First results on charge collection efficiency of heavily irradiated microstrip sensors fabricated on oxygenated p-type silicon

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Abstract

Heavy hadron irradiation leads to the *type inversion* of n-type silicon detectors. After type inversion, the charge collected at low bias voltages by silicon microstrip detectors is higher when read out from the n-side compared to p-side read out. The n-side read out has been successfully used in combination with oxygen enriched n-type silicon substrate to maximise the radiation hardness of microstrip detectors. Alternatively, the n-side read out can be implemented on p-type substrates reducing the complexity of fabrication. Miniature silicon microstrip detectors made on standard and oxygen enriched p-type substrate have been produced. The charge collection properties of such detectors with and without oxygenation are here compared for the first time after severe charged hadron irradiation.

Silicon microstrip detectors, radiation hardness, charge collection.

1. Introduction

After the type-inversion induced by hadron irradiation on silicon detectors made on n-type doped substrates, the charge collection of n-side read-out (n-in-n) microstrip detectors is superior to the more standard p-strip read-out (n-in-p) [1]. This is due to the migration of the junction (and therefore of the high electric field) on the n^+-implanted side. A similar advantage is found using detectors with n-strip implanted on p-type substrate (n-in-p) [2]. The advantage of this latter compared to the n-in-n is the simpler and cheaper processing. Segmented n-in-p detectors only require one side processing while n-in-n require the double side processing due to the necessity of implanting guard-ring structures on the back-side [3].

On the other hand, the degradation of the electrical properties of n-type silicon after hadron irradiation is reduced by the introduction of interstitial oxygen to a concentration of ~10^{17} cm^{-3} in the silicon crystal by high temperature diffusion from a SiO_2 surface layer. A similar effect might be expected with p-type substrates. The same technique to enhance the oxygen content on p-substrates has been used and the charge collection properties of silicon detectors made with these substrates have been measured after irradiation for the first time.

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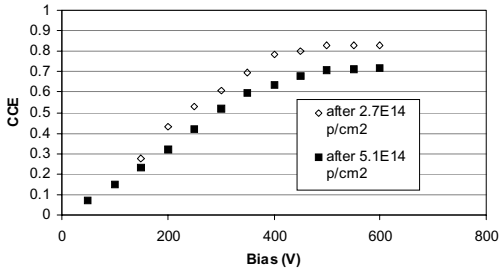

Fig. 1 Charge collection efficiency, normalised to the preirradiation value, of oxygen enriched silicon detectors after 2.7 and 11 10^{14} p cm^{-2}.

2. Experimental results

The oxygen concentration of a few wafers of p-type silicon substrates with an initial resistivity of about 2.5 kΩ cm^{-1} was enhanced to about 10^{17} cm^{-3} throughout the wafers by high temperature diffusion from a SiO_2 layer [4]. Various sets of small (1×1 cm^2) microstrip detectors have been produced by CNM using a mask-set designed by the University of Liverpool using oxygen enriched and standard p-type wafers. The initial full depletion voltage (V_{fd}) was about 350 V.

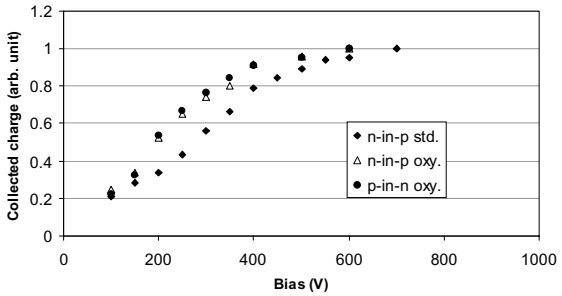

Fig. 2 Charge collection of oxygenated and standard n-in-p detectors after 1.1 10^{15} p cm^{-2}. The collected charge is normalised to the maximum charge collected at 700 volts.

Two sets of oxygenated and standard detectors have been irradiated to 2.7 and 11.5×10^{14} p cm^{-2} in the CERN-PS [5] at room temperature and unbiased. After irradiation they were kept at low temperature.

Figure 1 shows the comparison of the charge collection efficiency curve, normalised to the value before irradiation, of the oxygen enriched detectors after the two irradiation doses. The maximum collected charge is consistent with the value found with similarly irradiated n-bulk detectors [6]. Figure 2 shows the comparison of the charge collection efficiency, normalised to the value collected at 700 V, of an oxygenated and a standard detectors after the higher radiation dose. The relative charge collection at low biases is improved in the oxygen enriched detector.

Figure 3 shows the dependence of the full depletion voltage (V_{fd}) on the proton fluence.

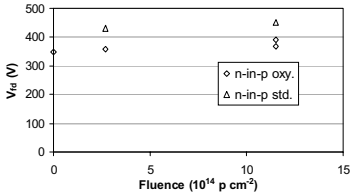

Fig. 3 V_{fd} as a function of the proton fluence

3. Conclusions

Oxygenated p-type substrate has been successfully used for the first time to produce miniature micro-strip detectors. These detectors show good charge collection properties also after heavy irradiation (~70% of the charge is collected after 1.1×10^{15} p cm^{-2}). The oxygenated p-type detectors show a slightly higher charge collection at low bias voltages, after heavy irradiation, compared to standard p-type substrates, due to a reduced value of V_{fd}. They both show a reduced dependence of V_{fd} on the radiation fluence (Fig. 3). This may be due to the low resistivity starting silicon or to a reduced change in the effective space charge in this type of material. Further studies with initial higher resistivity p-type silicon are needed to demonstrate this option for lower cost high radaition tolerant detectors as needed, for example, at an upgraded LHC.

References

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