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INVESTIGATION OF THE DYNAMIC CHARACTERISTICS OF SILICON DOUBLE-SIDED MICROSTRIP DETECTORS

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The energy resolution of both microstrip and pad detectors, fabricated on the same wafer, is investigated. Isotopic sources of gamma-radiation are used for energy resolution measurements. The active area of the planar detector is identical to the area of a single strip of the microstrip detector. Study of this pad detector gives the maximal possible energy resolution, since the influence of interstrip capacitance and other properties of the extended microstrip structure that decrease the energy resolution are excluded. Characteristics of the microstrip structure that diminish the energy resolution and methods of research of such characteristics are considered.
KEY WORDS: silicon microstrip detectors, energy resolution, signal-to-noise ratio

Microstrip detectors are the most widespread type of position-sensitive semiconductor detectors [1-3]. With their application the highest spatial resolution can be achieved while keeping the number of detecting channels relatively small in comparison to, for example, pixel detectors. Also, microstrip detectors are simpler to fabricate and to operate than, for example, solid-state drift detectors. A number of measurements of dynamic characteristics of the detector with use of a single-channel readout system with high-energy resolution were carried out with the purpose of investigating the performance limitations of the entire detecting system. This single channel readout system has been developed in NSC KIPT especially for semiconductor detectors with less than 10 pF capacitance. It consists of a low noise charge sensitive preamplifier, a semi-Gaussian shaper and a 12-bit peak-sensing ADC. The equivalent noise (ENC) of the readout system is 0.75 keV + 15 eV/pF (FWHM, in silicon). Isotopic sources of gamma-radiation ^{241}Am (primary) and ^{57}Co (auxiliary) were used for energy resolution measurements. The energy resolution of both microstrip and pad detectors, fabricated on the same wafer, was investigated. Because the active area of the planar detector is identical to the area of a single strip of the microstrip detector, study of this pad detector gives the maximal possible energy resolution, since the influence of interstrip capacitance and other properties of the extended microstrip structure that decrease the energy resolution are excluded. All microstrip detectors described in this work have been designed at NSC KIPT as detectors for the inner tracking system of the ALICE (CERN) experiment. The thickness of the detectors is 300 μm and the strip pitch of is 95 μm. Pad detectors were fabricated on the same wafers with the microstrip detectors to be used as test structures. Before conducting the measurements, the detectors have been thoroughly tested to measure static characteristics such as leakage currents and interstrip capacitances to recognize their quality and suitability for detecting low energy gamma radiation. All strips of the detectors have less than 1 nA leakage current and less than 4 pF capacitance ($C_{bulk} + C_{interstrip}$) while operating at 50 V depletion voltage and at room temperature.

ENERGY RESOLUTION OF PAD DETECTORS

Pad detectors are used often as test structures for measurements of C-V curves and of the depletion voltage of microstrip detectors. The pad detectors are fabricated on the same wafer with microstrip detectors and they possess all the necessary guard rings and contact pads but they do not have any additional elements such as resistors or capacitors and they are free from parasitic interstrip effects. Therefore, these detectors are the purest test structures for microstrip detectors and they allow effective research of key properties of much sophisticated microstrip detectors. In addition, pad detectors allow to determine the maximal possible energy resolution for strips because they have exactly the same active area size as strips do, so their bulk capacitances and leakage currents are approximately the same either. A compact single channel readout system with high-energy resolution was used for thorough tests of pad detectors and low capacitance strips. The first stage of the preamplifier was thoroughly designed to reach optimal performance and a dual-gate ultra low input capacitance JFET was chosen to ensure the lowest noise at zero input capacitance. 1.0 keV FWHM (59.6 keV gamma, ^{241}Am) energy resolution was obtained for the square silicon pad detector with 4 mm^2 active area. The spectrum of the ^{241}Am gamma-source is shown on Fig. 1. All measurements were performed at room temperature which is a usual demand for such investigations.

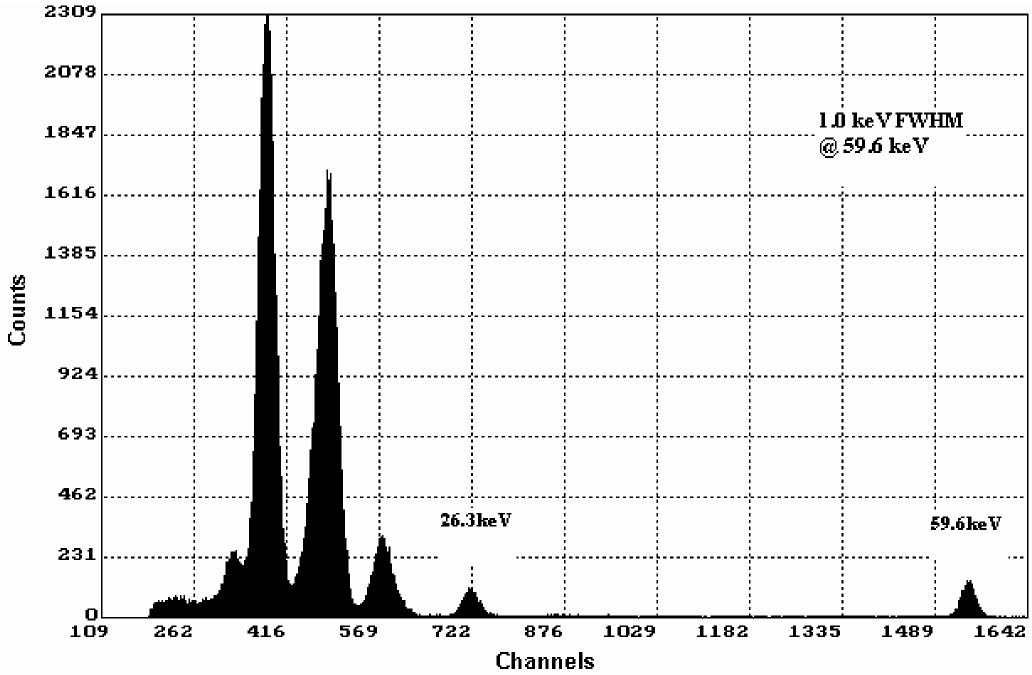

Fig. 1. ^{241}Am gamma spectrum obtained with the small 4 mm^2 silicon pad detector at room temperature

ENERGY RESOLUTION OF STRIPS

Dynamic characteristics of strips of a double-sided detector were tested. A simple test module was assembled in order to achieve this goal. The module includes one double-sided silicon microstrip detector and pads on a thin ceramic board. The detector is connected to the pads by means of ultrasonic bonding. An isolated strip, without integrated bias resistor, was tested in DC-coupling mode. 6 keV FWHM (59.6 keV gamma, ^{241}Am) energy resolution was obtained in first series of tests of the strip, see Fig. 2.

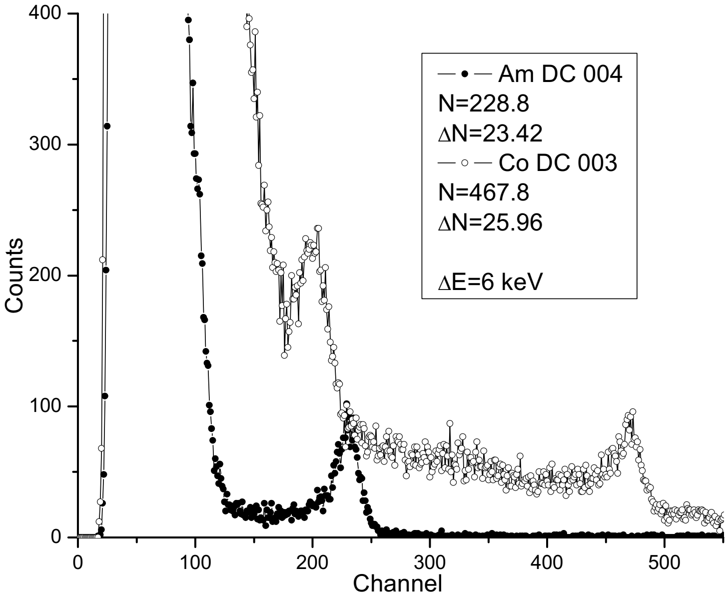

Fig. 2. Spectrum of gamma radiation detected with DC-coupled isolated strip, energy resolution is 6 keV FWHM (59.6 keV gamma, ^{241}Am). ^{57}Co was used to identify the zero energy channel of the ADC.

A regular strip was tested in AC-coupling mode, its energy resolution was measured and it was 4.5 keV FWHM (59.6 keV gamma, ^{241}Am), shown on Fig. 3. This is much worse resolution than one for the pad detectors, even if the pad detectors have approximately the same capacitances and leakage currents as strips do. It happened because of clusters of signals, which appear when charge is distributed among a group of strips, and such an event causes distortion in spectra. This is a weak spot of a single-channel readout system and a multi-channel readout system should eliminate the problem. The isolated strip in DC-coupling mode had a worse spectrum than a regular one with AC-coupling and this fact shows that additional charge loss had taken place during tests of the isolated strip.

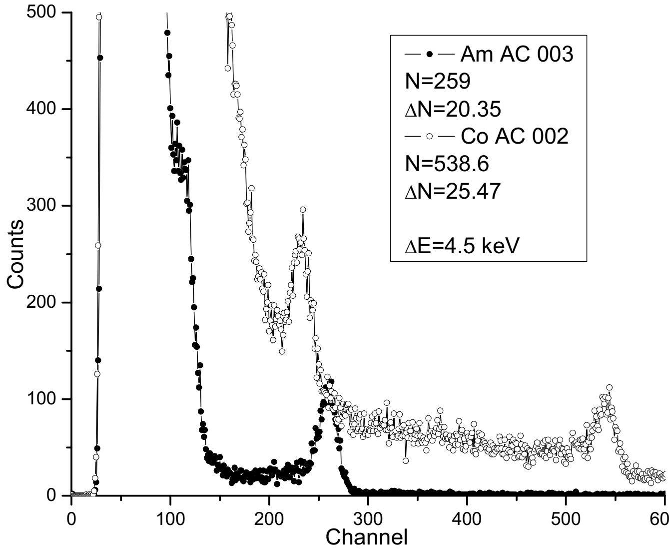

Fig. 3. Spectrum of gamma radiation detected with AC-coupled regular strip, energy resolution is 4.5 keV FWHM (59.6 keV gamma, ^{241}Am)

To understand this point, measurements were made with two neighboring strips grounded for both types of strips and the gamma-source was strictly collimated and positioned sequentially at five places above the strip, starting from a pad connected to the preamplifier. Grounding the neighboring strips resulted in 8% lower amplitude of signals from the main strip (see Fig. 4) and we suppose that took place because signals from adjacent strips were not fed into the main strip via interstrip capacitances as they were with neighboring strips floating free.

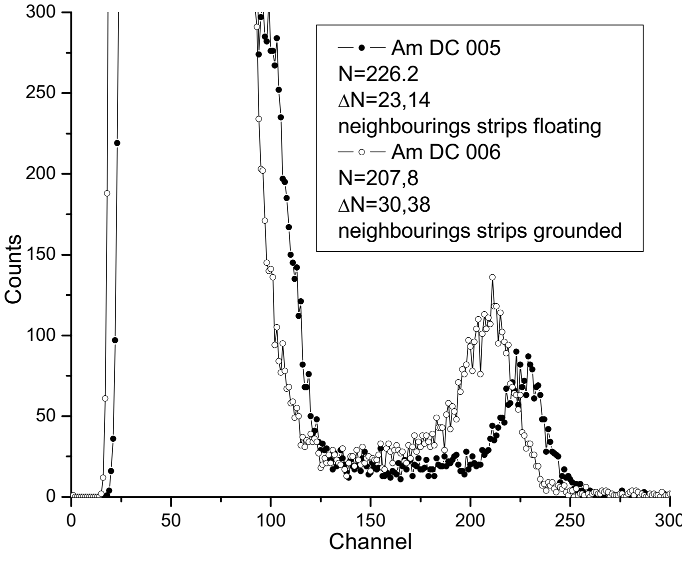

Fig. 4. ^{241}Am gamma 59.6 keV peaks in cases of floating and grounded neighboring strips

This could happen also when the X-ray-generated charge was deposited under the central strip and in that case when the adjacent strips were grounded the central strip had higher ratio of parasitic C to C vs. the readout node (coupling C) so that more charge was being lost in comparison to the case of floating adjacent strips. Positional measurements with a collimated gamma-source demonstrated full independence of amplitude vs. position in case of AC-coupling, as anticipated. The energy resolution of the DC-coupled strip was 20% lower when the gamma-source was above the opposite end of the strip because of resistance of the p+-implantation of the strip, which goes up to 10^5 ohms at full length. Supposedly, that resistive effect made charge go via an integrated capacitance of the strip instead of a direct way through a thin p^+-implantation layer as such a large resistor on the way of charge would cause excessive noise but peaks in the spectrum were quite clear and with 6 keV FWHM (for 59.6 keV gamma peak, ^{241}Am) energy resolution. This will be investigated further with more attention in order to propose changes to the existing detector design for better compatibility with DC-coupling readout mode and the detector module will be redesigned to continue investigation of energy resolution of strips. AC-coupling method has proven to be the best choice for the tested microstrip detector as it has fewer problems with readout in contrast to DC-coupling.

CONCLUSION

Analysis of the energy resolution measurements on strips and pad detectors with the single channel readout system has shown their efficiency and usefulness. The maximal energy resolution for strips was not achieved during the tests though, but those tests were quite informative in obtaining more data about strips behavior in gamma-spectrometry applications. Pad detectors have demonstrated the maximal energy resolution in these measurements and this fact shows the real benefit of using them as tests structures for larger microstrip detectors. It is also planned in the near future to perform similar measurements on IRST double-sided detectors developed at INFN Trieste.

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ИССЛЕДОВАНИЕ ДИНАМИЧЕСКИХ ХАРАКТЕРИСТИК КРЕМНИЕВЫХ ДВУХСТОРОННИХ МИКРОСТРИПОВЫХ ДЕТЕКТОРОВ

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Исследовано энергетическое разрешение микрострипового и планарного детекторов, изготовленных на одной пластине. Для измерения энергетического разрешения использовались изотопные источники гамма-излучения. Площадь активной области планарного детектора идентична площади одного стрипа микрострипового детектора. Изучение планарного детектора дает максимально возможное значение энергетического разрешения, так как исключено влияние межстриповой емкости и других протяженных структур, ухудшающих энергетическое разрешение. Рассмотрены параметры микростриповой структуры, уменьшающие энергетическое разрешение, а так же методы исследования таких параметров.

КЛЮЧЕВЫЕ СЛОВА: кремниевые микростриповые детекторы, энергетическое разрешение, отношение сигнал/шум