Cosmic Dust detector using Piezoelectric PZT with current-to-voltage conversion amplifier.
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Introduction: Cosmic dust with a mass of 10^{-18} – 10^{-6}g is a basic component of space and has been directly observed by space-borne missions in interplanetary space since the 1960. Dust particles observed in interplanetary space were identified as interplanetary dust particles (IPDs), *β* meteoroids, interstellar dust (ISD), and dusts ejected from the Jovian and Saturnian systems by in-situ observations with the spacecrafts between 0.3 AU and 18 AU heliocentric distances [1]. The number of observed dust particles, however, has been statistically limited due to its low spatial density. Several models of dust flux in interplanetary space have been developed [2][3]; the dust flux models could be improved by future observation with higher statistical precision. Recently, large-detection-area dust counters and analyzers have been proposed for a future space mission, DuneXpress [4]. The payload of DuneXpress consists of seven sophisticated instruments for dust observation. If the mission DuneXpress is realized, many science topics that have been left due to insufficient statistics of dust observation may be solved. Some of them can be solved even by instruments less sophisticated instruments:

- What is the size distribution of interstellar dust and what is the variation in flow direction and its dispersion with particle size?
- How time variable is the interstellar dust flow of various sizes?
- What is the ratio of cometary versus asteroidal particles?
- What are the orbital characteristics of different types of cometary and asteroidal particles?

In this paper, we studied a dust particle detector with large-detection area as much as one of ALADDIN [5]. This study assumed a small spacecraft such as HAYABUSA that cruised in interplanetary space for long time, thus the dust instrument should have less resource requirement. We adopted PZT sensor for this purpose because it is mechanically simplicity and compactness. A PZT sensor is widely accepted as a momentum sensor, but it cannot uniquely determine the trajectory of dust particles.

Here, we are suggesting that the signals from PZT sensors are read in current mode by the amplifier. As a result, it is considered that the additional function can be given to PZT sensor. It may become to be able to predict not only the momentum but the size and the speed separately for hypervelocity microparticle and true-false discrimination may become much easier.

Signal readout of PZT sensor by Current-to-Voltage Conversion Amplifier (CVA): By reading the signal during the dust impact, we may separately know the mass (as predicted from the size assuming the mass density) and speed of the dust particle. Now we consider the detection of dust particle of a few μm or less. CSA is not appropriate for fast signal readout Instead, we can use an amplifier called current-to-voltage conversion amplifier (CVA), which reads the signal from a sensor in current mode and outputs the amplified signal in voltage. A CVA should have low input impedance compared to the impedance of the sensor (capacitative reactance, in this case), so that the electric charge generated in the sensor is likely to flow out into the CVA as electric current.

Experiments of current signal readout of impact on PZT sensor: We used a YAG pulse laser unit (λ=1064 nm, about 7 ns pulse duration, < 30 mJ) to simulate impact on the surface of a PZT sensor by light pressure. The PZT sensor with a detection area of 8 mm × 8 mm and a thickness of 8 mm and thin layers of silver electrode with a thickness of 5 μm are put on the both sides. It has an electric capacitance of 0.23 nF. Laser spot was focused to approximately 1 mm in diameter on the sensor surface. Impact generation by the light pressure of pulse laser is not the same as one by the collision of materials, laser pulse impact, however, is adequate for our purpose to investigate the signal response of PZT sensor read by CVA.

We fabricated a CVA whose response time of about 6 ns and input impedance is 20 Ω. The CVA is a hand-made amplifier just for trial experiment, the response time, however, is much faster than ones used in the previous studies by a factor of about 10. Laser pulses were irradiated at right angles to the PZT sensor and generated light pressure on the PZT sensor. The output waveforms of the CVA were recorded by a digital oscilloscope, LeCroy WaveMaster 806Zi, 6 GHz and 40 GS/s.

Figure 1 shows a typical waveform of the current signal of laser shot on the PZT sensor. In this figure, the vertical axis shows output voltage signal of the CVA corresponding to the current flowing to the CVA. This CVA is a non-inverting amplifier, hence, the positive output signals show compression and the negative signals show rarefaction in the thickness direction of the PZT sensor. As shown in Figure 1, the first pulse has a pair of a positive peak and a negative peak. There are two vertical solid lines in the figure; (1) the positive peak (compression) was definitely generated at the timing of a laser pulse impact and (2) the negative peak (rarefaction) could be generated by restoring. After about 2 μs corresponding to the propagation time of longitudinal wave along the thickness direction of 8 mm, the next sharp pulse appeared but the phase was inverted and the amplitude was attenuated. Subsequently the pulses appeared every about 2 μs with the phase inversion. Such a waveform as shown in Figure 1 is different from signal waveforms of PZT sensor read by a CSA in hypervelocity microparticle experiments, e.g., see [6].

As mentioned in the previous section, a current signal waveform is in the form of the time derivative of a charge signal waveform. The first pulse has a very fast rising time for the leading edge and subsequent pulses had the edge become slower. It can be considered that stress wave propagated through the PZT sensor to the other surface and was reflected at the free end with dispersing. There are only small variations between pulses in the waveform in Figure 1, but the electric charge indeed appeared on the surface of the PZT sensor.

It was found that a linear relation between the amplitudes of the first pulses of the signal waveforms and the laser pulse energies. Actually, the time profile of laser pulse shot (approximately rectangular pulse of about 7 ns duration) could not be determined because the response speed of the CVA is not sufficiently fast. The first-pulse amplitude is related to the impulsive force produced by laser shot. Impact by laser shot, however, is technically different from one by material collisions, so we have to prove in further studies with dust particle acceleration experiments.

Conceptual design of a large area dust detector using PZT sensor with CVA: As mentioned in the previous section, we demonstrated the possibility of PZT sensor with CVA within a certain definite range. From the viewpoint of practical use, the response speed of the CVA should be faster and we have to consider the digital electronics counting "duration time" of the pulse signal of the stress wave. Ultrahigh speed comparator is commercially available from several industrial companies, for example, ADCMP582 from Analog Devices whose equivalent input rise time bandwidth is 8 GHz. Therefore it can be affordable to count "duration time" of the pulse signal with the precision of 0.5 ns even in space.

Considering elastic approximation, the dust particle with a radius of about 0.5 μm generates the pulse duration of about 0.5 ns in current signal. From the viewpoint of hardware design, the lower limit of dust size measurement by PZT sensor with CVA can be 0.5 μm. According to Grün et al. [1985], the flux of interplanetary dust greater than 0.5 μm at 1 AU heliocentric distance is about 10-4 m-1 s-1 and thus it is expected that about 1700 dust impacts are obtained by a sensor with a detector area of 0.54 m2 that is the same area as ALADDIN. Detection area of a PZT sensor is limited by the input load capacitance of the amplifier for signal readout. Given the rated input load capacitance is 100 nF as the same as the CVA used in this study, the capacitance corresponds to a PZT sensor with a dimension of 120 mm × 120 mm × 2 mm. Then about 37 plates of PZT sensor are necessary to cover 0.54 m^2. If the CVA specification is improved by using a dedicated circuit, the rated input load capacitance can be larger. Thus, the detection area of PZT sensor may be larger and the number of PZT sensor may be reduced.

Perspective: The existing technology can realize the instrumentation for this conceptual design. We will fabricate a CVA using printed-circuit board for faster response and vacuum use. For further advancement, we will conduct dust acceleration experiment using the PZT sensor with the CVA using light gas guns and electrostatic accelerators.

References: [1] Grün et al. (2001) *In Interplanetary Dust* (Grün et al. eds.), pp. 385-444. [2] Divine, N., J GR, **98**, 17029-17048 (1993). [3] Dikarev, V. et al., ASR, **35**, 1282-1289 (2005) [4] Grün et al., Exp. Astron., **23**, 981-999 (2009) [5] Yano et al., AOGS PS02-A047 (2011) [6] Seidensticker et al. (2007) *Space Sci. Rev.* **128**, pp. 301-337. [6] Miyachi et al. (2005) *J. Appl. Phys.* **98**, 014110.

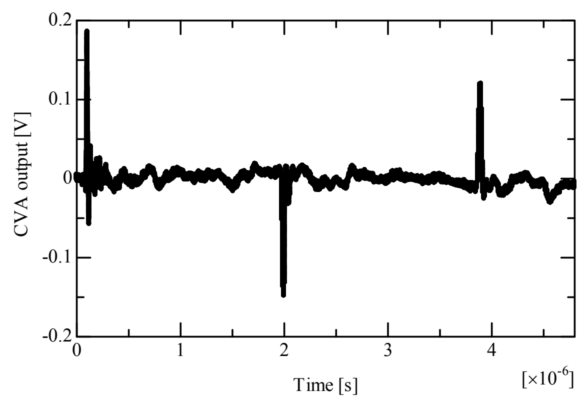

Figure 1 Example of typical waveform of the current signal of a 25.9 mJ laser pulse shot on the PZT sensor