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# Status of silicon edgeless detector developments for close-to-beam experiments

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ABSTRACT

The development of silicon edgeless strip detectors was stimulated by the needs of the TOTEM experiment at CERN to detect protons scattered at very small angles (i.e. close-to-beam applications). The setup of the TOTEM Roman Pots demands a dead region at the detector-sensitive diced side (or cut) that should be less than 50 μm.

During the design phase, two approaches were proposed: detectors with current terminating structure (the CTS approach) and 3D active edge detectors. The planar detectors with a CTS were developed by a collaboration of TOTEM and Russian institutions. The key idea of the CTS approach is the ability to control the current distribution at the sensitive cut by incorporating special rings along the detector edge. In the study, the approach using edgeless detectors with a CTS is overviewed in its physical background and its potential for future applications in close-to-beam experiments, including the requirements for the radiation hardness of the detector. The current experimental results on edgeless p-on-n detectors obtained in the framework of the TOTEM experiment and the INTAS-CERN project are also presented. This approach, using an edgeless p-on-n detector with a CTS design, was successfully realized in the final size TOTEM detectors and allowed achieving a total non-sensitive width of about 50 μm.



## 1. Introduction

The development of silicon edgeless strip detectors was stimulated by the CERN TOTEM experiment's need to detect protons scattered at very small angles (i.e. close-to-beam applications) [1]. The hardware of the TOTEM experiment restricts the dead region width at the detector sensitive side to less than 50 μm. Furthermore, the placement of the Roman pots requires the detectors to be able to withstand an equivalent neutron fluence $F_{eq}$ up to $1\times10^{15}\,\mathrm{cm}^{-2}$.

The damaged surface of the cut edges of the detector chip leads to an increased current. The primary problem in detector operation is to eliminate the influence of this current on the overall detector current and the signal-to-noise ratio. The first attempt to process Si edgeless detectors was described in Ref. [2], in which the dicing was done directly across the p–n junction of a pad detector. This led to an enhanced detector current, in which partial recovery occurred within 1 or 2 days. Nevertheless, the detector current remained prohibitively high and very sensitive to the ambient conditions.

To meet the requirements of the TOTEM experiment, two novel approaches have been proposed: constructing detectors with a diced (or cut) side and a current terminating structure (CTS approach) [3], and making full 3D active edge detectors [4]. The planar CTS detectors were developed by a collaboration of TOTEM and the team of Russian institutions—Ioffe Physico-Technical Institute, St. Petersburg and Research Institute of Material Science and Technology, Zelenograd. The key idea for this approach is to control the current distribution at the sensitive cut by incorporating two rings at the detector edge supplied by fixed potentials. This innovative design was successfully realized with p-on-n edgeless detectors processed in Russia using the standard planar technology, and a maximum non-sensitive width of about 60 μm was achieved [5].

The 3D approach exploited the 3D technology for extending the sensitive region of the detector towards the chip cut. Using the plasma etching techniques, the approach makes it possible to have an extremely small dead region at the cut. The major drawback in the performance of the detector is a low operational voltage, which is restricted by the technological aspects and limitations on the device area. The main studies of these detectors [4] were focused on the known advantages of 3D design for improving radiation hardness and are beyond the subject of this work.

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In the current investigation, the approach using Si edgeless detectors with a CTS will be overviewed with respect to its physical background and potential for future application in close-to-beam experiments including the requirements for the detector radiation hardness. Recent experimental results on edgeless p-on-n detectors will be also presented.

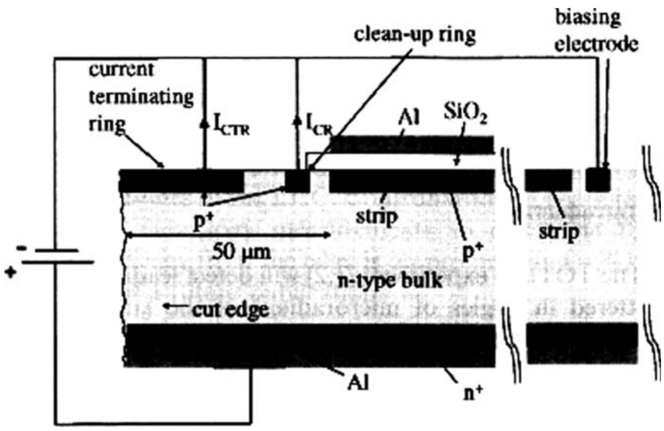


**Fig. 1.** Schematic cross-section of edgeless detector with CTS.

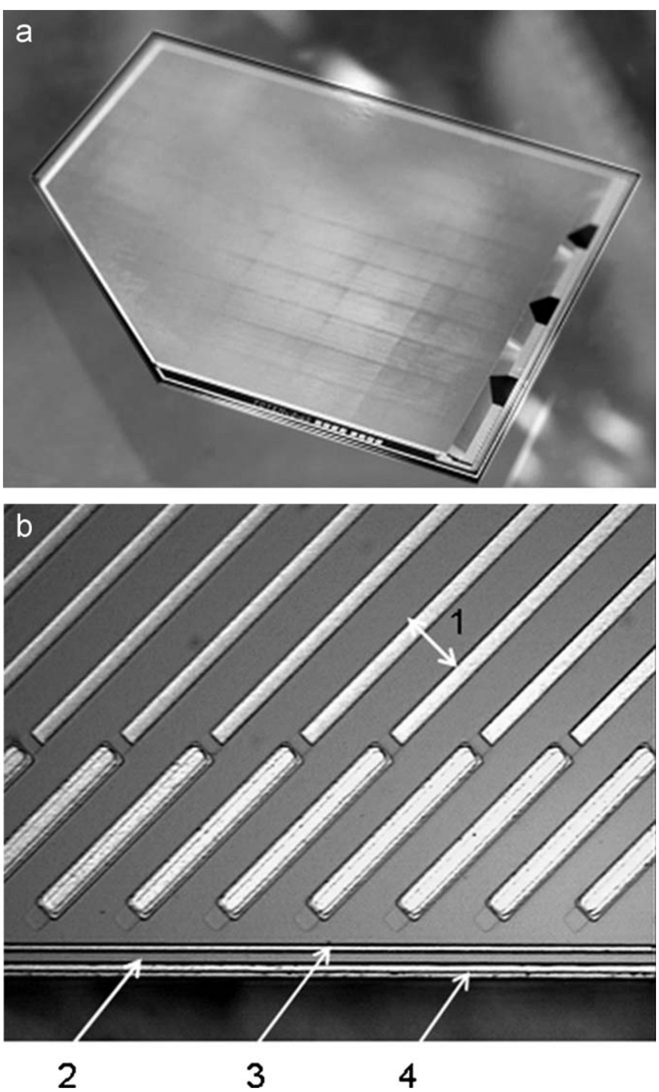


**Fig. 2.** Photos of TOTEM final size edgeless microstrip detector: (a) with an area of 8 cm$^2$ and a fragment in the vicinity of the cut edge (b). 1–pitch, 2–CTR, 3–CR, 4–cut edge.

## 2. Design and electrical characteristics of edgeless strip Si detector with CTS

The basic idea of the CTR approach is the reduction of the insensitive region by applying the main fraction of the detector bias voltage across the chip cut through the outer ring of the CTS. A schematic design of a p-on-n edgeless strip Si detector with CTS (Fig. 1) is presented in detail in Refs. [3,5]. The detector is processed on the n-type float zone Si with a resistivity $\rho$ of more than 10 k$\Omega$ cm and a wafer thickness $d$ of 300 µm. The strips are biased via the punch-through mechanism between the biasing electrode and the strips. The standard voltage terminating structure (VTS) contains several rings. The CTS consists of two rings biased at the same voltage: an outer current terminating ring (CTR), which collects the major fraction of the edge current, and a clean-up ring (CR). These rings collect the total edge current, thus isolating the cut from the sensitive bulk. This behavior was confirmed by the *I–V* characteristics of TOTEM detectors with an area of 8 cm$^2$: at $-12\,^\circ$C the CTR current was in the range $10^{-4}$–$10^{-3}$ A, whereas the detector leakage current was the tens of nA [5].

Further development of edgeless detectors focused on a radiation hard version; a consortium of six institutions have joined their efforts within the framework of INTAS-CERN project, which started in 2006. For the study, small test samples and p-on-n strip detectors of area 8 cm$^2$ with the TOTEM design (Fig. 2) were processed on the same wafers with a resistivity of 20 k$\Omega$ cm. Statistics of the total strip current over 204 detectors at $V = 100$ V is shown in Fig. 3. The total current and the corresponding current density are 120 nA and 15 nA/cm$^2$, respectively; this gives a single strip current of 20 pA.

## 3. Models of potential and electric field distribution in edgeless p-on-n detectors

Edgeless detectors represent a structure in which the potential and electric field near the cut edge have two-dimensional distributions. The detector cross-section is depicted in Fig. 4a in which, for simplicity, strips and CTR are substituted for a simple pad structure that does not affect the considerations below. The potential and electric field in the detector bulk are $V_{xb}$ and $E_{xb}$, respectively. These values are defined by the effective space

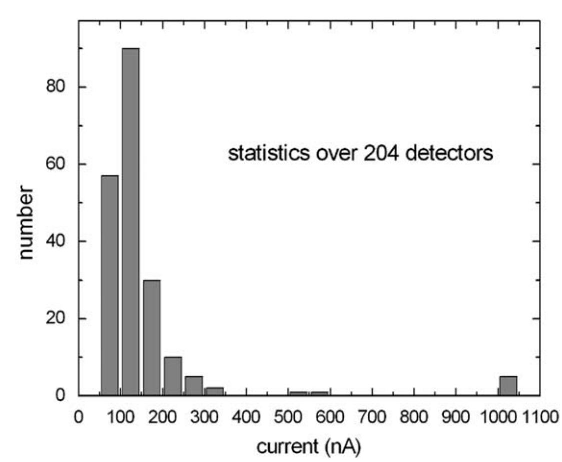


**Fig. 3.** Statistics of the total current of the strips of final size edgeless strip p-on-n detectors with the area of 8 cm$^2$.