Marco Boccarossa

TCAD simulations for semiconductor power devices designing and modeling
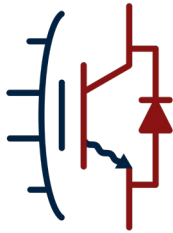
Tutor:
prof. Andrea Irace

co-Tutor:
prof. Luca Maresca

Cycle: XXXVII

Year: First

My background

- **M.Sc.** In Electronic Engineering – 26th Oct 2021

- **Electrothermal Characterization Laboratory** – DIETI

- **Tutor:** prof. Andrea Irace

- **Co-Tutor:** prof. Luca Maresca

- PhD started 1st Nov 2021 (**XXXVII cycle**)

- Scholarship funded by **DIETI**

- **Partners:** Vishay Semiconductor, Università Ca' Foscari Venezia

Research field of interest

What is the scope of **Power Electronics**?

Changing, controlling, conditioning and processing the power coming from the power supply to provide the conditioned on required by the load.

The **loads** can be very different:

Motors, actuators, lamps, trasducers, displays, …

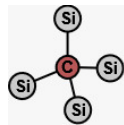**SEMICONDUCTOR POWER DEVICES**

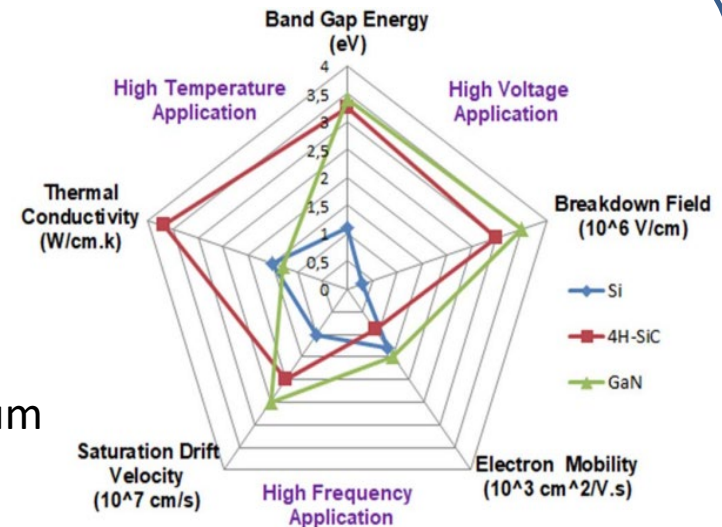Main material

→ **Silicon (Si)**

Wide-bandgap materials

Gallium Nitride (GaN)

Silicon Carbide (SiC)

Others (Gallium Oxide, Diamond)

MATERIALS FEATURES

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Research activity: Overview

- Problem

  ➢ *Reduce the losses of power devices*

- Objective

  ➢ *Improvement of the perfomance and reliability of semiconductor power devices*

  ➢ *Adoption of wide-bandgap materials*

- Methodology

  ➢ *Calibrated TCAD simulations*

TCAD simulations
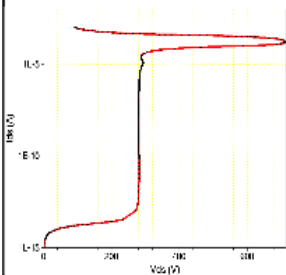## *Technology Computer Aided Design*

Device Simulation
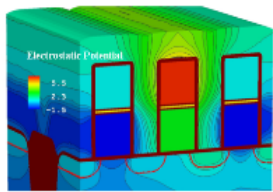
$$\vec{J}_n = -nq\mu_n\nabla\Phi_n$$

Current in Drift-Diffusion Model
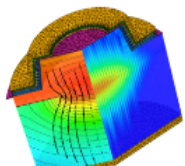
Potential distribution in flash memory
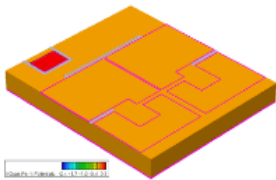
Snapback of a UMOS
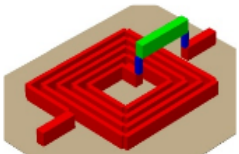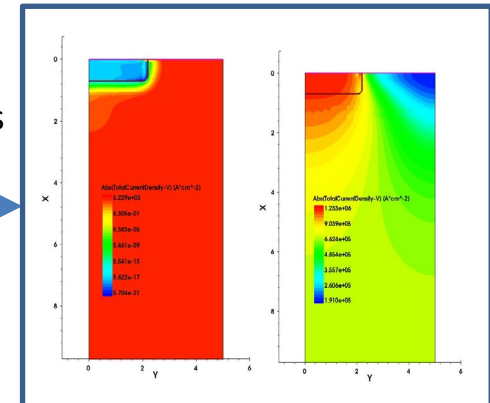
Inductance Simulation

AlGaAs VCSEL

Full Chip H-Bridge

EM Wave

- Predicts the behavior of the device before its physical fabrication

- Reduces development time and costs

- Allows to study the internal phenomena into the device

Current distributions inside the device

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Fast recovery epitaxial Silicon diodes

Investigation of different **anode designs** to evaluate the impact on the perfomance of the resulting devices.

1. Calibration of the simulator based on a reference device

REFERENCE DEVICE

Simplest design possible

PiN

CONCEPT DESIGNS | **IMPLEMENTED STRUCTURES**

Anode

P+   P+

Schottky Metal

N-

N+

Cathode

MPS Structure

Anode

P+   P-   P+

N-

N+

Cathode

SPEED Structure

Anode

P+ poly   P+ poly

N- Drift

N+ Substrate

Cathode

MPS

SPEED

TRENCH

VISHAY®
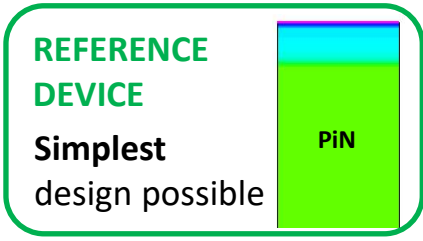
2. Changing the anode **design** and other design parameters
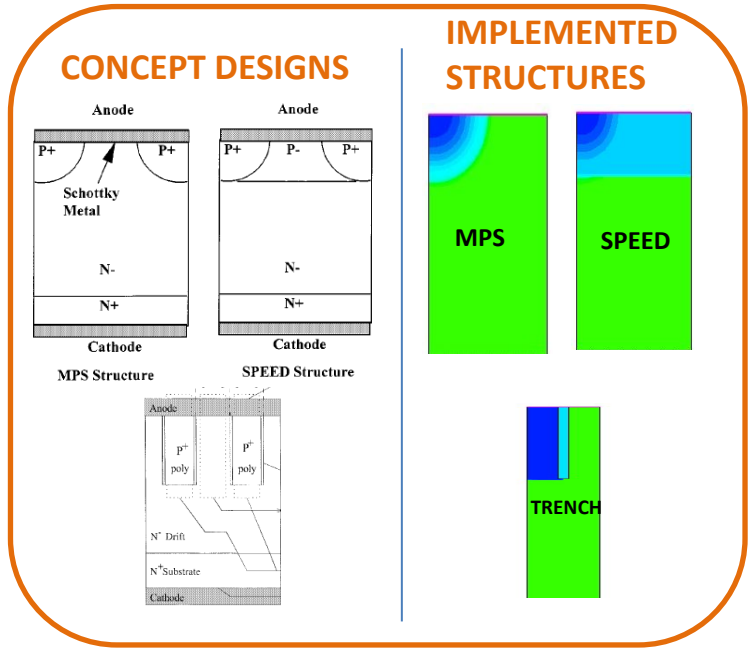
3. Evaluation of the **trade-offs** in terms of **perfomance**.
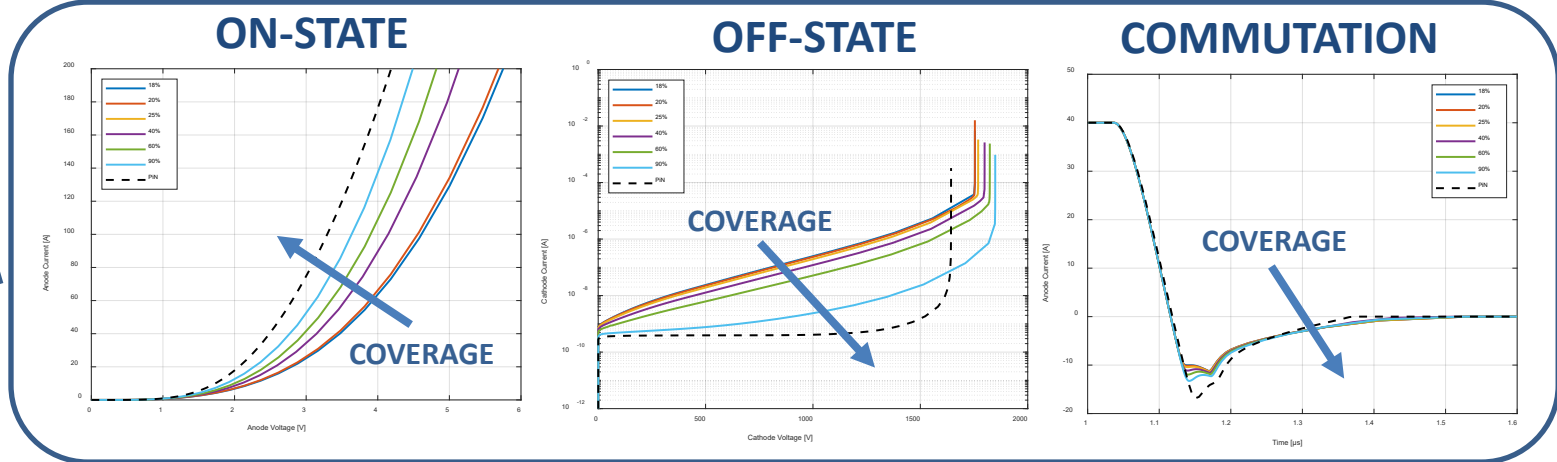
Coverage: ratio between P zone and N zone

ON-STATE

OFF-STATE

COMMUTATION

COVERAGE

COVERAGE

COVERAGE

COVERAGE

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Silicon Carbide diodes

➢ As for Si diodes, an accurate study of the parameters that affect the perfomance of SiC diodes and their effect have been conducted.

Effect of the **design parameters** on forward and reverse perfomance.

FORWARD
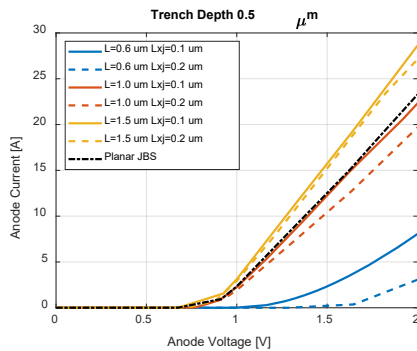
REVERSE
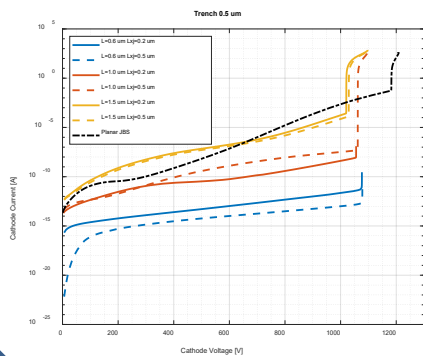
SiC devices have more **complex structures**.

Asiists during surge events

Main part of the device

MPS
double anode contact

JBS
single anode contact
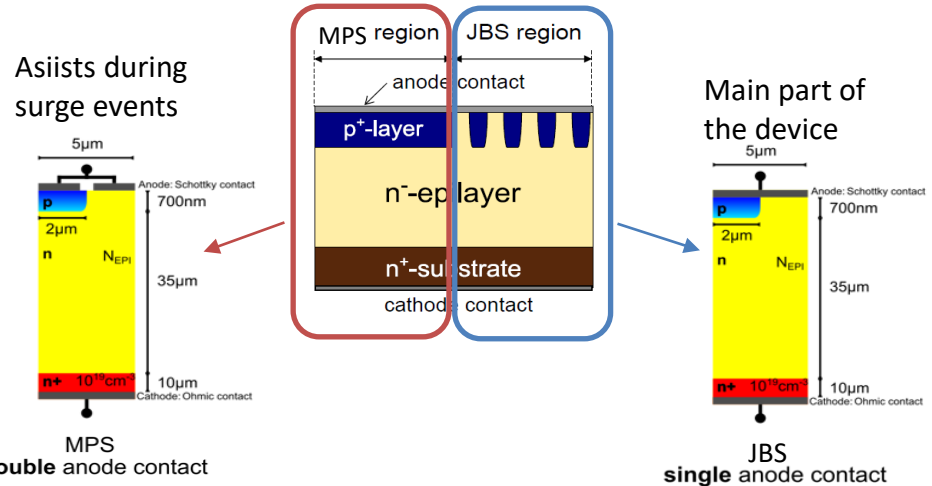
Study on how to **model** the anode **contact** of a SiC diode

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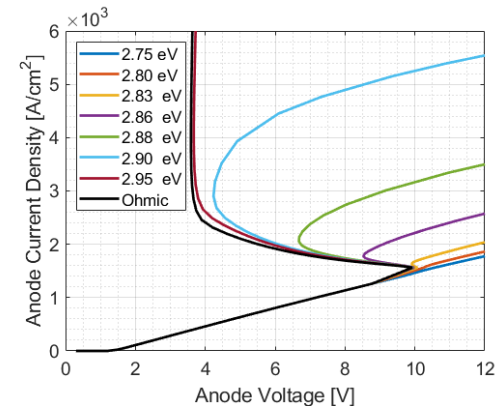
Advanced compact models

Diodes are included in complex circuits, often used to test the device itself.

DOUBLE PULSE TEST CIRCUIT

$+V_{dc}$

Physical model

450µH

Device Under Test I_L

Double pulse

Gate Drive

R_g

V_{ds}

$+V_{gs}$

I_d

Physical model

Very accurate simulation result

High simulation time

Needs to know the physical strcture of the device

Compact model provided by simulator

D

G

S

Very short simulation time

Not suitable as power device

Custom compact model

Drain

R_{Dint}

R_{DRIFT}

R_{AJ}

V_{SENS}

C_{GD}

C_{DS} I_{AV}

ΔV_{TH} $k_F V_{DS}$

Gate R_{Gint} G' M_1 Q_1 I_{MOS} V_{DS}

C_{GS} $V_{G'S}$ R_{B2} R_{B1}

R_{Sint}

V_{drift}

T

T_0

Source

D

G

S

Accurate simulation result

Accetable simulation time

Needs to be built with a C++ interface

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Products

[P1]	**M. Boccarossa**, A. Borghese, L. Maresca, M. Riccio, G. Breglio, A. Irace, *"Numerical Analysis of the Schottky Contact Properties on the Forward Conduction of MPS/JBS SiC Diodes",* International Conference on Silicon Carbide and Related Materials (ICSCRM), 2022. (*Accepted*)
[P2]	**M. Boccarossa**, A. Borghese, L. Maresca, M. Riccio, G. Breglio, A. Irace, *"TCAD Analysis of the Impact of the Metal-Semiconductor Junction Properties on the Forward Characteristics of MPS/JBS SiC Diodes",* Workshop on Wide Bandgap Power Devices and Applications (WiPDA), 2022. (*Accepted*)
[P3]	A. Borghese, **M. Boccarossa,** M. Riccio, L. Maresca, G. Breglio, A. Irace, *"Short-circuit and Avalanche Robustness of SiC Power MOSFETs for Aerospace Power Converters",* The International Conference for Aerospace Experts, Academics, Military Personnel, and Industry Leaders, 2022. (*Submitted*)

Summary of study activities

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	0	1.8	8.2	0	10
Bimonth 2	0	1.7	8.3	0	10
Bimonth 3	2	1.7	6.3	0	10
Bimonth 4	6	0.6	3.4	0	10
Bimonth 5	8	0	2	0	10
Bimonth 6	5	0	5	0	10
Total	**21**	**5.8**	**33.2**	**0**	**60**

Conferences and PhD Schools:

- *IEEE Workshop on Wide Bandgap Power Devices and Applications in Europe (WiPDA Europe 2022),* University of Warwick (UK), 18-20 Sep 2022. I presented one contribution.
- *Summer School of Information Engineering (SSIE 2022),* Brixen (BZ), Italy, 11-15 Jul 2022.
- *China-Italy Joint Laboratory on Advanced Manufacturing (CI-LAM 2022),* Bergamo, Italy, 18-22 Jul 2022.

Thank you for your attention!