CONTINUUM RADIATION DURING ION BOMBARDMENT OF METALS

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The kinds of continuum radiation arising from metal surfaces and secondary emitted particles during ion bombardment are considered. Some experimental results of the investigation of molecular broad band emission, surface plasmon radiation are given. The mechanisms of excitation processes have been discussed.

When atomic particles bombard metal surfaces a variety of energy transfer processes occur including ion implantation, scattering, sputtering and collective excitation. Each of this processes is accompanied by the formation of excited states of secondary emitted atomic particles or excited states within the metal surfaces itself. Some of these excited states decay by photon emission, and this phenomena were called ion-photon emission (IPE) [1]. The study of IPE of metals remains an area of active research for purpose of understanding the basic mechanisms leading to excited states formation of particles or collective excitations. At present time only one of the components of IPE of metals is considered to be investigated sufficiently enough. This component is the radiation of spectral lines from excited secondary atoms and ions. The component of IPE which is conditioned by the radiation of the metal surface itself, i.e. ionoluminescence, has not been practically studied yet. Some results of its investigation are in [2] and will be not consider here. Another component is continuum radiation (CR), which consists of molecular bands or wide continuum. This type of radiation is caused by sputtered excited particles which form the extent shining region in front of the bombardment target. Many experiments of molecular photon emission investigation have been carried out by us and other researches (see, for example, the reviews [1-3]). But so far there is no general opinion even about nature of wide continuum. Therefore the first aim of the experiments carried out in our laboratory was to identify the different emitters of CR.

We varied both the interacting systems (ion-target), and the conditions of interaction (bombardment energy, angle of incidence and the coverage of metal surface by particles of active gases). We used beams of K^+, He^+, Ne^+, Ar^+, O_2^+, N_2^+, NO^+ ions with energy 10÷20 keV. The bombardment of different metallic targets (Ag, Cr, V, Ti, Fe, Ni, Zr, Mo, Nb, Hf, Ta, W, Gd, Tb, Ho, Yb, Tm) was carried out both in the residual vacuum conditions and at the controllable leak-in of O_2, N_2, CCL_4, SF_6, CF_4, NF_3 gases. Fig. I shows, for example the spectrograms of radiation resulting from K^+ bombardment of Ho target in residual gas pressure $5\cdot10^{-8}$ Torr (the lower curve) and in atmosphere of O_2, SF_6 and CCl_4 at gas pressure $1\cdot10^{-5}$ Torr [4]. The narrow bands are emitted by simple excited molecules such as MO, MF, MCL and MN, where M is the atom of metallic target. Broad bands and continuum radiation which were observed for many d- and f- metals in presence of chemically active gases were not identified. Evidently this radiation is emitted by molecules M_nX_m type, where M is target atom and X is an atom of adsorbed gas (indexes n and m point the number of atoms in molecules). The magnitude of absolute photon yield from excited molecules is rather large, especially for rare-earth, metals, when the target surfaces are covered by a monolayer of adsorbed particles. For example, the photon yield is $2\cdot10^{-4}$ photon per incident ion in the spectral region 496 ÷ 602 nm for case $K^+ \rightarrow Ho+O_2$ interaction. We considered that the excited molecules are sputtered from the surface layer at the last phase of the linear collisions cascade, because of they have low escaping energy (some eV) [5].

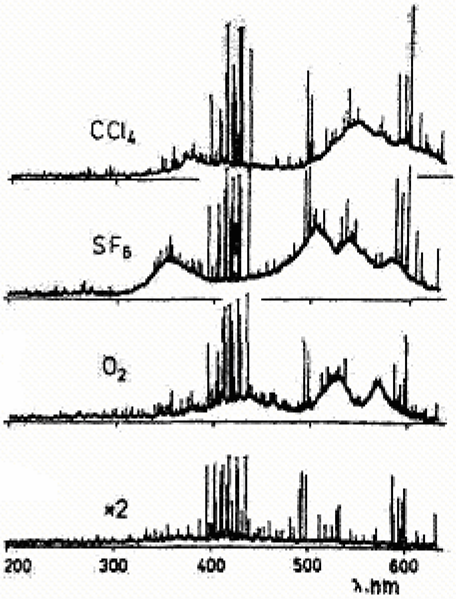

Fig. 1. Ho-target radiation spectrograms during K^+ ion bombardment of 12 keV energy.

Another component of IPE in the cases of Ag, Al and Mg-targets ion bombardment was founded [6-10]. This is radiation of surface plasmon (SP). Our experiments were carried out on a set-up in details circumscribed in [8]. In spectral range 20-150 nm the radiation was analyzed by vacuum monochromator with a diffraction grating 1200 slits/mm and radius 0,5 m and registered by the channel electronic multiplier. We consider that observed CR is due to radiative relaxation of surface plasmons of Al and Mg. The position of radiation maximum on a wavelengths scale makes ~78 nm for Al and ~ 81 nm for Mg. Theoretically expected position makes 120 nm and 165 nm for Al and Mg, consequently. Such differences can be stimulated by several reasons. First of all, the energy of surface plasmons depends on concentration of free electrons and electronic energies structure. As shown [9], the presence of oxygen increases in magnification of an energy of photons during radiative relaxation of SP. As to clear surfaces Al and Mg during bombardment by He^+ ions (15 keV, 0,2 A/m^2, in vacuum 10^{-7} Torr) is impossible, we consider, that we have surfaces of Al and Mg with oxygen contamination. Besides this the modification of the electronic states density of surface layers due to implantation of helium ions is possible. The third reason is the influence of adsorbed atoms on the transmission coefficient of photons from Al and Mg targets.

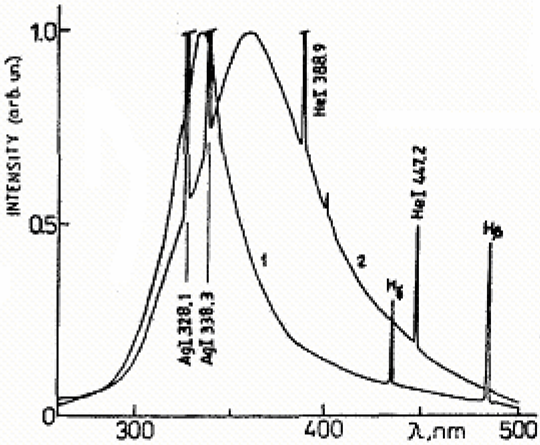

Fig. 2. Spectra of Ag surface IPE measured during H^+ (curve 1) and He^+ (curve 2) ion bombardment of 15 keV energy.

The excitation of silver SP and its decay during ion bombardment is accompanied by an emission of CR in a broad wavelength region $\lambda = 200 \div 600$ nm. The studying of angular, energy, polarizing peculiarities of this radiation, and also influence of Ag surface degree of coverage by adatoms on an intensity of radiation and form of a spectrum have allowed to identify it as a radiation of silver SP. Fig. 2 shows the typical examples of such spectra, obtained during bombardment of polycrystal silver surface. Besides spectral lines from excited sputtered (AgI) and scattered (HI and HeI) atoms the CR from surface plasmon relaxation also presence. The position of the CR maximum on the wavelength scale was found to be at $\lambda = 360$ nm during bombardment of silver by He^+, Ne^+ and Ar^+ ions [9].

The presence of oxygen atoms on Ag surface leads to appearance of second maximum at 330 nm (at coverage degree ~ 0,01 of monolayer). Its observation also was in experimental investigation of electron-photon emission [11] of Ag. We made simultaneous measurements of silver SP radiation during ion and electron bombardment at the same set-up. The energy E_o of H^+, H_2^+, H_3^+, He^+,O_2^+ ions varied from 6 to 21 keV and the energy of bombarding electrons was fixed at E_0=570 eV. The CR spectra of electron-induced photon emission were measured both before ion bombardment and after. Initially electron-photon emission was measured (Fig. 3, curve 3). Besides the maximum near λ=360 nm one could also see a short wavelength maximum at λ = 330 nm correlated with the presence of oxygen on the surface of target. Following this, the Ag target was bombarded by He^+ ions (E_o = 15 keV) for 40 min and CR spectrum of ion-photon emission was measured (curve 1). Its maximum position was found to be at λ = 360 nm. Immediately after stopping the ion bombardment, the spectrum of electron-induced photon emission was measured once again and it was found to be identical to the ion-photon CR spectrum (curve 2). After ~ 20 min the maximum at λ = 330 nm appeared again. This suggests that the oxygen was adsorbed on the surface in amounts sifficient to display the observed effect. If O_2^+ ions were used in such experiments the position of electron-induced photon CR maximum after ion bombardment was found to be at λ = 330 nm. Therefore we conclude that the observed CR arising from the silver surface during ion and electron bombardment has the same properties, and results from radiative relaxation of surface plasmons from clean (λ = 360 nm) and covered by oxygen (λ = 330 nm) silver surface.

The problem of determination of the processes which result in excitation of SP still remains open. Among the most probable the following processes were considered: 1) - transmission of kinetic energy to bound electrons and formation of secondary electrons (including Auger electrons), whose motion results in perturbation of charge density oscillations; 2) - neutralization of an incoming ion by an electron of silver conduction band with transmission of released energy to electronic gas, or neutralization of ion with formation of Auger electron. The weak dependence of the photon yield J of plasmon radiation (PR) from bombardment energy in a range of E_o = 6÷21 keV, and also the absence of PR in the case of interaction of K^+ ions with the surface of silver (due to small amount of energy liberated during neutralization of the potassium ion) witness in favor of the second one. At the same time in 1 ÷ 4 keV bombardment energy range and grazing incidence of H^+ and H^- ions the intensity of PR slowly increase, as well as energy losses of scattered particles [7].

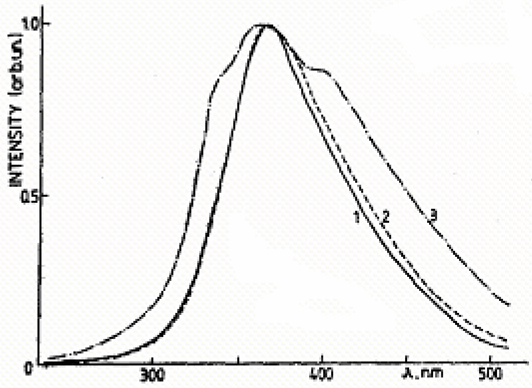

Fig. 3. Spectra of the Ag surface continuum radiation: 1 – He^+; 2 – e^- after bombardment by He^+ ions; 3 - e^- before ion bombardment.

With the purpose of the further study of SP excitation mechanisms during interaction of H^+,H^- and He^+ ions, as well as He atoms with silver surface the experiments were carried out on the set-up [12] at grazing angles 3°<α<12° and in the energy range E_0=1-4 keV. As the dispersing element the interference filter with a maximum of a passband located at λ =351 nm was used. The radiation of SP was observed in a plane formed by the direction of beam and normal to the target surface. The measurements were carried out in vacuum P < 1 x 10^{-9} Torr. Cleaning of the surface by Ar^+ ions with 3 keV energy at grazing incidence during ~ 1 hour preceded the experiment. A flux of neutral helium atoms received by resonance charge transfer of helium ion beam on helium atoms. The bombardment by H^+ and H^- ions reduces to practically identical, in limits of an experimental error, photon yield of PR. The measured dependencies $J(E_0)$ in the range 1÷4 keV have appeared monotonous growing functions. At such geometry of experiment the excitation of the oscillations of electronic gas, most probably, are carried out by direct transmission of kinetic energy to electrons at braking of particles. The measured dependences of the energy losses of scattered particles on E_0 have appeared also monotonous growing in this range of energies. Therefore the choice of the mechanism of silver SP excitation essentially depends on the trajectory of the ion motion. It was found that the interaction of neutral atoms of helium with the surface of silver is not accompanied by radiation of SP. It means, that the absence of neutralization processes between incident particle and silver conduction band does not produce surface plasmon excitation. Also it means, that the energy losses of the neutral projectiles in the electron gas of silver cannot be at the origin of the plasmon excitation and subsequent photon emission. Thus, during ion bombardment of metal surfaces, one can be observe different kinds of CR.

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НЕПЕРЕРВНЕ ВИПРОМІНЮВАННЯ ПРИ БОМБАРДУВАННІ ІОНАМИ МЕТАЛІВ

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В роботі розглянуто типи неперервного випромінювання, що виникають від поверхні металів та вторинно емітованих частинок при іонному бомбардуванні. Представлено деякі експериментальні результати досліджень широких молекулярних смуг, випромінювання поверхневих плазмонів. Обговорено механізми процесів збудження, які ведуть до емісії неперервного випромінювання.