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Matching physical and electrical measurements (OBIC) to simulation (FEM) on high voltage bipolar diodes

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Bipolar components (diodes, transistors, thyristors) are essential for very high-voltage power electronics. Recently, an optical 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 $8 \times 10^{14} \text{ cm}^{-3}$ [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.

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. 1, a prerequisite for OBIC characterization measurements in reverse. This paper aims to demonstrate how the micro-OBIC technique [3] can be used to assess the efficiency of peripheral protection by analyzing the 2D distribution map of the currents within the device structure, particularly at the junction periphery.

2 types of circular diodes were chosen for illustration: a MESA diode and a MESA diode with JTE and 6 rings. Micro-OBIC measurements were carried out in air, limiting the reverse voltage applied to avoid breakdown.

The OBIC 2D-maps are shown in Fig. 2, where the junction is clearly evidenced. At the same time, finite element simulations were carried out with SentaurusTM [4] in transient mode, taking into account the diode structure (Fig. 3) and the characteristics of the laser optical beam. Simulations of this kind are rare [5] and time-consuming. Fig. 4 shows currents as a function of diode diameter for the diode protected with the MESA. 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.

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[1] P. Brosselard, D. Planson, D. Tournier, P. Bevilacqua, C. Sonnevile, L. V. Phung, M. Lazar, B. Vergne, S. Scharnholtz and H. Morel, presented at ICSCRM'23 – Sorrento – Italy

[2] A. Ammar, M. Lazar, B. Vergne, S. Scharnholtz, L. V. Phung, C. Sonnevile, C. Raynaud, H. Morel, D. Planson and M. Zielinski, IEEE 2022 International Semiconductor Conference (CAS), p. 191

[3] C. Sonnevile, D. Planson, L.-V. Phung, P. Bevilacqua, B. Asllani, Materials Science Forum Vol. 1004 (2020) p. 290

[4] Sentaurus Device User Guide Version V-2023.09, <http://www.synopsys.com/home.aspx>

[5] F. Yin, W. D. Hu, B. Zhang, Z. F. Li, X. N. Hu, X. S. Chen, W. Lu, Opt Quant Electron (2009) 41:805–810

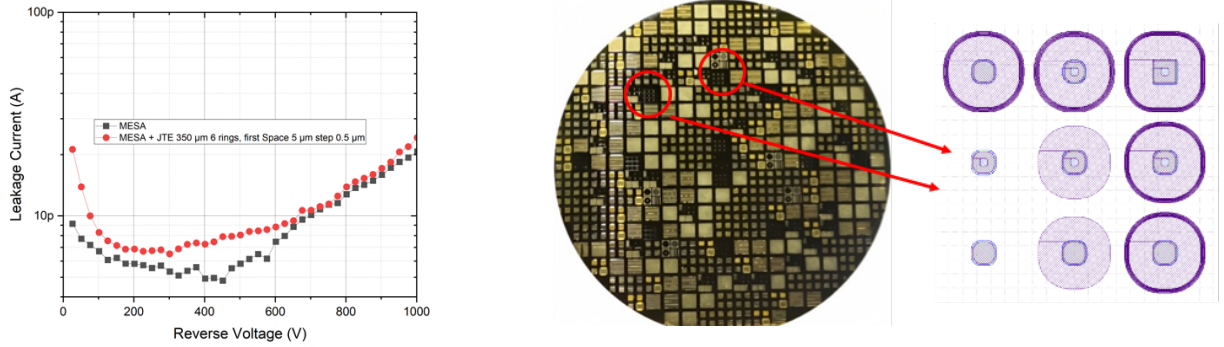


Fig. 1. Leakage current versus reverse voltage for two periphery protections in the vacuum chamber (1.2×10^{-6} mbar) on the left and image of the fabricated wafer with OBIC design on the right

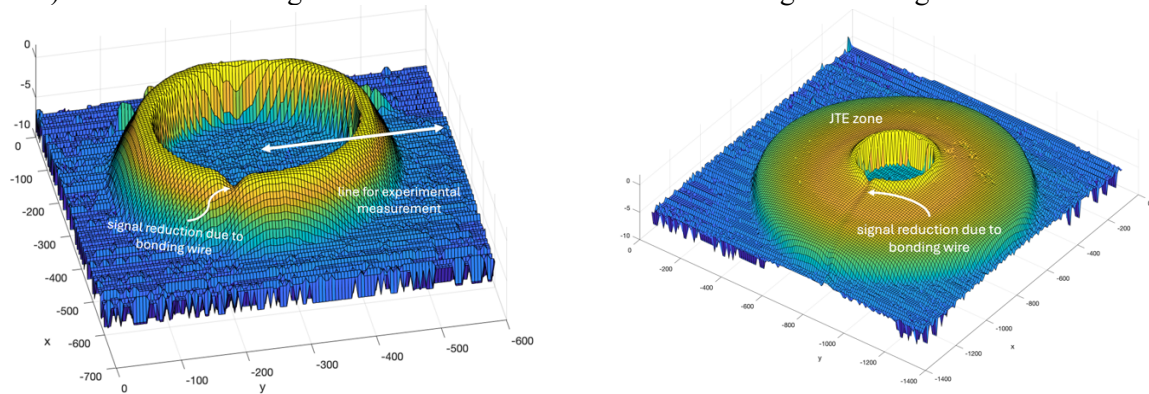


Fig. 2. OBIC 2D-mapping of circular diodes with MESA (left) and with MESA combined with JTE (right) (under 100V). Experimental measurements of the OBIC current expressed in logarithmic scale (the displacement step in both direction is $10 \mu\text{m}$).



Fig. 3. 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 [4].

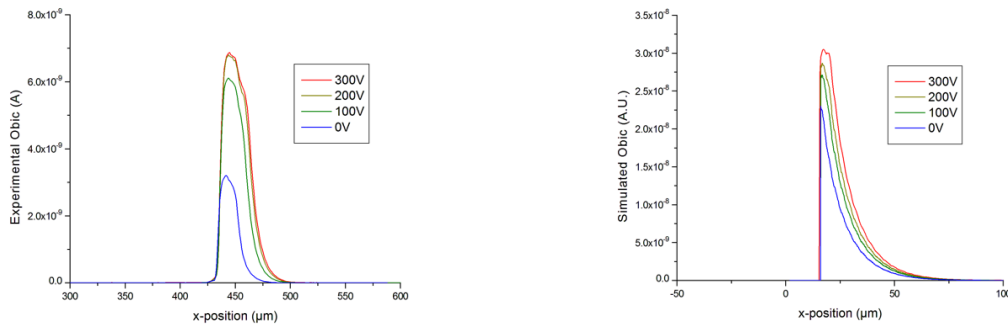


Fig. 4. Left: experimental measurements of the OBIC signal according to the diameter of the diode protected by MESA. The displacement step is $1 \mu\text{m}$. Right: simulation of the scanning of the laser beam from the edge of the diode protected by MESA for voltages ranging from 0 to 300V.