Laser Tests of the DEPFET Gated Operation

L. ANDRICEK[a], Z. DOLEŽAL[b], C. KOFFMANE[a], P. KODYŠ[b], H-G. MOSER[a], F. MÜLLER[c], J. NINKOVIC[a], C. OSWALD[d], R. RICHTER[a], A. RITTER[a], S. RUMMEL[c], J. SCHEIRICH[b, e] (jscheir@ipnp.troja.mff.cuni.cz), A. WASSATSCH[a]

[a] Max-Planck Institute for Physics, Föhringer Ring 6, 80805 München, Germany
[b] Charles University,Faculty of Mathematics and Physics, V Holešovičkách 2, 18000 Prague, CzechRepublic
[c] Ludwig-Maximilians University, Excellence Cluster Universe, Boltzmannstrasse 2, 85748 Garching, Germany
[d] Bonn University, Physical Institute, Nussallee 12, Bonn, Germany
[e] Czech Technical University, Faculty of Electrical Engineering Technická 2, 166 27 Prague, Czech Republic

Abstract

DEPFET is an active pixel particle detector, in which a MOSFET is integrated in each pixel, providing first amplification stage of readout electronics. Excellent signal over noise performance is provided this way. The DEPFET sensor is planned to be used as an inner pixel detector in the BELLE II experiment at electron-positron SuperKEKB collider in Japan. Gated operation of the DEPFET is a unique function which allows making sensor insensitive for incoming radiation for defined time interval. The charge previously integrated is saved and integration can continue afterwards. Laser tests of gated DEPFET operation and their results are presented.

DEPFET Particle Detector

DEPFET pixel detector with internal signal amplification is based on a Field Effect Transistor (MOSFET) which is integrated directly into each detector's pixel and provides first charge amplification stage. The detector itself consists of a high-resistivity depleted n-substrate and two p-regions. The n-substrate is depleted sidewards.

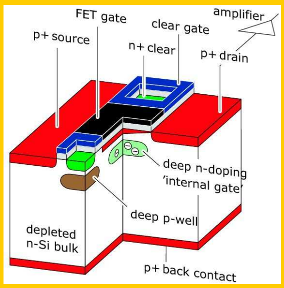

Fig. 1 - DEPFET Pixel Cross-section

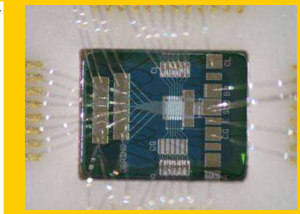

Fig. 2 - Photo of the Detector Prototype

Electron potential minimum is located close to the front surface, where the MOSFET is integrated. Electrons are concentrated in a small region under the MOSFET channel, which is called an internal gate (see *Fig. 1*). When a charged particle generates electron-hole pairs in the depleted n-substrate (bulk), the holes drift to the backside contact, but the electrons are trapped in the internal gate. As the internal gate is located directly under the MOSFET channel, the charge stored in it affects the MOSFET current, which is measured. After the reading cycle is completed, the stored electrons are extracted via clear contact and the current is measured again. The current difference is proportional to the collected charge and defines the signal.

Laser Test System

A versatile measuring system was designed to measure and characterize small prototypes of the DEPFET with 48 active pixels. Variable steering sequences can be configured in the system (20 µs up to several ms for frame readout time) with high resolution step 7.5 ns. The measuring system is controlled by the PC and steering and evaluation software were programmed.

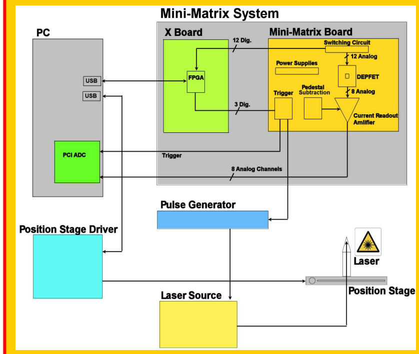

Fig. 3 – Test System Diagram

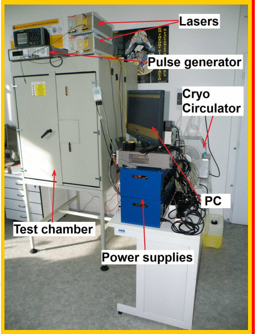

Fig. 4 – Photo of the Test System

Laser and 3-axis positioning stage with spatial resolution of 1.25 µm is integrated into the system. DAQ and control software allows automatic positioning and scanning of the DEPFET array with the laser beam. These scans are used for optimization of the operational voltages and evaluation of the spatial response of the matrix. The test system has a thermally controlled test chamber where constant temperature is maintained with precision of 0.1 °C.

Noise levels as low as 20 electrons can be achieved using the described system which allows detailed performance studies of the sensors.

DEPFET Gated Operation

Gating the DEPFET is a unique function of the detector:

- ➔Makes sensor insensitive for incoming radiation for defined time interval
- ➔Charge previously stored in the internal gate is saved and integration can continue afterwards

This operation stage is achieved by:

- ➔Applying Gate OFF and Clear ON voltages in the same time

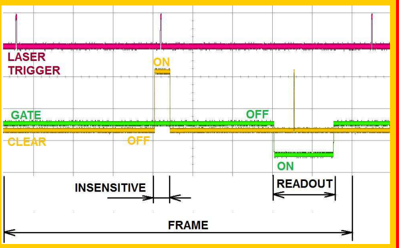

Fig. 5 – DEPFET Steering Sequence

In contrast to the normal clear, when Gate ON voltage is applied during the clearing and electrons can escape from the internal gate by thermoionic emission, during the suppressed clear a potential barrier for electrons in the internal gate is formed and electrons cannot be cleared. Newly generated electrons flow directly to clear contact.

Results

The gated mode operation introduces additional clear pulse to the sequence. This pulse might cause additional loses of charge in the internal gate. Therefore, measurement which determines charge loss due to the additional shielding clear pulse was carried out. In this test, charge was generated during the integration time, before the shielding clear pulse. Difference of charge stored in the internal gate with and without the shielding clear pulse versus generated charge was measured and shown in *Fig. 6*. Charge loss not higher than **200 electrons** was observed.

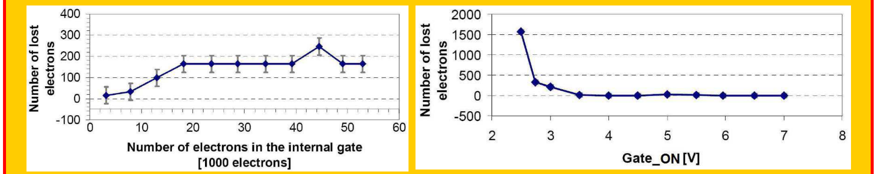

Fig. 6 – Charge Loss Due to the Shielding Clear Pulse vs. Charge in the Internal Gate -left and vs. Gate_ON Voltage –right (Generated 12 000 electrons)

When the DEPFET is switched into the insensitive (blind) mode, charge generated during this period (junk charge) goes directly to the clear electrode. Small fraction of the generated charge gets anyway into the internal gate (see *Fig. 7*). For measurement of junk charge selectivity, charge was generated by laser only during the insensitive mode. Surface scan with the infrared laser (1060 nm) of the 50 µm thick matrix was done and because the infrared laser beam penetrates through full thickness of the sensor, sharp increase of junk charge selection is observed when the beam hits the internal gate (*Fig.8*).

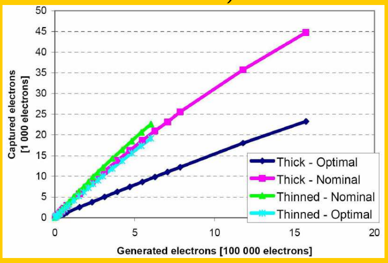

Fig. 7 – Single Point Junk Charge Selection vs. Generated Junk Charge. This plot illustrates the worse case scenario where the charge is injected directly into internal gate for different thicknesses and operational voltages

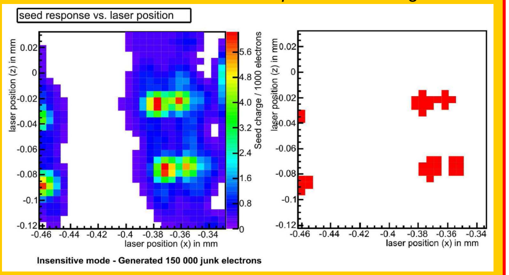

Fig. 8 – Left:Surface IR Laser Scan of the PXD6 50 µm Thick Detector; Right: Regions of the detector where junk charge selectivity is higher than 2% of generated junk charge

Average junk charge selection over the whole area of the sensor is rather low **0.34 %.**

Conclusions

Such fast mechanism which can define a time window, where detector stops integration of new charge, can be used for example to select out noisy bunches injected by an accelerator. To prove this concept of operation, measurements with red and infra red laser were carried out on the DEPFET Mini-matrix system. It was proven, that DEPFET can operate in this way. The average charge selection in the insensitive mode is lower than 0.4% and the suppressed clear mechanism doesn't cause charge loss higher than 200 electrons.

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