GAMMA RADIATION DETECTORS ON THE BASE CdTe FOR ENVIRONMENTAL MONITORING

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1. INTRODUCTION

The purpose of the given work is development and manufacturing of pre-production samples of small-sized dosimeters of gamma - radiation on basis *CdTe* for definition of a radiations level in an environment and for the control over the illegal moving of radioactive substances. It is supposed, that these dosimeters will replace devices in which as Heyger detectors are used [1].

In our days, *CdTe*-detectors are widely used in development of different devices for detecting and analyzing nuclear radiation (dosimeters, spectrometers, etc.), which are used in nuclear-power engineering, radiation monitoring systems, medicine.

Cadmium telluride (*CdTe*) is the first material to have been developed as a room-temperature semiconductor detector. Its E_{gap} of 1,45eV gives a high enough resistivity for room temperature operation, and Z of 48 and 52 gives a higher gamma radiation detection efficience that either *Si* (E_{gap}=1,12 and Z=14) or *Ge* (E_{gap}=0,66 and Z=32) [3-5].

Gamma rays and charged particles interact with a solid by converting most of their energy into electron-hole pairs. In scintillators like *NaI*(*Tl*) the intensity of the fluorescence arising from these charge carriers is observed with a photomultiplier tube and is proportional to the radiation energy. Semiconductor detectors instead use an electric field to collect the charge carriers and the resulting current pulse is amplified and is proportional to the radiation energy. Polarization effects, which are a time dependent decrease in either the depleted thickness or the charge collection properties.

2. CRYSTAL GROWTH AND CONTROL OF THE ELECTRICAL CONDUCTIVITY

CdTe crystals grow by the Bridgman technique [6,7] in a closed ampoule with small tellurium excess. Therefore the pressure in the ampoule is nearly equal to the tellurium vapor pressure at the growth temperature. Under these conditions the crystal contains excess of tellurium atoms that during cool down come out as precipitates, mainly at dislocations and grain boundaries.

The crystal quality improves by applying the modified Bridgman technique where one ampoule end is kept at lower temperature. There is a small cadmium excess in the ampoule. So the cold end determines the cadmium vapor pressure that is nearly equal to the over all pressure.

The growth procedure starts by melting the separate cadmium and tellurium loads, under hydrogen atmosphere, in order to remove oxygen from the system. The materials are then brought into contact and heated until they react and produce *CdTe,* or, *CdZnTe* if zinc is also present. Good quality crystals, practically free of precipitates, grow when the cold end temperature is about 300° C below the melting point, and when this difference stays during the cool down stage

High resistivity pure *CdTe* is not a good gamma detector since the lifetimes of the gamma generated holes and electrons are relatively short. Addition of dopants, mainly chlorine or indium, activates the material. The amount of chlorine that may be introduced into the crystal is limited, but there is no such limit with indium. These dopants act as electron donors in *CdTe* so that the crystal is expected to become highly conducting n-type. However, tellurium excess in the crystal transforms the dopants into a compensated state resulting in a crystal of high electrical resistivity and high sensitivity to gamma radiation.

In crystals that grow by modified Bridgman the amounts of cadmium and tellurium are balanced, therefore, addition of donor dopants will make them highly conducting. However, by annealing the crystal in saturated tellurium vapors, tellurium atoms will diffuse into it, or, cadmium atoms will diffuse out of it, and transform the dopants into a compensated state. Annealing at low enough temperature will not damage the crystal and precipitates will not appear.

Diffusion processes are slow at low temperatures. Cutting the crystal into wafers of the required thickness, before this step, will reduce the annealing time. One end of the annealing ampoule should be kept at

somewhat lower temperature in order to avoid tellurium vapor condensation on the wafers when it cools down.

The residual uncompensated donors determine the degree of electrical conductivity. The amount of donors is a fraction of the over all dopant amount, and increase of the over all doping will increase the donor amount as well. Therefore, the electrical conductivity will also increase. The conductivity is, therefore, controllable by adjustment of the doping level.

Donor dopants have two-fold effect within the crystal. In a compensated state they neutralize traps, and in an uncompensated state they push up the Fermi level and inactivate electron trap levels that go below it. Therefore, higher doping level will increase the electron lifetime, but it will also increase the leakage current and the current noise. A series of iterations of crystal growth experiments with different doping levels, followed by subsequent annealing, can yield optimal detector composition.

The usable thickness and energy resolution for *CdTe* detectors are primarily determined by their charge collection properties. The charge collection efficiency η for an interaction at a distance x from the negative contact in a detector is given by

$$\eta = \frac{Q}{Q_0} = \frac{\lambda_e}{L}\left[1 - \exp\left(-\frac{L-x}{\lambda_e}\right)\right] + \frac{\lambda_h}{L}\left[1 - \exp\left(-\frac{x}{\lambda_h}\right)\right] \qquad (1)$$

here:
Q – collected charge (C), Q_0 – full charge collection (C), λ_e – electron trapping length (cm),
λ_h – hole trapping length (cm), L – detector thickness (cm).

$$\lambda_e = \mu_e \tau_e E \ , \quad \lambda_h = \mu_h \tau_h E \qquad (2)$$

here:

μ_e – electron mobility (cm^2/Vs), μ_h – hole mobility (cm^2/Vs), τ_e – electron trapping time (s),
τ_h – hole trapping time (s), E – electric field (V/cm).

Energy resolutions of a few percent require an η of at least 90% or λ/L being at least 4. For values of λ/L less than 1, a detector is usable only as a counter. Values of $\mu\tau$ and of E for CdTe are $\mu\tau_e = (2\div3)\cdot10^{-3}$ cm^2/V, $\mu\tau_h = (1\div6)\cdot10^{-4}$ cm^2/V and $E = 7\cdot10^3$ V/cm.
Hence, $\lambda_e = 14\div21$ cm and $\lambda_h = 0{,}7\div4{,}2$ cm.

The primary limitation on increasing E for *CdTe* detectors is the requirement to avoid excessive noise due to a high leakage current. Low resistivity n-type *CdTe* has resistivity ρ between $10\div10^4$ Ω·cm, which limits both E and depleted thickness. High resistivity *CdTe* has ρ between $10^6\div10^{10}$ Ω·cm. *CdTe* detectors with ρ between $10^6\div10^7$ Ω·cm have been operated at 0°C which reduces the leakage current and allows E to be increased. However, a major disadvantage is the lack of room-temperature operation.

Trapping of the charge carriers, which causes incomplete charge collection in a detector, may reflect extended crystalline defects (voids, dislocations) or impurities, or native defects (vacancies or interstitial atoms). For *CdTe* hole trapping is more important than electron trapping. For CdTe improvements in trapping in very early crystals were generated by improving the purity of the starting material.

Polarization, which is a time dependent thickness or in the charge collection properties, manifests itself as a shift in the photopeak position. Polarization effects are in general unacceptable in usable devices. Detectors made from high resistivity *CdTe* grown by the traveling heater method and doped with *Cl* have the best $\mu\tau$ values and give the best energy resolution. Unfortunately, these detectors tend to have severe polarization problems. No significant polarization exists in low resistivity In-doped *CdTe* or in electrodeless *Au* contact detectors.

Technology has been developed for growing high-quality *CdTe* single crystals doped with chlorine. Using the grown crystals, testing samples of planar detectors of γ- and *X*-radiation has been developed with parameters which correspond to those of the best foreign analogues (Table 1).

Table 1

operation square	6x6 mm^2
sensitive region thickness	2-3 mm
operation voltage	~100 V
leakage current	~50 nA
sensitivity	~500 min^{-1}/μSv/h
energy range	20 - 3000 keV
energy resolution at 122 keV	<5 %
operation temperature	-40 - +60°C

3. DEVICE FABRICATION

Device fabrication can proceed by standard techniques. Mechanical polishing removes the cutting damage from the wafers, and then they are chemically etched by a solution of bromine in methyl alcohol. Recently solutions of bromine in ethylene glycol have become popular.

Chemical deposition of gold or platinum does not yield good ohmic contacts to n-type material. Contacts to semiconductors are usually prepared by deposition of thin metal film followed by heat treatment. Advanced designs apply multi layers of different metals and other materials. Evaporated indium or aluminum can be used as ohmic contacts to n-type *CdTe*. Indium, however, cannot be heated above its low temperature melting point, 156° C, and a double layer of indium and aluminum may enable heat treatment at higher temperatures. There is a need, however, of further development of ohmic contacts to *CdTe*.

The efficiency of the detector is a measure of its ability to detect the gamma rays. It is generally defined as the ratio of the counts in the spectrum full energy peak and the source emissions. For the efficiency measurement, several different geometry sources can be used. Each source has several nuclides which together emit gamma rays over a wide energy range. The sources are a point source and a flat disk source. A recommended list of nuclides is ^{241}Am, ^{57}Co, ^{137}Cs, and ^{60}Co. In all cases, material around the source should be minimized to reduce backscatter and other interfering peaks.

The point source must be less than 2 mm in diameter and located at 10 cm from the front face of the detector housing and along the principal axis of the detector. The disk source must have the activity uniformly deposited on a material such as filter paper and be 5 cm in diameter. The efficiency is measured at two source positions. For the close efficiency, the source is positioned at the front of the detector housing and along the principal axis of the detector. For the distant measurement, the source is located at 10 cm from the front face of the detector housing and along the principal axis of the detector.

For all detector-source geometries, the efficiency is calculated as follows:

$$\eta_E = 100 \cdot \frac{A_E}{N_E}$$

where η_E is the counting efficiency in percent; A_E is the total net peak count rate (cps);
N_E is the total number of full-energy photons emitted by the source in one second.

There is shown in Fig.1 the spectrum of γ-ray from Cs^{137} (662 keV) given by CdTe detector at 25°C, FWHM = 14 keV.

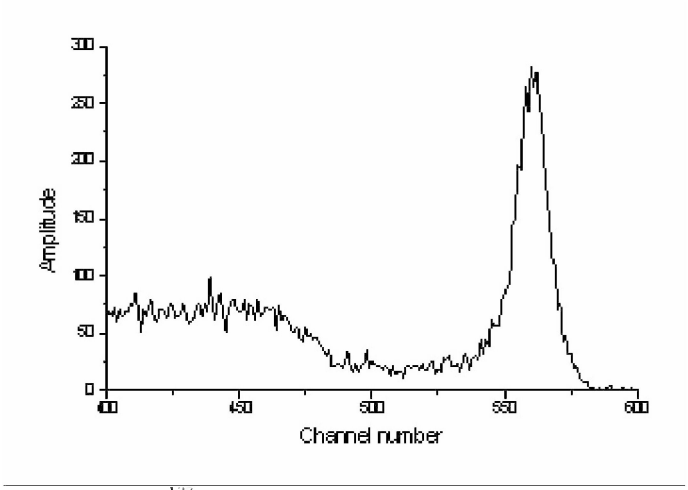

Fig. 1. Spectrum of γ-ray from Cs^{137} (662 keV) given by CdTe detector at 25°C, FWHM = 14 keV.

4. CONCLUSION

High-*Z* room-temperature detectors have a number of different applications as spectrometers, radiation counters. Applications of *CdTe* detectors include use of a portable scanner in measure loss of bone mineral, use of detectors operating at 70°C in monitoring activity at nuclear power stations, use in reentry vehicle applications, and use in fuel gauging operations.

A wide variety of different medical applications exists. In the field of X-ray imaging, better image quality results from improved energy resolution. *CdTe* provides improved energy-resolution compared to *NaI* without the need for bulky cooling systems. Work on *CdTe* probes has reached the clinical stage in both tracer studies (diagnostics) and dosimetry (therapy). The advantages of these probes are:

- high sensitivity which allows small sized probes,
- body temperature operation,
- good energy resolution.

These probes have been used in presurgical oral diagnosis, and *CdTe* needle probes have been constructed for potential eye or body use. In dosimetry the problem of tissue equivalence arises. Some examples of tracer applications are: detection of corneal lesions in animals using ^{75}Se, venous thrombosis detection using ^{125}I labeled fibrinogen and radiocardiographic studies. Other uses have been suggested such as absolute lung densitometry using a ^{153}Gd source and use of beta-emitting ^{14}C in dynamic biochemical studies.

Future technical improvements in *CdTe* detectors will expand the number of feasible device applications. Theoretical predictions, projections and limitations of possible improvements have proven to be unreliable.
As the number of applications expands, the decrease in detector cost will in turn increase the number of applications. Such potential low-cost detector applications include use in a photoconductivity mode for computer tomography scanners, as high speed counters in positron camera, and as gamma-ray imaging systems.

So, due to specific features of *CdTe*, the detectors created on its basis, are considered as the most perspective among a wide spectrum of detectors developed at present gamma-radiations. Simplicity, compactness, sensitivity, work room temperature cause advantages of use of *CdTe*-detectors in portable dosimetric devices.

5.REFERENCES

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