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Contributions of Electrons and Holes to Total Collected Charge in Heavily Irradiated Si Pad and Strip/Pixel Detectors: A Comparison Simulation Study

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A simplified approach to compare quantitatively the contributions of electrons and holes to the total collected charge in heavily irradiated Si pad detectors and strip/pixel detectors has been developed in this study. By applying a step function to approximate the weighting field and a step function to approximate the linear- and/or double junction- electric field, in the detector, one can obtain analytical solutions of total collected charge and contributions from electrons and hole for irradiated Si detectors with various electric field and weighting field profiles combinations. Although the results do not exactly replicate the situation in a real detector, they qualitatively and quantitatively explain the contributions of electrons and holes in various detectors with different segmentation- and field-profiles.

Summary

A simple model has been developed utilizing step functions for both the weighting field and electric field, to calculate the contributions of electrons and holes to the total collected charge by MIP in strip- (or pixel) and pad- detectors at various radiation fluences. With this model, I obtained analytical solutions for the collected charge, together with much simplified forms for approximating various special situations, thereby gaining much better insight on the underling physics of charge collection in strip/pixel and pad detectors, especially at high fluences.
1. At low radiation fluences (< 2x1015 neq/cm2), the contribution of electron drift (for n+ collection electrodes; holes for p+ collection electrodes) dominates the total collected charge in a segmented detector, especially for ones with small pitches (P«d). For partially depleted detectors, the total collected charge in segmented detectors is zero provided that the junction is on the opposite side to the collection electrodes (Strip-Front-Junction-Back (SFJB)). In all other cases (segmented detectors: SFJF (Strip-Front-Junction-Front); pad detectors: PFJF (Pad-Front-Junction-Front), and PFJB), the total collected charge is proportional to the detector's depletion depth w (L (JF) or d-L (JB) in this paper): . For fully depleted detectors, the total collected charge is proportional to the detector's thickness d: . The relative loss in charge due to trapping in partially depleted pad detectors is or , where are the carrier drift velocities and the trapping time. 2 At high radiation fluences (> 4x1015 neq/cm2), the contribution of hole drift (for n+ collection electrodes; electrons for p+ collection electrodes) to the total collected charge in segmented detector increases to the same level of that of electrons because the charge-collection distances of both carriers are less than the pitch P. At extremely high fluences, about 1x1016 neq/cm2 (the maximum SLHC fluence), the total collected charge in any detector (pad and segmented detectors) is independent of both the detector's thickness and depletion depth: it exhibits a little dependence for bias voltage V > 1000 volts. For pad and segmented detectors, this takes the analytical form of , and it is around 2000 to 3000 es, where are the charge collection distances for electrons and holes.
3 The total collected charge in a segmented (strip or pixel detector) Si detector is dominated by carriers the collecting electrodes (strips or pixels) collect (in our cases, electrons for n+ collecting electrodes) at low fluences. However, at high fluences, the contribution by the other carriers will increase and becomes comparable, especially at the SLHC fluence of 1x1016 neq/cm2, as shown in Fig. 1a). In other words, for electron collecting n+ electrodes in typical n on n and n on p detector configurations, although the electron contribution is the main part of total collected charge, the contribution by holes at very high fluence can be significant as well.
4 The best detector configuration is to have the detector junction (high electric field) on the same side of the collecting electrodes (Fig. 1a), as otherwise the total collected charge can be significantly reduced after irradiation Fig. 1b), and may be diminished in a partial depletion condition.

a) SFJF b) SFJB

Fig. 1 Collected charges for a strip or pixel detector with a) junction on the strip side (SFJF), and, b) junction on the backside (SFJB). The high-weighting field is 100 times more than the low one (⊠ = 0.01), and the high-electric field is 30 times more than the low one (⊠ = 0.03 for JF, and 33.33 for JB).

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