EFFECTIVE THICKNESS OF THE PLANAR DETECTOR IN MEASUREMENTS OF ELECTRONS ENERGY LOSS

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An experimental method of determining the active region thickness of Si planar detector was used. The method based on the dependence the depletion layer thickness from voltage applied to the detector ($U = 0...60\,V$). The electron energy loss spectra emitted by $^{90}Sr -^{90}Y$ in silicon planar detector were measured. The relative values of most probable energy loss of electrons were defined for different thickness of detector. The planar detector was considered as a parallel-plate capacitor. The static (capacity) and dynamic (the detection efficiency and the energy deposit) characteristics had a root dependence on voltage.

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1. INTRODUCTION

In the present work, an experimental method for determining the thickness of the active region Si of a planar detector was used, based on the dependence of the thickness of the depleted layer of the Si pin detector on the voltage applied to it. The measurements electrons energy loss was used for determination effective thickness of the planar detector [1, 2, 3]. For this experiment spectrometric equipment was available, including the required amount of Si uncooled detectors developed in NSC KIPT [4, 5, 6]. The detectors have good energy resolution ($FWHM$=0.9 keV). Detectors with an area of $2\times2\,mm^2$, $5\times5\,mm^2$ and a thickness of $0.3\,mm$ were used. The design of an uncooled planar Si detector is described in detail in [5]. The features of gamma-ray detection [7, 8] and electrons [9, 10] have been experimentally studied in detail.

2. RESULTS AND DISCUSSION

2.1. Measuring of the depletion layer thickness by electrophysical characteristics of detector

The thickness of the depleted (working) layer for planar detector depends on the voltage depletion submitted to it. In the first approximation planar detector seen as a flat capacitor. Volume capacity C_b per unit area detector (approximation of plane capacitor) was calculated using the depletion layer depth (d) and depletion voltage U_b in [11, 12]:
$C_b = (q * e_{Si} * N_{eff}/2 * U_b)^{1/2}$ for U_b less U_d,
$C_b = e_{Si}/d_d$, for U_b more U_d, where: d_d – depth of complete depletion; U_d – full depletion voltage; e_{Si} – dielectric permittivity of silicon; q – charge of electron; and N_{eff} is the effective charge carrier density. Fig.1 schematically shows the working layer thickness of the Si planar detector (blue).

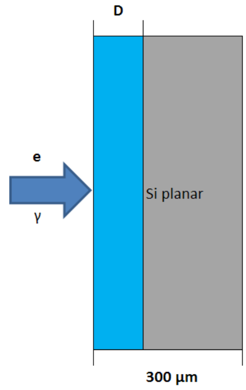

Fig.1. *Cross-section of Si planar detector* $300\,\mu m$ *thick, D = thickness of the depleted layer.*

Fig.2 shows the results of measurements of the detector capacitance as a function of the depletion voltage for the Si planar detector $5\times5\times0.3\,mm^3$

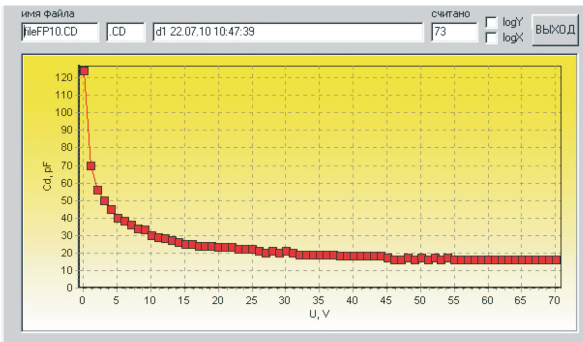

Fig.2. *The results of measurements of the detector capacitance as a function of the depletion voltage for the Si planar detector* $5\times5\times0.3\,mm^3$

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Fig.3 shows how this results transformed to the depletion layer thickness as a function of the depletion voltage for the Si planar detector $5 \times 5 \times 0.3\,mm^3$.

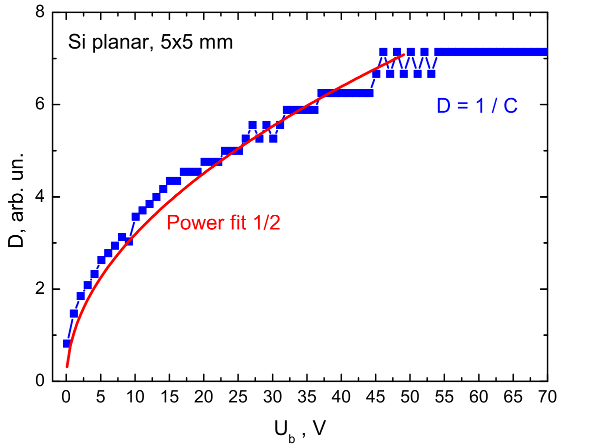

Fig.3. *The depletion layer thickness as a function of the depletion voltage for the Si planar detector* $5 \times 5 \times 0.3\,mm^3$

The dependence of the thickness of the active layer on the voltage is well approximated by the root dependence. The difference in the thickness of depletion layer D measured by electro-physical method reaches 8 times. For the other detectors reduction D was about 4.5...7. Note that the root dependence of the thickness of the working layer for voltage greatly smoothes the numerical reduction of thickness. Thus, by changing the voltage of $36\,V$ to $1\,V$ we can reduced thickness of no more than 6 times, accounting for 300/6 about $50\,\mu m$.

2.2. Measurement of the active layer thickness from the change in the spectra of the energy losses of electrons as a function of the detector depletion voltage

Earlier in [9, 10], we showed that the use of dual detectors and the coincidence circuit makes it possible to obtain the classical Landau distribution using $^{90}Sr - ^{90}Y$ source [13] for the energy loss of electrons, and also allows to register electrons at a high level of the gamma background. It is difficult to precisely determine the energy of electrons from the spectra of the extracted energy because of the absence of a pronounced maximum (MPV) in the distribution of losses. In addition, energy losses in silicon are practically constant in the range $0.5...5\,MeV$.

Here, the electron energy loss spectra are measured in a silicon planar detector from a $^{90}Sr - ^{90}Y$ source depending on the depletion voltage U_b of the detector in the range $0...60\,V$. Energy loss spectra were obtained both for a single detector and for a system of two detectors in the coincidence mode, where the second detector was used as a trigger.

Accordingly, the experimental schemes differ for the two measurement options. The scheme for measuring the energy loss spectra of electrons in a single silicon planar detector is shown in Fig.4, and scheme which use two detectors with a coincidence circuit is shown in Fig.5.

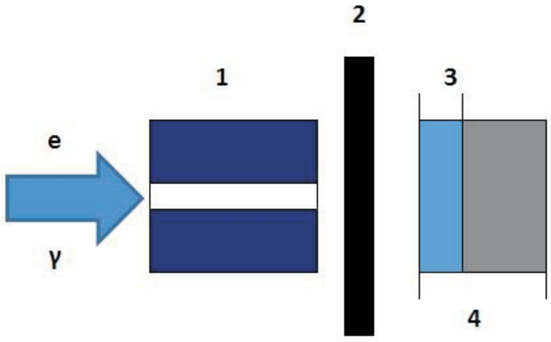

Fig.4. *Scheme of the experiment using a single planar detector: 1 – diaphragm; 2 – a thin filter to remove the low-energy component of electrons from the* $^{90}Sr - ^{90}Y$ *source; 3 – depletion layer D; 4 – the total thickness of the planar detector*

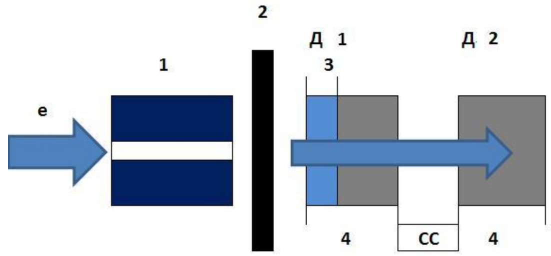

Fig.5. *Scheme experiment using two planar detectors and coincidence circuit (CC): 1 – diaphragm; 2 – a thin filter to remove the low-energy component of electrons from the* $^{90}Sr - ^{90}Y$ *source; 3 – depletion layer D; 4 – the total thickness of the planar detector*

In Figs.6 and 7 show the results of measuring energy loss spectra of electrons from the source $^{90}Sr - ^{90}Y$ in silicon planar detector $5 \times 5 \times 0.3\,mm^3$ depending on depletion voltage $U_b = 0...60\,V$. Fig.6 – energy losses spectra obtained for a single detector, Fig.7 – spectra for system of two detectors.

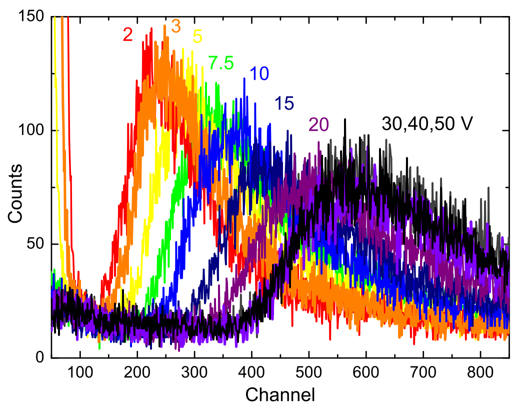

Fig.6. *Spectra of energy losses. Source* $^{90}Sr - ^{90}Y$ *for single Si detector* $5 \times 5 \times 0.3\,mm^3$

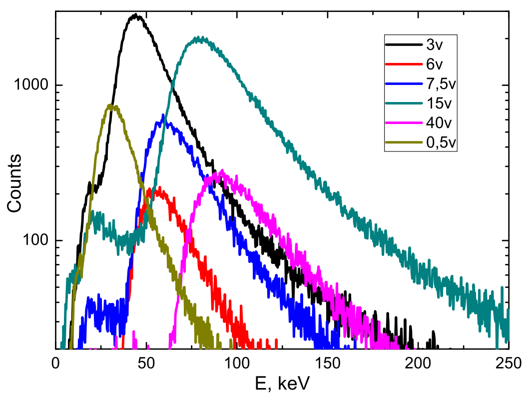

Fig.7. *Spectra of energy losses. Source* $^{90}Sr - ^{90}Y$ *for system of two detectors*

Processing of spectrum was performed in Landau approximation in *ROOT*5 [14]. The most probable electron energy loss value *MPV*, mean energy loss value and dispersion (*Sigma*) was defined (Figs.8, 9).

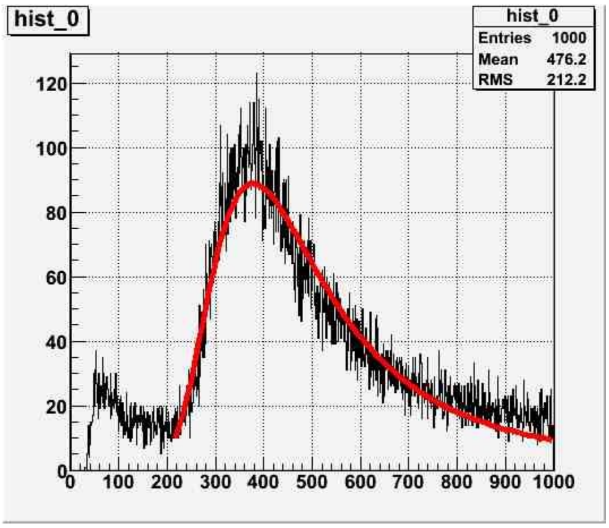

Fig.8. *Spectra of energy losses for single Si detector. Landau approximation in ROOT* 5

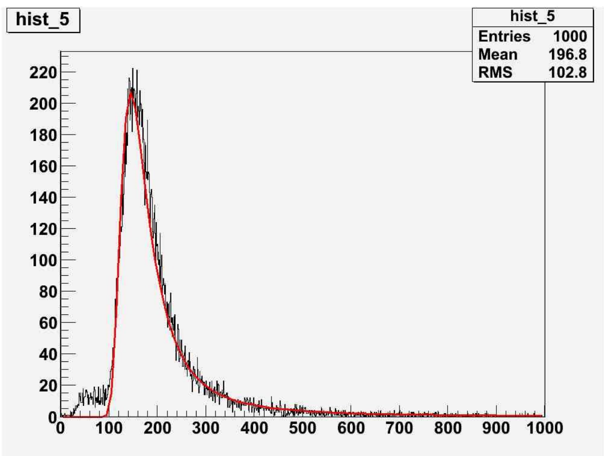

Fig.9. *Spectra of energy losses for system of two detectors. Landau approximation in ROOT* 5

The results of processing the experiments are shown in Figs.10, 11.

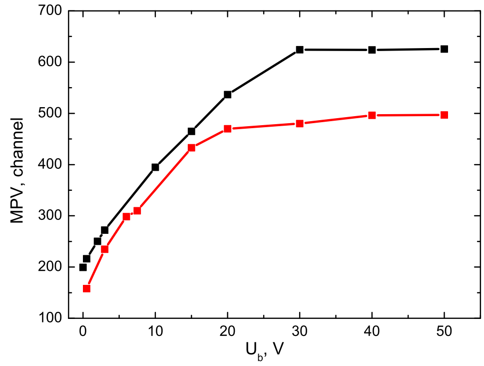

Fig.10. *Dependence MPV on depletion voltage* U_b*: measurements for single Si detector* $5 \times 5 \times 0.3\,mm^3$ *(upper curve); measurement for two detectors in the coincidence mode (lower curve)*

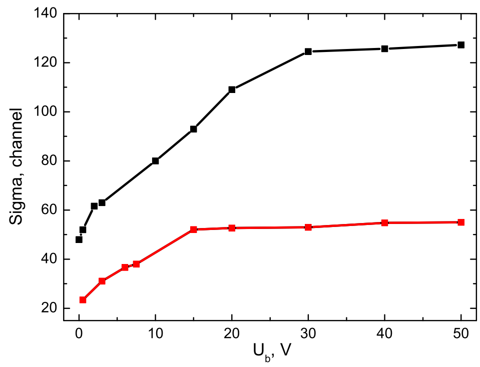

Fig.11. *Dependence Sigma on depletion voltage* U_b*: measurements for single Si detector* $5 \times 5 \times 0.3\,mm^3$ *(upper curve); measurement for two detectors in the coincidence mode (lower curve)*

Dependence *MPV* (see Fig.10) and *Sigma* (see Fig.11) smoothly increase with increase depletion voltage U_b and go on a plateau in the region of 30...60 V. These dependencies are close to the root dependence.

Estimates show a decrease in *MPV* with a decrease in the thickness of the depleted detector layer to 3.55 times. Change for *Sigma* parameter up to 2 times for the coincidence circuit, up to 2.5 times for a single planar detector.

As the depletion voltage decreases, the thickness of the active region decreases correspondingly and the capacitance of the detector increases. As a result, noise in spectrometric electronics increases. This makes it difficult to obtain experimental data at low values of the depletion voltage U_b.

3. CONCLUSIONS

An experimental method for determining the active region thickness for *Si* planar detector was developed and used, based on the dependence of the depleted layer thickness *D* on the depletion voltage applied to it.

The electron energy loss spectra are measured in a silicon planar detector from a $^{90}Sr - ^{90}Y$ source depending on the depletion voltage U_b of the detector in the range 0...60 V. Energy loss spectra were obtained both for a single detector and for a system of two detectors in the coincidence mode, where the second detector was used as a trigger.

The thickness of the depleted (working) layer for planar detector depends on the voltage depletion submitted to it. In the first approximation planar detector seen as a flat capacitor. The dependence of the thickness of the active layer on the voltage is well approximated by the root dependence.

Dependence MPV and $Sigma$ smoothly increase with increase depletion voltage U_b and go on a plateau in the region of 30...60 V. These dependencies are close to the root dependence.

This behavior is similar to the measured volt-faradic characteristic of a silicon planar detector and is explained by a decrease in the depleted layer thickness with a decrease in the depletion voltage. The numerical values of the MPV parameter allow us to estimate the thickness of the working layer of the detector. The possibility of obtaining experimental data while reducing the depletion layer thickness up to 85 μm was shown. For the experimental data with thinner depletion layer requires further optimization spectrometric system including the optimization of the detector.

References

1. O.S. Deiev, N.I. Maslov, S.K. Kiprich, et al. Investigation of a depletion layer of an uncooled Si detector at various depletion voltage //*Theses XII Conference on high energy physics, nuclear physics and accelerators. Kharkov, NSC KIPT, March 17-21, 2014, p.102* (in Russian).
2. O.S. Deiev, N.I. Maslov, S.K. Kiprich, et al. The minimum thicknesses of the depletion layer of an uncooled Si-detector when measuring X-ray emission and electron loss spectra //*Theses XIII Conference on high energy physics, nuclear physics and accelerators. Kharkov, NSC KIPT, March 16-20, 2015*, p.109 (in Russian).
3. A.V. Shchagin, N.F. Shulga, S.V. Trofymenko. Semiconductor detector with smoothly tunable effective thickness for the study of ionization loss by moderately relativistic electrons //*Nucl. Instr. Meth. In Phys. Res. B*. 2016, v.387, p.29-33.
4. G.P. Vasilyev, V.K. Voloshin, S.K. Kiprich, et al. Encapsulated modules of silicon detectors of ionizing radiation //*PAST*, 2010, N3, *Ser. "Nuclear Physics Investigations"* (54), p.200-204.
5. N.I. Maslov. Physical and technological aspects of creation and applications of silicon planar detectors //*PAST*. 2013, N2, *Ser. "Nuclear Physic Investigations"* (84), p.165-171.
6. V.I. Kulibaba, N.I. Maslov, S.V. Naumov, V.D. Ovchinnik, I.M. Prokhorets. Readout electronics for multichannel detectors //*PAST, Ser. "Nuclear Physics Investigations"*. 2001, N5(39), p.177-179.
7. G.L. Bochek, O.S. Deiev, N.I. Maslov, V.K. Voloshyn. X-ray lines relative intensity depending on detector efficiency, foils and cases thickness for primary and scattered spectra//*PAST, Ser. "Nuclear Physic Investigations"*. 2011, N3(55), p.42-49.
8. G.P. Vasiliev, V.K. Voloshyn, O.S. Deiev, et al. Measurement of Radiation Energy by Spectrometric Systems Based on Uncooled Silicon Detectors //*Journal of Surface Investigation. X-ray, Synchrotron and Neutron Techniques*. 2014, N4, p.94-100.
9. G.L. Bochek, A.S. Golovash, A.V. Kosinov, et al. Examination of multi-layer silicon detector in measurement of electron spectrum for beta-decay of $^{90}Sr - ^{90}Y$ // *PAST. Ser. "Nuclear Physics Investigations"*. 2005, N6(45), p.54-58.
10. G.L. Bochek, N.I. Maslov, S.V. Naumov, et al. Registration of charged particles in a gamma-ray background // *Journal of Surface Investigation. X-ray, Synchrotron and Neutron Techniques*. 2005, N4, p.68-71.
11. S. M. Sze. *Semiconductor Devices. Physics and Technology*. New York: "Wiley", 1985.
12. M.A. Frautschi, M.R. Hoeferkamp, S.C. Seidel. Capacitance measurements of double sided silicon microstrip detectors // *Nucl. Instrum. Meth. A*. 1996, v.378, p.284-296.
13. L.D. Landau. On the energy loss of fast particles by ionization //*J. Phys. USSR*. 1944, v.8, p.201.
14. A modular scientific software framework // *http://root.cern.ch/drupal/*

ЭФФЕКТИВНАЯ ТОЛЩИНА ПЛАНАРНОГО ДЕТЕКТОРА ПРИ ИЗМЕРЕНИЯХ ПОТЕРИ ЭНЕРГИИ ЭЛЕКТРОНОВ

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Использовался экспериментальный метод определения толщины активной области Si-планарного детектора. Метод основан на зависимости толщины обедненного слоя от напряжения, приложенного к детектору ($U = 0...60\,B$). Измерялись спектры потерь энергии электронов, испускаемые $^{90}Sr -^{90}Y$ в кремниевом планарном детекторе. Были определены относительные значения наиболее вероятных потерь энергии электронов для различной толщины детектора. Плоский детектор рассматривался как конденсатор с параллельными пластинами. Статическая (емкость) и динамическая (эффективность регистрации и энергетические потери) характеристики имеют корневую зависимостью от напряжения.

ЕФЕКТИВНА ТОВЩИНА ПЛАНАРНОГО ДЕТЕКТОРА ПРИ ВИМІРАХ ВТРАТИ ЕНЕРГІЇ ЕЛЕКТРОНІВ

А. С. Деев, С. К. Кіпріч, Г. П. Васильев, В. І. Яловенко, В. Д. Овчинник, М. Ю. Шуліка

Використовувався експериментальний метод визначення товщини активної області Si-планарного детектора. Метод заснований на залежності товщини збідненого шару від напруги, прикладеної до детектора ($U = 0...60\,B$). Вимірювалися спектри втрат енергії електронів, що випускаються $^{90}Sr -^{90}Y$ в кремнієвому планарному детекторі. Були визначені відносні значення найбільш ймовірних втрат енергії електронів для різної товщини детектора. Плоский детектор розглядався як конденсатор з паралельними пластинами. Статична (ємність) і динамічна (ефективність реєстрації та енергетичні втрати) характеристики мають кореневу залежністю від напруги.