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CONTAMINATION CONTROL RESEARCH ACTIVITIES FOR SPACE OPTICS IN JAXA R&D

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ABSTRACT

Contamination control research activities for space optics projects in JAXA R&D are described. More accurate contamination control techniques are requested because of intensified recent science mission requirements. One approach to control the contamination effects is analysis by software. JAXA has been developing a contamination analytical tool "J-SPICE" (Japanese Spacecraft Induced Contamination analysis software) as well as experiment facilities to improve the J-SPICE. A reflection model in J-SPICE has been experimentally verified and outgassing model data has been acquired by a facility. JAXA has developed a facility which could determine the influence of the contamination at a specific wavelength by combining a vacuum chamber with an I-R spectrometer and performed an experiment to inspect the effect of baking. Space material exposure experiment results reveal the actual thickness of the contamination layer in ISS orbit.

I. INTRODUCTION:

Spacecraft projects should control and design the amount of molecular and particle contaminants and their effects on the critical surface below a specified level, as determined by the mission lifetime of the spacecraft. The spacecraft project, which has a telescope for Earth observation, X-ray observation and solar observation, tries to adopt the evaluation based on a contamination standard. However, more accurate contamination control techniques are requested because of intensified recent science mission requirements.

One approach is analysis by software. Here, JAXA has been developing a contamination analytical tool "J-SPICE" (Japanese Spacecraft Induced Contamination analysis software.) This can estimate the magnitude of contamination on a spacecraft surface based on mathematical models, the analytical results of which can be utilized to manage the contamination of spacecraft critical surfaces. This analytical tool predicts the amount of molecular contaminants on critical surfaces based on various input data (outgassing property of materials, geometry or thermal property of spacecraft, etc.) and mathematical models showing the behavior of contaminants (outgassed molecules from materials, transport of outgassed molecules from one surface to another, and reflection characteristics.) Accordingly, the prediction accuracy is highly dependent on the validity of the input data and mathematical models and JAXA have improved J-SPICE in both theoretical and experimental terms. For example, we have verified the validity of the diffuse reflection model applied in J-SPICE by comparing the reflection flux of contaminant molecules measured from the ground experiment to the analytical J-SPICE result. We also developed an optical measurement chamber system estimate correlating with the optical performance and the contamination layer.

We have conducted space material exposure experiments on-board spacecraft and the International Space Station (ISS), which not only reveal the degradation of materials but also their contamination condition. This paper includes an overview of contamination research activities in JAXA R&D.

II. Contamination Analysis Tool improvement:

JAXA have developed the J-SPICE analytical software application to predict the mass of molecular contaminants that could potentially accumulate onto the spacecraft's surface. To enhance the reliability of the software program, we improve the J-SPICE based on ground-based test data and Hinode (Solar-B) and SUZAKU (Astro-EII) flight data [1, 2, and 3]

A. Verification of reflection model by experiment [4]

Several kinds of reflection model exist, such as specular and diffuse reflection models, Maxwell model, etc. A specular reflection model is one in which the incident- and reflection angles of molecules converge. Conversely, in the diffuse reflection model, incident molecules are reflected isotropically from the surface, independent of the incident angle. The Maxwell model is defined as a mixture of specular and diffuse reflection models and J-SPICE has applied the diffuse reflection model among various others. JAXA establishes an apparatus to investigate the reflection behavior of molecules, the facility diagram of which is shown in Figure 1. The apparatus comprises several parts such as a vacuum chamber, cryogenic shroud, effusion cell with an orifice, mirror, and two CQCMs (Cryogenic Quartz Crystal Microbalances.) One of the purposes of this equipment is to correlate the reflected molecular flux with incident molecular flux to the mirror with several reflection angles. Moreover, we also investigate the validity of the diffusion reflection model by comparing the analytical result of the experiment calculated by J-SPICE with the data of the experiment.

In conclusion, it seems the accuracy of the diffuse reflection model suffices for practical contamination analysis (determining whether the amount of contaminants on orbit is within the acceptable limit.)

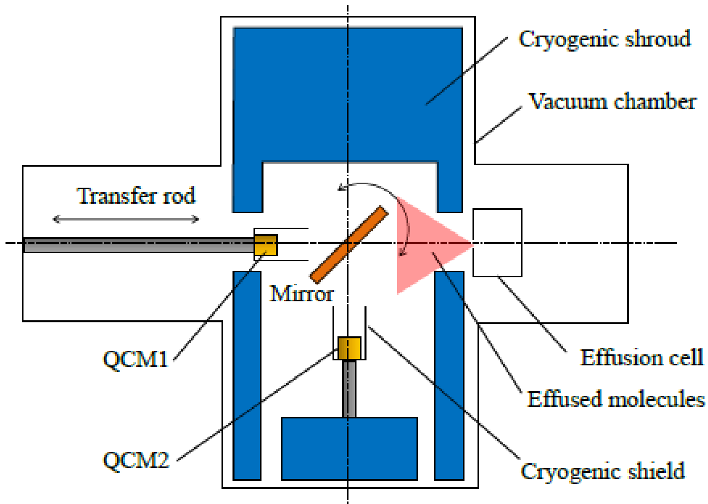

Fig. 1. Diagram of the facility.

B. Outgassing rate measurement technique

J-SPICE basically using uses the power model for the outgassing model and JAXA has maintained an outgassing rate measurement facility at the Tsukuba Space Center. This facility is made in accordance with ASTM E 1559 and includes 4 CQCMs, an Effusion Cell and a Shroud at Liquid Nitrogen temperature. Figure 2 depicts the facility scheme.

Fig. 2. Outgassing rate measurement equipment in JAXA.

We tested the outgassing rate test using approx. 40 samples per year and compared some of the results to data obtained by another test facility. Some parameters which affect the outgassing rate data, such as the baking condition, are included in the experiment.

III. Basic experiment:

A. Evaluation of the bakeout process [5]

Bakeout is commonly applied to the components and materials used for satellites before launch, since such components and materials include volatile low molecular elements emitted in a space environment. Moreover, this molecular contamination is known as one of the most serious problems for satellites, typically including optical components and solar panels that are sensitive to contamination which impairs their performance. However, the effectiveness of bakeout may also depend on conditions such as temperature, duration, and configuration. It is believed that bakeout should be conducted at high temperatures, for extended periods, and in configurations conducive to emission. Moreover, bakeout under such ideal conditions is unrealistic, given the temperature limits imposed by the specifications of components and facilities, limited durations typically imposed by cost or system timeline considerations, and configurations limited by the development phase. Consequently, the bakeout conditions vary in line with the limitations regarding each object, resulting in different bakeouts on a case-by-case basis.

In this experiment, the outgassing source is heated to 80°C. The effectiveness of bakeout in terms of directly measuring optical properties could be shown by an In-situ Contamination Spectroscopic Analysis Chamber. The “In-situ Contamination Spectroscopic Analysis Chamber”, developed by JAXA, is located at the Tsukuba Space Center and features heating and cooling parts located within a single vacuum volume. The sample (i.e. outgassing source) is set at the heating part and the gold-coated mirror at the cooling part. During protracted heating of the sample, volatile materials from the outgassing source are deposited on the gold-coated mirror, while the IR beam from FT-IR traverses an IR transmissive window and is reflected on the mirror, thereby allowing the IR detector to measure the spectral reflectance. When the mirror is contaminated by the absorption of contaminants, the spectral reflectance changes. This design allows us to observe changes in the optical properties of a critical surface contaminated by the outgassing source in real time. One TQCM sensor unit is also placed in a position allowing a view factor equivalent to that of the mirror from the outgassing source under a regulated temperature to measure the deposition of mass on a critical surface at specific temperatures. The TQCM can thus measure the correlation between deposition thickness and optical properties. Figure 3 shows a full photo of this equipment.

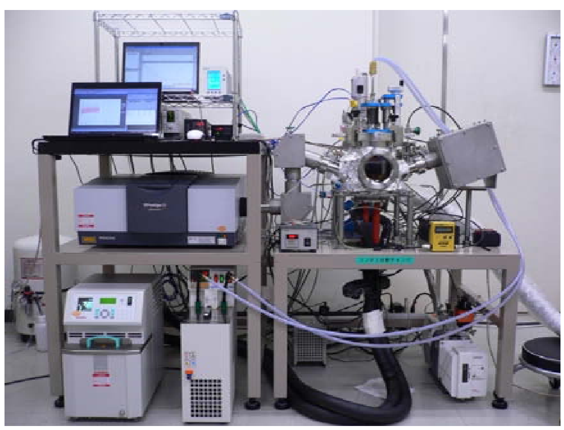

Fig. 3. In-situ Contamination Spectroscopic Analysis Chamber.

Four cured samples were prepared, three (in a vacuum oven at temperatures of 60, 80, and 125°C, respectively) of which were subject to bakeout under the various conditions. Figure 4 shows the FT-IR spectral absorbance for only samples of baked-out at 125°C, when the sample is heated to 80°C respectively. The spectral absorbance is overlaid with the spectrum of each elapsed time period. The horizontal axis denotes the wave number, and the vertical axis indicates absorbance.

This experiment attempted to evaluate the effectiveness of bakeout for RTV-S 691 by employing quantitative and optical methods using the “In-Situ Contamination Spectroscopic Analysis Chamber.” The quantitative measurement results confirmed that the thickness of contaminants existing on the surface at the same time was reduced by bakeout and that the reduced thickness then increased with bakeout temperature. The optical measurement results, however, revealed certain cases in which bakeout increased the absorption coefficient, which suggests that relying on the deposition thickness on an optical surface alone is insufficient.

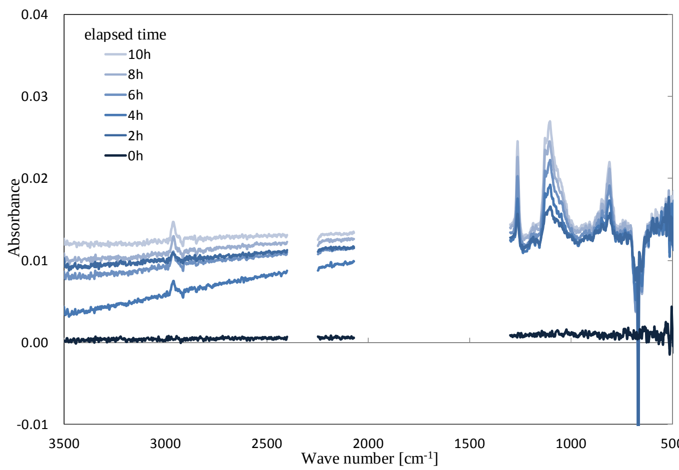

Fig. 4. FT-IR spectral absorbance overlaid with the spectrum of each time elapsed (Bakeout at 125°C)

VI. Flight experiment analysis:

JAXA developed the Micro-Particles Capturer and Space Environment Exposure Device for space material exposure experiments on the exterior of the Japanese Experiment Module (JEM/MPAC&SEED) on the ISS. JEM/MPAC&SEED was launched on Space Shuttle flight 127 (2J/A mission) on 15 July, 2009 and retrieved after 259 days (8.5 months) of in-orbit exposure [6]. After retrieval to the ground, several points on JEM/MPAC&SEED hardware, the aluminum alloy frame surfaces of which were used to hold the film samples and surfaces of film samples mounted as SEED samples, were observed from a contamination perspective. Figure 5 shows a close-up picture of the aluminum alloy frame becoming brown except for the unexposed area covered by washers. The top surface of both unexposed/exposed areas was analyzed by XPS and carbon, oxygen, fluorine, aluminum, nickel, nitride, sulfur and zinc were detected in both unexposed and exposed areas, while silicon only on the exposed area. Moreover, the chemical state of Si is SiO_2 due to the result of the energy detected. SiO_2 constitutes the main contaminant adhering following exposure to the space environment. At almost all points of JEM/MPAC&SEED, the thickness of the SiO_2 contamination layer was under 5nm [7].

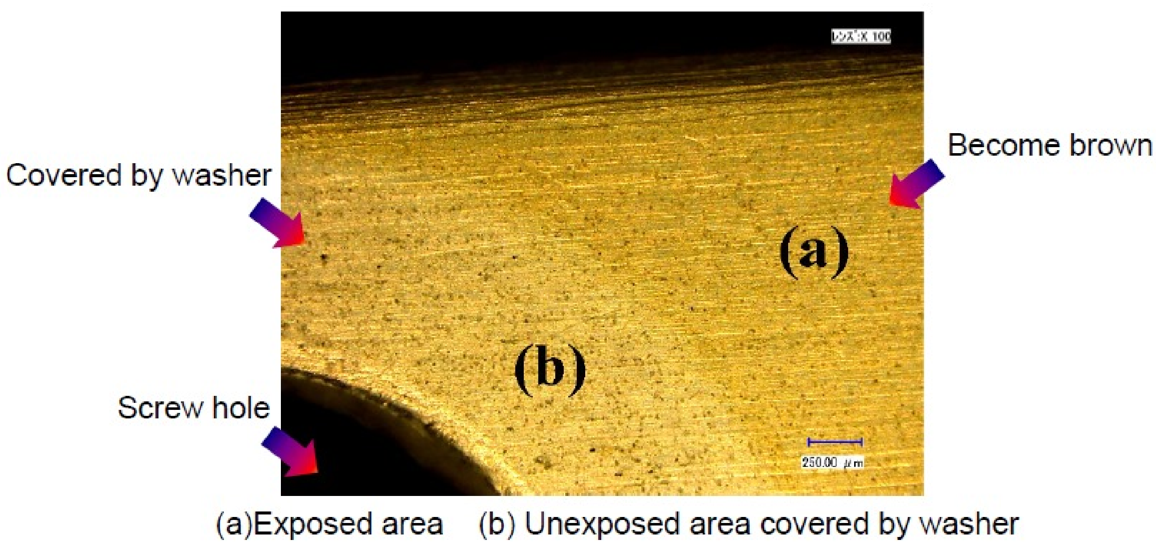

Fig. 5. Picture of the aluminum alloy frame surface becoming brown except for the unexposed area covered by washers.

V. Conclusion:

An overview of recent contamination research activities in JAXA R&D is described. The study centers on J-SPICE and examines contamination research in more detail. JAXA will improve J-SPICE in theoretical and experimental terms and these activities will contribute to future space optics projects regarding contamination control.

REFERENCES

[1] K. Yano, N. Baba, "Development of Japanese Spacecraft Induced Contamination Environment Analysis Software (J-SPICE)," *JAXA-SP-05-008*, 2006.
[2] F. Urayama, K, Yano, R. Yamanaka, E. Miyazaki, Y. Kimoto, "Molecular contamination assessment on Hinode solar optical telescope," *Jpn Soc Aeronaut Space Sci* Vol. 56: pp. 543-550, 2008
[3] F. Urayama, F. Atsushi, E. Miyazaki, Y. Kimoto, "Molecular contamination analysis on SUZAKU X-ray telescope," *Astrophysics and Space Science Proceedings, Vol. 32*. Protection of Materials and Structures From the Space Environment: pp. 235-242, 2013
[4] S. Baba, E. Miyazaki, Y. Miura, R. Yamanaka, O. Numata, J. Ishizawa, Y. Kimoto and T. Tamura, "Experimental measurement of the reflection behavior of contaminant molecules," *Proc. SPIE Optical Engineering + Applications 2014* in press.
[5] H. Yokozawa, S. Baba, E. Miyazaki, Y. Kimoto, "Evaluation of Bakeout effectiveness of Satellite Materials by Optical Measurement of a Contaminated Surface," *Proc. of the 12th ISMSE (CD-ROM)*, 2013
[6] Y. Kimoto, J. Ishizawa, H. Shimamura, "Passive Space Environment Effect Measurement on JEM/MPAC&SEED," *Astrophysics and Space Science Proceedings, Vol. 32*. Protection of Materials and Structures From the Space Environment: pp. 73-82, 2013
[7] S. Baba, J. Matsuyama, E. Miyazaki, J. Ishizawa, Y. Kimoto, "Evaluation of contamination on the JEM/MPAC&SEED," *2011 Contamination, Coatings, & Materials Workshop NASA/GSFC, USA (CD-ROM),2012*