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Influence of soft X-ray of a vacuum spark with laser initiation on the surface properties of solid solutions $Cd_XHg_{1-X}Te$

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Abstract. At a certain form of broadband source soft X-ray spectrum is expected to achieve selective radiation exposure to one of the elements of a multi-component material $Cd_xHg_{1-x}Te$. In this case we can talk about a change of the surface properties of the substance as a result of selective absorption of soft X-rays.

1. Introduction

It has been previously shown that the soft X-ray radiation from laser plasma (wavelength range 0.3 ÷ 30 nm or energy range 0.1 ÷ 10 keV, respectively) leads to a change in the surface morphology of the mono crystals and epitaxial layers of solid solutions $Cd_xHg_{1-x}Te$ [1,2]. In these works soft X-ray radiation of the laser plasma was used, which has over 80% of energy lying in the region of 50 ÷ 250 eV. Thus there was no significant change in either carrier concentration or carrier of charge mobility in the bulk material and in the surface region. However, it can be expected that the increase in the degree of surface defects should lead to a change in its galvanomagnetic characteristics.

In this paper the effects on the semiconductor by the plasma generated by the laser-initiated vacuum spark hard X-rays with photon energies $E_{\text{X-ray}} = 0.5 \div 10$ keV are considered.

2. Experimental installation

The experimental setup consists of a vacuum interaction chamber (pressure $P \approx 10^{-5}$Torr), a high-voltage discharge system, initiating Nd: YAG laser ($\lambda = 1.06$ µm, the pulse energy $E_{laser} = 20 \div 35$ mJ and a pulse duration $\tau \approx 15$ ns) and diagnostic systems. In turn, the high-voltage discharge system consists of the conical electrodes, low inductance capacitor bank (capacitance $C = 0.011$ uF), a high vacuum current lead and high voltage DC ($U = 12 \div 15$ kV). The laser radiation is focused on the Fe-cathode. The anode is made of brass.

The vacuum spark forming region and a holder for mounting the irradiated sample are shown in figure 1. The distance from the discharge plasma to the sample is about 30 mm. To protect the sample from the optical range of the radiation and corpuscular streams Mylar filter with thickness about 3 µm is used with a 200 nm thick layer of Al deposited on it. The irradiation of the sample was done in the periodical pulsed mode with a repetition rate of discharge pulses $f \approx 1$ Hz.

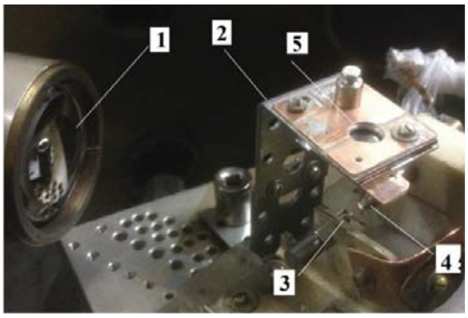

Figure 1. The area forming a vacuum spark in a pilot plant:1 - lens for focusing the laser beam; 2 - bracket for mounting the sample; 3 - cathode (Fe); 4 - anode (brass); 5 - protective filter.

In order to control the charging current Rogowski coil with a time resolution better than 10 ns is used. Two identical *pin*-diode with a matched pair of edge filters were applied for the registration of X-ray radiation. They were placed inside the vacuum chamber at the distance of 20 cm from the discharge area.

3. Experiment and results

3.1. The spectrum of the source Soft X-ray from vacuum spark.
Experimental technique and method for reconstructing the X-ray spectrum are described in [3]. A form of the X-ray spectrum of a vacuum spark is shown in figure 2.

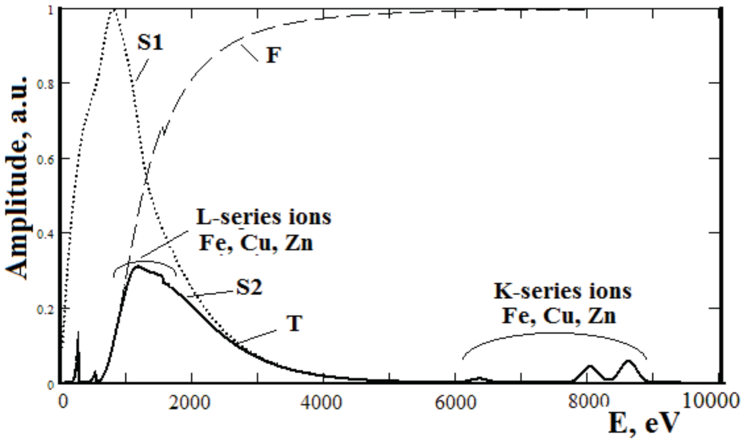

Figure 2. The figure shows the spectrum: 1) **S1 -** synthesized by the experimental data range soft X-Ray induced laser-discharge plasma; 2) **S2 -** spectrum soft X-Ray after Mylar filter; 3) **F -** transmission spectrum of 3μ Mylar filter; 4) **T -** *bremsstrahlung*.

The samples of semiconductor were irradiated by soft X-Ray from vacuum spark, with the above range. The latter is an epitaxial p-$Cd_{0.22}Hg_{0.78}Te$ and about 10 μm thick, grown in a coherent single-crystal substrate. The absorbed dose of soft X-Ray was estimated in the range of 0.15 ÷ 1.5 J/cm^2, depending on the exposure time in the range of 15 ÷ 150 minutes. This estimate was obtained assuming that the soft X-ray source is a point source.

Figure 3 shows the spectra that characterize the spectral parameters of soft X-Ray source and model the X-ray transmission spectra of the investigated solid $Cd_{0.22}Hg_{0.78}Te$ solution [4].

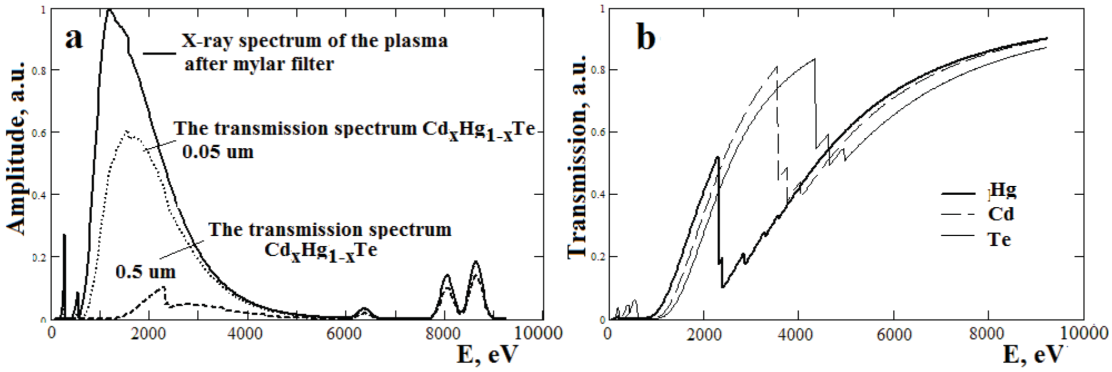

Figure 3. a - the calculated spectra of the plasma X-ray source and X-ray absorption in $Cd_xHg_{1-x}Te$ samples with the thickness of 0.05 µm (30%) and 0.5 µm (90%) [5]; b - the transmission of individual elements Hg, Cd, Te at the sample thickness of 0.5 mm [6]

Figure 3a shows the calculated spectral characteristics of the X-ray source for irradiating semiconductor and transmission of X-rays of the investigated solid solution $Cd_xHg_{1-x}Te$ with $x \approx 0.22$. One can see the presence of the transmission spectrum characteristics of the semiconductor in the range of 2.3-3.6 keV due to the presence of mercury in the sample. In figure 3b the transmission spectrum of mercury structure consisting of absorbing shocks at the following levels: MI (3.56 keV), MII (3.28 keV), MIII (2.85 keV), MIV (2.38 keV) and MV (2.29 keV) - is shown. Furthermore it should be understood that the intensity of radiation X-ray source used sharply decreases in the area of characteristic absorption of ions of Cd and Te (figure 2). From a comparison of figure 3a and figure 3b it follows that radiation of the X-ray source will be absorbed primarily by the Hg atoms, resulting in increased probability of the atoms migration from the lattice points and thus formation of the defects in the crystal structure [7]. This in turn can affect the electrical properties of the material.

3.2. Investigations of surface properties of irradiated samples p-$Cd_xHg_{1-x}Te$

Soft X-ray penetrates samples $Cd_xHg_{1-x}Te$, as shown above, to a depth of about 1 µm. To study the processes of its effect on the properties of the material it is necessary to use techniques that are sensitive to changes in the surface properties of semiconductors. The latter includes capacitive spectroscopy. Therefore, the samples were subjected to irradiation, conducted research capacity characteristics according to the method discussed in [8-10]. It was found that the temperature dependence of the capacity-voltage characteristics (CV characteristics) after exposure to X-ray radiation in the form of a singularity "shelf" due to the influence recharge of surface states (figure 4, C is the specific capacity of the MIS (metal- insulator- semiconductor) structure in the F/m^2). This dependence can be considered with good accuracy as a linear. From this it follows that the density of the surface states concentration of majority carriers within the thickness of the space charge is uniformly distributed. Furthermore, from the slope of this line integrated concentration of the majority carriers of charge can be determined.

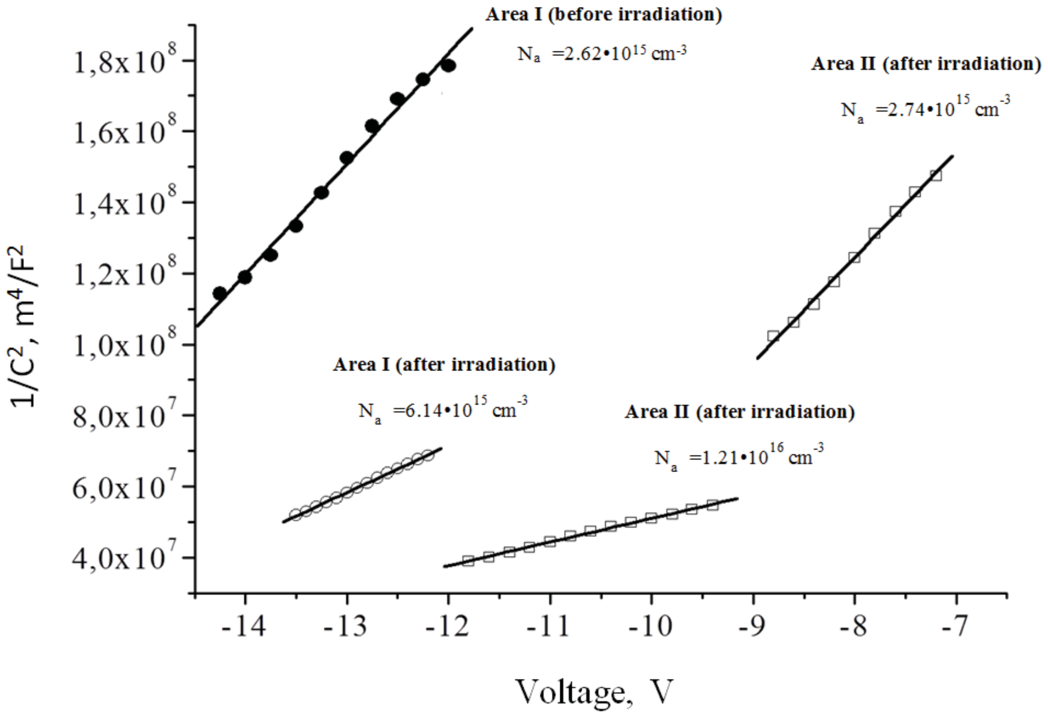

Figure 4. Dependence of 1/C2 in the depletion mode, the bias voltage to the source of MOS structures based on p-HgCdTe before and after the soft X-ray, built according to the capacitance-voltage measurements at a temperature of 770K at a frequency of 50 kHz with a direct scan voltage.

Processing of measurement results presented in figure 4 based on the assumptions above, showed that the concentration of holes in the surface layer to the source of MOS structure is $2.6{\cdot}10^{15}$ cm^{-3} and $2.7{\cdot}10^{15}$ cm^{-3}, and for MIS structures after exposure to X-ray radiation – $6.1{\cdot}10^{15}$ cm^{-3} and $1.2{\cdot}10^{16}$ cm^{-3}, respectively [11]. Thus, the concentration of majority carriers in the surface layer of the semiconductor after exposure to soft X-ray increases by 2-4 times, which may be related to the preferential knocking out of mercury ions and thereby forming defects of the acceptor type.

Further analysis of CV characteristics shows that original samples surface states are missing, while they appear in the irradiated samples. For one of them after exposure by soft X-ray maximum surface states appears at energies E_{v+} (0.37-0.45) eV (or E_{c-} (0.065-0.145) eV) at an average density of states in the energy range of $1.63{\cdot}10^{12}$ eV^{-1} · cm^2. In another area of the sample after exposure maximum of surface states appears at energies E_{v+} (0.34-0.39) eV (or E_{c-} (0.125-0.175) eV) at the average density of surface states in the energy range of $7.40\cdot10^{12}$ eV^{-1} · cm^2. Here, E_v and E_c are the top of the valence band and the conduction band bottom, respectively.

4. Conclusion

Thus, for the first time it has been shown that the use of a source of X-ray with the same spectrum as in Figure 2 for irradiation of solid solutions $Cd_{0.22}Hg_{0.78}Te$ creates a surface energy levels on the surface of epitaxial layers of this substance. The concentration of the majority carriers in the surface layer of the semiconductor after exposure to X-rays increases by 2-4 times. We note that our investigations were carried on samples excluding the crystallographic orientation of the surface, although earlier it was found that for these solid solutions such relationship exists. Therefore, it can be expected that the results of X-ray exposure will depend on this factor.

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