

# CHARACTERIZATION OF INITIAL DEFECT LANDSCAPES AND METHODOLOGY DEVELOPMENT FOR LGAD-RELATED P-TYPE SILICON APPLICATIONS

Faustina Kiaušaitė<sup>1</sup>, Tomas Čeponis<sup>1</sup>, Jevgenij Pavlov<sup>1</sup>

<sup>1</sup>Vilnius University, Faculty of Physics, Institute of Photonics and Nanotechnology, Vilnius, Lithuania  
[faustina.kiausaite@ff.stud.vu.lt](mailto:faustina.kiausaite@ff.stud.vu.lt)

Low-Gain Avalanche Detectors (LGADs) represent a promising technology for high-energy physics, particularly for the ATLAS and CMS experiments at CERN, due to their high-precision timing performance. However, the radiation-induced deactivation of dopants - known as the Acceptor Removal Effect [1] - remains a critical challenge for the boron-doped gain layer.

This study was carried out within the CERN DRD3 WP3 (WG3) project [2], "Defect engineering in PAD diodes mimicking the gain layer in LGADs." The project investigates the acceptor removal process (ARP) in irradiated LGAD gain layers to understand and parameterize its behavior as a function of boron, carbon, oxygen concentrations and irradiation fluence. The objective is to identify defect-engineering strategies that enhance radiation hardness.

Thermally Stimulated Current (TSC) spectroscopy was performed on non-irradiated and neutron irradiated p-type silicon PIN diodes to imitate the LGAD gain layer [3]. The sample set includes Diffusion Oxygenated Float Zone (DOFZ) and phosphorus-doped (*P*-plateau) substrates, with carbon co-implanted at fluences from  $5 \times 10^{12}$  to  $5 \times 10^{14} \text{ cm}^{-2}$ . TSC was selected to bypass capacitance-related distortions in highly-doped structures, ensuring more accurate defect characterization compared to other transient methods [4].

A significant focus was placed on developing and optimizing the experimental setup for high-sensitivity TSC measurements. The setup used a Keithley 6430 electrometer and Lake Shore 336 controller, automated via custom LabVIEW. Samples were cooled under reverse bias, followed by trap filling through forward bias injection (60–360 s). During heating at a constant rate  $\beta$ , the resulting current  $I_{TSC}$  was recorded against temperature to characterize structural defects from spectral peaks [1].

Defect parameters, including activation energy ( $E_a$ ) and capture cross-section ( $\sigma$ ), are extracted from  $I_{TSC}$  signals using Arrhenius plots of  $\ln(T_m^4/\beta)$  versus  $1/T$ . Trap concentration ( $N_t$ ) is determined by integrating TSC peaks after background subtraction [4]. This initial characterization provides the baseline for investigating radiation-induced changes, with higher trap densities expected at the maximum carbon fluence of  $5 \times 10^{14} \text{ cm}^{-2}$ .

Overall, carbon co-implantation combined with DOFZ substrates is expected to be the most effective strategy to withstand the acceptor removal effect and enhance radiation tolerance. These findings will be presented and discussed at the conference.

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[1] A. Himmerlich et al., "Defect characterization studies on irradiated boron-doped silicon pad diodes and Low Gain Avalanche Detectors," Nucl. Instrum. Methods Phys. Res. A, vol. 1048, p. 167977, 2023.

[2] <https://drd3.web.cern.ch/wg3>

[3] G. Pellegrini et al., "Technology developments and first measurements of Low Gain Avalanche Detectors (LGAD) for high energy physics applications," Nucl. Instrum. Methods Phys. Res. A, vol. 765, pp. 12–16, 2014.

[4] P. Blood and J. W. Orton, The Electrical Characterization of Semiconductors: Majority Carriers and Electron States. San Diego, CA, USA: Academic Press, 1992