Research Activities about Spacecraft Materials

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ABSTRACT

Space environment effects on materials are very severe and complex because orbital environments include influential factors such as high-energy radiation particles, atomic oxygen (AO), ultra violet (UV) radiation and micron size particles (space debris, etc.). Furthermore, surface degradation associated with contamination can negatively impact optics performance. The space environment and data related to its effects are therefore extremely important for spacecraft design. One approach to solving this problem is ground-based evaluation of materials. Ground simulation technology is therefore a key technology for space exploration. Moreover, materials that have high tolerance against the space environment have been developed. In this paper, these research activities in the Space Materials Section, Electronic Device and Materials Group of JAXA are summarized.

1. Introduction

Our mission is to establish fundamental technologies and enhance the reliability and performance of materials for spacecraft. Therefore we support projects concerning space materials.

For the mission, we have evaluated materials on the ground in the spacecraft design phase. We provide the material data at the end of life of the spacecraft. Thus it is important to simulate the space environment. We also have proceeded with a space exposure experiment for to demonstrate space materials and enhance the ground evaluation test technology.

In this paper, research activities concerning space material evaluation are summarized. First, we describe the specification of ground simulation test facilities and a research activity where they are used. Next, an example of development of materials with high tolerance against the space environment is presented. Activities related to spacecraft material exposure experiments are described in the following section. In addition, the group also treats the safety of space materials and equipment used in manned space systems. The associated research activities are also introduced in this paper.

2. Ground simulation technology

2.1 Combined Space Effects Test Facility

We utilized the Combined Space Effects Test Facility, which accommodates the irradiation of independent or coincidental electron beams, vacuum ultraviolet (VUV) rays, and atomic oxygen. The equipment specifications are presented in Table 2-1 [1].

Table 2-1 Specifications

Equipment	Specification
Irradiation Chamber	Inner volume: 250 l Ultimate Pressure: 10^{-7} Pa (Under AO irradiation: 10^{-3}–10^{-2} Pa) Temperature control: -150–100°C Standard test sample: 25 mm ϕ × 3 mm thickness MAX up to 18 pieces
EB Irradiation Facility	Accelerating voltage: 100–500 kV Current: 2–20 mA
AO Irradiation Facility	Type: Laser detonation AO velocity: ca. 8 km/s AO fluence: ca. 5 × 10^{16} atoms/ cm^2 s
VUV Irradiation Facility	VUV source: 30 W VUV lamp × 48 pieces Spectrum: 115–400 nm

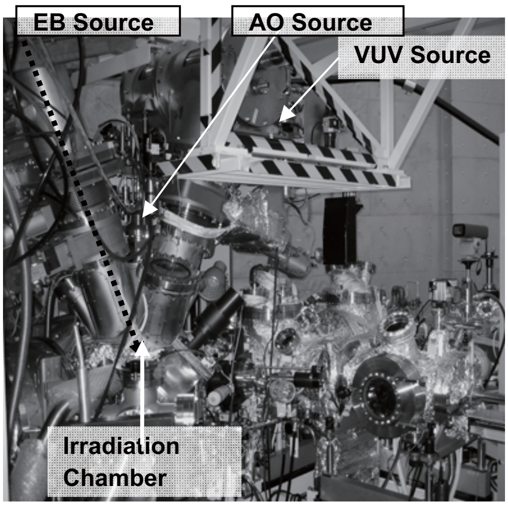

Fig. 2-1 Combined space effects test facility [1]

The visual appearance of the Combined Space Effects Test Facility is portrayed in Fig. 2-1.

Surface topographies of AO-irradiated polyimide films at 1.30 x 10^{21} atoms/cm^2 are shown in Fig. 2-2. The sample surfaces were deeply eroded by AO attacks, exhibiting a rough texture with numerous cones.

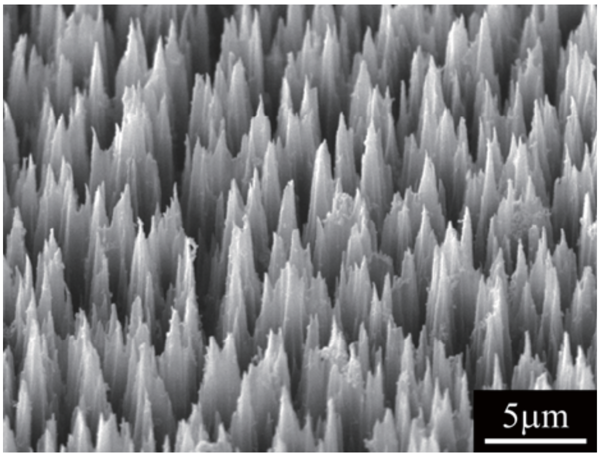

Fig. 2-2 Surface topographies of polyimide film [2].

An example of research activity related to combined space effects is described [2]. The synergistic effects of AO and VUV on Kapton H and Ag-coated FEP were investigated using single, sequential, and simultaneous irradiation, where both AO and VUV fluence were equivalent to the LEO environment at an altitude of approximately 400 km for 3 months. The results showed no obvious difference in erosion yields attributable to irradiation method for either material. Thermo-optical properties of Kapton H were degraded by AO irradiations, and the degradation levels were similar in each sample. The Ag-coated FEP underwent no marked changes in thermo-optical properties after each irradiation. These results indicate that the synergistic effects of AO and VUV have no influence on the erosion yield and the thermo-optical properties for either material under the experimental conditions used in this study. Kapton H samples exhibited needle-like surfaces after AO irradiation; the VUV irradiation had no effect on the Kapton H surface morphology. For Ag-coated FEP, the surface irradiated by AO was also characterized by a needle-like surface. The surface of Ag-coated FEP irradiated by VUV became flatter than the original, which suggests that VUV might have a smoothing effect on Ag-coated FEP surfaces. After sequential irradiation, the surface morphology differed depending on the irradiation sequence. A rougher surface with low blunt cones was produced by simultaneous irradiation resulting from the interaction between the erosion by AO attacks and smoothing by VUV irradiation.

2.2 UV Test equipment

We also have a Xenon source type UV irradiation facility called JAXA UV test equipment, shown in Figure 2-3. Table 2-2 presents the UV irradiation specifications. UV flux and fluence levels were obtained from the spectral radiant intensity at a wavelength of 200 - 400 nm, as measured using a multispectral radiometer. Because the Xenon lamp light includes an infrared wavelength region resulting in heating of the samples, the base plate to hold the samples was cooled by water flow to prevent sample heating. The irradiation area temperature was monitored by using thermocouples attached to the reference sample.

Fig. 2-3 JAXA UV test equipment

Table 2-2 Specifications of UV test equipment.

Spectrum	200–400 nm
Power	6000 W
UV flux	12 Solar Constant (Max.)
Irradiation area	150mm × 150mm
Sample temperature	< 60 °C (Nornal)
Vacuum	10^{-4}–10^{-5} Pa

2.3 Outgassing

Outgassing is the release of a gas from an organic or other material in a vacuum environment. Since 1980, the National Space Development Agency of Japan (NASDA), the forerunner of JAXA, has been measuring outgassing in accordance with ASTM E 595 [3].

Fig. 2-4 shows the outgassing measuring system and table 2-3 presents the system's specifications. Three items are measured as outgas data: total mass loss (TML), collected volatile condensable material (CVCM), and water vapor regained (WVR) in accordance with ASTM E 595. All the data has been compiled in a database [4].

Fig. 2-4 Outgassing measuring system

Table 2-3 Specifications of outgassing measuring system.

Sample numbers	For normal measurement (26mm φ): 15 chambers For standard reference samples (26mmφ): 3 chambers For large samples (40mmφ): 3 chambers For film thickness measurement (26mmφ): 1 chamber Five tests can be undertaken simultaneously
Temperature control	Heating Rod: Normally heated to 125°C. Cooling for Condensation: Normally 25°C.
Vacuum	7× 10^{-3} Pa or less

Contamination effect is one of the concern for high resolution optics sensors. Numerical analysis of molecular contamination deposition has been conducted in order to identify a major contaminant source and contaminated optics. Some assessments and experiments have been in progress [5-8].

3 Advanced material research

Materials with high tolerance against the space environment have been developed. Silicon containing polyimide is proposed as an AO-tolerant material for Low Earth Orbit flight [9]. AO irradiation tests were performed at the Combined Space Effects Test Facility. The results demonstrate that the polysiloxane-block-polyimide mass loss is one hundredth or less than that of Kapton®. Cross-sectional transmission electron microscopic (TEM) observation and X-ray photoelectron spectroscopic (XPS) analysis reveal that the AO protective SiO_2 layer is self-organized by AO irradiation. In addition, the self-organized SiO_2 layer was damaged intentionally to investigate the formation of a new layer on it. After further AO irradiation on the damaged surface, it was found that a new layer was built with a 500-nm-deep eroded region. It can be said that the result confirms the “self-healing” ability of polysiloxane-block-polyimide.

These results suggest that polysiloxane-block-polyimide has high potential to provide many advantages for use in space, especially on LEO spacecraft. This polysiloxane-block-polyimide will be evaluated on the International Space Station (ISS) in the space environment exposure experiment which is described in the next section.

4 Space demonstration experiment

We conducted research through spacecraft materials exposure experimentation, which assesses and demonstrates the performance of prospective spacecraft materials on the space shuttle and the ISS. JAXA conducted space-material exposure experiments in the STS-85/Evaluation of Space Environment and Effects on Materials (ESEM) mission in 1997 [10], and in the Exposed Facility Flyer Unit (EFFU) of the Space Flyer Unit (SFU) in 1996 [11]. Micro-Particles Capturer and Space Environment Exposure Device experiments (MPAC&SEED) is a JAXA-owned experiment for particle capture and material exposure, mounted on the Russian Service Module (SM) and the KIBO Exposed Facility (EF) of the International Space Station (ISS) [12,13]. The MPAC&SEED experiment that used the Russian SM on the ISS was executed from 2001 to 2005 (SM/MPAC&SEED). This was the first experiment that prepared the same samples in three sets and evaluated the relation between material deterioration and exposure period (ten months (0.9 years), 28 months (2.4 years), and 46 months (3.8 years)). In the SEED experiment, we were able to get data on space environmental effects on the material, as well as orbital induced environment effect data such as contamination effect data [14-18]. The MPAC experiment succeeded in capturing dust and a component analysis was performed. The impact flux from captured dust and debris models were compared. The impact fluxes of aerogel appeared to be inversely proportional to the exposure period and the fluxes were greater than the model results [9]. Combined scanning electron microscopy (SEM), transmission electron microscopy (TEM), micro Raman spectroscopy, and synchrotron radiation X-ray diffraction analyses revealed the existence of space debris, secondary debris and a micrometeoroid [13]. Figure 4-1 shows the orbit configuration of SM/MPAC&SEED.

Fig. 4-1 Orbit configuration of MPAC&SEED (October 2001).

JEM/MPAC&SEED is exposed to the space environment attached to the Space Environment Data Acquisition Equipment-Attached Payload (SEDA-AP). This is on the KIBO Exposed Facility (EF) and is mounted on the Experiment Logistics Module-Exposed Section (ELM-ES) to be launched by Space Shuttle flight 127 (2J/A mission) [19]. The position of JEM/MPAC&SEED on SEDA-AP is shown in figure 4-2. This picture was taken at the Kennedy Space Center (KSC) when JEM/MPAC&SEED was attached to the SEDA-AP. After the experiments are completed, the JEM/MPAC&SEED sample assembly will be returned to the Earth by the space shuttle 19A mission (2010) according to the current plan. Currently, the ground irradiation test for SEED samples is in progress [20].

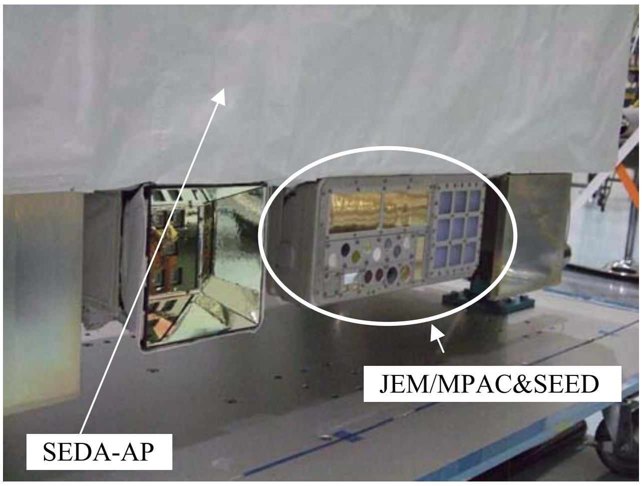

Fig. 4-2 JEM/MPAC&SEED attached to the bottom of the SEDA-AP at KSC.

5. Safety and compatibility of materials

JAXA conducted experiments to evaluate inflammability, offgassing of equipment, parts and materials used in a manned space environment such as “Kibo”, installed on the ISS and H-II Transfer Vehicle (HTV) to verify the safety of the equipment, parts, and materials for astronauts. JAXA has been conducting these tests in accordance with NASA-STD-6001 [21]. Table 5-1 shows the test contents. Figure 5-1 shows a test chamber for Tests 1, 4, 8, and 18. Figure 5-2 shows gas chromatography equipment for Test 7 for CO, H_2, organic and inorganic gas measurement.

Table 5-1 Safety and compatibility of materials test contents at JAXA.

Test No.	Test name
Test 1	Upward flame propagation test
Test 3	Liquid flashing point test
Test 4	Electric wire insulating material combustion test
Test 6	Odor test
Test 7	Offgassing test
Test 8	Combustion test of materials inside container
Test 18	Arc Tracking Test

Figure 5-3 shows the annual number of tests for safety and compatibility of materials at JAXA. Tests 1, 3, 4, 8, and 18 are defined as inflammability tests. Approximately 250 tests are conducted per year. 144 offgassing tests and 38 inflammability tests were conducted in 2008. In 2006, the odor requirement was changed and thus offgassing tests have been conducted instead of odor tests since 2007 [21].

Fig. 5-1 The test chamber for Tests 1, 4, 8, and 18.

Fig. 5-2 Gas chromatography equipment for Test 7.

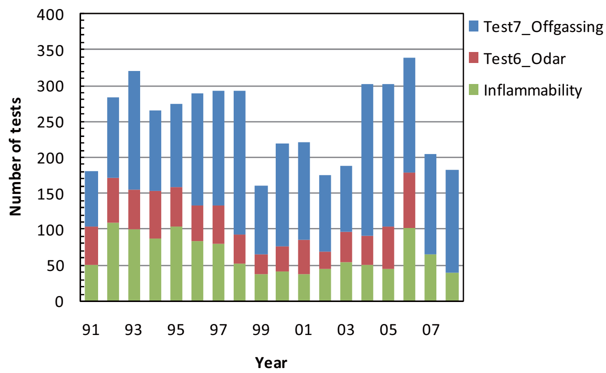

Fig. 5-3 Annual number of tests for safety and compatibility of materials at JAXA.

6. Conclusion

The research activities of the Space Materials Section, Electronic Device and Materials Group of JAXA are summarized. In designing spacecraft, we should reflect on the results from ground evaluation tests and space material exposure experiments. These activities have been conducted in order to develop a Materials database [4] which is utilized to improve spacecraft design.

6. References

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