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X-Ray Photoacoustic Effect of Solid Materials

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Heat generation of solid materials on X-ray absorption was found to be detected by microphonic photoacoustic method using strong X-rays from a synchrotron orbital radiation source. The wave form of the X-ray photoacoustic spectroscopic (XPAS) signal was similar to those of UV, visible light PAS. The intensity of photoacoustic signal for white X-ray showed linear dependence on the beam current. The difference in photoacoustic signal of various samples is discussed.

Photoacoustic effect which is originated from the finding by A.G. Bell[1] is based on the heat generation in materials by light absorption. When materials are irradiated by X-rays, several effects occur, e.g. absorption, scattering, and X-ray fluorescence. The heat generation should also be observed on the absorption of an electro-magnetic wave even on X-ray absorption process. However, it has not been reported that the transient heat generation by X-ray absorption was detected, and so much attention has not been paid to the heat on X-ray irradiation in scientific sense, while we sometimes observe the heat generation in, for example, the deterioration of a silicon single crystal by strong X-ray irradiation.

The photoacoustic method, especially microphonic detection is one of the most sensitive method to detect the heat generation from the solid surface.[2] Using the strong X-ray from the electron storage ring at the Photon Factory(PF) (Beam Line 15A1(monochromatic X-ray), A2(white X-ray)) of the National Laboratory for High Energy Physics (KEK), the heat generation was found to be detectable as the

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photoacoustic effect.

Our old photoacoustic cell was modified for this experiment and is detailed elsewhere.[2] A microphone cartridge was electret type (10 mmϕ) and two windows of the cell were beryllium (18 mmϕ x 0.5 mm thickness) discs. The X-ray was chopped by a rotating lead plate (1 mm thick) at 8.13 Hz. Figure 1 shows the photoacoustic signal of various solid materials for white X-ray. Strong signal for copper(50 µm) (a) shows a typical saw shape with a little convex form rising as seen in the photoacoustic signal by the UV or visible light source. As shown in (d), the signal of the air in the cell chamber (and from the inner faces of beryllium windows) shows a convex shape rising up and seems to overlap to the genuine signals of metal samples as seen in (a) and(b). Thus the original signals of copper, aluminum, and lead should be more triangular shaped: it is consistent with the Rosencwaig and Gersho theory for the general photoacoustic effect.[4] Furthermore, even for the organic material like paper, a weak heat generation was detected as seen in Fig. 1(c). The photoacoustic signal intensity (sample: lead plate (400 µm thick)) for white X-ray was proportional to the ring current in the range of 110-140 mA as shown in Fig. 2. Since the ring current is the measure of the beam photon flux, this method can be applied to the estimation of X-ray dose.

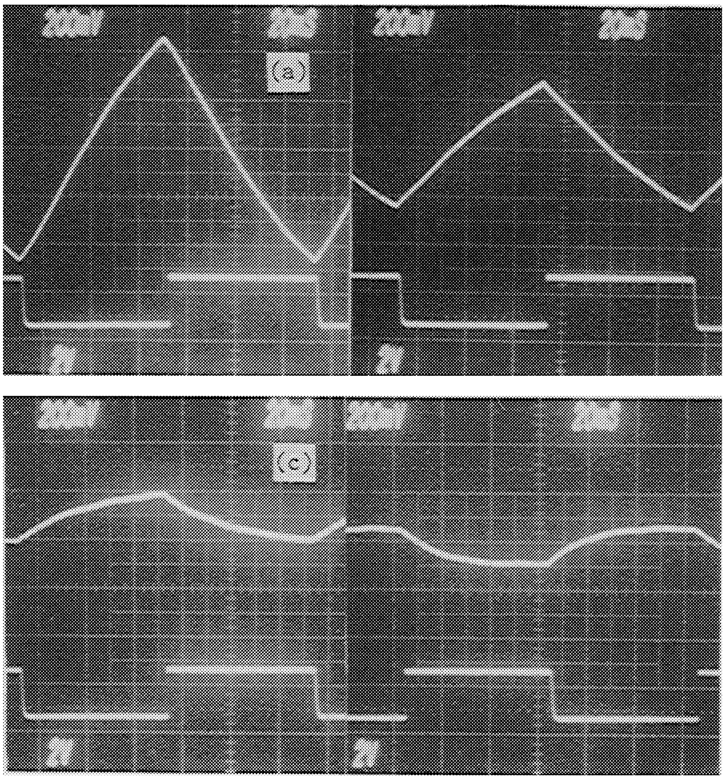

Fig. 1. Photoacoustic signals of solid samples with white X-ray. (a); copper(50 µm thick),ring current(R.C.) 107.4mA, (b); lead(400 µm), R.C. 140.9 mA, (c); paper(100 µm), R.C. 84.9 mA, (d); no sample, R.C. 87.2 mA. The numerals in figures are scales per division. The pulse signal in each fig. is chopping signal. In this case, its phase was inverted by 180 degree due to the setting position of chopper. Thus the lower side of pulse is X-ray "<u>on</u>".

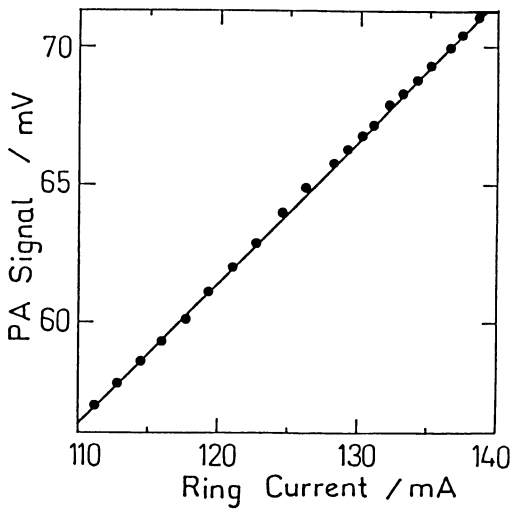

Fig. 2. Dependence of photoacoustic signal intensity of lead(400 µm thick) sample on ring current using white X-ray.

Figure 3 shows the wave forms of various samples for monochromatic X-ray (1.56 Å). The signal decreased to 1/100-1/200 (by signal intensity/ring current) of those for white X-ray. The signal of the air (and beryllium windows) was so weak in this case that the triangular shape of the signals for metal samples was discernible. The detectability of this method is about 10^{10} photon/s (using copper(50 μm) and at S/N=1) at this stage. The improvement of detectability is in progress. Table 1 summarizes the signal intensity per unit ring current. Although the mass absorption coefficient of copper is similar to that of aluminum at this X-ray energy, the difference in density gave quite different transmittance (I/I_0) for X-rays. Thus the total absorbed beam is higher for copper than that for aluminum. One unexpected result was on the lead sample. Mass absorption coefficient of lead is 5 times higher than copper and its transmittance is almost zero, however

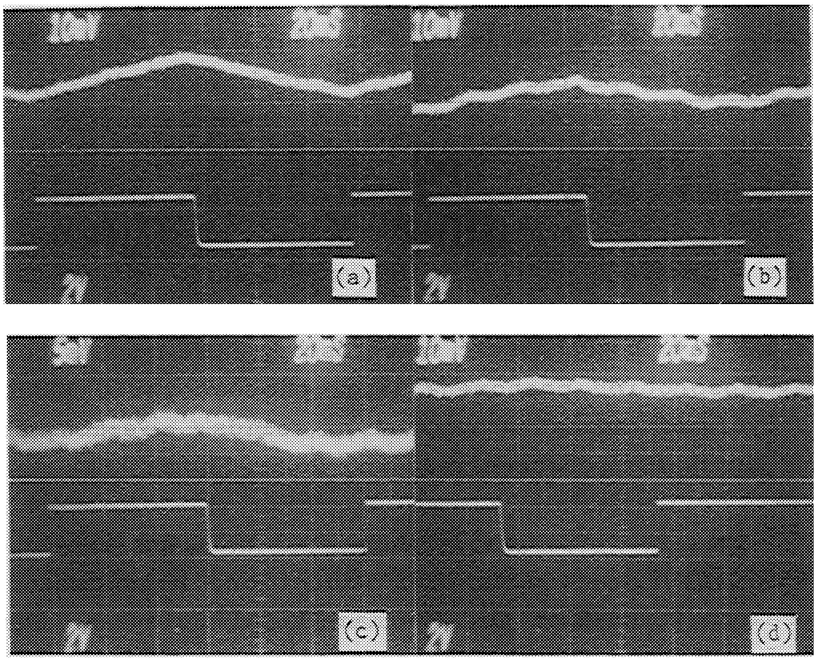

Fig. 3. Photoacoustic signals of solid samples with monochromatic (1.56 Å) X-ray. (a); copper, R.C. 140.8 mA, (b); lead, R.C. 133.8 mA, (c); paper, R.C. 67.0 mA, (d); no sample, R.C. 108.0 mA. The same samples as in figure 1. The numerals in figures are scales per division. The chopping pulse signals were in phase for these cases.

Table 1. Photoacoustic signal intensities of solid materials

Sample(thickness)	White X-ray PA Signal/R.C. (mV/mA)	1.56 Å X-ray PA Signal/R.C. (μV/mA)	Mass Abs.Coeff.[5] $(\mu)\times10^{-2}$ $(cm^2\cdot g^{-1})$	I/I_0
Copper(50 μm)	2.50	13.4±0.3	0.551	0.0856
Aluminum(100 μm)	1.50	7.8±0.4	0.527	0.243
Lead(400 μm)	1.02	6.8±0.5	2.41	0
Glass(150 μm)	1.43	6.7±0.7	-	-
Paper(100 μm)	0.69	2.7±0.9	-	-
No Sample	0.63	2.2±0.6	(0.083	0.998)[a]

R.C.; Ring Current of Strage Ring (mA), I/I_0; Transmittance
a) Calculated for air(20.93 v/v% O_2, 78.10 v/v% N_2)(2 mm thick)

the photoacoustic signal was about two times smaller than that of copper. Other factors which explains this inconsistency should be heat capacity, and/or heat conductivity of the sample. The precise studies of signal intensity for various samples of different thickness and thermal property are now in progress.

The X-ray photoacoustic effect of solid materials seems to be a result of multiprocesses and the mechanism of this effect has not been resolved at this stage. However, the lattice vibration of the ionized atoms seems to be a cause of this effect.

This finding expands the photoacoustic spectroscopy to the X-ray region and this X-ray photoacoustic spectroscopy (XPAS) seems to reveal new aspects of the X-ray absorption phenomena (e.g. photoacoustic EXAFS) and also useful for the analysis of thermal properties of solids. Various studies are now in progress in our group (Cooperative research No.86-020 at KEK).

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