PROFILING OF CURRENT TRANSIENTS IN LGAD AND PIN PARTICLE DETECTORS

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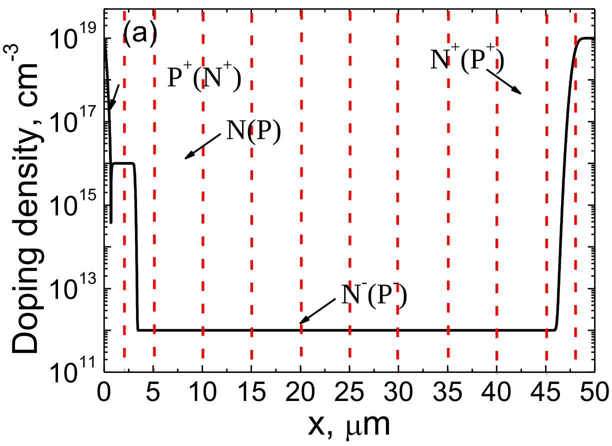
Silicon sensors with charge multiplication layer, known as Low Gain Avalanche Detectors (LGAD), are anticipated to be the functional particle detectors after heavy irradiations by hadrons. The concept of internal gain due to charge multiplication is addressed to an enhancement of the signal-to-noise ratio (SNR). The LGAD detectors become the most promising devices for applications in high energy physics experiments where harsh radiation environments, such as the inner detectors of Large Hadron Collider (LHC), are met.

Conventional a P-type LGAD consists of $N^{+}PP^{-}P^{+}$ layers with P-well formed by deep diffusion of boron (B) into P^{-} layer. However, it was shown that an effect of the "acceptor removal" occurs in irradiated LGAD sensors which causes the loss of internal gain [1]. Radiation damage partially removes a boron from the multiplication layer, thereby reducing the effective doping concentration. This detrimental effect might be partially suppressed by forming the N-well ($P^{+}NN^{-}N^{+}$) Si structure with the phosphorus doped an epitaxial (N-well) layer. PIN structure ($N^{+}P^{-}P^{+}$) was formed from P-type LGAD structure by skipping the P-layer. In this work, the results of simulations of the operation characteristics for the P-type, N-type LGAD and PIN devices are reported.

A functionality of LGAD device has been validated by digital experiments performed using of Technology Computer-Aided Design (TCAD) algorithms and the Drift-Diffusion (DD) approach. Simulations have been carried out employing a Sentaurus Device software platform. It has been obtained that the breakdown voltages are approximately 8 times higher for the PIN structure than for the LGAD structures. One of the possible reasons is the absent P-layer in PIN structure compared with P-type LGAD structure. To evaluate those voltage differences the profiling of current transients for P- and N-type LGAD (Fig. 1 a) and PIN (Fig. 1 a) structures have been performed. Moreover, the shape and duration of current pulses is quite different in N- and P-type Si LGAD's mainly due to the difference of the ionization coefficients. These coefficients are approximately 10 times greater for electrons than for holes ($\alpha_e \cong 10 \cdot \alpha_h$). Nevertheless, the collected charge is almost the same for P-type and N-type Si devices if radiation traps are ignored in simulations.



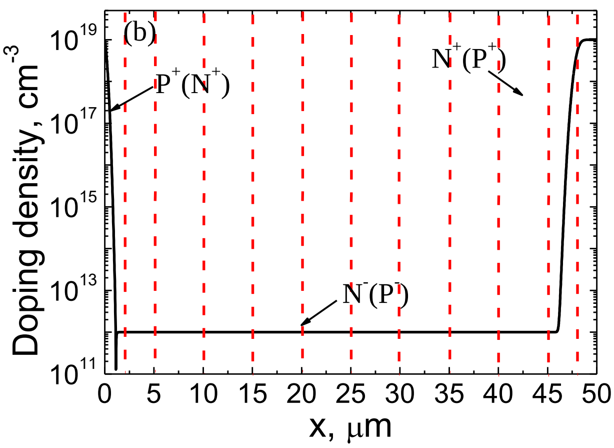


Fig. 1. Doping profiles (solid curves) in P as well as N type LGAD (a) and PIN (b) structures. The dashed lines represent the initial localizations of the photo-injected carrier domain.

It was assumed in simulations that a probability of carrier trapping during their drift increases with irradiation fluence. It has been shown that the thickness of the active layer within a sensor plays an important role in charge collection. Nevertheless, it has been demonstrated that even a rather thin (~50 μm) LGAD sensor can be functional with proper charge collection efficiency (CCE). The persistent CCE results from the carrier density increase through the internal amplification, proportional to a density of the radiation injected secondary carrier pairs. It has been demonstrated that the rather low bias voltage, applied to LGAD, is sufficient to get proper charge collection. Comparative analysis of the simulated and recorded current transients in the epitaxial LGAD structures will be presented. The impact of the radiation induced traps on detector current and charge collection efficiency, results of the detector current profiling in LGAD and PIN structures will be discussed.

[1] G. Kramberger, et al, Radiation effects in Low Gain Avalanche Detectors after hadron irradiations, Journal of Instrumentation **10**, P07006 (2015).