PhD in Information Technology and Electrical Engineering

Università degli Studi di Napoli Federico II

PhD Student: Paolo Mirone

XXIX Cycle

Training and Research Activities Report – First Year

Tutor: Prof. Andrea Irace

1. Information

Paolo Mirone received B.S. (2010) and M.S. (2013) degrees in Electronic Engineering from the University of Naples "Federico II". He is currently PhD Student with the Department of Electrical Engineering and Information technologies (DIETI) at University of Naples "Federico II". His tutor is the Assoc. Prof. Andrea Irace. His research interests include modeling, simulation and experimental characterization of semiconductor power devices.

2. Study and Training activities

The first year activities are reported in the following table:

Summary	
Activity	**Credits**
Modules	6
Seminars	5
Research	35

Didactic Activity		
Course Title	**Given by**	**Credits**
Meccanica Quantistica	Prof. Miano	3
Europrogettazione	Dr. Varchetta	3

Conferences		
Title of work	**Conference**	**Date**
An area-effective termination for PT-Trench IGBTs	IEEE, MIEL '14	12-15 May 2014

Seminars	
Seminar Title	**Organized by**
Quantum Teleportation	Prof. Miano G.
Novel tendencies in power devices and circuits (3 seminars)	Prof. Castellazzi A.
High dimensional pattern recognition	Prof. Sansone C.
Fractional programming for energy efficiency in wireless networks	Prof. De Maio A.
Nano-carbon based components and materials for high frequency electronics (4 seminars)	Prof. Miano G.
Circuiti quantistici	Prof. Miano G.
Towards agile flight of vision-controlled micro flying robots: from frame-based to event-based vision	Prof. Siciliano B.
Site reliability engineering at google	Prof. Tramonatana P.
Reliability and availability modeling in practice	Prof. Cotroneo D.
Capacity planning for infrastructure as a service cloud	Prof. Cotroneo D.
Efficient service distribution in next generation cloud networks	Prof. Antonia Tulino

Currently, I am following the “English course” of 6Cr and I am preparing the exam “Integrated Photonics” of 9Cr. For the second year of doctorate, I expect to reach a total credit numbers equal to 20Cr for the Didactic and 10Cr for Seminars.

3. Research activity

Doctorate Target

My research activity is in the field of power electronic. The main theme of my research regards the study, the analysis and development of a new type of device called Reverse Conducting IGBT (RC-IGBT). It was born in recent years by merging in a unique monolithic block both IGBT and Freewheeling Diode (FWD) structures. Insulated Gate Bipolar Transistor (IGBTs) are widely adopted in a variety of switching applications particularly in the automotive field. It has high current capability with low on-state voltage drop in forward blocking, and specially the Punch-Through structure can commute with lower turn-off losses; while FWD can be used in applications where needs to guarantee a current continuity to the load. RC-IGBT realizes a more compact IGBT modules to reduce cost and size of the products, moreover thermal oscillations are greatly reduced improving power modules reliability. They are typically employed in Soft-Switching mode [1] since the presence of extra-current in turn-on and extra-voltage in turn-off. It is possible to operate in Hard-Switching only in some applications without overcoming SOA limits. For this reason, it is currently in way of developing and innovation [2]. The main problems can be summarized as:

- The formation of the “first” and “second” snapback on the conduction curve, due to the presence of FWD structure delays the “conductivity modulation” of IGBT cells.
- Trade-off between IGBT and FWD performances influences also SOA and losses of the device.
- Termination design in order to improve the device robustness.
- Packaging in order to improve the reliability.

Due the problems aforementioned, RC-IGBTs are employed in a limited field of applications. By studying and analyzing the commercial devices and patents, and by means of TCAD simulations, the idea is to realize innovative design solutions that could improve the performances in particular applications. It is important activating an external collaboration to give the possibility to realize physically the device. This would allow me to achieve experimental characterization, and hence calibrating the models used in simulations, than to conclude with a validation phase.

First year of research

RC-IGBT device presents a complex structure, and, in order to work on that it necessary acquiring a deep knowledge of physical phenomena that govern it. In this first year of activity, I studied the main power devices like Power Diode, Power MOS, IGBT and their possible configurations like PT, NPT, Planar Gate, Trench Gate, Silicon Carbide, etc. After that, I focused my study on Electrical-Over-Stress (EOS) conditions , in particular of IGBT devices. I studied and analyzed the interaction between Active Cell and Termination. Since the forward blocking voltage is severely dependent on the edge termination structure, the device ruggedness is strictly related to the termination design [3]. Different solutions was developed to approach the issue, one of this is the Floating Field Ring (FFR) termination. It exploits the floating rings combined action, to couple electric field from active area toward periphery. Another technique uses the SIPOS layer action onto the oxide to prevent the accumulation of trapped charges, and to reduces the electric field peaks at the semiconductor surface. Both actions allow to improve the device stability and make the SIPOS technique effective to solve walk-out problems. By means of TCAD simulations, both terminations was optimized for a PT-TIGBT 600V structure, in order to investigate and compare the efficiency and performance of the proposed solutions. The effect of geometrical dimensions and doping values was evaluated in order to

maximize the breakdown voltage. Secondly, the impact of the function depth and termination length on breakdown voltage was analyzed.
Avalanche effects in reverse polarization was studied, with particular focusing on FFR structure. Typically, the study of the termination is limited on evaluating the behavior only at Low Current Levels (LCL), when the carriers-electric filed interaction does not occur. My analysis was enlarged up to High Current Levels (HCL), by means of both isothermal and electro-thermal TCAD simulations. This last was carried out to investigate the dynamic of the carriers flows when a current is forced in the termination[4]. At HCL filamentation effect was highlighted. This effect reduces drastically the reliability in avalanche conditions since all the power is dissipated in a reduced area of the device. Indeed, for very high currents, the strong NDR region can lead to the current filamentation in the periphery of the device, leading to a further weakness of the device.
A multicellular structure of RC-IGBT devices was achieved in order to approach with a first phase of study and simulation analysis.

References:

[1] S.Voss, O.Hellmund, W.Frank, “New IGBT concepts for Consumer Power Applications,” IEEE IAS, 2007, New Orleans 2007
[2] Chen, W., Li, Z., Ren, M., et al.: ‘A high reliable reverse-conducting IGBT with a floating P-plug’. Proc. ISPSD, Kanazawa, 2013,pp. 265–268
[3] G. Breglio, et Al., "Experimental Detection and Numerical Validation of Different Failure Mechanisms in IGBTs During Unclamped Inductive Switching," Electron Devices, IEEE Trans. , vol.60
[4] Schulze H.-J., et Al., "Increase of the Robustness of the junction terminations of power devices by a lateral variation of the Emitter Efficiency," ISPSD, 2013 25th Int. Symposium on , 26-30 May 2013

4. Products

Published works:

Mirone P., Maresca L.,Riccio M., De Falco G., Romano G., Irace A., Breglio G., “An Area-effective Termination Technique for PT-Trench IGBTs”, International Conference on Microelectronics 29th, 2014;

Accepted but not yet published works:

Mirone P., Maresca L.,Riccio M., De Falco G., Romano G., Irace A., Breglio G., “A comprehensive study of current conduction during breakdown of Floating Field Ring terminations at arbitrary current levels”, IEEE International Conference PCIM, 2015;

For the second year it is in program to prepare a work for a IEEE Transaction. It will regard the EOS analysis on the interaction zone between Active cell and Termination with particular focusing on Electrothermal instability problem like filamentation.

5. Conferences and Seminars

I participated as Poster presenter at IEEE International Conference:

MIEL 2014, 2014 29th International Conference, Belgrade, 12-14 May 2014, "An area-effective termination technique for PT-Trench IGBTs"

In May 2015 I will participate as Poster presenter to IEEE International Conference PCIM 2015 in Nuremberg.