



UNIVERSITÀ DEGLI STUDI DI NAPOLI
FEDERICO II

itee^{PhD}
information technology
electrical engineering



DIE
TI

UNI
NA

Marco Boccarossa

TCAD simulations for semiconductor power devices design and modeling

Tutor:

prof. Andrea Irace

co-Tutor:

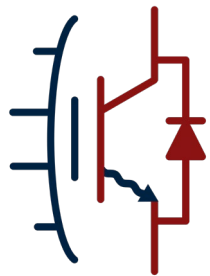
prof. Luca Maresca

Cycle: XXXVII

Year: Second

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, Hitachi Energy



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 one required by the load.

The **loads** can be very different:

↳ Motors, actuators, lamps, trasducers, displays, ...

SEMICONDUCTOR POWER DEVICES

Main material

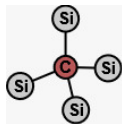
Silicon (Si)

Wide-bandgap materials

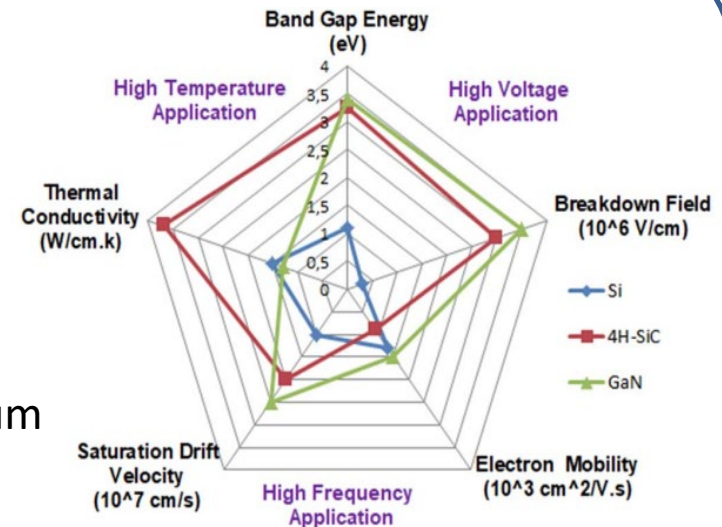
Gallium Nitride
(GaN)



Silicon Carbide (SiC)



Others (Gallium Oxide, Diamond)



MATERIALS FEATURES

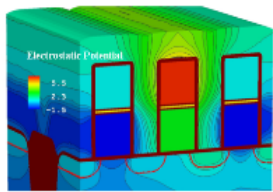
Research activity: Overview

- Problem
 - *Losses of power devices*
- Objective
 - *Improvement of the performance and reliability of semiconductor power devices*
 - *Adoption of wide-bandgap materials*
- Methodology
 - *Calibrated TCAD simulations*

TCAD simulations

Technology Computer Aided Design

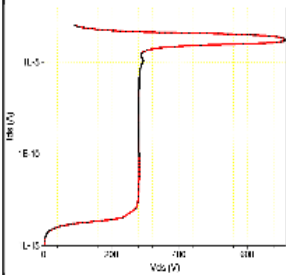
Device Simulation



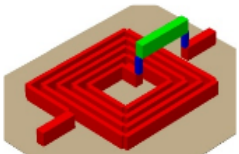
$$\vec{J}_n = -nq\mu_n \nabla \Phi_n$$

Current in Drift-Diffusion Model

Potential distribution in flash memory



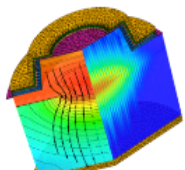
Snapback of a UMOS



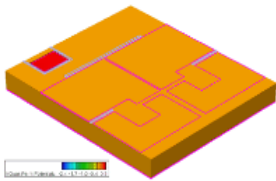
Inductance Simulation



EM Wave



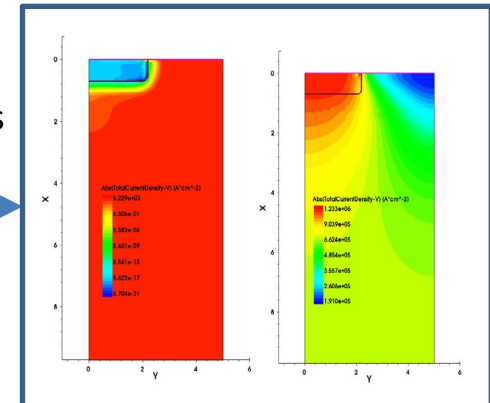
AlGaAs VCSEL



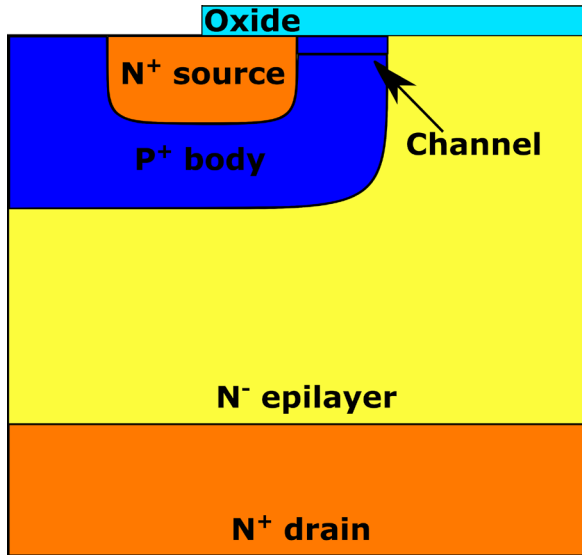
Full Chip H-Bridge

- 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



Silicon Carbide MOSFETs



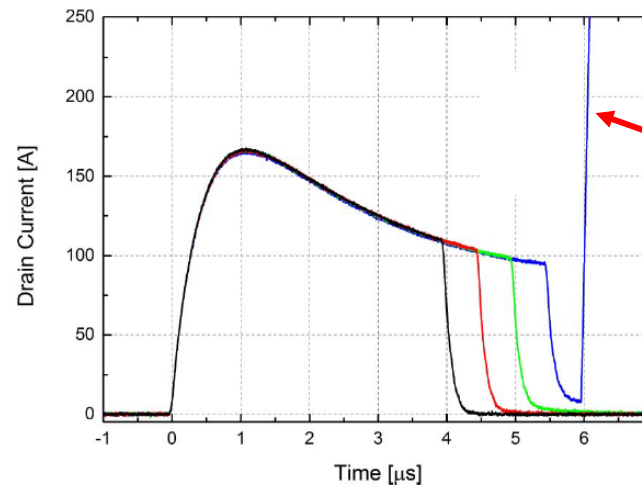
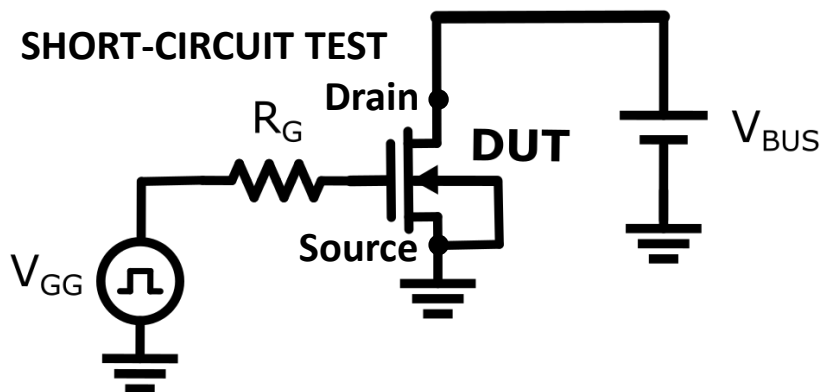
Pros:

- High breakdown voltage
- High switching speed
- Low on-resistance
- High temperature operation

Cons:

- Reliability problems → **Short-circuit capability**

A possible short-circuit event occurs gating on the device with the supply voltage applied between drain and source terminals.



FAILURE DUE TO THERMAL RUNAWAY

Ferroelectric materials in SiC MOSFETs

MOSFET Drain Current

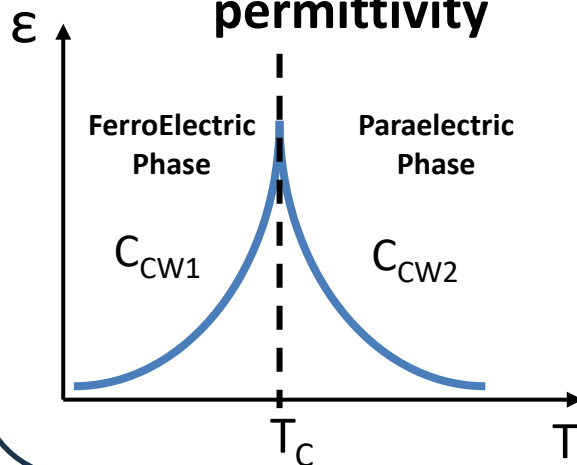
$$I_D \propto \frac{\mu_n C_{OX}}{L} W \quad \text{with} \quad C_{OX} = \frac{\epsilon_{ox}}{t_{ox}}$$

Curie-Weiss law

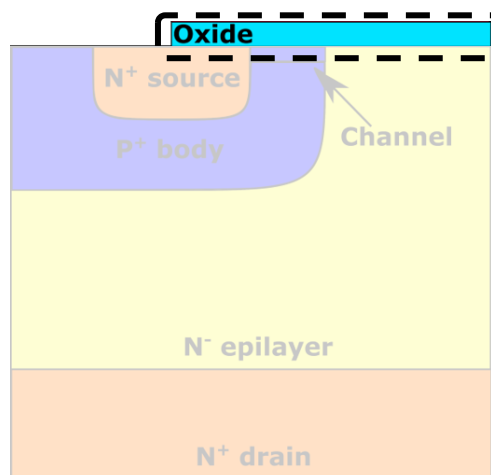
$$\epsilon = \lambda \frac{C_{CW}}{T - T_C} \quad \text{with} \quad \begin{cases} \lambda = -1/2 & \text{for } T < T_C \\ \lambda = 1 & \text{for } T > T_C \end{cases}$$

Replacing the standard gate oxide with a stack formed by oxide and a ferroelectric material is possible to exploit the temperature dependent permittivity to limit the current increase due to temperature.

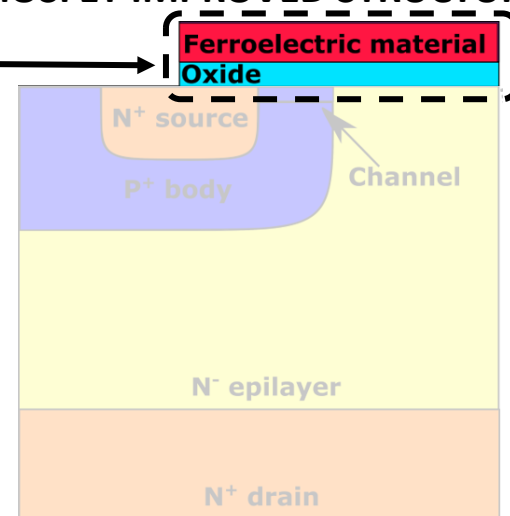
Typical ferroelectric permittivity



MOSFET STANDARD STRUCTURE



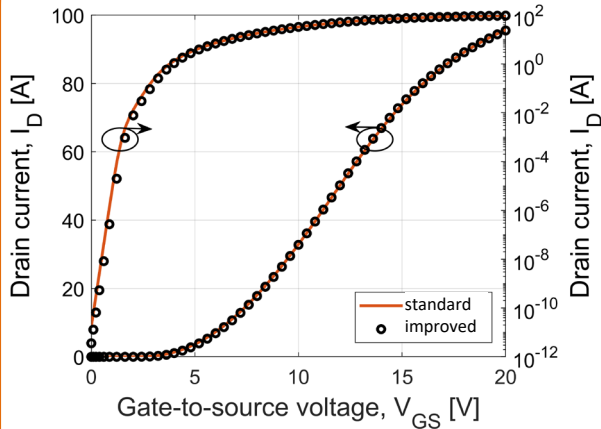
MOSFET IMPROVED STRUCTURE



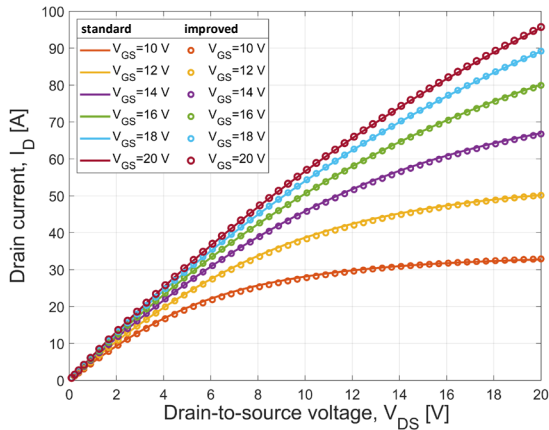
Short-circuit capability

STATIC OPERATION

TRANSFER CHARACTERISTICS

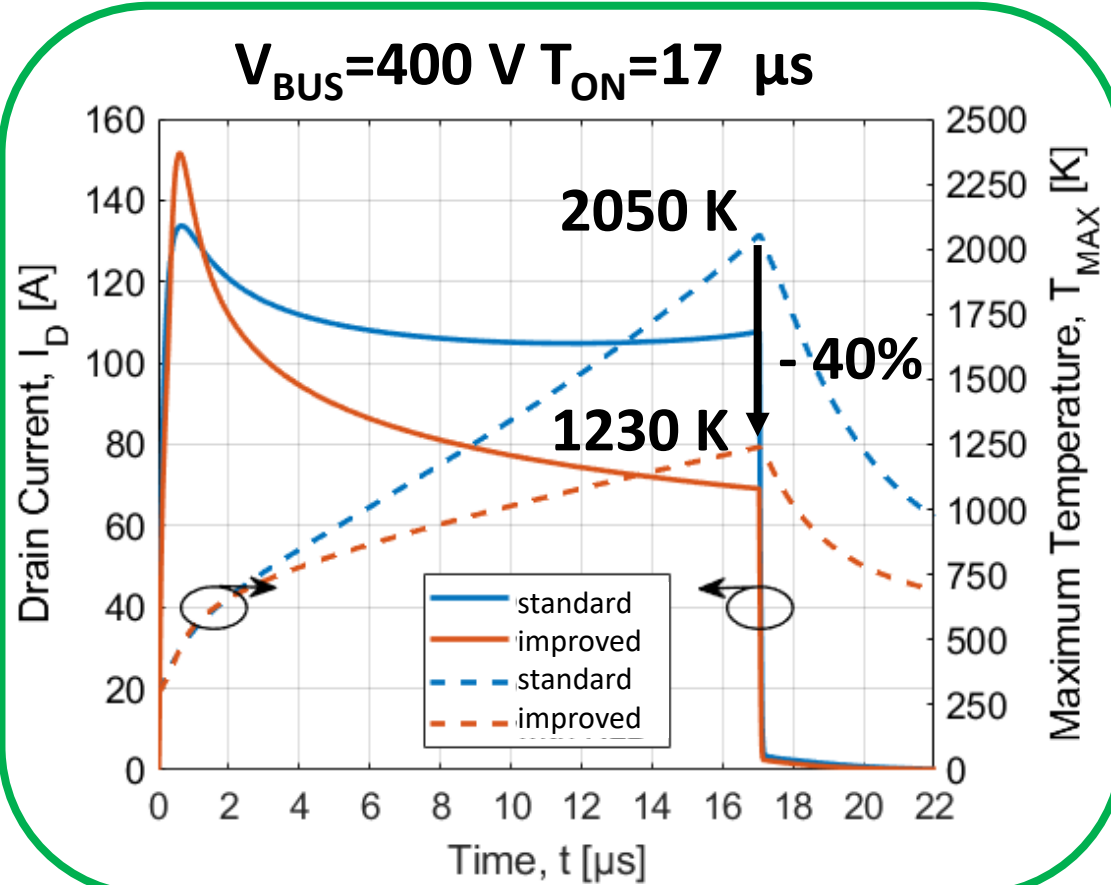


OUTPUT CHARACTERISTICS



Same behaviour!

SHORT-CIRCUIT WAVEFORMS



Sentaurus
TCAD

The maximum temperature reached by the improved device is 40% lower than the reference one.

Products (1/2)

[P1]	M. Boccarossa , L. Maresca, A. Borghese, M. Riccio, G. Breglio, A. Irace, and G. A. Salvatore, "Short-Circuit Rugged 1.2 kV SiC MOSFET with a Non-Linear Dielectric Gate Stack," <i>2023 35th International Symposium on Power Semiconductor Devices and ICs (ISPSD)</i> , Hong Kong, 2023, pp. 354-357, doi: 10.1109/ISPSD57135.2023.10147604.
[P2]	V. d'Alessandro, V. Terracciano, A. Borghese, M. Boccarossa , and A. Irace, "A Simple Electrothermal Compact Model for SiC MPS Diodes Including the Snapback Mechanism," <i>2023 29th International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)</i> , Budapest, Hungary, 2023. <i>(in press)</i>
[P3]	M. Boccarossa , L. Maresca, A. Borghese, M. Riccio, G. Breglio, A. Irace, and G. A. Salvatore, "Threshold Voltage Temperature Dependence for a 1.2 kV SiC MOSFET with Non-Linear Gate Stack," <i>2023 International Seminar on Power Semiconductors (ISPS) Proceedings</i> , Czech Technical University in Prague, Czech Republic, 2023. <i>(in press)</i>
[P4]	M. Boccarossa , L. Maresca, A. Borghese, M. Riccio, G. Breglio, A. Irace, and G. A. Salvatore, "Non-Linear Gate Stack Effect on the Short Circuit Performance of a 1.2-kV SiC MOSFET," <i>2023 20th International Conference in Silicon Carbide and Related Materials (ICSCRM)</i> , Sorrento (NA), Italy, 2023. <i>(in press)</i>

Products (2/2)

[P5]	A. Borghese, S. Angora, M. Boccarossa , M. Riccio, L. Maresca, V. R. Marrazzo, G. Breglio and A. Irace, "Analysis of Electrothermal Imbalance of Hard-Switched Parallel SiC MOSFETs Through Infrared Thermography," 2023 <i>20th International Conference in Silicon Carbide and Related Materials (ICSCRM)</i> , Sorrento (NA), Italy, 2023. <i>(in press)</i>
[P6]	L. Maresca, V. Terracciano, A. Borghese, M. Boccarossa , M. Riccio, G. Breglio, A. Mihaila, G. Romano, S. Wirths, L. Knoll, and A. Irace, "SiC GAA MOSFET concept for high power electronics performance evaluation through advanced TCAD simulations," 2023 <i>20th International Conference in Silicon Carbide and Related Materials (ICSCRM)</i> , Sorrento (NA), Italy, 2023. <i>(in press)</i>
[P7]	V. Terracciano, A. Borghese, M. Boccarossa , V. d'Alessandro, and A. Irace, "A Geometry-Scalable Physically-Based SPICE Compact Model for SiC MPS Diodes Including the Snapback Mechanism," 2023 <i>20th International Conference in Silicon Carbide and Related Materials (ICSCRM)</i> , Sorrento (NA), Italy, 2023. <i>(in press)</i>

Summary of study activities

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	0	1	9	0	10
Bimonth 2	2	4.2	3.8	0	10
Bimonth 3	4	0	6	0	10
Bimonth 4	0	0.4	9.6	0	10
Bimonth 5	0	0	10	0	10
Bimonth 6	5	0	5	0	10
Total	11	5.6	43.4	0	60
Expected for II year	10 - 20	5 - 10	30 - 45	0 - 1.6	

Conferences:



- *35th IEEE International Symposium on Power Semiconductor Devices and ICs (ISPSD 2023)*, SHAW Auditorium, Hong Kong University of Science and Technology (HKUST), Hong Kong, 28 May – 01 June 2023, **poster presentation**.



- *16th International Seminar on Power Semiconductors (ISPS 2023)*, Czech Technical University in Prague, Czech Republic, 30 August – 01 September 2023, **oral presentation**.



- *54th annual Meeting of the Società Italiana di Elettronica (SIE 2023)*, Noto (SR), Italy, 06 – 08 September 2023, **poster presentation**.



- *20th International Conference on Silicon Carbide and Related Materials (ICSCRM 2023)*, Sorrento (NA), Italy, 17 – 22 September 2023, **poster presentation**.

Next Year

- Engineering of the ferroelectric material needed to achieve the better trade off between improved short-circuit performance and current capability during normal operation
- Study on technological problem for the physical realization
- **ABROAD RESEARCH:** six months at the University of Warwick, Coventry, UK, to go deeper in the technological fabrication of semiconductor power devices.



Thank you for your attention!