University „POLITEHNICA” of Bucharest

Faculty of Electronics, Telecommunications and Information Technology

Department of Electronic Devices, Circuits and Architectures

TESTING AND INTERFACING SYSTEMS FOR ELECTRONIC DEVICES ON WIDE BANDGAP SEMICONDUCTORS

Habilitation thesis

-Abstract-

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Bucharest, 2021

This habilitation thesis presents the most relevant academic and scientific achievements of the author, as well as future career development plans as a member of the Devices, Circuits and Electronic Architectures Department (DCAE) in the Faculty of Electronics, Telecommunications and Information Technology (ETTI), University Politehnica of Bucharest (UPB).

The content of the habilitation thesis is structured into seven chapters detailing both the academic (didactics and department duties) and scientific activities.

Chapter 1 presents wide bandgap semiconductors, with emphasis on the advantages and limitations of these materials. The scientific and didactic activities are based on devices fabricated with such semiconductors, testing systems and circuits for interfacing with existing infrastructure.

Chapter 2 is dedicated to wide bandgap semiconductor devices' characterization and testing systems with temperature. The specific feature of these systems is their ability to run high temperature investigations at levels that exceed two or even three-fold the limits of silicon devices. So far, the systems were used to characterize silicon carbide (SiC) based devices: Schottky and *pn* diodes, as well as MOS capacitors. Solutions were developed for characterizing and testing both packaged devices and on-wafer. Automatic control of the main characterization parameters, such as current, voltage or temperature is a feature of the systems. The software-control interfaces of the installations can be remote-accessed, including the selection of tested device type. For packaged devices, the temperature interval covers –90…800°C with a setting error of at most 1°C, while wafer investigations can be carried at up to 300°C.

Chapter 3 is dedicated to gas and temperature SiC-sensors (with 4H- and 6H- polytype substrates) and their affiliated circuitry, which are products of the activities carried out during research projects I've been involved in. Sensor-structures were fabricated at IMT Bucharest, a project-partner of UPB-ETTI, which possesses the necessary facilities for their manufacture. The first part of the chapter presents the personal contributions in developing the sensors: design (analytic/simulations), sensor-structures and measurements/characterization with the testing systems described in chapter 2. An essential contribution was testing of temperature sensors up to 450°C. The measurements validated the concepts for both the sensors and the testing systems.

The second part of *Chapter 3* is focused on sensor interfacing systems, which are circuits that acquire and process the signals (CAPS) at the sensor's output. Concretely, the target is obtaining interfacing systems mainly for temperature sensors, but also for gas detectors. The chapter details my essential contributions in the conception, design, implementation and testing of CAPS.

Initially, a general presentation of the signal processing circuit for SiC-based temperature sensors is done. The concept of the circuit took into account, first of all, the electric compatibility with the production-line instrumentation from a cement factory. The designed, manufactured and tested circuit presented a very good linearity and dynamic response. The performance was achieved with a minimum number of components, low power consumption and low cost.

I have also conceived and implemented interfacing circuits (two versions based on different concepts) for gas sensors based on SiC-MOS capacitors. The first variant, detailed in this chapter, is based on modifying the resonance frequency of an RLC tank, with the MOS-Sensor as the capacitor. A variation in gas concentration will lead to a shift in the resonance frequency and, implicitly, modify the voltage on the RLC group. This variation is then amplified by an instrumentation amplifier, yielding a voltage which is strictly dependent on gas concentration.

Another paragraph of *Chapter 3* describes a two-input analog interface conceived for acquisition, storing and transmission of data from a gas analyzer. The interface was conceived based on specifications of another industrial partner (beneficiary) and solved the problems of active probe selection of the analyzer and the serial transmission of stored data in real time, on two 4-20mA lines. A patent for this interface was granted to me from OSIM in 2010.

Another section of this chapter is dedicated to an interface for a complex environmental parameter detection and measurement system. It comprised sensors for temperature, wind direction, pyranometers, rain gauges and anemometers. Just like the interface for the gas analyzer, the proposed schematic converts the different signals from the sensors into currents ranging from 4 to 20mA. This was a cost-effective solution to unify sensor outputs into a standard which is compatible with the installations of an industrial laboratory for environment parameter monitoring.

The final paragraph of *Chapter 3* presents a temperature probe for industrial applications based on the SiC-temperature sensor and its readout circuit. The probe has been designed to comply with the mechanical and electrical specifications of the probes currently used to monitor the production process. Thus, the industrial partner where we performed the testing in real conditions did not have to modify and adapt its existing monitoring infrastructure. Testing on the production line was successful and certified the robustness of the proposed solution. Results comparable to those of temperature monitoring systems currently used at the factory and a guaranteed operating time at least equal to that of thermocouple probes were obtained.

Chapter 4 describes switching test systems for high-voltage power-diodes, a continuation of my doctoral activities. During a postdoctoral internship at Centro Nacional de Microelectronica (CNM), Barcelona, in 2012, I designed, implemented and tested a circuit for studying the switching operation of SiC diodes at reverse voltages of up to 7kV. The circuit is still successfully used in CNM's power-devices laboratory.

The presentation of scientific activities is concluded in *Chapter 5*, detailing a research project for which I have been responsible on behalf of UPB. The project, titled „*Hydrocarbon SiC-sensors for operational safety in industrial environments – SiC-SENS”* was implemented during 2017-2021 as component P2 of the complex grant „*Sensors and Integrated Electronic and Photonic Systems for people and Infrastructures Security (SENSIS)”*, financed following the PN-III-P1-1.2-PCCDI2017-0419 competition. Project objectives are specified, alongside structure, coordination and activity allocation for the research team. The work plan is supported by the obtained results, with emphasis on those achieved by the UPB team. Publications resulting from project research activities are also mentioned, with future directions outlined in *Chapter 7*. Three of the most relevant publications yielded from project results mark the conclusion of *Chapter 5*. Original contributions from each paper are summarized, with an analysis of scientific impact, number of citations and theses (master and doctoral) they have inspired.

Chapter 6 focuses on my didactic activities, including courses, seminars, laboratories, projects, bachelor's and master's theses coordination, PhD student guidance committee participations, as well as summarizing my research activity.

Foremost, my contributions in coordinating the Electronic Devices and Circuits Project (DCE) are evinced. This is the first project taken by all ETTI students in their undergraduate cycle. As the person in charge of this discipline, I proposed and implemented a new approach which is based on requirements from relevant industry employers. Throughout the project, students undergo the entire flow of design, implementation and testing of a functional electronic module. Practically, the DCE Project has become an example of engineering for students. The chapter also covers my teaching (course, seminar and laboratory) and publishing activities (lectures, textbooks, laboratory guidebooks) for the Electronic Devices (DE) and Fundamental Electronic Circuits (CEF) disciplines.

The undergraduate, masters and PhD student guidance activities are also presented in chapter 6. An undergraduate thesis and dissertation title list is given. The involvement in guidance and evaluation committees for PhD students is mentioned.

Finally, chapter 6 details the activities carried out for the DCAE Department. Participations in the examining committees for undergraduate theses and admission to Master programs are mentioned, as well as the tasks undertaken as member in the department council. Additionally, activities carried out as responsible for the ARACIS audit documentation since 2014 are mentioned, including the yearly updates of MON Subject Outlines and re-accreditation of this program in 2015 and 2021.

Plans for further developing my academic career are discussed in *Chapter 7*. They promote the continuation and progression of research, didactic, human-relations and professional activities inside the department, faculty, university and industry.

Initially, the objectives regarding academic activity (course, seminar, laboratory and project) are mentioned. One of the challenges is adapting and improving didactic materials to fit the on-line environment. Another undertaking is publishing/re-editing laboratory and project-specific documentation.

Research activity projections for the following years are specified next. One of the main objectives is involvement in new projects targeting the development of solutions to current national and international matters in the field of electronics, especially sensors and detection systems. Thus, I can broaden and improve my sphere of expertise and competences, while staying in touch with the latest results and discoveries in the field. Particular focus is given to pursuing interdisciplinary projects.

Interface circuitry development will be continued with a new circuit which will enable the transition of SiC-MOS gas sensors from laboratory testing to real environment validation.

Literature pertaining to this subject is scarce, with very few examples of concrete signal processing circuits for MOS sensors. Completion of this task creates new horizons towards publishing scientific papers and patents.

My scope also includes development of new sensor structures on SiC and other emerging materials (such as nanocarbon), partnering with IMT Bucharest, alongside implementation of dedicated signal conditioning circuits. Furthermore, my research group has initiated research efforts in the field of minimizing switching times (especially for the conduction-to-blocking transition) of Insulated-Gate-Bipolar-Transistors (IGBT). To this end, a project proposal was elaborated and is currently pending evaluation in the PN-III-ID-PCE-2021-3 competition.

Department-level involvement will be materialized by attracting funds through project/research grant proposals. Part of these funds will be used for equipping the DCAE laboratories with PCs, measurement and characterization hardware, as well as for maintenance of current installations. I will also continue taking part in organizing the professional competition “Tudor Tănăsescu” and encouraging talented ETTI students to attend both it and the Scientific Communication Session.

I will continue to participate as DCAE representative in the coordination of internal and external ARACIS audit for improving the didactic quality and maintaining accreditation of the MON undergraduate study program.

I will be prioritizing discussion/consulting sessions with students before the exams, guiding graduates in elaborating their diploma projects and dissertations, thereby having the opportunity to meet and attract talented students for the MON program and identify promising candidates for PhD studies.

The content of the thesis is based on a selection of results published or pending publication, as a result of the scientific activity carried out after the completion of the doctoral studies in 2004.The entire research publications has materialized into 20 papers published in international specialized ISI (WOS) (14 articles) or BDI (6 Scopus articles) journals and one paper published in a national journal. Four papers are rated ISI-Q1, while three are ISI-Q2. Another 41 papers have been published in international ISI (WOS) conference proceedings, while 7 papers were published in proceedings indexed by other databases such as Scopus, IEEExplore, Science Direct, etc. Innovative ideas were patented at OSIM (1 granted patent and 1 patent pending). The published papers have accumulated over 125 citations, out of which 113 are from ISI (WOS) books, journals and conference proceedings.

Academically, the entire publishing activity includes 4 books and two laboratory guidebooks as author or co-author. Two of the books were dedicated to applications for the Electronic Devices and Fundamental Electronic Circuits courses. These were appreciated by students, which is why they were printed in several editions, each accumulating over 2000 copies sold.