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ELECTRON IMPACT EXCITATION OF Ag ATOM: ENERGY-LOSS SPECTROSCOPY

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Abstract. Here we present the results of electron spectroscopy measurements of electron collisions with Ag atom at medium electron impact energies up to 100 eV. Data obtained include the energy-loss spectra of Ag recorded at different scattering angles using a crossed electron-atom beam technique in the electron spectrometer ESMA that operates in energy-loss mode.

1. INTRODUCTION

Electron energy-loss spectroscopy (EELS) is based on measuring the energy which electron loses in inelastic electron-atom scattering. Since the electron excitation process is energy dependent, EELS is recognized to be very useful tool for the investigation and determination of atomic excited states. If a target atom is in the ground state, lines observed in the energy-loss spectra are directly attributed to their excited states. Generally, EELS technique is important in many applications ranging from various surface science researches to medical diagnosis. It is widely employed for the study of electronic structures, electronic correlation and elemental composition of different materials (Hebert et al. 2006, Schone et al. 2003, Salaita et al. 2000), as well as for analyzing biological structures and detection of a single atom contained in the macromolecule assembly (Leapman 2003). In comparison with optical spectroscopy and optical-like spectra, electron spectroscopy has worse resolution. On the other hand, the EEL spectra obtained at different energies and observation angles can focus either on the optically allowed or optically forbidden transitions. Allowed transition will dominate the spectrum for higher incident energies and smaller scattering angles while the forbidden transitions could dominate at lower energies and larger scattering angles. To the best of our knowledge, there are no studies of EEL spectra resulting for electron excitation of Ag atom. The reason for the lack of experimental investigations on this topic could be the high working temperature (approximately 1300 K) which is necessary for vaporization of the silver sample and for production

of well collimated effusive atomic beam. In this paper we present the results of experimental investigation of the unresolved silver resonance lines ($4d^{10}5p\ ^2P_{1/2,3/2}$) excited by electron impact using EEL spectroscopy. We have employed an electron spectrometer in a crossed-beam arrangement to record energy-loss spectra over the range of incident electron energies from 10 to 100 eV at various scattering angles.

2. EXPERIMENT AND PROCEDURE

EEL spectra were measured with the hemispherical electron spectrometer ESMA described earlier (Tošić et al. 2008). In brief, the experiment was carried out by utilizing a crossed electron-atom beam technique. A hairpin thermoelectron source was used and electron beam was formed by the electron monochromator which consists of systems of cylindrical electrostatic lenses and hemispherical electrostatic energy selector. Inelastically scattered electrons were detected by the hemispherical electron energy analyzer with a channel electron multiplier as a single-electron detector at the end. Analyzer is of the same type as the monochromator and it can rotate around the atomic beam axis from -30^o to 150^o with respect to the incoming electron beam. The spectrometer operates in energy-loss mode. Typical overall energy resolution (full width at half maximum FWHM) was 120 meV while the angular resolution of the spectrometer is estimated to be 1.5^o. The position of the zero scattering angle was determined according to the symmetry of angular distribution of scattered electrons at negative and positive scattering angles (from -10^o to +10^o) around the instrumental zero. An atomic oven heated by two resistive bifilar heaters was used to produce well collimated effusive Ag vapor beam. The working temperature was about 1300 K and it was controlled by two thermocouples (top and bottom). Transfer of heat and radiation losses from the oven are minimized and reduced by additional foil shields. Overheating of surrounding components was avoided by additional water-cooling. A liquid-nitrogen cold trap was placed above the oven and interaction region in order to prevent contamination of the chamber. Background pressure was of the order of 10^{-5} Pa.

3. RESULTS AND DISCUSION

We have recorded electron energy-loss spectra of Ag at incident electron energies of 10, 20, 40, 60, 80 and 100 eV and various scattering angles. Figure 1 shows an energy loss spectrum taken for primary electron beam energy of 60 eV and small scattering angle of 6^o. The assignment of atomic energy states is given following Moore (1958). Under these conditions (impact energy, scattering angle) the allowed transitions are somewhat favoured, but other contributions, i.e. other peaks, each characteristic of particular forbidden transitions can also be present in the spectrum. As one can see, this EEL spectrum of silver shows structures which are related to the electron excitation of the first excited states and also covers the autoionization region from the first ionization limit of 7.57623 eV (Sansonetti and Martin 2005) up to 10.5 eV. At the overall energy resolution mentioned above, the spectrum contains well resolved feature that corresponds to the elastic scattering (zero energy-loss). It is also evident that the low energy region of this spectrum is dominated by an intense and sharp excitation at about 3.7 eV. The EEL spectrum is obtained under the conditions where we could not separate $4d^{10}5p\ ^2P_{1/2}$ and $4d^{10}5p\ ^2P_{3/2}$ levels (energy losses of 3.664 and 3.778

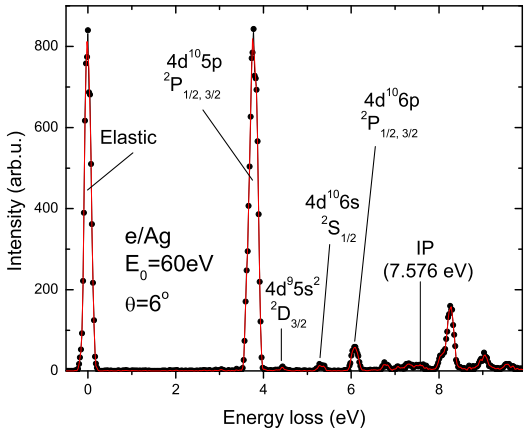

Figure 1: Energy-loss spectra of silver at 60 eV electron impact energy and scattering angle of 6^o.

eV). Energy resolution was not high enough not only to resolve these two states but also to enable their decomposition so we obtained only one feature at about 3.7 eV that corresponds to the summed $4d^{10}5p\ ^2P_{1/2,3/2}$ excitation. On the other side, this structure is clearly resolved from the other ones in the spectrum. Below the first ionization limit, spectrum contains at least three more features. The features at 4.304 and 5.276 eV correspond to the electron excitation of the $4d^95s^2\ ^2D_{3/2}$ and $4d^{10}6s\ ^2S_{1/2}$ states but, as one can see, their intensities are more than 50 times smaller than that of unresolved silver resonant line. The excited state at about 6 eV is labeled as $4d^{10}6p\ ^2P_{1/2,3/2}$. The $4d^{10}6p\ ^2P_{1/2}$ and $4d^{10}6p\ ^2P_{3/2}$ states (energy losses of 5.988 and 6.013 eV) are separated by only 25 meV and overall energy resolution of 120 meV was not sufficient to resolve them. The features in the energy-loss region above first ionization potential (7.57623 eV) correspond to the autoionization processes. In order to experimentally investigate electron impact excitation of silver, we have also recorded autoionizing energy-loss spectra for energies between 10 and 100 eV. As one can see clearly resolved lines that appear in autoionization region of the EEL spectra at 60 eV (Figure 1). As shown in Figure 2, the same energy- loss structures occur at the silver EEL spectrum taken at 40 eV electron impact energy and scattering angle of 10^o, again with the very similar intensity ratios.

4. CONCLUSION

Electron impact excitation from the ground state of silver has been studied with electron energy-loss spectroscopy. We have recorded energy-loss spectra for incident electron energies between 10 and 100 eV at different scattering angles using the electron spectrometer with crossed electron-atom beams. Here we have presented EEL spectra recorded at 60 eV and 6^o, i.e. at 40 eV and 10^o. Both spectra show the same

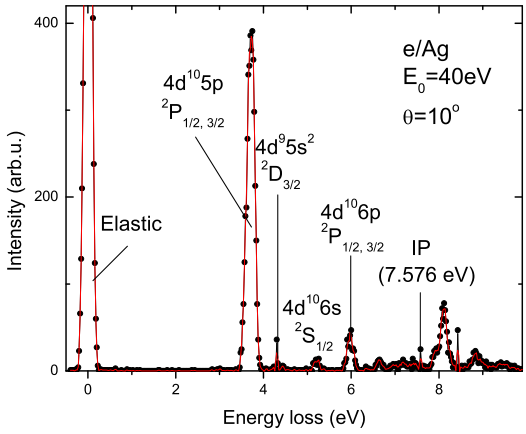

Figure 2: Energy-loss spectra of silver at 40 eV electron impact energy and scattering angle of 10^o.

features with very similar intensity ratios, including the lines in the autoionization region covered by these spectra from the first ionization limit (7.57623 eV) up to 10.5 eV. Currently, detailed analysis of the spectra taken at higher electron impact energies and different scattering angles are underway. The obtained data will give more insight into the electronic structure of Ag atom and give the basis for a further detailed study of the electron-Ag scattering processes.

Acknowledgments

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