Advanced Testing of the DEPFET Minimatrix Particle Detector

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Abstract

The DEPFET (DEPleted Field Effect Transistor) is an active pixel particle detector with a MOSFET integrated in each pixel, providing first amplification stage of readout electronics. Excellent signal over noise performance is gained this way. The DEPFET sensor will be used as an inner pixel detector in the BELLE II experiment at SuperKEKB, electron-positron collider in Japan. The DEPFET sensor requires switching and current readout circuits for its operation. These circuits have been designed as ASICs in several different versions, but they provide insufficient flexibility for precise detector testing. Therefore, a test system with a flexible control cycle range and minimal noise has been designed for testing and characterization of small detector prototypes. Sensors with different design layouts and thicknesses are produced in order to evaluate and select the one with the best performance for the Belle II application. Description of the test system as well as the first measurement results are presented.

DEPFET Particle Detector

DEPFET pixel detector [1] with internal signal amplification is based on a Field Effect Transistor (MOSFET) which is integrated directly into each detector's pixel and provides the 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.

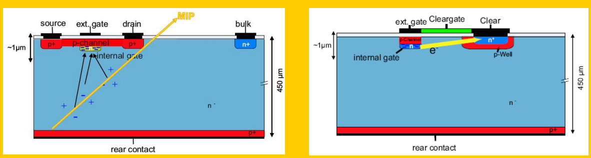

Fig. 1 - DEPFET Pixel Cross-section

Electron potential minimum is close to the front surface, where the MOSFET is located. Electrons are concentrated in a small region under the MOSFET channel, which is called an internal gate (see *Fig. 1*, left).

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, as illustrated in *Fig. 1*, right, and the current is measured again.

Fig. 2 - Photo of the Detector Prototype

The current difference is proportional to the collected charge and defines the signal [2]:

Testing the DEPFET Detectors

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.

The system is composed of commercial and custom-made blocks, such as a PC with an 8-channel PCI data acquisition card, FPGA control card, current readout and switching circuit. The specially designed current readout circuit consists of 8 low noise trans-impedance amplifiers and the control circuit with 12 individual analogue switches that are necessary for control of the DEPFET gate and clear electrodes

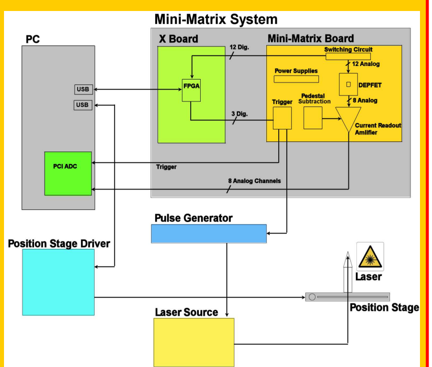

Fig. 3 – Test System Diagram

Red laser and 3-axis position stage with spatial resolution of 1.25 µm was integrated into the system. DAQ software system 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.

In addition, the system allows calibration and a study of the sensor response using different radioactive sources (e.g. Cd^{109}, Fe^{55}, Am^{241}…). Noise levels as low as 8 electrons can be achieved using the described system which allows detailed performance studies of the sensors.

Laser Measurements

Red laser (686 nm) penetrates in about few microns under the surface [3] and charge shearing effect is higher than we will see with particles, but the systematic laser scan of the detector surface gives anyway good information about homogeneity of the charge collection and functionality of the sensor. The position of the laser is known and the laser is triggered by the system, so the exact reproduction of the laser pulse for each point is guaranteed .

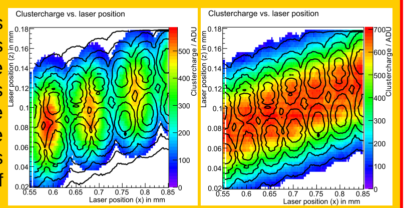

Fig. 4 – Matrix Laser Scan

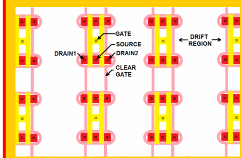

Fig. 5 – DEPFET Layout

Laser scans of several detector productions were done, as PXD5 and new, Belle design, PXD6 thick matrix. The PXD6 design has regions with MOSFETs and drift regions as illustrated in *Fig. 5.* The voltage applied to the drift regions V_{DRIFT} has strong effect on the charge collection of the detector. Too high drift voltage cause inefficient charge collection which is concentrated in the center of the quadruple pixels with a common gate, as visible in *Fig. 4*, left. Black contours indicate the centers of the pixels. *Fig. 4* right shows the same part of the detector with the optimized drift voltage V_{DRIFT} = -7 V, where the charge collection is homogeneous.

A fast voltage optimization scan can be obtained with single pixel arrangement, when the laser beam is focused in the middle of the pixel and operation voltages are swept. This method is however useful for MOSFET operation and clearing voltages which has little effect on charge collection homogeneity. In particular, the drift voltage (see *Fig. 6*) has to be investigated in 2D space, because single point measurement is affected with inhomogeneous electron drift.

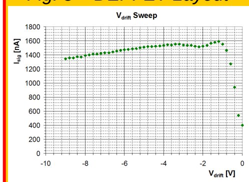

Fig. 6 – V_{DRIFT} Sweep

Radioactive Source Test

Detector tests with a radioactive source are convenient because the energy spectrum can be used for calibration of the detector and gives us information about the detector performance in a more natural way than the laser test. However, since the sensitive area of the minimatrix detector is very small and the system readout is relatively slow (20 to 200 µs / frame), acquisition of a single spectrum takes several hours.

Fig. 7 presents a spectrum obtained by irradiation of the PXD5 series detector with a Fe^{55} source (5.9 keV). Internal amplification of the DEPFET pixels g_q [1] can be calculated when ADU is calibrated in the scale of pA. The calculated internal amplification was 457 pA/e-. Other radioactive sources were also used.

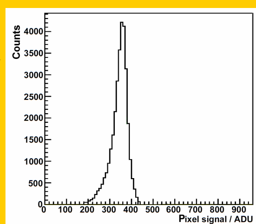

Fig. 7 – Fe^{55} Spectrum

Conclusions & Acknowledgments

We presented complex system for testing of the various production prototypes of the DEPFET detector with the laser beam and radioactive sources. We have shown good functionality of the DEPFET prototypes after voltage optimization. Radioactive source testing allowed us to calculate the internal amplification of the detector to be 457 pA/e-. New version of the system with 16 channels has been designed for future measurements.

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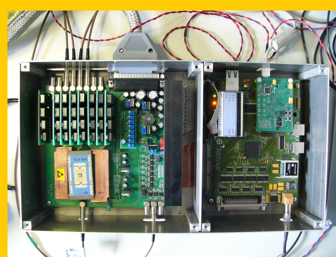

Fig. 8 - Photo of the FPGA control card and the readout and steering electronics

References

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