Ultimate limits for the radiation hardness of silicon strip detectors for sLHC

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Abstract

The new SuperLHC upgrade will impose severe restrictions on the radiation hardness of silicon detectors since a maximum fluence of 10^{16} particles/cm^2 is foreseen in the innermost region. Microstrip detectors have been fabricated in p-type high resistivity float zone silicon at CNM facilities, been irradiated at the TRIGA reactor in Ljubljana to a fluence of 10^{16} neutrons/cm^2 and characterized at IFIC laboratory. The total collected charge before and after irradiation in the detectors has been measured by ^{90}Sr beta source and by infrared laser illumination. The results show that even after this extreme radiation fluence, p-type substrate detectors collect 3 500 electrons when biased at 800 V, which is enough charge to induce a measurable signal with standard readout electronics. P-type strip detectors could be suitable for the middle and even inner regions of sLHC.

1 Introduction

Over the recent years an upgrade of the LHC, the SuperLHC (sLHC), towards higher luminosities is being discussed [1,2]. The luminosity of the LHC may increase over the years of operation and reach 10^{35}cm^{-2}s^{-1} thus requiring detector upgrades in critical areas.

High fluences of radiation in silicon detectors have two main macroscopic effects. First, there is an increase in acceptor defects, affecting the effective doping. If the substrate is n-type, for a high enough radiation fluence, it is inverted, changing to p-type. Obviously, for p-type substrates there is no inversion. In both cases we observe an increase in the full depletion voltage, and from certain fluence, it is not longer possible to fully deplete the detector bulk.

The second effect is a decrease in carrier lifetime, or conversely an increase in carrier generation-recombination. This gives rise to an increase of reverse current, and also to a decrease in collected charge.

For n-type detectors, after substrate type inversion, the strip junction moves from the junction side to the back side. If we operate the detector in partial depletion, the collected charge has to cross a non-depleted region before reaching the electrodes, and most of it is lost through recombination. By using p-type substrate silicon sensors the inversion is avoided and thus the migration of the junction. In this way, space charge region is always in contact with the strips, and partially depleted detectors can still be operated. With a reverse bias high enough to deplete several tens of microns it is still possible to collect a measurable signal, limited by the trapping increase [3].

The behavior of p-type detectors under proton irradiation at different fluences up to $7.5 \times 10^{15}\mathrm{n/cm^2}$ has already been reported [4–7]. In order to explore the ultimate limits of p-type detectors for their use in SuperLHC we fabricated strips detectors and irradiated them with neutrons at the TRIGA Mark II reactor in Ljubljana up to a fluence of $10^{16}\mathrm{n/cm^2}$. After irradiations total collected charge was measured.

2 Experimental

A technology for the fabrication of p-type (n-type strips on p-type substrate) microstrip silicon radiation detectors using p-spray implant isolation has been developed at CNM-IMB [8,9]. The p-spray isolation has been optimized in order to withstand the irradiation fluences expected in the middle region of the SCT-ATLAS upgrade. The starting material was p-type Float Zone <100> silicon wafers, thickness $285 \pm 15\mu$m and resistivity $\rho = 20$ kΩ·cm.

The mask set was designed within the CERN RD50 Collaboration [10]. On the wafer there are 26 miniature strip detectors, 20 pad detectors, 12 pixel devices, and test structures. The devices used in this work have 130 strips, 80 μm pitch, AC coupled, with poly resistor bias.

The detectors were irradiated with neutrons at the TRIGA Mark II nuclear reactor in Ljubljana, Slovenia. Samples were irradiated with 1 mm thick Cadmium shield which absorbs thermal neutrons but does not influence the fast part of the spectrum. The dosimetry was provided by the facility and is based on activation measurements; fluences are estimated with accuracy better than 10%. Different samples were irradiated at four fluences: 10^{14} cm^{-2}, 10^{15} cm^{-2}, 2×10^{15} cm^{-2}, and 10^{16} cm^{-2}.

Absolute collected charge was measured at IFIC. The measurements in the detectors were performed with all the strips shorted, using a single channel charge amplifier. Two different sources were used: beta source ^{90}Sr, with an energy deposition comparable to minimum ionizing particles (mip) and near infrared pulsed laser, with a wavelength $\lambda = 1\,060$ nm.

Absolute collected charge was measured by ^{90}Sr beta source at -30°C. The amplifier gain was calibrated assuming 80 electron-hole pair creation per micron in non irradiated samples. The detector thickness was measured using a SEM microscope, and it confirmed the nominal value of 285 μm. Therefore, a total charge of 22 800 electrons was assumed. The calibrated gain was within 10% error with respect to the nominal value, as expected.

Measurements using an infrared laser were also performed. The gain of the laser setup was calibrated for each detector using the measurements with the beta source as reference. Integration time was set to 10 minutes to ensure more than 2 000 events for each data point.

3 Results

Results of the measurement of collected charge for the non-irradiated and irradiated samples are shown in figure 1. Data for both beta source and laser are plotted as a function of bias voltage. As can be observed, for non-irradiated and 10^{14} cm^{-2} samples, a plateau, corresponding to full depletion is reached. For the samples irradiated at higher fluences, the plateau is not reached at 1 100 V, which is the maximum bias voltage allowed by our setup. Nevertheless, partially depleted operation is satisfactory.

In figure 2, the total charge collected with the detectors biased at 800 V is plotted for comparison. For the non-irradiated and 10^{14} cm^{-2} samples, the data plotted is the charge collected at the plateau, as they were not biased at 800 V. From this graph it seems that the damage saturates at high radiation fluences.

The minimum S/N ratio to detect signals in real life operation can be estimated to be bigger than 7, and the minimum noise expected in readout electronics about 400 electrons, therefore, the minimum operable detected charge is about 2 800 electrons. From our measurements, the charge collected in the most damaged detector with a reverse bias of 800 V is 3 500 electron, so it is suitable to be used in real experiments.

4 Conclusions

In the framework of the RD50 Collaboration a complete study on neutron irradiated p-type strip detectors has been performed. Even after the highest neutron fluence (equivalent to 10 years of sLHC operation in the middle region) the detectors are still operational and the signal generated at a bias of 800V is 3 500 electrons.

New detectors on alternative substrates (Magnetic CZ and diffusion oxygenated FZ) have been fabricated, are under irradiations and will be characterized in the coming months. Until we have new results with high oxygen concentration p-type substrates, it seems that standard p-type strip detectors could be suitable for the middle and even inner regions of sLHC.

5 Figure captions

Fig. 1: Charge collected vs. reverse bias of p-type strip detectors irradiated with neutrons. Open circles are beta source measurements, solid line and circles are laser measurements.

Fig. 2: Charge collected vs. reverse bias of p-type strip detector biased at 800V for different neutron irradiation fluences.

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