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Radiation induced performance degradation of p-type silicon devices by acceptor removal effects

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New sensor technologies are constantly under development to cope with the ever increasing requirements for high energy physics (HEP) detectors. For the High-Luminosity LHC (HL-LHC) and the Future Circular Collider (FCC-hh) higher radiation hardness, improved timing performance and lower cost large area detector technologies are essential, to name just some of the major challenges. Recent developments of radiation hard p-type silicon planar sensors, sensors with intrinsic gain for timing applications and monolithic sensors are examples for upcoming new detector technologies. A commonality of these new sensors is the use of boron doped p-type silicon, while present HEP silicon sensors are essentially based on n type silicon. Consequently, radiation effects in p-type silicon have been less studied in the detector community, but are now of high relevance. In this presentation, we review radiation effects in p-type silicon devices with focus on acceptor removal effects.

In p-type silicon doped with Boron exposure to radiation cause an apparent deactivation of the dopant. This so-called acceptor removal effect is for example evidenced by an initial decrease of depletion voltage in p-type sensors with rising particle fluence, while after exposure to higher fluences the Boron is de-activated and the device behavior is dominated by other radiation induced defects. Low Gain Avalanche Detectors (LGADs) are the baseline technology for future solid-state timing layers at the HL-LHC. Their good timing performance is based on the intrinsic amplification of the signal by impact ionization in a p-type layer, the gain layer. Radiation effects reduce the active Boron concentration in the gain layer and lead to a reduction in field-strength and consequently loss of intrinsic signal amplification, thus limiting the radiation hardness of this technology. Monolithic detectors, especially High Voltage CMOS, is another technology affected by acceptor removal, as the bulk silicon used for the sensor is typically of p-type. We review the impact of radiation damage on the depleted volume as function of the initial Boron concentration and the corresponding change in signal charge and device performance.

The origin of the radiation induced de-activation of the Boron acceptor is found in the creation of defect levels that contain Boron, that is consequently no longer acting as shallow dopant. Defect spectroscopy techniques like TSC (Thermally Stimulated Currents) and DLTS (Deep Level Transient Spectroscopy) allow detecting these levels, help to understand the defect formation kinetics on the microscopic level and open the door to defect engineering approaches to mitigate the acceptor removal effect. Latest RD50 results in this research field are reviewed.

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