

Ref: TOTEM NOTE 07-04

Technical Note

HV Test of the CTS Edgeless Silicon Detector in Vacuum and Close to a Grounded Plate

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24 May 2007

1. Introduction

The TOTEM Roman Pot Silicon sensors will be operated in vacuum to minimise the mechanical stress of the thin metal window which separates the detector package from the ultra high vacuum of the beam. To approach the beam axis as close as possible the detectors will be mounted with their edge at a distance of the order 100 - 200 μm from the thin metal window. As the detectors will be run in overdepletion mode to allow the full charge collection within the shaping time of the readout electronics, there will be a potential drop of more than 100V across their edge. Moreover this potential drop might need to be further increased with the accumulated radiation dose.

The main goals of the tests described in this note are:

- Characterisation of the voltage-current characteristics when the detector edge is in the direct vicinity of a grounded metal plate which simulates the above mentioned vacuum window;
- Demonstration of the detector operation in vacuum at different pressures.

2. Experimental Setup

A Si-sensor of the pre-production series was glued on a dummy kapton PCB which was laminated on a ceramic substrate plate. The PCB contained a wide metallisation zone on which the Si-sensor was glued and through which the bias was supplied to the back side of the sensor (see Fig. 1). The standard biasing of these edgeless detectors was applied with both biasing ring and current terminating structure wire bonded to ground.

A mechanical set-up was designed and built, which allows positioning a metal (stainless steel) block by means of a micrometric screw at a well controlled distance from the cut edge of the Si-sensor. The set-up guarantees that the gap between the sensor and the block is parallel.

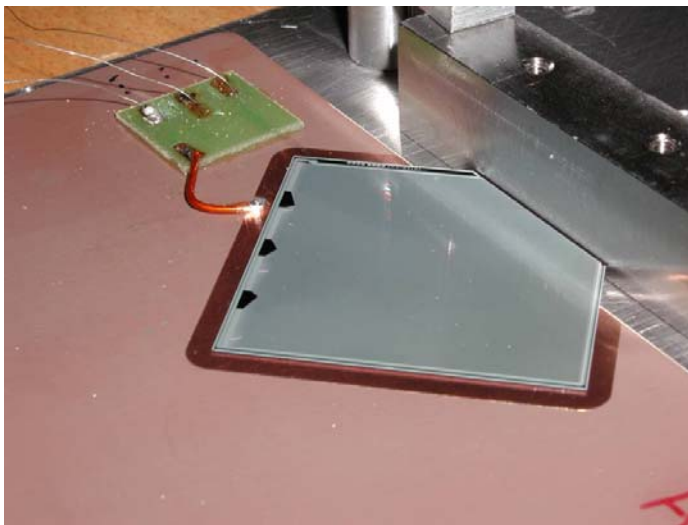


Fig. 1: Photo of the Silicon sensor mounted on the PCB. On the right side one can see the metal block which simulates the thin vacuum window of a Roman Pot.

The set-up was mounted in a high vacuum plant in the PH/DT2 Thin Film and Glass lab, which is normally used for vacuum evaporations (*Fig. 2*). The plant is equipped with a rotary roughing pump plus a turbo molecular pump and reaches end pressures in the 10^{-5} mbar range. The pressure was measured by Pirani ($>10^{-1}$ mbar) and Penning ($<10^{-1}$ mbar) gauges. Pressure values above a few mbar could also be measured with a membrane manometer. No specific effort was made to calibrate the gauges. The uncertainty in the pressure measurement is estimated to be 50%.

The plant was equipped with a needle valve such that nitrogen could be introduced into the vacuum tank at a controlled rate. The equilibrium of pumping speed and N_2 introduction rate allowed to roughly stabilize the pressure at a desired value.



Fig. 2: Photo of the vacuum plant.

The vacuum tank was equipped with three BNC vacuum feedthroughs with common ground. Detector bias was supplied by means of a Keithley source meter (type 2410-c) which also measured the total current. For the measurement of the bulk current a Keithley picoampere meter (type 487) was used. The electrical scheme for the measurements is shown in Fig. 3.

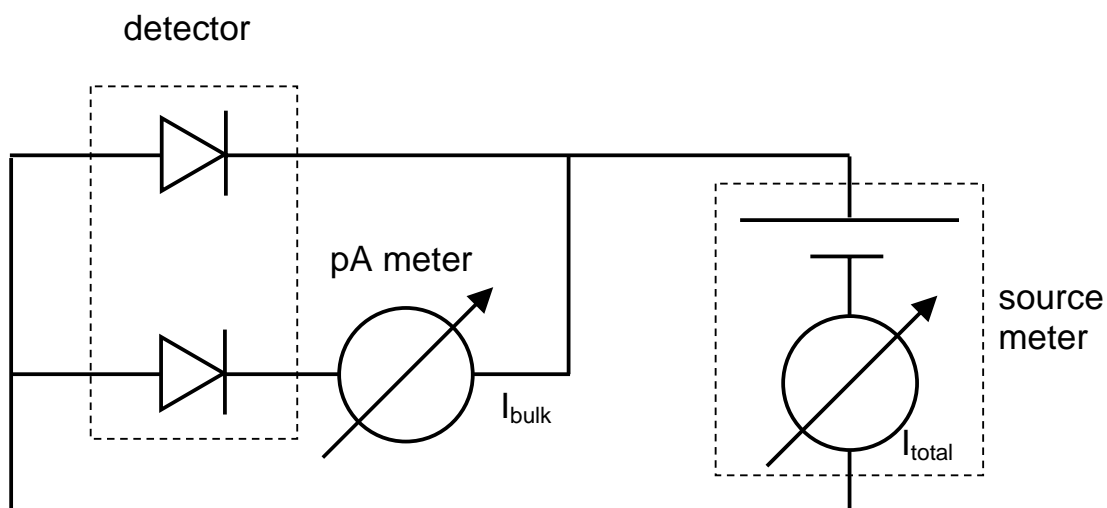


Fig. 3: Electrical circuit to measure total and bulk currents. The detector is represented as two parallel reverse biased diodes.

On the body of the vacuum plant an optical window would allow a partial visual inspection of the PCB with the sensor, once it was placed inside the plant. This window has been kept shut during the electrical tests, to avoid charge injection in the detector from external light.

3. HV performance for different pressure conditions

With the detector positioned at a defined distance from the grounded metal plate, the mechanical set-up was placed in the light-tight vacuum plant and the first check of electrical stability was made at atmospheric pressure. The detector was biased up to 500V and the current flowing across the cut edge and the current flowing through the sensitive part of the sensor were recorded. If there would be an important current flowing between the detector's cut edge and the grounded electrode this would cause a change of the current flowing through the cut edge which, by modifying the electrical boundary conditions of the detectors, would reflect in a change of the current flowing through the sensitive volume.

Then the detector was unbiased and the vacuum plant was evacuated. As the pressure reached the 10^{-3} mbar region the current-voltage characteristics of the detectors was checked again up to 500V. At these two pressure conditions (atmospheric and high vacuum) the detector current showed the normal expected behaviour, with the sensitive volume current several orders of magnitude lower than the cut edge current. The presence of a grounded metal block close to the detector edge has no noticeable impact on the I-V characteristics.

With the detector left biased at this potential, the pressure was smoothly increased by means of the needle valve and the electrical stability was monitored in the different pressure regions.

This exercise was repeated with the detector's edge positioned at different distances from the grounded electrode, starting from 500 μm down to 100 μm .

The resultant electrical stability seemed not to depend on the particular distance in the defined range. However, the pressure had a strong influence on the observed behaviour. As the region around 1mbar was reached, an overflow of the currents was recorded. This overflow would reduce only if the pressure rose higher than 10 mbar.

To better understand the limits of the detector operation in the 1mbar region, a voltage scan was made at this pressure. Independently of the detector edge-electrode distance, the detector behaved normally up to 400V and then lost its electrical stability.

Fig. 4 and Fig. 5, respectively, show the voltage scan for the current flowing across the edge and the current flowing through the sensitive volume in the three different pressure condition for a distance detector edge- electrode of 200 μm

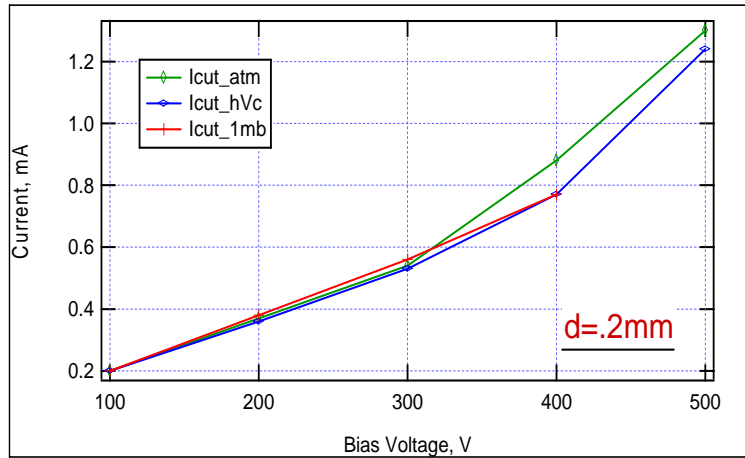


Fig. 4 Edge current-voltage characteristics in case of atmospheric pressure (I_{cut_atm}), high vacuum (I_{cut_hVc}) and at about 1mbar (I_{cut_1mb}) for the detector with the edge 0.2mm away from the grounded electrode.

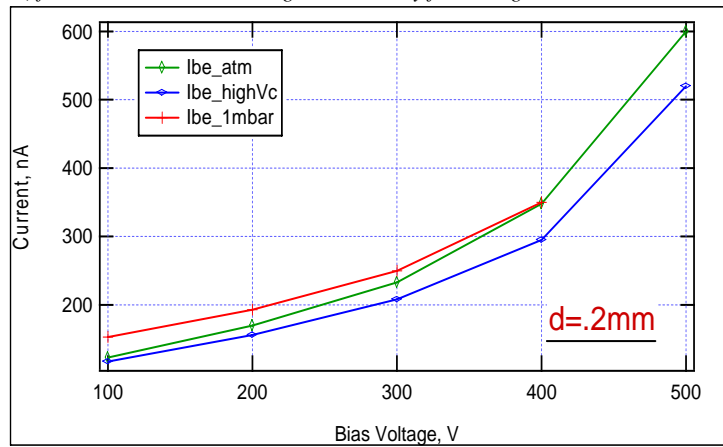


Fig. 5 Sensitive volume current-voltage characteristics in case of atmospheric pressure (I_{be_atm}), high vacuum (I_{be_highVc}) and at about 1mbar (I_{be_1mbar}) for the detector with the edge 0.2mm away from the grounded electrode.

In Fig. 6 and Fig. 7 the voltage scans are repeated for a distance of 100 μm .

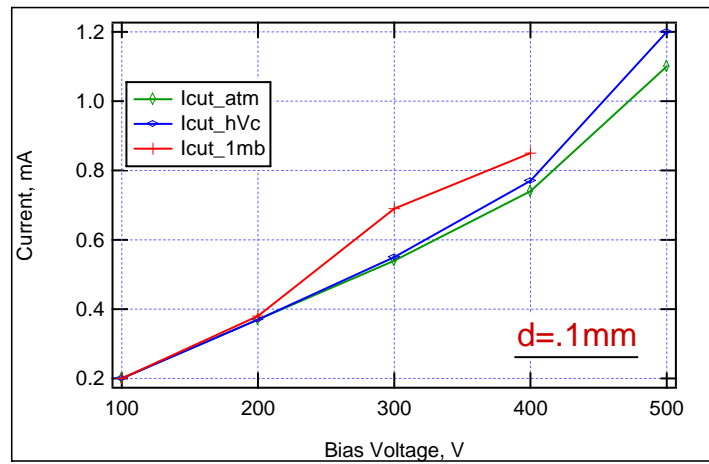


Fig. 6 Edge current-voltage characteristics in case of atmospheric pressure (I_{cut_atm}), high vacuum (I_{cut_hVc}) and at about 1mbar (I_{cut_1mb}) for the detector with the edge 0.1mm away from the grounded electrode.

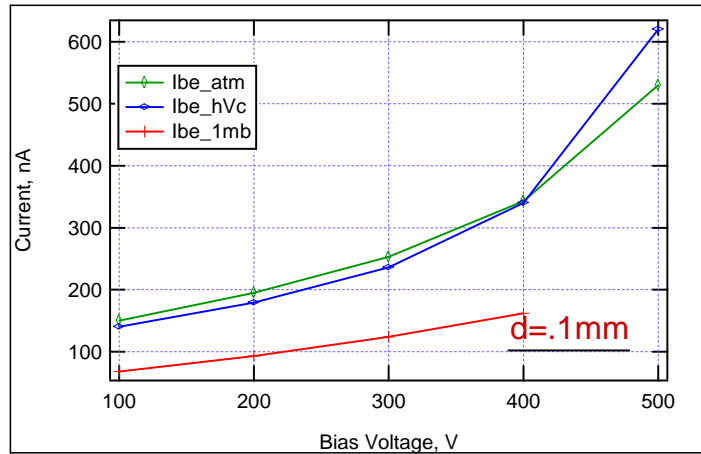


Fig. 7 Sensitive volume current-voltage characteristics in case of atmospheric pressure (I_{be_atm}), high vacuum (I_{be_hVc}) and at about 1mbar (I_{be_1mb}) for the detector with the edge 0.1mm away from the grounded electrode.

With the currents highly increasing over the set compliance limit of the Keithley 487 and 2410 at 400V, it was noticed that to regain a stable system, lowering the bias by few tens of Volts was not sufficient and only a pressure change of almost an order of magnitude would return the detector to operate in a stable manner.

4. Instability in the 1mbar region

Further investigations have been made within the pressure region around 1 mbar. In particular it was investigated what was the maximum bias voltage that one could apply to the detector before running into high current conditions. The test was made for a pressure range between 0.6 and 3 mbar. Outside this range, the system ran in a stable mode with bias voltages up to 500V

As it is shown in Fig. 8, the detector operated safely at 1 mbar up to 450V volts. For higher pressures (2 and 3 mbar) the maximum applicable voltage dropped to 400 and 350 V, respectively.

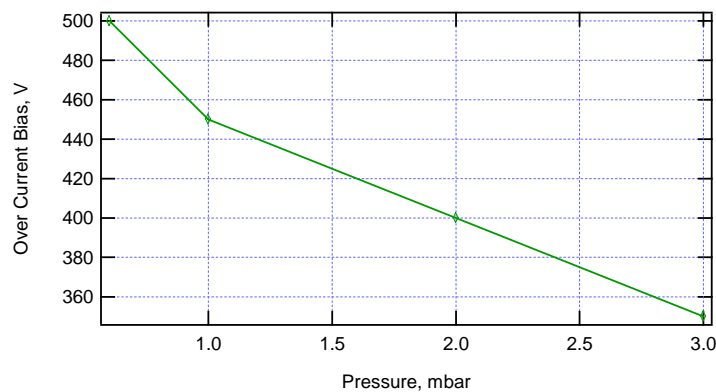


Fig. 8 Maximum bias to apply before the current registered in the ampermetres overflows at the different pressures.

The sudden rise of the currents occurring beyond this bias was due to the ignition and persistence of a glow discharge inside the volume of the vacuum plant. The glow discharge was observed through the optical window. In Fig. 9 are shown picture of the inside of the vacuum plant taken through the optical window. The discharge was most intense around the thin wires which supplied the detector bias and around the metallisation on the PCB, however also filled the volume up to several centimetres from the detector.

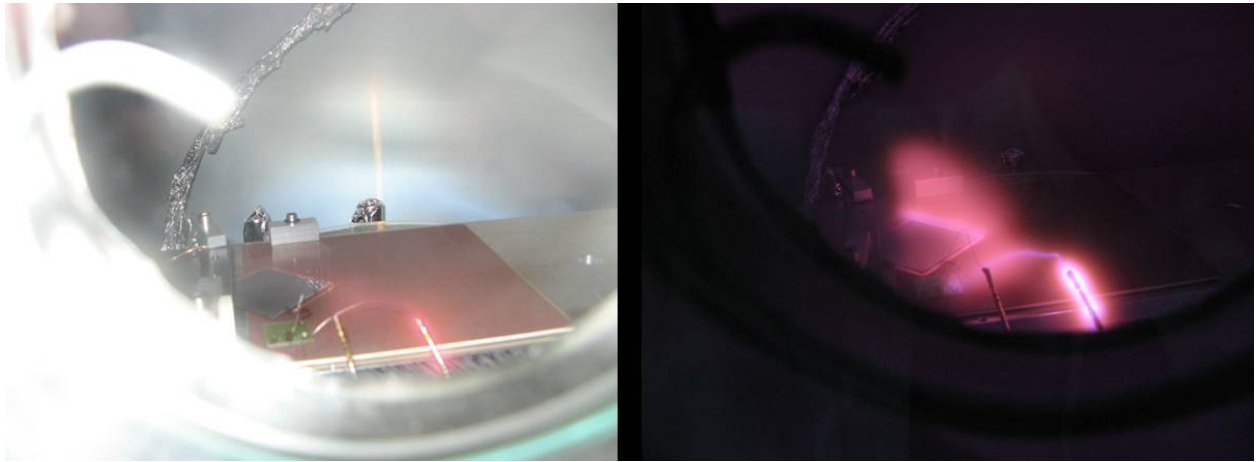


Fig. 9 Gas ionisation in the vacuum plant at a pressure of 3mbar when a bias of 500V was supplied to the detector (the picture on the right has been shot with the flash off to evidence the glow discharge).

5. Conclusions

The TOTEM Roman Pot Si-sensors with current terminating structure could be operated when the sensor edge is in direct vicinity of a grounded metal plate. At gap sizes down to 100 μm , no effect of the presence of the grounded plate on the I-V characteristics of the sensor was observed. The bias could be raised to +500 V.

The sensor operated without problems in good vacuum, i.e. pressure below 0.1 mbar. The same I-V characteristics as at atmospheric pressure were found. Again, operation at a bias voltage up to +500 V was possible without any signs of discharges.

The same behaviour was observed when the pressure remained at values of about 5-10 mbar. No discharges were observed. This could also suggest an optional range of operation in which the pressure should be kept above 10 mbar.

In the intermediate pressure range, i.e. between 0.1 and 5 mbar, safe operation was only possible if the applied voltage was not raised above a value which depended on the pressure. It appears that operation at bias voltage below 300 V was possible independently of the chosen pressure value. It is worth noting that this bias is well above the bias required for the detector operation at the start of the experiment. Nevertheless this value would be approached, or even overcome if the accumulated radiation dose on the whole detector will appear to be a relevant issue.

The onset of discharges in partial vacuum (0.1 – 5 mbar) is not only a function of the applied voltage but is expected to depend also on the test geometry. A final conclusive test must therefore be performed with a complete Si-detector module inside a Roman Pot.

Acknowledgement

We would like to thank M. v. Stenis and Claude David (both CERN PH/DT2) for their competent help in preparing the mechanical set-up and preparing the vacuum plant.