PhD Vincenzo Terracciano

Design and Development of Semiconductors for High-Efficiency Power Systems

Tutor: Andrea Irace

Co-Tutor: Vincenzo d'Alessandro

Cycle:XXXVIII

Year: Second

My background

- MSc degree: *Electronic Engineering*
- Research laboratory: *OPTO-POWER LAB*
- PhD start date: *01/11/2022*
- Scholarship type: *ITEE*
- Partner company: *Vishay Semiconductor*

SUMMARY OF ANNUAL ACTIVITIES

Ad hoc PhD courses	Courses
Numerical Methods For Thermal Analysis, Modeling, And simulation: Application to Electronic Devices And systems (DIETI)	• *Numerical Models For The Fields(DIETI)* • *Analitycal Mechanics (Physics)*

Contributions To Conferences

International Conference on Silicon Carbide and Related Materials (ICSCRM), *Raleigh USA 2024*

European Symposium on Reliability of Electron Devices, Failure Physics and Analysis (ESREF), Parma Italy 2024

POWER SEMICONDUCTOR PHYSICS

- ***Power Semiconductor Physics*** is concerned with the study of the physical principles and properties of semiconductors used in **power electronic devices**.
- The power devices include components like diodes, transistors, and rectifiers.
- In power electronics systems, power devices are used as **solid-state switches**.

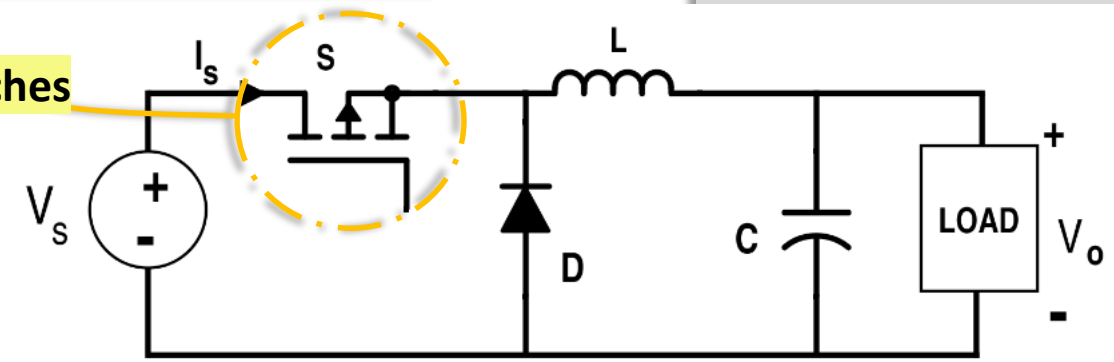
IDEAL SWITCH

1) To conduct infinite current **(R_{ON}=0)**
2) Block infinite voltage **(BV=∞)**
3) Switch at infinite frequency with zero power loss **(P_d(t)=0)**

REAL SWITCH

1) Low on-state resistance **(R_{ON}>0)**
2) High breakdown voltage **(BV<∞)**
3) Small switching loses **(P_d(t)≠0)**

solid-state switches



Buck Converter

RESEARCH ACTIVITY[1]

RESEARCH ACTIVITY PROBLEM

REAL SWITCH

1) Low on-state resistance (R_{ON})
2) High breakdown voltage (BV)
3) Small switching loses (P_d)

TRADE-OFF

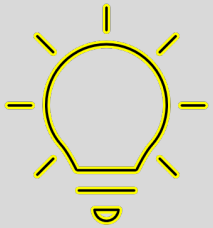
R_{ON} ↓ BV ↑

P_d ↓

APPROACHES TO IMPROVE THIS TRADE-OFF

I Employ semiconductors with **superior properties** for power switching, such as **wide-bandgap (WBG) materials**

II Involves innovation in **device architecture**



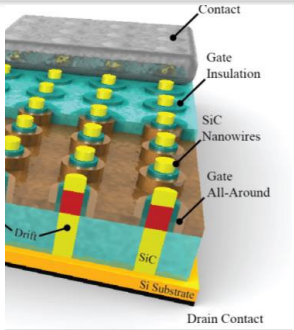
RESEARCH ACTIVITY[1]

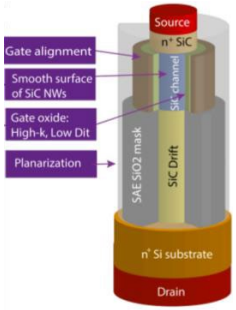
I **Silicon carbide (SiC)** belongs to the class of **wide-bandgap** materials, i.e., semiconductors showcasing a forbidden energy band wider than silicon (Si).

Advantages of SiC

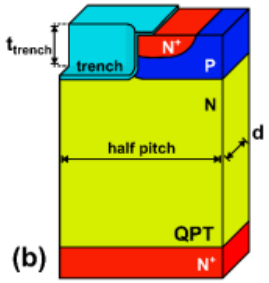
- *Higher thermal conductivity*
- *Higher working temperature*
- *Higher saturation velocity*
- *Higher breakdown voltage*

II **SiC power MOSFET** based on innovative vertical Gate All Around (GAA)





II **SiC power MOSFET** based on Quasi-Planar Trench Architecture



Through campaign of TCAD simulations, it was possible to observe, for both design, an improving of electrical behaviour.

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information technology
electrical engineering

Products

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"*, 29th International Workshop on Thermal Investigations of ICs and Systems (THERMINIC), 2023.

V. Terracciano, A. Borghese, M. Boccarossa, V. d'Alessandro, and Andrea Irace "*A Geometry- Scalable Physically-Based SPICE Compact Model for SiC MPS Diodes Including the Snapback Mechanism"*, International Conference on Silicon Carbide and Related Materials (ICSCRM), 2023.

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"*, International Conference on SiliconCarbide and Related Materials (ICSCRM), 2023.

A. Borghese, **V. Terracciano**, M. Boccarossa, A. Irace, and V. d'Alessandro, "*Geometry-Scalable Electrothermal Compact Circuit Model of SiC MPS Diodes Accounting for the Snapback Mechanism: Application to Current Surge Events"* 35th European Symposium on Reliability of Electron Devices, Failure Physics and Analysis (ESREF), 2024.

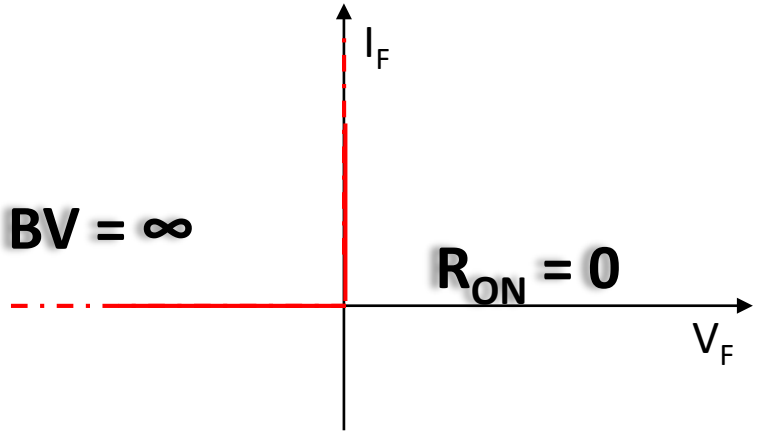
C. Scognamillo, A. Borghese , K. Melnyk, I. Nistor, V. d'Alessandro, M. Boccarossa, **V. Terracciano**, M. Riccio, A. Pio Catalano, G. Breglio, N. Lophitis, M. Antoniou, M. Rahimo, A. Irace, and L. Maresca "*Enhanced Out-of-SOA Performance in 3.3 kV SiC MOSFETs: A Comparative Study of Planar and Quasi-Planar Trench Architectures*" ICSCRM 21: International Conference on Silicon Carbide and Related Materials (ICSCRM), 2024.

L. Maresca, **V. Terracciano**, A. Borghese , M. Boccarossa, M. Riccio , G. Breglio, S. Wirths and A. Irace "*Evaluation of Switching Performances and Short Circuit Capability of a 1.2 kV SiC GAA MOSFET through TCAD Simulations*" ICSCRM 21: International Conference on Silicon Carbide and Related Materials (ICSCRM), 2024.

Thank You For Your Attention

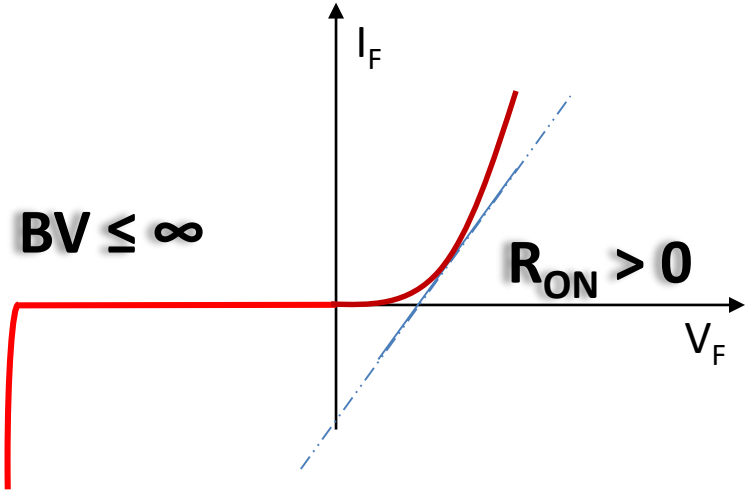
EXAMPLE: IDEAL VS REAL DIODE

IDEAL SWITCH

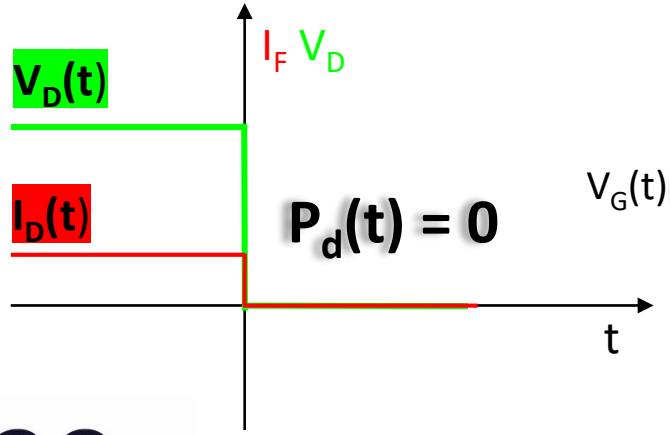


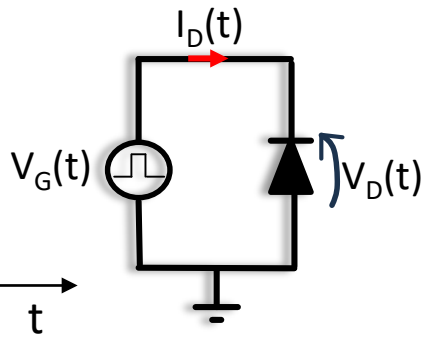
STATIC

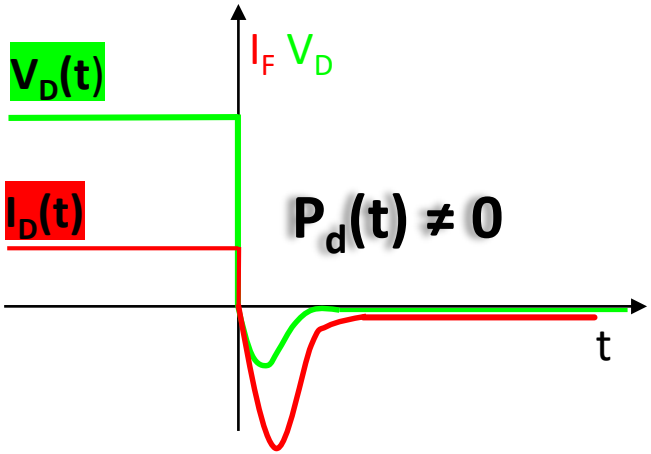
REAL SWITCH



DYNAMIC: REVERSE RECOVERY







RESEARCH ACTIVITY[2]

RESEARCH ACTIVITY PROBLEM

To realize a **compact model** in the form of a **SPICE-compatible subcircuit** describing the **electrical and electrothermal behavior** of a particular SiC diode: **Merged PiN Schottky (MPS)**. In addition, the model has to take into account of the detrimental **snapback mechanism**, which can lead, where we have multiple cells in parallel, **to current-focusing**.

Through a **compact model**, it would be possible to reduce both the **time** and **complexity of a TCAD simulation**, as in the case of **TCAD electrothermal simulations**.

APPROACHES TO REALIZE THESE MODELS

The approach is based on a **comparison** of **Sentaurus TCAD simulations** and the **SPICE simulations**, while specifically for **electrothermal analysis** we exploited the **thermal equivalent of Ohm's law (TEOL)**

SYNOPSYS® V S LTspice®

RESEARCH ACTIVITY[1]

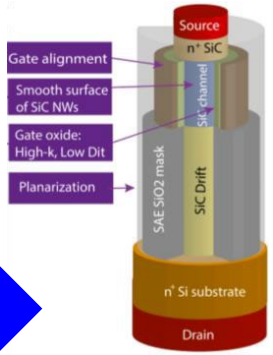
PAPER

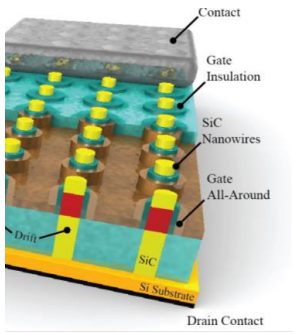
"SiC GAA MOSFET Concept for High Power Electronics Performance Evaluation through Advanced TCAD Simulations"

Silicon carbide (SiC) belongs to the class of **wide-bandgap** materials, i.e., semiconductors showcasing a forbidden energy band wider than silicon (Si).

Advantages of SiC

- *Higher thermal conductivity*
- *Higher working temperature*
- *Higher saturation velocity*
- *Higher breakdown voltage*





SiC power MOSFET based on innovative vertical Gate All Around (GAA)

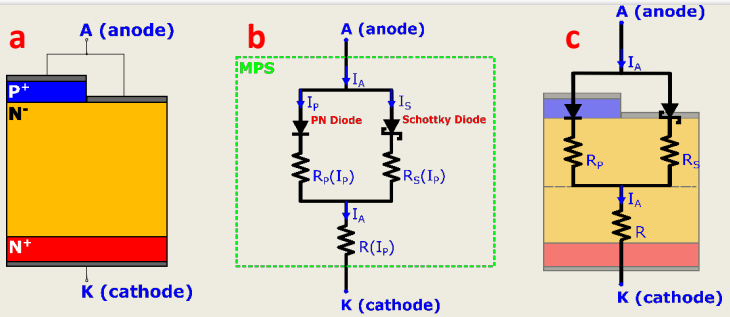
Through campaign of TCAD simulations, it was possible to observe a **decrease in R_{ON}** compared to the usual planar MOSFETs, while maintaining relatively **very high BV**.

RESEARCH ACTIVITY[2]

PAPERS

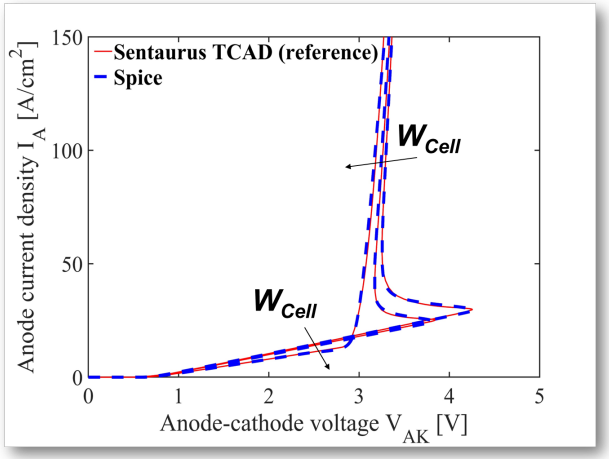
I *"A Geometry-Scalable Physically-Based SPICE Compact Model for SiC MPS Diodes Including the Snapback Mechanism"*

MPS compact model



(a) **MPS cross section**
(b) **SPICE-compatible subcircuit** of **MPS** diode
(c) Overlap between the simplified **lumped element circuit** and the **MPS** cross section

I_A–V_{AK} characteristics



Thanks to this **compact model**, it is possible to estimate with **good accuracy** the effect of the **snapback** in conditions not feasible for TCAD analysis, such as **converter-level simulations**.

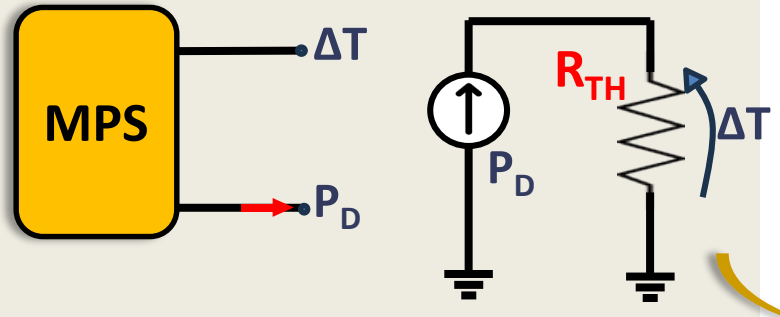
RESEARCH ACTIVITY[2]

PAPER

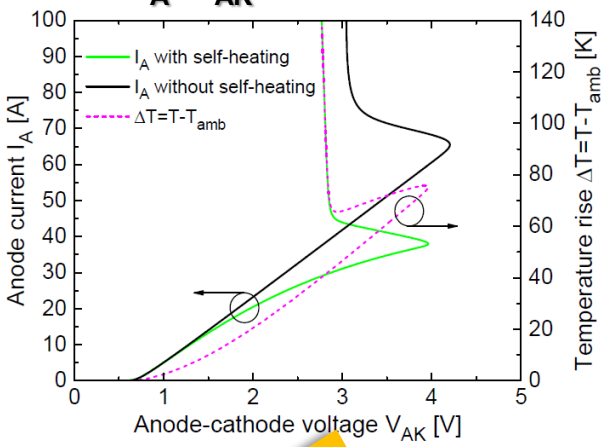
II ***"A Simple Electrothermal Compact Model for SiC MPS Diodes Including the Snapback Mechanism"***

TEOL approach

$$\Delta T = T - Tamb = P_D \cdot R_{TH}$$
$$P_D = IA \cdot VAK$$
$$R_{TH} = 0.5\ K/W$$



ET I_A–V_{AK} characteristics



An **electrothermal compact model for static simulations of SiC MPS** diode has been implemented in the form of **SPICE-compatible subcircuit** and thanks to the **TEOL** approach, It was possible to account for **self-heating**

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