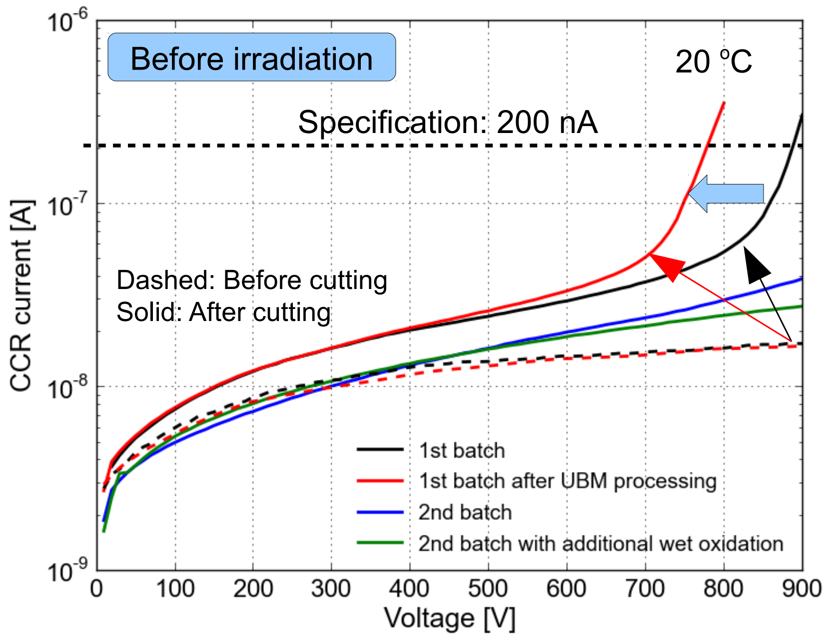
– After irradiation: Sensor current increases with bias voltage but all currents < 50 µA

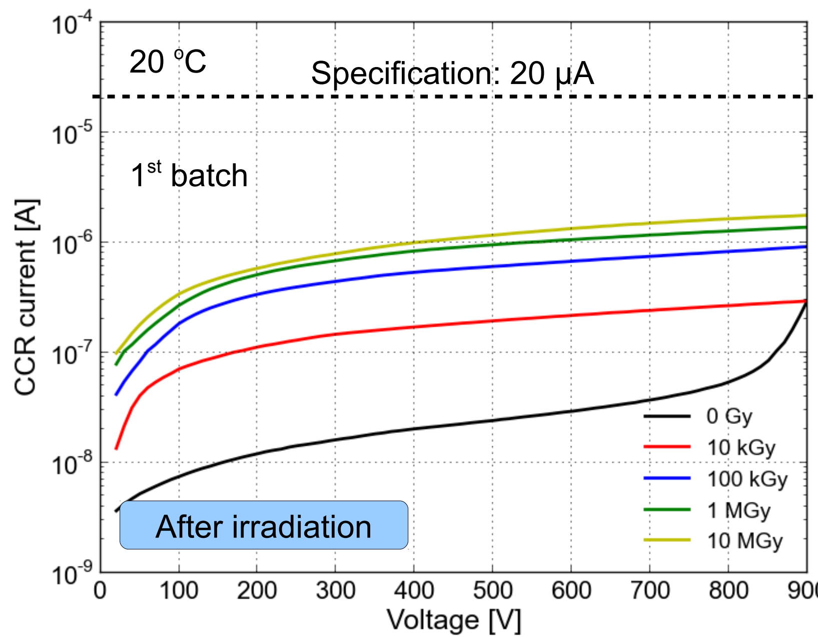
Within specification!

CCR current



- CCR current of AGIPD sensor:
  - Determined from test sensor with 7x7 pixels → scaled to AGIPD CCR
  - Measurements done before and after irradiation





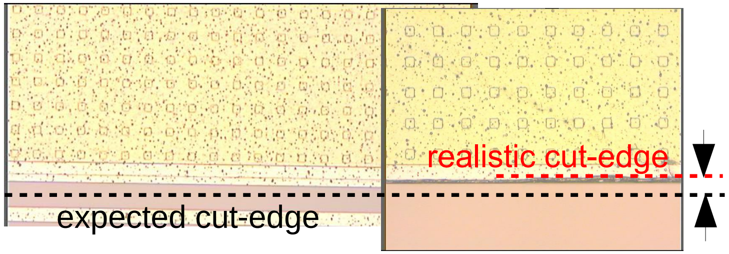
– Before irradiation: CCR current ~ 15 nA/21 nA@500 V wo/w cutting; no soft breakdown observed for 2nd batch after cutting ← resistivity

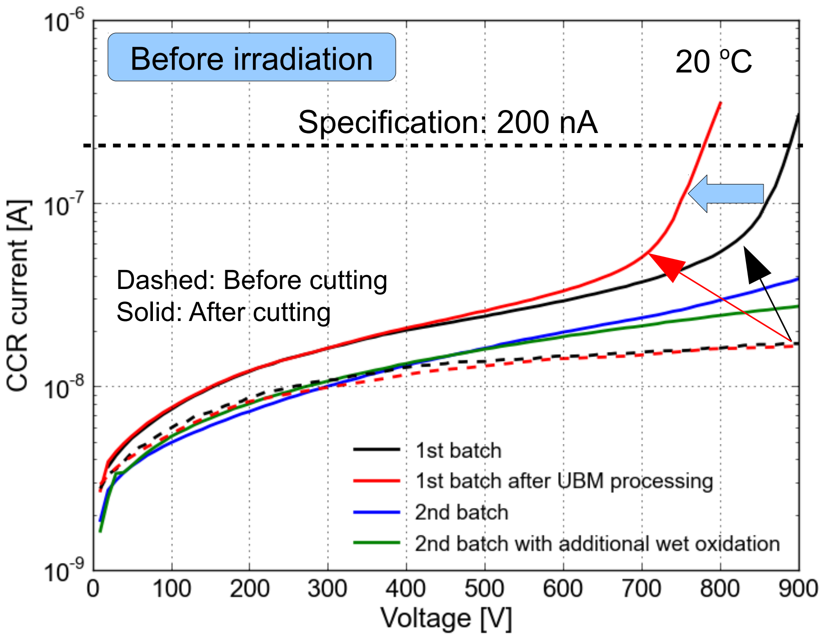
– After irradiation: CCR current increases with bias voltage but all currents < 20 μA

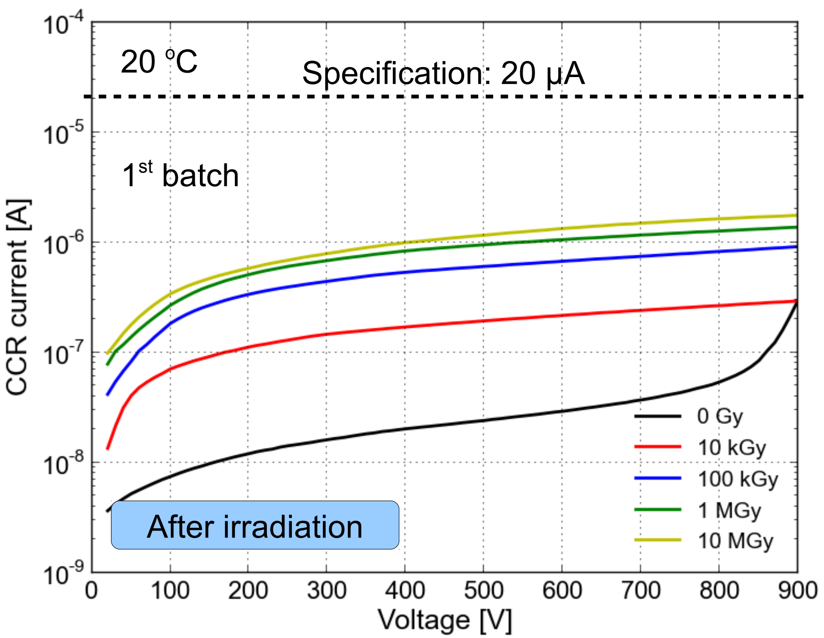
Within specification!

CCR current

- CCR current of AGIPD sensor:
  - Determined from test sensor with 7x7 pixels
  - Measurements done before and after irradiation







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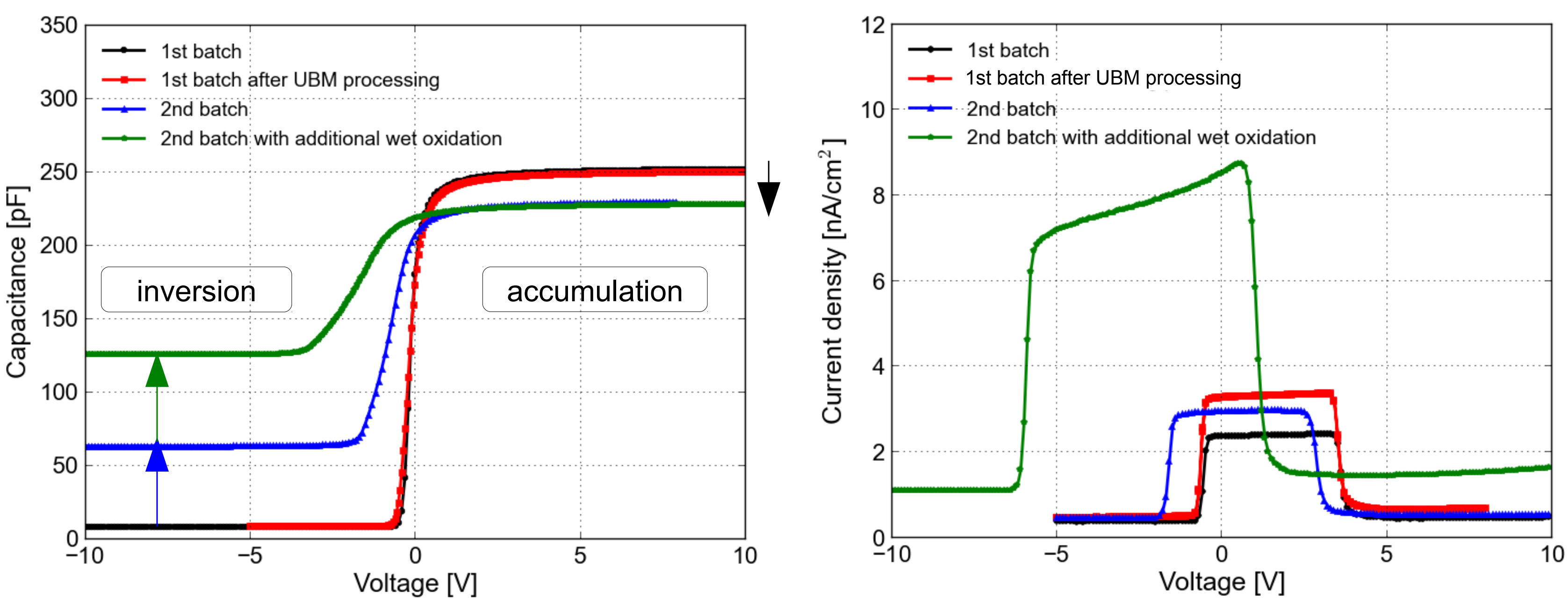
Within specification!

N_{ox} and J_{surf}

- Oxide charges and surface current:
  - Oxide charges determined from MOS-C
  - Surface current from GCD with 4 V bias



– 1st batch: Slight increase of J_{surf} after bonding process, but negligible change in N_{ox}

– 2nd batch: Lower oxide capacitance → thicker oxide? (250 nm → 266 nm?)

Larger inversion capacitance → reason unclear!

Yield

- Statistics for the yield of sensors from 1st and 2nd batches:

900 V

	Cat.	Batch-1	Batch-2
1	V_{bd} > 900 V & I(900 V) < 200 nA	27 (67.5%)	34 (68%)
2	V_{bd} < 900 V & I(900 V) < 200 nA	2 (5%)	2 (4%)
3	V_{bd} < 900 V & I(900 V) > 200 nA	11 (27.5%)	14 (28%)

500 V

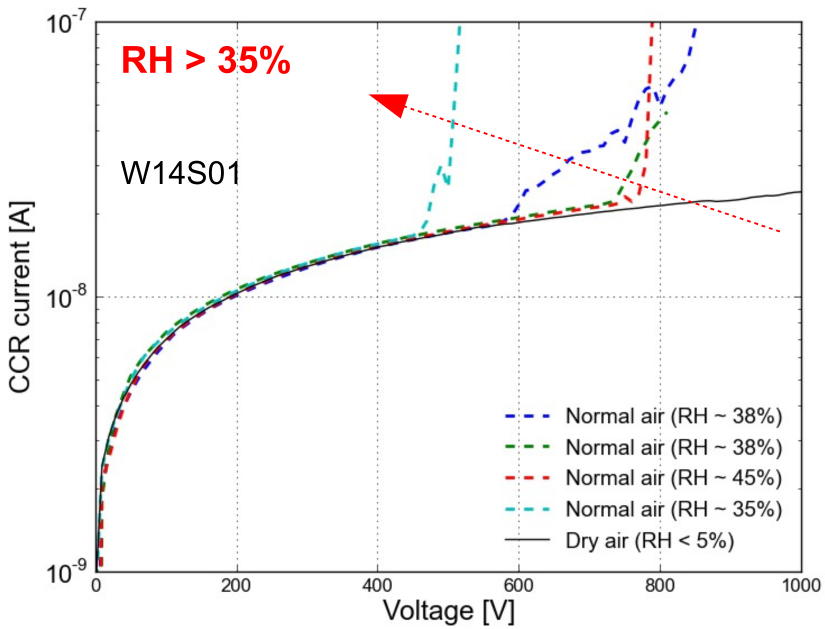
	Cat.	Batch-1	Batch-2
1	V_{bd} > 500 V & I(500 V) < 200 nA	32 (80%)	42 (84%)
2	V_{bd} < 500 V & I(500 V) < 200 nA	2 (5%)	1 (2%)
3	V_{bd} < 500 V & I(500 V) > 200 nA	6 (15%)	7 (14%)

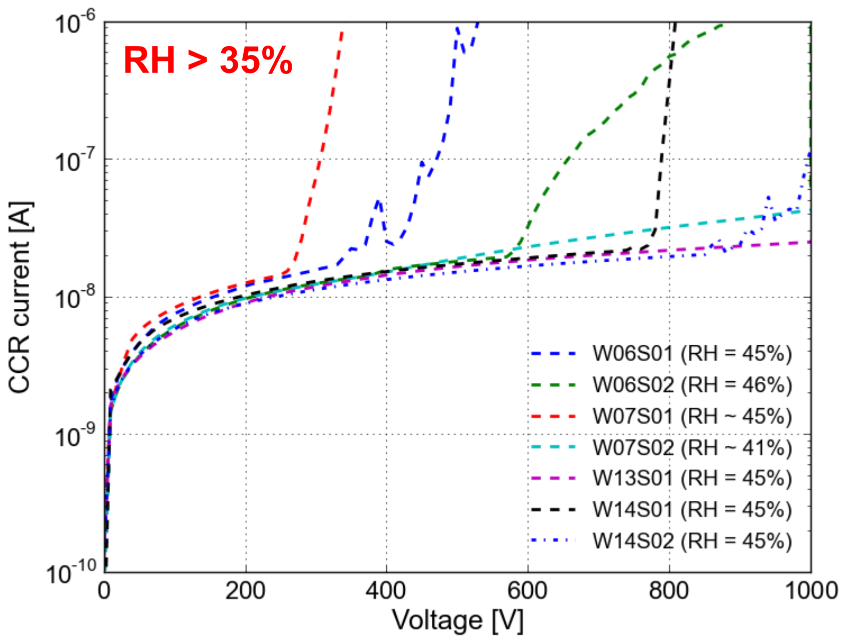
Reminder: RH effect

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

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

    → similar for irradiated sensors





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

- V_{bd} sensitive to RH and time dependence: Currently not a concern for the AGIPD sensors (operation of detector in vacuum)!

Reminder: RH effect

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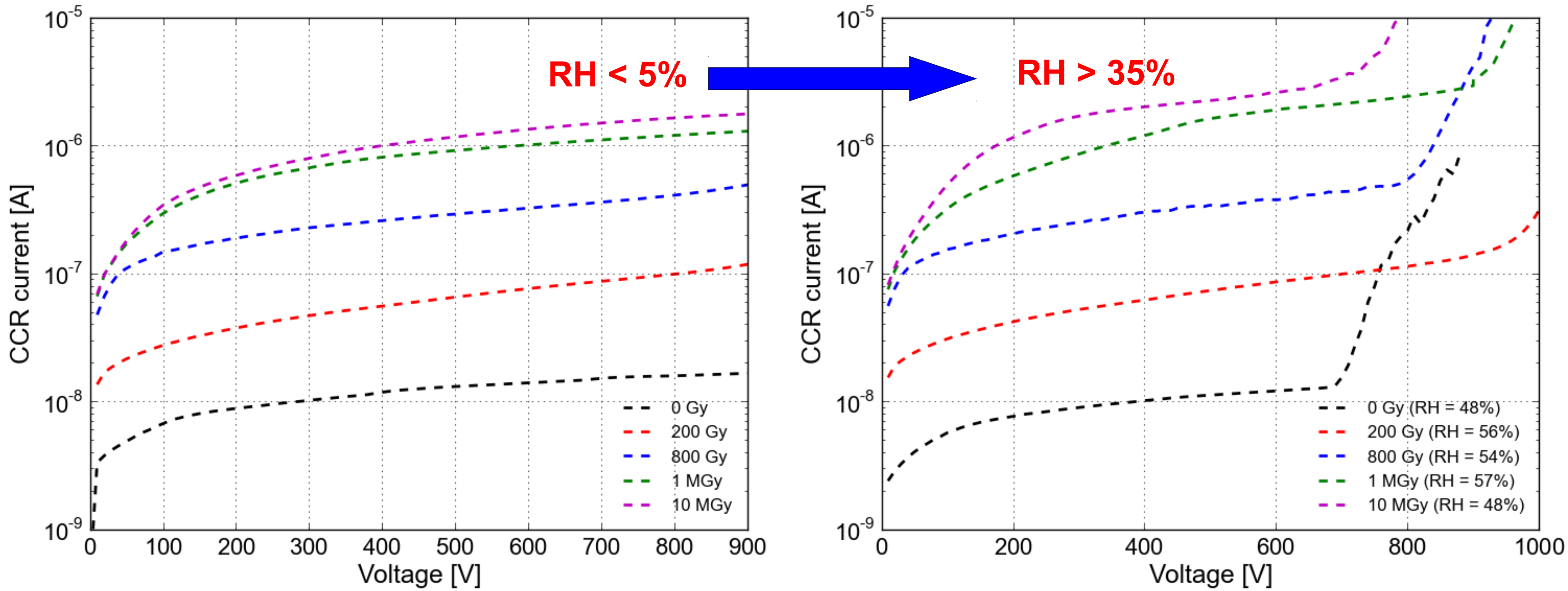
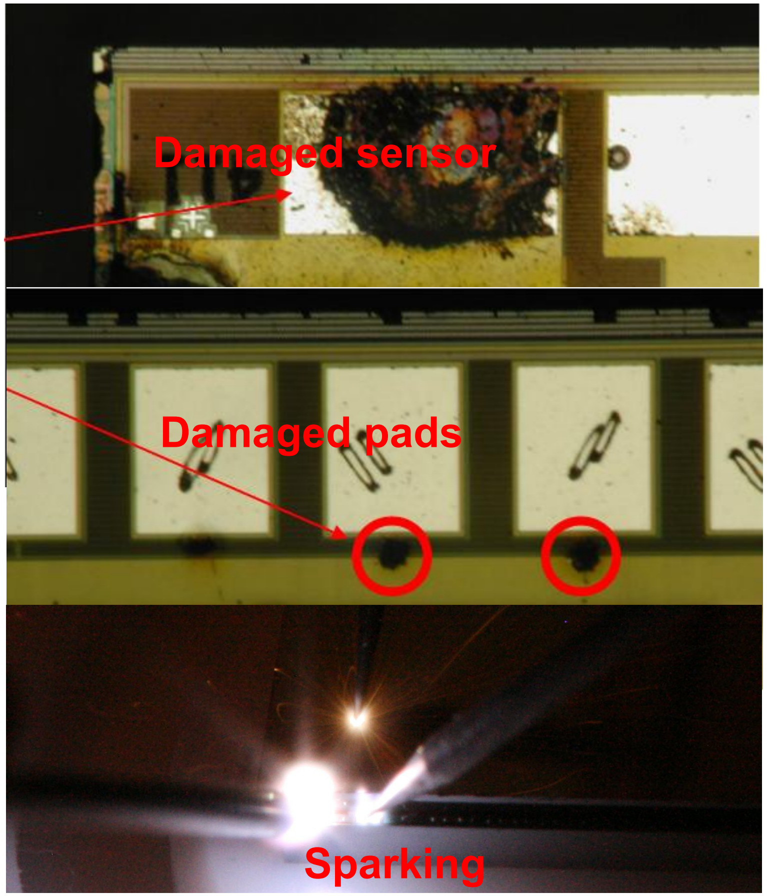


For non-/irradiated sensors: Reliable operation only in dry atmosphere

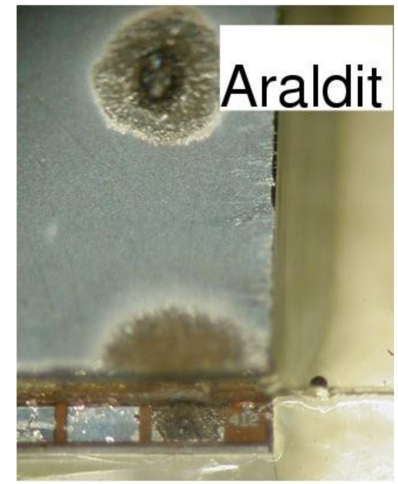
- In the long term, RH dependence should be understood and improved!
  (painful for test!)

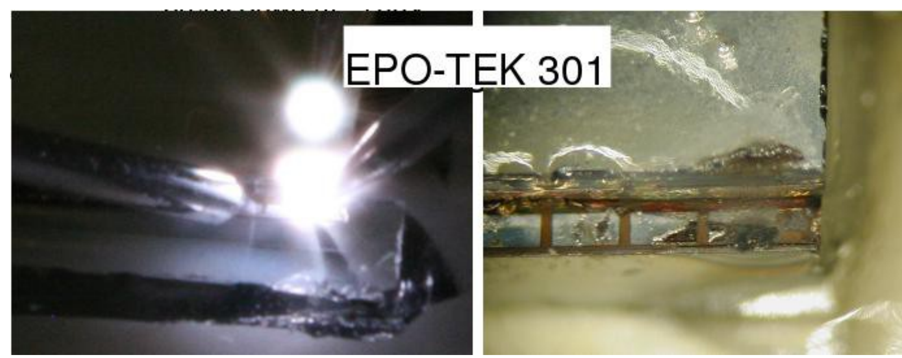
Reminder: HV protection

- Sparking of assemblies at high voltages! (lessons learnt from Pilatus)
  - HV sparking between sensor edge and bonded wire/chip (zero potential!)



- Pilatus single assemblies (p^+n sensor + defective ROC) tested by T. Rohe and J. Sibille
- Sparking at 500 V
- Two coating (glue):
  Araldit → No improvement
  EPO-TEK 301 → 700 V





- HV protection has to be taken into consideration in order to achieve > 500 V!

Summary

- **2 batches of AGIPD sensors received from Sintef**
- **Sensor quality:**
  - (Almost all) specifications met
  - Sensor performance (breakdown after cutting) from 2nd batch improved
  - 2nd batch shows thicker oxide! and higher doping close to interface? → reason unclear so far
  - Sensor yield ~ 65-70% for V_{bd} > 900 V
- **Next steps:**
  - Verify radiation hardness of sensors from 2nd batch and 1st batch with additional processes
- **Reminders:**
  - Attention to humidity effects should be paid (may influence test setups)
  - HV sparking could be a potential problem for AGIPD operated at high voltages