ELSEVIER

Nuclear Instruments and Methods in Physics Research A 460 (2001) 27–34

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.nl/locate/nima

Technological aspects of development of pixel and strip detectors based on CdTe and CdZnTe

V. Gostilo[a,*], V. Ivanov[a], S. Kostenko[a], I. Lisjutin[a], A. Loupilov[a], S. Nenonen[b], H. Sipila[b], K. Valpas[b]

[a] *Baltic Scientific Instruments, Ganibu dambis 26, P.O. Box 33, LV-1005 Riga, Latvia*
[b] *Metorex International Oy Nihtisillankuja 5, FIN-02631 Espoo, Finland*

Abstract

Current and spectrometrical characteristics, stability in time and reliability of pixel and strip detectors depend on initial material properties, crystal processing quality and contacts manufacture technology. The work presents analysis of current–voltage and spectrometrical characteristics for initial CdTe and CdZnTe crystals applied for pixel and strip detectors manufacture. The crystal surface preparation before contacts manufacture comprises a modified technology. The contacts were made by photolithography with the surface protected by photoresist with further windows lift-off and crystal surface metallization in lifted-off windows. Metal pads were made by gold deposition from chloroauric acid. Thermocompression, ultrasonic and pulse wirebonding, as well as traditional contacts glueing method for CdTe and CdZnTe detectors have been tested for contacts wiring. The pulse wirebonding has revealed the best results. Wiring is made of gold wire with a diameter of 30 μm and is good enough for pixel and strip wirebonding, providing rather low labour-intensiveness for their assembly by standard equipment. The possibility of fabrication of pressing contacts to strip and pixel detectors by Zebra elastomeric connectors has been investigated. The pressing contacts have provided qualitative and reliable electrical contact and signal layout from pixels and strips to readout electronics. Developed technologies were applied in the manufacture of the following CdTe and CdZnTe detectors: 4×4 pixels detector with rectangular pixels 0.65×0.65 mm and pitch 0.75 mm; 4×4 pixels ring miltiple-electrode detector with anode diameter 0.32 mm and pitch 0.75 mm; strip detector with 100 μm width strip and 125 μm pitch. The 4×4 pixels CdZnTe detector has provided at optimal temperature energy resolutions of 808 eV and 1.19 keV at energies of 5.9 and 59.6 keV, respectively. Interstrip resistance between two strips with a distance of 25 μm on detector was 2–8 GΩ.

1. Introduction

Multidetector structures, created in one semiconductor crystal, are found to have wider application in imaging systems in gamma and X-rays astronomy, medicine and technical sphere [1]. Such detectors belong to pixel or strip detectors depending on contact pads design [2–6].

The main requirements to obtain semiconductor CdTe and CdZnTe crystals for such detectors are high values of charge carriers transport characteristics (the product of mobility and lifetime), high specific resistance, high level of crystals homogeneity, lack of impurities, crystal borders, and twins.

*Corresponding author.

0169-8141/01/$ - see front matter
PII: S 0 1 6 8 - 9 0 0 2 (0 0) 0 1 0 9 1 - 3

Manufactured detectors should have high spectrometrical characteristics, low level of leakage current to avoid additional noises and high stability of the available characteristics in time. The execution of these requirements depends on crystal processing quality and contacts manufacturing technology.

The big problem is to provide good adhesion and contacts reliability to CdTe and CdZnTe crystals [5,6]. This problem is intensified by the fact that contact pads dimensions may be 50–100 μm and their quantity at such detectors may be up to hundreds and more. It is obvious that contacts at such detectors should stand the machine assembly.

The given work is devoted to the technological aspects of development of pixel and strip detectors based on CdTe and CdZnTe crystals and their characteristics investigations.

2. Initial crystals characteristics investigation

CdZnTe crystals were delivered as plane parallel certificated spectroscopy and discriminator grade detectors with gold contacts by eV Products. Thicknesses of CdZnTe detectors were 1.0 and 2.0 mm. The area of all detectors was $5 \times 5\,\mathrm{mm}^2$.

CdTe crystals were delivered as plane parallel certificated detectors with platinum contacts. There were spectrometric CdTe detectors by Acrotec. The thickness of CdTe detectors was 2.0 mm. The area of all detectors was $5 \times 5\,\mathrm{mm}^2$.

Current–voltage (*I–V*) characteristics have been measured. Crystals with linear *I–V* characteristics were sampled for pixel and strip detectors manufacture. As a rule, detectors with non-linear *I–V* characteristics were non-stable in time. The average specific resistance of CdZnTe crystals was $6 \times 10^{10}\,\Omega\,\mathrm{cm}$. The average specific resistance of CdTe crystals was considerably lower, $2.4 \times 10^{9}\,\Omega\,\mathrm{cm}$.

The product of mobility and lifetime value was measured also. The measurements have been carried out by standard time-of-flight method using alpha particles. The average value of $(\mu\tau)_e$ in CdZnTe crystals was $4 \times 10^{-3}\,\mathrm{cm}^2/\mathrm{V}$, $(\mu\tau)_h$ did not exceed $5 \times 10^{-6}\,\mathrm{cm}^2/\mathrm{V}$. The average value of $(\mu\tau)_e$ in CdTe crystals was $1.5 \times 10^{-3}\,\mathrm{cm}^2/\mathrm{V}$, $(\mu\tau)_h$ was $5 \times 10^{-5}\,\mathrm{cm}^2/\mathrm{V}$.

Spectrometrical characteristics measurements at room temperature and lowered temperature $-30^{\circ}\mathrm{C}$ were made for all crystals . Energy resolution at the 59.6 keV line for CdTe was 4.3–5.0 keV at room temperature and 2.4–4.4 keV at an optimal one. The same parameters for CdZnTe were 2.7–3.9 and 1.5–3.5 keV, respectively for 2 mm thick crystals and 3.2–4.4 and 1.8–2.1 keV, respectively for 1 mm thick crystals. Crystals which do not change characteristics in time were sampled for pixel and strip detectors. Typical spectra registered by planar CdZnTe and CdTe detectors are shown in Figs. 1 and 2.

The applied crystals have inclusions, crystalline borders and twins which may considerably deteriorate pixel and strip detectors characteristics, namely, results reproducibility from pixel to pixel. The crystals with the least units of borders and twins were selected for pixel and strip detectors manufacture. The homogeneity check has been made visually after removing electrodes.

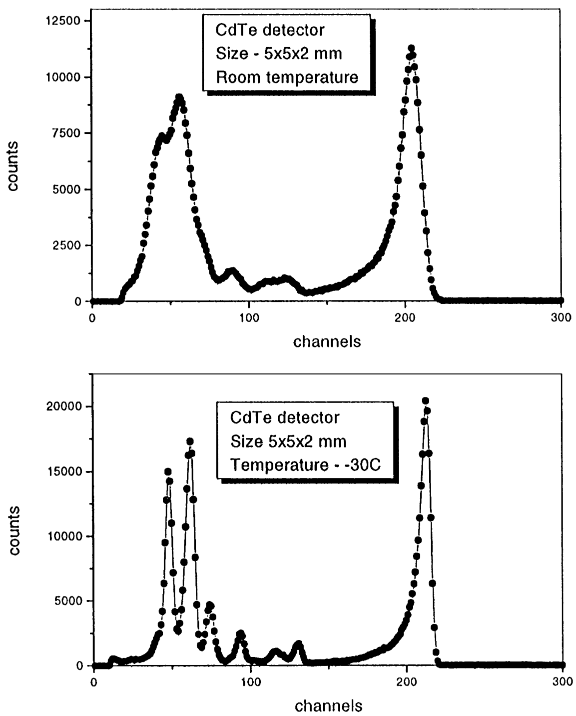

Fig. 1. Spectra of ^{241}Am obtained with planar CdTe detector.

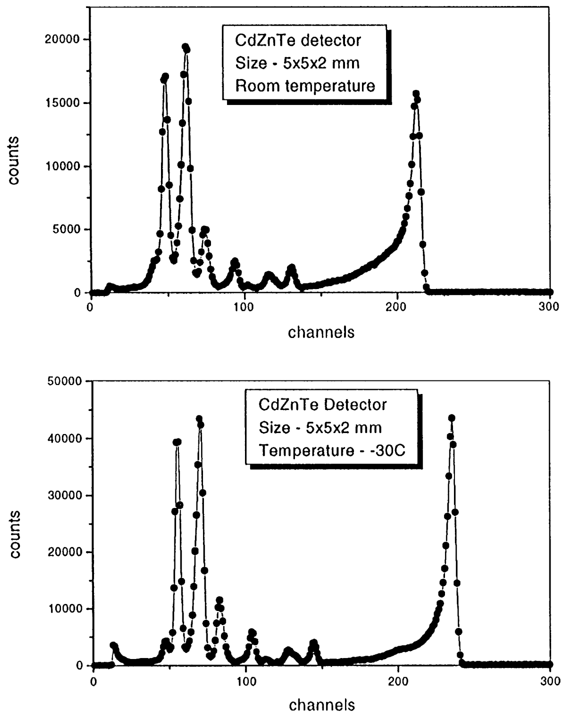

Fig. 2. Spectra of ^{241}Am obtained with planar CdZnTe detector.

3. Contact pads manufacture

To provide high spectrometrical characteristics the detectors should have contacts assuring low current leakage level, not introducing additional noises and be stable in time. Besides, pixel contact pads manufacture technology should provide a high level of interpixel resistivity. The other important requirement is contacts mechanical strength. They should allow electrode layout for connection to readout electronics.

The crystals were supplied by the manufacturers as planar detectors with gold and platinum electrodes (see Section 2). That is why we have investigated at first the possibility to fabricate pixel and strip contact pads by standard photolithography technology with continuous contacts manufactured by the company-supplier. However, windows lift-off in photoresist and further etching operations have lead to resistance decrease between adjacent electrodes, leakage current increase, and energy resolution deterioration. Besides, the contacts fabricated by this method had small thickness and very weak adhesion.

Proceeding from the above-mentioned facts, we have tested the modified technology for contact pads manufacture. By standard technology anode and cathode contacts are made by gold or platinum deposition at the chemically polished crystal surface. In our case anode has been manufactured by standard technology. Cathode was fabricated by gold deposition at mechanically polished crystal surface. As it is known, mechanical damage of crystal surface of p-type causes conductivity type inversion. That is why a mechanically damaged layer at the crystal surface has n-type conductivity. The structure gold–(p-CdTe)–(n-mechanically damaged surface)-gold will work as a p–n barrier. Fig. 3 shows *I–V* characteristics of such a structure and ordinary ones. The presence of a p–n barrier causes some reduction of reverse leakage current. Besides, developed polished surface allows to make contact pads by one of the traditional methods. Also, such pads are considerably less sensitive to mechanical damages and have improved mechanical strength because of developed surface. Measurements of spectrometrical characteristics of the detectors with such contacts manufactured from one and the same crystal, have shown rather improved results in comparison with the contacts manufactured by the standard technology. Changes in characteristics stability in time have not been observed.

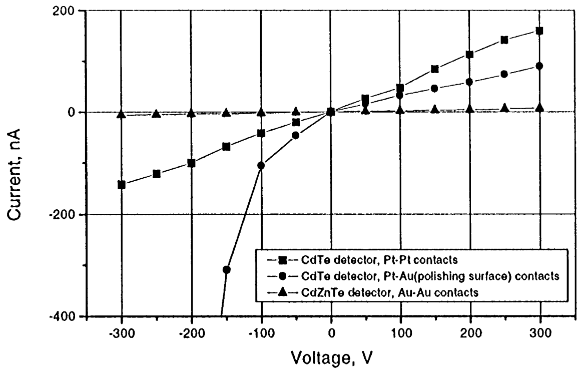

Fig. 3. Current–voltage characteristics for detectors with different contacts.

4. Wirebonding

For contact pads connection on strip and pixel detectors the methods of thermocompression, ultrasonic and pulse wirebonding as well as the traditional method of contact gluing for single CdTe and CdZnTe detectors have been tested. The testing results have shown that traditional contact gluing may be applied for wirebonding on pixel and strip detector pads only to dimensions up to 0.3–0.4 mm. By this the quality of such contacts is low but labour intensiveness is high. The thermocompression method is not applied at wirebonding with CdTe and CdZnTe detectors because heating of the crystal up to $T > 390°C$ which is required for the thermocompression contacts creation, is higher than the admissible temperature (150°C) [5], and this leads to noticeable deterioration of detectors characteristics.

Ultrasonic wirebonding has no such disadvantage as heating. However, in our case the ultrasonic power was high enough and contact pads could not stand it, lifting off the crystal which further could not provide contacts safety. Nevertheless, ultrasonic remains one of the most perspective methods for wirebonding on pixel and strip detectors [5]. Modification of ultrasonic wirebonding technology in future is connected with improvement in adhesion of metal contact pads to CdTe and CdZnTe crystals and optimization of ultrasound power.

We have obtained the best results by applying pulse welding. Wirebonding made by pulse welding has provided acceptable connection safety and did not cause noticeable deterioration of detectors. Wirebonding has been made with gold wire of 30 μm diameter and may be fully applied for the manufacturing of pixel and strip structures with dimensions of approximately 50 μm, providing low labour intensiveness of their assembly by standard equipment.

5. Pressure contacts for pixel and strip structures

The flip-chip technology is widely applied at the contact fabrication in segmented semiconductor elements, including layout for CdTe and CdZnTe strip and pixel detectors also [7,8]. In this technology electrical contact of detector pads and input of readout electronics is realized by indium bump bonds. Such a technology has some undeniable advantages at the manufacturing of the detectors with great number of contact pads. At the same time in the some tasks, where the pressed contacts for pixel and strip detectors are necessary, such a technology is surplus.

We have developed pressure contacts applying Zebra elastomeric electronic connectors [9]. Such contacts are used in LCD and El displays, Ball Grid Arrays and in various other tasks where miniature and low-profile interconnections are necessary. Each type of elastomeric connectors consists of integral conductors, insulators and self-support structures and added components are not required for installation. Contact density of elastomeric connectors is greater than the contact pads density of either pixel or strip detectors. When placed between detector and layout substrate at least one conductor will connect matched contact pads. Elastomeric connectors are non-abrasive and will not damage gold contact pads on the CdTe and CdZnTe detectors. They allow repeated assembly and disassembly of detectors, which is suitable for example at their preliminary testing. Elastomeric-type connectors eliminate technological processes of tinning or wirebonding at the assembling of pixel and strip detectors and provide high cost-effectiveness for this process. Developed construction of the pixel and strip detectors with elastomeric connectors provided qualitative and reliable electrical contacts and signal layout from pixel and strip pads to front-end electronics.

6. CdZnTe detectors with rectangular pixels

4×4 pixel detectors on the crystals $5 \times 5 \times 1$ and $5 \times 5 \times 2$ mm were made using developed technologies. Pixels dimensions were 0.65×0.65 mm, and interpixels distance 0.1 mm. Crystal topology is shown in Fig. 4a. Pixels are surrounded by a guardring. Pixels leakage currents at room temperature and operating voltage 200 V did not exceed 8 nÀ. The basic function of the guardring

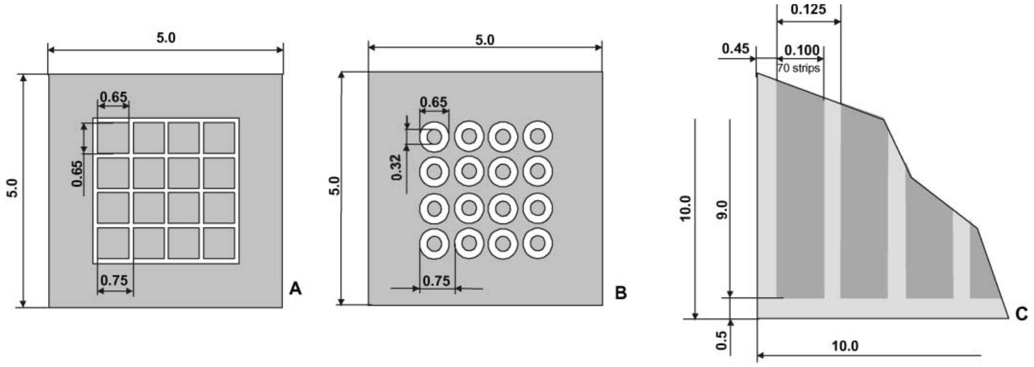

Fig. 4. Topologies for pixel and strip detectors.

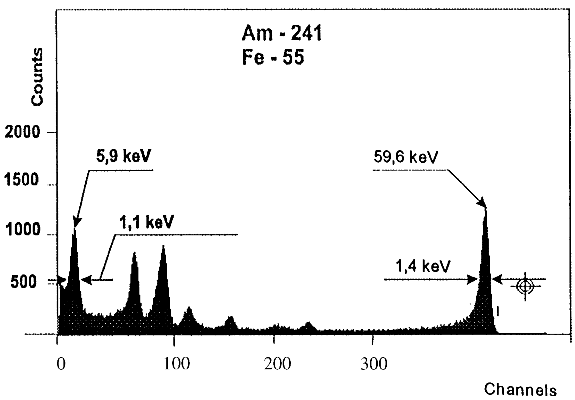

Fig. 5. Spectrum for single rectangular pixel at room temperature.

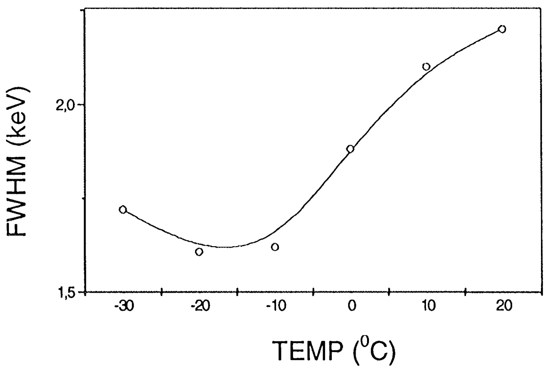

Fig. 6. Energy resolution at 59.6 keV versus temperature on detector for single pixel.

is to reduce the influence of surface leakage currents. Besides, the presence of the guardring reduces the influence of edge effects, approximating the charge collection conditions for the edge pixels to the charge collection conditions for the central ones.

Pixels energy resolution at room temperature was 1.09–1.26 and 1.41–2.34 keV at energies of 5.9 and 59.6 keV, respectively. Typical spectra of ^{55}Fe and ^{241}Am sources for the single pixel are presented in Fig. 5. Energy resolution values spread is caused probably by the presence of structural crystal heterogeneities in the points of pixels creation (see Section 2).

Energy resolution of the detectors has improved on cooling. Typical energy resolution at energy 59.6 keV dependence on detector temperature is shown in Fig. 6. All investigated detectors have temperature optimum in the range of $-(20–25)°C$. Energy resolution improvement at temperature decrease is connected with current noises level reducing and also with operating voltages level possible increasing.

At optimal temperature detectors energy resolution was 0.81–0.93 and 1.3–1.6 keV at energies 5.9 and 59.6 keV, respectively. Typical spectrum for single pixel at optimal temperature is shown in Fig. 7.

7. Multielectrodes pixel detectors based on CdTe and CdZnTe

Such structures were developed to reduce the influence of holes collection effect in

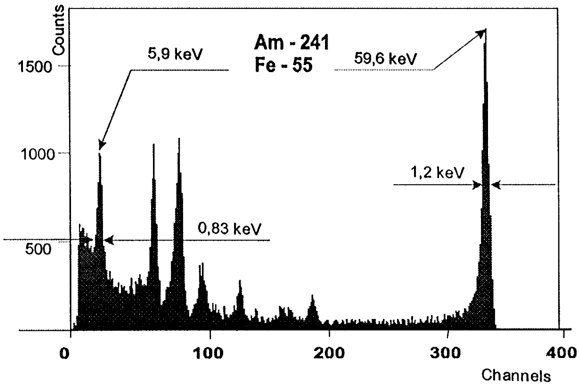

Fig. 7. Spectrum for single rectangular pixel at optimal temperature.

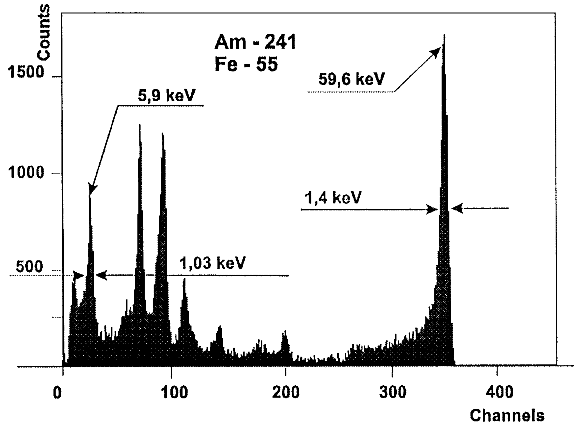

Fig. 8. Spectrum for single multielectrode pixel at optimal temperature.

gamma-radiation detectors [10]. In case of gamma-radiation high energies, a uniform generation of carriers in sensitive volume of the detector is observed. The presence of the third electrode allows to apply an additional operating voltage and its adjustment makes it possible to obtain optimal conditions of charge carriers.

In our case we have tried the given method to improve conditions of charge collection in comparatively thin detectors for registration of low-energy radiation. The topology of developed structure is shown in Fig. 4b. The detectors were manufactured on CdTe and CdZnTe crystals of 1 and 2 mm thickness. Anode diameter was 0.32 mm, pitch 0.75 mm. The third electrode takes all the remaining crystal surface. Ring gap between anode and the third electrode was 0.16 mm.

Energy resolution at optimal temperature was (0.88–1.13) and (1.29–2.45) keV for energies 5.9 and 59.6 keV, respectively. Typical spectrum for the single pixel on CdTe detector is shown in Fig. 8.

In the choice of the optimal conditions for the measurements of detectors parameters we had some difficulty in selecting bias voltage on the detector common electrode HV1 and on the third electrode (HV2). This difficulty is probably connected with the heterogeneity of the initial material and pixel detector manufacture quality. The gap between anode and the third electrode was considerably small (0.16 mm), and thus even small difference in potentials may cause breakdown or large leakage currents. Any impurity at the crystal surface in the gap may increase leakage. The ratio between HV1 and HV2 was approximately 10:1. For example, for CdTe detector of thickness 2 mm HV1 = (−700B), HV2 = (−60 V).

Thus, the research of characteristics of the multi-electrodes pixel detectors at registration of low-energy radiation, executed on the given stage, did not show any advantages over usual detectors with rectangular pixel (see Section 6). Nevertheless, this result does not reject advantages which are potentially appropriate for these structures at registration of high-energy gamma-radiation [7]. To obtain improved results with multidetector pixel detectors optimization of topology of such structures for concrete problem with computer simulation usage is necessary.

8. Strip detectors

Detectors with strip contacts were manufactured on CdTe crystals with dimensions $10 \times 10 \times 1$ and $10 \times 10 \times 2$ mm. The pitch of the structure was 125 μm, strips width 100 μm, inter-strips distance 25 μm. The topology of the developed crystal is presented in Fig. 4c. *I–V* characteristics of the single strips are presented in Fig. 9. When these characteristics were measured, all the other strips were grounded. Inter-strip resistance, measured at voltage 10 V was 2–8 GΩ.

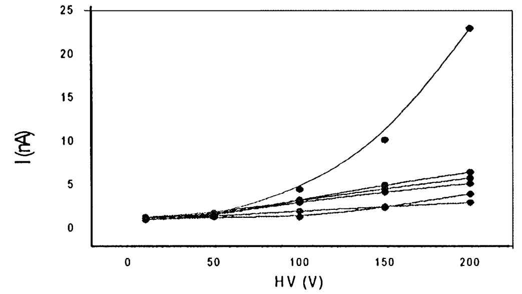

Fig. 9. Current–voltage characteristics for a few strips.

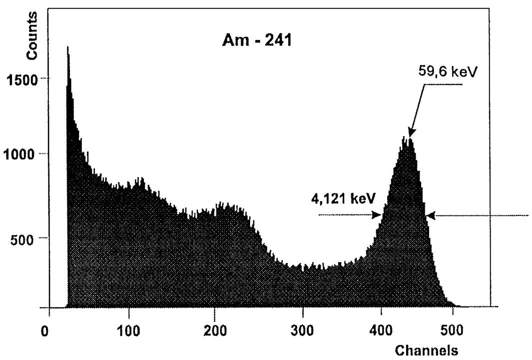

Fig. 10. Spectrum of ^{241}Am for single strip at room temperature.

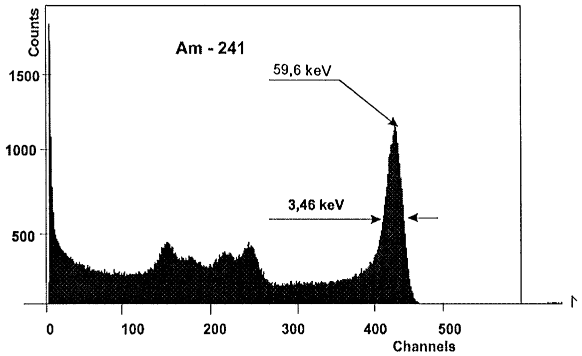

Fig. 11. Spectrum of ^{241}Am for single strip at optimal temperature.

The task of obtaining spectrometrical characteristics was not set at the creation of the strip detectors. That is why CdTe crystals of medium quality (counting grade) were applied with a specific resistance of approximately $8 \times 10^8\,\Omega\,\mathrm{cm}$. Nevertheless, manufactured strip detectors allow to execute spectrometrical measurements mode. Fig. 10 shows the spectrum of ^{241}Am at room temperature, and Fig. 11 shows the spectrum of ^{241}Am at a temperature of -20°C. Resolution at energy 59.6 keV was 6.54 keV at room temperature and 3.08 at optimal one.

9. Conclusions

Thus, the developed technology allows to manufacture multidetector structures based on CdTe and CdZnTe crystals. Manufactured crystals hold wirebonding by pulse welding providing low labour-intensiveness of their assembly of standard equipment. Zebra elastometric electronic connectors are used for creation of the pressed contacts when necessary.

The developed technology permits to create strip structures with inter-strip resistance 2–8 GΩ with inter-strip distance 25 μm. 4 × 4 pixel detectors, made with usage of developed technology had energy resolution 0.81–0.93 keV at energy 5.9 keV and 1.3–1.6 keV at energy 59.6 keV. All results in the present report were measured without applying radiation collimation or correction-selection systems.

The results obtained in this paper can be used for development and manufacture of pixel and strip detectors of different design for solution of various scientific, medical and technical tasks.

References

[1] Semiconductors for Room-Temperature Detectors Applications II. Materials Research Society, Symposium Proceedings Vol. 487, Warrendale, PA.

[2] Y. Eisen, A. Shor, Semiconductors for Room-Temperature Detectors Applications II. Materials Research Society, Symposium Proceedings Vol. 487, Warrendale, PA. p. 129.

[3] A. Parsons, D.M. Palmer, P. Kurczynski, et.al., Semiconductors for Room-Temperature Detectors Applications II. Materials Research Society, Symposium Proceedings Vol. 487, Warrendale, PA. p. 147.

[4] P.F. Bloser, T. Narita, V.E. Grindlay, K. Shah, Semiconductors for Room-Temperature Detectors Applications II. Materials Research Society, Symposium Proceedings Vol. 487, Warrendale, PA, p. 153.

[5] Z.Q. Shi, C.M. Stahle, P. Shu, Semiconductors for Room-Temperature Detectors Applications II. Materials Research Society, Symposium Proceedings Vol. 487, Warrendale, PA, p. 159.
[6] C.M. Stahle, Z.Q. Shi, K. Hu, et al., Semiconductors for Room-Temperature Detectors Applications II. Materials Research Society, Symposium Proceedings Vol. 487, Warrendale, PA, p. 257.
[7] H.B. Barber, H.H. Barret, F.L. Augustine et al., J. Electron. Mater. 26 (6) (1997).
[8] M. Cuzin, F. Glasser, R. Marmet, et al., Proceedings of the SPIE, Vol. 2278, 1994, p. 21.
[9] Electronic Packaging Components. Fujipoly Catalog.
[10] C.L. Lingren, B. Apotovsky, V.F. Butler, et al., Semiconductors for Room-Temperature Detectors Applications II. Materials Research Society, Symposium Proceedings Vol. 487, Warrendale, PA, p. 263.