Coincident Measurement of a Weakly Backscattered X-ray with a CPA Laser-Produced X-ray Pulse

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Backscattered X-ray intensity was measured coincidently with a CPA laser-produced X-ray pulse. Results show that the coincident measurement is useful in reducing the effect of natural radiation. Even for signals at the photon counting level, we can distinguish the scattering materials and their thickness from the difference in backscattered X-ray counts. These results suggest that the backscattered X-ray can be used for imaging any distant object.

Keywords: backscattered X-ray, coincident measurement, X-ray pulse, laser-produced X-ray, imaging

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Nowadays, we can detect a single X-ray photon. However, natural radiation in an ordinary environment makes it difficult to obtain meaningful single photon data. Coincident measurements reduce the effects of natural radiation when extremely short X-ray pulses are used. Then, meaningful data can be obtained from weak X-ray signals even in open space. Thus, we can use this technique for remote imaging of strange objects and for non-destructive inspection of huge structures. Recently, the generation of extremely short X-ray pulses by laser-based techniques has been reported [1, 2]. We report here the coincident measurement of weakly backscattered X-ray signals using extremely short X-ray pulses. In addition, we discuss the possibility of imaging distant objects.

A schematic diagram of the experimental arrangement is shown in Fig. 1. An extremely short X-ray pulse was generated from a table-top laser accelerator [3]. The pulse width was 200 fs, the energy was 62 mJ, and the focused beam intensity was 1.9×10^{17} W/cm^2. Aluminum plates of 0.5 mm-thickness were used as the irradiation targets as well as the X-ray emission sources. The X-rays were extracted from the chamber through a 5-mm-thick BK7 window. The shots were repeated at 10 Hz. We used a plastic scintillation counter with a diameter of 90 mm to detect the backscattered X-rays. We registered the meaningful X-ray signals as long as they were coincident with the primary X-ray pulses. We also used a CdTe X-ray detector for monitoring the primary X-ray spectrum.

In the case of continuous measurement, the plastic scintillator counted 12 signals for 10 ms as the natural radiation noise. For the coincident measurement, the counter, on the other hand, counted no signal even for 500 s. Therefore, we confirmed that the coincident measurement was useful for noise reduction.

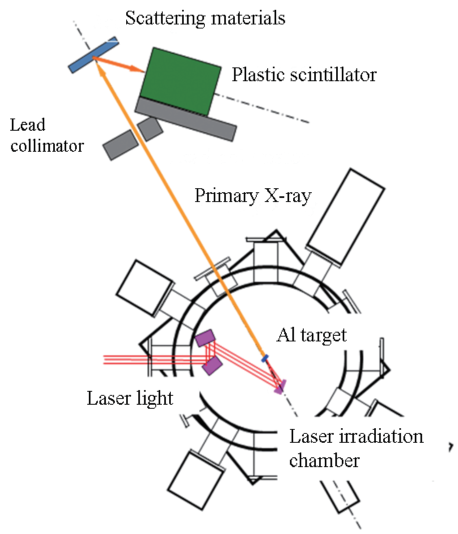

Fig. 1 Schematic setup for measurement of backscattered X-ray intensity.

We used 10-mm-, 20-mm-, and 30-mm-thick acrylic plates as well as 1 mm and 20 mm lead plates as the scattering materials. The counter for 100 s detected around 1000 primary X-ray pulses, and the backscattered X-ray pulses were very few. In the case of continuous measurement, the backscattered X-ray signals were embedded in the natural radiation noise. We constructed a theoretical model consisting of both the X-ray attenuation in scattering materials and the X-ray backscattered interaction with electrons. We used the Klein-Nishina formula [4] for calculating X-ray scattered probabilities.

Figure 2 shows the dependence of the backscattered X-ray counts on scattering materials and their thickness,

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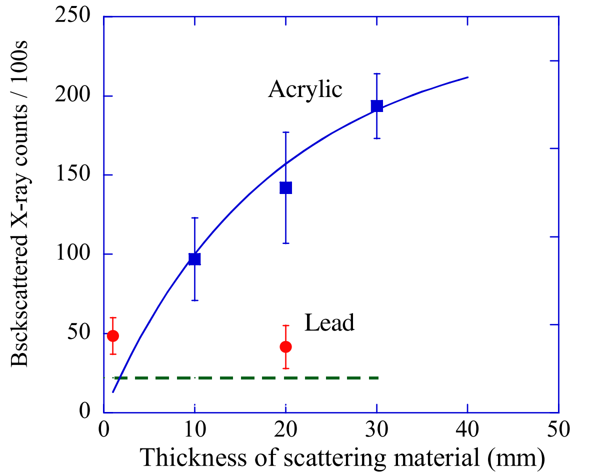

Fig. 2 Dependence of backscattered X-ray counts on scattering materials and their thickness. Dashed line indicates the background level. Solid line indicates the theoretical model for acrylic.

as well as the calculation. The backscattered X-ray yield is the summation of backscatter along the depth of the scattering material. Therefore, it depends on the X-ray attenuation in scattering materials as well as on their electron density. The thicker the material, the larger the backscattered X-ray yield for low density materials.

Figure 3 shows the result of backscattered X-ray imaging from a scattering object consisting of a sandwich structure, as shown in the bottom of Fig. 3. The background, shown as a horizontal dashed line in Fig. 3, is signal level without the scattering material. A lead block collimator shaped a rectangular primary beam with 5.8 mm width, as shown in the top right window. The difference at the left ($x = -15$ mm) acrylic-lead boundary is greater than 70 counts. On the other hand, the difference at the lead-air boundary ($x = -25$ mm) is not clear under the influence of background. However, this background is not the effect of natural radiation. Since the coincident measurement dose not count natural radiation for 100 s, the cause of this background must be emissions from the laser irradiation chamber. We can reduce this background using an appropriate X-ray shield around the X-ray source. In addition, the result shows that the space resolution of the backscatter image agrees with the primary beam width. Therefore, we expect that a narrow primary beam will improve the space resolution of the backscattered images.

Figure 4 shows that the scattering materials shifted the energy spectra of the backscattered X-rays. We can distinguish the scattering material by the measurement of the backscattered X-ray spectrum.

One advantage of the extremely short X-ray pulse and its coincident measurement is that they can be used to detect weakly backscattered X-ray signals. In addition, we show that backscattered X-ray imaging can distinguish the materials even for signals at the photon counting level. This technique can be used for detecting weakly backscattered X-ray signals from a distant object and for imaging the object.

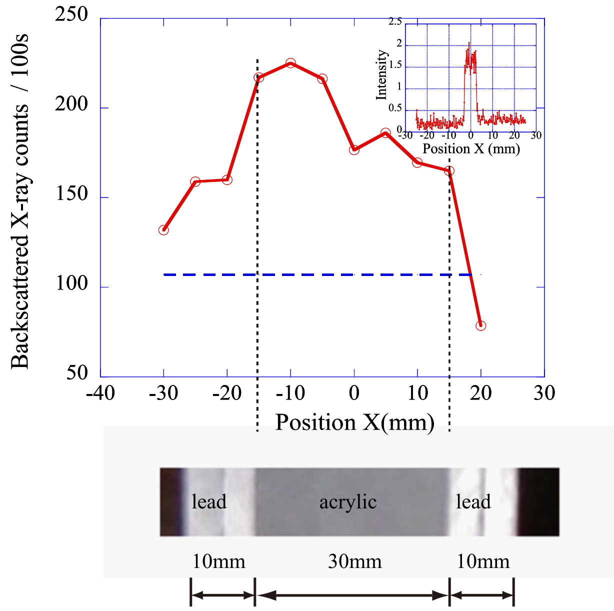

Fig. 3 Upper: Backscatter X-ray imaging. The top right window is the primary X-ray shape. Lower: Structure of the scattering material. Circles indicate the experimental results. Horizontal dashed line indicates the background level. Vertical lines correspond to the boundary between the lead and the acrylic, as shown in the bottom.

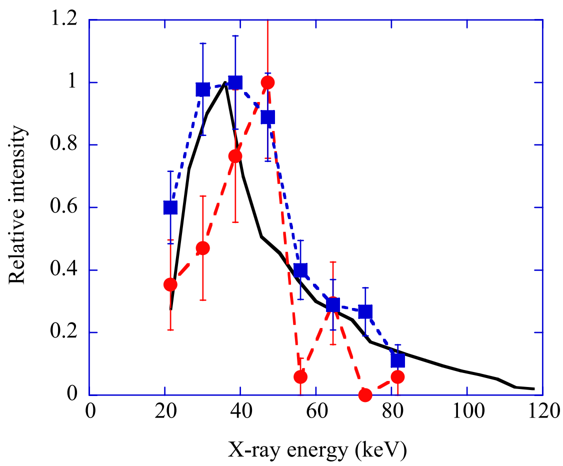

Fig. 4 Backscattered spectrum shifts from the primary X-ray. Solid line: Primary X-ray. Circle: Lead of 20 mm thickness. Square: Acrylic of 30 mm thickness.

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