# Measurements and TCAD simulations of guard-ring structures of thin silicon sensors before and after irradiation


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## Motivations

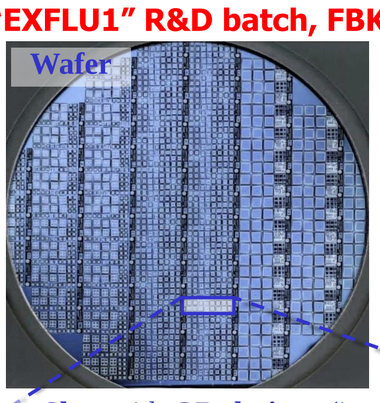
- ✓ Developing high performing silicon detectors for particle tracking in the next generation of high-energy physics experiments at future colliders (e.g., HL-LHC, FCC) able to operate efficiently up to very high fluences, $\Phi \sim 1\times10^{17}$ 1 MeV $n_{eq}/cm^2$.
- ✓ To sustain high voltage values with minimum leakage current injection into the core region of the sensor, the design and optimization of the Guard-Ring (GR) protection structure is crucial, especially when small substrate thicknesses are used.
- ✓ In a recent R&D batch produced at FBK in the framework of the "eXFlu" project, different optimisation studies of GR structures for thin substrates (45, 30, 20 and 15 µm) up to high fluences ($2.5\times10^{15}$ 1 MeV $n_{eq}/cm^2$) have been addressed.
  - ad-hoc advanced Technology CAD (TCAD) modelling of the different GR design strategies, accounting for the radiation-induced damage effects (bulk + surface);
  - extensive test campaign on these GR structures, both before and after irradiation.

  → **Validation** of the development framework and **evaluation** of the impact of the various GR design options on their performance, before and after irradiation.

## Measurements

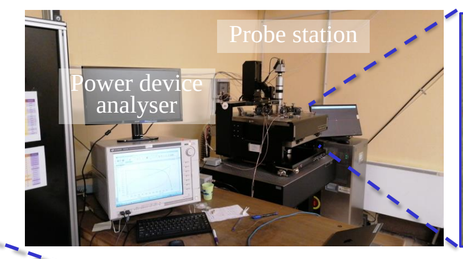
### DUT & Setup

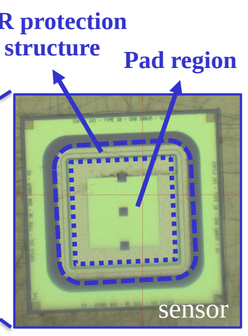
**"EXFLU1" R&D batch, FBK**



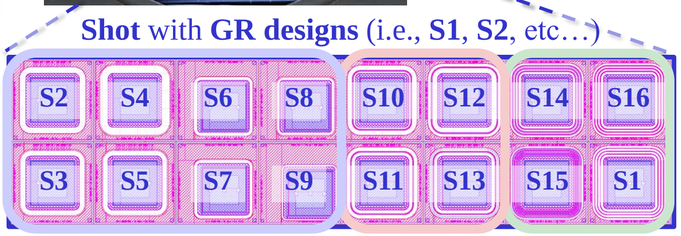

**Temperature-controlled probe station**

**Current-Voltage (I-V) setup**




**Shot** with **GR designs** (i.e., **S1**, **S2**, etc…)



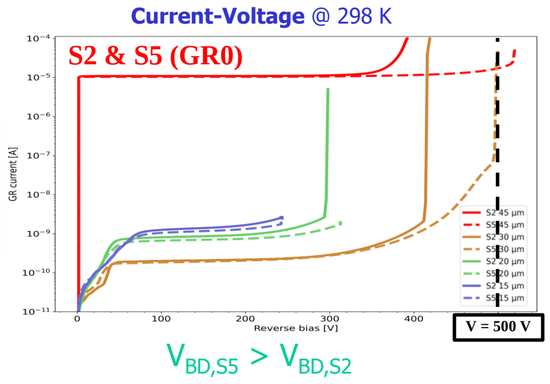

- ✓ Four substrate **thicknesses**:
  - **45**, **30**, **20** and **15 µm**
- ✓ **Irradiation** campaign with **neutrons** at the JSI TRIGA reactor (Ljubljana, Slovenia)
  - Fluences (Φ): **8-15-25E14 1 MeV $n_{eq}/cm^2$**

- ✓ **GR0**: **no floating GRs**, varying
  - *edge* region size
  - *void* region size (i.e., scribeline)
  - metal *overhang*
- ✓ **GR1**: **1 floating GR**, varying
  - floating GR *position*
- ✓ **GR3**: **3 floating GRs**, using one or both of:
  - single *n-deep* implant
  - single *p-stop* implant

#### I-V

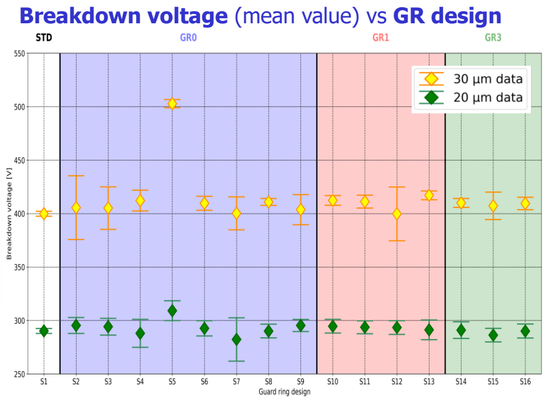
**Before irradiation**

**Current-Voltage** @ 298 K




$V_{BD,S5} > V_{BD,S2}$

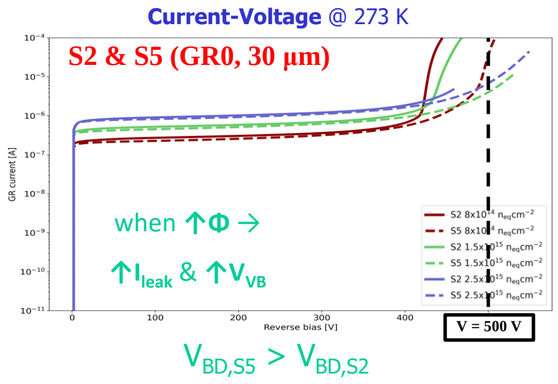
**Breakdown voltage** (mean value) vs **GR design**




**GR0 ≈ GR1 ≈ GR3** & **S5 best** GR design

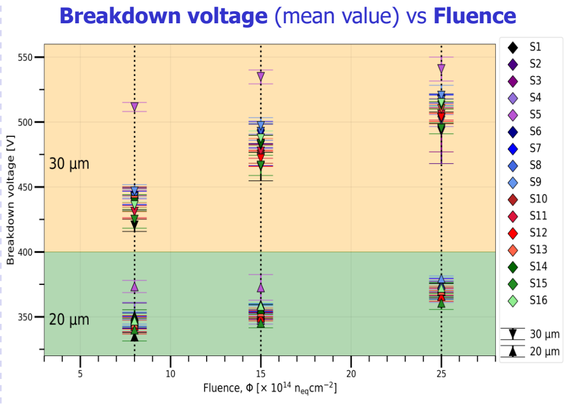
**After irradiation**

**Current-Voltage** @ 273 K




$V_{BD,S5} > V_{BD,S2}$

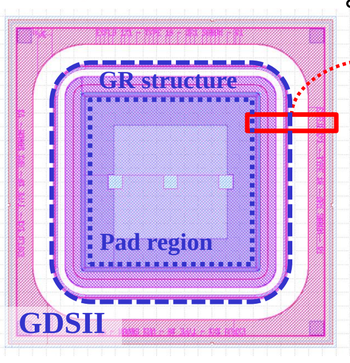
**Breakdown voltage** (mean value) vs **Fluence**

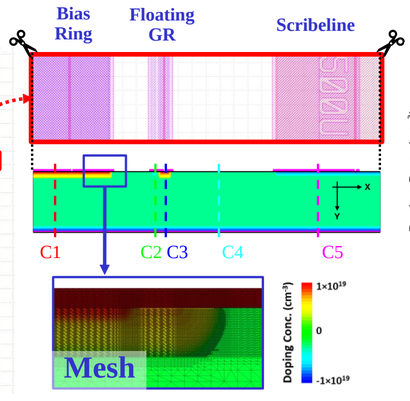



**GR0 ≈ GR1 ≈ GR3** & **S5 best** GR design

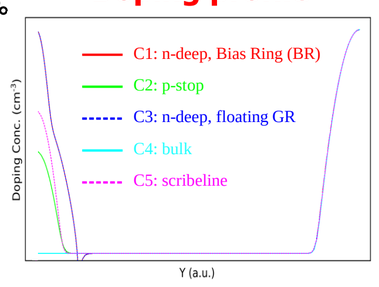
### TCAD model

**Layout and mesh**




**Doping profile**



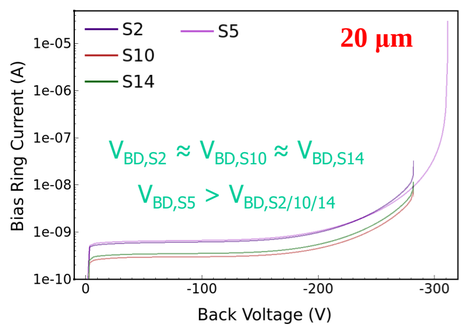

The "Perugia Modified Doping" [1] numerical radiation damage model has been used for the simulations after irradiation.

[1] P. Asenov *et al.*, NIM, A 1040 (2022) 167180.

#### I-V

**Before irradiation**

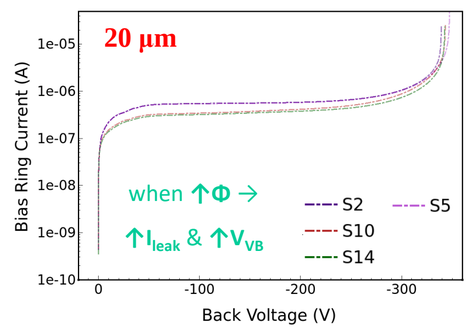
**Current-Voltage** @ 298 K




**GR0 ≈ GR1 ≈ GR3** & **S5 best** GR design

**After irradiation**

**Current-Voltage** @ 273 K, 2.5E15 $n_{eq}/cm^2$



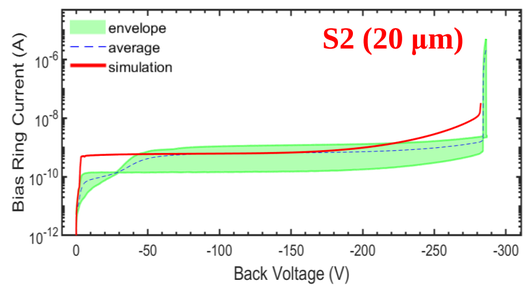

**GR0 ≈ GR1 ≈ GR3** & **S5 best** GR design

## Simulations vs. Measurements

#### I-V

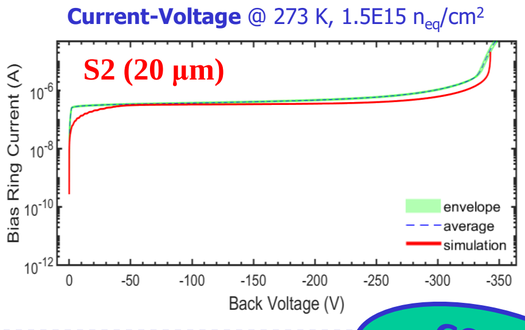
**Before irradiation**

**Current-Voltage** @ 298 K




**After irradiation**

**Current-Voltage** @ 273 K, 1.5E15 $n_{eq}/cm^2$

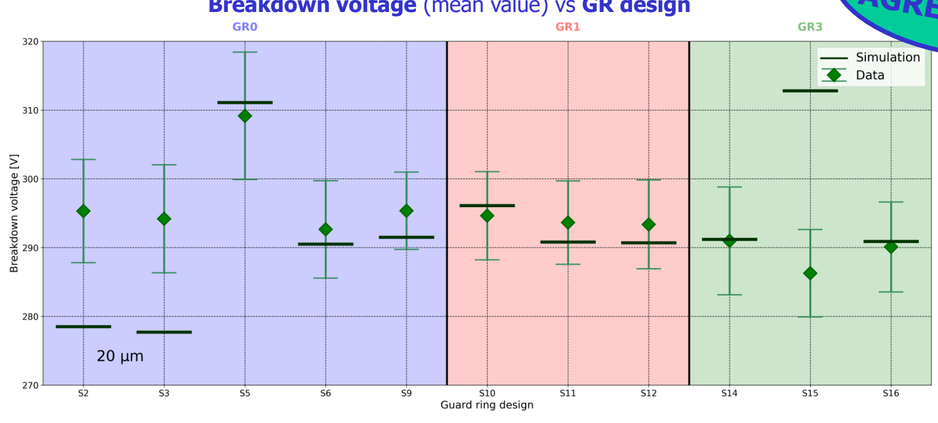



GOOD AGREEMENT

#### $V_{BD}$

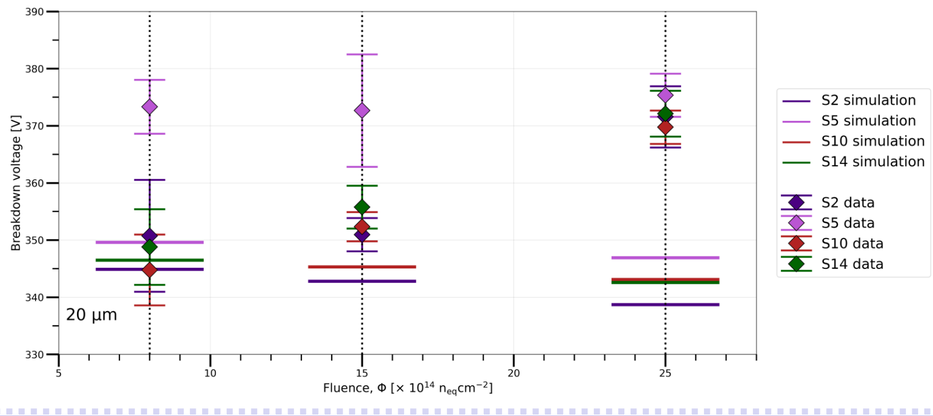
**Before irradiation**

**Breakdown voltage** (mean value) vs **GR design**




**After irradiation**

**Breakdown voltage** (mean value) vs **Fluence**




## Outcome

- ✓ The I-V characteristics and breakdown voltages of different Guard-Ring protection structures coming from the "EXFLU1" R&D batch (FBK) under different operating conditions (i.e., T and Φ) have been well reproduced in simulation

  → **General-purpose** and **high-predictive TCAD model.**
- ✓ The GR structures without any floating GR (i.e., GR0) have shown almost the same breakdown voltage of the GR1 and GR3 design options before and after irradiation

  → **GR structures without any floating GR are a viable design option.**
- ✓ An improvement of the breakdown voltage in GR0 structures has been obtained by increasing the overhang size of the metal contact over the bias ring.


### *Acknowledgement*

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