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Detection of acoustic wave excited in chloroform bombarded with high-energy xenon beam

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Abstract

A pressure wave excited by irradiating liquid chloroform ($CHCl_3$) with a 400 MeV/n xenon (Xe) beam was observed using a detector composed of piezoelectric lead–zirconate–titanate (PZT) elements. The acoustic signals were examined for various beam pulse durations. The amplitude obtained in the first cycle was inversely proportional to the beam pulse duration. It was also found that the time at which the peak in the first cycle appeared was dependent on the location at which each element was set. This suggests that the position at which the Xe beam stops in $CHCl_3$ may be precisely determined with the PZT detector.

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1. Introduction

For radiation detectors, there have so far been only a few reports on acoustic-principle-based methods [1–4]. We are interested in a radiation detector that is exclusively prepared with piezoelectric lead–zirconate–titanate (PZT) material, because the PZT can be utilized not only as a sensor of acoustic signals but also as an absorber of radiation [5–7]. We detect the radiation by the following two methods: one is a direct method in which the sensor and absorber are unified in one element, and the other is an indirect method in which the sensor and absorber are separated.

In previous studies based on the direct method [5–7], the characteristics of the PZT detector in the form of a disk were studied by directly irradiating one with a 400 MeV/n xenon (Xe) beam, while changing the beam pulse duration. It was found that the amplitude of the output signal obtained from the detector was almost independent of the beam pulse duration [7]. On the other hand, in the case of the indirect method [8,9], when water was used as the absorber, a pressure wave was detected by the PZT detector in the form of a cylinder set in water as the beam pulse duration was varied. The amplitude explicitly depended on the beam pulse duration. Therefore, these results suggest that the mechanisms of producing the acoustic signal by radiation differ between the direct and indirect methods. However, there have been no reliable theories that explain the production mechanism.

In this study, when a 400 MeV/n Xe beam was irradiated onto liquid chloroform ($CHCl_3$), the acoustic wave excited was investigated using an array composed of eight PZT elements arranged in $CHCl_3$, while changing the beam

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pulse duration. The amplitude of the wave generated in $CHCl_3$ is expected to be larger than that in water because the ratio of the coefficient of cubical expansion to specific heat for $CHCl_3$ is larger than that for water [1]. In addition, it is deduced from the Bethe–Bloch formula that the range of 400 MeV/n Xe ions in $CHCl_3$ is shorter than that in water. Therefore, the experiment was carried out using the smaller chamber in which the absorber is enclosed to confine of the Xe ions. Since there are very few reports on the production mechanism, the results presented were considered to improve the detector that is based on the acoustic principle at room temperature.

2. Experimental methods

Fig. 1(a) shows the PZT element used in this experiment schematically. The element had a cylindrical shape 28 mm in inner diameter, 30 mm in outer diameter, and 4 mm in length. Silver electrodes with a thickness of a few μm were coated onto both inner and outer sides. The Xe beam was incident to the *z* direction as indicated in Fig. 1(a), and the pressure wave exited in the absorber was measured as the voltage across the inner and outer electrodes, that is, in the *r* direction as indicated in Fig. 1(a). A frame made of epoxy resin supported the element. The frame was suspended by four springs to prevent noise arising from mechanical disturbances. These eight elements, which were spaced 2 mm apart, were assembled to be used as a detector.

The experimental arrangement is schematically shown in Fig. 1(b). A 400 MeV/n Xe beam was supplied by the Heavy Ion Medical Accelerator in Chiba (HIMAC) at the National Institute of Radiological Sciences [10]. The beam was originally extracted for 0.3 s within a period of 3.3 s. A chopper was used to obtain a short-pulsed beam. The chopper was a rotating stainless-steel disk with a diameter of 30 cm and a thickness of 10 mm, in which four slits with a length of 10 mm and a width of 1 mm were perforated in an equiangular manner. The disk was installed ~73 cm downstream of the exit of the beam duct. By adjusting the rotation speed, the beam intensity could be varied in accordance with the change in the pulse duration from 50 to 200 μs [6]. When the rotation speed was 30 rps, the beam duration became ~120 μs and the typical number of xenon ions was ~200 per slit window. A 1-mm-thick plastic scintillation counter was placed ~36 cm downstream of the chopper. The beam intensity was monitored by the counter. A chamber, in which $CHCl_3$ of 200 cm^3 volume was enclosed, was placed ~18 cm downstream of the

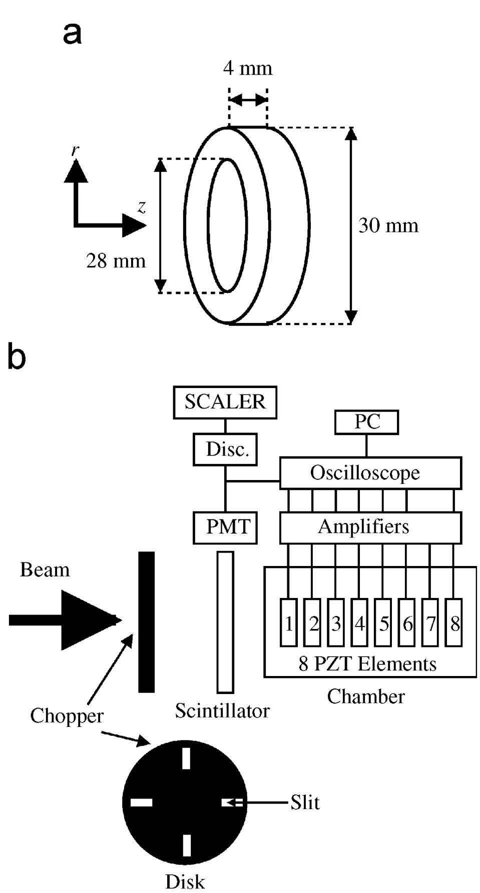

Fig. 1. Schematic views of (a) PZT element and (b) experimental configuration. Here, the photomultiplier is indicated as PMT, the discriminator as Disc, and the personal computer as PC.

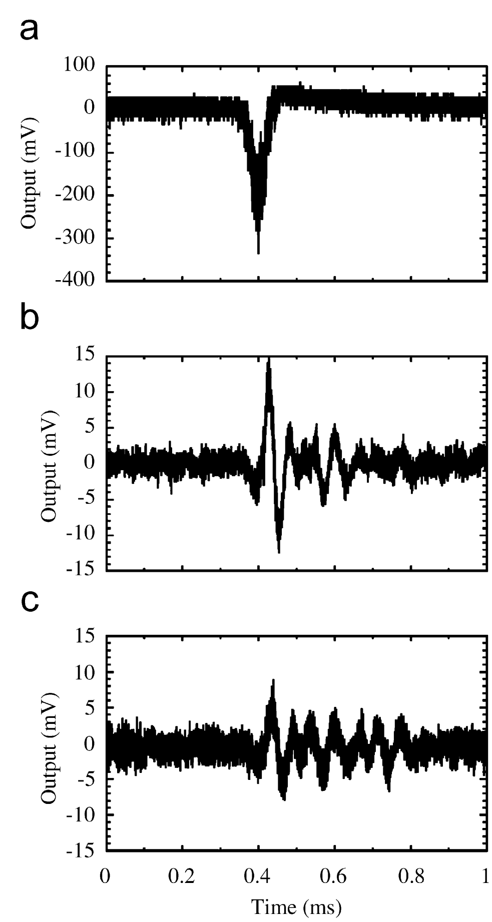

Fig. 2. Typical waveforms of output signal observed from (a) photo-multiplier, (b) element No. 3, and (c) element No. 5 when chopper disk rotated at 50 rps.