GUARD RING OPTIMISATION OF PASSIVE-CMOS PIXEL STRUCTURES

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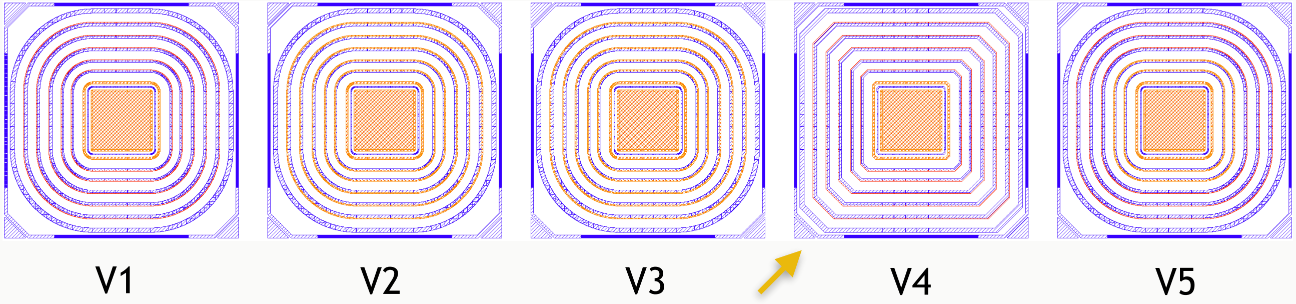
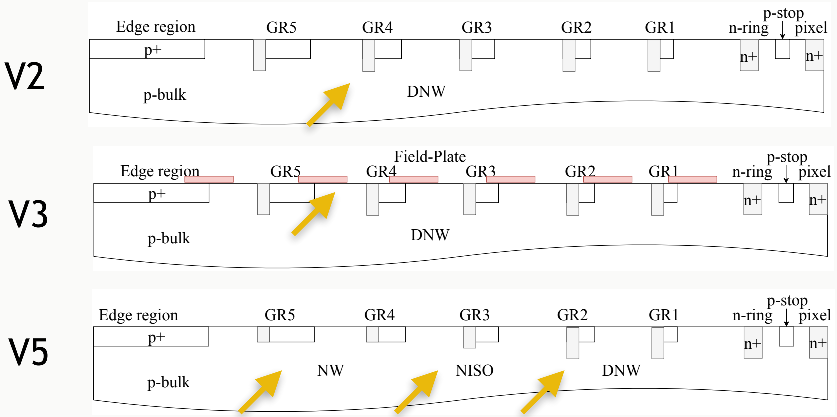
RECAP: THE PASSIVE-CMOS TEST STRUCTURES

- From MPW3 submission
- Geometry
  - Pad (Pixel) + guard rings
  - Substrate resistivity: 1.9 kOhm & 3 kOhm
  - Thickness: 280 um



- Guard ring types:
  - V1 old design: n+p GR, large spacing between n-ring and GR1
  - V2 based on V1: deep n-well replaces standard n-well at GR
  - V3 based on V2: large overhang
  - V4 based on V1: with chamfer corner
  - V5 based on V1 & V2: with reducing n-well depth from inner to outer GR



BREAKDOWN SIMULATION

- Deduce from the potential distribution @~ -200V:
  - Breakdown likely between N-ring and GR1, due to large potential drop (i.e. high E-field)
  - DNW suppresses this effect by elevating the potential

➡ Visible increase of breakdown voltage after using DNW : $V2 > V1$ (ref)

➡ Overhang can suppress the potential at GR, meaning a higher E-field: $V2 > V3(\gtrsim V1)$

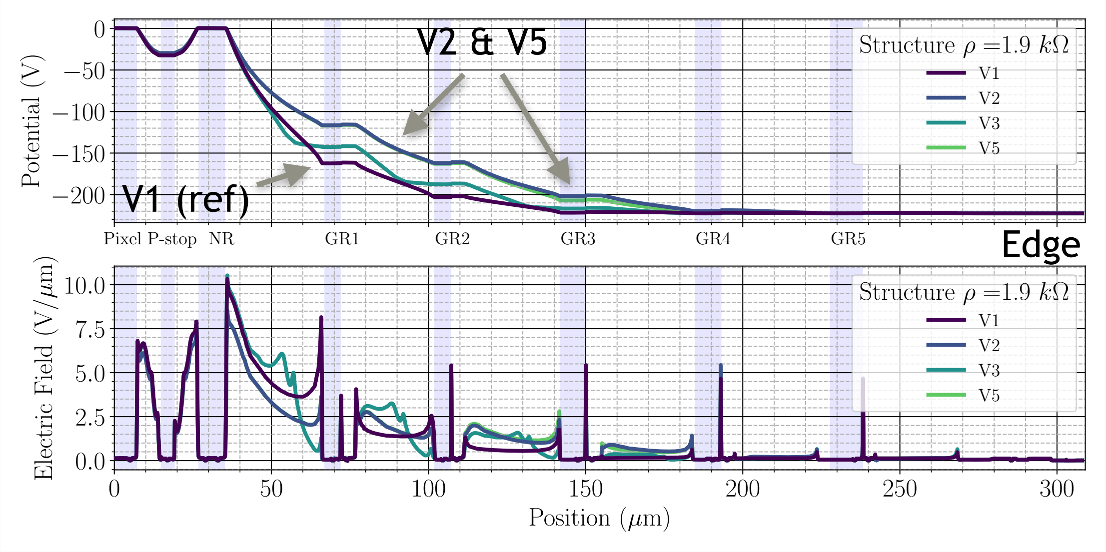
➡ Most critical location is between GR1 and N-ring,
DNW in the inner GR can already reduce the field: $V5 \approx V2 > V3(\gtrsim V1)$

➡ Chamfer GR corners should have higher field & according to the breakdown simulation:

$$V5 \approx V2 > V3 \approx V1 > V4$$

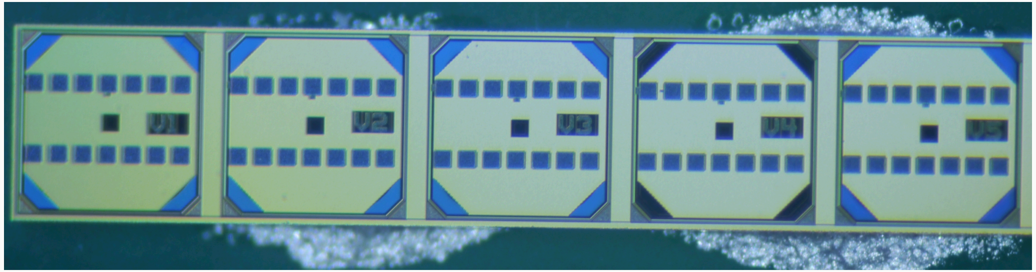
Reminder:

V1: ref
V2: Full DNW
V3: Full DNW + overhang
V5: DNW + gradient

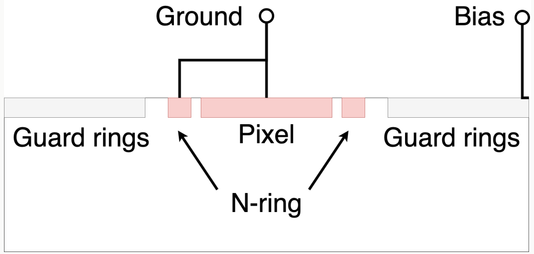


BREAKDOWN MEASUREMENT

- Measurement ambient:
  - T ~ 20 C
  - RH ~ 50%



- IV measurements
  - Ground the pixel and the n-ring
  - Frontside bias



BREAKDOWN VOLTAGES

Reminder: expect $V5 \approx V2 > V3 \approx V1 > V4$

- 4 samples, 2 per resistivity
- Structures exhibit 2-stage current increase
  - Especially for the high resistivity substrate

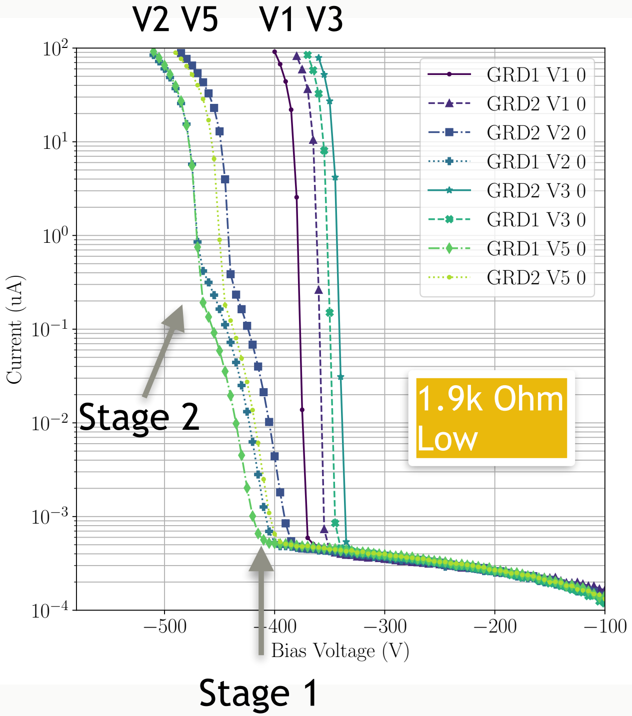
- Stage 1 near full depletion
  may relate to the unprocessed backside

https://cleanroom.byu.edu/pn_junction https://www.pvlighthouse.com.au/resistivity

  full depletion voltage:
  - 1.9k Ohm @ ~ -400V bias
  - 3 kOhm @ ~ -320V bias

Similar effects see:
http://dx.doi.org/10.1088/1748-0221/12/06/P06020

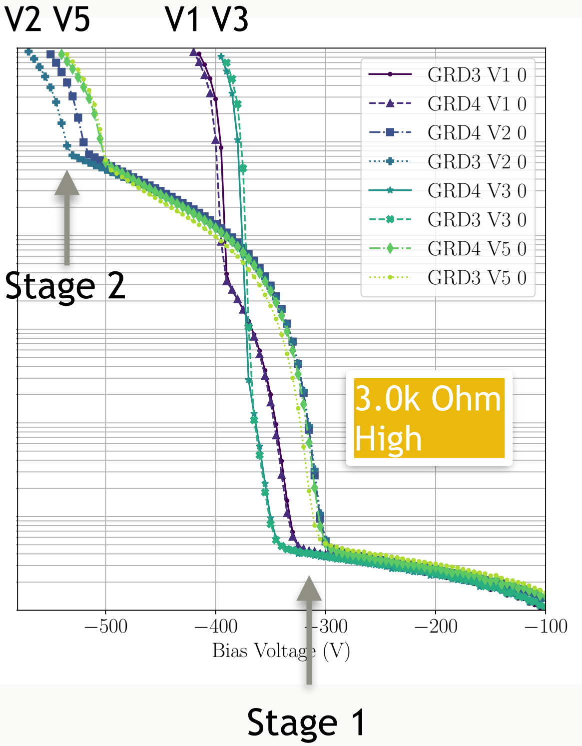
- Stage 2 may be the real junction breakdown
  - Increased by approx. 100V
  - Revealed the expectation
- Structure V4 has a breakdown smaller than 300 V



Stage 2

Stage 1

1.9k Ohm
Low



Stage 2

Stage 1

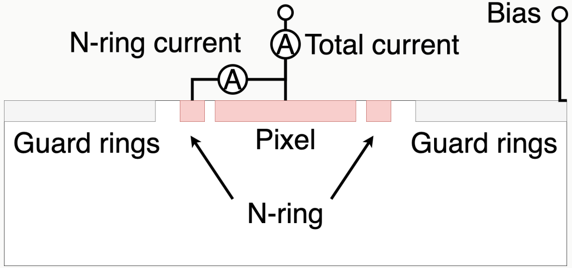
3.0k Ohm
High

CURRENT THROUGH N-RING &VOLTAGE PROBING

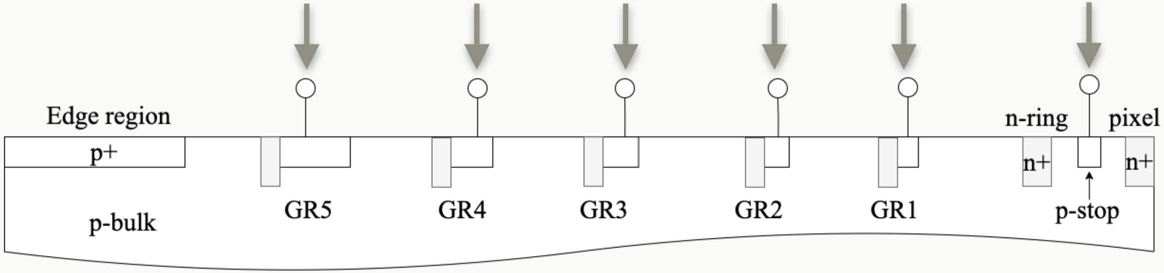
- 4 new samples, 2 per resistivity
- Wire-bond all the guard ring implants

- IV measurements
  - Ground pixel and n-ring
  - Frontside bias
  - Monitor total current and n-ring current simultaneously

- Voltage probing
  - Ramp the bias voltage to -200 V
  - Monitor a p-implant for each bias ramp



Monitor voltages



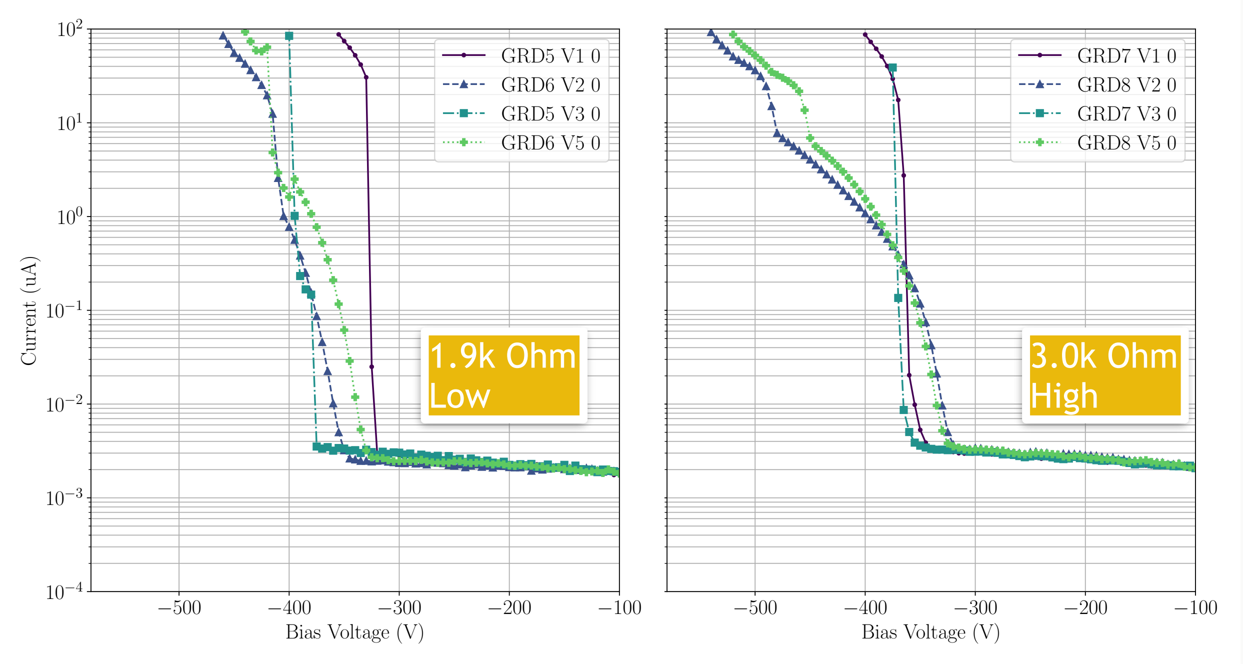
IV-CURVES OF FULLY BONDED SAMPLES

Compare with previous samples

- Smaller breakdown voltages

  Until now, the uncertainty of the breakdown voltage is roughly within 50V

- Similar characteristics:
  - Relation between structures in terms of breakdown voltage
  - 2-stage current increase
  - 1st current increase near the full depletion

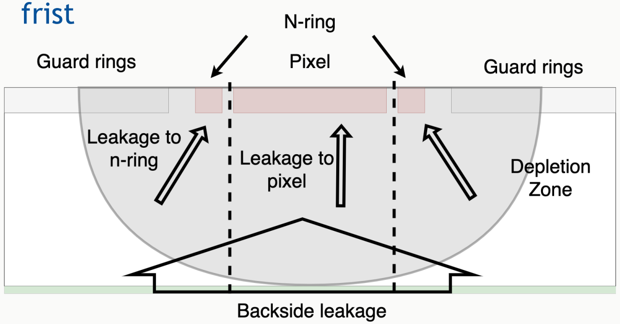


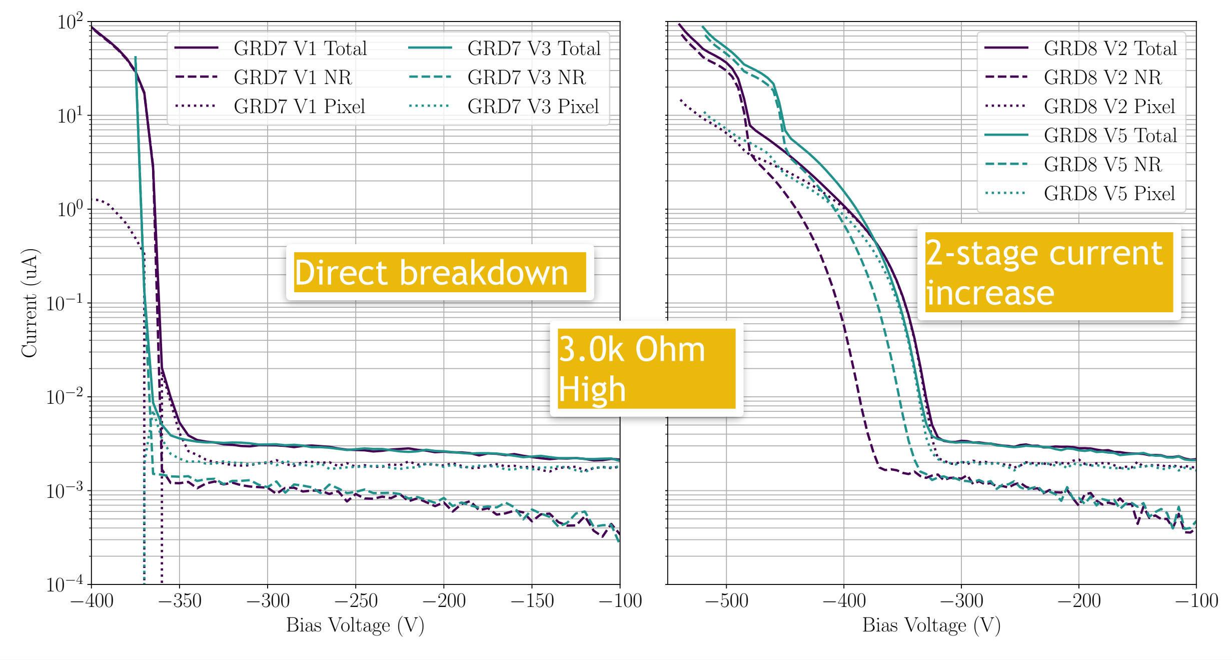
1.9k Ohm Low

3.0k Ohm High

THE 2-STAGE CURRENT INCREASE

- Total current, n-ring current, and pixel current
- Direct breakdown (V1, V3):
  - N-ring dominates the total current —> high current from the guard ring region
- 2-stage current increase (V2, V5):
  - Pixel current dominates the 1st step
  - The 2nd step mainly from guard rings
- conjecture: depletion region under pixel touches backside frist





Direct breakdown

3.0k Ohm High

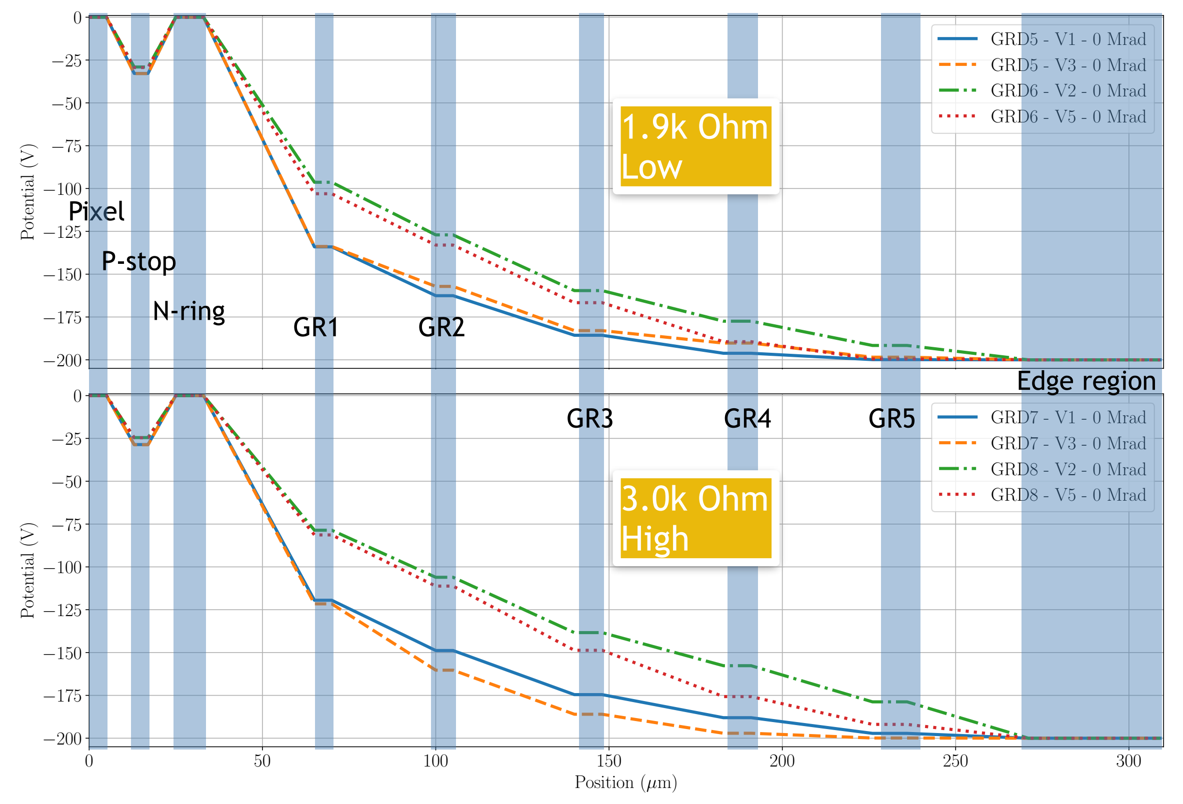
2-stage current increase

POTENTIAL DISTRIBUTION OF GUARD RINGS

- Potential decreases from the N-ring to the edge ✔
- Largest potential drop between N-ring and GR1 ✔

- Effect of deep n-well:
  - Elevate the overall potential ✔ (comp. V1 & V2)
- Reducing n-well depth:
  - Lift the inner rings ✔ (comp. V2 & V5)
- Effect of overhang:
  - Suppresses the potential ✔ (comp. V2 & V3)
  - Effect is stronger than simulations (comp. V1 & V3)

➡ Potential distribution validated



SUMMARY & OUTLOOK

- Expect a visible increase of breakdown voltage after modifying guard ring structure with DNW
- Breakdown Measurements:
  - Current increases in 2 stages: backside leakage (1st stage, from pixel) + real junction breakdown (2nd stage, from guard ring)
  - Expected relation is validated: $V5 \approx V2 > V3 \approx V1 > 300\ \mathrm{V} > V4$

DNW + gradient

Full DNW

Full DNW + overhang

ref

- Voltage probing:
  - DNW delivers a more smooth potential distribution, as predicted by simulations
- Further investigation:
  - Are there currents from the edge? —> bias outer rings together with edge to limit the depletion at breakdown —> how to avoid this?
- More ideas:
  - Smaller guard ring region?: use small size of implants and small gaps —> space efficient
  - No implantation?: modulate the potential using polysilicon rings (MOS capacitors) —> optimise potential distribution using voltage divider
  - Etc.
  - Many test structures were submitted to explore the possibilities of the guard ring design

SIMULATION: BREAKDOWN IV