Beam loss induced electrical stress test on CMS silicon strip detectors

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Abstract

Based on simulated beam loss scenarios at LHC, fully depleted CMS silicon strip detectors and sensors were exposed to 42 ns long beam spills with 10^{11} protons per spill at PS at CERN. This high ionising dose is sufficient to short-circuit the silicon sensors. The dynamic behaviour of bias voltage, leakage currents and voltage drop over coupling capacitors had been monitored during the impact. The results of pre- and post- qualification as well as the dynamic behaviour will be presented.

I. INTRODUCTION

It is assumed that a beam loss caused by kicker magnet pre-fire or unsynchronized beam abort may occur once a year at the LHC. Simulations [1] predict for the most probable scenario of an 'unsynchronized beam abort' the loss of 10^{12} protons. Taking into account the spreading, as given by the simulations, this will result in 10^9 protons per cm^2 passing the CMS detector within 260 ns. This will immediately ionise the space charge region of the silicon sensors and may cause irreversible damage to the detector and its components.

II. SETUP

A 24 GeV proton beam at CERN PS have been used for this study. Two possible beam setups were used to simulate the conditions in the Tracker Endcap due to an unsynchronized beam abort, a fast extracted spill of 42 ns length and a double bunch of two 42 ns spills separated by a 525 ns long gap. $7\text{x}10^{10}$ protons, each spill consists of, were deposited on an area of 10x3 cm^2.

Three different configurations of module carriers were exposed to the beam. Each carrier hosted a silicon sensor, one was additionally equipped with an end cap module, one with an outer barrel module and one with a bare hybrid.

Preamplifier electronics on top of the modules carriers were used to drive a dozen differential signals over a distance of 30 m between the beam area to the counting house. In figure 1 shows a schematic of monitored sensor parameters, bias voltage (V_{bias}), global leakage current, voltage over the dielectric (V_{diel}), strip leakage current (I_{strip}), front end hybrid (FEH) supply currents and voltages. The readout of these parameters was done by scopes, triggered by the rising edge of the sensor leakage current.

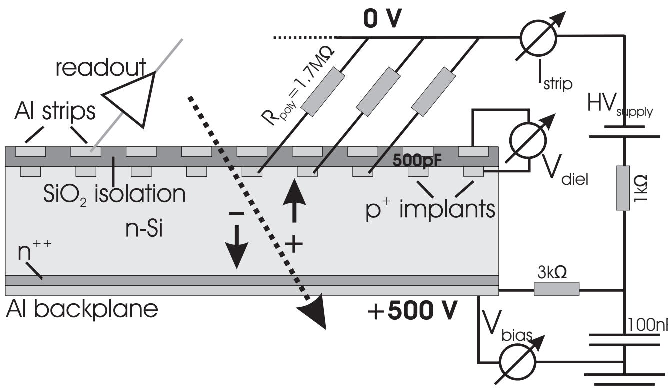

Figure 1: Schematic for the electrical readout of the sensor parameters

III. RESULTS

In this section the dynamical behaviour of the silicon sensors is shown as well the data of the pre- and post-qualification for sensor and modules is presented.

A. Dynamical behaviour of the silicon sensors

The high ionisation of a beam loss will completely nullify the space charge region created by the bias voltage and therefore short circuit the high voltage from the backplane to the p^+ implants.

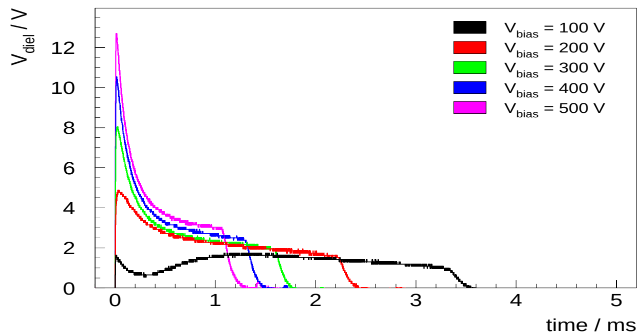

Figure 2: Voltage drop over dielectric for different bias voltages

The high voltage behaviour is driven by the filter capacitances and the long distances between the power supplies and the sensor. The breakdown of the high voltage prevents the full high voltage from reaching the p^+ implants. The remaining voltage drop over the coupling capacitances dielectric (Figure 2) is of crucial importance for the functionality of the sensors after the beam loss. For a bias voltage of 500 V before the beam loss, the voltage drop over the dielectric peaked at 13 V, which is far below the value of 120 V the sensor are specified for. Another important parameter is the strip current (Figure 3) peaking at 13 µA and therefore not harming the poly resistors.

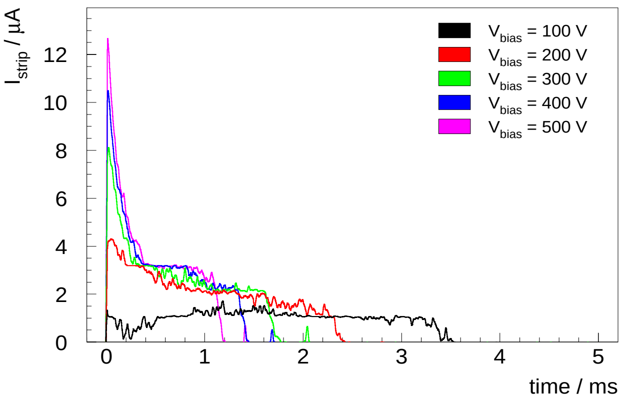

Figure 3: Strip current behaviour for different bias voltages applied

The time behaviour seen in the voltage over the dielectric and the strip leakage current (Figure 4) fits well to RC element defined by the poly resistor (1.7 MΩ) and coupling capacitance (~500 pF) of the readout strip.

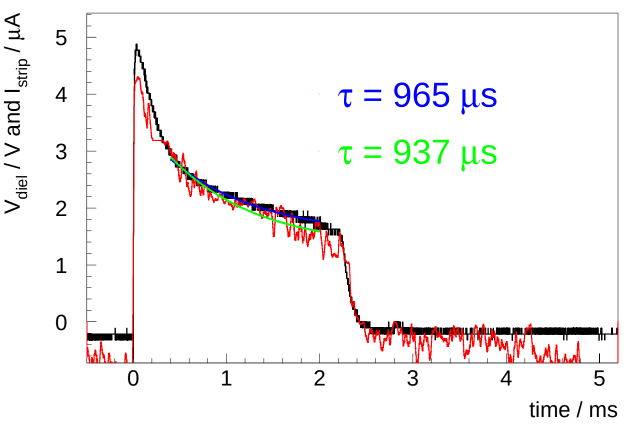

Figure 4: Time behaviour of voltage over dielectric (black) and strip leakage current (red) at a bias voltage before the impact of 200 V. The time constant of 950 µs for V and I_{leak} fit well to the poly resistor (1.7 MΩ) and the coupling capacitance (~500 pF). The discharging of the coupling capacitances stops abrupt (kink at 2.5 ms) when all free charge carriers have been removed

All sensors were fully qualified before the test, applying the standard CMS quality control test procedures [2, 3] and after the test. The checked parameters are not affected as expected from the outcome of the dynamical behaviour seen in the beam test. In Figure 5 and 6 the comparison of the IV and CV scan are displayed. The leakage current slightly increased due to light exposure and handling, but still far below the limits for non irradiated sensors [3].

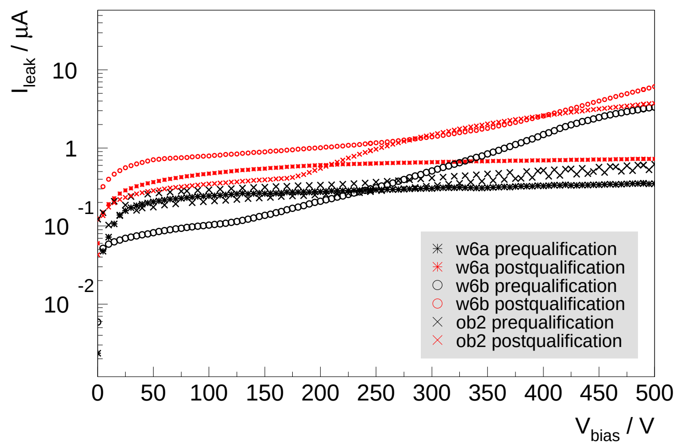

Figure 5: Scan of the leakage current over the depletion voltage

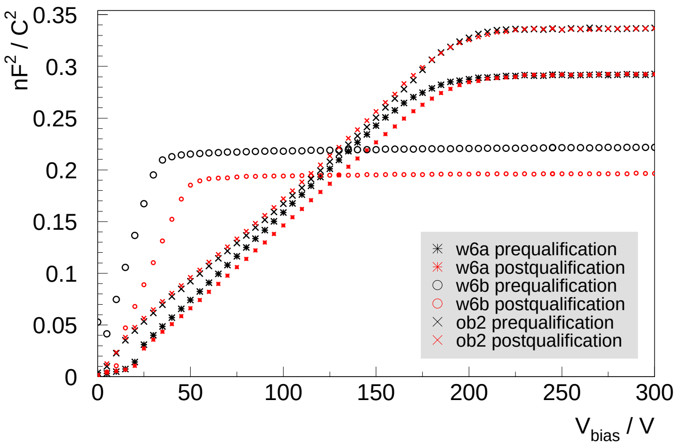

Figure 6: CV scan for all three sensors (w6a, w6b and ob2 are abbreviations for the geometries of the sensors). No change in the CV behaviour was observed

B. Module behaviour

Two modules from the CMS pre-series with the final design were used for this test. One module was exposed to a single shot the other one was exposed to several shot at different bias voltages ranging from 100 V to 500 V.

The results presented here are restrained to the pre and post qualification data, because the strip parameters are not accessible to fully bonded sensors. As seen in the data after the test beam the modules worked perfectly fine, no additional defective channels were found.

The noise of a module (Figure 7) does not only depend on the strip length and preamplifier electronics, but also on the test facility and shielding. The noise performance was improved between pre and post qualification which explains the absence of the high noisy strips seen in the pre qualification (especially at the edges of the readout chip). If one compares the measured noise with the expected changes during the operation in the experiment, which will increase from a value around two to a value of three or even more, one could conclude that there is no change in the noise due to radiation effects.

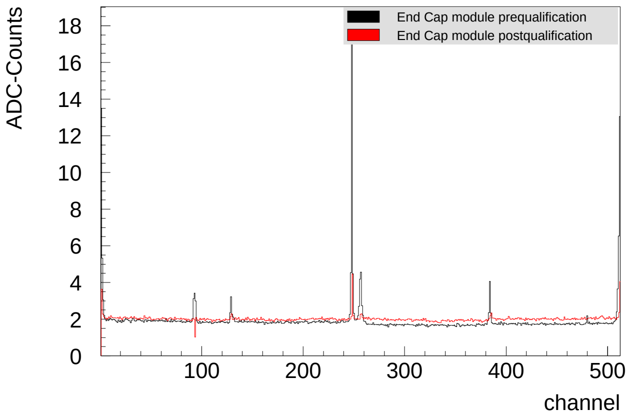

Figure 7: Noise of a CMS pre-series module exposed to several beam losses (black pre and red post qualification), no additional noisy or defective strips were found

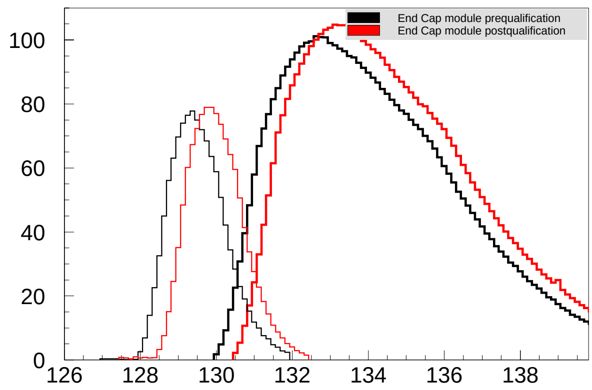

Figure 8: Calibration pulse shape for pre and post qualified module

IV. Summary

There is strong evidence that CMS silicon strip modules will survive a beam loss, because the fast breakdown of bias voltage protects electronics and sensors, especially the dielectric layer and the poly silicon resistors.

V. References

[1] M. Huhtinen et al., Impact of LHC beam abort kicker pre-fire on high luminosity insertion and CMS detector performance, Proceedings of the 1999 Particle Accelerator Conference, New York, p. 1231-1233

[2] F. Hartmann on behalf of the CMS silicon tracker collaboration, The CMS All-Silicon Tracker – Strategies to ensure a high quality and radiation hard Silicon Detector, NIM A 478 (2002)

[3] F. Hartmann et al., The silicon sensors for the Compact Muon Solenoid Tracker – Design and qualification procedure, submitted to elsevier science (2003)