B12

ポリイミドフィルムと圧電素子を利用した大面積微小デブリセンサーの開発

Micro-debris sensor with large sensitive area utilizing polyimide film and piezoelectric elements

小林正規，奥平修，石丸亮，平井隆之（千葉工大）
Masanori Kobayashi, Osamu Okudaira, Ryo Ishimaru and Takayuki Hirai
(Chiba Institute of Technology)

0.1～数ミリサイズの微小デブリは、宇宙機に対する甚大な衝突被害を生じさせる可能性があるにも関わらず、計測データが限られているため、軌道上の分布の情報は精度が高いものと言えない。特にこの範囲のサイズのデブリは、センチ?数メートルサイズのデブリに比べて数が急速に増加していくことが分かっていて、その軌道上の分布状況を示す計測データの取得が、宇宙機のデブリ衝突リスクの評価やモデル開発にとっての課題であるということが国際的に共通の認識となっている。我々は大きな検出面積（>1m2）を持つ軽量なポリイミド膜と圧電素子を利用した微小デブリセンサーの研究開発を行っている．このセンサーは，ポリイミドフィルムに圧電素子をピックアップセンサーとして貼りつけて，ダストが超高速でフィルムに衝突して発生する固体中の弾性波をその圧電素子で読み取る方法でマイクロデブリセンサーを実現しようとしている．本講演ではそのセンサーの詳細と開発状況について紹介する。

Although micro debris of 0.1 to several millimeters in size may cause serious collision damage to the spacecraft, the measurement data of orbital distribution of such micro debris are limited in availability. Particularly, it is known that the number of micro debris in the size range increases rapidly as compared with debris of centimeter to several meters in size. For evaluating debris collision risk of spacecraft, it is common knowledge that the precise measurement of the micro debris is a problem to be solved.
We conduct research and development regarding a micro debris sensor with a large detection area (> 1 m2) utilizing a lightweight polyimide film and piezoelectric elements. We attempt to realize a micro debris sensor by attaching piezoelectric elements as pickup sensors onto a polyimide film, in which the pickup sensors read acoustic signals generated by collision of micro debris on the film.
In this presentation we introduce the sensor and report the current status of the development.

Micro-debris sensor with large sensitive area utilizing polyimide film and piezoelectric elements

Masanori Kobayashi, Osamu Okudaira, Ryo Ishimaru, Takayuki Hirai

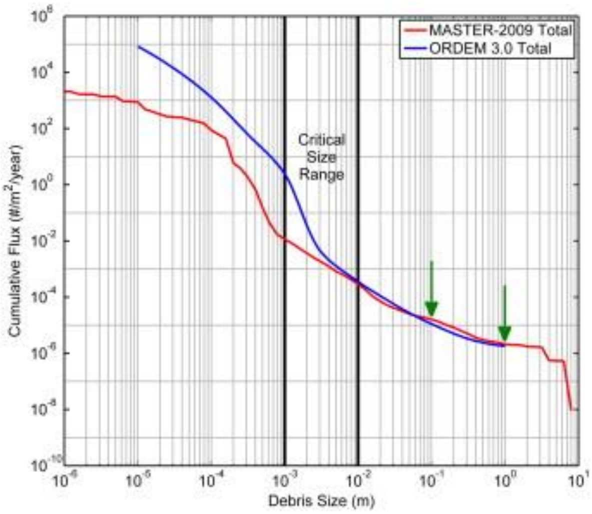
Planetary Exploration Research Center
Chiba Institute of Technology

8th JAXA Space Debris Workshop
JAXA Chofu Aerospace Center, December 3 – 5, 2018

Observational data gap in the range of 100μm to 1cm which has damage risk on S/C

- Micro-debris particles (100μm to 1mm in size) may cause damage on spacecraft partly, while one of 1cm may cause serious damages on entire spacecraft system
- Over 10cm sized debris in orbit are tracked regularly by ground stations and maintained in catalogue while micro-debris particle (100um to 1cm) has lack of observational data due to difficulty of observation
  - Optical and radar observations from ground are not useful to survey micro debris particles with the size of 100μm to 1cm
  - With traditional dust/micro-debris particle sensors, the sensitivity is too low because the spatial density of the micro-debris is too low

Large sensitive are necessary for micro-debris particle surveillance



From Fig. 4. ORDEM 3.0 and MASTER-2009 orbital debris fluxes for the SSO orbit in 2014 in Krisko et al. Acta Astronautica in 2015.

- There are two major space models; ORDEM and MASTER, however, there are big discrepancy between their fluxes for micro-debris particle in 100µm to 1cm
- Validation (or benchmarking) of orbital debris model are limited due to low statistics of measurement data
- The sensor should have a sensitive area of $1m^2$ or larger for the realistic observation time in orbit.

Requirement to micro-debris particle sensor

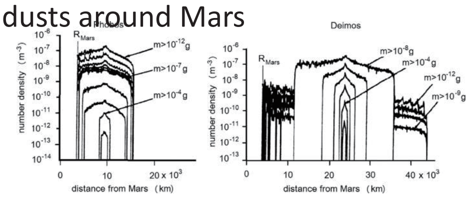
- The sensor shall have a large sensitive area of > $1m^2$
- (Such large sensitive area sensor is likely to be large in volume and weighty,) the sensor shall have low mass
- The sensor shall have an ability of true-false judgment of detected signals (to be reliable sensor)

For the purpose, we have a suggestion for the sensor with a large sensitive area of > $1m^2$ which we are developing for the other purpose

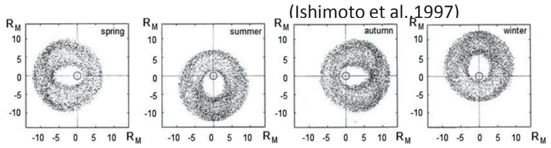
The details will be shown in the following slides

By the way, Martian Dust Rings….
We develop a sensor for the purpose

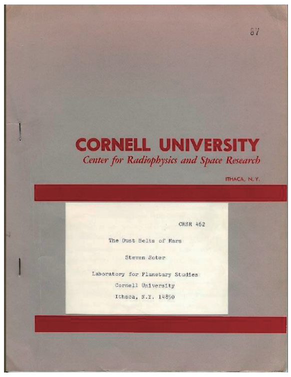
Martian Dust Ring: Previous theoretical studies on dusts around Mars



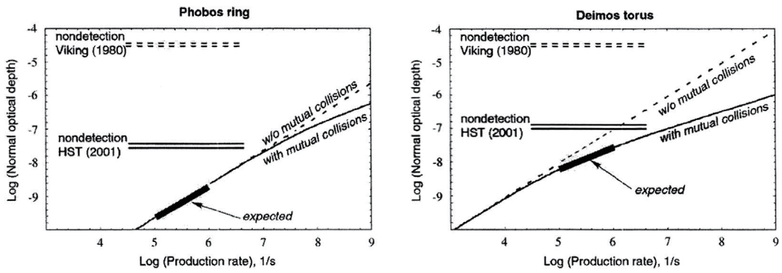
(Ishimoto et al.,1997)



Krivov and Hamilton (1997)



Soter, PhD Thesis in 1971



(Krivov et al.,2006)

Previous observational studies on dusts around Mars: Optical observation

Optical observation in the past missions:

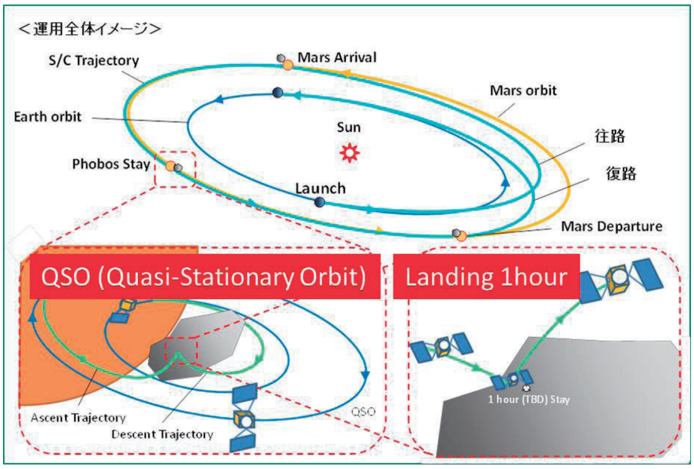
- Imagery analysis by Viking1, Duxbury and Ocampo (1988),
- Imagery analysis by HST, Showalter et al. 2006

Current theoretical prediction shows the spatial density of dust belt particles according to Krivov and Hamilton (1997)

- 6×10^{-6} [particles/m^2] for > 30μm-sized dust, for Phobos
- 9×10^{-5} [particles/m^2] for > 15μm-sized dust, for Deimos

The sensor for Martian Dust Ring can be used for in-situ micro-debris observation

MMX, Martian Moons Explorer



Launch Mass : 3000kg

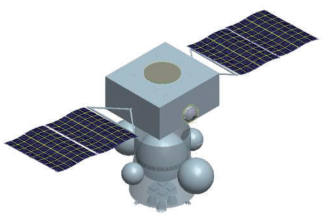
Three stages system.

Return module: 1050kg

Exploration module: 150kg

Propulsion module: 1800kg

Mission Duration : 5 years



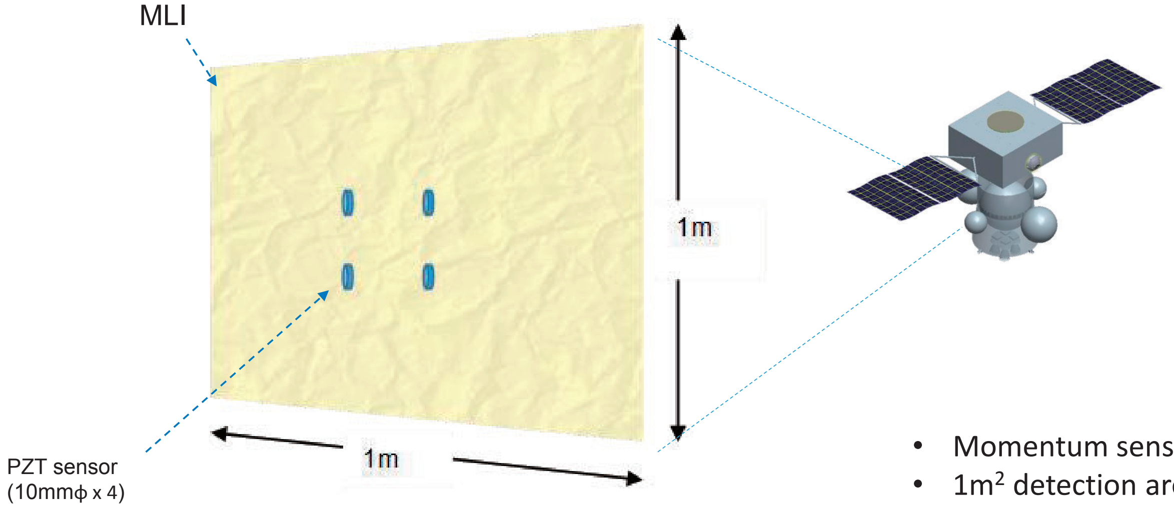
Time frame of MMX

Launch	Aug, 2024
Mars Arrival	July, 2025
Mars Departure	May, 2028
Earth Arrival	April, 2029

In-situ Dust Measurement to discover Martian Dust Ring: the requirement to the sensor hardware is very similar to one for **micro-debris**

- **Low resource requirement (simple dust sensor needed)**
  - This is a dust mission for undiscovered objects, the agency basically does not want to invest much resources; mass, volume, power, data downlink and also financial cost for development.
- **Large sensitive area needed**
  - The spatial density of the ring dust particles are theoretically predicted, however, dust density will not be sure until discovery. We may find the enhancement in dust flux from the background level of interplanetary dust particle flux.
- **Other type of dust sensor than impact ionization**
  - Impact speed to the spacecraft in orbit around Mars is < 0.68 km/s for Phobos ring and < 0.82 km/s for Deimos ring, the dust sensor shall be sensitive to such low speed impact as less than 1 km/s. Impact Ionization detection does not work.

Circum-Martian Dust Monitor (CMDM) being developed for Martina Dust Rings, and can be useful for micro-debris surveillance



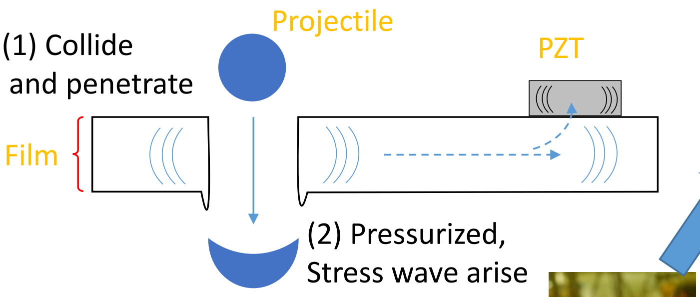
- Some small pieces of piezoelectric sensors put on the top layer of MLI made of polyimide film.
- The piezoelectric sensors detect elastic wave induced by dust impact on the polyimide film.

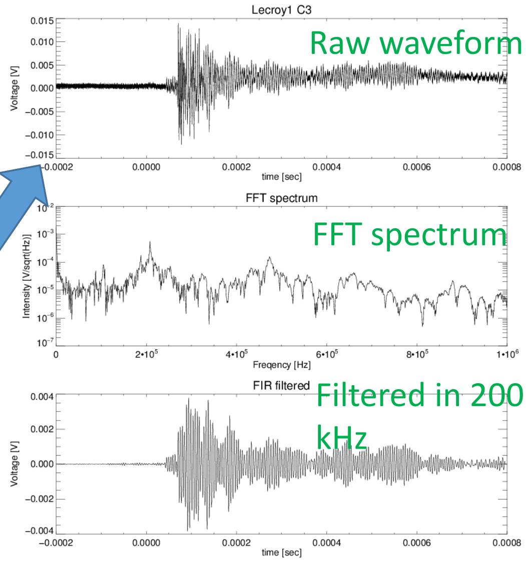
Sensitive area can be expanded by putting more piezoelectric sensor

- Momentum sensor.
- $1m^2$ detection area is needed, to find the enhancement in dust flux from the surrounding environment (interplanetary dust)

Measurement principle is established by experiment

Penetration measurement by detecting impact acoustic emission wave

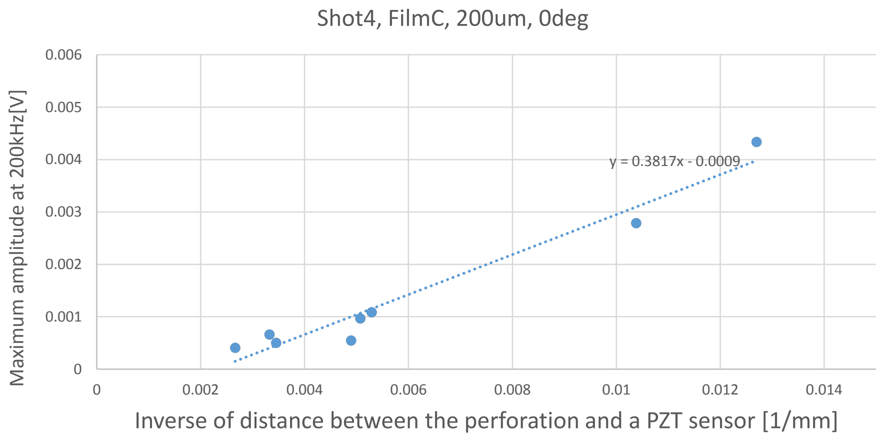




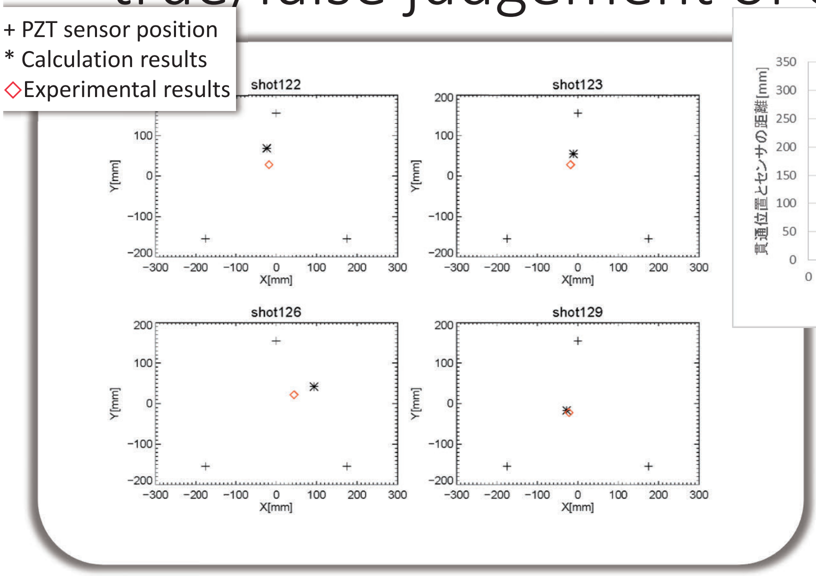
- Light gas gun experiment in JAXA
- 330µm, Almina (@30cm), 5.20 km/s
- Target is 25µm thick polyimide
- No amplifier used.

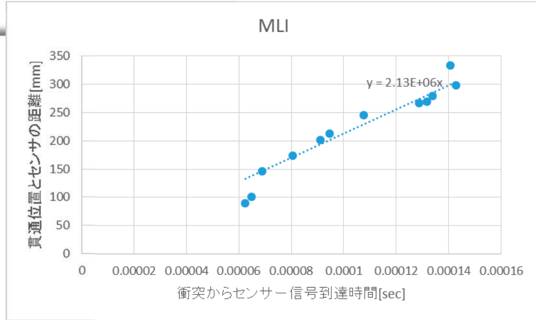
Actual signal from the dust ring particle impact may be smaller by a factor of 1000.

Signal level is inversely proportion to propagation distance



Penetration positioning is useful for true/false judgement of event





- wave speed in the film is about 2.1 km/s.
- Time-difference-of-arrival algorithm can derive source position of the stress waves from arrival times of stress wave signals at three different location.

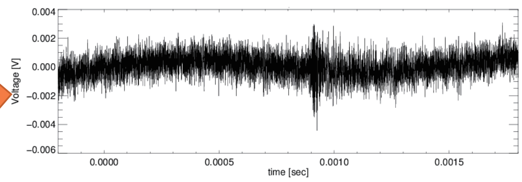
Results of positioning perforation.
Estimation accuracy is about 1 cm.

Positioning resolution is poor but still available to verify that the signal event is caused by dust impact (**true/false judgement**).

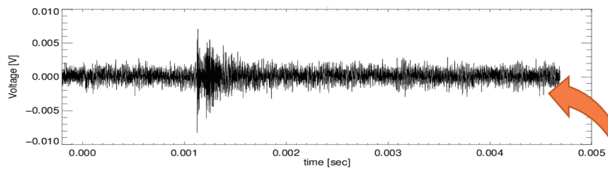
Even smaller dust particles are detectable.

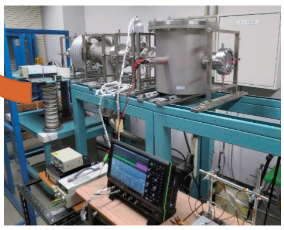
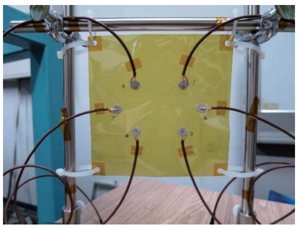
Tiny dust particle measurement with an amplifier using dust accelerators

1.0µm (Ag, 43 pg), 400m/s, at 4.5cm

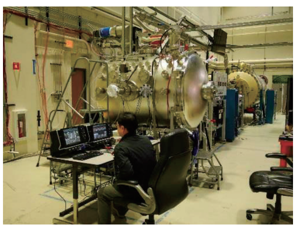
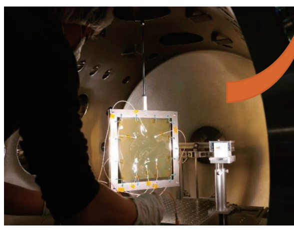


1.7µm (Fe, 166 pg), 1.66km/s, at 7.0cm



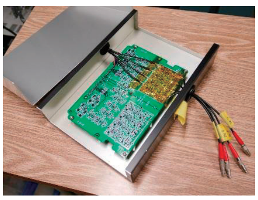



Osaka University, 100kV dust accelerator

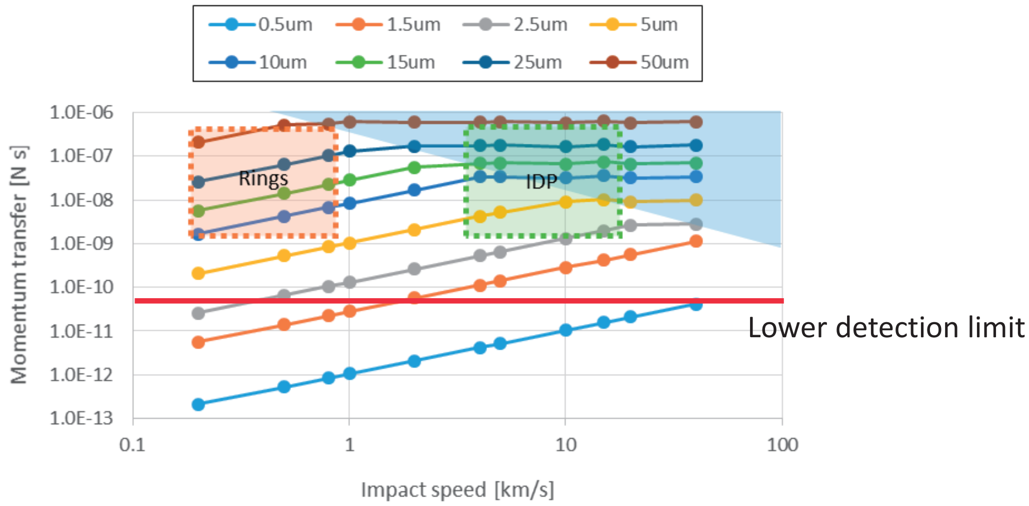



Colorado University, 3MV dust accelerator

- With the knowledges from light gas gun experiments, breadboard model of amplifier is made up.

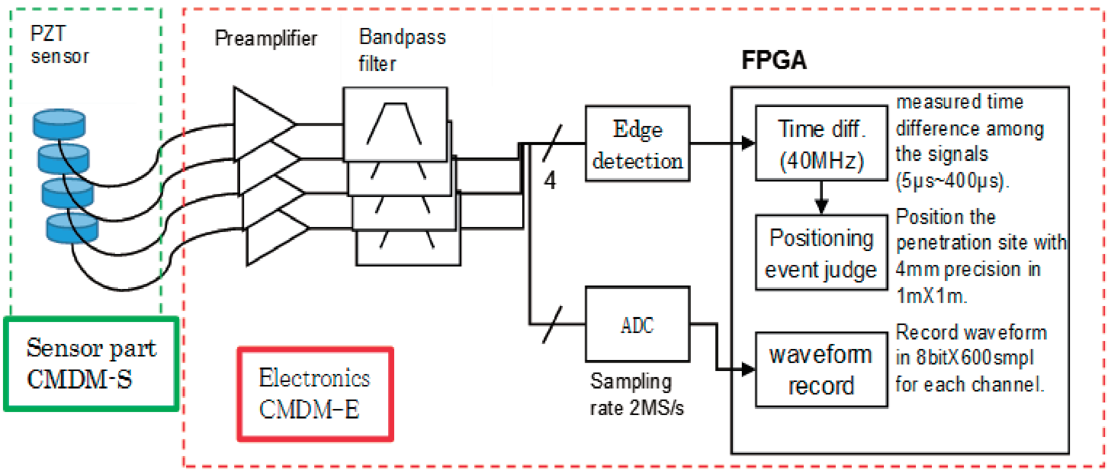


Signal levels of the impact acoustic emission sensor derived from experiments



- Signal level corresponding to momentum transfer, 6.1×10^{-11}[Ns] is detectable at the propagation distance of 50cm.
- Momentum transfer from the dust ring particles is > 7.2×10^{-9} [Ns].

Simple and compact electronics



- Electronics has no technological challenge
- Electronics can be compact like CUBESAT 1 U volume
- Signal detection rate should be low even if including noise event, telemetry is low as HK

Resource requirements

Item		value
Mass	Sensor	0.05 kg
	Electronics	0.65 kg
	Harness	TBD
Power	Standby	< 2W
	Operation	< 3W
Size	Sensor (PZT)	10mmφ×2mm×4pcs.
	Electronics	200mm×120mm×40mm
	Harness	TBD

Technological feasibility in space

Parts and materials for the dust sensor should have sufficient tolerance to harsh space tolerance (which are placed on the outer layer)

- Thermal tolerance
  - PZT sensor has very wide range of operational temperature, -196 ^{o}C to +170 ^{o}C.
  - There are some space products of glue available in such wide temperature range. Those products will be evaluated in terms of sensor performance.
- Radiation tolerance
  - Piezoelectricity of the PZT sensor is not significantly deteriorated by radiation.
  - There are some space products of glue available in high radiation field. Those products will be evaluated in terms of sensor performance.

Glue for adhesive bonding of PZT sensor on MLI might be key issue.

Summary

- Large sensitive area sensor for dust particles which is developed for Martian Dust Rings can be used for in-situ micro-debris particle (100μm to 1cm) in orbit
- The sensor configuration is very simple and the expansion of the detection area is very easy by increasing the number of piezoelectric sensors for signal pick up
- Other than the footprint of the sensor, the sensor system has low resource requirement; low weight and small volume, low power, low telemetry

17

Please find more details in

Planetary and Space Science 156 (2018) 41–46

ELSEVIER

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

In situ observations of dust particles in Martian dust belts using a large-sensitive-area dust sensor

Masanori Kobayashi [a,*], Harald Krüger [b], Hiroki Senshu [a], Koji Wada [a], Osamu Okudaira [a], Sho Sasaki [c], Hiroshi Kimura [a,d]

[a] *Planetary Exploration Research Center, Chiba Institute of Technology, 2-17-1 Tsudanuma, Narashino, 275-0016, Japan*
[b] *Max-Planck-Institut für Sonnensystemforschung, Justus-von-Liebig-Weg 3, D-37077 Göttingen, Germany*
[c] *Graduate School of Science, Osaka University, 1-1 Kaneyama-cho, Toyonaka, 560-0043, Japan*
[d] *Graduate School of Science, Kobe University, 1-1 Rokodai-cho, Nada-ku, Kobe, 657-8501, Japan*

Now you can download it for free! (before July 07, 2018)

Thank you!!