Instrumental Achievements

Detection of Photoacoustic Signals Produced by Conventional X-ray Tube Excitation

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Photoacoustic experiment is known to be conducted in any wavelength region of excitation. It has mostly been conducted in UV, visible and infrared regions but for an experiment of X-ray dosimetry.¹ Recently the photoacoustic experiment in X-ray wavelength region was successfully conducted with the use of synchrotron radiation as an excitation source.² Although the synchrotron radiation is an excellent X-ray source because of its strong intensity, wide selectivity of exciting wavelength, directional nature of beam line, and so on, its difficulty lies in the fact that the facility of the synchrotron radiation is not easily accessible.

The present paper preliminarily reports that the photoacoustic signal can be detected by the conventional X-ray excitation.

Experimental

A built-in type X-ray tube with molybdenum target was used as the exciting source in the present experiment. An aluminum blade sector was used for chopping the X-ray beam. The transmittance of the aluminum blade for the Mo K α radiation was estimated to be approximately 25% from the mass absorption coefficient and the thickness of the blade (1 mm), being considered to be effective for the purpose of modulation.

Fig. 1 X-ray photoacoustic cell. X: Exciting X-ray, F: beryllium filter, B: beryllium window, S: sample, M: microphone, ●: viton O-ring.

Figure 1 shows the sample cell designed and used for the present experiment. The thickness of each beryllium window (upper and bottom) was 0.25 mm. A beryllium filter (0.25 mm thick) was placed in front of the photoacoustic cell to eliminate the X-ray component which may be absorbed by beryllium window. The output of the microphone was impedance transformed at the source follower of an FET, and then introduced to lock-in amplifier (NF Electric Instruments, LI575). The amplified signal was recorded on an XYT-recorder. The background signal without the sample in the photoacoustic cell was also recorded and subtracted from the photoacoustic output signal. Sheets of copper foil (thickness 0.01, 0.1, 1 mm, diameter 13 mm) were used as samples. In the photoacoustic measurement each sample sheet was placed to be in contact face to face with the bottom beryllium window.

Fig. 2 Photoacoustic intensities versus X-ray tube current. A: Direct read, B: background.

Results and Discussion

Figure 2 shows the plots of photoacoustic signal intensity for the 0.01 mm copper foil versus the current of the X-ray tube at a chopping frequency of 40 Hz. The photoacoustic signal intensity is considered to be proportional to the exciting X-ray power, since the latter is proportional to the current of the tube. Taking the efficiency of the X-ray generation as 1.7×10^{-3} , the X-ray power generated at 40 kV and 40 mA is estimated to be 2.7 W.³ The incident X-ray energy to the sample is calculated as $2.7 \times 1.3 \times 10^{-3} = 3.5$ mW under the experimental conditions: the distance $l = 70$ mm between the molybdenum target and the sample, the radius $r = 5$ mm of the beryllium window, the steric angle of the X-ray radiation on the sample $(1/4\pi)(\pi r^2/P) = 1.3 \times 10^{-3}$. Consequently, the signal sensitivity of the photoacoustic cell with the 0.01 mm copper foil is found to be 47 mV/W.

Figure 3 shows the dependence of the photoacoustic signal on various chopping frequencies. The thermal diffusion length μ_s , which is defined as $\mu_s = \sqrt{2k/c\rho\omega}$ with k thermal conductivity, ρ density, c specific heat, and ω the angular chopping frequency, is calculated to be 1.9 mm at $\omega = 2\pi \times 10$ and 0.5 mm at $\omega = 2\pi \times 120$, respectively, for the copper sample with the values $k = 0.923$ cal $\text{cm}^{-1} \text{s}^{-1} \text{°C}^{-1}$, $c = 0.0919$ cal g^{-1} , $\rho = 8.93$ g cm^{-3} . The optical penetration length $\mu_\beta (= 1/\beta)$ of the copper sample for the Mo K_α radiation is calculated to be 0.022 mm with the absorption coefficient $\beta_m = 0.504 \times 10^2$ $\text{cm}^2 \text{g}^{-1}$. Consequently, the sample foil of 0.01 mm thick is optically and thermally transparent, while those of 0.1 mm and 1 mm thick are optically opaque but thermally transparent at $\omega = 2\pi \times 10$. The sample of 1 mm thick is thermally opaque at $\omega = 2\pi \times 120$. The signal intensity has approximately $\omega^{-1} - \omega^{-1.15}$ dependence (Fig. 3), which is consistent with the theory by Rosencwaig and Gersho.⁴ The sample of 1 mm thick showed $\omega^{-1.4}$ dependence at chopping frequencies larger than 20 Hz. This seems

Fig. 3 Photoacoustic intensities versus sample thickness.

to be due to the intermediate state between thermally thin and thick case. Details for this results should be left to further experiments.

References

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