A change in the electro-physical parameters of narrow-gap CdHgTe solid solutions acted upon by a diffusion discharge in the air, argon and nitrogen at atmospheric pressure

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Abstract. The effect of a nanosecond volume discharge forming in an inhomogeneous electrical field in various gas environments at atmospheric pressure on the CdHgTe(MCT) epitaxial films of the p-type conduction is studied. The measurement of the electrophysical parameters of the MCT specimens upon irradiation shows that a layer exhibiting the n-type conduction is formed in the near-surface region of the epitaxial films. Analysis of the preliminary results reveals that the foregoing nanosecond volume discharge in various gas environments at atmospheric pressure is promising for modification of electro-physical MCT properties.

At present ternary semiconductor MCT compounds are one of the major materials for producing IR photodetectors for the 3–5 and 8–14 µm wavelength ranges [1]. The main tendencies in the development of modern technologies are aimed at production of highly effective multi-element photodetector devices based on the epitaxial MCT material grown by molecular-beam epitaxy (MBE). Along with examination of initial properties of epitaxial MBE MCT films, a controlled change of the material parameters is important for producing semiconductor structures with specified properties.

Electric discharges of different types as well as electron beams are now widely used for the modification of near-surface layers of various materials [2]. It was reported that a high-voltage diffuse discharge at a low gas pressure and a low power could be used for the inactivation of microbiological cultures [3]. As is known [4], a volume discharge can be generated using inhomogeneous electric field in gases at atmospheric pressure. For this purpose, high-voltage (≥100 kV) pulses of nanosecond duration are applied to a gas-filled interelectrode gap. A specific feature of such discharges in air at atmospheric pressure is the accompanying X-ray emission and the formation of runaway electron beams [5].

In recent years, it was established that a volume discharge could be generated in air at atmospheric pressure in an inhomogeneous electric field for both polarities of the high-voltage pulses applied to an electrode with a small radius of curvature [6]. Another feature of volume discharges in inhomogeneous electric fields, which are initiated by supershort avalanche electron beams (SAEBs), is the possibility of reaching high levels of specific power (up to 800 MW/cm³ [7]) deposited in the discharge. In such regimes, runaway electron beams emitted from the discharge plasma are

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characterized by the beam current amplitudes reaching tens and hundreds of amperes (behind the foil), while the current pulse duration (defined as the pulse full width at half maximum, FWHM) does not exceed 100 ps [8]. Such discharges in inert gases are also accompanied by high-intensity vacuum ultraviolet (VUV) emission. Thus, the generation of SAEB-induced volume discharge in gases at high pressures leads to a complex action of the high-density nanosecond discharge plasma (with a specific deposited power of several hundred megawatt per cubic centimeter), SAEBs (with a broad energy spectrum), shock wave and radiation in various spectral ranges (including UV and VUV emitted from the discharge plasma) on the anode.

The aim of this work is to study the effect of a nanosecond volume discharge in various gas environments at atmospheric pressure on the electro-physical properties of epitaxial film CdHgTe grown by molecular beam epitaxy.

Investigation of the discharge influence for semiconductors was carried out on narrow-band material Cd$_x$Hg$_{1-x}$Te. To perform the investigations, epitaxial Cd$_x$Hg$_{1-x}$Te (x=0.22) films were grown by molecular beam epitaxy at the Semiconductor Physics Institute of the Siberian Branch of the Russian Academy of Sciences in Novosibirsk. The material was grown on a GaAs substrate backing in the (013) orientation with buffer layers of ZnTe and CdTe. After growth, the films had n-type conductivity with carrier concentration $10^{14}$ cm$^{-3}$ and mobility $\sim 10^5$ cm$^2$V$^{-1}$s$^{-1}$. For conversion to p-type conductivity, the films were annealed in a neutral atmosphere of hydrogen or helium. After annealing, the samples had p-type conductivity ($p = 1.1 \div 2.5\times10^{16}$ cm$^{-3}$, $\mu_p = 300 \div 500$ cm$^2$V$^{-1}$s$^{-1}$).

The experiments were performed using a discharge chamber. A distance from a sample holder to a tubular electrode was 20 mm. The interelectrode voltage was supplied from a pulser of the RADAN-220 type, which generated voltage pulses with an amplitude of $\sim 230$ kV (in the open-circuit regime), a current pulse duration (defined as the pulse full width at half maximum) of $\sim 2$ ns (on a matched load), and a leading front width of $\sim 0.5$ ns. The results of discharge current measurements showed that the current pulse amplitude was $\sim 3$ kA and the total duration of the discharge current pulse was $\sim 30$ ns (the first half-period of the discharge current pulse had a duration of $\sim 8$ ns). The Cd$_x$Hg$_{1-x}$Te specimens were irradiated in the pulsed-periodic mode at the pulse repetition rate 1 Hz. The action was realized through 100–1200 pulses for a series of specimens irradiated in air and 600, 1200 pulse irradiation in an atmosphere of argon and nitrogen. 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 surface irradiated MCT sample has been studied by atomic force microscopic (AFM) system Solver HV.

Analysis of the surface structure of the initial and irradiated epitaxial films (fig. 1) showed, that
the quality of the specimen surface upon volume-discharge action is not affected, that is, no changes in the surface structure of the irradiated specimens occur. The surface roughness slightly increases from 1.46 to 2.2 nm.

The measurement of electrophysical parameters of the MCT epitaxial-film samples after exposure to discharge pulses in the air atmosphere showed that for all the samples an increase in conductivity. The specimens irradiated by 100 – 400 pulses, however, exhibit a decrease in the Hall coefficient. In so doing, the field dependence of the Hall coefficient is characterized by a shift of the inversion point of the Hall coefficient sign to the region of higher magnetic fields from 0.17 T to 0.28 T (fig. 2). An increase in the number of volume-discharge pulses up to 600 results in the inversion of the Hall-coefficient sign in the range more than 0.2 T (fig. 3). A still further increase in the number of pulses exposure leads to a decrease in the value of the Hall coefficient. Also the lack of relaxation of electrical parameters of irradiated specimens within 3 months is noted (fig. 3, curve 3).

It has been suggested that, on or near the surface of the film formed by a layer of highly conductive n-type, whose parameters are such that the measured field dependence of the Hall coefficient corresponds to the n-type conductivity.

For specimens irradiated in argon and nitrogen, there is a change in the field dependence of the Hall coefficient as in the case of irradiation in air. For the specimens irradiated at 1200 pulses under a nitrogen atmosphere after exposure in the field of 0.2 T (fig. 4a). The observed inversion of the sign of the Hall coefficient, which is not on the original field dependence, for a specimens irradiated with 600 pulses in an argon atmosphere, after exposure to the field dependence of the Hall coefficient noticeable change in the sign of a 0.2 T (fig. 4b). The field dependence of the specimens corresponds to the field dependence of the material n-type conductivity. It has been suggested that, on or near the surface of the film formed by a layer of highly conductive n-type similar to the case of irradiation in air, whose parameters are such that the measured field dependence of the Hall coefficient corresponds to the n-type conductivity. It also marked relaxation of the electrical parameters of epitaxial films irradiated to baseline values within 6 months (fig. 4, curves 3).

Based on the Petriz model [9] the theoretical calculation of the Hall coefficient field dependence was carried out. Theoretical calculation and experimental data are in good agreement. The calculation showed that the integrated conductivity of the resulting highly conductive n-type layer is for air $8.6 \times 10^{-3}$ ohm$^{-1}$ at 600 pulses and $9.6 \times 10^{-3}$ ohm$^{-1}$ at 1200 pulses, for nitrogen $10^{-2}$ ohm$^{-1}$ at 600 pulses and $10^{-4}$ohm$^{-1}$ at 1200 pulses, for argon $5 \times 10^{-3}$ohm$^{-1}$ at 600 pulses and $5 \times 10^{-5}$ ohm$^{-1}$ at 1200 pulses.
Thus, our experimental data show that the action of pulses of nanosecond volume discharge in air, argon and nitrogen at atmospheric pressure leads to changes in the electrophysical properties of CdHgTe epitaxial films. These changes are due to formation of a near-surface high-conductivity layer of the n-type conduction. The electrophysical parameters of this layer are such that the measured field dependence of the Hall coefficient of p-type CdHgTe epitaxial films corresponds to the n-type material conductivity. This result suggests it is possible to use such discharge in various gases for the controlled change of the properties of CdHgTe narrow-band solid solutions.

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