ID149

Technology and Instrumentation in Particle Physics 2011 (TIPP2011), 9-14 June, 2011

Design of Punch-Through Protection of Silicon Microstrip Detector against Beam Splash

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MOTIVATION

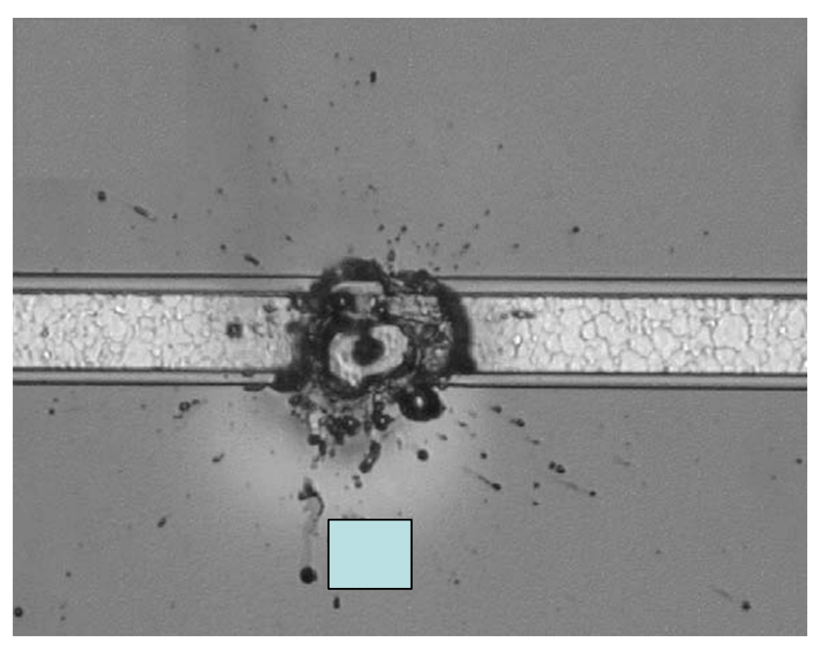
At high intensity accelerators such as the LHC and its planned upgrade, the silicon microstrip detector is required to be designed to survive against possible beam loss that may create large amount of signal charges in short period. We have designed a protection structure based on punch through mechanism, and its performance is evaluated using a pulsed infrared laser system.

1. What may happen in High Intensity Environment

The LHC is colliding the proton bunches (10^{11} protons/bunch) at 40 MHz (at design). At an incident of large beam loss, a beam aborting system is activated within typically 1μs. Therefore several times 10^{12} protons could be splashed over the detector area in worst case.

Fig. 1 shows a hole created on a present ATLAS SCT n-bulk sensor operated at 500 V when a charge equivalent to 10^8 mips was injected using an infrared pulsed laser in an area 10 μm square aside from the electrode. This sensor went un-operational. Other effects such as several strips at neighbors or whole chip becoming noisy were observed.

[1] K. Hara et al., NIM A565 (2006) 538.



■FIG. 1. A hole created in Al electrode [1]. Laser equivalent to 10^8 mips was spotted in the region indicated by a square.

mip=minimum ionizing particle

2. P-Type Sensor and Punch Through Protection

Microstrip sensors of p-bulk and n-readout show superior performance [2], being regarded as the baseline sensor for the ATLAS upgrade, where the detector is expected to receive up to 10^{15} 1-MeV n_{eq}/cm^2 of radiation.

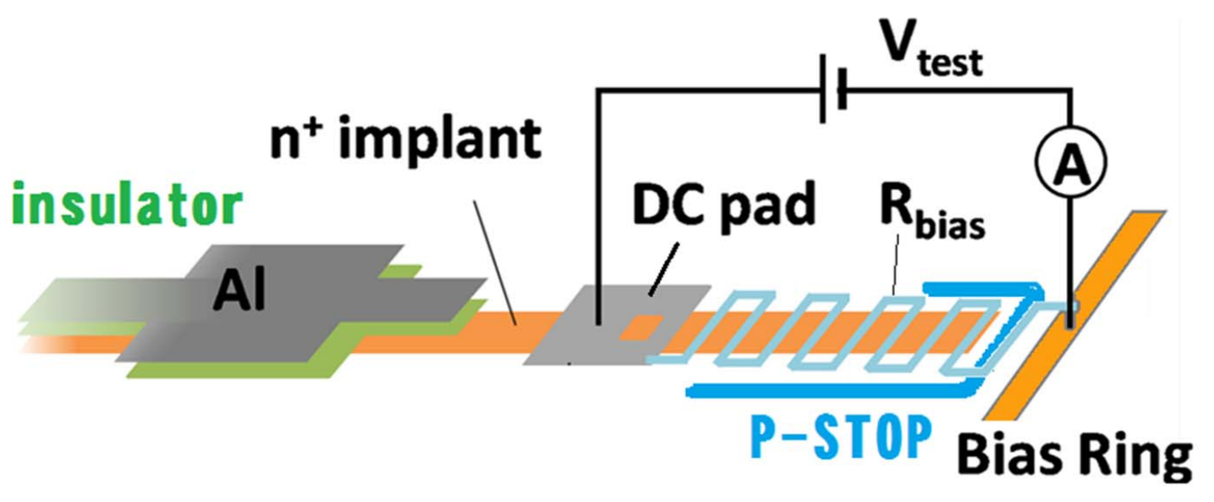
In an event of large beam loss, the implant strip voltage is pulled down by the induced current flowing through the bias resistor and the implant itself. Since the aluminum electrode on top is tied to the amplifier input, the voltage across the insulator may reach beyond its rating the insulator is and eventually broken.

The built-in protection is realized by a punch through (PT) mechanism of the strip implant to the bias ring which is held at ground, see Fig. 2.

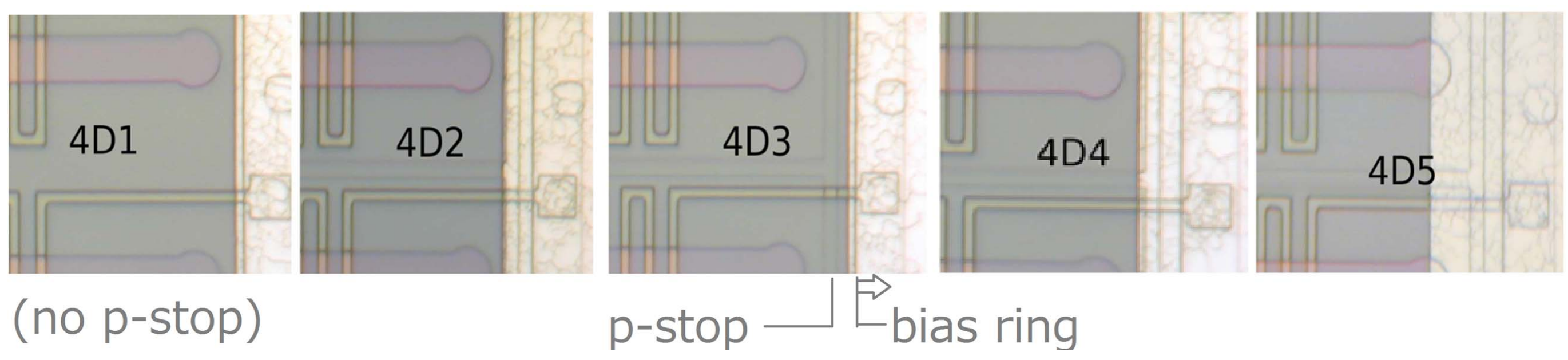
The design of PT protection (PTP) focused on:

1. distance between the strip end to the bias ring (⇒5 or 7 μm)
2. p-stop density in between
3. gate structure over the PT region

Among these, 1. (7 μm is nominal) is limited to 5 μm for reliable sensor fabrication.
2. is specific to p-bulk sensors since p-stop which acts as a PT blocker is required to prevent mobile electrons to degrade the electrical isolation of the strips.



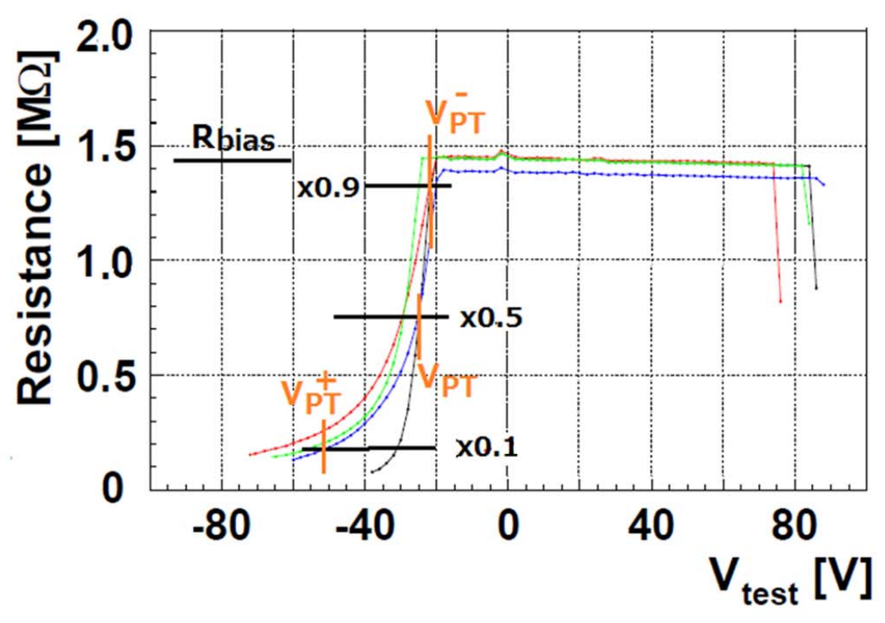
■FIG. 2. Schematics of a strip end of our p-bulk sensor. The network with V_{test} is referred to the DC test.



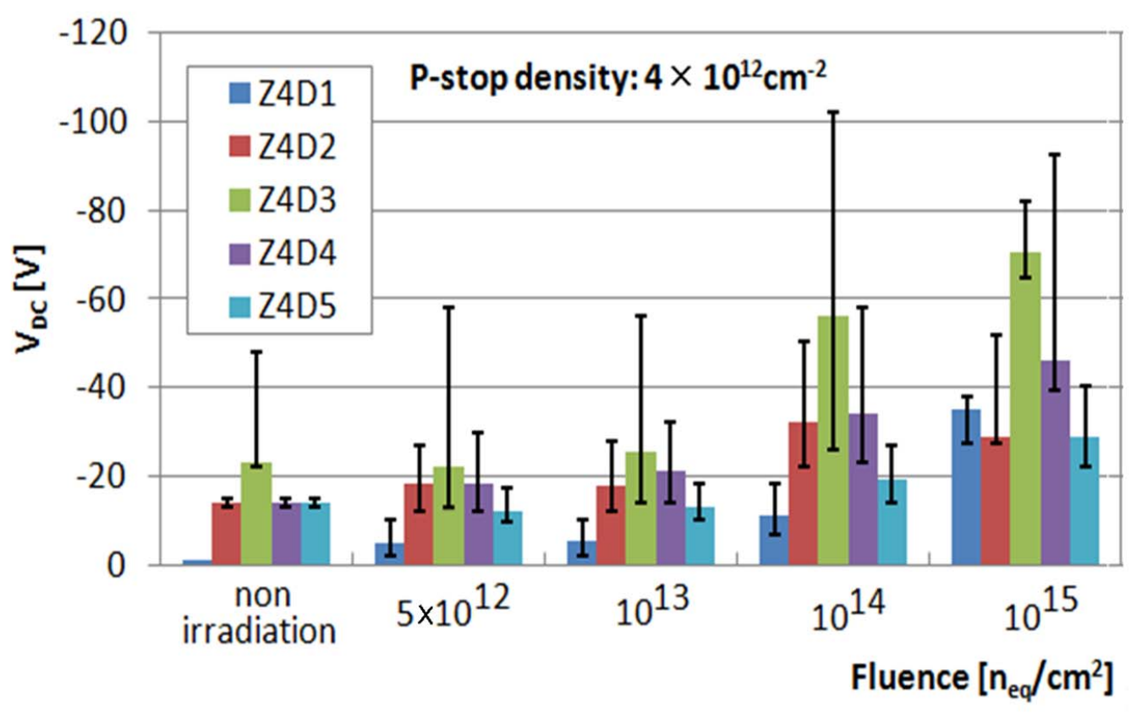
■FIG. 3. Four PTP structures with and one (4D1, for comparison) without p-stop. The PT region is covered partially in 4D3 and completely in 4D5 by the ground extended from the bias ring at right. The strip pitch is 74.5 μm. The PT spacing between implants is 5 μm for 4D2 and 7 μm for the others.

[2] Y. Unno et al., NIM A656 (2011) S24; K. Hara et al., NIM A656 (2011) S83.

3. DC Test and Results



■FIG.4 (L). The effective resistance is derived from I and V_{test} applied on the DC pad. The PT voltage is defined by V_{test} where the resistance is 50% of R_{bias} with its spread given by V_{test} at 10% and 90%.



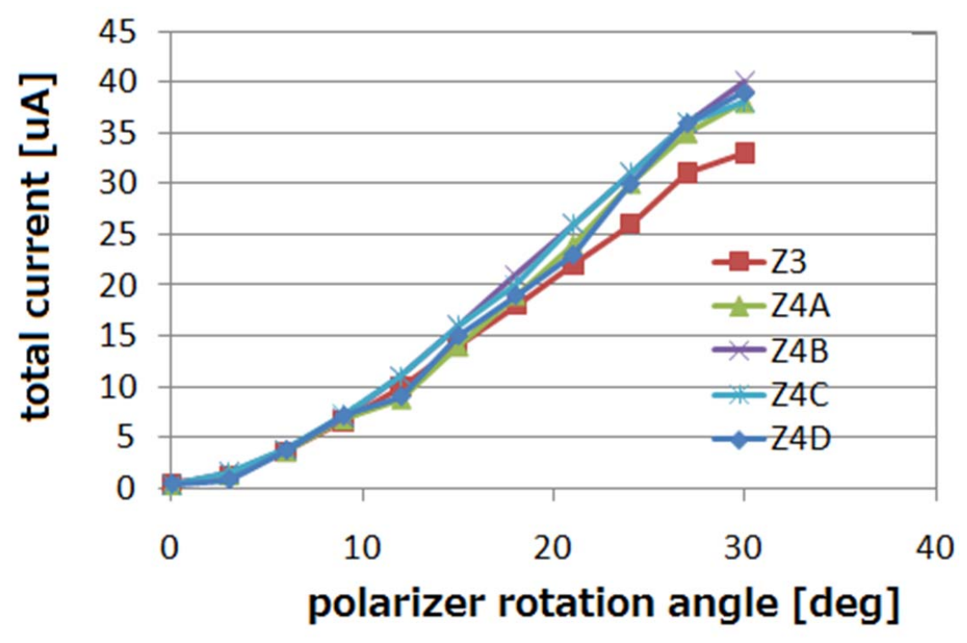
■FIG.5 (R). Results for the samples irradiated up to 10^{15}/cm^2 and for non-irradiated. The bias was 300 V. The density of the p-stop (6 μm wide) is 4x10^{12}/cm^2.

The PT voltages are degraded but slightly by irradiation. D5 is as good as D1 that has no p-stop. The performance is better by increasing the gate coverage on top of the PT region. D2 (5μm gap) is not particularly superior than D4 (7μm).

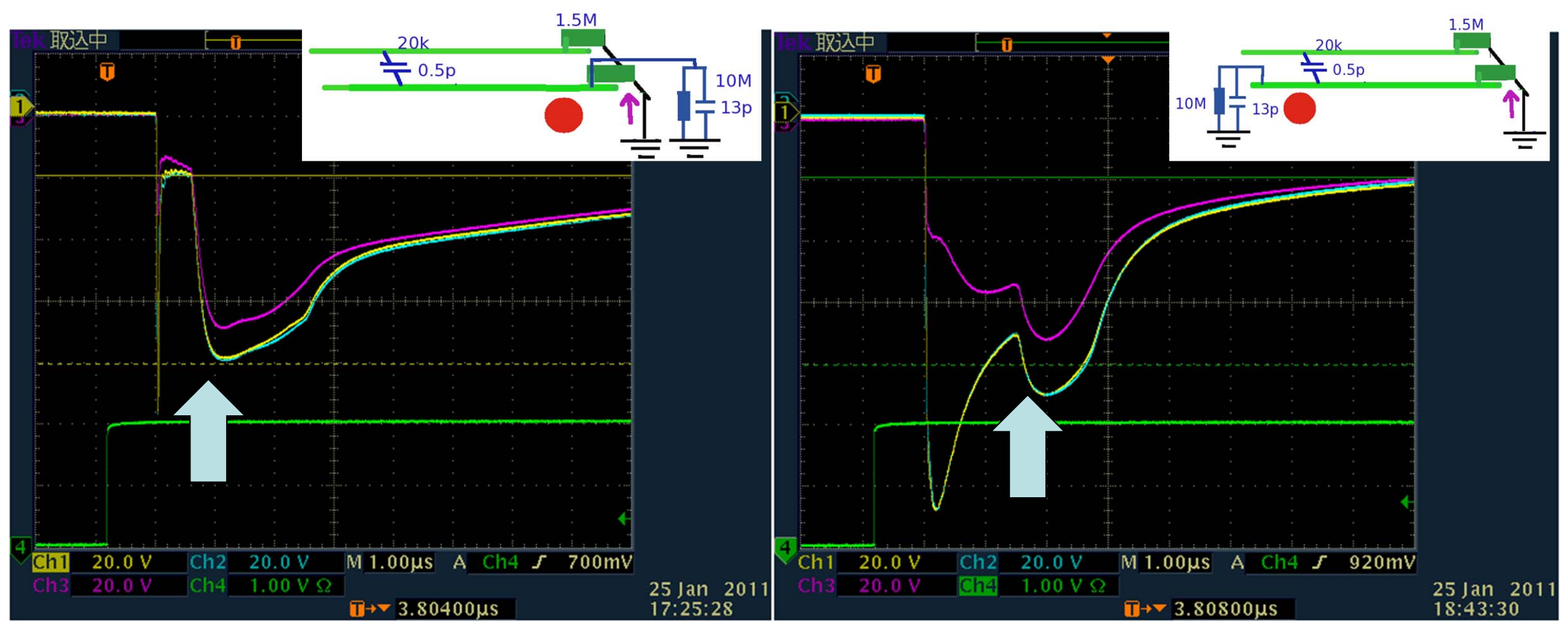
4. AC Test with Pulsed Infrared Laser

A 1mW infrared pulse laser (λ=1064nm, base width=10ns), focused to a 10μm square, was injected halfway between two neighboring strips either close to the PT ends (NEAR injection) or to the other ends (FAR injection). The implant strip length is 8 mm. The laser intensity was adjusted by a polarizer. Fig. 6 shows a reproducibility of the intensity measured with different samples and at a repetition rate of 1 kHz. The laser intensity in mips/pulse was calibrated from the total induced current, the laser being operated at 1 kHz.

The strip signals from the two (yellow and blue in Fig. 7) near the injection and a neighbor (pink) were read out with an oscilloscope via passive probes with 10 MΩ - 13 pF characteristics. The readout was also made from the DC pads close to the PT ends (NEAR R/O) or other ends (FAR R/O).



■ FIG. 6. Reproducibility of laser intensity adjusted by a polarizer. 40 μA corresponds to 1x10^6 mips/pulse.

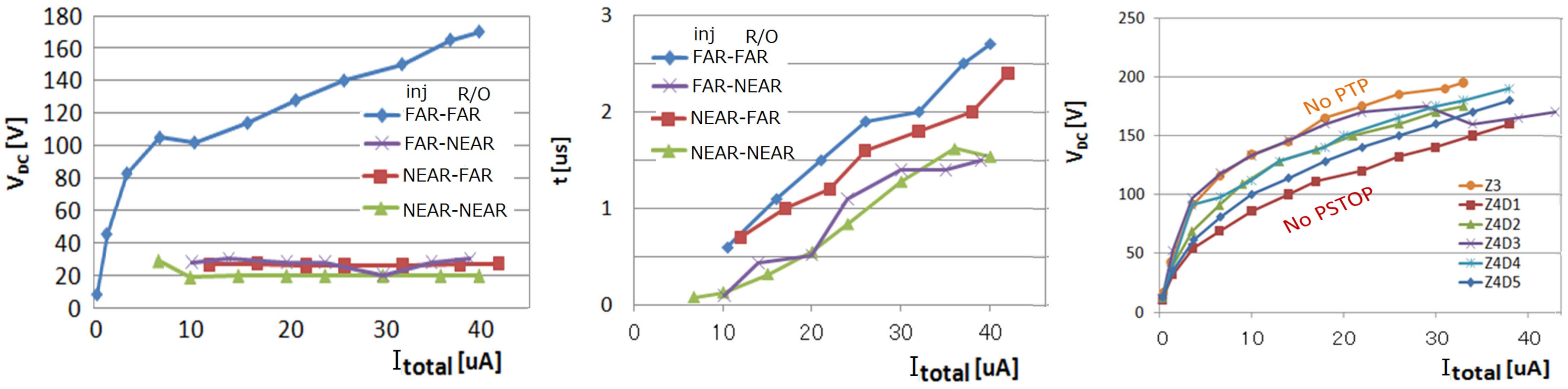


■FIG. 7. Signal shapes for (left) NEAR injection and NEAR R/O and (right) FAR injection and FAR R/O. 1 μs/div, 20 V/div for a laser intensity of 10^6 mips/pulse.

Characteristic pulse shapes were observed depending on whether the injection and readout were NEAR or FAR. The signals are shown in Fig. 7 for two extremes, NEAR-NEAR (injection-R/O) and FAR-FAR configurations. From the amplifier impedance characteristics [3], the observed signal should coincide with the shape on the implant in real situation for fast pulses (10 ns) and overestimate by one order for 1 μs pulses. The quick rises (<20ns) are immediately dumped by the PTP for NEAR-NEAR while it takes a while for FAR-FAR due to the finite implant strip resistance. In both cases, the signals rose again when the impedance changed by losing PT (therefore the signal shapes after the arrows are spurious and not relevant in real situation).

The voltages while the PT is on are plotted in Fig. 8(left). All except in FAR-FAR configuration are quickly dumped showing a constant representing the finite resistance times the current being swept away. For FAR-FAR, the maximum voltages right after the quick rise are plotted. In Fig. 8 (middle), the times up to the arrows are plotted. We notice that the time scale of a few μs increases with the total current and is shorter when readout is from NEAR.

The voltage in FAR-FAR configuration is most dangerous for the insulator break, which is plotted in Fig. 8 (right) in comparison with other configurations.



■FIG. 8. (left) The maximum voltage while PT is on, and (middle) its duration. (right) The maximum voltage in FAR-FAR configuration for various PTP designs.

The spacing between the implants is 30 μm for Z3, no PTP design being applied. The similarity of Z3 and D3 (smallest gate coverage) curves suggests that the gate is more important than the separation of the PT electrodes. The effectiveness of p-stop as the PT blocker is seen from the D1 data. The D5 (PT region covered entirely) is the best among the applicable designs.

Small degradation was observed due to irradiation for the discussed quantities.

[3] J. Kaplon and W. Dabrowski, IEEE TNS 52-6 (2005) 2713.

Summary

A design based on punch through is discussed for the protection of p-bulk microstrip sensors against possible accelerator accident of beam loss. Among some design issues, the most critical is to stabilize the potential around the punch-through region. We realized this by adding a gate structure on top. Although the design minimizes the impedance through the punch-through circuit, the finite implant strip resistance remains critical when the loss hits away from the punch through structure and the signal is read out from far side. We have evaluated the time structure of the voltage that may present between the insulator. The next step is to qualify the durability of the insulators for pulses with such time structure. Similar evaluation is required also for the readout amplifiers.