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SPECTROMETRIC REGISTRATION OF X-RAY AND GAMMA RADIATION BY DETECTING MODULES "SILICON PLANAR DETECTOR–SCINTILLATOR"

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The use of detection modules based on a silicon planar uncooled detector and a scintillator in combination with readout electronics makes it possible to create detection complexes for spectrometric detection of X-ray and gamma radiation in various fields of research, including nuclear physics, nuclear power engineering, high-energy physics, medicine, etc. The results of a study of detection complexes with silicon detectors with an active area of 2×2 and 5×5 mm and cesium iodide scintillators doped with thallium in the energy range from 50 keV to 0.662 MeV are presented.

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INTRODUCTION

The use of a silicon planar detector with a thickness of 300 µm as a detector makes it possible to reliably and with high energy resolution register radiation in the energy range from 5 to 50 keV. The advantages of a silicon detector are the small energy that is spent on creating an electron-hole pair, which is about 3.6 eV in silicon, high speed of statistics collection, the most developed technology for the manufacture of silicon detectors, high radiation resistance, the ability to work in magnetic fields, in vacuum and in liquid. However, at energies above 50 keV, the effectiveness of silicon detectors is significantly reduced.

Radiation with an energy of more than 50 keV should be registered with the help of detection systems consisting of a scintillator and a photodetector, as which a silicon planar detector is used. When X-ray and gamma radiation pass through the volume of the scintillator crystal, light photons are generated in it, which are registered by a silicon detector. The number of photons emitted in the scintillator is equal to the absorbed energy, which allows obtaining energy spectra of radiation.

The CsI(Tl) scintillator has a number of advantages over other scintillators, including high light output (54 photons/keV), good agreement between the emission spectrum and the spectral characteristics of a silicon detector, low hygroscopicity and low hardness, which facilitates machining [1, 2].

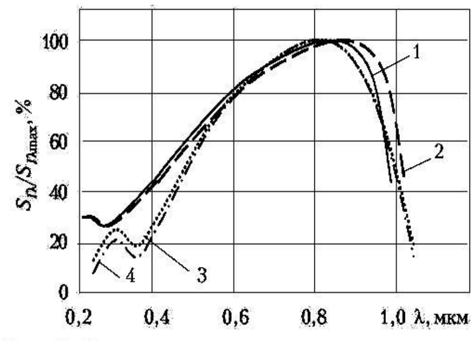

Fig. 1. Spectral characteristics of the sensitivity of silicon detectors in various detectors [1]

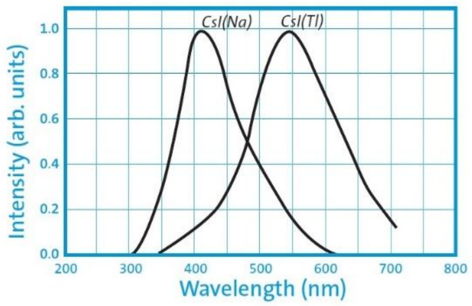

Fig. 2. Scintillation emission spectrum of CsI [2]

Sensitivity of silicon is 70% for emission with wavelength close to 550 nm, with a maximum of emission of the scintillator, which makes it possible to efficiently use the combination of CsI(Tl) scintillator and silicon detector (Figs. 1, 2).

DESIGN AND MANUFACTURING OF SPECTROMETRIC ELECTRONICS

For registration of X-ray and gamma-ray production in the spectrometric mode, the electronics for reading signals from a planar silicon detector were prepared. The read-out system is composed of a charge-sensitive amplifier (CSA), able to work with silicon planar detectors with a capacity of up to 50 pF and input current up to 10 nA (at 200 MΩ feedback resistors), and a forming amplifier made in a form of Gaussian CR-(RC)^n amplifier. To reduce the dimensions of CSA, SMD elements were used. The scheme of the electronic layout is classical, similar to those used for other types of detector systems [3–5], but the parameters are other then in the layout presented in the article [5].

For optimal filtering of signals from planar silicon detectors at room temperatures, it has been experimentally established that a peak forming time of up to 1.5 µs gives the best result, since the current of an uncooled detector gives additional low-frequency noise, reducing the signal-to-noise ratio at long edge pulses. Optimal filtering of signals from the "silicon detector-scintillator" module is somewhat different from filtering signals from the detector without a scintillator, since the charge collection time in the detector is significantly longer (up to 1 μs) and depends on the scintillator luminosity characteristics. The signal-to-noise ratio increases with peak formation time to approximately 6 μs.

DESIGN OF DETECTING MODULES

Detection modules for spectrometric detection of X-ray and gamma radiation are based on design and technological solutions similar to those adopted in the detection of ionizing radiation based on planar silicon uncooled detectors and in the detection of thermal neutrons using a metal gadolinium converter developed at NSC KIPT [3, 6] .

Structurally, the modules consist of a base on which a dielectric board with intermediate terminals and an unpackaged silicon planar detector chip is fixed, a scintillator glued to the active area of the detector, a collimator surrounding the scintillator, a housing with an inlet window and external terminals for connecting to the preamplifier of the readout electronics. The modules can be manufactured either in a remote version or integrated one in the same housing with a preamplifier.

Schematically typical designs of detecting modules are shown in Fig. 3.

As a detectors, a bare silicon planar detector chips developed by NSC KIPT, 300 μm thick, with an active area of 2×2 or 5×5 mm, are used.

The CsI(Tl) scintillator, in the form of a prism or cylinder, one of the ends of which is cut in the form of a square with sides equal to the size of the active area of the detector, is wrapped with a reflective film.

To minimize contaminants that could degrade the energy resolution of the silicon detector, the scintillator is glued to the active region with an optically clear, high purity adhesive.

A silicon detector crystal and intermediate terminals made of gold-plated copper foil are glued to a dielectric board made of glass-ceramic with a thickness of 0.6 mm, fixed on the base of the housing. Intermediate terminals are designed for bonding aluminum wire loops between intermediate terminals and pads of the detector chip, as well as for soldering external terminals.

Due to the small size of aluminum pads on the silicon chip of the detector (~ 150×150 μm), aluminum wire with a diameter of 25 μm is used for bonding jumpers, which is widely used in microelectronic production in the manufacture of microcircuits.

A lead or tungsten collimator surrounding the detector and the scintillator, or the scintillator alone, provides the directional action of the detection module.

Depending on the purpose of the detecting module, the housing designed to protect against destabilizing environmental factors can be made of aluminum (see Fig. 3,a) or stainless steel (see Fig. 3,b). The inlet window in the module housing, located on the side of the scintillator end, is covered with beryllium or aluminum foil.

External terminals (see not shown in Fig. 3) provide connection between the detecting module and the preamplifier.

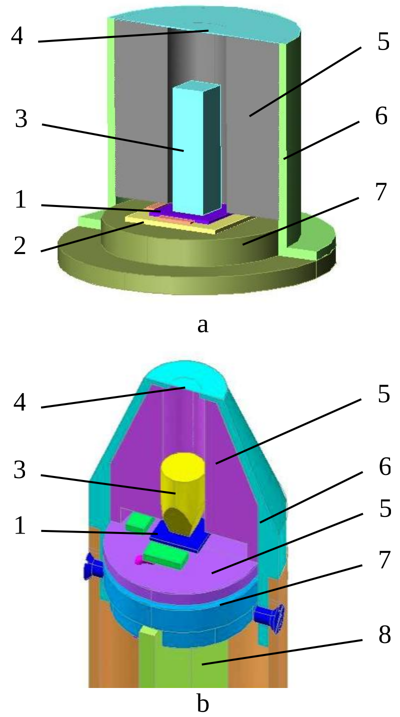

Fig. 3. Schematic design:
a – remote module; b – integrated module;
1 – silicon planar detector, 2 – dielectric board,
3 – scintillator, 4 – inlet window,
5 – collimator, 6 – body, 7 – base, 8 – CSA

In order to select detectors for the manufacture of detecting modules, studies of the static characteristics of a batch of silicon planar detectors were carried out, for which an automated test station for planar detectors was used (Fig. 4), which provides the ability to measure leakage currents and capacitance-voltage characteristics with high accuracy [4].

A light-protected manual probe station with a microscope and micropositional probes is used to connect bare silicon planar detector chips to the instruments. Measurements are made with a KEITHLEY Model 6487 Powered Picoammeter and an LCR Meter.

Fig. 4. Automated test station for measuring the static characteristics of silicon planar detectors

The developed software of the test station allows to automatically plot the graphs of the dependence of the active region and the protective ring leakage currents, as well as the capacitance on the depletion voltage.

Typical graphs of the static characteristics of the detectors are shown on Figs. 5–7.

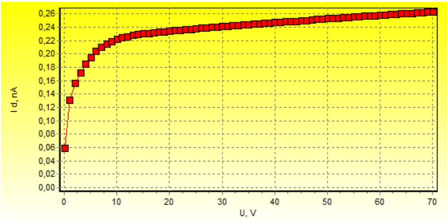

Fig. 5. Dependence of the active region leakage current of the detector on the depletion voltage

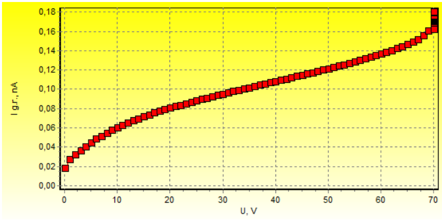

Fig. 6. Dependence of the protective ring leakage current of the detector on the depletion voltage

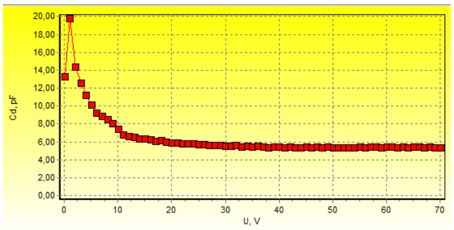

Fig. 7. Dependence of the detector capacitance on the depletion voltage

According to the results of the measurements, detectors with satisfactory characteristics were selected for the manufacture of research detecting modules.

The photographs of the manufactured research samples of two types of detecting modules without a housing and in housings are shown on Figs. 8, 9.

Fig. 8. Samples of detecting modules at various stages of assembly (collimator and housing removed)

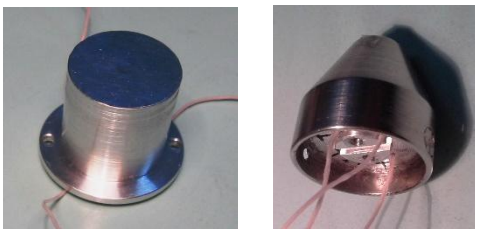

Fig. 9. Research detecting modules in the housing

INVESTIGATION OF SPECTROMETRIC CHARACTERISTICS

Studies of spectrometric characteristics during the registration of X-ray and gamma radiation were carried out using manufactured research samples of detecting modules with detectors sized 2×2 and 5×5 mm (see Fig. 9), developed spectrometric readout electronics, spectrometric measuring complex and certified gamma radiation sources of ^{57}Co, ^{137}Cs, and ^{241}Am in the energy range from 60 keV to 0.662 MeV. A feature of the electronic circuit is the use of the 2SK932 transistor in the SOT-23 package, while the formation time constant was 6 µs.

The spectra obtained during the study are shown in Figs. 10–13.

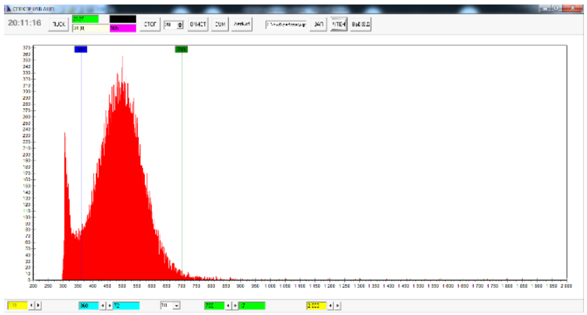

Fig. 10. Detector 2×2 mm, source ^{57}Co, resolution 35.3 keV

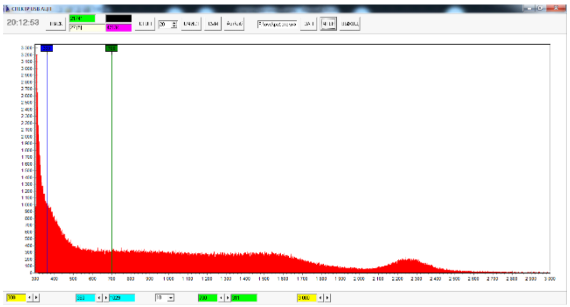

Fig. 11. Detector 2×2 mm, source ^{137}Cs, resolution 59.7 keV

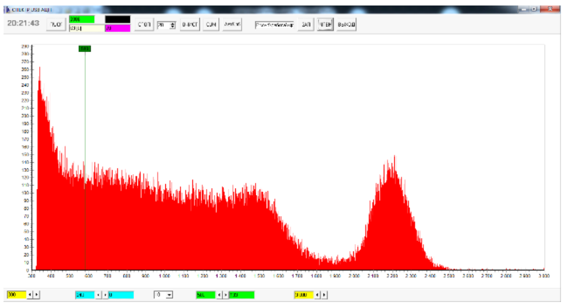

Fig. 12. Detector 5×5 mm, source ^{137}Cs, resolution 65.5 keV

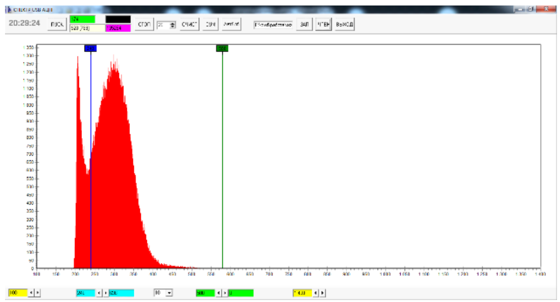

Fig. 13. Detector 5×5 mm, source ^{241}Am, resolution 29.4 keV

The obtained experimental spectra were compared with the theoretical ones and showed satisfactory agreement.

CONCLUSIONS

A design has been developed and research samples of the “silicon planar detector-scintillator” detection complex based on an uncooled silicon detector developed by NSC KIPT and a CsI(Tl) scintillator have been manufactured.

An electrical circuit of a charge-sensitive preamplifier using SMD components and a forming signal amplifier for detecting complex for spectrometric registration of X-ray and gamma radiation has been developed.

Studies of the spectrometric characteristics of the fabricated research samples were carried out in the energy range from 60 keV to 0.662 MeV, with certified ^{57}Co, ^{137}Cs and ^{241}Am radiation sources.

Studies have shown the efficiency of the developed detector design and satisfactory results of energy resolution. Solutions are proposed to improve the design of the detecting module and the preamplifier to improve the energy resolution.

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СПЕКТРОМЕТРИЧНА РЕЄСТРАЦІЯ РЕНТГЕНІВСЬКОГО І ГАММА-ВИПРОМІНЮВАННЯ ДЕТЕКТУЮЧИМИ МОДУЛЯМИ «КРЕМНІЄВИЙ ПЛАНАРНИЙ ДЕТЕКТОР–СЦИНТИЛЯТОР»

Г.Л. Бочек, О.А. Каплий, С.К. Кіпріч, Г.Д. Коваленко, М.І. Маслов, В.Д. Овчинник, І.Л. Семісалов, Ф.О. Широкопєтлєв, І.М. Шляхов, М.Ю. Шуліка, Г.П. Васильєв, В.І. Яловенко

Використання детектуючих модулів на основі кремнієвого планарного неохолоджуваного детектора і сцинтилятора в поєднанні з реєструючою електронікою дозволяє створювати комплекси для спектрометричної реєстрації рентгенівського і гамма-випромінювання в різних областях досліджень, включаючи ядерну фізику, ядерну енергетику та інші дослідження детектуючих комплексів з кремнієвими детекторами і активною площею розміром 2×2 та 5×5 мм та сцинтиляторами з іодиду цезію, легованого талієм, у діапазоні енергії 50 кеВ…0,662 МеВ.