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Electron-stimulated desorption of sodium atoms from the surface of intermetallic compound CsAu

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In this work we have studied electron-stimulated desorption of Na atoms from the surface of 2D intermetallic CsAu during depositing Na atoms on it. Desorption of Na atoms was shown to be associated with excitation of adsorbent core levels Cs $5s$ and Au $5p_{3/2}$ and of adsorbate core level Na $2p$.

Keywords: electron-stimulated desorption, intermetallic, adsorption, sodium, CsAu.

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Intermetallic compounds (alloys) of two and more metals possess properties non-characteristic of initial materials. At present, intermetallics are widely used in various branches of science, industry, engineering and medicine [1–5]. Among them, compounds of gold with alkali metals should be highlighted which are able to exhibit semiconducting properties (CsAu, RbAu) [6,7]. 2D layers of Au intermetallic compounds with alkali metals also may be semiconductors (see, e. g. [8–10]). The possibility of obtaining semiconductors from metals, as well as properties of such materials, stimulates interest in their research.

An Au intermetallic compounds with alkali metals was for the first time studied in [6] where CsAu was shown to be a wide-bandgap (2.6 eV) semiconductor. Formation of semiconductor compound CsAu by depostion Cs atoms onto Au was a focus of number of studies (see, e. g. [8,10]). Calculations performed in [11] demonstrated the semiconductor nature of the 2D CsAu layer. Formation of the 2D semiconductor layer of Na_xAu_y during depositing Na atoms onto the Au surface was studied in [9] by the method of electron-stimulated desorption (ESD) of sodium atoms. ESD of metal atoms may be observed only from semiconductor or dielectric surfaces provided the bombarding electron energy is lower than 100 eV and electron beam does not heat the target [12,13]. Earlier our team has studied ESD of Sm atoms from the CsAu surface [14].

This work was the first that set the task of studying the electron-stimulated desorption of alkali metal atoms during their adsorption on the surface of intermetallic compound of Au with another alkali metal taking as an example adsorption of Na on CsAu. Such a complex system was chosen because of the necessity to obtain new results for ensuring progress in understanding the ESD mechanism.

The measurements were performed *in situ* in ultrahigh-vacuum setup „ESD spectrometer“ [12]. As the substrates, textured W(100) tapes were used, which were cleaned by 3 hour heating at 1800 K in the O_2 atmosphere at $p = 1 \cdot 10^{-6}$ Torr. Gold was deposited onto the ribbon from a directly heated tungsten tube wherein pieces of 99.99% pure gold foil were placed. The tube was installed in parallel to the ribbon and had holes arranged so as to deposit Au uniformly along the ribbon. As the source of the Cs and Na atom flows, standard directly heated tubular evaporators containing a thermally decomposable mixture of Cs (or Na) chromates with Zr and Al were used. The samples to be studied were prepared according to the following procedure: a 5 monolayer (5 ML) Au film was deposited by depostion onto a clean tungsten tape at room temperature. After that, Cs atoms were deposited onto the Au layer at $T = 300$ K in the dose corresponding to the layer thickness of 5 ML; as a result, intermetallic CsAu got synthesized [9]. The surface layer of Cs was removed by heating for 80 min at $T = 320$ K [9]; thus, a pure CsAu surface was obtained. Next, Na atoms were deposited onto the CsAu surface in the dose of 0 to 1.5 ML. Upon the measurements, the W surface was cleaned and prepared again. The measurements were performed at $T = 300$ K with bombarding electron energies ranging from 0 to 100 eV. The Cs and Na concentrations on the ribbon surface were determined through the time of deposition with a constant flow whose intensity was evaluated by measuring the surface ionization current on the refractorymetal tape [15]. The desorbing cesium atoms were ionized using a heated a heated W ribbon, while the desorbing sodium atoms were ionized by using a heated Ir ribbon.

Fig. 1 shows the bombarding electron energy dependence of the Cs atoms yield during ESD from the surface of the 2D intermetallic CsAu layer after removing the Cs surface layer; the dependence was measured at $T = 300$ K (curve *1*). Dependence of the Cs atom ESD yield exhibits a resonance peak with the maximum at the energy of 65.6 eV corresponding to ionization of the Au $5p_{3/2}$ level (binding energy $E_b = 57.2$ eV). The peak corresponding to excitation of the Au $5p_{1/2}$ ($E_b = 74.2$ eV) level is not observed, since the hole neutralization occurs at the Au $5p_{1/2}$ level due to the electron transition from the Cs $5d$ level (binding energy of the $E_b = 77.5$ and 79.8 eV doublet),

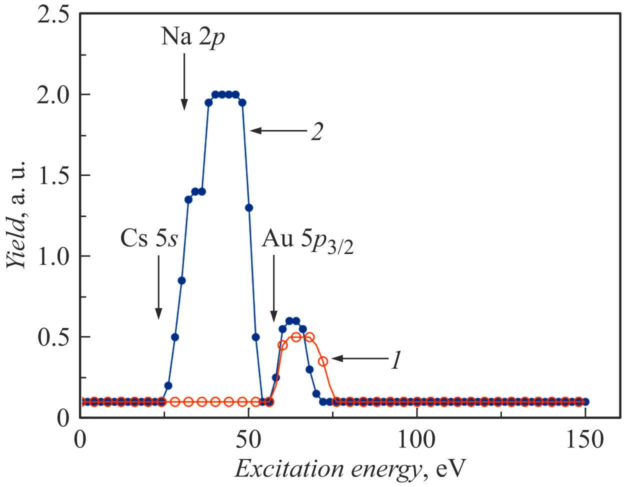

Figure 1. Yield of Cs (*1*) and Na (*2*) atoms during ESD from the CsAu surface at $T = 300\,\mathrm{K}$ versus the bombarding electron energy. *1* — pure CsAu surface, *2* — CsAu surface with the deposited 0.25 ML sodium coverage. Arrows point to the Cs $5s$, Na $2p$, and Au $5p_{3/2}$ levels.

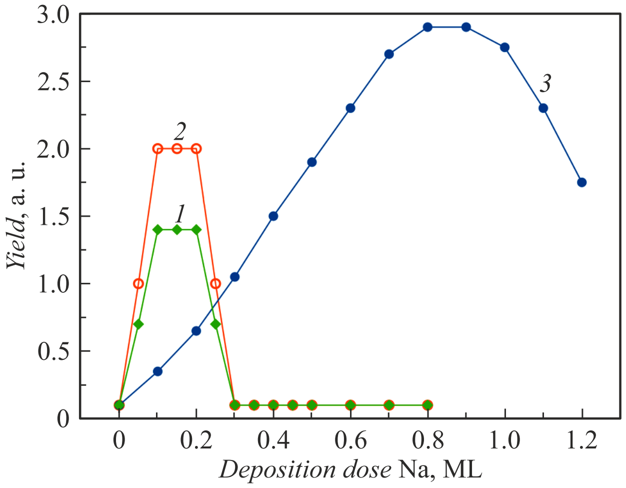

Figure 2. Yield of Na atoms during ESD from the CsAu surface at $T = 300\,\mathrm{K}$ versus the dose of deposited Na. *1* — at the bombarding electron energy of 34 eV, *2* — at the bombarding electron energy of 42 eV, *3* — at the bombarding electron energy of 64 eV.

which was previously observed in studying ESD of the Cs/CsAu system [8]. The peak full width at half maximum (Γ) is 10.8 eV.

Fig. 1 presents also the bombarding electron energy dependence of the Cs atoms ESD yield from the surface of the 2D intermetallic CsAu layer coated with the 0.25 ML sodium layer (curve *2*). Dependence of the Na atoms ESD yield exhibits two peaks with the maxima at ~ 42 and 63.3 eV corresponding to ionization energies of levels Cs $5s$ ($E_b = 22.7\,\mathrm{eV}$), Na $2p$ ($E_b = 30.8\,\mathrm{eV}$) and Au $5p_{3/2}$ ($E_b = 57.2\,\mathrm{eV}$). The poorly resolved peak in the region of low excitation energies can be decomposed into two ones, at 34.6 and 44.8 eV, with almost the same peak widths Γ (10.4 and 10.6 eV). Notice that the area of the peak at 44.8 eV is 1.6 times larger than that of the peak at 34.6 eV. This may be due to both the difference in spectral dependences of excitation probability of these levels and in the numbers of subsurface layer Cs atoms in CsAu and of adsorbed Na atoms. The peak corresponding to the Au $5p_{3/2}$ excitation is 25% lower than that in the case of Cs atoms ESD from the pure CsAu surface; its maximum is shifted towards lower energies down to 63.3 eV, and the width is significantly less (by 3.4 eV). It may be assumed that there is an additional channel of hole neutralization at the Au $5p_{3/2}$ level due to the electron transfer from the Na $2s$ core level ($E_b = 63.5\,\mathrm{eV}$). The peak corresponding to excitation of the Au $5p_{1/2}$ level ($E_b = 74.2\,\mathrm{eV}$) is not observed, since the hole is neutralized at the Au $5p_{1/2}$ level due to the electron transition from the Cs $5d$ level, which was previously observed in studying ESD of the Cs/CsAu system [8]. Various Auger processes occurring therewith in the Na/CsAu interface lead to electron capture by the adsorbed Na atom at the local level getting formed near and below the conduction band bottom, as implied in the ESD model of the Cs/CsAu adsorption system [16].

In contrast to ESD of Na and Cs atoms during adsorption of these alkali metals on the pure Au surface [8,9], ESD of Na atoms is observed even for submonolayer Na coverages (Fig. 1, 2). This is because the Na adsorption occurs on the created semiconductor 2D CsAu layer. In the case of absorption of the Na and Cs submonolayer coverages on the Au surface, the adsorbed submonolayer Na (Cs) coverage does not initiate formation of intermetallic compound, and ESD of alkali metal atoms is not observed on these coatings [8,9].

Fig. 2 shows the dependence of ESD yield of Na atoms from the CsAu surface at $T = 300\,\mathrm{K}$ on the dose of deposited Na for the excitation energies of 34, 42 and 64 eV. Those energies were chosen because of the presence in the Na ESD yield dependence of three peaks corresponding to excitation of the Cs $5s$, Na $2p$, Au $5p_{3/2}$ core levels. Let us consider the dependence of the Na atoms ESD yield for the case of excitation of the Au $5p_{3/2}$ core level. One can see that, when excitation energy is 64 eV, the ESD yield of Na atoms is observed over the entire studied range of Na deposition doses. Since the adsorption of Na atoms proceeds on the surface of 2D semiconductor intermetallic CsAu, ESD of Na atoms is observed already at the 0.12 ML sodium layer. An increase in the deposition dose of Na atoms leads to a linear increase in the ESD yield of Na atoms up to the sodium deposition dose of 0.87 ML. After reaching the maximum ESD yield of Na atoms at the monolayer coating, the ESD yield begins decreasing. Deposition of more than 1 ML of Na atoms results in formation of a second layer of Na atoms on the Na monolayer surface. The second (upper) layer of Na atoms prevents atoms of the lower Na layer (monolayer) from leaving it. Therefore, the ESD yield of Na atoms decreases with increasing area of the second (upper) Na layer. A similar situation occurred when deposting Na and Cs atoms onto an adsorbed monolayer of Na and Cs atoms on the surface of a 2D Au layer with a thickness of 2ML [8,9]. An absolutely different picture is observed for the dependence of the Na ESD yield at the excitation energies of 34 and 42 eV (corresponding to excitation of the Cs 5s and Na 2p core levels, respectively). ESD of Na atoms is observed in a very narrow range of Na deposition doses: it vanishes at the deposition dose of 0.3 ML. The maximum ESD yield of Na atoms is achieved at the deposition dose of 0.15 ML. This behavior of Na atoms ESD at the excitation energies of 34 and 42 eV may be explained by some peculiar features of the submonolayer Na coverage formation. In the case of small-size coverages, adsorption of Na atoms most likely occurs in the troughs above the Cs atom and between Au atoms. Therefore, it becomes possible to excite the Cs 5s and Na 2p core levels with subsequent hole neutralization at those levels due to various Auger processes in the Na/CsAu interface. Further, as implied by the ESD model for the Cs/CsAu system [16], the electron gets captured at the local level formed near and below the conduction band bottom by the adsorbed Na atom. An increase in the deposition dose of Na atoms leads to lateral interaction between Na atoms, which causes a decrease in the hole lifetime at the Na 2p level, and, hence, to a decrease in the Na ESD yield. An increase in the distance between Na adatoms and Cs atoms in the CsAu intermetallic compound leads to a decrease in the probability of formation of a neutral Na atom with its subsequent desorption.

Thus, electron-stimulated desorption of alkali metal atoms from the surface of intermetallic compound of Au with another alkali metal was studied for the first time using as an example the Na/CsAu adsorption system.

There exist two regions of Na ESD excitation: in the first one, core levels of the CsAu adsorbent (Cs 5s and Au 5$p_{3/2}$) are excited, while in the other one excitation of adsorbed sodium core levels (Na 2p) takes place. ESD of Na atoms with excitation of the Au 5$p_{3/2}$ level is observed in the entire range of Na deposition doses, while Na ESD with excitation of the Cs 5s and Na 2p levels is observed only at low Na deposition doses, which is caused by enhancement of the lateral interaction between Na adatoms and enlargement of distances between the Na and Cs atoms in the 2D CsAu intermetallic layer.

Conflict of interests

The authors declare that they have no conflict of interests.

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