Changes in the electro-physical properties of MCT epitaxial films affected by a plasma volume discharge induced by an avalanche beam in atmospheric-pressure air

2015 J. Phys.: Conf. Ser. 652 012025

(http://iopscience.iop.org/1742-6596/652/1/012025)

Changes in the electro-physical properties of MCT epitaxial films affected by a plasma volume discharge induced by an avalanche beam in atmospheric-pressure air

D V Grigoryev[1,2], A V Voitsekhovskii[1], K A Lozovoy[1], V F Tarasenko[2], M A Shulepov[2]

[1] National Research Tomsk State University, 36 Lenin Av., Tomsk, 634050, Russia
[2] Institute of High Current Electronics SB RAS, 2/3 Akademichesky, Tomsk, 634055, Russia

denn.grig@mail.tsu.ru

Abstract. In this paper the influence of the plasma volume discharge of nanosecond duration formed in a non-uniform electric field at atmospheric pressure on samples of epitaxial films HgCdTe (MCT) films are discussed. The experimental data show that the action of pulses of nanosecond volume discharge in air at atmospheric pressure leads to changes in the electrophysical properties of MCT epitaxial films due to formation of a near-surface high-conductivity layer of the n-type conduction. The preliminary results show that it is possible to use such actions in the development of technologies for the controlled change of the properties of MCT.

1. Introduction

The semiconductor narrow-band material $Hg_{1-x}Cd_xTe$ (HgCdTe, MCT) is one of the basic materials for creating sensitive elements of IR photo-receiving devices in the wavelength range from 8 to 14 micrometres [1]. At present the epitaxial MCT films grown by the method of molecular-beam epitaxy (MBE) present a promising material for creating multi-element semiconductor detectors of IR radiation providing signal processing directly in the focal region [1, 2]. Along with the study of the initial properties of epitaxial films of MCT grown by MBE a very urgent task is controlled changing of the parameters of the material in order to obtain the desired semiconductor structures.

Nowadays various discharges and electron beams are widely used for modification of near-surface layers of materials [1]. In [3] the possibility of forming volume discharge at atmospheric pressure in a non-uniform electric field was demonstrated. In air at atmospheric pressure and non-uniform electric field volume discharge forms at both polarities of voltage pulse on the electrode with a small radius of curvature [4]. Under the influence of such discharge it is possible to realize high power density of the energy input (up to 800 MW/cm3 [5]). At the same time runaway electron beam with a current amplitude beyond the foil in the tens to hundreds of amperes is generated from the discharge plasma, and the beam current pulse width at half-maximum is less than 100 ps [6]. Thus, the feature of such discharges is the combined effect of the plasma of dense nanosecond discharge with energy input specific power of hundreds of megawatts per cubic centimeter, ultrashort electron beam with a broad energy spectrum and the optical radiation of different spectral ranges from the plasma discharge.

The aim of this work was to study the effect of volume nanosecond discharge in air at atmospheric pressure on the electro-physical properties of epitaxial HgCdTe grown by MBE.

2. Experimental samples and methods

For experiments the samples of epitaxial HgCdTe films of the p-type conductivity HgCdTe ($p = 1 \div 2 \cdot 10^{16}$ cm^{-3}, $\mu_p = 300 \div 500$ cm^{2}V^{-1}s^{-1}) grown by MBE were prepared at the Institute for Semiconductor Physics of the Siberian Branch of the Russian Academy of Sciences (Novosibirsk). The composition of the working layer of epitaxial films was x = 0.22.

Prepared samples were placed in a gas diode on the copper anode. The distance between flat anode and tubular cathode was 8-16 mm. As a source of voltage pulse generator RADAN-220 was used. The generator formed voltage pulses with an amplitude of ~ 230 kV (open circuit voltage), pulse duration at half-height of ~ 2 ns (a matched load) and a rise time of ~ 0.5 ns. The samples were irradiated in the repetitively pulsed mode with a pulse repetition rate of 1 Hz. Exposure was carried out in the range of $100 \div 1200$ pulses. Electro-physical parameters of the MCT samples before and after exposure were determined from measurements of the Hall effect by van der Pauw method. The measurements were performed at a constant current flowing through the sample (I = 1 mA) for the two directions of the current and two directions of a constant magnetic field. Removal of thin layers from irradiated material's surface was carried out in a 0.2 % solution of bromine in dimethylformamide. The surface of the irradiated samples was studied using atomic force microscope (AFM) "Ntegra Prima" (by NT-MDT) and optical profilometer MicroXAM-100 at ambient conditions.

3. Experimental results and discussion

Analysis of the results of measurements of electro-physical parameters of the irradiated samples of epitaxial MCT have shown that after irradiation in the range of $100 \div 1200$ pulses the conductivity of all samples are increases. Moreover, for samples exposed to pulses in the range from 100 to 400, a decrease in the value of the Hall coefficient is observed (figure 1). In this case, on the field dependence of the Hall coefficient shift of the inversion point for the sign of the Hall coefficient in the region of higher magnetic fields (from 0.17 T to 0.28 T) is observed. Increasing the number of pulses of impacts of volume discharge to 600 pulses results in a reversal of the sign of the Hall coefficient (figure 2, curve 2). Further increasing of the number of pulses reduces the Hall coefficient values (figure 2, curves 2, 3, 4), wherein the epitaxial HgCdTe samples are characterized by low electron mobility values ~$(2 \div 3) \cdot 10^3$ cm^{2}V^{-1}s^{-1}, which is two orders of magnitude lower than the corresponding values for the epitaxial n-type material of high quality.

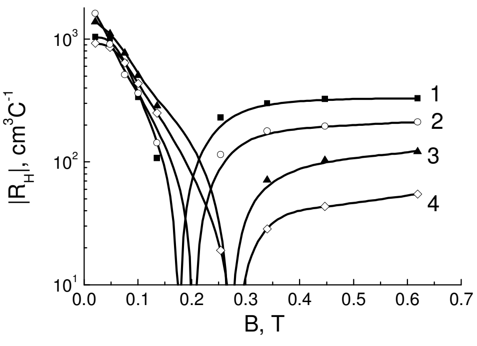

Figure 1. The field dependence of the Hall coefficient for samples of CdHgTe epitaxial films before (1) and after exposure to a volume discharge. The number of exposure pulses: (2) - 100, (3) – 200, (4) – 400.

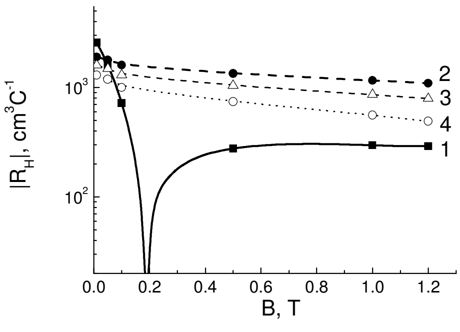

Figure 2. The field dependence of the Hall coefficient for samples of CdHgTe epitaxial films before (1) and after exposure to a volume discharge. The number of exposure pulses: (2) - 600, (3) – 800, (4) – 1000.

The results obtained made it possible to suggest that in the process of impact of volume discharge on the samples of epitaxial films a layer with high electron concentration is formed at the surface or in the surface region of the material. The conductivity of this layer is such that it bypasses the bulk of the epitaxial film in the measurements of the Hall effect.

The study of the surface structure of initial and irradiated epitaxial films with atomic force microscope revealed that the surface quality of the samples after exposure to a volume discharge is not changed. Surface roughness slightly increases from 1.6 to 2.2 nm. Additionally, the distribution profile of the sample surface for which part of the surface was closed with the dielectric plate during irradiation was investigated. Surface profile measurements were carried out with an optical profilometer MicroXAM-100. Analysis of measurement results have shown that the interface irradiated/unirradiated sample has no a characteristic step that leads to the conclusion about the absence of an alien film on the surface of the exposed part of the test sample (figure 3).

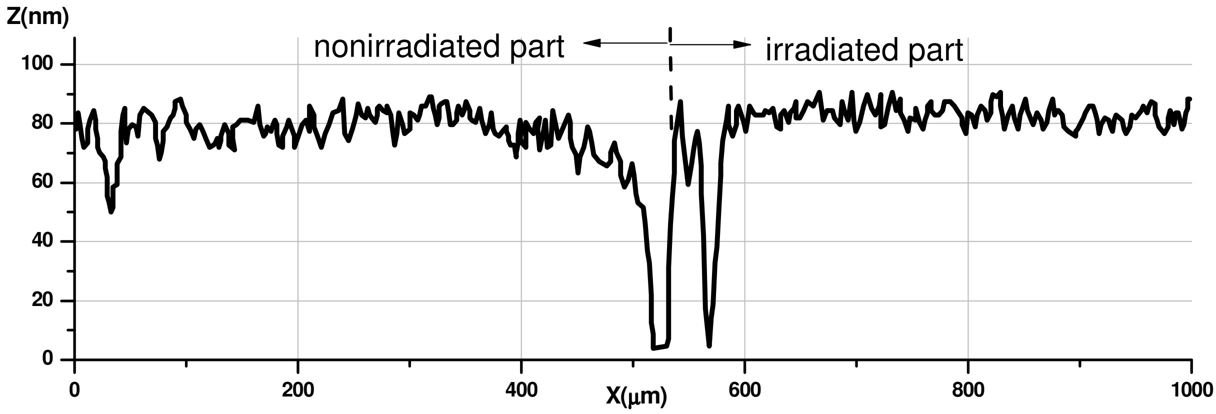

Figure 3. The surface profile of the MCT sample for which part of the surface was closed with dielectric plate during irradiation.

When etching the surface of the irradiated material by 0.1 mm electrophysical parameters of the samples irradiated return to baseline values (figure 4, curve 3). The obtained results allow concluding that during the impact of volume discharge on the samples of epitaxial films high conductivity layer forms in the surface region of the material.

Furthermore, it was found that after treatment of the irradiated samples in a solution of concentrated hydrochloric acid the restoration of the original values of electrophysical parameters of the material is taking place (figure 4, curve 4).

However, hydrochloric acid does not chemically react with initial MCT or with a material subjected to a radiation treatment. In the gas diode during a volume nanosecond discharge in air after a short voltage pulse in the discharge gap plasma consisting of an electron beam of positively and negatively charged ions is formed and the current flows through the diode. In this case, the sample of epitaxial MCT film located at the anode is exposed to complex effect consisting of a beam of electrons and negative ions, which cause the formation of different chemical MCT compounds after the influence on the sample surface.

The obtained data allow concluding that in the surface region of irradiated material the formation of chemical compounds of MCT with oxygen and nitrogen atoms occurs (such as anodic oxide which dissolve in hydrochloric acid). Analysis of published data shows that such chemical compounds contain significant concentration of positively charged centers that lead to the formation of an inversion layer at the interface with the epitaxial MCT film of p–type of conductivity. The formation of such an inversion layer is shown during the study of the properties of the interface between the oxide film and MCT [7].

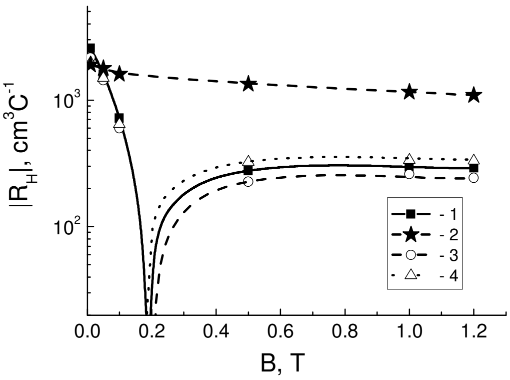

Figure 4. The field dependence of the Hall coefficient for samples of CdHgTe epitaxial films. (1) – before exposure; (2) – 600 volume discharge pulses; after etching of the irradiated sample in a solution of bromine dimethylformamide (3) and hydrochloric acid (4).

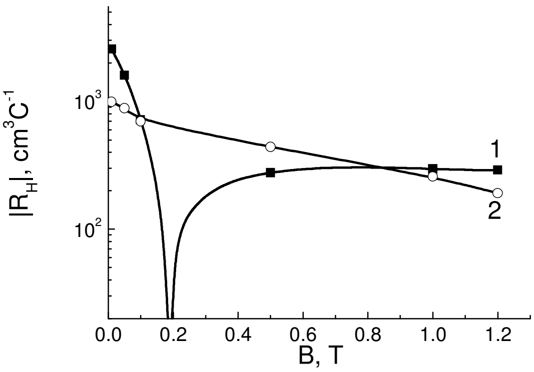

Figure 5. The field dependence of the Hall coefficient for samples of CdHgTe epitaxial films before (1) and after (2) growing of anodic oxide on the surface.

Modeling for this assumption was conducted by growing oxide on the surface of the MCT epitaxial layer by the method of anodic oxidation. After growth of anodic oxide electrophysical parameters of obtained multilayer structure were measured. The measurement results have shown that the observed changes in the field dependence of the Hall coefficient before and after the deposition of anodic oxide are similar to the results observed after irradiating the samples of MCT by volume discharge (figure 5).

4. Conclusion

Thus, the experimental data have shown that the exposure of MCT epitaxial films to the pulse volume nanosecond discharge in air at atmospheric pressure leads to formation of chemical compounds of MCT with oxygen and nitrogen atoms in the surface layer of material. The formed layer has a built positive charge that leads to the formation of an inversion layer at the oxide/MCT interface which "shunts" the rest of the sample so that the measured field dependence of Hall coefficient corresponds to the material of n-type of conductivity.

This research carried out in 2015 was supported by grant (№ 8.2.10.2015) from “The Tomsk State University Academic D.I. Mendeleev Fund Program”.

Acknowledgments

The authors gratefully acknowledge N.N. Mikhailov and V.S. Varavin for providing the MBE HgCdTe epitaxial films.

References

[1] Rogalski A 2012 *Opto-electronics Review* **20** 279
[2] Shulepov M A, Tarasenko V F, Goncharenko I M et al 2008 *Tech. Phys.* **8** 51
[3] Tarasova L V, Khudyakova L N 1969 *Sov. Phys. Tech. Phys.* **14** 1148
[4] Kostyrya I D, Orlovskii V M, Tarasenko V F et al 2005 *Technical Physics Letters* **31** 457
[5] Alekseev S B, Gubanov V P, Kostyrya I D et al 2004 *Quantum Electron* **34** 1007
[6] Tarasenko V F, Shpak V G, Shunailov S A, Kostyrya I D 2005 *Laser Part. Beams* **23** 545
[7] Brogowski P and Piotrowski J 1990 *Semicond. Sci. Technol.* **5** 530