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Characteristics of piezoelectric lead zirconate titanate multilayered detector bombarded with hypervelocity iron particles

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Abstract

A cosmic dust detector is currently being developed using a piezoelectric lead zirconate titanate (PZT) element. The characteristics of the multilayered detector (MD), which was composed of one hundred PZT disks, were investigated by bombarding it with hypervelocity iron particles supplied by a Van de Graaff accelerator. It was confirmed that there was a linear relationship between the signal amplitude observed from MD and the momentum of the particles. As compared with the single-layered detector (SD) that was composed of one PZT disk, it was found that the sensitivity of MD was ~3 times higher than that of SD within the limits of the experimental conditions.

Keywords: Cosmic dust; Dust detector; Piezoelectricity; Lead zirconate titanate (PZT); Multilayers

1. Introduction

Lead zirconate titanate (PZT) is piezoelectric ceramic (Jaffe et al., 1971). It has some distinct features: it is easy to be shaped arbitrarily and can be operated without a power supply for driving, and its weight is light. These features are considered to be favorable for an observational instrument which a satellite will carry. Weishaupt (1987) had proposed a dust detector system using a plate of piezoceramic material for space research. For exploring Mercury in the near future, the aim of the BepiColombo project (Hayakawa et al., 2004), most of the observational instruments onboard the satellite have now been built. We have been developing a Mercury dust monitor (MDM) using PZT, which will detect cosmic dust around Mercury (Miyachi et al., 2003, 2004, 2005a,b,c).

To not only act as the counter but also measure for the parameters of the cosmic dust such as mass and velocity, we have investigated the behaviour of the PZT element upon collision with hypervelocity particles supplied by a Van de Graaff accelerator. These experiments were performed at the University of Tokyo and Max-Planck-Institut für Kernphysik (MPI-K). Miyachi et al. (2005a,c) had found as follows; the output waveform observed from the detector using one PZT element was explicitly related to the particle's velocity on impact. When the particle's velocity was less than ~6 km/s, the appearance of the output sig-

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nal became an oscillation pattern and the amplitude in the first cycle was proportional to the particle's momentum on impact.

In this study, the characteristics of the detector using one hundred PZT disks were investigated by collision with iron particles having the velocity less than ~5 km/s, which were supplied by a Van de Graaff accelerator at MPI-K, as compared to those of the detector using one PZT disk. The results presented are considered to be useful for improving the sensitivity of PZT detector. This will enhance the potential of the PZT detector used as the MDM.

2. Experimental Setup

Fig. 1(a) shows schematic illustration of PZT detector. Two PZT detectors were used in this experiment. One consisted of a single-layered PZT disk that was 20 mm in diameter and 8 mm in thickness. Hereafter, this detector is referred to as the single-layered detector (SD). The other was fabricated by stacking 80-μm-thick PZT disks of 20 mm diameter. A 2-μm-thick metal sheet made of Ag–Pd was sandwiched between each pair of disks. To adjust the thickness to 8 mm, one hundred disks were joined by baking. Hereafter, this detector is referred to as the multi-layered detector (MD). Silver (Ag) electrodes with a thickness of a few μm were coated onto both front and back surfaces of each detector. Both detectors were polarized in the direction normal to the surface.

The experimental arrangement is schematically shown in Fig. 1(b). Iron (Fe) particles were used to simulate cosmic

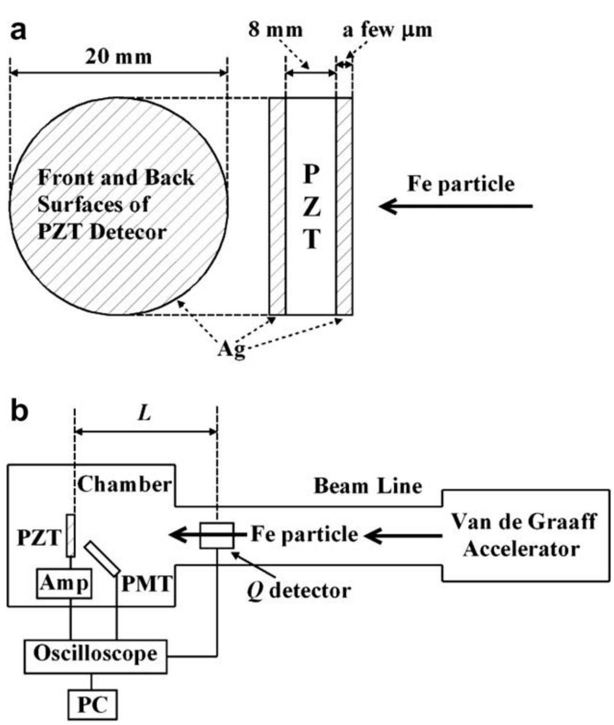

Fig. 1. Schematic views of (a) PZT detector and (b) experimental configuration. Here, the photomultiplier is indicated as PMT, the amplifier as Amp and the personal computer as PC.

dust. The Fe particles were supplied by the Van de Graaff accelerator at MPI-K, Heidelberg. In this experiment, the Fe particles were accelerated with an acceleration voltage (U) of 2 MV. The charge (q) of the particles was determined by the induced voltage (V_Q) on the Q detector which was installed in the beam line, that is, $q = C_Q V_Q$ (here, C_Q is the electrostatic capacitance of the Q detector, 0.147 pF). The PZT detector was placed at a distance of 91 cm downstream from the Q detector (L). The detector was supported by a frame made of epoxy resin. The frame was suspended by four springs to prevent noise arising from mechanical disturbances. The beam line and the chamber, in which the PZT detector, an amplifier and a photomultiplier were set, were maintained at a pressure of $\sim 10^{-6}$ Torr.

Using the photomultiplier (PMT), the light flash on impact was just directly detected and used as a time reference (T_L). When T_Q was the time at which the signal of V_Q appeared on the Q detector, the velocity of the Fe particle (v) was determined by $v = L/(T_L - T_Q)$. Consequently, the mass of the particle (m) was estimated from $mv^2/2 = qU$. The signal obtained from the PZT detector was processed using a fast amplifier with a bandwidth of ~400 MHz. Each signal obtained from the Q detector, PMT and PZT detector was transferred to a digital oscilloscope (LeCroy products, WavePro7300A, with a bandwidth and sampling rate of 3 GHz and 10 GS/s, respectively). Digitally processed data were stored in a personal computer.

Fig. 2 shows the signals of a typical event, where (a) is a signal obtained from the Q detector, (b) is a signal from the PMT and (c) is a signal from MD. In this case, the parameters of the Fe particle were as follows; $q \sim 0.06$ pC, $v \sim 5.0$ km/s, $m \sim 10$ pg and the momentum $p = mv \sim 50$ pgkm/s. It was also observed that the signal began to appear at the PZT detector simultaneously with the flashes of light.

3. Results and discussion

We have investigated the response of the two PZT detectors, that is, both SD and MD to hypervelocity Fe particles. Fig. 3 shows the distribution of the mass (m) versus the velocity (v) of the Fe particles used in this experiment. The range of m was from 2 to 40 pg, and the range of v was from 3 to 5 km/s. This range of v corresponded to the case of results obtained as follows: the output signal obtained from the detector at the time immediately after the collision took place appeared in the form of an oscillation pattern, and the amplitude in the first cycle was proportional to the particle's momentum (p).

In the previous reports (Miyachi et al., 2005a,b,c), the dependence of the waveform obtained from the PZT detector on v was estimated in terms of the Young's modulus (E) of the PZT material. According to the estimation, it was considered that the PZT material underwent a stress $\sigma < E$ from impact with a Fe particle below ~5 km/s.