GUARD-RING OPTIMISATION FOR SENSORS IN LFOUNDRY 150NM CMOS TECHNOLOGY FOR THE RD50-MPW3 SUBMISSION

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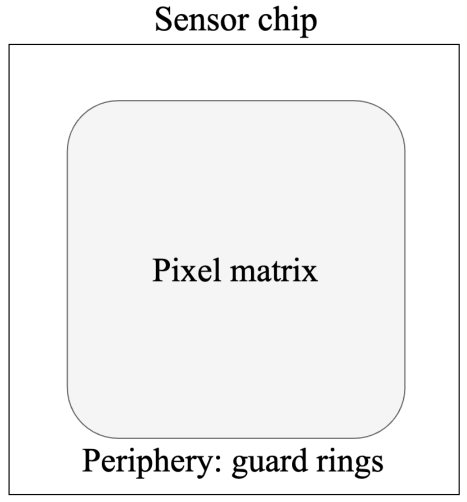
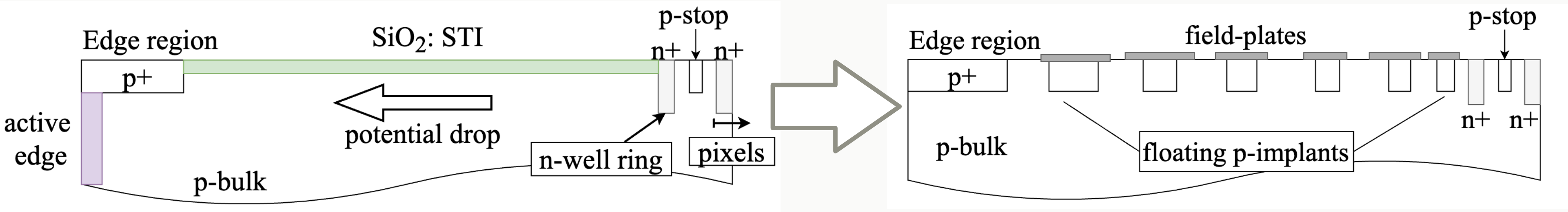
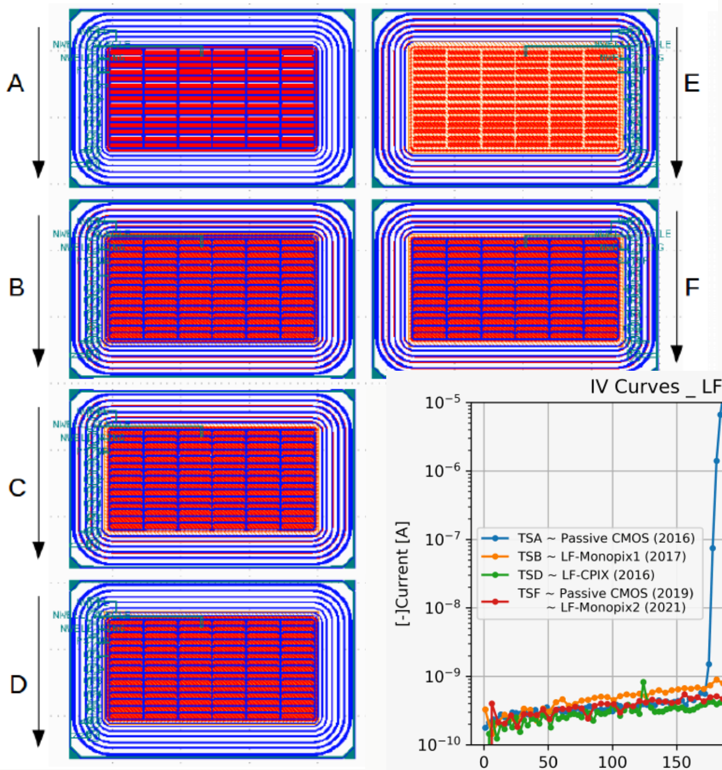
THE GUARD-RING OF SENSORS



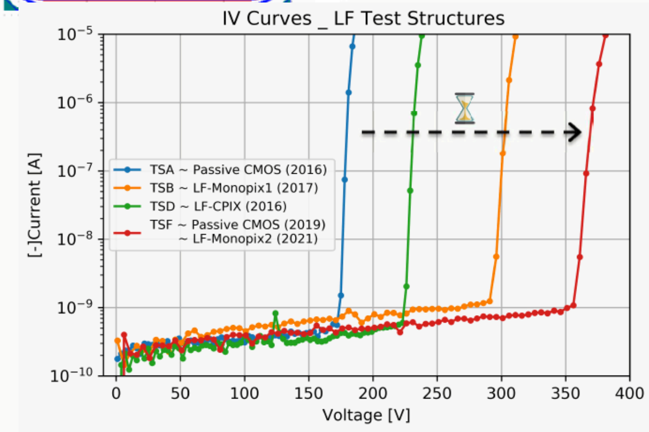
- Potential drop from the matrix to the edge of chips —> sideward depletion
- Challenge:
  - **Complex condition of the surface conductivity** due to e.g. imperfection of manufacturing, TID, ambient
  - ➡ Depletion and potential distribution not predictable
  - ➡ High leakage (depletion region touches the cutting edge)
  - ➡ Low breakdown voltage (local high electric field)
- **P-type floating guard-rings:**
  - ➡ “Pin” the surface potential at the designed distance from the active region
  - ➡ Interrupt the electron accumulation layer under STI
  - ➡ Provide a more smooth potential drop, predictable and good breakdown

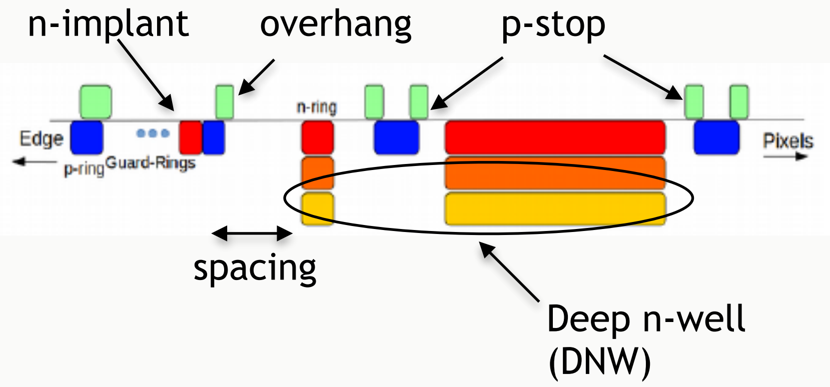


CURRENT STRUCTURES ON LFOUNDRY CMOS SENSORS



- LF CMOS test structures for monolithic detectors (~2017)
  - 6 types (A—F) with distinct features & breakdown performance
  - implementation in various monolithic/passive sensors
  - newest applications based on **structure F**





by Ivan Caicedo

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MEASUREMENTS AND SIMULATIONS

- **Higher breakdown voltage:**
  - large spacing between 1st GR and n-well ring (NWR)
  - with n-implant
  - NWR with deep N-implant (requires more tests)
  - overhang: dependence not clear (requires more tests)

➡ Structure C (with overhang) and F (without overhang) are the optimum choices

➡ Simulation qualitatively reproduced the relations

Measurements

	B	C	D	F
GR1 gap	small	large	small	large
n-GR	yes	yes	no	yes
overhang	yes	yes	yes	no
Breakdown (Grounded NWR)	~260V	~340V	~170V	~300V

*Simulation

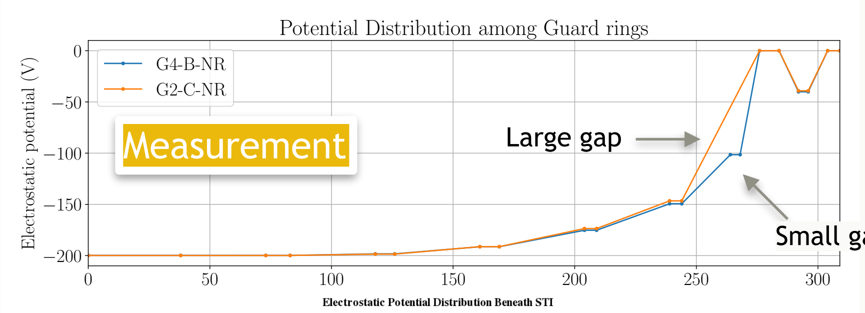
	B		D	C & F
Breakdown (Grounded NWR)	~334V		~234V	~509V

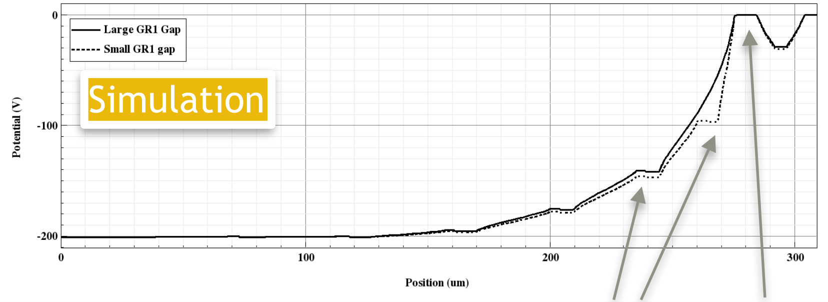
✴ 2D simulation —> corners are not considered
✴ Overhang on GR not considered
✴ etc.
➡ **Quantitatively: overestimation of breakdown voltage**

MEASUREMENTS AND SIMULATIONS

- Voltage probing (Keithley 6517A electrometer, @RT) vs. Potential distribution under STI (TCAD simulation)

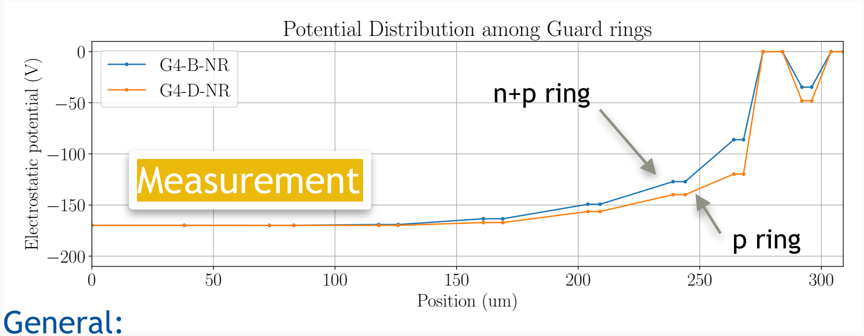
Large vs. small gap





Sensor Edge … GRs … 1st GR N-well Ring

n+p ring vs. p-ring



- General:
  - Potential distributions are (well) reproduced
  - Highest potential drop between N-well ring and first GR
  - Highest field at the same location (—> possible location of avalanche breakdown)
  - Outer rings not easy to be depleted

➡ Large gap —> less steep curve —> smaller field (revealed in TCAD)

➡ N-implant —> lift the potential at GR —> reduce voltage drop

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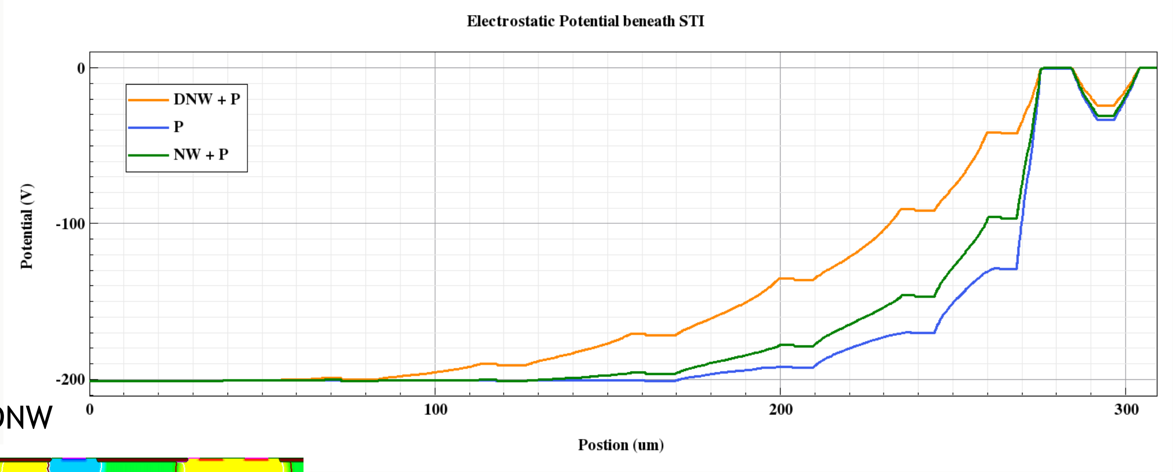
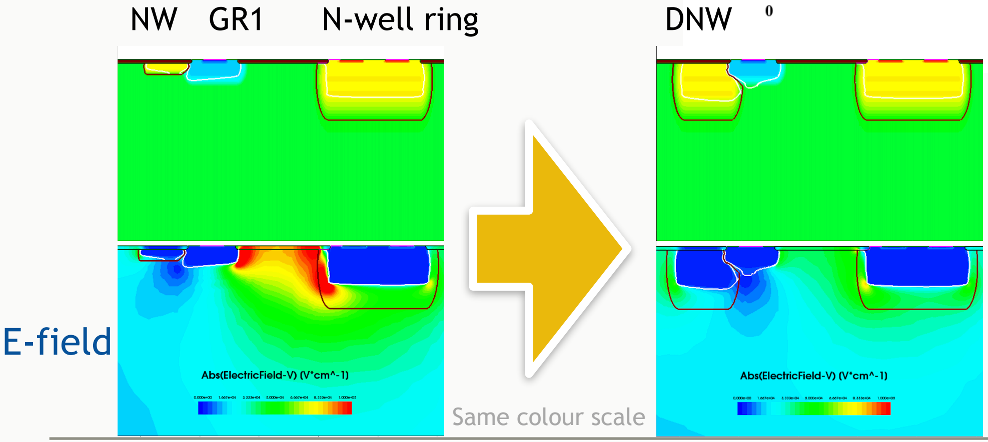
TOWARDS HIGHER BREAKDOWN VOLTAGES

- Inspired from the current n-GR structure:
  - deep N-well besides p-ring
  - further lift up the potential





- From simulation:
  - more uniform potential drop
  - larger depletion region at the same bias voltage
  - ➡ higher breakdown voltage (neglecting OxC, field-plate, edge states)

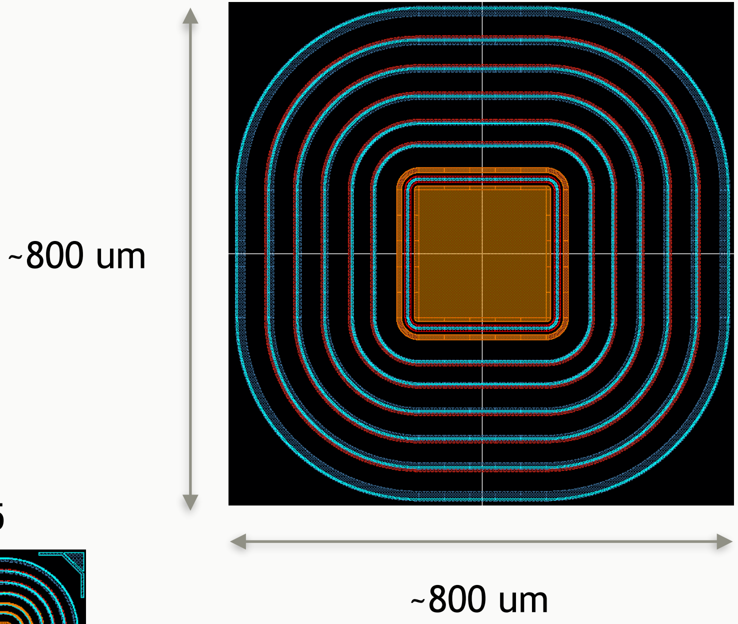
➡Possibly a way to further improve the breakdown

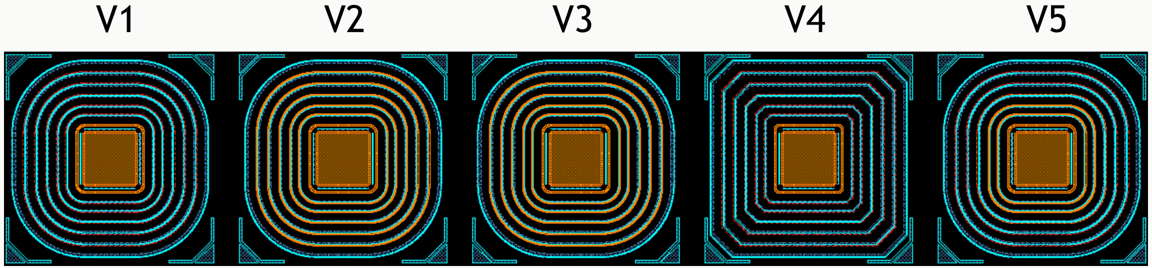
AN OPPORTUNITY TO HAVE A TRY

- RD50 MPW3 submission 2021
- LFoundry 150 CMOS technology

➡ Five small test structures with full guard rings

➡ Pad diode (~ 200um x 200um) in the centre (no pixel structure)



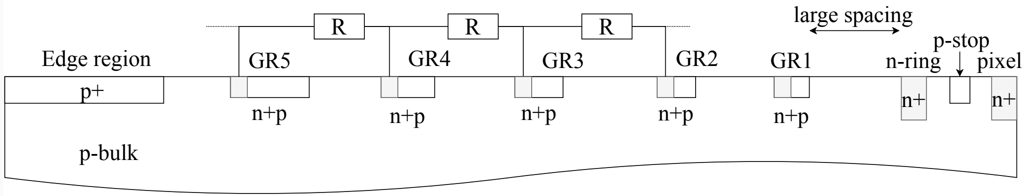


GENERAL FEATURES

- Structure V1:
  - GR spacing and size based on structure F
  - The basic geometry for other structures
- Contacts on all n-GR —> wire-bonding possible

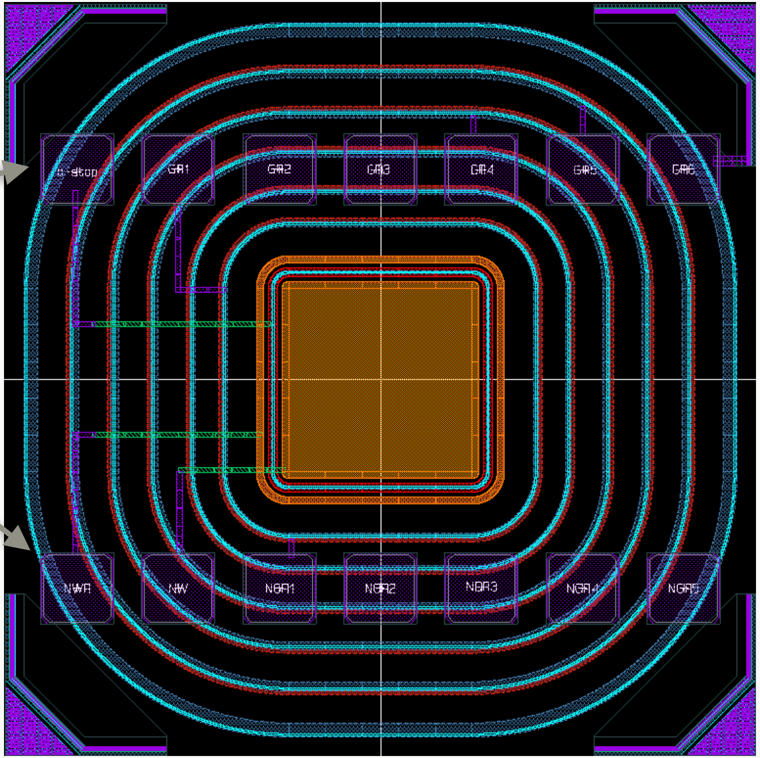
➡ Possibility for voltage probing

➡ Control voltage distribution via resistors on PCB board



Bonding pads for p

Bonding pads for n



V1: GR design based on the current structure F

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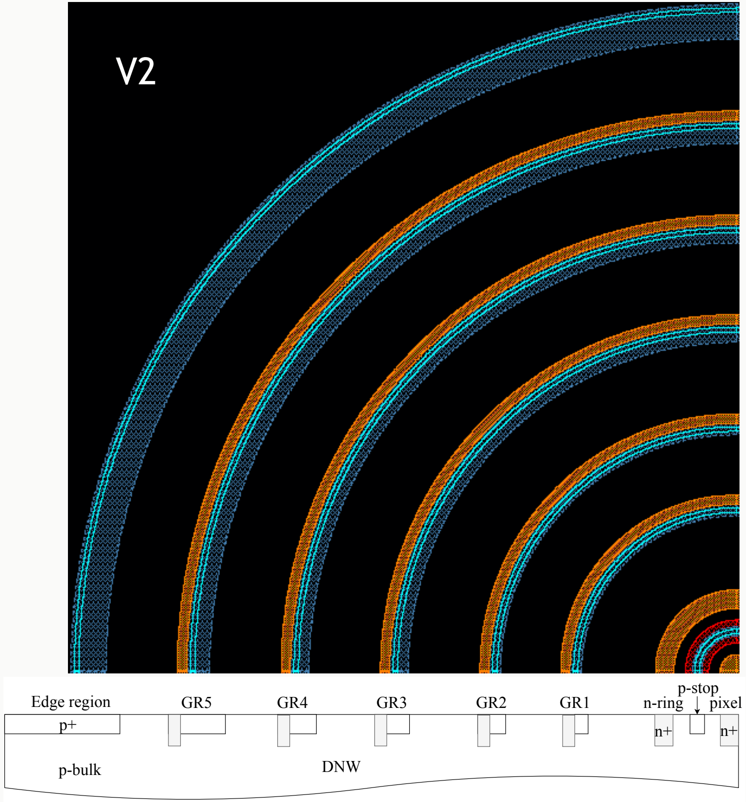
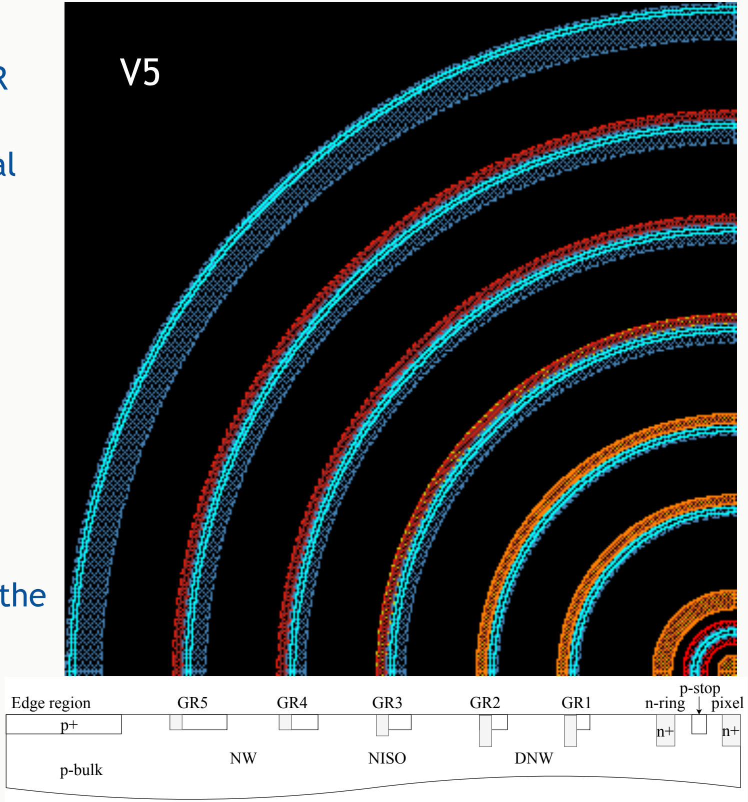
STRUCTURE V2 & V5: DEEP N-WELL



- V2:
  - DNW on all floating GR
  - expect:
    more uniform potential differences
    large depletion
    —> higher breakdown
- V5:
  - depth of N decreases towards outside
  - inner DNW: reduces largest potential drop
  - outer NW: suppresses the depletion and voltage close to the edge



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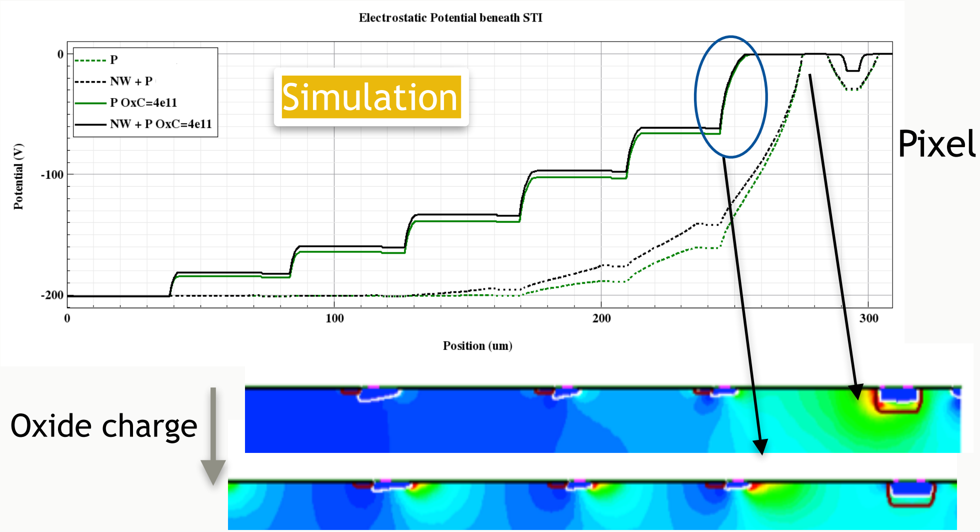
THE TID

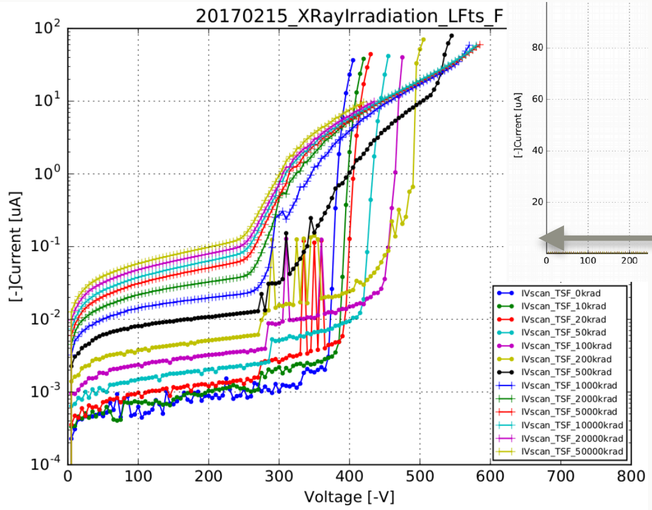
- Oxide charges built-up after TID
  - higher conductivity at the surface
  - lift the potential of & between GR
  - move high-field regions (see figure)

Edge



Pixel

Oxide charge



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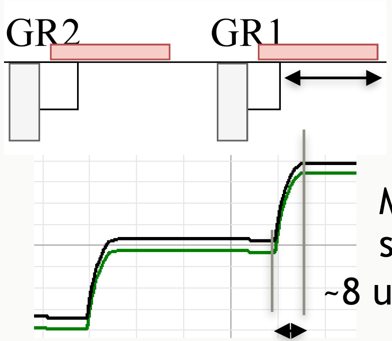
- Low doses
  - Potential differences are reduced
  - increases breakdown voltage
- High doses
  - local potential distribution very steep
    —> local high E-field
    —> breakdown point

STRUCTURE V3: WITH OVERHANG

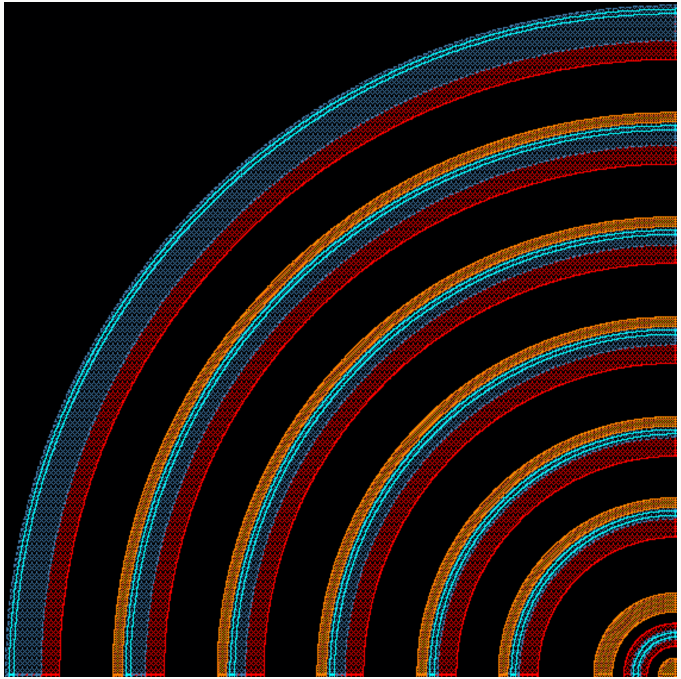
- Poly Si + 2 metal layers as the field plate on all GRs
- overhangs extend >10um towards pixel matrix
- Voltage is adopted from the p-GR
- Expect:
  - lower potential on the field-plate above oxide (MOS-like structure)
  - suppress the voltage close to the edge of p-GR implant
  - more smooth voltage drop

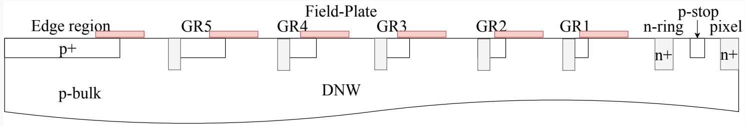


16 um: Metal 2
13 um: Metal 1
10 um: Poly-Silicon

Matrix side

~8 um

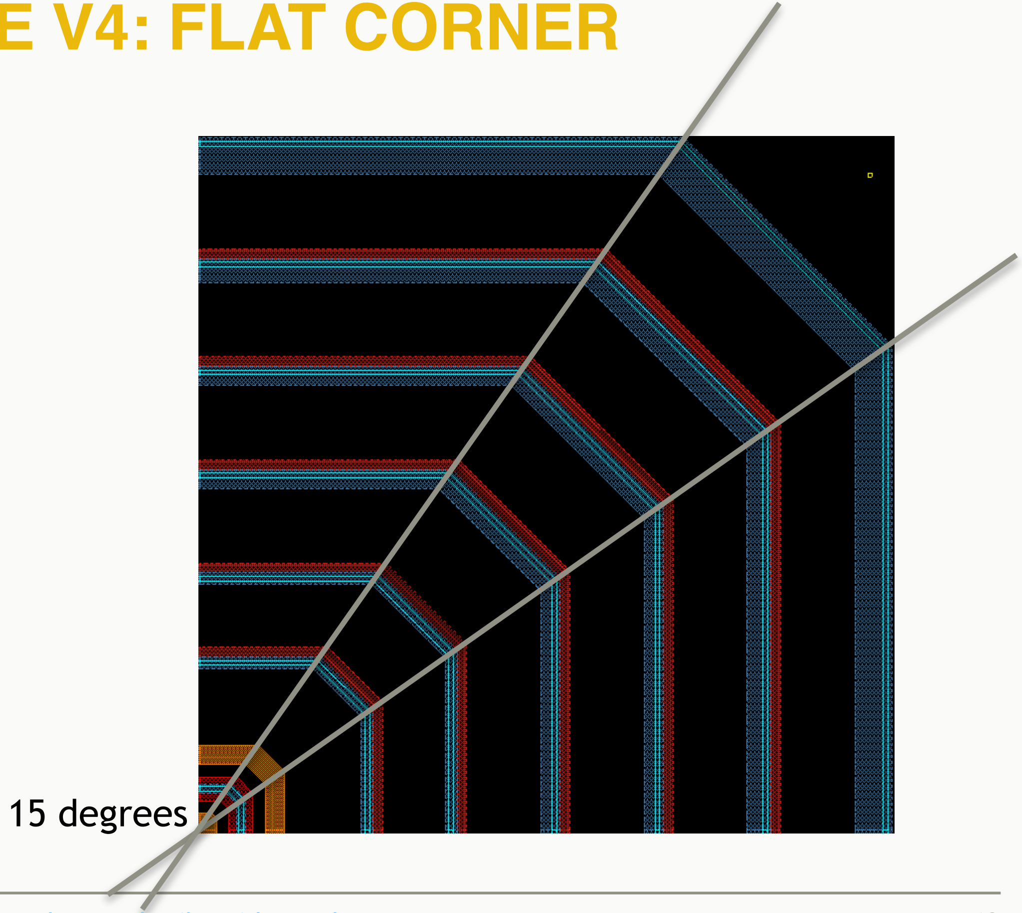




STRUCTURE V4: FLAT CORNER

- Same implantation profile as V1:
  NW + PW as GR
  same size and spacing
- Opening angle: ~15 degrees

- Check and compare the performance



SUMMARY AND OUTLOOK

- 5 test-structures were designed for the RD50-MPW3 submission
- Modifications of guard-rings based on the current structure F:
  - V1 standard n-well —> same design as structure F —> reference
  - V2 deep n-well —> lift potential on GR —> more uniform potential drop
  - V3 DNW+overhang —> suppress local E-field —> smoother distribution after TID
  - V4 flat corners —> compare the performance with round corner
  - V5 varying n-well depth —> reduce potential differences in inner and outer part of GR region

- Next:
  - Add field-plate, radiation damage in simulation
  - Prepare test structures for proton & X-ray irradiation
  - What if…
    - DNW not available?
    - Smaller sensor periphery?

Thank you

LITERATURES

- Avset 1996: 10.1016/0168-9002(96)00194-5
  - Field-plate (overhang) — n-bulk
- Kobasy 2010: 10.1109/TNS.2010.2063439
  - N-in-p sensor — field plate
- Rossi 2006: Pixel detectors: From fundamentals to applications
  - General knowledge — mostly n-bulk

- And there are more

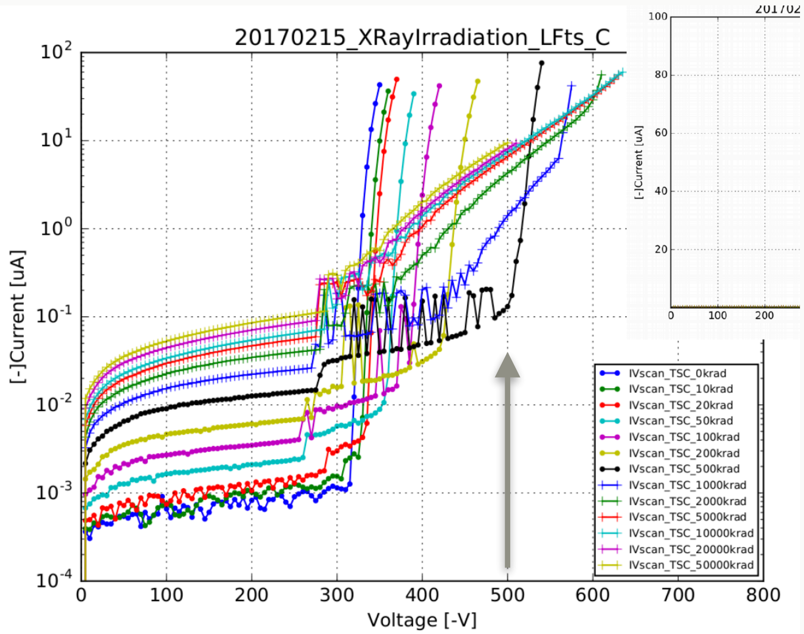
	A	B	C	D	F
GR1 gap	small	small	large	small	large
n-GR	no	yes	yes	no	yes
overhang		yes	yes	yes	no
DNW on NWR	no	yes	yes	yes	yes
Breakdown (Grounded NWR)	-	~260V	~340V	~170V	~300V
Breakdown (floating NWR)	-175 (2017)	~295V	~305V	~240V var.	~316V var.

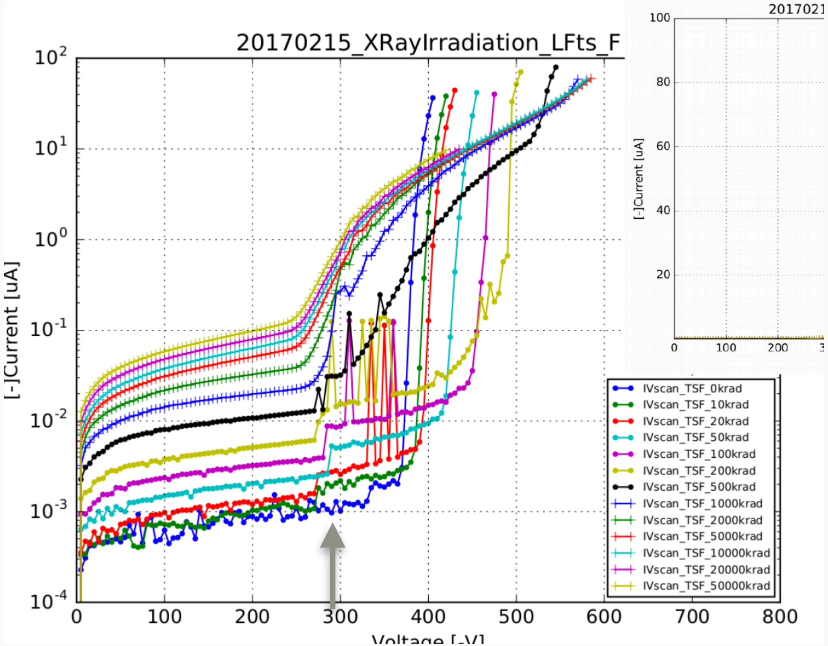
measurements summary of measured breakdown voltage for two schemes:

-> grounded N-well Ring
-> floating N-well Ring

var.: relatively large variation among samples
(year): previous measurements

With overhang





same TID, overhang results in higher breakdown voltage (see the black curve as an example)