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Influence of a high-frequency pulsed nanosecond diffusion discharge in the nitrogen atmosphere on the electrical characteristics of a CdHgTe epitaxial films

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Abstract. The effect of a high-frequency nanosecond volume discharge forming in an inhomogeneous electrical field at atmospheric pressure on the CdHgTe (CMT) epitaxial films is studied. The measurement of the electrophysical parameters of the CMT specimens upon irradiation shows that the action of pulses of nanosecond volume discharge leads to changes in the electrophysical properties of CMT 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 CMT narrow-band solid solutions and production of structures heterogeneous with respect to conduction.

1. Introduction

Gas discharges of various types are widely used for the modification of material properties. The authors have demonstrated the possibility of the formation of a volume discharge at atmospheric pressure. Such a volume discharge is something like a corona discharge. In both cases, the electrodes need special configuration allowing to create a strongly non-uniform electric field in the discharge gap. Therefore, at least one of the electrodes should have a small radius of curvature. The formation of a corona discharge occurs efficiently under reduced pressure, and to obtain the corona discharge under high pressure it is necessary to supply voltage of hundreds of kilovolts. At the same time discharge quickly passes into the spark stage, a breakdown and the evaporation of the electrode material occur.

In recent years, a wide interest is focused on the study of the properties of a volume diffuse discharge induced by a beam of runaway electron avalanches (REP DD) and its application for modification of the properties of various materials [1]. A feature of this discharge is that it is weakly dependent on the ambient pressure (can be quite easily formed at high pressure). It is not necessary for its formation to collect the ions and electrons in the discharge gap, as is the case of the corona discharge. Also there is no need for pre-ionization of the gap by any third-party source. Under the influence of such a discharge it is possible to realize high power density of energy deposition (up to 800 MW/cm³). At the same time the runaway electron beam with a current amplitude behind the foil of tens to hundreds of amperes is generated from the discharge plasma. The beam current pulse



duration at half-height is not higher than 100 ps. In addition, a feature of such discharges is the combined effect of plasma of a dense nanosecond discharge with power density of the energy deposition of hundreds of megawatts per cubic centimeter, ultrashort electron beam with a broad energy spectrum, and the optical radiation of the plasma discharge in different spectral ranges. REP DD is a pulse discharge due to the nature of its formation. In this case most of the time of the existence of discharge, an external voltage, applied to the discharge gap, is small (less than 10 kV) or does not exist. That is, the discharge exists until the end of the recombination of ions. The value of the accelerating voltage in the gap is insufficient for effective ion implantation. So, during the existence of the accelerating voltage only those ions formed by the flown wave of runaway electrons are introduced, which were directly near the surface. Therefore, the impact of REP DD modifies only the surface layers of the material samples, not deeper than 10-200 nm, depending on the material.

Ternary semiconductor compound mercury cadmium telluride ($\text{Cd}_x\text{Hg}_{1-x}\text{Te}$, CdHgTe, CMT, x – material composition) is currently one of the basic materials for the creation of highly efficient photodetectors operating in the infrared region [2]. For temperature imaging the most commonly used region of wavelengths is 8-14 μm , which corresponds to the $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$ composition with $x = 0.22$. Despite the great advances made in the technology of photodetectors based on CMT, the search for new and effective methods for the controlled management of the properties of the original material is still an urgent task. The first experimental data on the effect of the REP DD on properties of epitaxial CMT are presented in [3-5]. The frequency of exposure pulses of volume discharge was 1 Hz (low frequency pulsed volume discharge). This paper presents the first experimental results of the effect of the high frequency volume nanosecond discharge in a nitrogen atmosphere on the electrical properties of epitaxial CdHgTe material. Selection of gas discharge media is determined by the necessity to compare the obtained results with the results of the impact of low-frequency pulsed volume discharge in air at atmospheric pressure.

2. Samples and experimental techniques

Two series of samples of CMT epitaxial films of p- and n-type grown by molecular beam epitaxy at the Institute of Semiconductor Physics SB RAS in Novosibirsk were prepared for conducting research. The material composition of the working layer of epitaxial films was $x = 0.22$.

The experiments were performed using a specially designed setups and discharge chamber. The design of the diffuse plasma generator that allows us to modify the surface of the flat circular samples with a diameter up to 10 mm is shown in figure 1. Point cathode 1 with a small radius of curvature, made of tool steel, was pressed into caprolon insulator 2. To control the operation of the generator quartz windows 4 with a diameter of 20 mm were made in a metal case 3. The voltage across the discharge gap was measured by capacitive divider 5 and the current of discharge was measured by shunt 6 made of a low-inductive chip resistors. The working gas was supplied into the discharge chamber through the opening 7. In the bottom of the housing 3 the outlet openings 8 are located. The laminar gas flow directed along the cathode was formed by caprolon conical nozzle 9. The distance from a point cathode to the plane anode 10 with a modifiable sample has the ability to be customized in the range of 1-20 mm. Figure 1b shows a photograph of a glow of discharge plasma in a stream of nitrogen at a pumping speed of 5 liters / min, the voltage pulse repetition frequency of 40 Hz and electrode gap of 12 mm. The cathode is located on the top.

An NPG-18/3500N high-voltage pulse-periodic generator was used as a voltage source, from which voltage pulses with an amplitude in the incident wave of up to 20 kV, a full width at half-maximum (FWHM) of 18 ns, and a rise time of 4 ns were supplied to the cathode. The discharge voltage was measured using a capacitive divider, and the discharge current was measured using a shunt connected between the anode and the chamber wall.

The $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$ specimens were irradiated in the pulsed-periodic mode at the pulse repetition rate 1200 Hz. The action was realized through 5, 10 and 20 minutes in an atmosphere of nitrogen. The nitrogen flow was 1.5 L/min. Measurements of the electro-physical parameters of the samples before and after irradiation were made at the temperature of liquid nitrogen using the Hall Electromotive

Force (EMF) method in the Van-der-Pau configuration. 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. The surface of the irradiated samples was studied using atomic force microscope (AFM) "Ntegra Prima" (by NT-MDT) at ambient conditions.

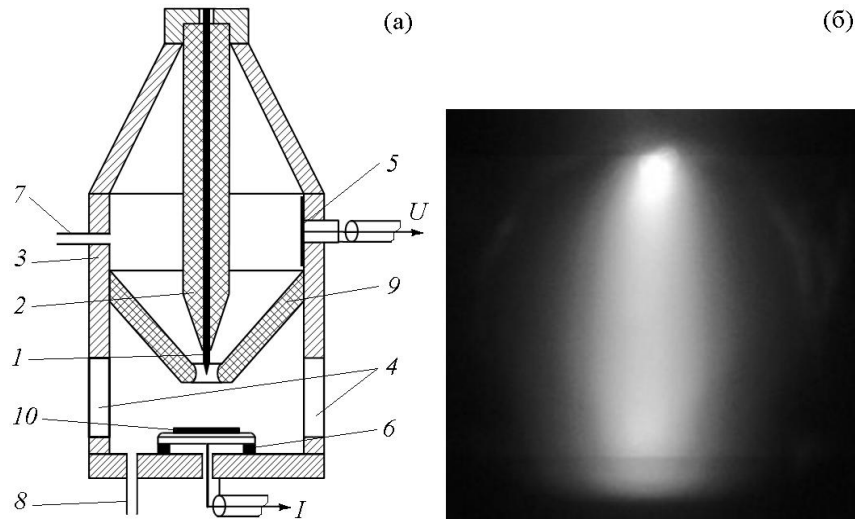


Figure 1. Discharge chamber (a) and photograph of a glow of discharge plasma (b).

3. Results and discussion

The study of the surface structure of initial and irradiated epitaxial films with an 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 1.7 to 2.1 nm.

Measurements of the electrical parameters of the samples of CMT epitaxial films after exposure to volume discharge pulses have shown that for all samples an increase in the conductivity of the material is observed.

As shown in figure 2 for p-type samples, a sharp change in the character of the behavior of the field dependence of the Hall coefficient is observed. For the initial sample alternating dependence of the Hall coefficient with a dot of inversion 0.2 T is observed. The irradiated material is characterized by the behavior of the field dependence which is characteristic for n-type material. At the same time samples of CMT epitaxial films are characterized by low values of electron mobility $\sim 2 \cdot 10^3 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$, which is two orders of magnitude lower than the values corresponding to epitaxial material of n-type conductivity of high quality.

The observed change in the behavior of the field dependence of the Hall coefficient and low values of charge carrier mobility for the irradiated material allows us to conclude that in the process of impact on samples of epitaxial films of the volume discharge, formation of a layer with a high concentration of electrons on the surface or in the near-surface region of the material occurs. Conductivity of this layer is such that it bypasses the bulk of the epitaxial film during the Hall effect measurements. This conclusion is confirmed by the values of the electrical parameters for the irradiated material of n-type conductivity (figure 3). The magnitude of the Hall coefficient decreases with increasing the irradiation time, while the value of the mobility of the charge carriers is not substantially changed. In addition, the experimental data are in good agreement with the results of the impact of low-frequency discharge in air at atmospheric pressure on the electrical parameters of epitaxial CMT [3-5].

However, the features of the impact of high-frequency volume discharge compared to the low-frequency are observed. Various changes in the value of the Hall coefficient over time of the impact of the volume discharge pulses is observed for investigated samples. For example, for the material of n-type the conductivity increase in exposure time from 5 to 20 minutes leads to a monotonic decrease of the

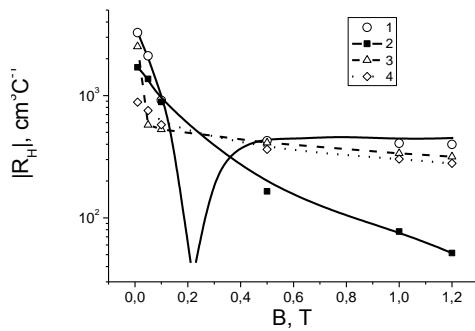


Figure 2. The field dependence of the Hall coefficient for samples of p-CdHgTe epitaxial films before (1) and after exposure to a volume discharge. The time of exposure (minutes): (2) - 5, (3) - 10, (4) - 20.

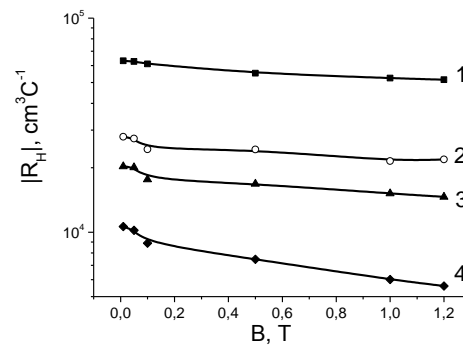


Figure 3. The field dependence of the Hall coefficient for samples of n-CdHgTe epitaxial films before (1) and after exposure to a volume discharge. The time of exposure (minutes): (2) - 5, (3) - 10, (4) - 20.

Hall coefficient value from $3 \cdot 10^4$ to $6 \cdot 10^3$ cm^3C^{-1} . While for the samples with p-type conductivity the Hall coefficient value increases with increasing the irradiation time. In addition, the stability study of the electrical parameters of the irradiated samples showed that the relaxation of the electrical parameter values over time is observed. Moreover, the character of relaxation for samples of different conductivity type is different. For p-type samples the Hall coefficient value is doubled for a period of 30 days. At the same time for the material of n-type conductivity the Hall coefficient value changes nearly ten times.

4. Conclusion

Thus, the obtained experimental data show that the effect of high-frequency pulses of nanosecond volume discharge in nitrogen atmosphere leads to a change in electrical properties of epitaxial CdHgTe, which is caused by the formation of the highly conductive surface layer of n-type conductivity during the process of exposure. The observed experimental data are in good agreement with the results obtained under the influence of low-frequency volume discharge in air at atmospheric pressure. At the same time revealed features of the high-frequency exposure (presence of relaxation of the electrical parameters of the irradiated samples, the dependence of the dynamics of the Hall coefficient values change over irradiation time on the type of conductivity of the material) allow us to make the assumption that the mechanisms of low- and high-frequency impact of volume nanosecond discharge on the electrical parameters are different.

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