Comparative Study of Impact Ionization Dust Detectors

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Abstract— The high velocity impact events have attracted more attention for the last two decades in the space research study. Hypervelocity study has reached to the level that impact velocity is achieved in several km/s for all materials. The collision of large objects like asteroids are a very few events but impacts of small dust particles, whose sizes are less than a micron are more frequent. These meteoroids may give the information regarding the solar system origin and evolution. A dedicated dust instrument can be useful to understand the physical properties of the micrometeorites or dust particles. In this paper we have presented a comparative study of different types of impact ionization dust detectors like metal plate dust detector, PVDF film based dust detector and a micro-channel plate dust detector.

Key words: CSA, PVDF, Dust Detectors

I. Introduction

Dust in the space may give researchers the idea of processes occurring in the galaxy and the solar system. The dust particles are produced by processes like high velocity impacts on airless bodies like the Earth's moon and external processes like the mutual collisions between asteroids. Space crafts are continually subjected to impacts by the micrometeorites and space scrap. Such impacts can provide an idea about the dust particles present in the upper atmospheres of any planet. High-velocity impacts result in ionization of the incoming particle and target material creating the plasma. We may also learn about the processes affected by the dust, as it travels everywhere in space.

II. Types of Impact Ionization Dust Detector

A few in-situ dust detectors have been developed over the last 50 years. Debris and micrometeorites in interplanetary space cover hypervelocity dust particles on spacecraft and satellites at velocity in the range of km/s. All of recent in-situ dust detectors onboard spacecraft follow an impact plasma detection method. There are mainly three types of impact ionization dust detectors:

1) Metal Target Dust Detector
2) Micro Channel Plate Detector
3) PVDF Film Based Dust Detector

A. Metal Target Dust Detector

Fig. 1: Metal plate dust detector [4]

It is a low weight impact ionization dust detector which can help derive mass and velocity of incoming dust particle with the help of time varying charge pulses.

When dust particle strikes on a metal coated target plate, plasma cloud is generated. This plasma cloud is separated into electrons and ions. Positive ions are collected by ion channel which is negatively biased and electrons are collected by electron channel which is positively biased. These impact charges are stored by both channels. There is a third channel, known as neutral channel which separates impact signals from the noise signals. All three channels basically use Charge Sensitive Amplifiers (CSAs). The CSA generates a peak output voltage from the generated charge signal. The output from the CSA is digitalized by an Analog-to-Digital Converter. The output of this detector gives a pulse which contains the information of rise time (t) and charge (Q). The rise time and charge are used to find the information of mass and velocity of particle by following equations [1].

$$t = k_1 v^{k_2} \quad (1)$$

$$\pm \frac{Q}{m} = k_3 v^{k_4} \quad (2)$$

where Q is peak charge, t is rise time of charge signal while k_1, k_2, k_3 and k_4 are constants which are determined from the calibration experiments. Velocity of dust particle is obtained from equation (1) and mass of dust particle is obtained from equation (2). Finally, the mass and velocity of dust particles may be achieved.

The Mars Dust Counter (MDC) onboard ISAS's spacecraft was a low weighted metal plate type impact ionization dust detector. MDC has detected around 100 dust particles during its cruise phase. The MDC could determine mass, velocity and direction of the dust particle from charge signal of impact-induced plasma [1, 4]. Most of the detected particles were interplanetary in nature [4]. From the total charge and rise time of the signal, the mass and velocity of detected particle can be obtained which may be compared with laboratory calibration data using Van de Graff dust accelerator. MDC can measure mass of particles between 5×10^{-15} and 10^{-10} g at 10 km/s impact speed [1].

B. Micro Channel Plate Detector

The Micro Channel Plate (MCP) is used for detection of particles like ions electrons, X-ray and ultraviolet radiation. MCP has many channels and each channel works as independent electron multiplier and hence it can provide good spatial resolution. Single particle enters into the channel and exports 2-3 electrons from the channel wall. These secondary electrons are accelerated by an electric field generated by the voltage applied at both ends of the MCP. They travel along their parabolic trajectories until they strike another channel surface which produces more secondary electrons. This process is repeated many times along the channel which provides a cloud of numerous electrons. If two or more MCPs are operated in series, a single input event will produce a pulse of 10^8 or more electrons at the output [6]

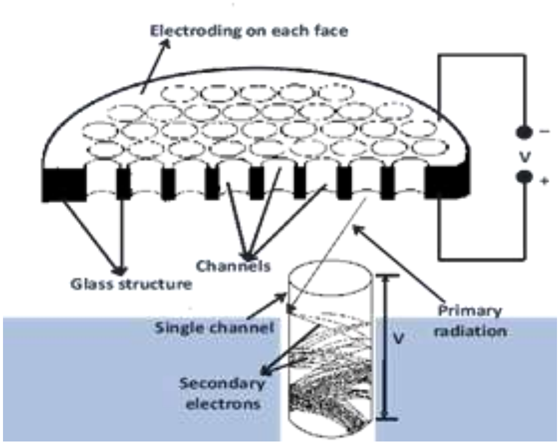

Fig. 2: Micro Channel Plate dust detector [6]

The LDEX was a micro channel plate type impact ionization dust detector onboard LADEE mission for the measurement of two types of dust sources, viz., the ejecta generation because of continuous bombardment on the moon by micrometeorites and the levitation of small dust particles from the lunar surface due to plasma induced electric fields [2]. LDEX measures the charges on target plate (Q_e) and the MCP plate (Q_I). Hence, the mass (m) and velocity (v) of dust particles may be derived. Calibration equations from MCP and the target stored impact charges are given by [2]

$$m = (9.74 \pm 0.07)\, Q_I v^{-4.76\pm0.15} \qquad (3)$$

$$m = (5.31 \pm 0.06)\, Q_e v^{-4.34\pm0.21} \qquad (4)$$

At the end of 2013, LDEX measured about 65000 MCP and target signal pairs [2].

C. *PVDF Film Based Dust Detector*

PVDF film based dust impact detectors have been utilized for some space crafts because of its radiation hardness and mechanical-thermal stability. The main purpose of this detector is to determine the mass of incoming dust particles by presuming the impact velocity and material density of interplanetary dust particles [5]. The dust detection is based on the use of polarized PVDF films. When a dust particle impacts on the detector, the depolarization charge signal is generated. This charge signal is processed using analog circuit and Analog-to-Digital Converter which generates a digital pulse and measures the amplitude of charge as well as the rise time. These parameters are used to obtain the mass and velocity of hypervelocity dust particles.

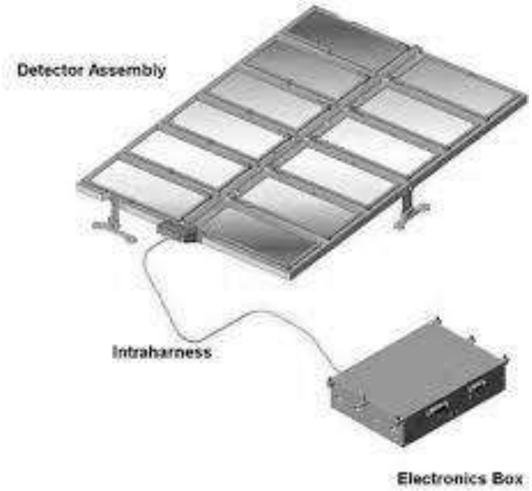

Fig. 3: PVDF film based dust detector [3]

The Student Dust Counter [3] was the first space instrument on the New Horizons mission to Kuiper Belt and Pluto to measure size distribution of dust particles across the solar system. The SDC is capable to measure dust particles outside 18 AU and it is expected to continue operating inside the Kuiper Belt. SDC is capable of detecting particles with mass greater than 10^{-12} g with total sensitive area of $0.1 m^2$ [3]. The average number of hits on the front end sensors was 19.7 ± 5.4, and on the reference sensors was 18.0 ± 4.2 during periods between 14 July and 15 August 2006 [3]. The difference of these data is taken to be real dust hits of 1.73 ± 6.9 during this period [3].

The comparison of various types of impact ionization dust detectors is shown in Table 1.

Detector Type	Mass of Detector (kg)	Aperture of Detector	Remarks
Metal Target	0.73	$12.4\times11.5 cm^2$	Simple, low cost ,easy handling, light weight
PVDF Film based	1.6	$45 \times 30 mm^2$	Simple, electrically & mechanically stable, no bias voltage, requires constant temperature
MCP	3.6	12.4 Dia.	High sensitivity, strong temporal variability

Table 1: Comparison of Impact Ionization Dust Detectors [1, 2, 3]

III. METAL TARGET IMPACT IONIZATION DUST DETECTOR

From Table 1, it may be observed that the metal target dust detector has some advantages, whose block diagram is shown in Figure 4.

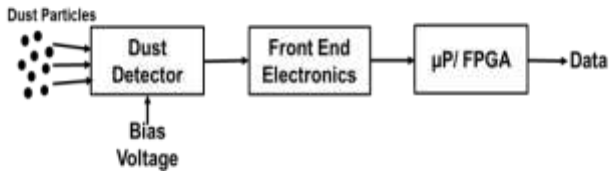

Fig. 4: Impact Ionization Dust Detector System

When dust particle strikes on a metal coated target plate in dust detector, impact plasma is generated. This impact plasma is a combination of electrons and ions. Positive ions are collected by ion channel which is negatively biased and electrons are collected by electron channel which is positively biased. These impact charges are processed using front end electronics and the µP/FPGA based back end electronics to obtain the information of rise time (t) and charge (Q) of detected dust particles, which are used to find the mass and velocity of incoming dust particles.

A. *Mechanical Design of Impact Ionization Dust Detector*

We have used PTC Creo parametric 3.0 software for simulating three dimensional design model of an impact ionization dust detector. A snapshot of the model is shown in Figure 5. Different layers of the detector are shown in Figure 5.

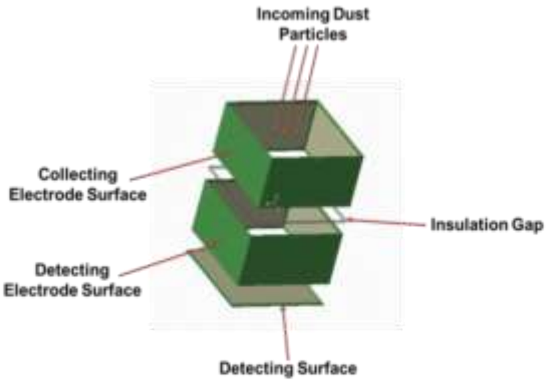

Fig. 5: Different layers of the detector

Initially, we had used Printed Circuit Board (PCB) plates for making a dummy detector as shown in Figure 6.

Fig. 6: Dummy Detector using PCB

The horizontal square plate of detector is basically a detecting plate and it is about 160×160 mm^2 in size. There are eight vertical rectangular plates of 160×85 mm^2 in size attached to in the detector. Out of these eight plates, four lower plates are also detecting plates and four upper plates are collecting plates. There is an insulation gap needed in between these four lower detecting plates and four upper collecting plates. For this insulation gap, we have used 5 mm size square Teflon ring between detecting and collecting plates. So they are not short circuited. There are two measurement angles of an impact ionization dust detector viz., collection angle and detection angle.

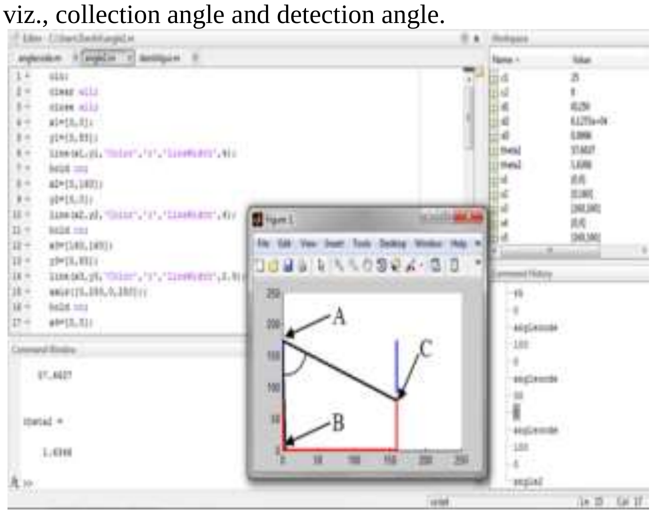

Fig. 7: Collection angle

Collection angle provides a maximum coverage region in which source of dust particles are collectable. The two dimensional view of detector is shown in Figure 7. Here point B is at distance of 5 mm on horizontal detecting plate and point C is at 80 mm on right side lower vertical detecting plate. These two points are fixed and the maximum source of dust particles is collected between these points. Point A is at 175 mm on left side upper vertical collecting plate. This is a least position at which dust particles enter into the detector. The angle between line AB and AC is known as collection angle. As shown in Figure 7, the collection angle is 57.6637°.

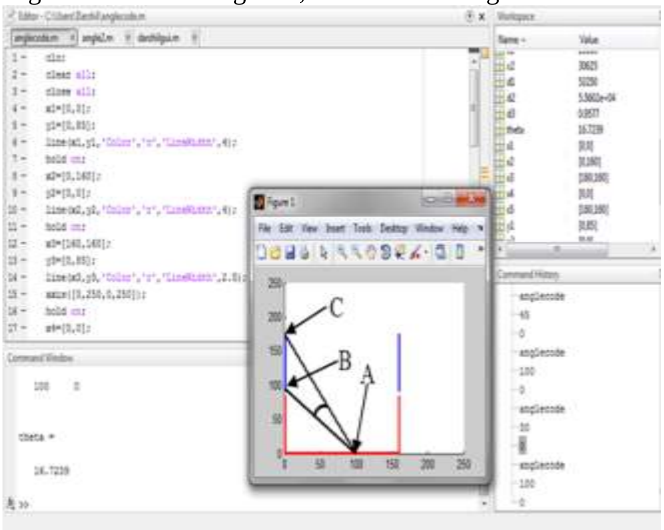

Fig. 8: Detection angle

The detection angle is the angle of particle detected on target plate. Consider two points B and C as shown in Figure 8. Point B is at distance of 95 mm and point C is at distance of 175 mm on left side upper vertical collecting plate. These two points are fixed when a dust particle enters into the detector. Suppose point A is anywhere in horizontal detecting plate where dust particle strikes. Let, point A is at 100 mm. Then angle between line AB and AC is known as detection angle. As shown in Figure 8, the detection angle is 16.7239°.

IV. SUMMARY

In this article, we have presented a comparative study about different types of impact ionization dust detectors such as metal plate type PVDF film based and micro-channel plate type dust detector. From all these three types of dust detectors, the metal plate dust detector has superior performance over other types of detectors because of simplicity, ease of handling, low cost operation and light weight. Also, we have simulated three dimensional design model of impact ionization dust detector. Further work for the development of a prototype dust detector is underway.

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