The “first and euRopEAn siC eigTh Inches pilOt line” - REACTION project as a Driver for key European SiC Technologies focused on Power Electronics Development

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ABSTRACT

This paper presents the European project REACTION (*first and euRopEAn siC eigTh Inches pilOt liNe*) [1] [2] which was launched in 2018 to push throughout the new and European first 200mm (8”) SiC Pilot Line in the world.

REACTION project partners including polish Research (Instytut Technologii Elektronowej – ITE [4]) and the SME (DACPOL [5]) are working on the battery charging modules focused on automotive & smart mobility application markets. It is one of project demonstrators The main project task is the physical migration of the technology from 6 inch to 8 inch (200mm) SiC substrate wafers. Project tasks cover development, low volume fabrication, assembly and testing of the SiC related technology demonstrators like driving modules for battery charging station run by ITE and DACPOL.

Keywords: SiC, silicon carbide, power electronics, REACTION EU project, pilot line, ECSEL JU, Łukasiewicz Research Network, ITE, DACPOL

1 INTRODUCTION

Electronic Components and Systems (ECS) technology is a high-growth area of industry. The ECS market is growing faster worldwide than any other the industry in average. Competitiveness of key European industrial domains heavily depends on the availability of leading edge ECS technologies such as the SiC one in the field of compound power electronic semiconductors. Above goals and objectives to be achieved require extended collaboration across the innovation and value chains between research institutes, academia, SMEs, large companies and R&D&I actors from substrate, through equipment to microchip suppliers and design tools and architecture developers and innovators.

Therefore, the European project REACTION [1][2] was launched to push throughout the new and European first 200mm (8”) SiC Pilot Line in the world.

2 REACTION EU PROJECT

This project profits of ECSEL (Electronic Components and Systems for European Leadership) Joint Undertaking [3] Innovation Action call together with European Public Authorities funding Alliance in a single European Strategy for ECS. The ECSEL Joint Undertaking is the Public-Private Partnership for Electronic Components and Systems funds Research, Development and Innovation projects for world-class expertise in these key enabling technologies, essential for Europe's competitive leadership in the era of the digital economy. Through the ECSEL JU, the European industry, SMEs and Research and Technology Organizations are supported and co-financed by 30 ECSEL Participating States and the European Union.

The main goal of REACTION project is to realize the first worldwide 8 inches wafer Pilot Line in SiC. The mission is to demonstrate the possibility of scaling the mass production of 200 mm substrates for SiC devices in power applications ranging from 600 V to 3.3 kV. The objective is to achieve the cost, performance and size requirements that will enable their broad adoption in emerging clean technology applications, including in electric cars, renewable energy systems and smart power grids.

The overarching goal of the REACTION project - is to ensure Europe’s key position in advanced SiC technology. The ambition is also to enable the European industry systems by setting up a fully operational fab facility at 200mm in Europe, focusing on leading edge SiC technology. Technology progress from 4” or 6” substrates only to 8” implementation is the REACTION project target along with numerous demonstration proofs developed within the project by the consortium

2.1 REACTION PROJECT PARTNERS

The REACTION project joins 27 partners from 13 countries. There are two partners from Poland: Instytut Technologii Elektronowej (RTO) and DACPOL (SME). The leader of the project is STMicroelectronics. Project participants in this EU Horizon 2020 [6] program represent the entire value chain for power electronics (Fig. 1).

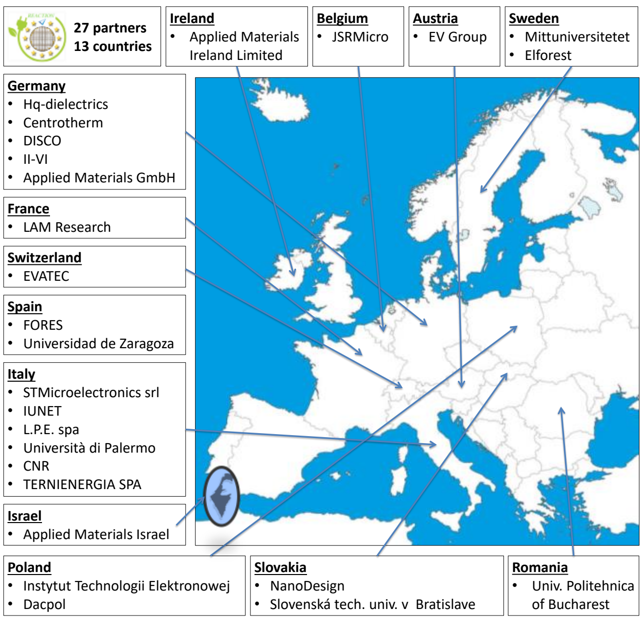

Figure 1: REACTION project Partners and countries.

2.1.1. POLISH CLUSTER: ITE

Instytut Technologii Elektronowej (ITE) [4] is a major Polish R&D Centre in the field of semiconductor electronics and physics research with a focus on development of innovative micro/nanotechnologies and systems. Since April 1st 2019 ITE is the member of the Łukasiewicz Research Network [7] in Poland. The main task of the Łukasiewicz Research Network is to conduct critical research and commercialize their results. The network includes 38 research institutes located in 11 cities in Poland, employing almost 8,000 employees. The creation of the Łukasiewicz Research Network will help to achieve the "economies of scale" and enable the creation of comprehensive research services for entrepreneurs based on their shared potential. The Research Network is an effective technological and intellectual background of public administration, but above all a real bridge between science and the economy. Its creation will positively affect the activity of micro, medium and small enterprises, which will gain easier access to the results of scientific research and know-how, thanks to which they will be able to develop faster. ITE has over 50 years of tradition and proven experience in development, dissemination and commercialization of innovative technologies and designs in a wide range of integrated circuits, detectors, sensors and microsystems. The ITE employs 250 people and is equipped with unique CAD, characterization and processing facilities. The ITE consists of the technology oriented research departments, research laboratories and design groups, working in close cooperation.

ITE has a CMOS/MEMS development and the fabrication facility combining technological flexibility and process stability required for research, design and device manufacturing. Two complementary ITE departments will be involved in the REACTION project: Department of Silicon Microsystem and Nanostructure Technology and the Department of Integrated Circuits and Systems Design.

The Department of Silicon Microsystem and Nanostructure Technology maintains the silicon CMOS/MEMS microfabrication processing line fitted on 1200 sq.m. Clean-Room area is available for R&D up to a demonstrator and prototype TRL stage as well as pilot production using a 100mm and 150mm wafers, with 0.9um up to tens of nm (nano photolithography) reachable feature size and nano scale equipment. The microfabrication facility is combines process stability with flexibility enabling ITE to undertake non-standard endeavors in the field of multi-domain sensors development. The Department is in excessive technology hardware investments setting-up the MEMS/MOEMS/heterogeneous systems fabrication and characterization lab recently.

The Department of Integrated Circuits and Systems Design has a long tradition and continuously develops its IC design skills since the beginning of seventies of 20th century. Experienced team and the professional EDA-CAD software assure the R&D potential in the field of dedicated electronic circuitry development on ASIC and system level. The Europractice program membership assures the Department an instant access to the leading CAD-EDA software and worldwide IC fabrication services for cost-effective educational and research licensing scheme. ITE profits from educational access to the software from vendors like Cadence, Synopsys, Coventor and cutting-edge IC fabrication services. It is vital for contemporary IC research, design and physical validation process for innovative technologies, systems and applications. There is a large design experience in the Department with IC development, SiP/SoC integrated solutions and systems design and software development since many years. ITE has design potential to create a dedicated low power control circuitry designs, i.e. drivers for smart sensors, automotive and IoT.

2.1.2. POLISH CLUSTER: DACPOL

DACPOL [5] is the polish SME Company. The scope of DACPOL activity and competence covers manufacturing, service, domestic distribution and export of power electronic components since 1991. DACPOL delivers components for power electronics, electrical engineering, electronics, power engineering, process automation. DACPOL represents more than 140 leading producers of active and passive power components, measuring equipment and power supply converters, fans, heat sinks, inductive components, equipment for cabinet air-conditioning, cables, connectors, insulating materials and others.

DACPOL offers wide range of elements for industrial process automation and equipment for workshops (tools and measuring equipment). DACPOL designs and manufactures power units, produces and services industrial equipment for process automation and induction heating. Main DACPOL customers are:

- producers of AC and DC drive units, electrical welding equipment, power supplies, equipment for electrical traction, control equipment for automation, electrical equipment for cars, consumer electronics,
- R&D institutes,
- business establishments,
- service centers.

DACPOL company exports materials, components and power electronics to Europe, USA, Canada and the Far East markets.

3 SIC TECHNOLOGY

From historical point of view, Silicon Carbide technology for electronics started at the beginning of the 20^{th} century. The SiC was originally used as a radio detecting diode (AM demodulator). It was also called a "*cat whisker detector*", which consisted of a piece of the crystalline mineral. In 1907 Henry Joseph Round produced the first LED by applying a voltage to a SiC crystal and observing yellow, green and orange light emission at the cathode.

The first commercially available SiC power device was the SiC Schottky barrier diode in 2001. It was expected that SiC would be a suitable semiconductor material for high-efficiency power electronics; however, difficulties in SiC substrate wafers manufacturing delayed the technology development. There are other factors, such as assembly and packaging costs to consider, blank SiC wafers and the cost of growing epitaxial layers on them fundamentally drive the prices of finished discrete SiC power semiconductor devices. Costs are not the only necessary improvements expected. SiC defect rates and low manufacturing yields cause many difficulties for power semiconductor device makers. Material defects inhibit advances in case of high performance device specification. Higher voltages need thicker epitaxial layers and thicker layers result in numerous defects lowering device reliability. Materials of improved quality (defects, homogeneity, structure, orientation) and stable epitaxial processes are necessary to reduce the substrate defect density, achieve satisfactory device reliability and the process yield also in high voltage region of device operation. Beyond the device structure and properties of the applied material, packaging issues are the next technical constrain of SiC semiconductor product development. Technology improvements are necessary to improve performance: increased power density, switching frequency, timing, reduced switching losses, price etc. Last, provision of reliability data is essential. SiC devices must show good long-term performance and reliability in critical applications.

It is of primary importance in case of safety-critical applications such as in hybrid/electric vehicles, traction/aerospace applications for military and civil target. There are mainstream SiC device applications in PV inverters, in renewable energy hardware. From a global perspective, the SiC pervasiveness roadmap is now stabilizing with no need for further effort in demonstrating the additional benefits compared to silicon technology. As it is well known, Silicon Carbide (SiC) represents, together with Gallium Nitride (GaN), the forthcoming alternative to Silicon (Si). The Silicon Carbide advantages (Table 1):

- higher power density in energy conversion systems,
- extremely low power losses,
- more energy efficient,
- faster and more robust than Si,
- high thermal conductivity,
- smaller die size for equivalent breakdown voltage,
- lower switching losses,
- higher operating temperature, operating up to 200°C junction,
- reduces cooling,
- increased lifetime,
- fully compatible with standard gate drivers,
- simpler design.

SiC devices are capable to operate (Figure 2):

- very high temperatures,
- high breakdown voltages,
- high frequency,
- high electric field.

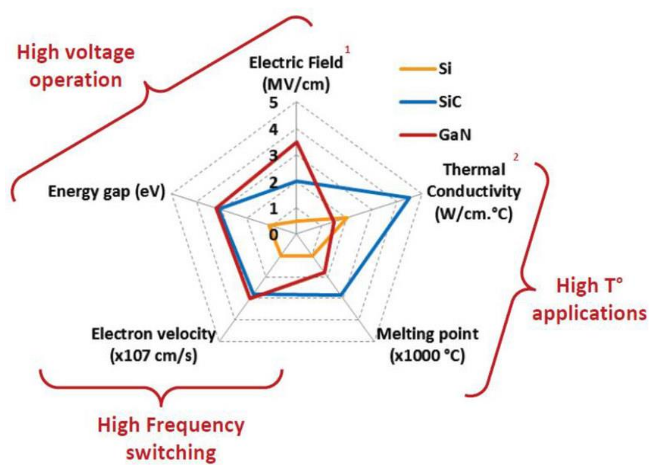

Figure 2: GaN Vs. SiC Vs. Si capabilities comparison [8].

Table 1 [8-11] summarizes the electrical and material properties of major substrate semiconductors. Among various SiC polytypes, 4H-SiC as the mostly used (mature technology) is selected for comparison. The figure-of-merit for power devices is given by $\varepsilon\mu E_B^3$ (Baliga's figure of merit) [8-11], where ε is the dielectric constant, μ the mobility, and E_B the breakdown field. The figure-of-merit for SiC exceeds 500 when the value is normalized by that of Si, indicating potential of SiC for power device applications.

	Si	GaAs	**4H-SiC**	GaN
Bandgap (eV)	1.12	1.43	**3.26**	3.39
Electron mobility (cm^2/Vs)	1350	8000	**1000**	1200
Breakdown field (MV/cm)	0.3	0.4	**2.8**	3.0
Saturation velocity (cm/s)	$1x10^7$	$1x10^7$	**$2x10^7$**	$2x10^7$
Thermal conductivity (W/cmK)	1.5	0.5	**4.9**	2.5
Johnson's figure of merit	1	1.8	**400**	480
Baliga's figure of merit	1	15	**610**	730

Table 1: Comparison of electrical and material properties of major semiconductors.

4 THE BATTERY CHARGING MODULE FOCUSED ON AUTOMOTIVE & SMART MOBILITY APPLICATION MARKETS (REACTION PROJECT DEMONSTRATOR)

Polish cluster partners of the REACTION project: the ITE (Research) and DACPOL (SME) in cooperation with project coordinator STMicroelectronics and technology operator and some other project partners are responsible for development of the one of several project demonstrators.

The demonstrator by ITE and DACPOL is a battery charging module for 15 kW focused on automotive & smart mobility application markets. The main task covers development, low volume fabrication, assembly and testing of the charging modules for battery charging station. Such modules consist of power bridges for DC-DC converters and driven power elements. As final application is the well-known piece of design work, power elements elaborated in frame of the REACTION project activities, fabricated SiC Power MOSFETs also need secure, gate drivers controlled externally by dedicated digital control modules. Schematic diagram of such a gate driver implements driving element (buffer) and at least gate separation by optoseparators or transformers. The dedicated gate driver will be designed and prototyped by ITE. Charger application will be developed by DACPOL in collaboration with ITE. SiC Power MOSFETs transistors will be developed and fabricated by STMicroelectronics.

5 CONCLUSIONS

Over 1 million electric vehicles is expected in Poland before 2025. Respectively more impressing eVehicle volume is expected on European streets in the same perspective. Booming market of electric vehicles results that minimum infrastructure necessary to be developed exceeds 5 million public charging points and proportional number of chargers house and garage chargers in Poland. It is area under very excessive developments, very high grow rate is expected in 2025 perspective and beyond. REACTION project is now on early stage, nevertheless power electronics hardware and software solutions development of the gate driver (controller and power elements) and charging module for battery are in scope of the ongoing activity and will be developed by consortium during next years.

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