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Features of the external photoelectric effect in $Cd_xHg_{1-x}Te$ caused by soft x-ray radiation of a laser plasma

V. Sredin, A. Voitsekhovskii, O.Anan'in, R.Ramakoti, A.Melekhov

Victor Sredin, Aleksandr Voitsekhovski
National Reserch Tomsk State University
36 Lenina Ave., 634050, Tomsk, Russia

Oleg Anan'in, Ravi Ramakoti, Andrei Melekhov
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)
31 Kashirskoe hwy, 115409, Moscow, Russia

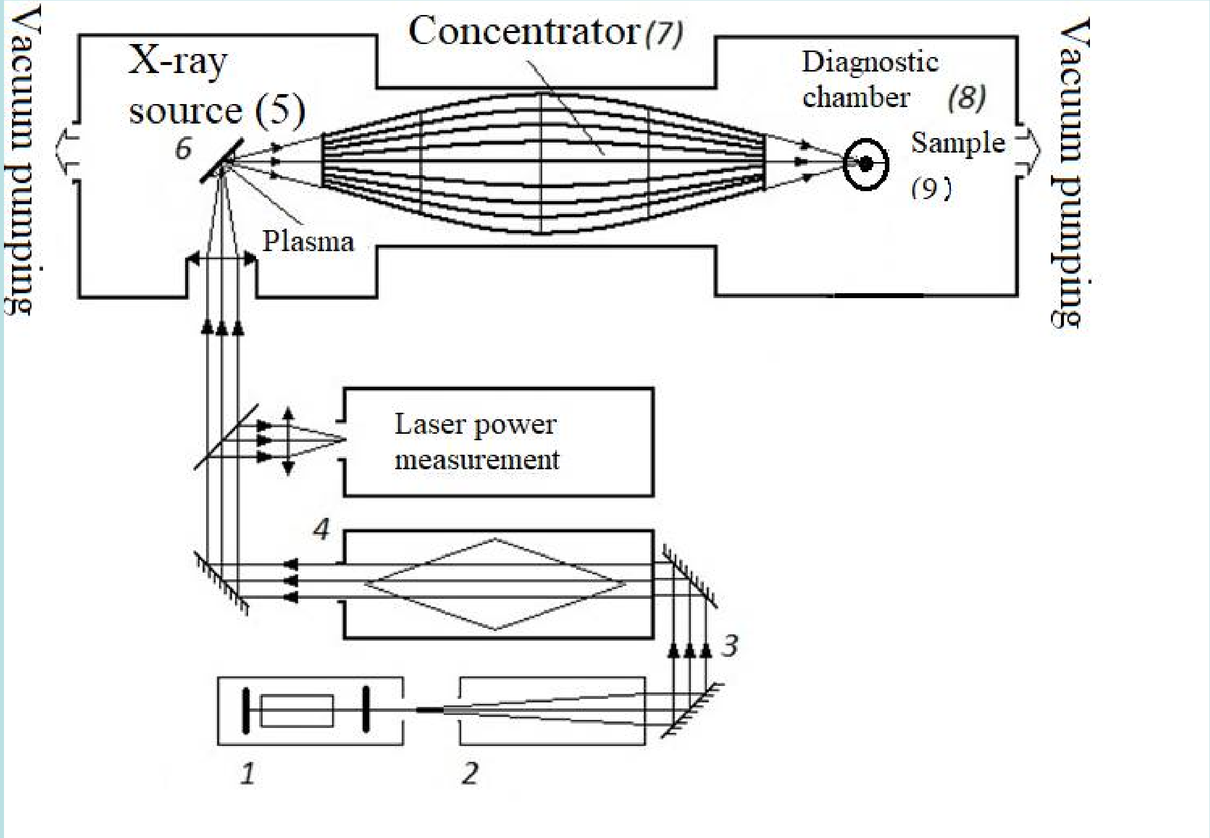
<u>Previous works</u>

1. Sredin V.G., Voitsekhovskii A.V., Izhnin I.I., Nesmelov S.N., Dzyadukh S.M., Anan’in O.B.,Melekhov A.P.Generation of surface defects in $Cd_xHg_{1-x}Te$ epitaxial layers by soft X-ray radiation of laser plasma. Prikladnaja fizika, 2018.
2. Sredin V.G, Voitsekhovskii A.V.,O.Anan’in, A. Melekhov, S.Nesmelov, S.Dzyadukh, V. Yurchak. Investigation of the effect of soft X-ray radiation on the electrophysical characteristics of n-$Cd_xHg_{1-x}Te$ epitaxial layers. Journal of Physics: Conference Series. 1115 (2018) 032057.doi:10.1088/1742-6596/1115/3/032057.

Soft x-ray radiation covers the wavelength range from 10 to 300 A (1240–41.3 eV) and can interact with the substance through elastic scattering, inelastic scattering or absorption caused by photoelectric effect. The scattering effects lead to a slight loss of soft x-ray energy in the substance. The main effect is related with the absorption of soft x-ray quanta, which occurs when an x-ray photon gives its energy completely to the electron of the inner atomic shell and exciting it from the atom. This leads to the appearance of external photoelectric effect and ionization of the excited atom. In the result, the atoms that absorb the photon are ionized by radiation, and most of the energy of the x-ray quantum is converted into the kinetic energy of the emitted electrons.

During the earlier research of effects caused by interaction of x-ray radiation with a quantum energy of the order of 60keV (and higher) in semiconductor materials and alkali-galloid crystals, a model of defect formation during relaxation of electronic atomic excitations was proposed to explain the emerging optical and electrophysical effects. Under certain conditions, the energy of exited atom with removed electron from the inner shell level is enough to transfer it to internode with the formation of a point defect. The process of defect formation according to this model assumed the appearance of a “group of separated ions”: local formation of ions of the same charge sign, additionally ionized by radiation [4,5]. In the selected group, instability arises due to Coulomb repulsion. In case if the lifetime of the excited state exceeds the time of irreversible displacement of the excited ion from the equilibrium position, a point defect is born. It is assumed that the effects of electrostatic instability are more pronounced in semiconductors containing charged impurity atoms [4,5].

Experimental setup



1- laser radiation generator, 2- single-pass amplifier, 3- rotary mirror system, 4- multi-pass amplifier, 5- soft x-ray source chamber, 6- laser-plasma target, 7- soft x-ray concentrator, 8- diagnostic chamber, 9- sample inside integrating the sphere

Laser radiation from a glass with Nd^{3+} and wavelength of 1.054 µm with an pulse energy in the range from 5 to 10 J was focused on a copper target located in a chamber with a vacuum of $P \approx 10^{-5}$ Torr. The power density of the laser radiation on the target was 10^{13}-10^{14} W / cm^2. To focus soft x-ray on a $Cd_xHg_{1-x}Te$(x=0.2) sample and to protect the sample from the flow of charged particles produced by laser plasma, x-ray concentrator was used. x-ray concentrator constitute assembly of quartz capillaries. The pulsed power of the x-ray radiation was 5 *10^4 W with a pulse duration of 20ns (energy in the soft x-ray pulse <= 1 mJ). The x-ray source is characterized by a continuous emission spectrum in the range of 80-600eV (Fig. 2). In this range, N edges of Hg and M edges of Cd and Te ions are located [10].

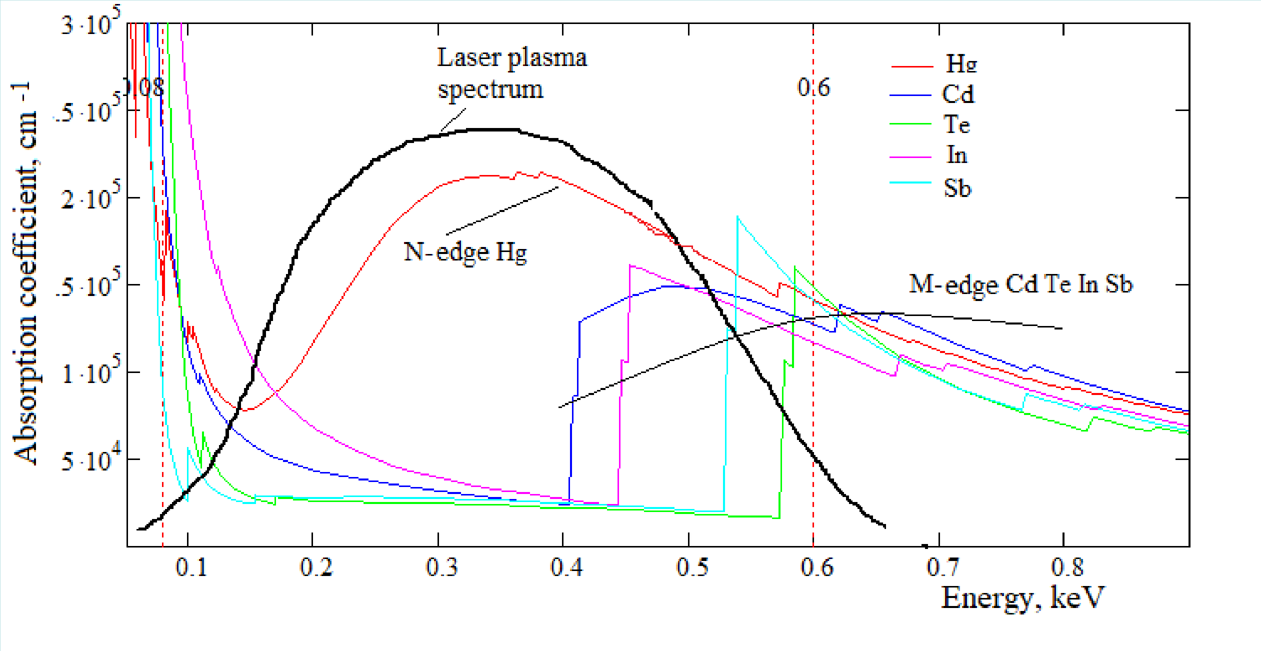


Fig. 2 The emission spectrum of a laser-plasma source

The diameter of the soft x-ray focusing spot after the x-ray concentrator was d = 2 mm. To collect electrons emitted by soft x-ray integrating aluminum sphere was used with an inner diameter d = 6 cm. In the center of sphere there was an electrode isolated from the sphere body. The studied sample was attached to the electrode, to which a negative potential was applied to push out electrons. Electrons through a 50-ohm resistor flow from the housing to the ground. The value of the emitted charge is determined by numerically integrating the signals recorded on the load over a time equal to the duration of the x-ray pulse. Figure 3 shows graphs of the dependence of the registered emitted charge on the applied voltage for for monocrystal $Cd_{0.2}Hg_{0.8}Te$. Immediately before measurements, the crystals went through standard chemical etching in a bromine etchant.

The basic idea of defect formation as a result of relaxation of electronic excitation caused by absorption of soft x-ray on the inner shells of atoms forming an idealized semiconductor can be represented using the modified Einstein equation for the external photoelectric effect:

$$h\nu_{soft\ x\text{-}ray} = mv^2/2 + A_{exit} + A_{ion} \qquad (1)$$

In (1) the first term on the right-hand side is the kinetic energy of a free photoelectron in a vacuum, A_{exit} includes the ionization energy of atom with formation of electron in the conduction band plus electron affinity, $A_{nuclear}$ is the atomic excitation energy. A_{ion} is energy of an ion with an additionally ionized by soft x-ray inner shell.

If the quantity $A_{ion} > \Delta Ed$ (ΔEd is the energy of point defect formation), then in addition to the generation of a free electron, the generation of a point defect is also possible. However, this model doesn't consider the effect of electric field generation in the near-surface region due to the departure of photoelectrons from this area. The time during which this field exists is apparently limited by the lifetime of the hole at the internal energy level of the atom.

For a detailed analysis of the external photoelectric effect under the influence of soft x-ray, it is necessary to use monochromatic radiation, nevertheless we will try to analyze the results using (1). Firstly, it can be seen from Fig. 3 that the external photoelectric effect, accompanied by the release of electrons, is also observed for the blocking directions of the external field (right upper quadrant). Apparently, this component of the photocurrent is associated with the release of valence electrons, for which the second term in (1), which describes the work function of the photoelectrons, doesn't include the ionization energy of the internal levels of the atom (Fig. 2), therefore it is relatively small, and the third the term is simply missing.

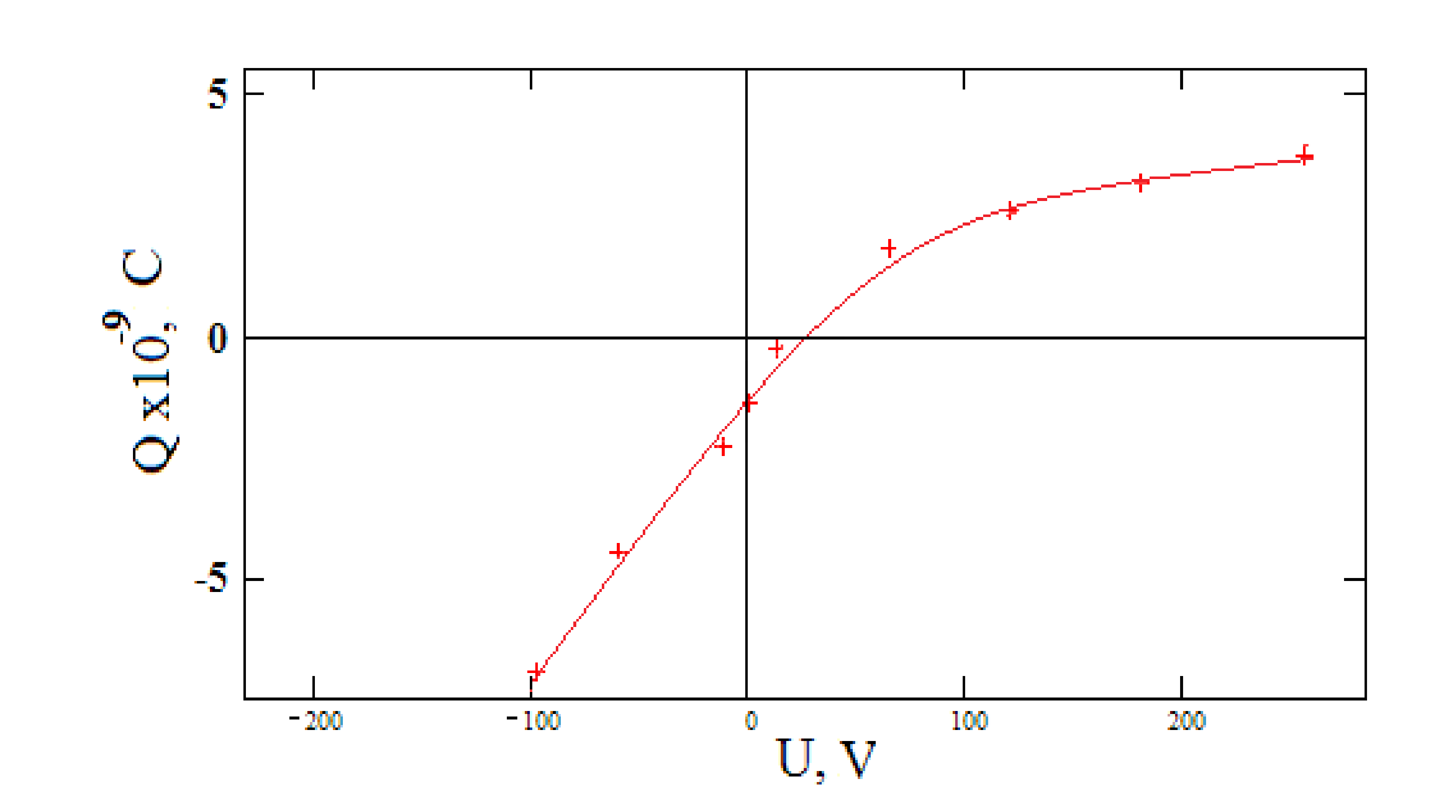


Fig. 3. Dependence of the registered emitted charge (in Coulomb) on the applied buoyant voltage. T = 300K

The second feature of the graph is a steeper increase in the magnitude of the emitted charge when the external field is pushed out (the lower left quadrant of the graph). We propose that in this case, in addition to valence electrons, the electrons of the inner shells of atoms, which are pulled out by soft x-ray quanta, also take part in the formation of the photo current. In our case (Fig. 2), these are electrons of the N-level of the Hg ion and electrons of the M-level of Cd. The energy of their ionization is hundreds of eV, to which the work of the exit from the crystal itself is added. The order of magnitude of ΔE_d can be taken from [3]: it is of the order of 10 eV for A^2B^6 materials. Thus, in addition to valence electrons, electrons released from the inner shells of atoms also fall under the action of the repulsive voltage. It was shown in [9] that, for the composition of the solid solution under consideration, it is more likely that these are electrons released from Hg ions than from Cd ions. And finally, thirdly, the model under consideration doesn’t consider the effect of electric field generation in the near-surface region due to the departure of photoelectrons from this region. The time during which this field exists is apparently limited by the lifetime of the hole at the internal energy level of the atom. The magnitude of the field induced by the external photoelectric effect, estimated in the classical approximation, is magnitude in order of 10^8 В $м^{-1}$.

The study of the external photoelectric effect caused by soft x-ray from laser plasma source in $Cd_xHg_{1-x}Te$ solid solution, demonstrated the possibility of excitation of the inner shells of atoms with their ionization and the generation of a pulsed electric field in the under-surface region of the crystal due to release electrons from the material.

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