Key Engineering Materials
ISSN: 1662-9795, Vol. 1023, pp 1-6
doi:10.4028/p-0v5tyE

Submitted: 2024-09-20
Accepted: 2025-02-28
Online: 2025-09-10

Matching Physical and Electrical Measurements (OBIC) to Simulation (FEM) on High Voltage Bipolar Diodes

D. Planson[1,a*], C. Sonneville[1,b], P. Bevilacqua[1,c], P. Brosselard[1,d], M. Lazar[2,e], S. Scharnholz[3,f], B. Vergne[3,g], H. Morel[1,h]

[1]Univ Lyon, INSA Lyon, Univ. Claude Bernard Lyon 1, Ecole Centrale Lyon, CNRS, Ampère, F-69621, France

[2]Light, Nanomaterials, Nanotechnologies, L2n, UMR CNRS7076, Université de Technologie de Troyes, 10004, Troyes, France

[3]French-German Research Institute of Saint-Louis (ISL), 5 rue du Général Cassagnou, 68300 Saint-Louis, France

[a]dominique.planson@insa-lyon.fr, [b]camille.sonneville@insa-lyon.fr, [c]pascal.bevilacqua@insa-lyon.fr, [d]pierre.brosselard@insa-lyon.fr, [e]mihai.lazar@utt.fr, [f]sigo.scharnholz@isl.eu, [g]bertrand.vergne@isl.eu, [h]herve.morel@insa-lyon.fr

Keywords: OBIC characterization, Bipolar diode, high voltage, device simulation, periphery protection

Abstract. This paper presents for the first time a comparison between experimental measurements of Optical Beam Induced Current (OBIC) and finite element simulations on high-voltage bipolar diodes. Two peripheral protection structures were chosen: a simple MESA protection and a MESA + JTE combination. Comparable experimental and simulated results were obtained in both cases.

Introduction

Bipolar components (diodes, transistors, thyristors) are essential for very high-voltage power electronics. Recently, an optical-controlled high-voltage 4H-SiC BJT (Bipolar Junction Transistor) has been designed, fabricated and characterized. The BJTs were fabricated on a 4H-SiC wafer using a 120 µm thick epilayer with a doping concentration of 8×10^{14} cm^{-3} [1] and were designed to withstand a voltage of 10 kV. After electrical characterization, a breakdown voltage of about 11 kV was obtained [2].

PiN diodes have been integrated in the mask layout as part of this project to optically trigger high-voltage bipolar components (Fig. 1, right). In order to verify the effectiveness of their peripheral protection, different geometries were considered: MESA only, MESA combined with JTE, with and without supplementary 6 JTE rings, with round and square shapes. Previous studies have shown the efficiency of the micro-OBIC technic to assess the efficiency of peripheral protection by analyzing the 2D distribution map of currents within the device structure [3, 4]. In this paper, we demonstrate that this technic can be used to characterize high-voltage bipolar diodes.

Experimental Results

Device fabrication and characterization. Bipolar diodes were fabricated at the same time as the vertical bipolar transistors. Eleven mask levels are required to manufacture the components. No passivation was applied to the OBIC test diodes. The purpose of these diodes is to test the effectiveness of the peripheral protection of the transistor's base-collector junction. Figure 1 shows the mask of the test structures with the various peripheral protections, and also a picture of the 100 mm wafer with the components produced. Numerous test structures have been planned, but for the purpose of this paper, only 2 structures are studied in detail. The manufacturing process is described in [1]. These diodes have been characterized in a vacuum chamber up to a reverse voltage of 1000 V and exhibit a low leakage current as shown in Fig. 2, a prerequisite for OBIC characterization measurements in reverse.

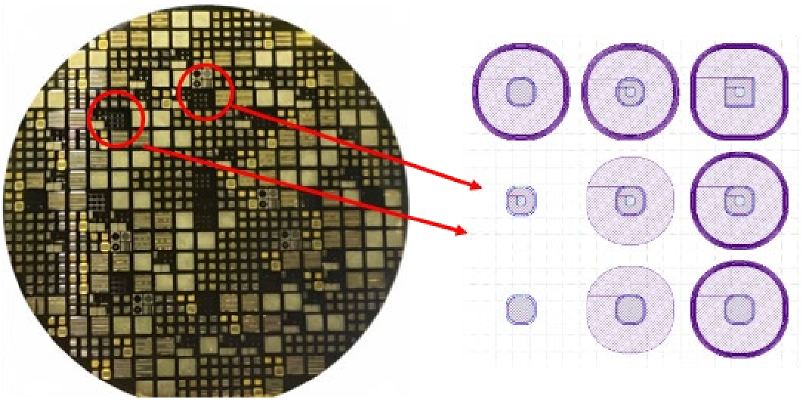

Fig. 1. Image of the fabricated wafer with 9 OBIC designs (MESA, MESA+JTE, MESA+JTE + 6 rings, round and square shapes).

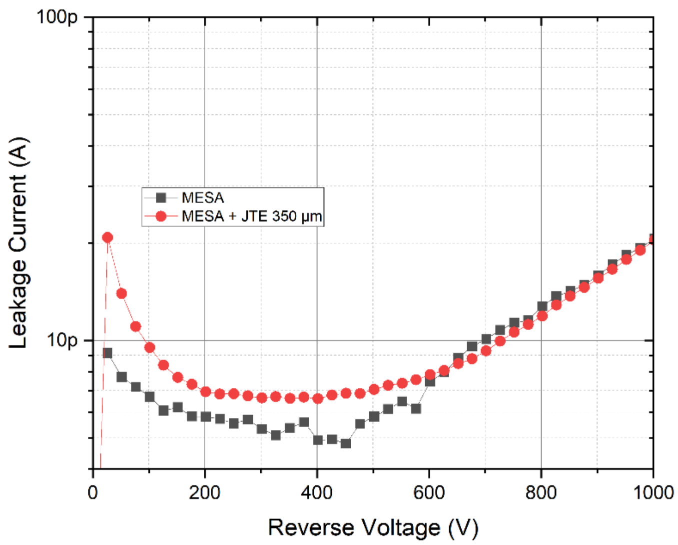

Fig. 2. Leakage current versus reverse voltage for two periphery protections (MESA and MESA + JTE) in the vacuum chamber (1.2×10^{-6} mbar).

Experimental OBIC measurements. Two types of circular diodes were chosen for illustration: a MESA diode and a MESA diode with JTE. Micro-OBIC measurements were carried out in air, limiting the reverse voltage applied to 400 V to avoid breakdown. Their cross-sectional view is shown in figure 3.

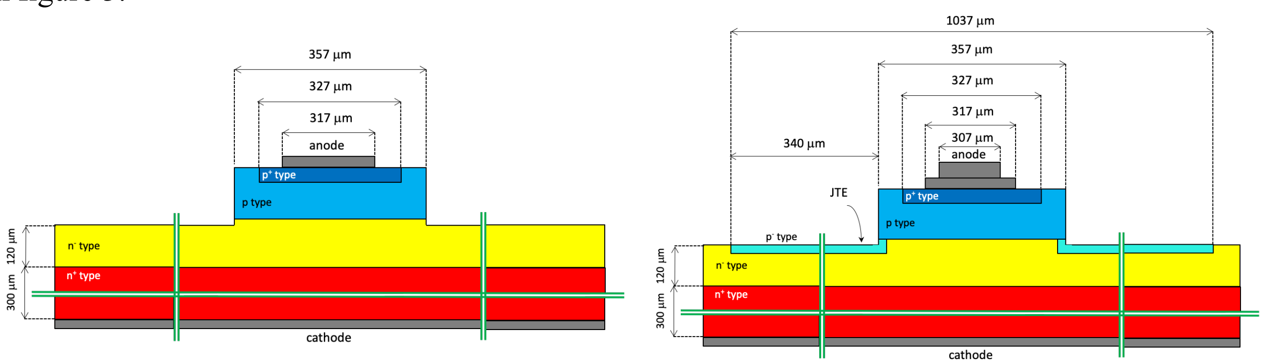

Fig. 3. Cross-sectionnal view of both vertical diode (MESA on the left and MESA+JTE on the right).

The OBIC (Optical Beam Induced Current) characterization technique has already been described in previous papers from our team [3, 4]. The 2D-maps OBIC show the evolution of the induced current within devices. These maps are shown in Fig. 4, where the junction is clearly evidenced. Blue colors represent the absence of signal, e.g. the outside of the diode and the metallization of the anode in the center of the figures.

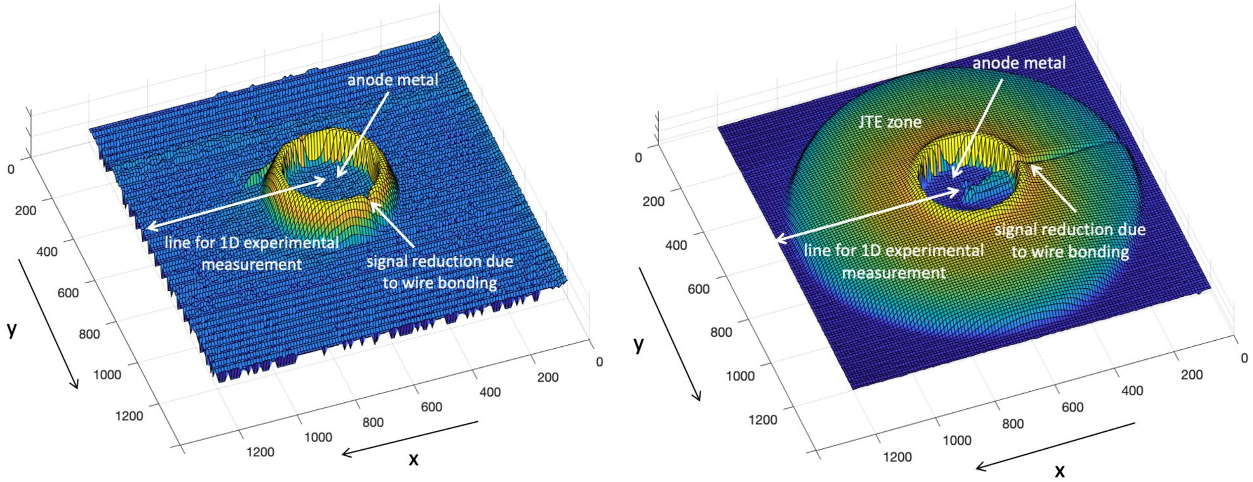

Fig. 4. OBIC 2D-mapping of circular diodes with MESA (left) and with MESA combined with JTE (right) (under 100V). Experimental measurements of the OBIC current are expressed using a logarithmic scale (the displacement step in both direction is 10 µm). The dimensions of the area scanned are a square of 1200 × 1200 µm for both structures.

OBIC measurements have also been studied on vertical lines (1D) as shown in Fig. 4, enabling much fa ster plotting as a function of the inverse voltage applied. These will be compared with the corresponding simulations in the next section. Fig. 6 (left) and Fig 7 (left) show the evolution of the experimental OBIC current with position for half a diameter of a diode protected by a single mesa (Fig. 3-left) and a MESA + JTE (Fig. 3-right). Experimental curves are plotted for voltages ranging from 0 to 300V. The different zones are clearly visible: metallization, MESA, JTE, as shown in the simplified cross-section above the curves.

OBIC simulations. At the same time, finite element simulations were carried out with Sentaurus™ [5] in transient mode, taking into account the diode structure (Fig. 5) and the characteristics of the laser optical beam (position, penetration depth, Gaussian parameters, power density…). The wavelength is identical to that of the experimental laser beam (349 nm), and the quantum yield is assumed to be unity. The beam is assumed to be continuous, and the displacement must be less than the mesh length. Figures 5 show how the two structures are entered into the simulator. For all simulations, only a few microns underneath the metallization is considered to focus on the peripheral protection in order to limit the number of mesh nodes and calculation time, which is already very long (several dozen hours). The same applies to the reduced thickness of the epitaxial layer (18 µm instead of 120 µm), but this has no impact as the maximum reverse voltage applied is 300V. The thickness of the N^+ substrate is also reduced for the same reason. However, the lateral dimensions are respected, as of course the doping of each layer.

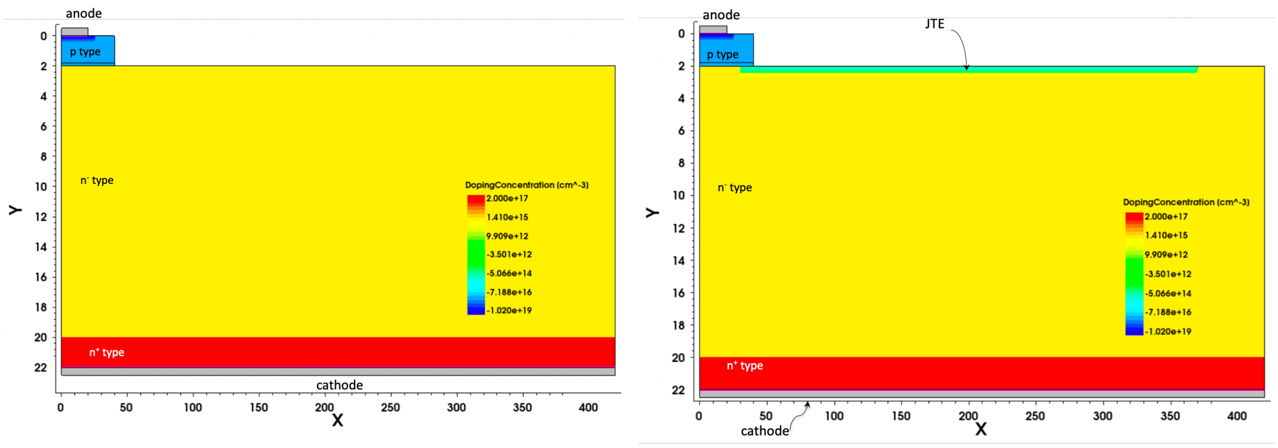

Fig. 5. Cross-section of the periphery protection (only half-cell to limit calculation time) of both diode structures with MESA (left) and MESA+JTE (right) defined with Sentaurus / Synopsys [5]. The distance are expressed in µm.

The optical beam moves across the structure from the outside towards the metallization, with small displacements at a given voltage. In this way, the current can be calculated as a function of the position. Fig. 6 (right) shows the evolution of the simulated currents for half a diameter of diode protected with the MESA, at reverse voltage between 0 V and 300 V. These simulations are compared with the experimental measurements (Fig. 6 (left)). As it can be observed, both the experimental and simulated OBIC behavior are almost identical: the optically induced current increases and widens at the junction if the reverse voltage increases. The singularity observed (at the edge of the MESA) with measurements is also reproduced in simulations, due to the beam passing over the edge of the MESA. Signal decay outside the MESA is linked to the lifetime of the minority carriers. This parameter could be better adjusted in the future.

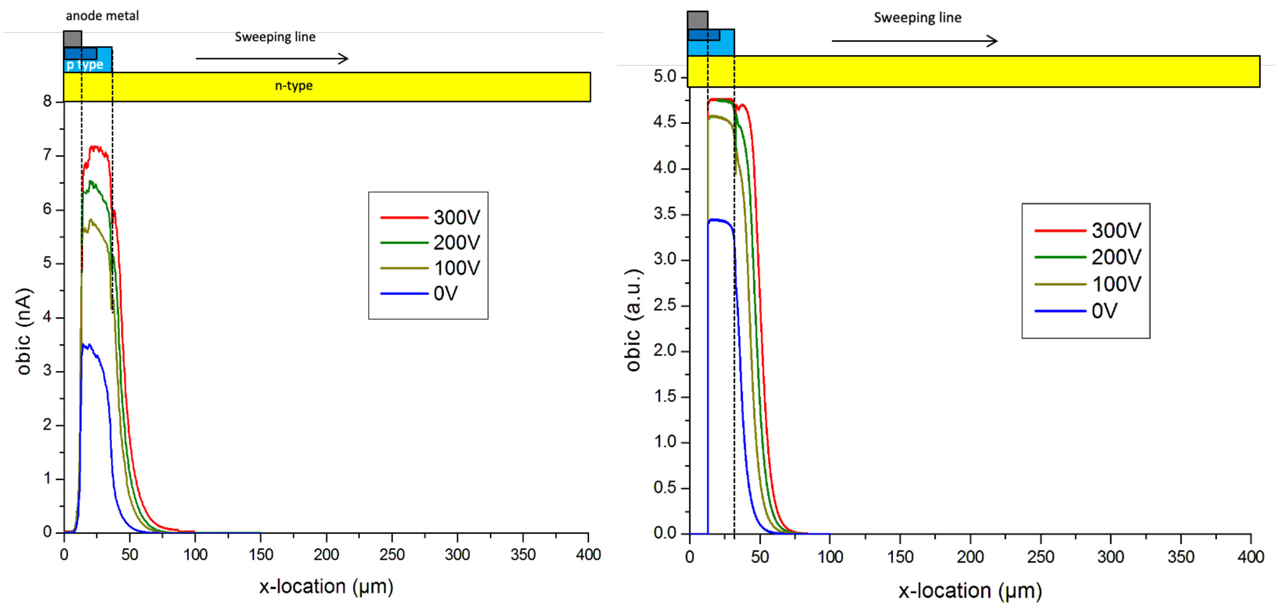

Fig. 6. Comparison between experimental measurements (left) and simulation (right) of the OBIC signal according to the diameter of the diode protected by MESA. The displacement step is 0.5 µm. The same colors are used for the same voltage for both results up to 300V.

Finite element simulations were also carried out for MESA + JTE protection.

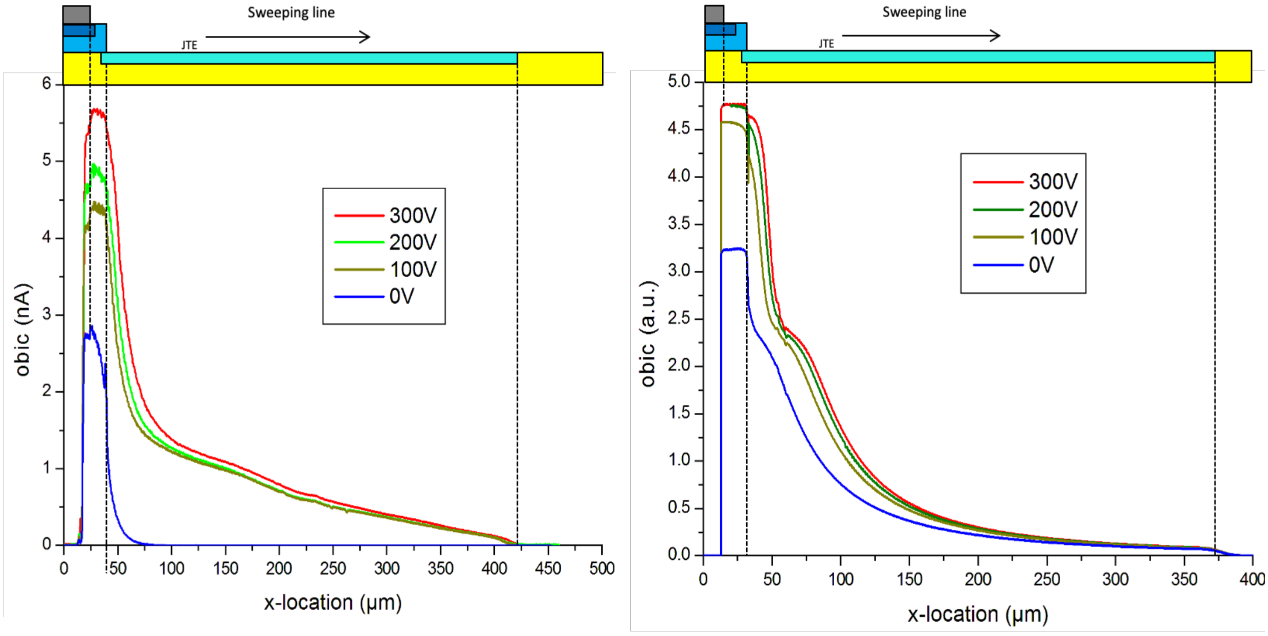

Fig. 7. Comparison between experimental measurements (left) and simulation (right) of the OBIC signal according to the diameter of the diode protected by MESA + JTE (340 µm). The displacement step is 500 nm. The same colors are used for the same voltage for both results up to 300V.

The simulated and experimental results are clearly similar. The length of the JTE is clearly visible, and the maximum current is close to the MESA and the junction. There is also an absence of current under the anode contact metal. The progressive increase in the experimental measurements is most probably linked to a charge density at the interface, unlike the simulated signal. This effect is not taken into account yet, and adjustments will be necessary.
Our results show that these TCAD simulations can be used to predict the experimental behavior of any structure.

Acknowledgements for French ANR contract HV-PhotoSwitch (ANR-18-CE05-0020-01).

Summary

This paper presents OBIC measurement and simulation results for 2 types of periphery protection: MESA and a combination of MESA + JTE. The OBIC measurements show that the good resolution of our test bench is capable of revealing the different zones of the protection and also the impact of the applied reverse voltage. In this paper, TCAD simulations have been developed for the first time for relatively high voltages. As illustrated, there is good agreement between experimental results and simulations with regards to JTE length and MESA structure. However, improvements could be future explored. The difference between the signals could come from the recombination current at the oxide/semiconductor interface that is not yet simulated.
In the future, the OBIC test bench will be adapted to a vacuum chamber, enabling characterization at higher reverse voltage, and thus revealing the full effectiveness of peripheral protection. It also could help to reach the optimal design of the JTE, even the additional JTE rings.

References

[1] P. Brosselard, D. Planson, D. Tournier, P. Bevilacqua, C. Sonneville, L. V. Phung, M. Lazar, B. Vergne, S. Scharnholz and H. Morel, Design and characterization of an optical 4H-SiC Bipolar Junction Transistor, Solid State Phenomena, Vol. 360 (2024) p 127-131

[2] A. Ammar, M. Lazar, B. Vergne, S. Scharnholz, L. V. Phung, C. Sonneville, C. Raynaud, H. Morel, D. Planson and M. Zielinski, Optimized Junction Termination Extension and Ring System for 11 kV 4H-SiC BJT, IEEE (2022) International Semiconductor Conference (CAS), p. 191

[3] C. Sonneville, D. Planson, L.-V. Phung, P. Bevilacqua, B. Asllani, Interest of using a micro-meter spatial resolution to study SiC semi-conductor devices by Optical Beam Induced Current (OBIC), Materials Science Forum Vol. 1004 (2020) p. 290

[4] D. Planson, C. Sonneville, P. Bevilacqua, L V Phung, B. Asllani, D. Tournier, P. Brosselard, 4H-SiC PiN diode protected by narrow fields rings investigated by the OBIC method, Materials Science Forum Vol. 1062 (2022) pp 341-345

[5] Sentaurus Device User Guide Version V-2023.12, http://www.synopsys.com/home.aspx

[6] F. Yin, W. D. Hu, B. Zhang, Z. F. Li, X. N. Hu, X. S. Chen, W. Lu, Simulation of laser beam induced current for HgCdTe photodiodes with leakage current, Opt Quant Electron (2009) 41:805–810