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TCAD analysis of leakage current and breakdown voltage in small pitch 3D pixel sensors

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Small-pitch 3D pixel sensors have been developed to equip the innermost layers of the ATLAS and CMS tracker upgrades at HL-LHC. They feature 50×50 and 25×100 μm^2 geometries, and are fabricated on p-type Si-Si Direct Wafer Bonded substrates of 150 μm active thickness with a single-sided process. Due to the short inter-electrode distance, charge trapping effects are strongly mitigated, making these sensors extremely radiation hard. Results from beam test measurements of 3D pixel modules irradiated at the large fluences of interest to HL-LHC ($\sim 10^{16} n_{eq} cm^{-2}$) indeed demonstrated high efficiency at maximum bias voltages of the order of 150 V. However, the downscaled sensor structure also lends itself to high electric fields as the bias voltage is increased, so that premature electrical breakdown due to impact ionization is a concern.
In this study, TCAD simulations incorporating advanced surface and bulk damage models are used to investigate the leakage current and breakdown behavior of these sensors. Simulations are compared with measured characteristics yielding a satisfactory agreement. The dependence of the breakdown voltage on geometrical parameters (e.g., the n^+ column radius and the gap between the $^+$ column tip and the highly doped p^{++} handle wafer) is also discussed.

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