Charge collection measurements in Magnetic Czochralski n- and p-type Si microstrip and diode detectors

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1. Introduction

In the ever increasing application needs for extremely radiation hard silicon detectors to be employed in the forthcoming elementary particle physics experiments, silicon is regarded to be the best choice as sensor material because of its unsurpassed material quality, best developed technology and low cost for mass production. However in future applications, as in the tracking area 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 achieved after five years operation [1]. The CERN-RD50 project ”Development of Radiation Hard Semiconductor Devices for Very High Luminosity Collider” has been set-up to explore detector technologies that will allow to operate devices up to, or beyond, this limit [2].

Radiation detectors had so far mainly produced from n-type high resistivity silicon grown by the Float Zone technique. Main radiation damage effects are: a strong increase of the detector leakage current (due to generation-recombination centres); main changes of the space charge concentration, N_{eff} , (due to the creation of deep acceptor like defects); 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 occurrence of a double junction 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 is the enriching of high resistivity silicon with oxygen [3]. The oxygen beneficial effect has been so far explained by the hypotesis 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 divacancy related defects which correspond to energy levels deeper in the gap. With the recently developed Magnetic Czochralski (MCz) growth technology [4] it is possible to produce Si devices intrinsically highly oxygenated and with suitable high resistivity. P-type MCz Si wafers, with respect to n-type ones, should be characterised by the further advantage of not suffering 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 efficiency in terms of collected charge after irradiation. This work is focused on the characterization of the charge collection efficiency of microstrip and diode detectors made from both n- and p-type MCz Si wafers after irradiation with 26 MeV protons.

2. Experimental Procedure

Silicon microstrip and diode detectors have been processed by IRST, Trento in the frame of the SMART INFN project on 4" n- and p-type 300μm-thick MCz Si wafers manufactured by Okmetic, Finland (CERN RD50 Collaboration procurement) [5]. The investigation has been carried out with a ^{90}Sr source and two different electronic read-out systems with shaping times respectively of 200ns and 2.4μs, before and after irradiation with 26 MeV protons. Irradiation have been performed at the Forschungszentrum Karlsruhe Cyclotron (fluences equivalent to: $1.2\text{x}10^{14}$ - $6\text{x}10^{15}$ 1-MeV n/cm^{2}). To reduce the leakage current noise, measurements have been carried out at low temperature (- 30÷ -10°C). Capacitance-Voltage (CV) measurements have been also performed to determine the full depletion voltage of the devices. CV and charge collection measurements have been carried out before and after various annealing steps at 60 or 80°C.

3. Experimental Results

A. *Diode detectors*

MCz Si diode detectors have been measured at INFN and University of Florence, Italy. Figure 1 shows the full depletion voltage of a set of p-type MCz Si diode detectors after irradiation at different annealing steps at 80°C. Fig. 2 reports the pulse-height spectra measured with two p-type MCz Si diode detectors (a) non-irradiated at full depletion voltage and (b) irradiated with 26MeV proton up to the fluence of $6.8\text{x}10^{14}$ cm^{-2} (1MeV neutron equivalent). This latter measurement is carried out at 800V and -30°C. The pulse-height spectrum has been de-convoluted with a Landau curve. The most probable value of the distribution indicate a charge collection efficiency of about 85% at this fluence (measurement carried out before annealing). The electronic read-out used here is characterised by a shaping time of 2.4μs.

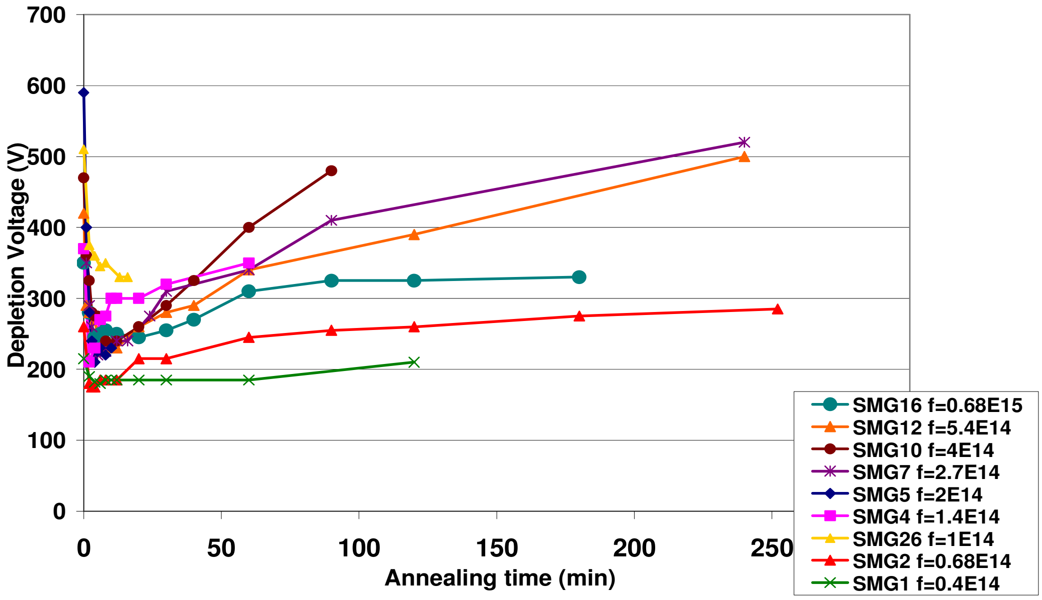

Fig. 1 Full depletion voltage of p-type MCz Si diode detectors irradiated with 26MeV protons at different fluences, as a function of the annealing time (80°C).

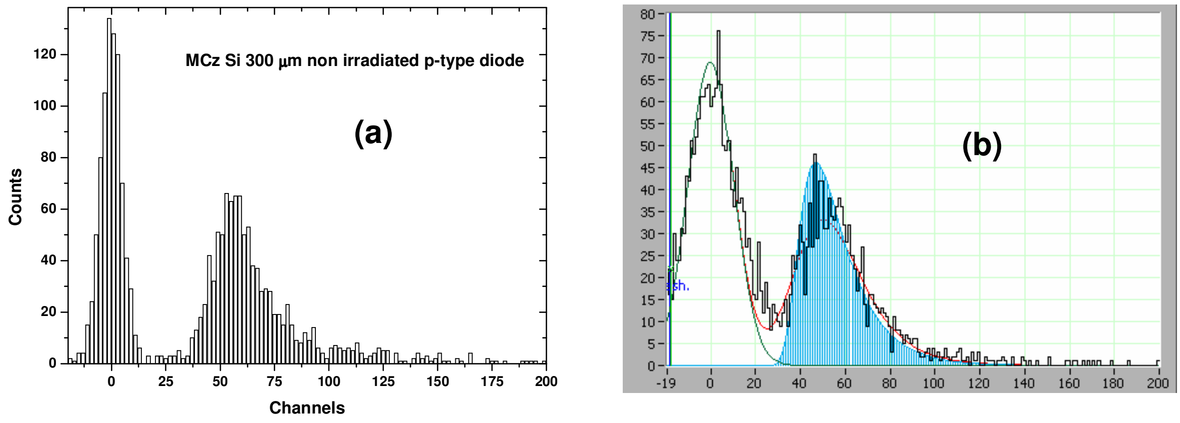

Fig. 2 Pulse-height spectra of p-type MCz Si diode detectors (a) non-irradiated at full depletion voltage and (b) irradiated with 26MeV proton up to the fluence of 6.8x10^{14}cm^{-2} (before annealing) at 800V and -30°C. The diode is SMG16 (see fig.1). The Landau distribution (cyan) and best fit (red line) are also shown: the most probable value indicate a charge collection efficiency of about 85%. Electronic read-out characterised by a shaping time of 2.4μs.

B. Microstrip Detectors

Microstrip detectors, 4.5cm long, 80μm pitch, processed on n-type and p-type MCz Si wafers [5] have been tested at SCIPP UC Santa Cruz, California. Measurements have been carried out at -10°C, with an electronic read-out system with shaping time of 200ns. Capacitance-Voltage have been performed at room temperature and at -10°C. For a quantitative comparison a proper scaling of the test signal frequency with the temperature has been employed [6]. First results are shown in Fig. 3 for a n-MCz Si microstrip detector irradiated with a fluence of 4x10^{14}cm^{-2}. Calibration measurements are in progress to determine the detector charge collection efficiency. The median value of the collected charge is compared with reciprocal Capacitance vs Voltage curves measured at Room T (with 10kHz) and at -10°C (with a lower frequency (LF) to attain the same CV profile), normalised to the collected charge profile at V = 250V. The match to the dependence of the depletion thickness on bias is very good.

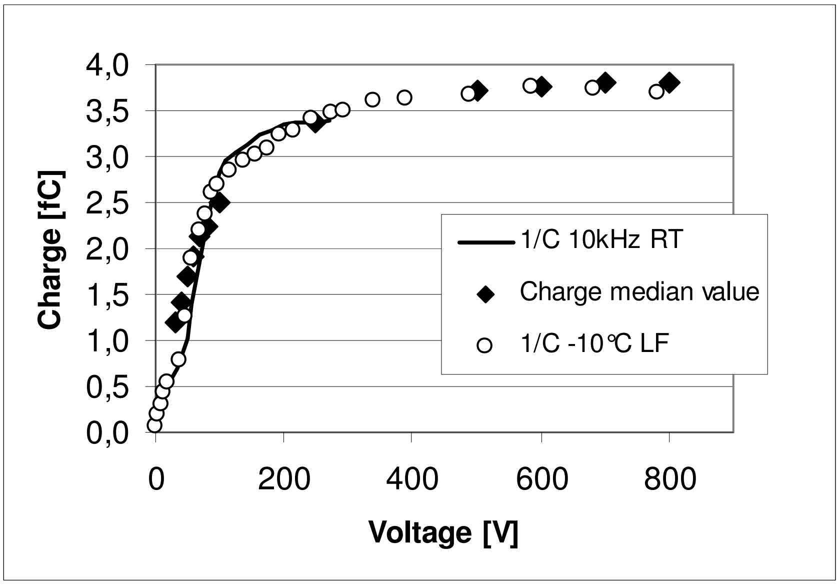

Fig. 3 Median value of the collected charge in an irradiated n-type MCz strip detector as a function of the reverse voltage. Measurements are carried out at -10°C with a 200ns electronic read-out system, after 5min at 60°C.

References

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