DEPARTMENT OF ENERGY TECHNOLOGY
AALBORG UNIVERSITY

PhD Public Defence

Title:	Advanced Modeling of SiC Power MOSFETs aimed to the Reliability Evaluation of Power Modules
Location:	Pontoppidanstræde 111, auditorium
Time:	Thursday 15 August at 13.00
PhD defendant:	Lorenzo Ceccarelli
Supervisor:	Professor Francesco Iannuzzo
Moderator:	Associate Professor Amjad Anvari-Moghaddam
Opponents:	Associate Professor Tamas Kerekes, Dept. of Energy Technology, Aalborg University (Chairman) Prof. Dr. Ulrike Grossner, ETH Zurich, Switzerland Dr. John Shen, Illinois Institute of Technology, USA

All are welcome. The defence will be in English.

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Abstract:

Power semiconductor devices are the core element in every electronic power conversion system. During the typical 20-year lifespan of a power electronic (PE) application, the devices undergo a significant amount of stress from operating in normal and abnormal conditions. The temperature fluctuations generated by the device power losses are the most significant stressors, eventually leading to thermo-mechanical degradation and failure.

A new range of wide bandgap (WBG) power semiconductor devices, especially those based on Silicon Carbide (SiC) and Gallium Nitride (GaN), are rapidly evolving to replace Silicon-based components. SiC power MOSFETs are already widely manufactured and are becoming the device of choice in the design of many low-to-medium power (<1 megawatt) PE applications. These devices are especially promising for their high power density, high-voltage blocking capability and very fast switching. Nevertheless, the widespread diffusion of such devices is slowed down by their significantly higher cost and the lack of solid reliability data and accurate models to support optimized circuit design. Moreover, high power density comes at the cost of increased thermal stress, especially during short circuit events, which may lead to instabilities and degradation phenomena at a chip and package level.

It is important to bear in mind that advanced models and simulation tools for WBG devices, can support the reliable and optimized design of next-generation power converters. Therefore, this Ph.D. project aimed at developing compact electrothermal models to explore the normal and abnormal behavior of commercial SiC MOSFETs. The research activity started with the implementation and identification of a physical device model, based on earlier work and expanded with additional features, such as self-heating and short circuit behavior. Several SiC discrete devices and power modules have been characterized experimentally in a wide range of operating conditions, providing data to validate the device model. Besides, realistic package models have been created using Finite-Element Analysis (FEA) software, in order to extract lumped circuit elements to couple with the device model, obtaining fast and accurate electrothermal simulations. The combined use of different software environments (e.g. PSpice, MATLAB/Simulink and ANSYS) allowed the optimization of computation time and co-simulation of different timescales. The main outcome of the project has been the implementation of advanced models for commercial SiC MOSFET devices and power modules. Moreover, the simulation results have provided a better understanding of the short circuit behavior and thermal instabilities in SiC power modules, the estimation of the device thermal loading during real mission profiles for DC-AC converter applications, and the impact of aging conditions on the device performance.