DEVELOPMENT AND APPLICATION OF A SILICON COORDINATE DETECTORS

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An attempt is made to consider general approach and the techniques for development, investigation and application of multichannel silicon coordinate detectors.

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1. INTRODUCTION

Silicon coordinate detectors (SCD) are widely used in physics, health care and various branches of technology [1,2]. SCD are working at room temperatures, what is very convenient for creation of a tracking system and multiplicity detectors in high energy physics experiment. There are designed multi-layer registering systems including tens square meters of silicon plates consisting of some millions of separate detectors [1,3].

SCD are designed and investigated by KhIPT groups more then 10 years. From 1995, KhIPT group is working on silicon microstrip detector investigation in CERN ALICE Collaboration. The single-sided full-scale prototype of microstrip detector for ALICE experiment has been developed and manufactured with CERN tightly cooperating since 1996 (Fig. 1), (http://alice.web.cern.ch/Alice/pictures/detectors/97-Si-strip-single-side.gif).

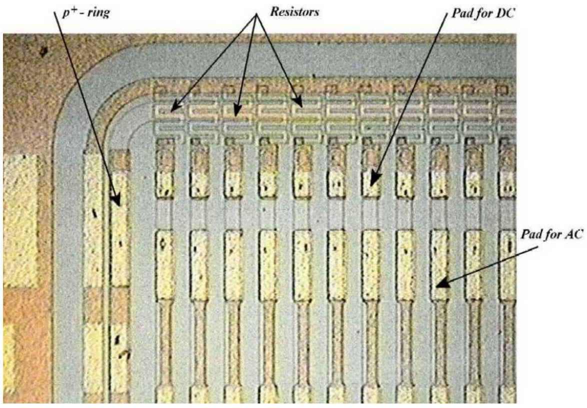

***Fig. 1.** Micrograph of the single-sided full-scale prototype of microstrip detector for ALICE experiment*

The microstrip detector was developed to be the p^+-side of the double-sided microstrip detector (DSMD). The single-sided detectors were used to investigate the influence of an additional insulating Si_3N_4 layer on leakage currents, the breakdown voltage of coupling capacitors, the interstrip resistance, etc. [4,5].

In 1998, the full-scale prototype of a DSMD was manufactured; studies were made of the static characteristics of the detector and their behavior under a 10-year dose of the ALICE experiment [6,7]. The experimental technical base was constructed at NSC KhIPT for design, production and studying the double sided planar and double sided microstrip detectors [8,9], <http://www.kipt.kharkov.ua/Baseinfeng/ALICE/>.

Simultaneously with the main microstrip detector, the planar diode test structures are designed [4,5], (Fig. 2). Diode test structures serve for studying the quality of silicon, for measuring the depleting voltage by a capacitive technique, for preliminary studies of the microstrip detector characteristics and evaluation of their behaviour under irradiation. Their application permits one to shorten the consumption of microstrip detectors at the stage of research and development and of studying the characteristics of the microstrip detector. Diode test structures may have their own importance as the samples of planar detectors and photo-diodes for applying as radiation probes in physics and medical practice [4,5].

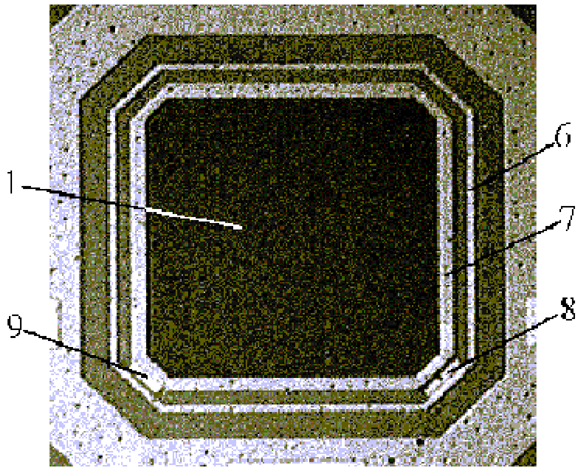

***Fig. 2.** Micrograph of the silicon planar detector: 1 is the active zone of the detector, 6 is the protective ring, 7 is the ring Al contact of the active zone, 8 and 9 are the contact pads of the protective ring and the active zone*

Silicon planar detectors were tested with the charge sensitive amplifier and the analog-to-digital converter

(ADC) of NSC KhIPT design. Spectra below (Fig. 3) show energy resolution 1.4 keV for 2x2 mm^2 planar detector.

Fig. 4 shows the spectral distribution for the photodiode-scintillator detecting system based on CsI scintillator and silicon spectrometric photodiode.

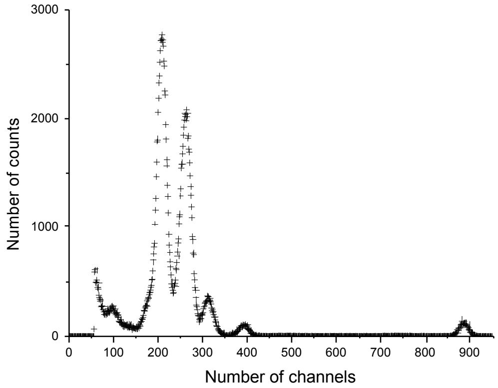

Fig. 3. *Spectral distribution of ^{241}Am 2x2 mm^2 pad detector at room temperature*

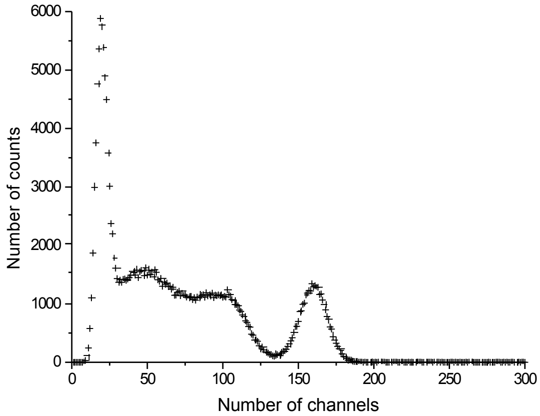

Fig. 4. *Spectral distribution for the photodiode-scintillator detecting system based on CsI scintillator and silicon spectrometric photodiode (5x5 mm^2)*

An attempt is made to consider a general approach and the techniques for development, investigation and application of multichannel silicon coordinate detectors.

2. SPECIALITY OF COORDINATE DETECTORS

Developed during last decades microelectronics technologies are used for production of multichanel silicon coordinate detectors (MSCD). However, construction and working principles of detectors have one radical difference in comparison with tradition integral microelectronics. Large number of detecting channels (up to several thousand) is not connected in common logic network. This fact is complicating, changing in principle and is doing the quality control as key element for all stages of MSCD design and production.

The strict requirements to MSCD with respect to efficiency necessitate the careful monitoring quality before assembling a detector module. The full set of measurements includes a large number of measuring techniques. However, at the final stage, when a large quantity of detectors are produced, it is necessary to determine a minimum number of measuring techniques for full testing that can be used at automated measuring stations.

The full set of techniques for measuring MSCD characteristics, in our opinion, may be grouped into six levels of measurements:

element technological measurements;
measuring physical static characteristics of MSCD;
measuring the good-to-bad MSCD element ratio;
test measurements of MSCD dynamic characteristics;
studying MSCD under conditions of an actual experiment;
monitoring the quality of a large number of MSCD.

Each level possesses its own features and includes several measuring techniques.

3. ELEMENT TECHNOLOGICAL MEASUREMENTS

Technological test structures are designed and created beside the main detector for the first level of measurements [1,2]. One measures mainly the resistance of implanted layers, contact resistance and capacitance. The measurements are performed during the technological process on the plate to adjust and monitor the technological process.

4. MEASURING MSCD STATIC CHARACTERISTICS

Measuring static characteristics of MCSD, especially those of double-sided ones, requires a specialised equipment [3]. Static characteristics measurement is complicated, prolonged and, perhaps impossible for full-scale performance at industrial plants.

Measuring static characteristics of MSCD includes:

- measuring leakage currents of the detector active zone, the guard ring and separate detecting elements (at the test structure) versus voltage;

- measuring the bulk capacitance of test structures and MSCD versus voltage and determining the depletion voltage;
- measuring the capacitance of coupling capacitors;
- measuring the magnitude of the strip biasing resistor;
- measuring the interelements leakage currents on test structures versus voltage and determining the interelements resistance;
- measuring the interelements capacitance versus voltage.

On the ground of the analysis of the data obtained the optimum mode of the MSCD operation is determined and the regime of testing good-to-bad MSCD element ratio is chosen.

Starting from this level, it is necessary to study the variation of detector characteristics resulting from irradiation, i.e., radiation tolerance. After the MSCD radiation test is completed, the full set of measurement is repeated.

5. MEASURING THE GOOD-TO-BAD MSCD ELEMENT RATIO

Measuring the good-to-bad ratio of the MSCD elements (p/n junctions of the detecting elements, integrated capacitors and resistors) even at the stage of the detector development is impossible without the automated (semi-automated) probe station [3]. It is explained by the necessity of measuring several parameters of a large number of strips. At this stage a necessity arises to determine the minimum number of measuring techniques for full testing the multichannel detector with respect to the good-to-bad element ratio.

In this section the possible MSCD defects are considered. Some of techniques for revealing these defects that may be applied for automatic measurement are also described.

5.1 DEFECTS

All defects affecting the good-to-bad detecting element ratio may be divided into three groups:

1. defects of p^+ and n^+ implantation;
2. defects of coupling capacitors;
3. defects of contacts and biasing resistors.

Group 1 includes the following defects:

- Breakdown of the p-n junction and n^+ implantation. This defect increases the leakage current of the detecting element;
- Short-circuiting p^+ implantation. This defect increases the interstrip capacitance and the interstrip leakage current;

Group 2 includes the following defects:

- Short-circuiting of aluminium layers of integrated coupling capacitors. This defect gives rise to the increase of the capacitance and the leakage current of coupling capacitors proportional to the number of short-circuited detecting elements;
- Breaking an aluminium layers of integrated coupling capacitors. This defect gives rise to the decrease of the capacitance and leakage current of coupling capacitors;
- Breakdown of a coupling capacitor. This defect gives rise to the strong increases of capacitance and leakage current of the capacitor.

Group 3 contains the following defects:

- Variation of the bias resistor value. This defect varies the voltage drop across the biasing resistor;
- Lack of contact and breaking of integrated polysilicon resistor. This defect strongly increases the voltage drop across the biasing resistor.

5.2 MEASURING TECHNIQUES APPLIED FOR AUTOMATED MEASUREMENTS

In order to reveal the defects described in preceding section the measurements of five parameters may be used:

- capacitance and leakage current of coupling capacitors;
- strip leakage current;
- interstrip resistance;
- interstrip capacitance.

Measuring these four parameters enables one to reveal all defects listed above. The capacitance and the leakage current of coupling capacitors reveal all defects associated with coupling capacitors. The voltage drop across the biasing resistor reveals the p-n junction breakdown, breaking p^+ and n^+ implantation as well as variation of the biasing resistor value and the lack of contact between p^+ detecting element and the basing line. Variation in the interstrip capacitance reveals the defects associated with short-circuiting and cuts of p^+ implantation.

For performing the measurements in the automated mode the detector is connected to the voltage supply via a special extender.

As a result of measuring one parameter we get a file containing strip numbers and the values of the parameter measured (for coupling capacitors there are two parameters, i.e., the capacitance and the leakage current). Performing the measurements considered above enables one to determine the efficiency of a future detector, its energy resolution, signal-to-noise ratio for a particle with minimum ionisation etc with high accuracy. However without test measurements of MSCD dynamic characteristics the performance of the initial testing of the detector cannot be regarded as completed.

6. TEST MEASUREMENTS OF DYNAMIC CHARACTERISTICS

Performing the measurements of MD dynamic characteristics enables one to obtain the signal-to-noise ratio as a universal characteristic of a detector. To this end one can apply isotope sources of electrons and gamma radiation. In the first case the measurements within the total spectrum may be performed for the detector as a whole and for each separate strip, whereas in the second case they are made only for each strip separately.

The test module of special design is manufactured for dynamic tests [10]. Apart from the detector it comprises the chips of the readout electronics, printed circuits for mounting chips and supplying control signals for them, microcables for welding contact pads of chips and the detector. Printed circuit boards (PCB) are designed in KIPT and use a full surface nickel coating that provides easy and durable bonding aluminium wires and microcables to contact pads on the PCB at low cost. Also this coating allows a good surface mounting for SMD components.

On using the source of electrons one determines the signal-to-noise ratio for a particle with minimum ionisation over all strips at once (Fig. 5). To this end one applies a fast analogue-to-digital converter with memory and specially designed software for the spectrum accumulation permitting to determine the clusters during the accumulation process.

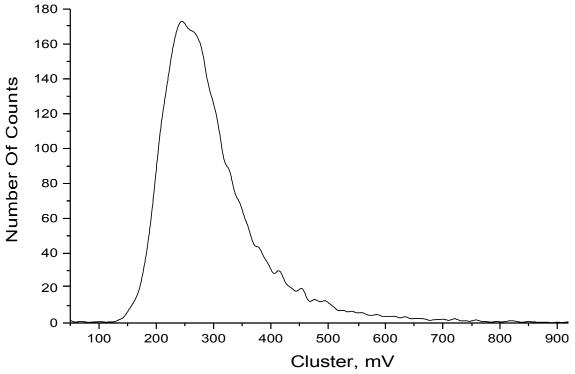

***Fig. 5.** Determination of the signal-to-noise ratio by using an isotopic electron source*

Application of a gamma source enables one to determine the energy resolution with high accuracy. Fig. 6 shows determination of the signal-to-noise ratio by using an isotopic gamma source ^{241}Am.

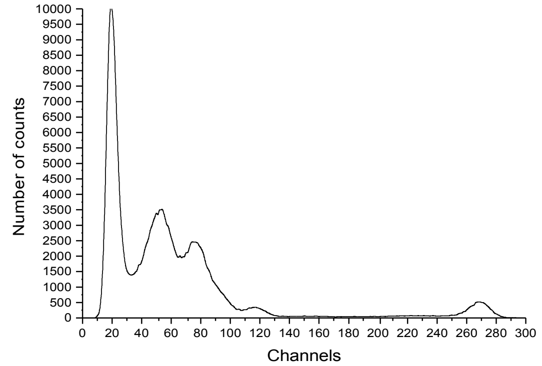

***Fig. 6.** Determination of the signal-to-noise ratio by using an isotopic gamma source ^{241}Am*

7. STUDYING DMSD UNDER CONDITIONS OF AN ACTUAL EXPERIMENT

Performing tests anticipates a beam experiment with the conditions closest to ones of an actual experiment. The beam experiment enables one to measure the spatial resolution of the detector with higher accuracy as well as to determine a possible variation of the detector efficiency in an actual module.

8. MONITORING THE QUALITY OF A LARGE NUMBER OF MSCD ON THE MODULE PRODUCTION STAGE

Measurement procedure on the stage of the MSCD production may consist of two main parts. In first part the typical physical characteristics are determined for each detector and detector long-term stability should be measured. In second measurement part the accordance of each strip characteristics to official detector specification are controlled and number of bad strips are determined. Each of both parts requires design and development specialised automated probe stations.

It is necessary, because the monitoring of MSCD quality requires the performance of a large number of measurements over a large number of detectors. Perhaps this problem should be solved via reasonable reduction in the number of measurements as well as via an increase in the number of a different automated probe stations. Both ways of solution are feasible and they will be realised depending on particular circumstances: total number of detectors, quality of detectors and conditions of testing. This monitoring of DSMD before detector modules assembling is finished in form a data sheet for each detector.

REFERENCES

1. G. Batignoni et all. Beauty physics and double-sided Si microstrip detectors // *Nucl. Phys. B (Proc. Suppl.).* 1991, v. 23A, p. 297-306.
2. Fabio Sauli. *High-rate, position-sensitive radiation detectors: recent developments and application in particle physics, medicine and technology.* CERN-PRE/94-150, 24 August 1994.
3. ALICE. *Technical proposal.* CERN/ LHCC/95-71 LHCC/P3 15 December 1995.
4. A.P. de Haas, P. Kuijer, V. Kulibaba, N. Maslov, V. Perevertailo, S. Potin, A. Starodubtsev. *Radiation tolerance of single-sided microstrip detector with Si_3N_4 insulator.* ALICE/PUB 98-24, 5 Nov. 1998.
5. N. Maslov, V. Kulibaba, S. Potin, A. Starodubtsev, P. Kuijer, A.P. de Haas, V. Perevertailo. Radiation tolerance of single-sided microstrip detector with Si3N4 insulator *// Nuclear Physics B (Proc. Suppl.).* 1999, №78, p. 689-694.
6. A.P. de Haas, P. Kuijer, V. Kulibaba, N. Maslov, V. Perevertailo, S. Potin, A. Starodubtsev. *Characteristics and radiation tolerance of a double-sided microstrip detector with polysilicon biasing resistors*. CERN, ALICE/99-21, Internal Note/SIL, 6 April 1999.
7. A.P. de Haas, P. Kuijer, V.I. Kulibaba, N.I. Maslov, V.L. Perevertailo, V.D. Ovchinnik, S.M. Potin, A.F. Starodubtsev. Characteristics and radiation tolerance of a double-sided microstrip detector with polysilicon biasing resistors //

Problems of Atomic Science and Technology. Ser.: NPI. 2000, №2(36), p. 26-33.

8. P. Kuijer, A. Kaplij, V. Kulibaba, N. Maslov, V. Ovchinnik, S. Potin, A. Starodubtsev. *Control complex for a double-sided microstrip detector production and tests.* CERN, ALICE/99-45, Internal Note/ITS, 5 October 1999.
9. P. Kuijer, A. Kaplij, V. Kulibaba, N. Maslov, V. Ovchinnik, S. Potin, A. Starodubtsev. Control complex for a double-sided microstrip detector production and tests // *Problems of Atomic Science and Technology. Ser.: NPI.* 2000, 2(36), p. 41-45.
10. V.I. Kulibaba, N.I. Maslov, S.V. Naumov, V.D. Ovchinnik, I.M. Prokhorets. Readout electronics for multichannel detectors // *Problems of Atomic Science and Technology. Ser.: NPI.* 2001, №5(39), p. 177-179.