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Cascade Auger decay in solid KCl following the Cl *K*-edge excitation

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1 Introduction

When a deep core-level electron in a heavy atom is ionized by high-energy radiation, consecutive Auger decays occur, such as *KLL*→*LMM* (*LVV*)→・・・, which is called “cascade Auger decay”. Cascade Auger decay process has attracted much attention in the following two fields. Firstly, it has been proposed that a cascade Auger decay can be possibly applied to the oscillation of X-ray laser [1]. Secondly, a cascade Auger decay has attracted in the field of radiation therapy for cancer. Cancer cells can be killed by the energetic electrons such as cascade Auger electrons emitted from radioisotopes [2] or excited non-radioactive elements doped at the cancer site [3].

The previous studies on cascade Auger decay have been conducted mainly on isolated gas-phase atoms and molecules [4]. For solid, the cascade Auger decay spectra have been measured [5], but the quantitative analysis of the Auger peak intensity has not been conducted, so the origin of the cascade Auger peaks have not been fully understood.

In the present study, we investigated the cascade Auger decays in solid KCl following the resonance photoexcitation at the Cl *K*-edges. KCl was chosen as a sample, because the energy of K *LVV* is close to that of Cl *LVV*, which enables to measure both Auger spectra simultaneously and clarify the origin of the cascade Auger decays. To elucidate the *LVV* Auger decay, the measurements of Auger electron spectra were concentrated on the low kinetic energy region. From the obtained spectra, the detailed energy and intensities of the cascade Auger electrons are presented.

2 Experiment

Fine powders of KCl (Kojundo Chemical Laboratory Co., Ltd.: 99.9%) were used as the sample. The powder was pressed into a pellet of 10 mmφ×0.3 mm at a pressure of 3 ton/cm^2.

The experiments were performed at the BL-27A, KEK-PF. X-ray absorption fine structure (XAFS) spectra around the *K*-edges were measured by plotting a sample drain current as a function of photon energy. The sample current was normalized by the photon intensity measured by the drain current of aluminium mesh located in front of the sample. Auger electron spectra were taken with hemispherical electron energy analyzer (VSW. CLASS-100). The photon beam was irradiated at 55 deg. from the surface normal, and the take-off direction of Auger electrons was the surface normal. An electron flood gun was used during the measurements to neutralize the surface charge.

3 Results and Discussion

Fig. 1 shows the XAFS spectra for KCl around the Cl *K*-edge. The spectral feature was basically in agreement with the previously reported spectra [6,7]. The first intense peak at 2827 eV (marked A) corresponds to the dipole-allowed Cl 1*s*→3*p** resonance excitations [7].

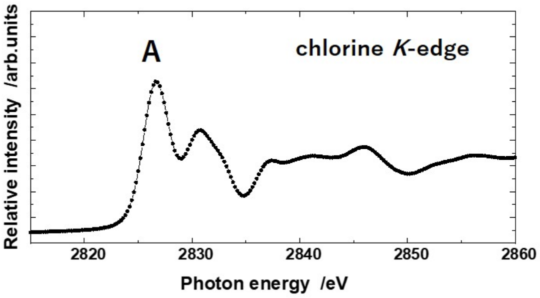

Fig. 1: XAFS spectra for KCl at Cl *K*-edge.

Fig. 2 shows the X-ray induced Auger electron spectra in low kinetic energy region for KCl excited by X-rays around the Cl *K*-edge. The X-ray energies were, (a) higher than the Cl 1*s*, (b) the resonance at the Cl 1*s*→3*p**, and (c) lower than the Cl 1*s*. In all spectra, small peaks (marked C) were observed around 235 eV. From the energy, these peaks were assigned to be K *LVV* Auger peaks. The intensity of the peak C did not change so much irrespective of the photon energy, because the K *LVV* Auger decay is triggered by the direct ionization of K 2*p*, which is nothing to do with the Cl 1*s* excitation. On the other hand, in the spectra (a) and (b), relatively large peaks marked A and B were observed at 166 eV and 185 eV, respectively. From the energy, these peaks are assigned to be Cl *LVV* Auger peaks. However, in the spectrum (c), only peak A was observed, but the peak B was missing. The result suggests that the peak B originates from Cl *LVV* Auger triggered by the excitation of Cl 1*s* electrons.

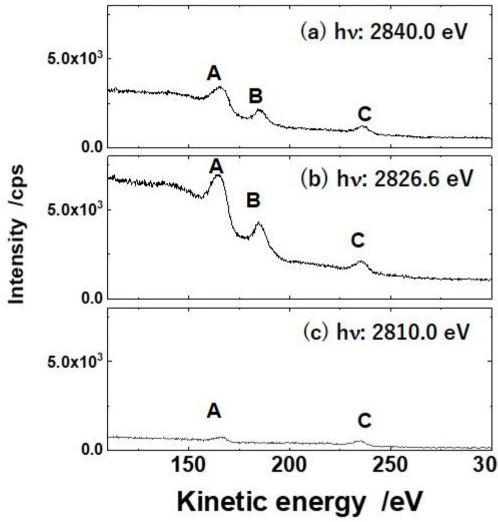

Fig. 2: Auger electron spectra for KCl excited by X-rays around the Cl *K*-edge. The photon energies were, (a) higher than the Cl 1*s*, (b) the resonance at the Cl 1*s*→3*p**, and (c) lower than the Cl 1*s*.

Fig. 3 shows the three-dimensional plot for the photon energy dependence of the Auger electron spectra. For all peaks, the intensity was maximum at 2827 eV, which corresponds to the Cl 1*s*→3*p** resonance (peak A in Fig. 1). Since the intensity of these peaks includes the background which was caused by inelastically scattered electrons, background subtraction was conducted using the Shirley method [8].

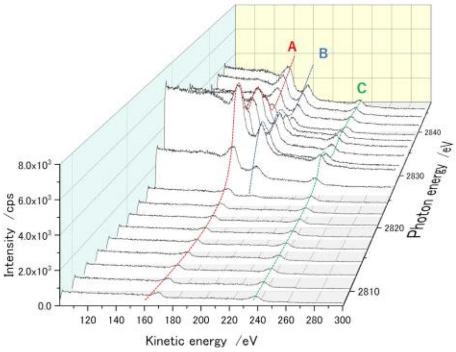

Fig. 3: Three-dimensional plot for the photon-energy dependence of Auger electron spectra for KCl.

Fig. 4 shows the intensity of the peaks A, B and C after the background subtraction as a function of the photon energy. Although the intensity changes in the K *LVV* (peak C) is small around the Cl 1*s*→3*p** resonance, the features of the intensity plot for the peaks A and B are quite similar to the XAFS spectrum shown in Fig. 1. This suggests that the peaks A and B originate from the Auger decay mainly initiated by the Cl 1*s* excitation or ionization. This means that these peaks are mainly due to Cl *KLL*→*LVV* cascade Auger decays. Comparing the plots A and B a little more closely, a clear difference is observed at the photon energy lower than 2822 eV. In this low energy region, the constant intensity is observed for the peak A, which means that the *LVV* Auger decay is initiated by the direct ionization of Cl 2*p*. On the other hand, the intensity of the peak B is zero at lower than 2822 eV. This means that the peak B does not originate from the direct ionization of Cl 2*p*, but initiated only by the Cl 1*s* excitation or ionization. The energy difference between the peaks A and B is due to the difference in the initial state as follows. For the peak A, the initial state of the *LVV* Auger decay at the photon energy lower than 2822 eV is L^{-1} ("-1" represents a hole) following the direct ionization of Cl 2*p*. In addition, at the photon energy higher than 2822 eV, the peaks initiated by the L^{-1} state produced by the *KLL* participant Auger decay [10], where the electron excited from the 1*s* state is directly decays into the 1*s* state, and L^{-1} state produced by *KL* fluorescent X-ray emission, are overlapped. On the other hand, for the peak B, the initial state of the *LVV* Auger decay is only L^{-2} state produced by the *KLL* spectator Auger decay [9] or normal Auger decay. The fact that energy of the peak B is higher than that of the peak A is interpreted by the higher number of the holes owing to the hole-hole interaction [10].

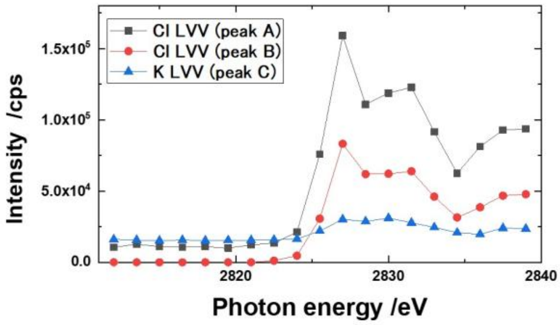

Fig. 4: Intensity of peaks A, B and C in Figs. 2 and 3 as a function of photon energy. The peak intensity was obtained by subtracting background by the Shirley method [8].

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