Cosmic Dust Detector Capable of Measuring Hypervelocity Speed Using Piezoelectric PZT. M. Kobayashi[1] (Kobayashi.masanori@perc.it-chiba.ac.jp), T. Miyachi[1] and M. H. Nakamura[2], [1]PERC/Chitech, [2]Univ. Tokyo.

Introduction: Cosmic dust (mass of 10^{-14} to 10^{-9}g) is a basic component of the space and has been observed by space-borne missions since the 1960's, the number of observed dust particles, however, has been limited because of its low spatial density. Most cosmic dust consists of interplanetary dusts and interstellar dust.

With regard to interplanetary dusts, the origin is believed to be asteroids and comets. Interplanetary dusts are considered to flow out from asteroids or comets while it enters into another celestial body, there is, however, no established theory of the supply ratio of the interplanetary dusts. On the other hand, the interstellar dust at the same velocity as the interstellar wind, in-situ observation is very limited due to its very little flux. For instance, there are only about 500 numbers of cosmic dusts that MDC (effective detection area 100cm^2) onboard to HITEN of Japan observed for about three years with 1AU [1].

The cosmic dust plays the key role in the evolution of the solar system even at the moment. It is necessary to observe cosmic dusts simultaneously, continuously and at the multipoint to investigate the transportation of the solar system material. In order to increase opportunities of dust detectors to be carried, dust detector is required to save space and weight for the resource suppression of spacecraft. Dust detector utilizing the piezoelectric crystals (PZC) can meet the requirement.

In this paper, we propose a cosmic dust detector capable of measuring speed using PZC. The dust detector can observe the momentum and the speed and as a result the mass can be also derived. The targets are hypervelocity dust particles with the speeds higher than about 7 km/s.

Dust Detectors using Piezoelectric Crystals in Past and Current Space Missions: PZC have been widely used as supersonic transducer and also used as momentum sensor for cosmic dust observation in space utilizing the piezoelectricity. Thick PZC and thin (typically 0.1 mm) piezoelectric diaphragms have been used on spacecraft [1]. Previous work has shown that only at low speed ($v < 0.55 \sim 1$ km/s) is the response of a momentum detector proportional to the momentum, mv, of the dust particle. At higher speed, the impact ejecta like gaseous, liquid, or solid secondary particles produces additional momentum imparted to the target is enhanced by a factor as a function of impact speed v [2][3]. Such piezoelectric detector has a great advantage that its mechanical simplicity and light weight can be easily utilized to space instrument. Several PZC were attached to the dust shields of the Giotto spacecraft to the comet Halley as part of the Dust Impact Detection System (DIDSY) [4].

In on-going and future missions scheduled to a lunch in a few years, PZC were adopted for dust observation. SESAME is an instrument complex built in international co-operation and carried by the Rosetta lander Philae intended to land on comet 67P/Churyumov-Gerasimenko in 2014 [5]. The main goals of this instrument suite are to measure mechanical and electrical properties of the cometary surface and the shallow subsurface as well as of the particles emitted from the cometary surface. Most of the sensors are mounted within the six soles of the landing gear feet in order to provide good contact with or proximity to the cometary surface.

In order to investigate the dust environment around Mercury, we have proposed that the Mercury dust monitor (MDM) should be onboard the BepiColombo/Mercury magnetosphere orbiter (MMO) [6]. The main objective of the project is to obtain new data on the flux and momentum of the interplanetary meteoroid complex near Mercury (0.31–0.47 AU). The MDM uses lightweight and heat-resistant piezoelectric ceramic sensors made of lead zirconate titanate or PZT. Four square plates of PZT, 40mm×40mm×2mm each, will be installed on a side panel of the MMO. Upon colliding with a dust particle, the piezoelectricity of PZT generates a transient voltage signal.

As described above, most previous studies of piezoelectric dust detector have focused on measurement of the piezoelectric signal waveform in terms of the amplitude and rise time. The measurement aims at observing the momentum transfer during the impact that is nearly proportional to the signal amplitude.

In contrast with other studies described above, this paper proposes a dust detector using PZC that is able to measure not only the momentum but the speed.

Development of Dust detector Using Piezoelectric PZT: As described above, PZC has been used to observe cosmic dust. It is, however, unclear of the physical process of the generation and propagation of shock wave in target materials when hypervelocity microparticles impact on the target material and how the shock wave generates electric signal by the piezoelectric effect is also unknown in detail. We have been studying PZT for the application to a dust detector [7]. We irradiated various shapes of PZT plates with hypervelocity microparticles in wide ranges of mass and speed using microparticle accelerators and investigated the waveforms of PZT signal outputs. Some results of our previous studies are summarized below.

(1)Wave propagations in the thickness and in-plate directions. In previous studies, we found that a PZT plate electrically outputs a complex waveform when a hypervelocity microparticle impacts on. The complex waveform can be divided into two components, short period and long period. The short period wave is longitudinal wave propagating in the thickness direction of PZT plate, while the long period wave is transverse wave propagating in the in-plate direction. For elastic wave in PZT, the speeds of propagation are 4.5 km/s and 3.0 km/s for longitudinal and transverse wave, respectively. Periods of both the short and long period waves are determined by the path and speed of wave propagation. For instance, in the case of a PZT plate with a thickness of 2 mm and a diameter of 20 mm, the short period and the long period are 890 ns and 8.9 μs, respectively.

The first peaking time of the long period wave is considered to be the arrival time of the transverse wave at the end of the plate. The duration time between the impact time and the first peaking time seems to correspond to propagation time of the transverse wave from the impact point up to the end of the plate. This feature might not be only for elastic wave but for shock wave in PZT. Shock wave generated by microparticle impact on PZT target has been never observed directly yet. It was, however, observed that the peaking time of the output waveform became earlier as the impact speed became faster [8]. Those results suggest that shock wave is generated by the hypervelocity impact and propagates with supersonic speed in PZT target.

(2)Position sensitivity of waves propagating in PZT. From the result of position sensitive detector experiments [9], the electric field generated by the piezoelectric effect is likely to travel only in the direction of the polarization but not in the perpendicular direction. Thanks to that feature, by means of charge appeared on the electrodes, we can sense the position of the strain caused by waves propagating in PZT. Also timing of wave passing can be provided by observing at a certain position.

From that knowledge, PZC can be used for hypervelocity cosmic dust observation in different way from previous studies; not only for momentum sensor but measuring the impact speed of microparticles faster than a certain speed.

Measurement of Dust Speed Using PZT: This method is based on propagation of shock wave generated in PZC as the post-impact process of hypervelocity microparticles. Regarding hypervelocity impacts of microparticles, the knowledge of the collision process in a cratering theory is extremely useful. The idea is described below with a schematic drawing in Fig. 1.

- Following hypervelocity impact that exceeds Hugoniot elastic limit HEL (part of the electrode at the center) (I), the high pressure state occurs and shock waves is generated in the target materials.
- The shock wave concentrically propagates outward (II). At this time, the strain occurs in highly compressed volume by the shock wave, so that electric field generates there due to the piezoelectric effect.
- The field propagates only in the direction of the polarization and electric charge appears on the electrode surface. Of the output waveform of the charge sensitive amplifier (CSA) A, the leading edge shows the timing of the impact and the first peak height shows the momentum.
- The shock wave surface propagates outward and reaches the end of the detector, and then electric charges appear on the surface of an electrode at the end. CSA B and C output waveforms. From the speed of the shock wave propagation, the impact speed can be derived.

Perspectives: For the practical realization of this idea, we will study fundamental property of PZT from a viewpoint of hypervelocity impact. For example, the physical properties of PZT in hypervelocity impact, shock wave propagation in PZT, positioning precision of strain in PZT, and so on should be investigated.

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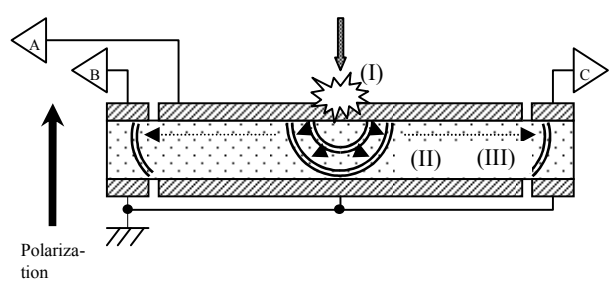

Fig. 1. Schematic drawing of cross sectional view of PZC detector. It shows a piezoelectric PZT (thin hatching part) sandwiched between electrodes (thick hatching parts). Those electrodes are followed to charge sensitive amplifiers, A, B and C.