Charge collection measurements with p-type Magnetic Czochralski Silicon single pad detectors

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Abstract

The charge collected from beta source particles in single pad detectors produced on p-type Magnetic Czochralski (MCz) silicon wafers has been measured before and after irradiation with 26 MeV protons. After a 1MeV neutron equivalent fluence of $1x10^{15}$ cm^{-2} the collected charge is reduced to 77% at bias voltages below 900 V. This result is compared with previous results from charge collection measurements.

Keywords: Radiation damage; Semiconductor detectors; Silicon particle detectors, Defect engineering; Super-LHC.

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61.82.Fk (Radiation effect on semiconductors)
29.40.Gx (Tracking and position-sensitive detectors)

1. Introduction

In the ever increasing need for radiation-hard tracking detectors in forthcoming elementary particle physics experiments, silicon is regarded to be the best choice as sensor material because of its unsurpassed material quality, mature technology and low cost for mass production [1]. However, in future applications, as in the inner tracking systems of the experiments to be installed at the LHC (Large Hadron Collider at CERN), the extremely intense hadron fluxes pose an unprecedented challenge to their operability. Recently, a luminosity upgrade to 10^{35} $cm^{-2}s^{-1}$ has been proposed (SuperLHC). To exploit the physics potential of the upgraded LHC, an efficient tracking down to a few centimetres from the interaction point will be required, where fast hadron fluences above 10^{16} cm^{-2} will be reached after five years operation [2]. The CERN-RD50 project ”Development of Radiation Hard Semiconductor Devices for Very High Luminosity Collider” has been formed to explore detector technologies that will allow to operate devices up to, or beyond, this limit [3].

Silicon radiation detectors have so far mainly produced from n-type high resistivity silicon grown by the Float Zone (FZ) technique. The main radiation damage effects are [4,5]: a strong increase of the detector leakage current (due to formation of generation-recombination centres); a change of the space charge concentration, N_{eff} , leading to changes in the depletion voltage (due to the creation of deep acceptor like defects); and a considerable reduction of the collected charge (due to trapping at radiation-induced defects). The generation of acceptor-like defects leads finally to type inversion (changing the space charge sign) and to the formation of a double junction (DJ) at both contacts of the detector. Beyond the inversion fluence the detector must thus be over-depleted to extend the electric field throughout the active detector thickness and maximise the charge collection efficiency.

One of the main strategies to improve the radiation hardness of silicon to charged particle beams is to enrich high resistivity silicon with oxygen [5]. The beneficial effect of oxygen has been so far explained by the hypothesis that oxygen acts as a sink for radiation induced vacancies, through the formation of the vacancy-oxygen (VO) complex, thus reducing the probability of formation of di-vacancy related defects which correspond to energy levels deeper in the gap. With the recently developed Magnetic Czochralski (MCz) growth technology [6] it is possible to produce Si devices which simultaneously are intrinsically highly oxygenated and have suitable high resistivity. Using p-type MCz Si wafers instead of n-type ones, has the further advantage of not encountering type inversion at high fluences. Various batches of n- and p-type MCz Si detectors have been recently manufactured, but yet very little data are available concerning their performance in terms of collected charge after irradiation [7]. This work is focused on the characterization of the charge collection efficiency of single pad diode detectors made on p-type MCz Si wafers after irradiation with 26 MeV protons.

2. Experimental Procedure

Silicon single pad detectors have been processed by IRST, Trento in the frame of the SMART INFN project on 4” p-type 300 μm thick MCz Si wafers manufactured by Okmetic, Finland (CERN RD50 Collaboration procurement) [8]. Full depletion voltages of the diodes under test in this work were in the range 50-250 V depending on the initial resistivity of the wafer and possible thermal donor activation during growth and/or process [9]. Capacitance voltage measurements and charge collection measurements have been carried out before and after irradiation and after various annealing steps at 80°C. Irradiation was performed at the Forschungszentrum Karlsruhe Cyclotron (fluences equivalent to: $4x10^{13}$ - $1x10^{15}$ 1-MeV n/cm^2). In this paper we discuss the behaviour of the charge collection efficiency of the devices as a function of the reverse voltage and fluence, a comparison between capacitance voltage characteristics and charge collection efficiency will be the subject of a forthcoming work [10]. The investigation of the collected charge has been carried out with a ^{90}Sr source and an electronic read-out system with a shaping time of 200ns, before and after irradiation. To reduce the leakage current noise, measurements have been carried out at low temperature (-30°C).

3. Experimental Results

Fig. 1 shows the pulse-height spectrum measured with a p-type MCz Si diode detector irradiated with 26 MeV proton up to the fluence of $1.0x10^{15}$ cm^{-2} (1MeV neutron equivalent = n_{eq}). This measurement is carried out at 775 V and -33 °C. The pulse-height spectrum has been deconvoluted with a Landau curve to determine the most probable pulse height. In Fig. 1, the most probable value of the distribution indicates a charge collection efficiency of about 77% at this fluence (measurement carried out before annealing).

Figure 2 shows the charge collection efficiency (CCE) as a function of the reverse voltage for three single pad detectors irradiated with different fluences. In the inset of fig. 2 we show, as a function of the fluence, the largest most probable pulse height measured in the voltage interval 600-900 V. These values are based on the relative size of the collected charge when compared to the most probable value of 73 e/μm before irradiation. All data are taken after irradiation and before annealing except for the samples irradiated with the lowest fluences ($1.4x10^{14}$ n_{eq}/cm^2 and $2.8x10^{14}$ n_{eq}/cm^2, annealed respectively for 10 min and 90 min at 80 °C). Recent studies of charge collection of p-type Float Zone Silicon after irradiation with high fluences of 24GeV protons have shown that the CCE is not affected by the annealing treatment [11]. In the inset, data are compared with charge collection measured with n-type MCz and FZ Si irradiated with $1x10^{14}$ and $5x10^{14}$ 24 GeV p/cm^2 [12]. The comparison takes into account that a 100% CCE for a 300μm thick silicon detector corresponds to 21900e; fluence are scaled to 1MeV neutron equivalent values considering a hardness factor of 0.62.

4. Conclusions

A set of single pad detectors fabricated with 300 μm thick p-type Magnetic Czochralski silicon have been irradiated with 26 MeV protons up to the 1 MeV neutron equivalent fluence of $1x10^{15}$ cm^{-2}. The charge collection efficiency of these devices has been investigated with a ^{90}Sr source and an electronic read-out system with a shaping time of 200 ns. Measurements have been carried out at -30 °C to keep leakage current noise to acceptable values. We found, for 10^{14}-10^{15} cm^{-2} 1 MeV n-equivalent fluence, a collected charge in the range 21-16 ke^-. This result is very promising and proves that planar detectors based on p-type magnetic Czochralski silicon could be a viable solution for part of the inner tracker of the SuperLHC.

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Figure Captions

Fig. 1 Pulse-height spectra of a p-type MCz Si diode detector irradiated with 26 MeV proton up to the fluence of $1x10^{15}$ n_{eq}/cm^2 (before annealing) measured at 775 V and -33°C. The de-convoluted Landau and Gaussian noise distributions are also shown . The most probable value indicates a charge collection efficiency of about 77%. The electronic read-out is characterised by a shaping time of 200 ns, and the noise is approximately 600 e^-.

Fig. 2 Charge collection vs. applied voltage of a set of p-type MCz Si diodes irradiated with 26MeV proton up to the fluence of $1.0x10^{15}$ n_{eq}/cm^2. In the inset: largest most probable pulse height measured in the voltage interval as a function of the fluence of irradiation for p-type MZ Si, compared with values for n-type MCz and FZ Si given in [12].

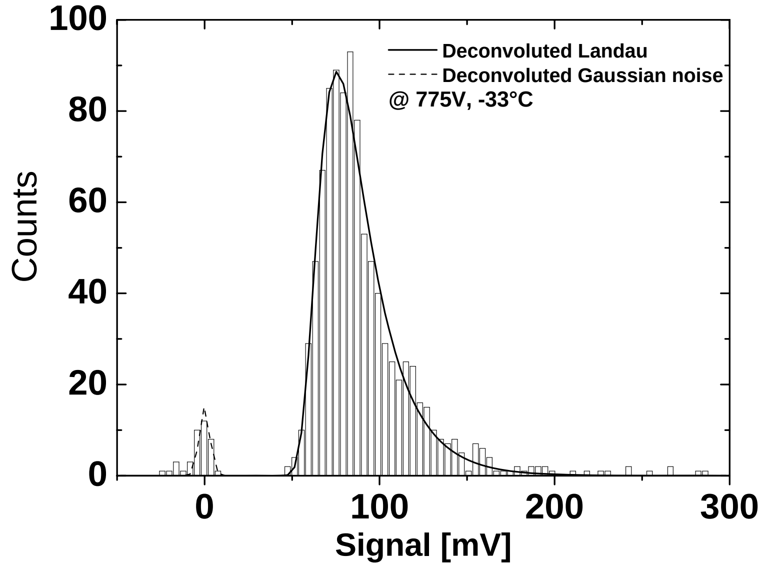

Figure 1

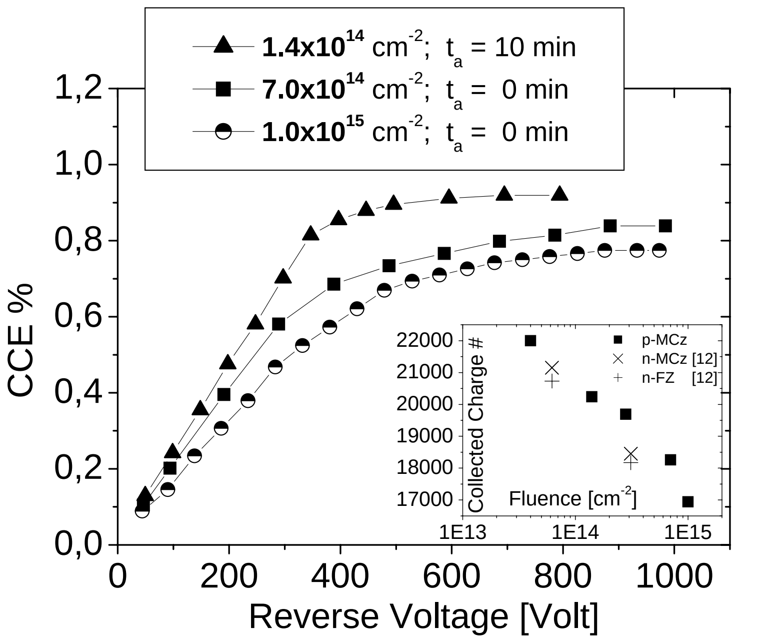

Figure 2