# Description of 3d-STC detectors from ITC-irst

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## Summary

This note describes the first 3d detectors fabricated at ITC-irst, Trento, Italy, and made available to SCIPP. Details about detector structure and layout are provided with the aim of facilitating the characterization work.

## 1. Background

In the past 2 years, ITC-irst has been developing detectors with three dimensional electrodes (3d detectors) in the framework of the CERN RD-50 collaboration. As a first step in this activity, we have fabricated detectors using a simplified approach, whose main characteristics are the following:

- all columnar electrodes are of the same doping type, i.e., n-columns on p-substrate;
- columnar electrodes are only partially etched through the wafer, with a depth ranging from 100 to 150 μm.

These features make the fabrication technology much easier, and, at the same time, allow useful information both on the critical process steps and on the detector characteristics to be obtained. TCAD simulations have been carried out to investigate the electrical behavior of these detectors. Moreover, technological tests have been performed to study the most critical process steps. Details on these aspects can be found in [1]. On the basis of simulation results, 3d-STC prototypes have been designed [2], and fabrication of the first batch has been completed in June 2005. Preliminary results from the electrical characterization have been presented at the PSD7 Conference in Liverpool on Sept.16, 2005 [3].

## 2. 3d-STC layout and fabrication

The main goal of the first batch was to learn as much as possible about the technological problems. Thus, several test structures, both planar and 3d, have been included in the wafer layout (see small structures in Fig.1). Moreover, 10 medium size detectors (~1cm$^2$ area) have been designed, that are labeled with numbers from 1 to 10 in the figure.

In order to facilitate the electrical tests and the bonding to standard read-out chips for functional characterization, a strip-like configuration has been chosen for the detectors. As an example Fig.2 shows the layout of a detector corner, where several columnar electrodes (one vertical row) are connected by a metal strip, with a bonding pad at the end. All around are two frames of columnar electrodes, acting as guard-rings.
All 10 detectors are different and feature the following layout options:

- column width: 6 - 10 μm;
- column pitch: 50 - 100 μm;
- p-stops (common or atoll) or p-spray surface isolation;
- DC or AC coupling between strip diffusions and metal layers.

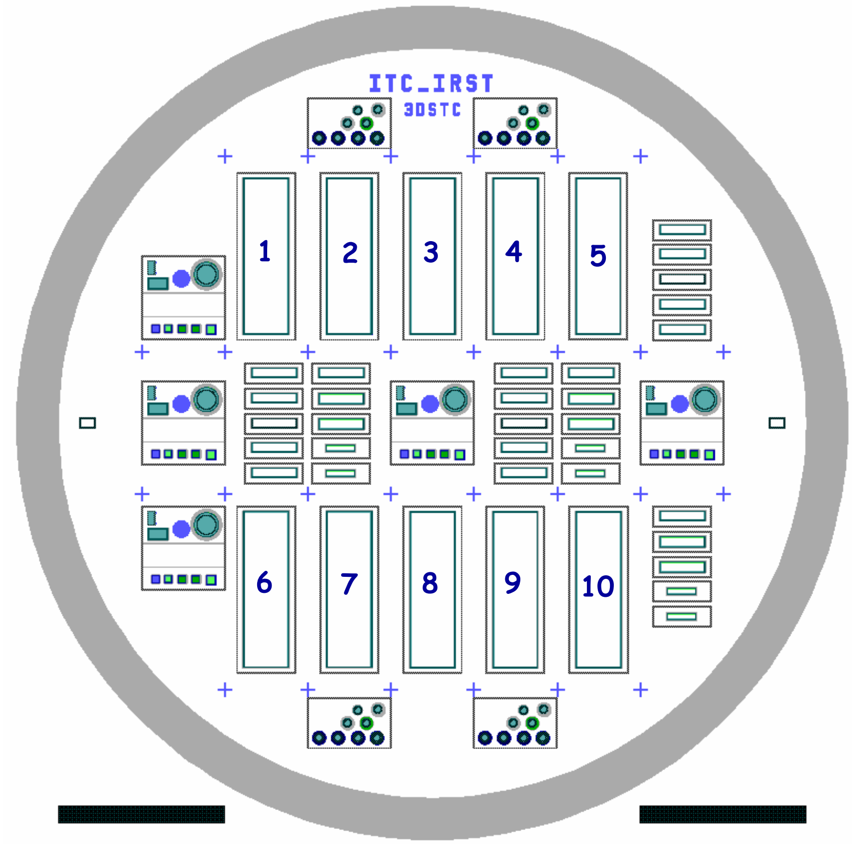


**Fig 1. Wafer layout for 3d-STC prototypes**

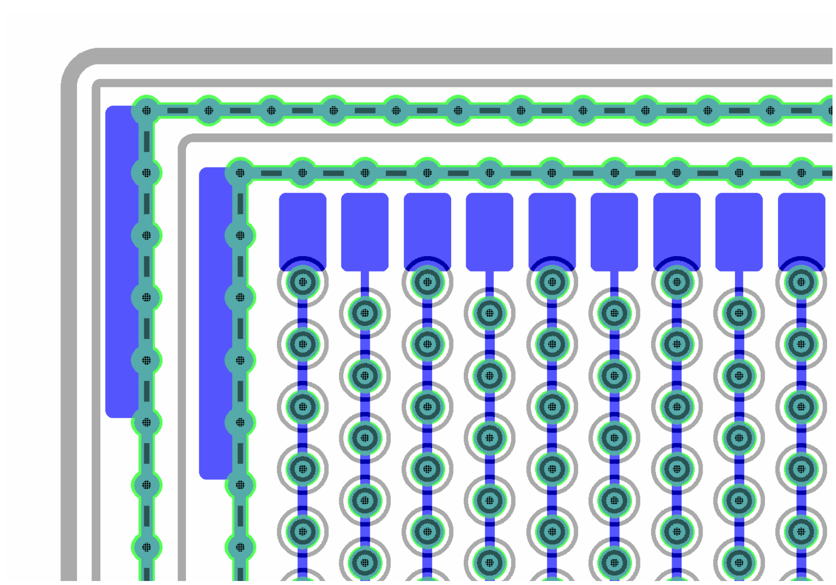

**Fig. 2: Example of a 3d-STC detector layout (corner)**

Detectors of the first batch have been fabricated on p-type, high-resistivity silicon substrates grown by Floating Zone (FZ) or Czochralsky (CZ) techniques, both with <100> crystal orientation. FZ wafers are 500-µm thick with a nominal resistivity of 5kΩ·cm, whereas CZ wafers are 300-µm thick with a nominal resistivity higher than 1.8 kΩ·cm. The columns extend deep into the bulk (down to 150 µm) but not all the way through it. A uniform, $p^+$ layer provides the ohmic contact on the detector backside.
The electrical characterization is still under way at Trento, and only preliminary results are available at this time [3], so it was decided to send to SCIPP only two S5 detectors, that are described in detail in the following section. More detectors will follow in the near future.

## 3. S5 detector

S5 detectors (labeled with 5 in Fig.1) are AC coupled, i.e., an oxide layer is present in between the strip diffusion and the metal layer (note that the coupling is only at the surface level, since metal does not penetrate into the column holes). The 2 detectors sent to SCIPP are both made on FZ wafers. They differ in the surface isolation adopted: one is with p-spray (from wafer 128) and one with p-stop (from wafer 130). Fig.3 shows the detector top view (after dicing). Note that the cutting scheme has been chosen to ease the detector handling by "extending" the shorter side. The die dimensions are about 1× 2cm$^2$, whereas the active area is about 5.3×18.6 mm$^2$, and contains a matrix of 64 rows × 184 columns.

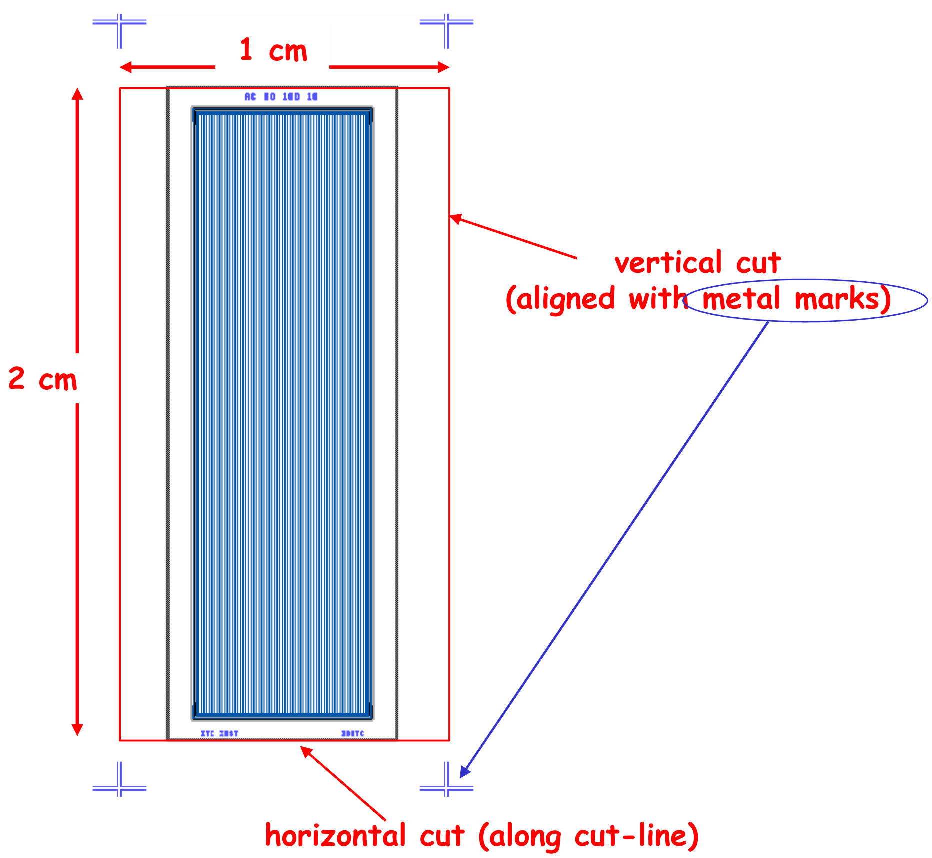


**Fig. 3: S5 detector die layout**

Fig.4 shows the layout of a detector corner. All the 184 columns belonging to a single row are surrounded by a common p-stop (5 μm wide). [Note that atoll p-stops around each column (like those shown in Fig.2) cannot be used with AC coupled detectors having a continuous n-diffusion along the strips, because the breakdown voltage would be too low. Of course, in case of p-spray, no mask is used and the isolation implant is everywhere: in this case, the breakdown voltage is indeed lower than for p-stop, because the p-spray is in direct contact with the n-diffusion.]

At both strip edges (top and bottom of the detector), 2 AC pads (60×90 $\mu m^2$) and 1 DC pad (40×60 $\mu m^2$) are present. All around are a bias line (inner) and a guard ring (outer), both of them formed by columnar electrode frames, connected together at the surface level by both n-diffusion and metal. At each detector corner, there are two large pads (60×400 $\mu m^2$) for probing and bonding the bias line and the guard ring. In between bias line and guard ring is another p-stop (10 μm wide), whereas two additional p-stops are outside of the guard-ring (10 μm and 20 μm wide, respectively).

The strips are biased by punch-through at both edges from the bias line: to this purpose, the n-diffusion at the top of the columns has been extended toward the strips. This concept can be better understood with the aid of the cross section of Fig.5, taken across line AA of Fig.4. Note that the contacts between the metal layer and the n-diffusion on the bias line are made far from the column holes and so are not shown in Fig.5. They can be observed in the cross section of Fig.6, taken across line BB of Fig.4.

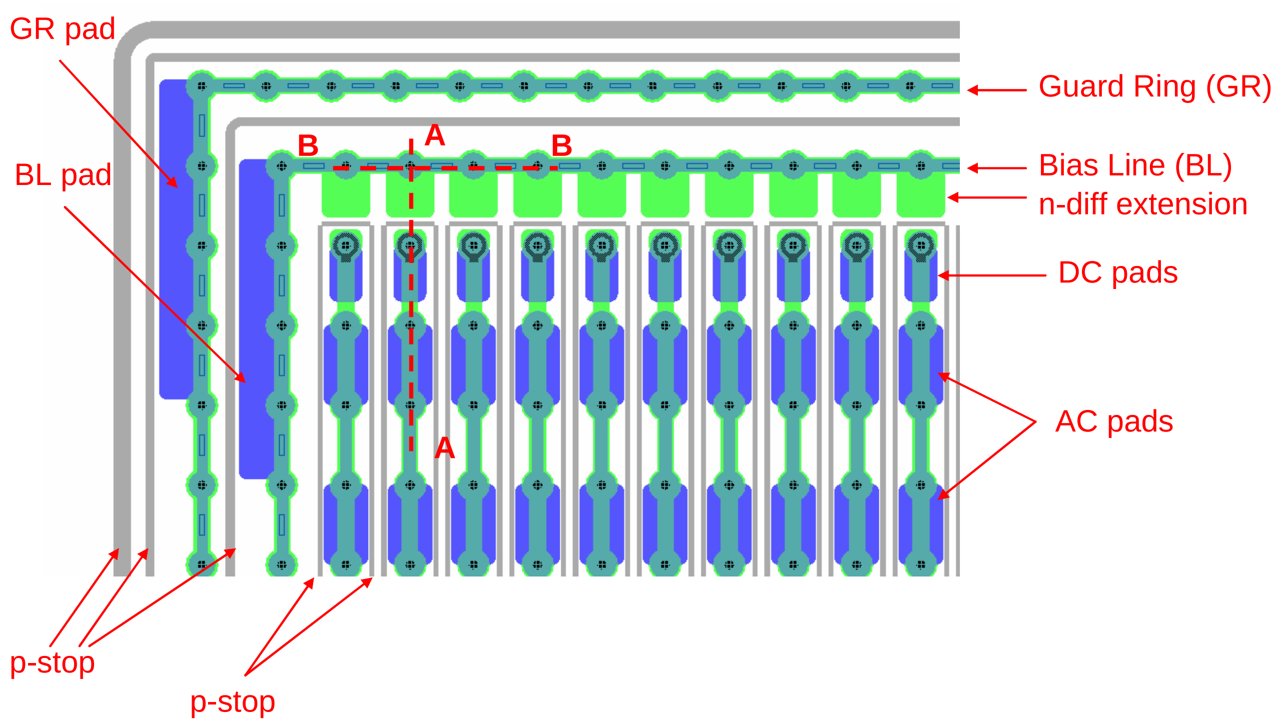


**Fig. 4: Layout of the corner of a S5 detector**

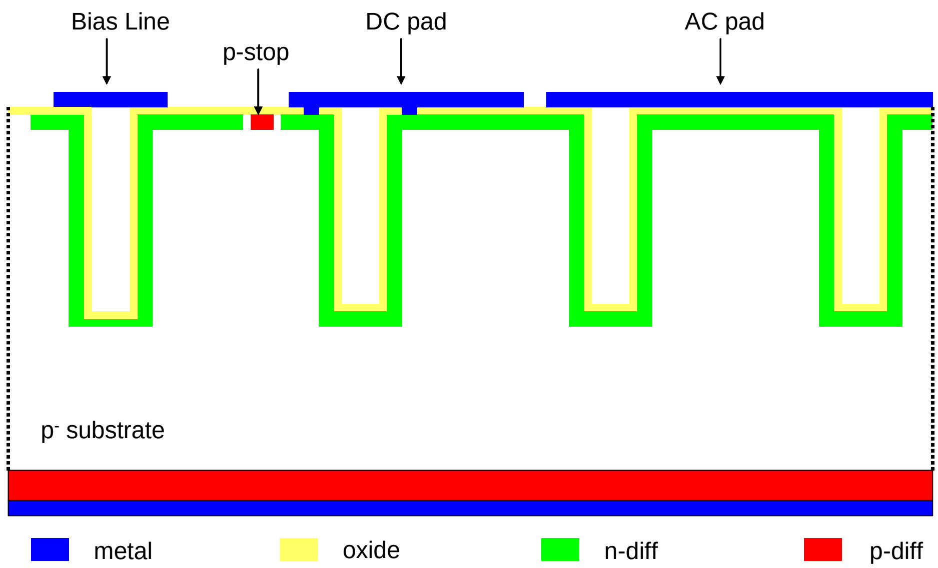


**Fig. 5: Schematic cross section of the S5 detector across line AA of Fig. 4 (not to scale).**

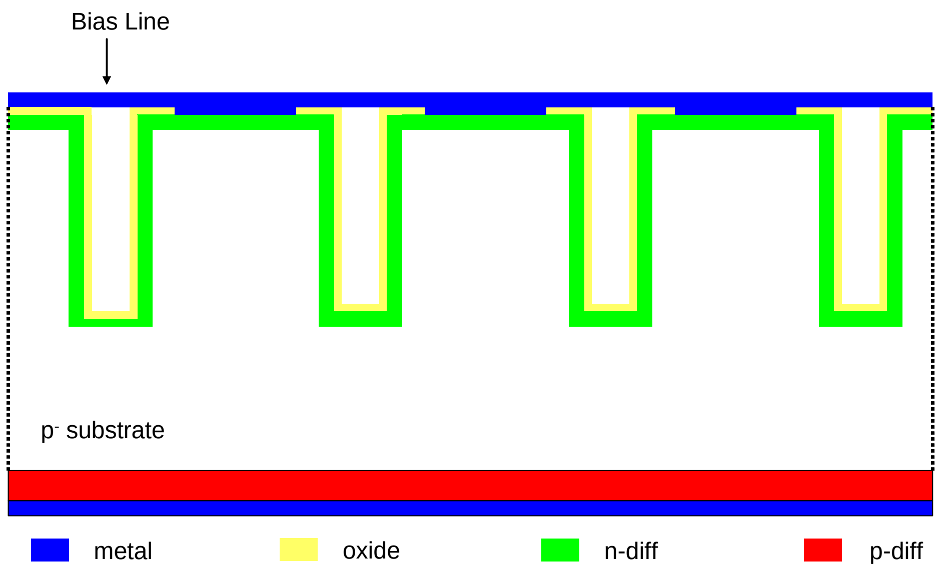


**Fig. 6. Schematic cross section of the S5 detector across line BB of Fig. 4 (not to scale).**

With reference to the layout detail of few columns shown in Fig. 7, Table 1 summarizes the main geometrical features of S5 detectors.

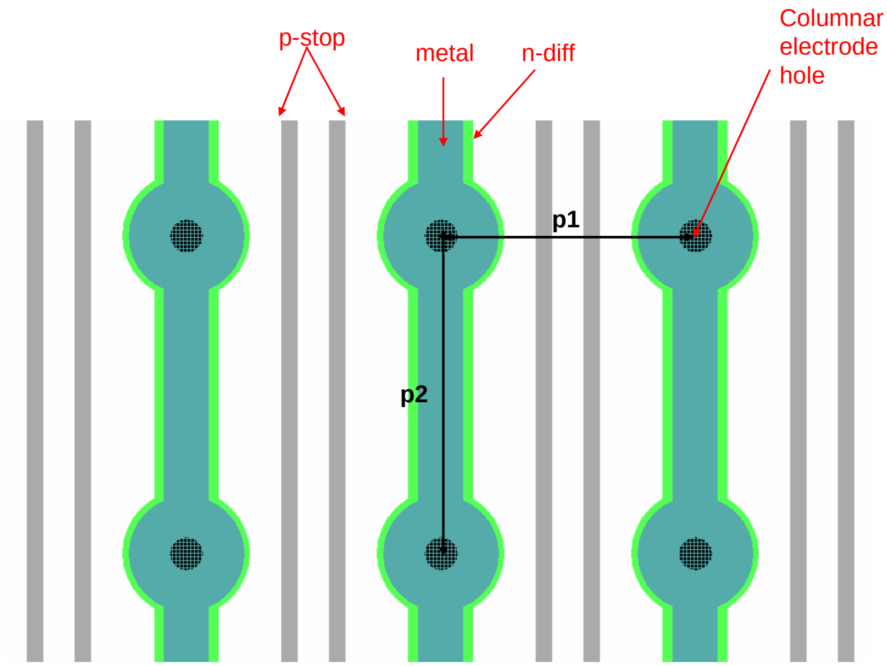


**Fig. 7. Layout detail of few columns**

Table 1: geometrical details for detector S5

| | |
|---|---|
| **Number of columnar electrodes per row** | **184** |
| **Number of rows** | **64** |
| **Pitch between adjacent rows (p1)** | **80 μm** |
| **Columnar electrode pitch within a row (p2)** | **100 μm** |
| **Columnar electrode hole diameter** | **10 μm** |
| **n-diffusion diameter around hole** | **40 μm** |
| **metal diameter around hole** | **36 μm** |
| **n-diffusion width along strip** | **20 μm** |
| **netal width along strip** | **14 μm** |
| **p-stop width** | **5 μm** |
| **p-stop gap** | **10 μm** |
| **Column hole depth** | **150 μm** |
| **Wafer thickness** | **500 μm** |

## 4. Preliminary results

An overview of preliminary results from the electrical characterization of 3d-stc detectors has already been given at SCIPP [4]. Additionally, before sending the detectors, total leakage current measurements have been performed at ITC-irst and compared to those made before dicing. Figures 8 and 9 show the results: note that the bias line leakage current is only slightly increased after cutting, whereas the guard ring current suffers a very large increase. This effect is to be ascribed to a current rising from the highly damaged cut edge. Note that the current increase is more pronounced in case of p-stop, for which the lateral depletion spreading from the guard ring columns is likely wider. It is therefore mandatory to bias the guard ring during measurements in order to prevent the edge leakage current to reach the active area. Breakdown can also be observed in the plots. Similarly to what measured before dicing, this happens at much lower voltage in case of p-spray [4].

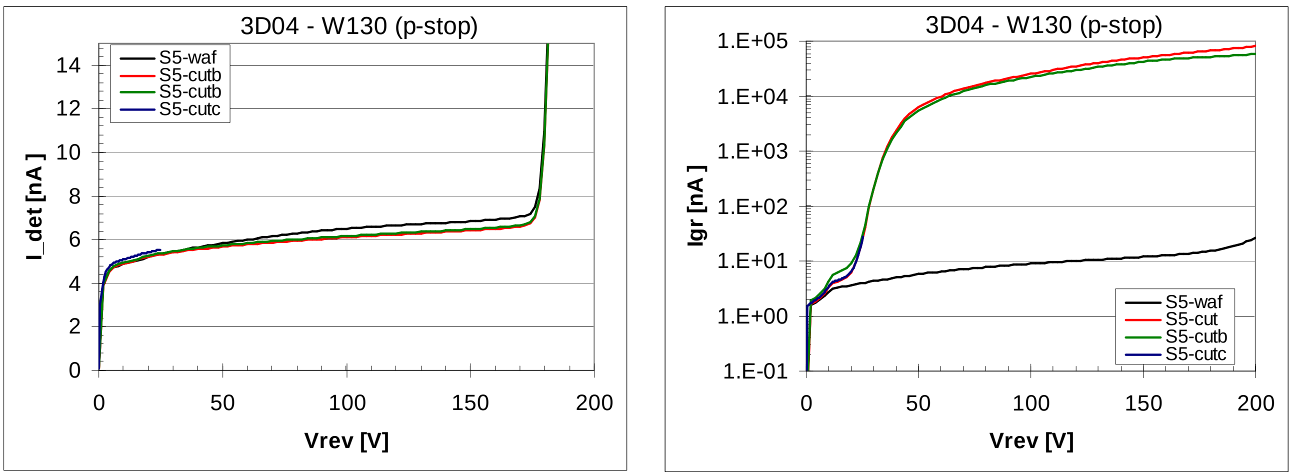


**Fig. 8 Bias line (left) and guard ring (right) currents before and after cutting for detector S5 from wafer 130 (p-stop)**

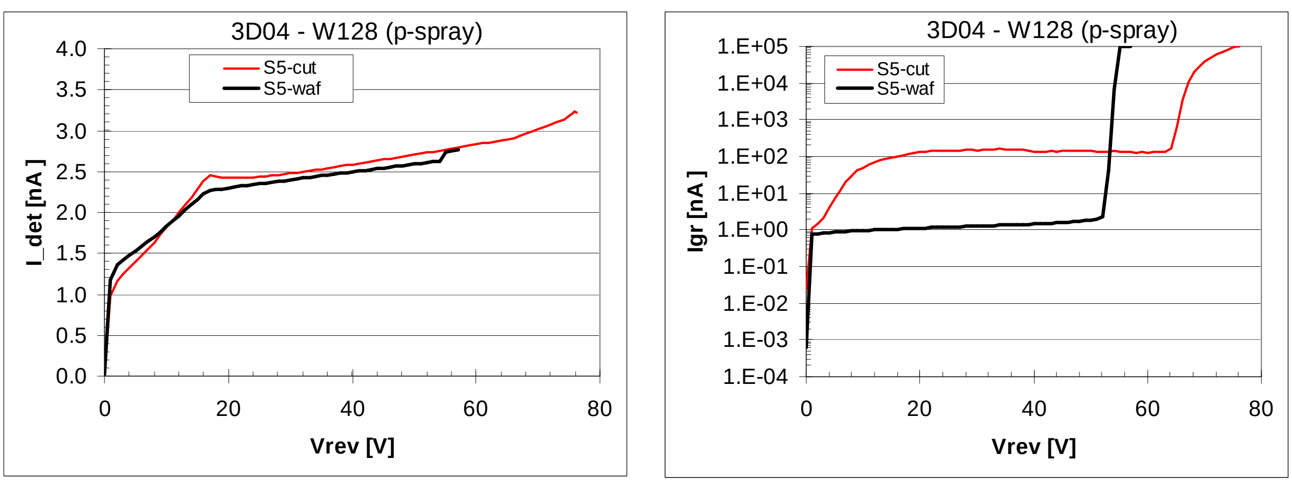


**Fig. 9 Bias line (left) and guard ring (right) leakage currents before and after cutting for detector S5 from wafer 128 (p-spray)**

## 5. Final remark

It should be stressed that, due to the punch-through mechanism, the voltage of the strips may differ by few Volts from the voltage of the bias line. Since punch-through phenomenon is quite sensitive to the substrate bias voltage, the strip voltage should be measured at the substrate bias point in order to learn which is the effective strip voltage. In this respect, note that p-spray and p-stop behave in a slightly different way: in fact, with p-spray the effective punch-through distance between the n-diffusions of the bias line and of the strips is wider (15 μm vs 5μm), so for p-spray the effective reverse bias of the strips is lower. This is also one of the reasons why lower leakage current are measured on the bias line for the detector with p-spray (see Figs. 8 and 9); however, also a higher surface leakage current with p-stop may contribute to the observed difference.

## 6. Handling instructions

The 2 detectors have been removed from the small gel-pack box in which they were sent and put into a SCIPP gel-pack box. Please remember that the presence of deep holes in the substrate makes these detectors not very robust from the mechanical viewpoint. Moreover, note that no final passivation layer has been deposited, so care must be taken with detector handling and with the needles in the probe-station, because the metal layer can easily be scratched.

## 7. References


[1] C. Piemonte et *al.*, "Development of 3D detectors featuring columnar electrodes of the same doping type", *Nucl. Instrum. Methods* A 541, pp.441-448, 2005

[2] C. Piemonte, "Simulation, design, and manufacturing tests of single-type column 3D silicon detectors", presented at RESMDD, Firenze, Italy, Oct.10-13, 2004. ( http://resmdd.web.cern.ch/RESMDD/talks/piemonte.pdf)

[3] S. Ronchin et *al.*, presented at PSD7, Liverpool, UK, Sept.12-16, 2005 and submitted to *Nucl. Instrum. Methods* A. Preprint is available.

[4] G.-F. Dalla Betta, "Development of 3D detectors at ITC-irst", Talk given at SCIPP, Sept.16, 2005. Power point presentation is available.