2055

Development of Cd(Zn)Te-based X- and gamma-ray detectors for high-performance medical imaging devices

［1］**Organization**

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Representative at RIE
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Participants :
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［2］**Research Progress**

The project research was dedicated to the development of Cd(Zn)Te semiconductor-based X- and gamma-ray detectors for high-resolution compact imaging systems which can be used for radiological and computer tomography investigations in medicine and for applications in custom service, industry, nuclear plants, cosmic astronomy etc. Obtained detectors with high energy resolution were studied at Research Institute of Electronics, Shizuoka University. The system of four stacked Ni/CdTe/Au Schottky diode detectors with the semiconductor wafer size of 10 x 10 x 0.75 mm^3 were created and tested in spectra measurements.

During Prof. *T. Aoki's* visit to Ukraine in June 2016, a plan of research was discussed in details. Dr. *K. Zelenska*, Dr. *V. Gnatyuk* and Prof. *T. Aoki* attended the 23rd International Symposium on Room-Temperature Semiconductor Detectors (RTSD 2016), 2016 IEEE Nuclear Science Symposium & Medical Imaging Conference (2016 NSS/MIC) in Strasbourg, France, 29 October-6 November 2016, where they presented scientific results and discussed further research plan.

The participants of the project were involved in organizing of the 17th Intern. Young Scientists Conf. "Optics & High Technology Material Science" SPO 2016 which was held at the Faculty of Physics, Taras Shevchenko National University of Kyiv, 27-30 October 2016. Dr. *V. Gnatyuk*, Prof. *T. Aoki* and his students presented the project-related results at SPO 2016. Dr. *K. Zelenska* and Prof. *T. Aoki* were the members of the Organizing Committee of SPO 2016.

［3］**Results**

In experiments, Ni/CdTe/Au Schottky diodes, which contacts (Schottky and near Ohmic) were created by ion bombardment-assisted formation technique, were used. Three types of detectors were studied in spectra measurements:

(1) Detector, created as a Ni/CdTe/Au Schottky diode with the semiconductor wafer size of 5 x 5 x 0.75 mm^3,

(2) Detector, created as a Ni/CdTe/Au Schottky diode with the semiconductor wafer size of 10 x 10 x 0.75 mm^3,

(3) Detector, created as a stack of four Ni/CdTe/Au Schottky diodes with the semiconductor wafer size of 10 x 10 x 0.75 mm^3.

A thickness of CdTe wafers was the same in all cases and equaled to 0.75 mm. To increase thickness and efficiency of high energy gamma-photons (Cs-137) detection stacked detectors were used. CdTe wafers had a square of 5 x 5 mm^2 and 10 x 10 mm^2. Larger square provided higher efficiency in detection of low energy gamma-photons (Am-241).

(1) 5 x 5 x 0.75 mm^3

Spectra of radioisotopes Cs-137, Co-57 and Am-241 taken by one 5 x 5 x 0.75 mm^3 Ni/CdTe/Au diode detector during 10 min at applied bias voltage of 600 V after 6, 9 and 12 hours of operation time in the dark, after voltage reset and after illumination are presented in Fig. 1. An efficiency of detection increased sufficiently in 9-12 hours after the voltage was applied to the detector.

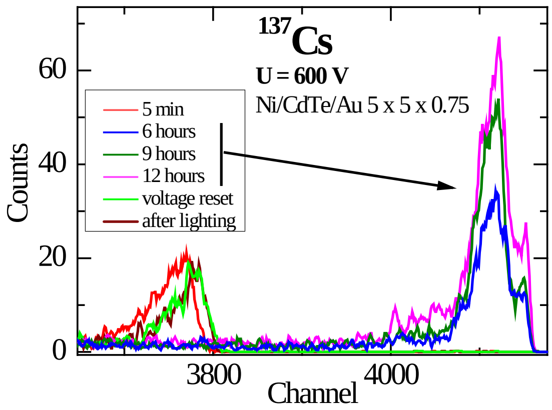

Fig. 1. Room temperature energy spectra of a radioisotope Cs-137 taken by the 5 x 5 x 0.75 mm³ Ni/CdTe/Au diode detector at applied bias voltage of 600 V after 6, 9 and 12 hours of operation time.

Fig. 2 shows that the best resolution (FWHM) was reached after 9 hours of the operation of the detector and equaled to 0.8 %. The best ratio of the peak to valley was observed after 12 hours of detector's operation (Fig. 2). A shift of the peak in the spectrum was observed after 6 hours of detector's operation as seen from Fig. 2.

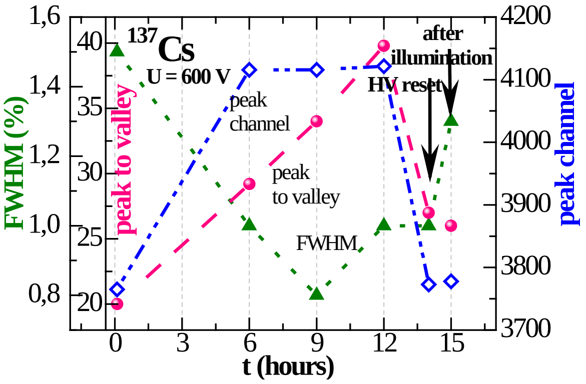

Fig. 2. Dependences of the energy resolution (FWHM), peak channel shift and peak-to-valley ratio on the operation time for the 5 x 5 x 0.75 mm³ Ni/CdTe/Au diode detector at applied bias voltage of 600 V.

(2) 10 x 10 x 0.75 mm³

Spectra of radioisotopes Cs-137, Co-57 and Am-241 taken by one 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detector during 5 min at applied bias voltage of 400, 600, 800 and 1000 V are presented in Figs. 3-5.

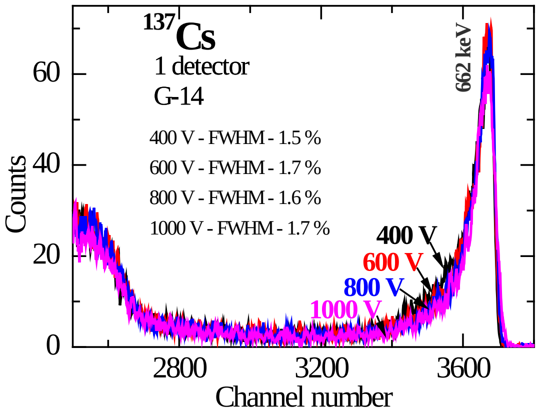

Fig. 3. Room temperature energy spectra of a radioisotope Cs-137 taken by the 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detector at applied bias voltage of 400, 600, 800 and 1000 V.

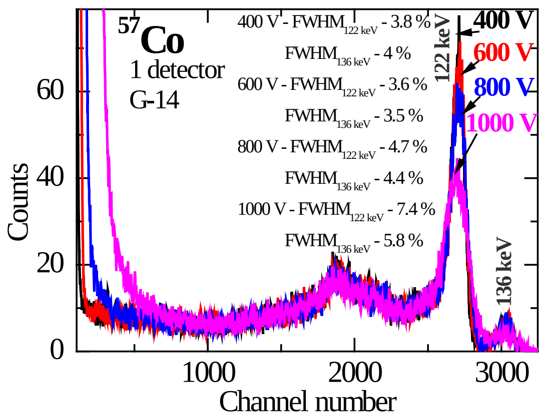

Fig. 4. Room temperature energy spectra of a radioisotope Co-57 taken by the 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detector at applied bias voltage of 400, 600, 800 and 1000 V.

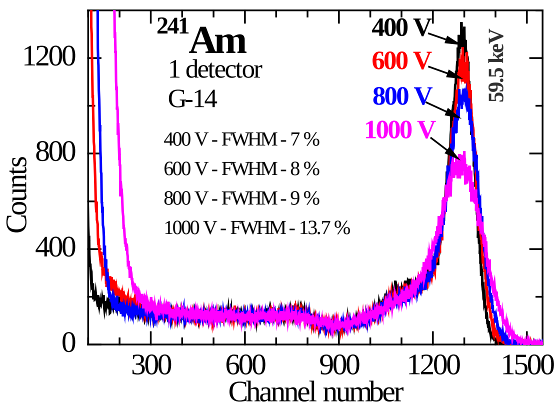

Fig. 5. Room temperature energy spectra of a radioisotope Am-241 taken by the

10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detector at applied bias voltage of 400, 600, 800 and 1000 V.

(3) Stacked detectors

In order to improve efficiency of detection of high energy gamma-photon from the Cs-137 radioisotope source, a system of the four stacked 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detectors were created, tested in spectra measurements under various conditions (value of the applied bias voltage, operation time, distance from the gamma-photon source and direction of the source) and compared with the spectra data obtained employing one detector.

Measurements of the spectra of radioisotopes Cs-137, Co-57 and Am-241 by four stacked 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detectors were performed at applied bias voltage of 400, 600, 800 and 1000 V and are presented in Figs. 6-8.

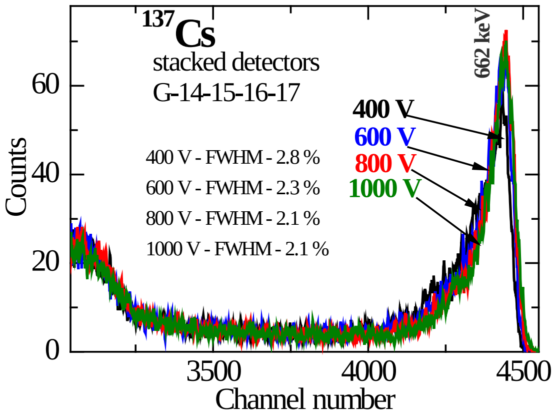

Fig. 6. Room temperature energy spectra of a radioisotope Cs-137 taken by four stacked 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detectors at applied bias voltage of 400, 600, 800 and 1000 V.

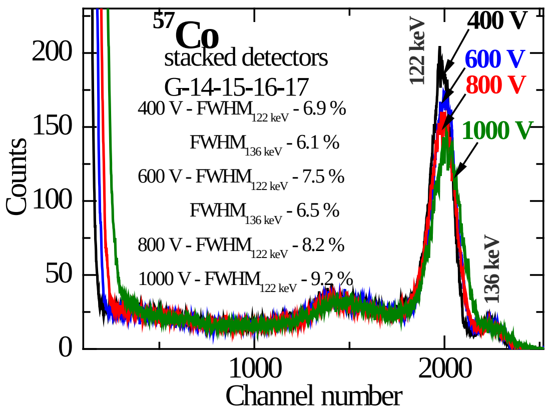

Fig. 7. Room temperature energy spectra of a radioisotope Co-57 taken by four stacked 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detectors at applied bias voltage of 400, 600, 800 and 1000 V.

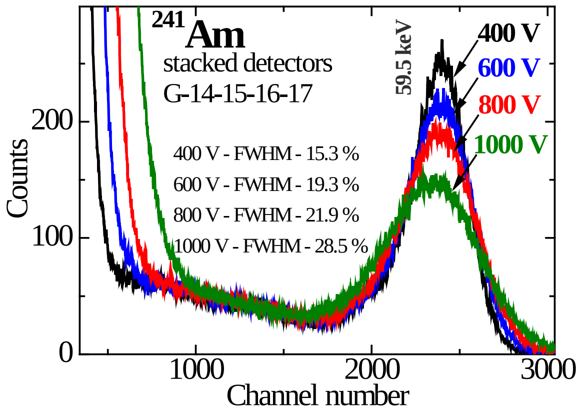

Fig. 8. Room temperature energy spectra of a radioisotope Am-241 taken by four stacked 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detectors at applied bias voltage of 400, 600, 800 and 1000 V.

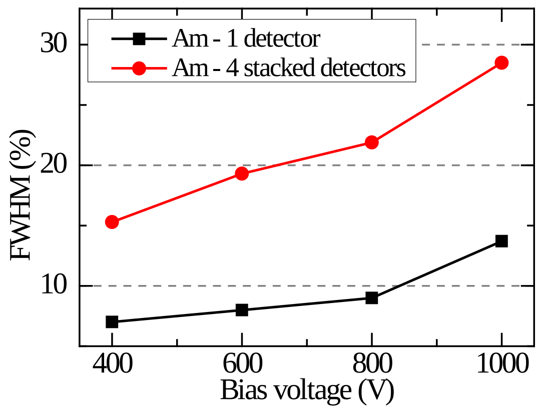

Fig. 9. Voltage dependences of the energy resolution (FWHM) for the spectra of a radioisotope Am-241 taken by four stacked 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detectors and by one 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detector.

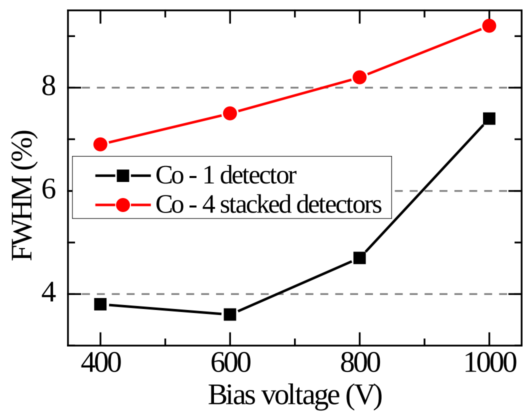

Fig. 10. Voltage dependences of the energy resolution (FWHM) for spectra of a radioisotope

Co-57 taken by four stacked 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detectors and by one 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detector.

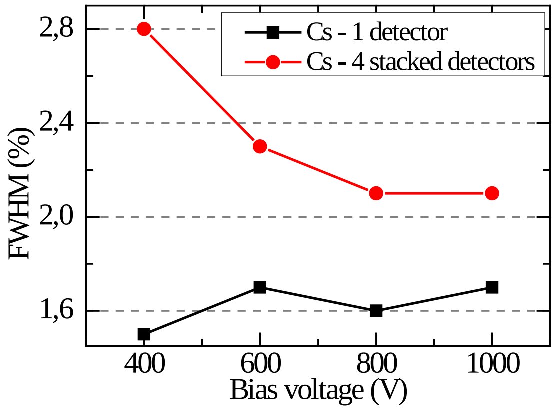

Fig. 11. Voltage dependences of the energy resolution (FWHM) for the spectra of a radioisotope Cs-137 taken by four stacked 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detectors and by one 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detector.

Energy resolution (FWHM) for the spectra of a radioisotopes Am-241, Co-57 and Cs-137 taken by four stacked 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detectors increased in two times in a comparison with FWHM for the spectra taken by one 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detector (Figs. 9-11).

Room temperature energy spectra of a radioisotope Cs-137 taken by four stacked Ni/CdTe/Au diode detectors at applied bias voltage of 800 V with a distance to a source of 4, 10, 15, 20, 25, 30, 40 and 50 min are shown in Fig. 12. The best energy resolution (FWHM) was reached when the distance was equaled to 15 cm.

As is seen from Fig. 13, the resolution slightly decreased when four stacked detectors used for taking the spectra of a radioisotope Cs-137. At the same time, the peaks of Cs-137 in the spectra, taken by four stacked 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detectors in 2 min and by one 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detector in 5 min at applied bias voltage of 800 V, were formed by the same number of counts for the both cases. It indicates an increase in the detection efficiency due to an increase in the gamma-photon passage path in the semiconductor wafers.

A longer gamma-photon passage path and as a result an increase in the number of counts can be achieved by placing a Cs-137 radioisotope source at the side of the stack (Fig. 14).

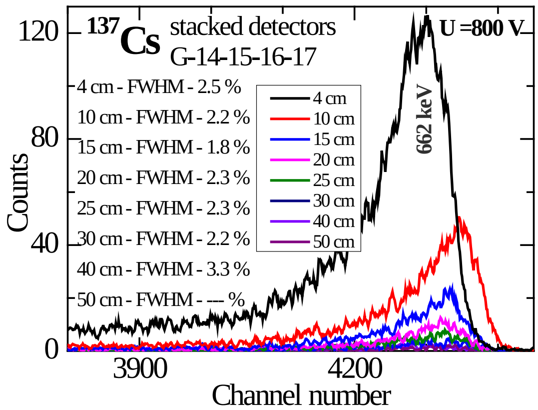

Fig. 12. Room temperature energy spectra of a radioisotope Cs-137 taken by four stacked Ni/CdTe/Au diode detectors at applied bias voltage of 800 V with a distance to a source of 4, 10, 15, 20, 25, 30, 40 and 50 min.

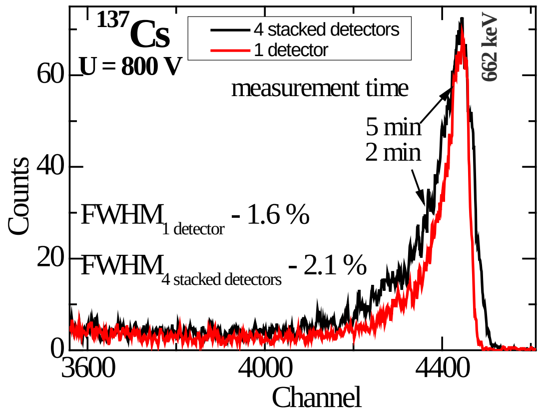

Fig. 13. Room temperature energy spectra of a radioisotope Cs-137 taken by four stacked 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detectors in 2 min and by one 10 x 10 x 0.75 mm³ Ni/CdTe/Au diode detector in 5 min at applied bias voltage of 800 V.

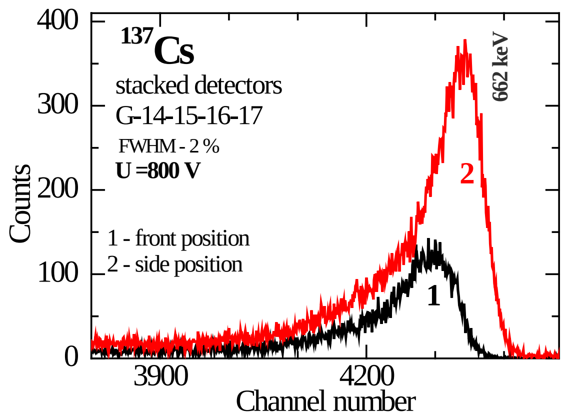

Fig. 14. Room temperature energy spectra of a

radioisotope Cs-137 taken by four stacked Ni/CdTe/Au diode detectors irradiated from the front (1) and side (2) at applied bias voltage of 800 V.

［4］**Achievements**

(1) H. Nakagawa, T. Terao, T. Masuzawa, T. Ito, H. Morii, A. Koike, V. Gnatyuk, T. Aoki, **Instability in CdTe detector characterized by real-time measurement of pulse height and carrier transit time**, in book: *"Recent Global Research and Education: Technological Challenges* (*Proceedings of the 15th International Conference on Global Research and Education Inter-Academia 2016), Series "Advances in Intelligent Systems and Computing"*, Vol. 519 (Sep. 2016) 499-505.

(2) V.A. Gnatyuk, O.I. Vlasenko, S.N. Levytskyi, T. Aoki, **Modification of the surface state of CdZnTe crystals and contact formation**, *2015 IEEE Nuclear Science Symposium and Medical Imaging Conference Record (NSS/MIC)*, (Oct. 2016) 1-2.

(3) K.S. Zelenska, D.V. Gnatyuk, T. Aoki, **Formation of diode detectors by nanosecond laser irradiation of CdTe-In interface from the semiconductor side**, *2015 IEEE Nuclear Science Symposium and Medical Imaging Conference Record (NSS/MIC)*, (Oct. 2016) 1-2.

(4) V.A. Gnatyuk, S.N. Levytskyi, O.I. Vlasenko, T. Aoki, **Formation of doped nano-layers in CdTe semiconductor crystals by laser irradiation with nanosecond pulses**, *Thai Journal of Nanoscience and Nanotechnology*, Vol. 1, No 2 (Dec. 2016) 7-16.

(5) V.P. Veleshchuk, O.I. Vlasenko, Z.K. Vlasenko, V.A. Gnatyuk, S.N. Levytskyi, **Dependence of the CdTe melting threshold on the pulse duration and wavelength of laser radiation and the parameters of non-equilibrium charge carriers**, *Ukrainian Journal of Physics*, Vol. 62, No 2 (Feb. 2017) 159-165.

(6) V.A. Gnatyuk, S.M. Levytskyi, O.I. Vlasenko, T. Aoki, **Method of solid-phase doping of a surface layer of $A^{II}B^{VI}$ semiconductors with A^{III} group elements by deformation and shock waves generated by nanosecond laser pulses in a liquid medium**, *The patent for useful model,* Patent (application No u 2016 11853) has been approved by The State Intellectual Property Service of Ukraine on 21 March 2017 (document No 6798/ЗУ/17), Kyiv Ukraine [*in Ukrainian*].

(7) V.P. Veleschuk, O.I. Vlasenko, Z.K. Vlasenko, V.A. Gnatyuk, S.N. Levytskyi, **The dependence of the CdTe melting threshold on the laser pulse duration and wavelength**, *The 17th International Young Scientists Conference "Optics & High Technology Material Science" (SPO 2016), Scientific Works*, 2016, Abstract No BP.3, 149-150. (27 – 30 October 2016, Kyiv, Ukraine).

(8) V.A. Gnatyuk, O.I. Vlasenko, S.N. Levytskyi, T. Aoki, **Laser-induced formation of surface state and highly doped layer in CdTe for diode type detectors**, *The 23rd International Symposium on Room-Temperature Semiconductor Detectors (RTSD 2016), 2016 IEEE Nuclear Science Symposium & Medical Imaging Conference (2016 NSS/MIC), Conference Program & Abstracts*, 2016, Abstract No R05-7. (29 October – 6 November 2016, Strasbourg, France).

(9) K. Zelenska, D. Gnatyuk, T. Aoki, **Laser-Based Technique of Formation of CdTe-Metal Diode Structures for High Energy Radiation Detectors**, *The 23rd International Symposium on Room-Temperature Semiconductor Detectors (RTSD 2016), 2016 IEEE Nuclear Science Symposium & Medical Imaging Conference (2016 NSS/MIC), Conference Program & Abstracts*, 2016, Abstract No R09-50. (29 October – 6 November 2016, Strasbourg, France).

(10) J. Nishizawa, D. Gnatyuk, K. Zelenska, T. Aoki, **Formation of the pn-junction in CdTe by Irradiation with Nanosecond Laser Pulses through the CdTe Crystal**, *Optics & Photonics Taiwan, the International Conference (OPTICS 2016), Conference Program & Abstracts*, 2016, Abstract No 270479 (3 – 5 December 2016, Taipei, Taiwan).

Travelling Report

Name : Kateryna Zelenska
Affiliation : Taras Shevchenko National University of Kyiv,
60 Volodymyrska Street, Kyiv, 01033, Ukraine
Period of time : 23 January – 21 February 2017
Destination : Research Institute of Electronics, Shizuoka University
Purpose : (1) study of spectral characteristics of CdTe semiconductor-based X- and gamma-ray detectors, (2) participation in scientific forums and meetings at Research Institute of Electronics, Shizuoka University during the staying period, (3) research activity with students of the laboratory headed by Prof. Toru Aoki.
Name of receiver : Prof. Toru Aoki