Development of a rad-hard switch for the HV power distribution in the ATLAS-Upgrade

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Abstract

- New silicon vertical JFET transistor to be used as switch for the HV powering scheme in the ATLAS upgrade Inner Tracker.
- Based on a trench technology developed at the IMB-CNM.
- Thorough optimization work has been performed by 2D and 3D TCAD simulations.
- Selected designs have been chosen for device fabrication at the IMB-CNM clean room. First prototypes have been recently produced.
- Features of the first fabrication devices are presented.
- First characterization results show excellent agreement with simulation, already meeting Iatron specifications.
- Simulations of radiation hardness show good performance.

Custom Vertical JFET switch for HV-MUX

Goal: Switching-off a malfunctioning sensor when it demands too much current to the power supply.

Features:
- Depletion mode device → Normally ON
- 3D Device with Vertical Conduction
- High voltage capabilities
- Rad-hard against ionization
- Low switching-off voltage
- P-type
- Lower (and known) displacement damage
- Cellular design
- Adaptable current capacity
- Custom mode
- Optimization for the requirements

Performance

- Inner cell (3D simulation)
- 10 µm parallel cells per device
- 2D cross-Section
- Cellular design
- Each cell presents a conduction channel, surrounded by a deep trench (with circular layout), which constitutes the gate-substrate reverse-biased junction
- The channel current is modulated by the depletion region extended from the gate-substrate reverse-biased junction

Optimization

Design Optimization Variables

- Channel width: 2r
- Trench Depth: D
- Substrate Doping Concentration: N$_d$

Requirements for the application

- Linear Region (ON)
- D is optimized ranging 60-100 µm
- Trenches with D = 50 µm lead to stronger hard switch for the HV power
- Deeper trenches lead to worse yield

Fabrication

- Cell Core
- Thermal Oxide
- Emitter
- polysilicon
- N+-Type Diffusion
- Non-polar diffusion
- Gate Oxide

Ramp-off current on 25% of the cell

Radiation Hardness

Requirements for the application (Strips)

- Devices are expected to operate under Fluence = 2 x 10$^{19}$ n$_{eq}$/cm$^2$ and Dose ~ 50 Mrad

- Ionization (NO) Effects
- Two physical mechanisms:
  - Accumulation of positive fixed charge within the oxide volume (N$_o$
  - Formation of charge traps at the Si/SiO$_2$ interface (N$_t$

- Expected electrical effects:
  - Minor effect on V$_on$, V$_off$, and I$_on$
  - Degradation of the voltage capability of the Gate-Source junction (V$_gs$)
  - Impact on edge termination efficiency (V$_es$) and $v$ in any case of V$_on$

- No significant TDDB effects have been observed in V$_on$, V$_off$, and I$_on$ in the performed TCAD Simulations

Displacement Damage (DD) Effects

- One effect depending on the operation mode
  - OFF-State: Charge generation, reduction of minority carrier lifetime, and trap assisted tunnelling are major issues
  - ON-State: Majority carrier removal and mobility degradation are important

- Expected effects:
  - In OFF-State: Increase of V$_on$, V$_off$, and I$_on$
  - In ON-State: I$_on$ decrease with an increment of V$_on$

- OFF-State issues can be studied with TCAD Simulations
- Perovskite Model of silicon traps

First Measurements

- Wide Channel Devices (2r = 53 µm; s = 10 µm)
- Narrow Channel Devices (2r = 23 µm; s = 10 µm)

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Conclusions

- A new silicon vertical JFET technology is now being developed at the IMB-CNM (CSIC) for the HV-MUX switches required in the future high luminosity upgrade Inner Tracker of the ATLAS experiment.
- Based on a 3D trench detector technology, the V-JFET has been optimized to meet the high voltage, low resistance, low-switch-off voltage, and radiation hardness requirements of the application.
- A complete fabrication procedure has been developed together with a specific layout, which includes a broad number of experiments.
- First prototype batch has been fabricated at the IMB-CNM clean room. Measurements show good agreement with simulations and already meet the HV-MUX specifications.
- Radiation hardness is now under study with the aid of both TCAD simulations and physical models reported in the literature. A thorough irradiation program is planned for the fabricated prototypes.


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