SODAD : FIRST RESULTS AND POST-FLIGHT ANALYSIS

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ABSTRACT

Micrometeoroids and orbital debris (M&D) are an important parameter of the space environment. High velocity interaction with spacecraft's could be of serious concern for the operation of long-lived space structures and for man operations in space.

Since the beginning of space exploration, dedicated experiments designed to sample the low Earth orbit orbital debris and meteoroid environment have been deployed in space.

During the STS-122 mission an experiment package, MEDET, deployed on the EuTeF platform, has been exposed on the Columbus module attached to the ISS. One of the experiments, SODAD, was devoted to the detection of micrometeoroid and space debris. The capacitor type sensors allows the detection of particles larger than 0.5-1 µm in diameter. The behaviour of the experiment was nearly nominal and impact flux data recorded are compared with pre-flight modelling done with current flux models. Preliminary analysis shows that the data are consistent with pre-flight predictions. However the impacts appears to be not random and could be associated with peculiar events. Furthermore, retrieval of the experiment is planned during the next STS-128 shuttle mission, in August 2009. It will be then possible to compare data obtained in-flight and data derived from the observation of impact craters, in the laboratory.

1. SCIENTIFIC OBJECTIVES

There is a growing need for a better knowledge of the solid particle environment in low earth obits. This is crucial for the design and the survival of space missions especially when human security is concerned. Indeed , surface damage resulting from the impact of small particles (less than 1 mm) which separately is not lethal for a spacecraft, may become one of the major concern for sensitive devices used in space. During the recent years, several spacecraft missions have flown sensors devoted to the monitoring of this special environment [1,2]. However most of the detectors consisted of passive surfaces, retrieved after their exposure to space. Moreover, a few active experiment did indicate a non-random distribution of particles, in space and in time [3]. It will be possible with active sensors to get a better understanding of the evolution of clouds of particles and to improve the current modelling.

During the STS-122 mission, launched on February 7, 2008 an experiment package , MEDET, has been exposed on the ESA Colombus module attached to the ISS. The aim of the MEDET experiments was primarily the study of the degradation of materials caused by the space environment

One of the experiments, SODAD, was devoted to the detection of small micrometeoroid and space debris. In addition to these dedicated active particle detectors, a wealth of information will be gained after the planned retrieval of the MEDET hardware. Laboratory analysis not only will give information on the environment, by possible analysis of particles remnants but also will provide a better knowledge of the hypervelocity impact phenomena on materials exposed to space. It will be also possible to improve the calibration of the sensors obtained before flight.

Small samples of aerogel have been also exposed on the payload. It is thus anticipated to retrieve particle remnants to identify their origin.

2. IMPACT CAPACITOR DETECTORS

2.1 MOS sensors The MOS sensors have been made by ONERA and CNES according to an original design developed earlier by NASA, for use on LDEF and on MTS satellites [4,5]. They are based upon the monitoring of the discharge of a parallel-plate capacitor using a thin dielectric.

The top electrode is made very thin and this surface is exposed to the impacting particles. The device is operated with an electrical potential (bias) applied across the capacitor plates : a charge is normally stored in the capacitor. When a high velocity particle impacts the exposed plate with enough energy, it can cause the dielectric to breakdown and results in a discharge of the capacitor. The event is measured by monitoring the charge required to recharge the capacitor. After discharge the sensor is recharged to the nominal value within a short time. Evaporation of the electrode around the impact site usually prevent the occurrence of a permanent short. The sensitivity of the sensor depends mainly on the dielectric thickness, the top electrode material and thickness and the bias voltage, and also on the velocity of impacting particle. The device is best suited to the detection of particles with diameter ranging from 0.5 µm to 100 µm.

2.2. Design.

The technology used to make the detectors is based on the technology used in the manufacture of microelectronics devices and pioneered by J.J. Wortmann [4]. Prototypes and flight units were made at LAAS, a Laboratory from the CNRS in Toulouse [6].

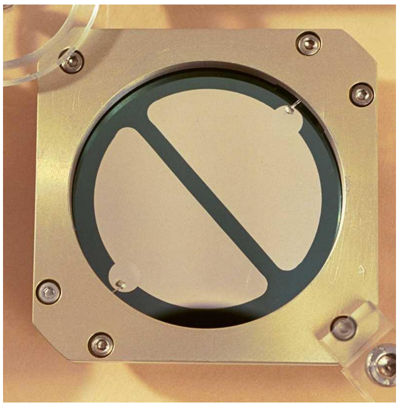

Figure 1 : MOS capacitor sensor

The substrate of the detectors consisted of silicon wafers, 2 in. in diameter, and polished on one side by mechanical and electropolishing. The silicon wafers were p-type with resistivities less than 0.01 ohm.cm. In order to form the capacitor, a layer of oxide was grown on one face of the wafer, by thermal oxidation. A thin layer of aluminium was then vapour deposited on each face to form the top electrode and electrical contact to the silicon wafer. Two dielectric thickness were investigated : 1.4 µm and 1.0 µm, a thickness of 0.1 µm was used for Al top and bottom electrodes. (Fig. 1 and Fig.. 2)

After fabrication the detectors were tested electrically to measure the internal leakage of the capacitor and to clear eventual defects. The maximum voltage that the capacitor can withstand depends on the dielectric strength of the silicon oxide (about 10 MV/cm) . The bias voltage is chosen accordingly; typical values are 40 volts for 1 µm dielectric and 50 volts for 1.4 µm dielectric.

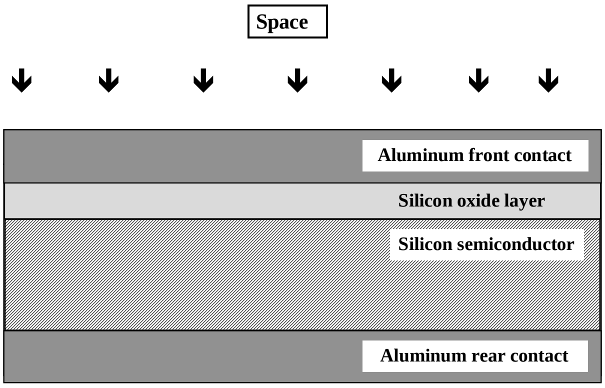

Figure 2 : Cross section of MOS sensor

Current flight design uses four individual sensors with an active area of 40.8 cm^2 , integrated in a self-contained unit, 120x120x90 mm (Fig. 3). The thickness of the dielectric is 1.4 µm. Each detector is divided into 2 sectors in order to avoid the loss of all the detector in case of permanent short-circuit.

2.3. Electronics.

The electronic board of the detectors has been developed by “ STEEL Electronics” for CNES. It consists of a voltage doubler providing the bias for the detector and of the circuits necessary to the detection of the discharge events and to the monitoring of the detector status. Detection threshold is set at 95 % of the 50 volt bias voltage. In the event of permanent short of the sensor, the measurement is automatically stopped if the leakage current is higher than 1100 µA. The signal of discharge is digitised into 16 points, for an event duration of 1 µs t 6 µs, thus allowing to monitor the shape of the pulse. Minimum time between 2 events is set to 100 ms. For each impact, the date is provided by the S/C. The experiment is self functional and only two links are necessary to communicate with MEDET (BNR and TM/TC).

2.4 Calibration

The sensors have been tested and calibrated with micro-particle accelerators during their development. For small particles (0.5 –3 µm) the electrostatic accelerator of the Max Planck Institute for Nuclear Physics in Heidelberg [7] has been used. For larger particles (50-100 µm) the gas drag accelerator from the Technical Uuniversity of Munich has been used [8}.

For a dielectric thickness of 1.4 µm it was established that the sensitivity threshold was 1.5 µm diameter particle at a velocity of 3.5 km/s and a 0.5 µm particle at 7 km/s.

Some typical signal of discharges are shown on the Figure 3.

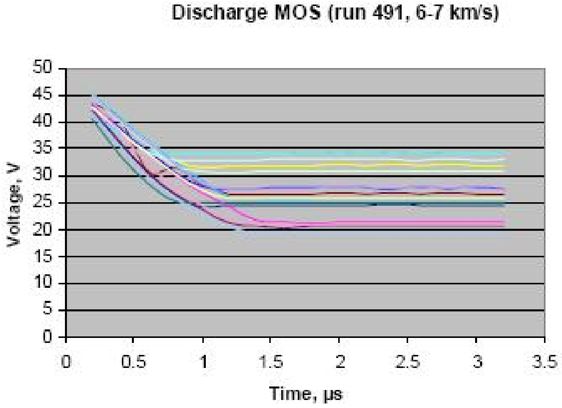

Figure 3. Typical signal of discharge of MOS sensor, obtained during calibration tests.

3. THE SODAD EXPERIMENT

EuTeF payload was exposed to space on February 7, 2008. The MEDET experiment package was deployed on February 15, 2008 and powered on February 22, 2008. The in-flght configuration is shown on Fig. 4.

Due to operational constraints power was interrupted from time to time, consequently the actual measuring time was only 85 % of the expected measuring time. The experiment was oriented most of the time in the direction of the velocity vector of the station, thus maximizing the detection of orbital debris, however the orientation is changing frequently during short period of time. The precise history of experiment orientation with respect to the RAM direction is not yet fully determined. Complete data will be available later.

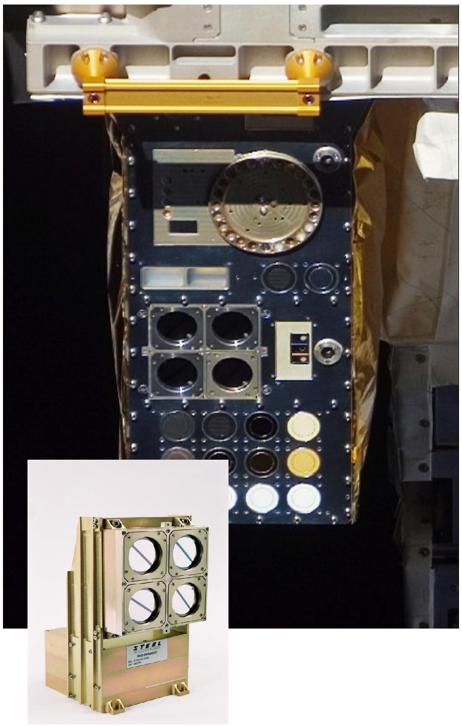

Figure 4. MEDET experiment on EuTeF, after deployment outside the ISS.

Insert shows a close-up view of SODAD detector.

3.1 In flight data

Data from the telemetry provide: date of impact event, identification of the sensor, electrical status of the different sectors (early in the exposure one sector on detector 2 was disabled), profile of the signal of discharge.

During the exposure of SODAD, 10 documented impacts have been measured up to May 26, 2009. Preliminary analysis of the data shows that the measured flux of microparticles is consistent with pre-flight estimate using the MASTER meteoroid and debris model. However it appears that the distribution of the impacts in time is not random (this was already noticed by measurements done on LDEF and on the MIR station) [3].

The shape and the amplitude of the discharge are shown on Fig. 5 . They are similar to the type of signal obtained during the calibration tests. Further investigation of the amplitude of the signal and comparison with laboratory data would give more information on the kinetic energy of the particles.

The maximum amplitude of the discharge is obtained within 1- 2 µs.

Observation of impact features, after retrieval, would provide more information on impact parameters, and possibly aid to iscriminate between micrometeoroids and orbital debris.

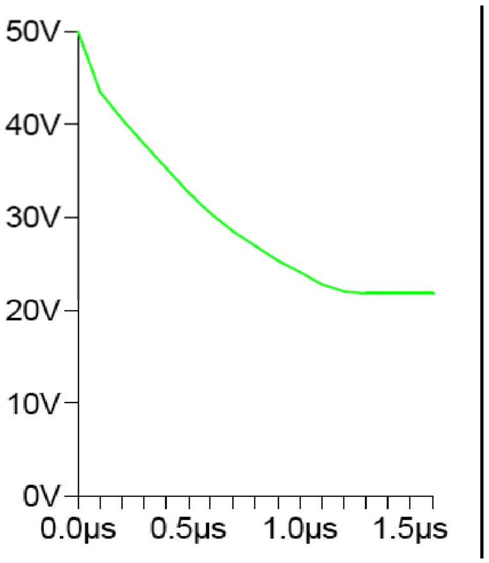

Figure 5. An example of discharge signal as recorded in flight.

The first event has been recorded 2 months after deployment, two events have been recorded in July and August 2008, possibly in relation with meteor streams. The impact rate increased in January 2009 and significantly in February 2009, when 3 events have been recorded on the 24 of this month. These 3 impacts could be related to the collision between Kosmos 2251 and Irridium 33 satellites that occurred on February 10, 2009. When data on the position and attitude of the ISS at the time of impact will be available a more precise analysis will be possible.

Taking into account for the 10 impacts an active area of 36 cm2 and an effective exposure time of 386 days, the average flux for 1 µm diameter particles is 2626 impacts/m^2/year.

3.2 Comparaison with models

It is possible to compare these preliminary data with the values given by the MASTER 2005 model: on the Fig. the flux, for a 1 µm particle, given for a randomly tumbling plate (RTP) at the orbit of the ISS is 1000 impact/m^2/yr; or a surface oriented in the Ram direction it is 2500 impact/m^2/yr. The second value is close to the one given in the last section for SODAD: 2626 impacts/m^2/year/

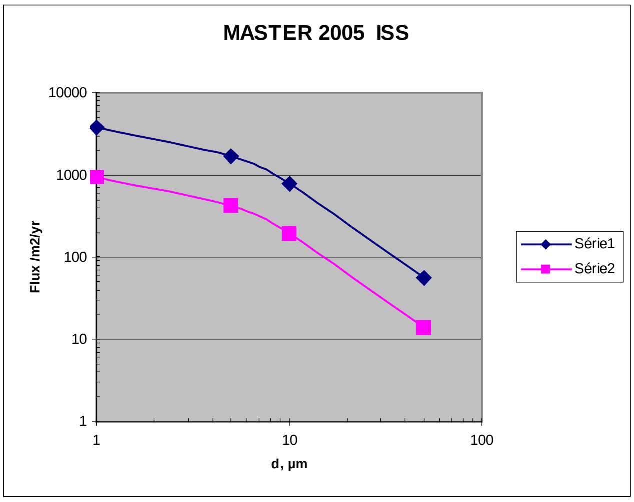

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Figure 6. Flux of particles (meteoroid and orbital debris) at the orbit of the ISS, as given by the MASTER 2005 model (squares RTP, diamonds plate oriented in the Ram direction).

Comparison of flux values derived from passive experiments (LDEF) or material retrieved from space (HST and MIR solar arrays) [13,14] is also possible: the flux of 1 µm particles (producing 10 µm diameter crater on glass surfaces) is about 2500 impacts/m2/yr, as shown on the Fig. 7

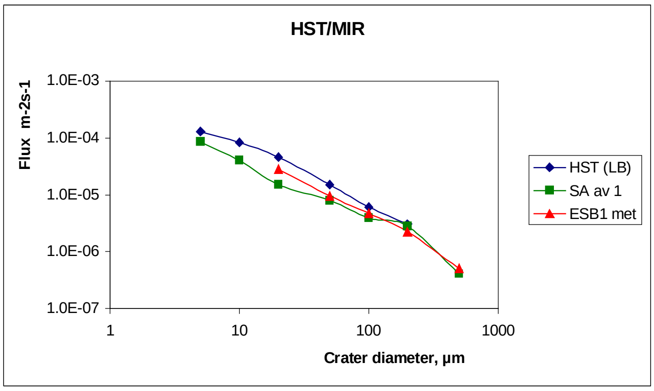

Figure 7. Crater size distribution on HST and MIR solar arrays .

3.3 Constraints

The use of the MOS sensors on the ISS was very valuable by the possible retrieval of the experiment after exposure to space. Further sensor development will greatly benefit from this possibility. However, implementation of experiments on the ISS implies some operational constraints : the orientation of the station and sensors with respect to the velocity vector changes many times. The experiment is shut down during some critical operational phases such as docking of shuttles or soyouz spacecraft. During some operational configurations the experiment was also shut down for several days due to temperatures lower than – 20°C.

3.4 Retrieval after exposure to space

Retrieval of the payload is expected during STS-128 mission. It will be then possible to search for a correlation between impacts registered by the active sensors and the number of impact craters observed on the surface of the MOS detectors. The observation will be compared with the results obtained during the calibration tests with particle accelerators. In peculiar the diameter and the depth of the impact craters will provide valuable data on the particles [9]. With an chemical analysis (EDX) detector attached to a scanning electron microscope it will be possible to make a chemical analysis of any projectile remnants present in the impact crater, in order to identify the origin of impacting micrometeoroids or orbital debris [10].

In addition, a complete survey of the other MEDET experiment surfaces will provide additional data. MLI as shown on previous analysis is likely to provide valuable information on particle composition [13,14].

3.5 Possible improvements

As the MOS sensors are mainly threshold sensitive, future implementation in space would benefit of the use of several dielectric thickness in order to increase the accuracy of mass determination. The sensitive area should be increased either by changing the shape of the sensors or increase their area. Determination of the velocity of particles is not easy with the present configuration (although some information can be derived from the discharge time); a possible improvement would require a two stage detector. A possible solution could be the use of an optical fence in front of the MOS sensors as proposed in Ref. [11].

3. CONCLUSIONS

MOS capacitor detectors have been exposed for more than 15 months outside the ISS (ESA Columbus experiment module). Behaviour of the device was nearly nominal and dust particles larger than 1 µm have been detected. Total flux (meteoroid and orbital debris) measured on the Ram direction is consistent with current modelling as given by MASTER 2005 environment tool., namely close to 2600 impacts/m^2/year. Experiment will benefit of the retrieval of the EuTeF platform upon the STS-128 mission. Analysis of the exposed material in the laboratory will significantly enhance the scientific return of the experiment. Possible discrimination between natural particles and orbital debris will be possible by the chemical analysis of projectile remnants. Future use of similar detectors will benefit from the post-flight expertise and possible improvement will be implemented if needed.

5. REFERENCES

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