Radiation Physics and Chemistry 113 (2015) 47–52

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

The comprehensive evaluation of the structural and functional properties of the gas- statically treated Au–CdZnTe–Au structures for X- and gamma-ray detectors

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HIGHLIGHTS

- Gas-static effect on physical properties of Au–CdZnTe–Au structures was studied.
- The processing was provided in a laboratory-scale setup GAUS-4/2000-35.
- Photoluminescence, Raman and electrophysical methods were used for study.
- The formation of TeO_2 (additional resistance) on the contact was determined.
- The destruction of the films of surface oxides and absorbed gases was obtained.

ARTICLE INFO

Article history:
Received 9 August 2014
Received in revised form
23 April 2015
Accepted 26 April 2015
Available online 28 April 2015

Keywords:
Au–CdZnTe–Au structures
Gas-static processing
Raman scattering
Gamma-ray detector
Photoluminescence
Energy spectra

ABSTRACT

The influence of the gas-static processing on the optical, structural and electrophysical properties of Au–CdZnTe–Au structures, used in X- and gamma-ray detectors, was investigated. The processing, which is described in detail in the experimental part, was done in a laboratory-scale setup “GAUS-4/2000-35” with the following process parameters: pressure = 0.32 ± 0.02 GPa, temperature ~170 °C, time = 2 h. The influence of the mentioned processing on the photoluminescence, the Raman scattering, the electric resistance, the *I–V* characteristics and the spectrometric parameters of the Au–CdZnTe–Au structures was determined. The physical mechanisms, through which the gas-static processing induces changes in the structural and functional properties, were analyzed. It was observed that the gas-static processing (with the above-mentioned process parameters) of the Au–CdZnTe–Au structures leads to a significant increase of the electric resistance of the structures; it also leads to the increase of the intensity of the photoelectric absorption peak when the respective detector is registering X- and gamma-radiation with energy near 32.19 keV. The Raman and photoluminescence data indicates the formation of the surface oxides TeO_x and the compensation of Cd vacancies by Au atoms. The assumption that, under the discussed processing, two different rival processes modify the Au–CdZnTe junction due to the influence of the increased temperature ~170 °C and pressure ~0.3 GPa, was suggested. The first process is the formation of TeO_2 oxide (which increases the electric resistance) on the contact; the second process is the destruction of the surface films of the oxides and the absorbed gases. Most likely, the first process is dominant, which was evidenced by the Raman and photoluminescence measurements.

1. Introduction

A semiconductor detector is basically a semiconductor crystal with metallic contacts fabricated on the opposite planes, namely, it is a metal–semiconductor–metal structure. The electrophysical and detecting characteristics of such structure depend on the physical properties of the semiconductor material as well as on the properties of the metal–semiconductor interfaces and the contact fabrication method.

In the manufacturing of semiconductor detectors for X-ray and gamma-radiation, the following two types of contacts are used: the rectifying (barrier) and the ohmic contacts. The ohmic contacts are intended for a passive connection of the semiconductor with the external electrical network, thus, they must possess a constant and extremely low electric resistance. The rectifying contacts

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http://dx.doi.org/10.1016/j.radphyschem.2015.04.024
0969-806X/

(Schottky barriers) are the active components of electronic circuits, they are characterized by non-linear current–voltage (*I–V*) curves and are similar to p–n junction diodes (Bedny, 1998) in many features.

The detectors with barrier contacts have the best energy resolution for X- and gamma-radiation which is caused by low values of the leakage currents and, consequently, low electronic noise levels. In order to be used for the quantification of nuclear materials, detectors must be manufactured from semiconductors of spectrometric grade.

In order to conduct qualitative or semiquantitative measurements, it is necessary for a detector to have high efficiency for gamma-radiation in a wide energy range, which is characteristic of large-volume detectors with ohmic contacts. Such detector selection is due to the fact, that for the identification of nuclear materials or nuclear waste with low activity level the sensitivity is more important than the accuracy. The measurement error in this case should be in the range $\pm 20\%$, which is sufficient, for example, for the nuclear waste sorting according to (Reilly et al., 1991).

Thus, the improvement of the electrophysical and the detecting characteristics of the metal–semiconductor–metal structures with ohmic contacts is relevant for their application as X-ray and gamma-radiation detectors.

One of the methods for improving the metal–semiconductor ohmic contacts is the so-called "contact forming". The contact forming is a method of mechanically or electrically damaging a semiconductor material surface (creating a damaged layer), onto which the contact is deposited.

A gold, widely used in the detector manufacturing, or another metallic contact can act as a current collector as well as a protective coating, thus it must be practically non-porous. In order to reduce the porosity, which the gold contact layers may have after the deposition, they can be relatively easily compacted or compressed (which leads to their brilliant appearance). The compaction is achieved by treating the metallic coatings with different methods of mechanical polishing.

The improvement of the metal–semiconductor contact and the contact metal compaction can also be achieved by the hydro- or gas-static processing. The mentioned processing causes substantial changes of the physical state of the surface, for example, a destruction of the surface oxides and the films of adsorbed gases due to the intensive shifts of the surface layers, and an increase in the number of the metallic contact regions (Uralskyi et al., 1976; Ignatchenko and Babushkin, 1994; Virt et al., 2000). The influence of the hydro-static treatment (processing) on the electrophysical properties of Au–CdZnTe–Au structures was discussed in works (Kutnij et al., 2003, 2005). The authors demonstrated that the hydro-static processing leads to decreasing in the structures' electric resistance due to the modification of Au–CdZnTe interface and the respective potential barrier height decrease. The mentioned changes have the positive effect on the detection of the high-energy gamma-radiation (661.65 keV), namely the photoelectric absorption peak intensity increases by more than two times.

Besides the pressure-related treatments, a simple thermal treatment can be carried out after the contact deposition on the semiconductor crystal, which will also have an effect of tuning of the potential barrier height at the metal–semiconductor interface. (Ilchuk et al., 2000; Mergui et al., 1992; Bedny, 1999). The barrier modification is caused by the fact that, under thermal annealing, the morphology and the chemical composition of the region directly under the contact changes. In the works (Liliental-Weber et al., 1986; Goldberg and Posse, 1998), the possibility of the tuning of the electrical characteristics of semiconductor–metal contacts by the thermal annealing, to the point of the complete conversion of the barrier contacts into the ohmic ones, was demonstrated. Applied to the Au–CdZnTe–Au structures, it was shown in the works (Kutnij, 2005; Kutniy et al., 2005) that the thermal annealing in the air allows to reduce the leakage current and to increase the operating voltage in the studied samples due to the formation of an oxide (which adds the series resistance) on the Au–CdZnTe interfaces, most likely the TeO_2. The leakage current and, consequently, the noise level decreasing have a positive effect on detection of gamma-radiation ($E_\gamma \leq 59.54$ keV).

Therefore, the aim of this work is the investigation of the complex influence of the isobaric and the thermal treatment on the structural, the electrophysical and the detecting properties of the Au–CdZnTe–Au structures for the detection of X- and gamma-radiation.

2. Experimental

2.1. Sample preparation

To prepare the Au–CdZnTe–Au structures, the crystals based on the ternary semiconductor compound $Cd_{0.9}Zn_{0.1}Te$ of the p-type conductivity, grown by the HPB-method (high pressure Bridgman) in the Institute for Single Crystals, NAS of Ukraine, were used. The crystals' dimensions were $5 \times 5 \times 3$ mm^3. Mechanically grinded and polished samples were chemically etched in 8% bromine–methanol. The gold contacts (electrodes) were deposited by the chemical deposition method from the $HAuCl_4 \times 4H_2O$ acidic solution with the gold mass fraction of at least 48%. The surface of $Cd_{0.9}Zn_{0.1}Te$ without electrodes remained only mechanically polished and etched in mentioned above etchant.

The isobaric treatment (or the gas-static processing is the submitting the sample to high pressure at high temperature in argon atmosphere) of the studied samples was carried out in the laboratory-scale gas-static setup GAUS-4/2000-35. The operating parameters of the mentioned gas-static setup are the following: the internal atmosphere is argon, the maximal pressure is 0.4 GPa, the maximal temperature is 2000 °C, work area dimensions are ∅ 35 mm, height 170 mm. The pressure up to 0.4 GPa is obtained by using the cryogenic thermocompressor KRIT-4L. The mentioned compressor was developed and fabricated in the National Science Center "Kharkov Institute of Physics and Technology". The thermocompressor's operation is based on a series of cycles of cooling down the working gas argon to a liquid state followed by its heating in a closed volume. The special feature of such construction is the absence of moving mechanisms and, hence, the absence of wear of rubbing parts, which could cause the contamination of the gas atmosphere by the grease materials and wear products. The Au–CdZnTe–Au structure samples were loaded in the working area using a specific setup. The temperature near the sample was controlled by the THA thermocouples. The heating control in the setup GAUS-4/2000-35 was done in an automatic regime by a program using a microprocessor equipped with the precision temperature regulator PROTERM-100 (the temperature control accuracy ± 1 °C). After the contacts deposition, the Au–CdZnTe–Au structures were submitted to a gas-static treatment at a pressure 0.32 ± 0.02 GPa and temperature ~170 °C during 2 h.

2.2. Optical measurements

The low-temperature photoluminescence (LTPL) and the Raman scattering (RS) methods were used as the tools for the investigation of the defect structure and the crystalline perfection in the Au–CdZnTe–Au structures. The Ar–Kr laser "Stabilite 2018-RM" from Spectra Physics with $\lambda_{ex} = 488$ nm (2.54 eV) was used as an excitation source for LTPL and RS. The Raman measurements were done at room temperature and LTPL at liquid nitrogen