Heavily irradiated double sided wedge silicon microstrip detector

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Abstract

One double sided trapezoidal microstrip n-type detector has been irradiated with 1 MeV neutrons up to a dose of 7.9 $10^{13}\frac{n}{cm^2}$ at PSAIF (CERN) and has been characterized with laboratory measurements. Biasing resistance and interstrip impedance measurements show that the silicon bulk is inverted to p-type, as expected. After irradiation the full depletion voltage is about 90 V, at which value the total leakage current is 56 $\frac{\mu A}{cm^2}$. The full depletion voltage value obtained from the I-V characteristics agrees with the value calculated with a bulk damage model [2,3].

1 Introduction

One trapezoidal detector prototype ($\approx 3\ cm^2$), designed in our laboratory has been uniformily irradiated at PSAIF (Cern) with 1 MeV neutrons up to a dose of 7.9 $10^{13} n/cm^2$, at room temperature. After irradiation the detector has been stored at -10 °C. The p-side is segmented into 128 p^+ strips, 62 mm long, with 38μm pitch at the smaller trapezium base and 50μm pitch at the larger one. The n-side of the detector has 495 n^+ strips, at 125μm pitch, orthogonal to the p^+ strips of the other side. The strips length varies from 4.8 mm to 6.3 mm. On both sides the implanted strips have integrated AC coupling capacitors and are biased through polysilicon resistors. The n^+ strips are insulated between each other by surrounding p-stop boxes. A detailed description of the detector can be found in [1].

Preprint submitted to Elsevier Preprint *11 October 1997*

2 Measurements and Results

Detector performance before and after irradiation was tested by measuring the total leakage current (I-V characteristics), bias resistances and interstrip impedances during a self annealing time of four months. Fig. 1 shows the comparison between the detector total leakage current measured before (Ipre) and after (Ipost) neutron irradiation. The leakage current is plotted as a function of the square root of the reverse bias voltage: a two-step linear dependence is observed for both curves. The change in the slope occurs when the detector is fully depleted: at about 30 V before irradiation, and at about 90 V after irradiation. The fits of the first 7 and last 9 Ipost data (solid lines) have been used to calculate the full depletion voltage which is in good agreement with the one calculated using a semi-empirical model ([2,3]). The model takes into account both the radiation induced generation of acceptors and the removal of shallow donors inside the detector bulk. According to the model the effective carriers concentration N_{eff} was calculated using the formula:

$$N_{eff} = |N_{D(0)}e^{-cf} - g_c f - g_y f(1 - \frac{1}{1 + g_y f K(T) t})|$$

where f is the neutron fluence; t is the elapsed time from the beginning of the irradiation; $N_{D(0)}$ is the shallow donor concentration before irradiation; c the donor removal rate; g_c the acceptor generation rate; g_y the reverse annealing generation rate; $K(T) = K_0 e^{\frac{-E_a}{K_B T}}$ is the reverse annealing constant at T temperature, with K_B the Boltzmann constant, K_0=0.85 $\frac{cm^3}{s}$ and E_a= 1.16 eV ([3]). The effective impurity concentration N_{eff} is related to the full depletion voltage by the following:

$$V_{dep} = \frac{W^2 q}{2\epsilon\epsilon_0 N_{eff}}$$

with W the depleted region depth, q the elementary charge, ϵ the relative dielectric constant of silicon.

Taking into account four months of self-annealing time at -10 °C, the expected depletion voltage is 96 V.

Type inversion of the bulk from n- to p-type has been clearly observed by measuring the bias resistance, i.e. the resistance between the implant strip and the guard-ring. In fig. 2 the bias resistance measured after irradiation on both sides is shown. While the resistance between the n^+ strips and the guard-ring on the n-side is almost constant with the bias voltage ($\approx 12.5 M\Omega$), on the p-side the resistance is strongly affected by it and reaches a constant value

($\approx 18 M\Omega$) above Vbias = 180 V. The reached values are respectively $\approx 30\%$ and 25% lower than the polysilicon resistor ones measured before irradiation. The p-side resistance behaviour is in agreement with the type inversion in so far as the depletion region grows toward the p-side and the bulk resistance shunting the implant strip and the guard ring increases with the bias voltage. In fig. 2 the measured resistance is still low at Vbias $\approx$ 90 V and reaches its constant value above 180 V. This effect can be explained with the existence of a thin residual conductive layer near the surface, which is removed only at high voltages.

References

[1] E. Catacchini et al., Nuclear Phys. B(Proc. Suppl.), 54B, 245-251 (1997).

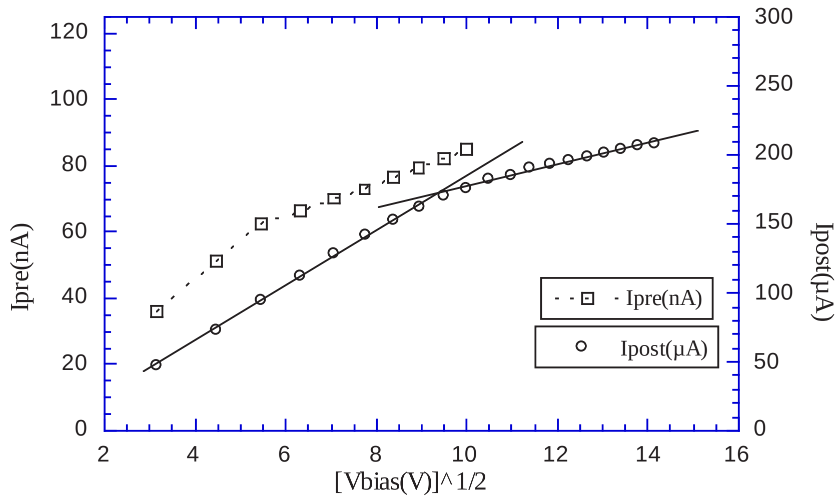
[2] M. Bruzzi et al., NIM A, 388, 345-349(1997).

[3] J.A.J. Matthews et al." *Bulk radiation damage in silicon detectors and implications for ATLAS SCT*", Atlas internal note, INDET-NO-118, 12 Dec. 1995.

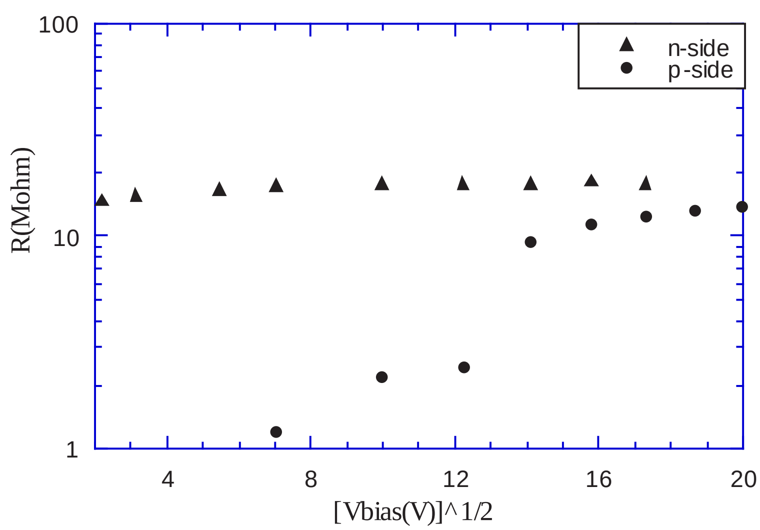
Figure Captions

Fig. 1 Total leakage current before (Ipre) and after (Ipost) neutron irradiation, obtained at 24 °C and at 20 °C respectively. The fit of the data shows that full depletion voltage of the bulk occurs at 90 V after irradiation.

Fig. 2 Bias resistance of a p^+ strip on the p-side (solid circle) and a n^+ strip on the n-side (solid triangle), as a function of the bias voltage. While full depletion voltage of the bulk is 90 V, the shunting resistance effect on the p-side is completely removed only above 180 V.



Ipre(nA)
Ipost(μA)
[Vbias(V)]^1/2
- - ⊡ - Ipre(nA)
○ Ipost(μA)



R(Mohm)
[Vbias(V)]^1/2
n-side
p-side