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Fundamental aspects of X-ray photoacoustic phenomena

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The mechanism why extended X-ray absorption fine structure (EXAFS) is observed in X-ray photoacoustic spectra, has been discussed from various points of view, however, it is still unclear. We continued to gather many aspects of data of X-ray photoacoustic phenomena in order to solve this question. Recently, we found EXAFS also in phase spectra of X-ray photoacoustic signal and related it with the signal shape. This phenomenon reflects the thermal depth depending on the absorption coefficients, however, there are left still unresolved aspects. All aspects of the data are shown and discussed in relation to its mechanism.

Since X-ray photoacoustic(PA) phenomena and its spectra were observed¹⁻⁴⁾, the mechanism why the extended X-ray absorption fine structure (EXAFS) is observed in these spectra, has been discussed from many points of view, not only from experimental evidence but also from theoretical simulation⁵⁾. However, we are far from the clearcut explanation. For example, as seen in Fig.1 which shows the parallel changes between absorption spectrum and X-ray PA spectrum⁴⁾, the abrupt change at the K-edge is same, however, the changing width of the fine structure is smaller in the PA spectrum than that for absorption. This means that the PA signal amplitude does not linearly correlate with the dependence of the absorption coefficient on the wavelength. It seems to show that the mechanism of heat generation is different in fine structure region. Of course, as seen in Fig. 2, the X-ray PA signal amplitude depends on not only the absorption coefficient but also on the heat conductivity and heat capacity of the sample²⁾. However, this is not the reason for the previous inconsistency.

Recently, we have found that EXAFS is also found in the phase spectrum as shown in Fig. 3. In this case, EXAFS is hardly seen in thinner foils and is clearly and strongly observed for thicker foils. Judging from the evidence that the amplitude of the changing width in the fine structure region is same as the absorption spectrum, the fine structure of the phase spectra seems to reflect the heat generation depth depending on the absorption coefficients. Fig. 4 shows the difference in the signal amplitude and phase at various thickness of sample. The

difference in the signal amplitude between above(9.00 KeV) and below(8.96 KeV) the K-edge, the maximum can be seen at 10 μm . Since the amplitude reaches a maximum when the sample thickness is close to the absorption depth, the maximum point differs at above and below the K-edge. The phase shows the depth the average PA signal comes from, so it shows similar depth in the regions less than the absorption length(<10 μm) and far more than that (>100 μm).

It was also found that a phase lag was not observed for the heat which comes from deep points, but the shape of the PA signal will change. Fig. 5 shows the PA spectra and signal shapes for the 0.65 μm Ni plated 10 μm Cu foil at the different chopping frequency of 117 Hz. As seen in the spectra, signal amplitude and phase show the abrupt increase at Ni K-edge energy (8.3 KeV) and abrupt changes at Cu K-edge energy (8.9 KeV). It has been found that even for thin 0.65 μm plated layer of Ni, EXAFS was observed at high modulation frequency. The signal wave forms were also recorded in this experiment and are shown in Fig. 6. We have said that when the phase is delayed, a time lag will be observed. However, these four figures show that when the phase shows delay, the wave rising points are the same, but the signal shapes are different. At 8.4 and 8.8 KeV where the signal mainly comes from the surface area of Ni, the initial rising shapes are a little convex. However, when the signal mainly comes from the Cu layer under the surface, the rising shape of waveform are a little concave. It seems that the phase difference comes from this difference in the waveform.

Due to its transparency, X-ray beams are ideal for depth-profiling. Using this beam, many unexpected phenomena were observed. The fundamental aspects of X-ray photoacoustic phenomena become clear steadily with experimental evidence, and will be discussed in relation to the mechanism of the photoacoustic EXAFS phenomena.

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Fig. 1 Photoacoustic EXAFS Spectrum of Cu Foil(5um) at Chopping Frequency 8 Hz in relation to the absorption spectrum.

Fig. 2 X-ray PA Signal Intensity Depending on the Thickness of Metal Foil. (1.56 A X-ray, 8 Hz)

Fig. 3 EXAFS in PA Phase Spectra

Fig. 4 Dependence of PA Signal Amp. and Phase on Sample Thickness at above and below K-edge (Chopping Freq. 9Hz)

Fig. 5 X-ray Photoacoustic Spectra of Ni(0.65 μm)-plated Cu(10 μm) at 117 Hz

Fig. 6 X-ray Photoacoustic Signal Waveforms at Various Energy Range Observed in the Measurement of Fig. 5.