Planar Edgeless Silicon Detectors for the TOTEM Experiment

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***Abstract*– Recently the first prototype of microstrip edgeless silicon detector for the TOTEM Experiment has been successfully produced and tested. This detector is fabricated with standard planar technology, reach sensitivity 50 µm from the cut edge and can operate with high bias at room temperature. These almost edgeless detectors employ a newly conceived terminating structure, which, although being reduced with respect to the conventional ones, still controls the electric field at the device periphery and prevents leakage current breakdown for high bias.**

Detectors with the new terminating structure are being produced now and will be installed at LHC in the Roman Pots, a special beam insertion, to allow the TOTEM experiment to detect leading protons at 10 σ from the beam. This paper will describe this new terminating structure for planar silicon detectors, how it applies to big size devices and the experimental tests proving their functionality.

1. INTRODUCTION

Radiation silicon detectors fabricated with standard planar technology require terminating structures to reduce electric field maxima at the detector periphery and enhance their breakdown performance. Also, the surface irregularities on the chip cut do not affect the device performance thanks to these terminating structures. They are generally a sequence of floating guardrings surrounding the sensitive part of the device and adding an external dead volume. This ring structure, called “voltage terminating structure”, controls the potential distribution between the detector's sensitive area and the cut edge to have a vanishing potential drop at the chip cut. This volume increases with the number of the rings and for high voltage applications, as it is the case of silicon detectors used in harsh radiation environment, it can be even more than 1 mm wide.

Recently a rising interest towards the reduction of this dead volume has lead different groups to look for new solutions [1], [2]. For the LHC TOTEM experiment [3], [4], which will install silicon detectors in Roman Pots, a special beam insertion, to detect leading protons close to the 10σ envelope of the LHC beam, this reduction is vital. These requirements triggered the development of a new terminating structure that allows detectors fabricated with standard planar technology to reach full sensitivity in less

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than 100 µm from the cut edge and operate with high bias at room temperature [5].

2. Current Terminating Structure

For segmented devices with this new terminating structure called Current Terminating Structure (CTS) the potential applied to bias the device has to be applied also across the cut edges via a guardring that is crossed by the die cut and that is around the whole sample. This external guardring, also called Current Terminating Ring (CTR) collects the current generated at the highly damaged region close to the cut edge avoiding its diffusion into the sensitive volume and is decoupled by the biasing electrode, which can be a guardring as well all internal to the CTR. In this manner the sensitive volume can start closer to the cut edge. To prevent any further diffusion of this edge current into the sensitive volume another implanted ring, the Clean-up Ring can be placed between the CTR and the sensitive volume. The first successful tests of microstrip detectors with this termination structure were made on 1x1 cm^2 test samples which had sensitive strips starting only 50 µm from the edge. The CTS and its biasing scheme are shown in Fig. 1.

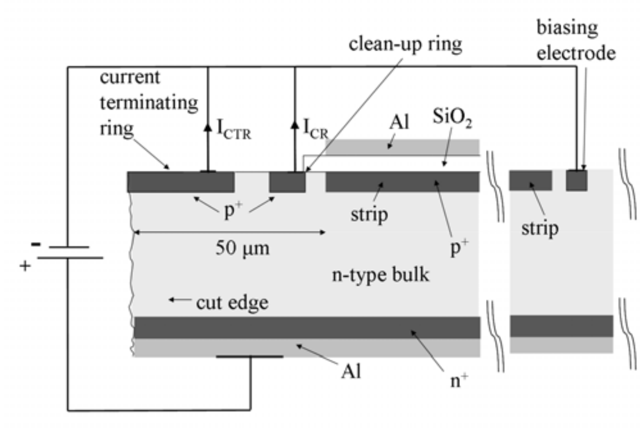

Fig. 1 Cross-section of a silicon detector with CTS in the plane parallel to the strips and its biasing scheme.

For devices with this type of CTS the leakage current in the sensitive volume (I_{BE}) which contributes to parallel noise is not affected by the edge current (I_{CTR} +I_{CR}). These two currents have shown to be completely decoupled. Moreover, for such devices, the charge collection efficiency has shown to rise steeply from the edge of the sensitive volume reaching full efficiency within a few tens of micrometers [5].

The electric potential distribution at the edge of a device with CTS has been modeled taking into account the highly damaged surface at the chip cut, where the irregularities within the first atomic layers could be assimilated to amorphous silicon. The results of this modeling have shown good consistency with respect to the experimental results [6]. The potential distribution calculated with ISE TCAD is shown in Fig. 2 and in Fig. 3.

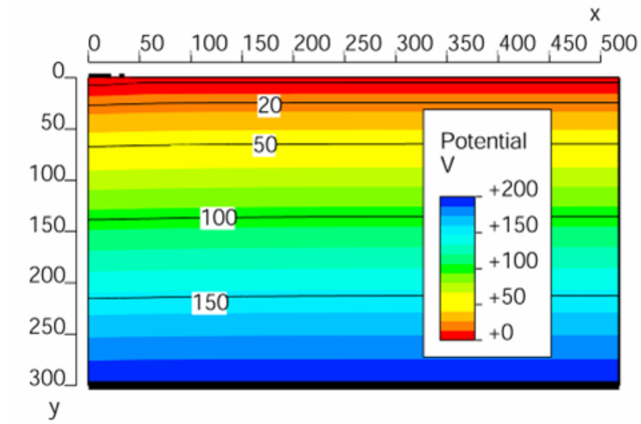

Fig. 2 Potential distribution at the edge of a silicon pad detector with CTS 300 µm thick, the calculation being extended up to 500 µm from the cut edge

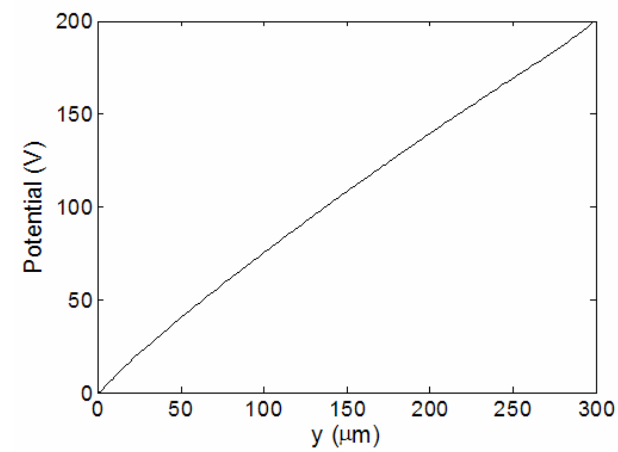

Fig. 3 Electric potential at the cut edge with an almost linear behavior.

As it is shown in Fig. 3, the potential at the cut edge varies almost linearly and shows that the biased cut surface has almost an ohmic behavior.

3. The Si Detector for The Totem Roman Pots

The possibilities offered by the CTS have been considered by the LHC TOTEM experiment and combined with the specific geometrical requirements and granularity for the detectors of the TOTEM Roman Pots [4]. The CTS will be adopted to enable the detection close to the 10 σ of the LHC beam of elastically scattered protons at 147 m and 220 m from the IP5.

Planar Edgeless Silicon Detectors have been developed and produced in a joint effort of the TOTEM group at CERN and the Megaimpulse, a spin-off company from the Ioffe Physico-Technical Institute in St. Petersburg (RUSSIA). These devices are single side AC p^+-n microstrip detectors with 512 strips, with a pitch of 66 µm processed on very high resistivity n-type silicon wafer (>10 kΩ·cm), 300 µm thick. All of them have the CTS as described in Section 2 on one edge, i.e. the edge approaching the beam. A picture of the Planar Edgeless Silicon Detector for the TOTEM Roman Pots and a detail of the CTS are shown in Fig. .

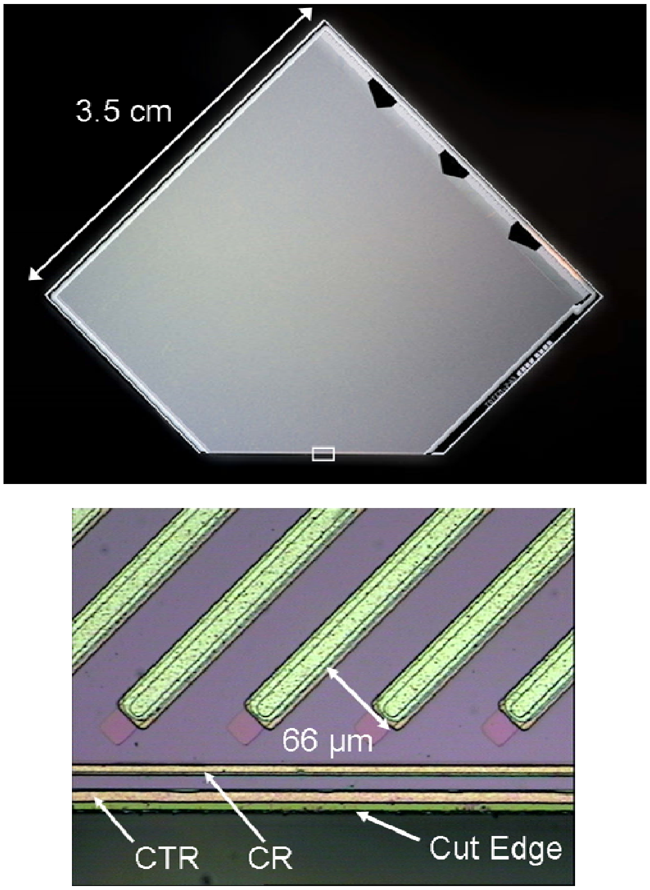

Fig. 4 Picture of a Planar Edgeless Detector with CTS (top). The magnification of a portion of the chip cut region (bottom) shows the details of the CTS.

In these sensors the biasing is made via punch-through with a Biasing Electrode (BE) placed inside the CR and the CTS is integrated into a standard voltage terminating structure on all the sides where the sensitivity to the edge is not required. The strips are at a 45° angle from the edgeless side. Flipping around the vertical axis yields strips reoriented orthogonally.

Electrical Characterisation

The TOTEM edgeless detector samples were tested in a probe station and the current of the detector under reverse bias was measured with a Keithley Picoammeter 6517.

For the detector polarized according to the bias scheme shown in Section 2, the typical values of currents measured at the CTR and the CR, $I_{CTR}+I_{CR}$, are compared to the current measured at the BE , I_{BE}, and shown in Fig. 5.

There is a difference of four orders of magnitude between the current at the BE flowing through the sensitive volume of the detector and the one flowing through CR and CTR. This evidences that virtually all the leakage current generated at the edge surface is collected by the CTR and the CR and does not flow through the sensitive volume where it would make detector operation impossible. The low current flowing into the BE confirms the validity of the current termination approach.

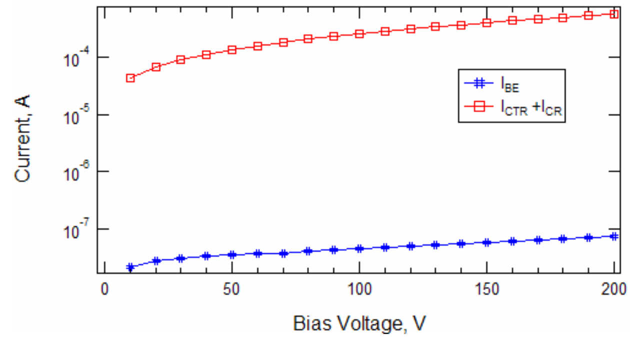

Fig. 5 Current vs. voltage characteristics measured at room temperature flowing through the biasing electrode (I_{BE}) and across the detector's edge ($I_{CTS}+I_{CR}$).

4. Radiation Studies

Silicon detectors with CTS have displayed good performance and stability in several test beams [5], [7]. Nevertheless their radiation hardness is still under study. In principle, if the edge current ($I_{CTS}+I_{CR}$) and the sensitive volume current (I_{BE}), whose dominant component is the bulk current, remain decoupled also after high irradiation there are no reasons to believe that the performance after high irradiation of these devices would degrade faster than the one with standard voltage terminating structures designed for harsh radiation environments.

This has been proven recently. A set of test samples with CTS of the type described in [5] have been irradiated at the neutron reactor TRIGA in Ljubljana at different fluences, up to 10^{14} $_{1MeV}$n cm^{-2}. The bulk current shows an increment which is linear with the fluence and a damage factor α of $5x10^{-17}$ Acm^{-1}, in agreement with experimental results found with similar devices but employing standard voltage terminating structures [8]. Moreover, the current from the edge remains almost the same. The edge current at the fixed bias voltage of 200 V and the sensitive volume current at full depletion for different fluences are shown respectively in Fig. 6 and Fig. 7.

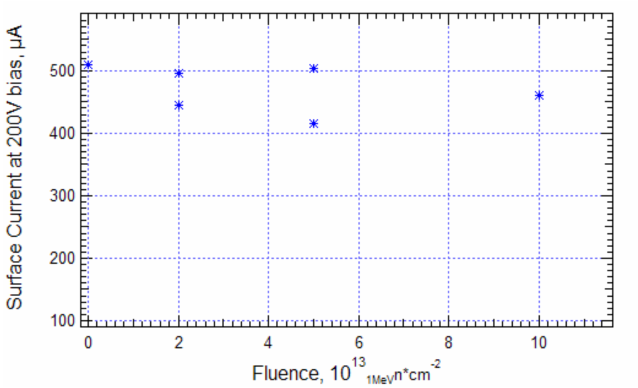

Fig. 6 Edge current of a test size edgeless detector biased at 200V, at different fluences.

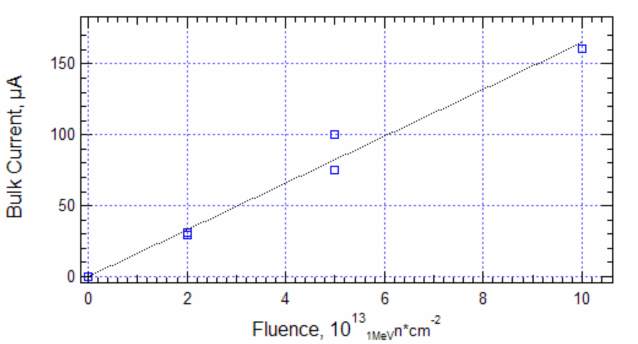

Fig. 7 Sensitive volume current for edgeless detectors with CTS at different fluences (markers) and its linear fit (dotted line).

5. Conclusions

The Current Terminating Structure has shown to be a very effective way to make edgeless silicon detectors fabricated with planar technology. Furthermore, there are strong hints that their good performance of sensitivity at their physical edge would hold also at high fluences. The mass production of these devices is ongoing now and their installation in the Roman Pot is foreseen in the summer of 2007 to allow the TOTEM Experiment to detect protons elastically scattered at very small angles from the beginning of LHC.

6. Acknowledgements

K. Eggert, E. Radermacher and all other members of the TOTEM group at CERN are greatly acknowledged for their encouragement and support in pursuing this work. We are also grateful to M. Zavrtanik for taking care of the irradiations at the TRIGA reactor and to the TOSTER project (INTAS Ref. Nr. 05-103-7533) dedicated to studies on CTS detectors.

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