Examination of the molecular contamination for the EXCEED optics

Kentaro Uji[1], Ichiro Yoshikawa[1], Kazuo Yoshioka[2], Go Murakami[2], Hiroaki Ishii[1]

[1] Department of Earth and Planetary Science, The University of Tokyo

[2] Japan Aerospace Exploration Agency, Institute of Space and Astronautical Science

ABSTRACT

The extreme ultraviolet (EUV) telescope EXCEED (Extreme Ultraviolet Spectroscope for Exospheric Dynamics) onboard the Japan's small satellite SPRINT-A will be launched in August 2013. EXCEED will observe the atmosphere and plasmas around various planets in our solar system in wavelength between 60nm -145 nm. The optical instrument consists of an entrance mirror, a grating and microchannel plates. It is essential that the detection efficiency is very high in order to detect the faint signals from its targets.

In the EUV range, performance of optical instruments is easily degraded by molecular contamination. Therefore, it is very important to evaluate the effect of molecular contamination on optics.

In this study, we prepared mirrors contaminated by some materials that are used in the EXCEED instrument. We compared the reflectivities of the contaminated mirrors in the EUV range both before and after contamination. In this paper, we report those results.

1 Introduction

Contamination is grouped in two categories labeled molecular contamination and particle contamination. Molecular contamination refers to the cumulative buildup of individual molecules of foreign matter and usually occurs on orbit. Particle contamination refers to the deposition of visible conglomerations of matter and usually occurs during ground operations. The presence of contamination will degrade the performance of spacecraft hardware such as thermal control surfaces, solar arrays and optical instruments. For this reason, effective contamination control is essential for the success of most aerospace projects.

The EXCEED (EXtreme ultraviolet speCtroscope for ExosphEric Dynamics) mission is the first project in the small scientific satellite series (SPRINT-A) managed by ISAS/JAXA. The EXCEED mission conducts spectroscopic imaging observations of the EUV (60nm-145nm) emissions from plasma around planets. The main scientific purpose of EXCEED is to observe the EUV emission from the Io plasma torus and to measure the plasma escape rate from the terrestrial planets. The nominal mission life is one year but it could be extended to several years.

It is well known that EUV optics is exceptionally sensitive to molecular contamination. Thus, evaluation of the effects of molecular contamination on the EXCEED optics must be carried out.

2 EXCEED optics

In this section/chapter, a description of the optical configuration and performance of EXCEED is given. The EXCEED optics consists of an entrance mirror, a grating and microchannel plates (MCPs). The major design parameters and the optical layout of EXCEED are shown in Table 1 and Figure 1.

Table 1. Major design parameters for EXCEED.

Spectral range	60 – 145 nm
Field-of-view*	400″ × (10″, 60″, or 140″)
Spectral resolution*	0.4 nm, 1.0 nm, or 0.4-1.0 nm (FWHM)
Spatial resolution	10″ (along the slit)
Entrance mirror	Diameter: 200 mm (effective area) Focal length: 1800 mm (F/8) Surface: CVD-SiC
Slit widths	0.08 mm (10″) 0.50 mm (60″) 1.10 mm (140″)
Filter	CaF_2, In, or none
Grating	Shape: toroidal Diameter: 50 mm (effective area) Focal length: 400 mm Lines: Laminar type, 1800 lines/mm Surface: CVD-SiC
Detector	5-stage MCPs with CsI photocathode and RAE

*Depending on the slit type

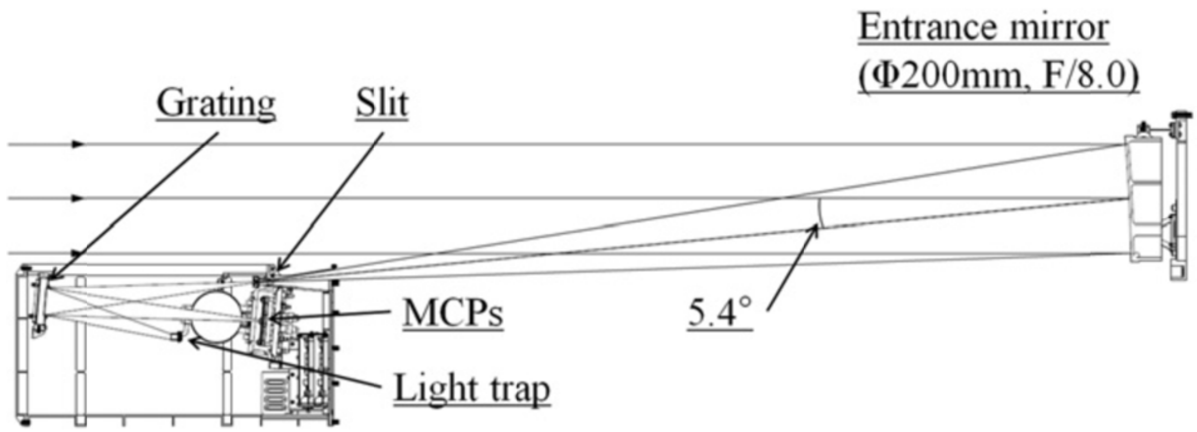

Figure 1. Optical layout of the EXCEED instrument. It consists of an entrance mirror, a grating and a MCP detector.

It is essential that the detection efficiency is very high in order to detect faint signals from the plasma. To be reflective enough in the EUV range, the surfaces of the entrance mirror and the grating are covered with chemical vapor deposited silicon carbide (CVD-SiC). In addition, to pick up photon events efficiently, the top MCP surface is covered with cesium iodide (CsI).

The efficiencies of each component are shown in Fig 2. The total efficiency of EXCEED can be described as the number of counts per photon (Fig 2) and must be higher than 0.003 counts/photon to achieve science objectives.

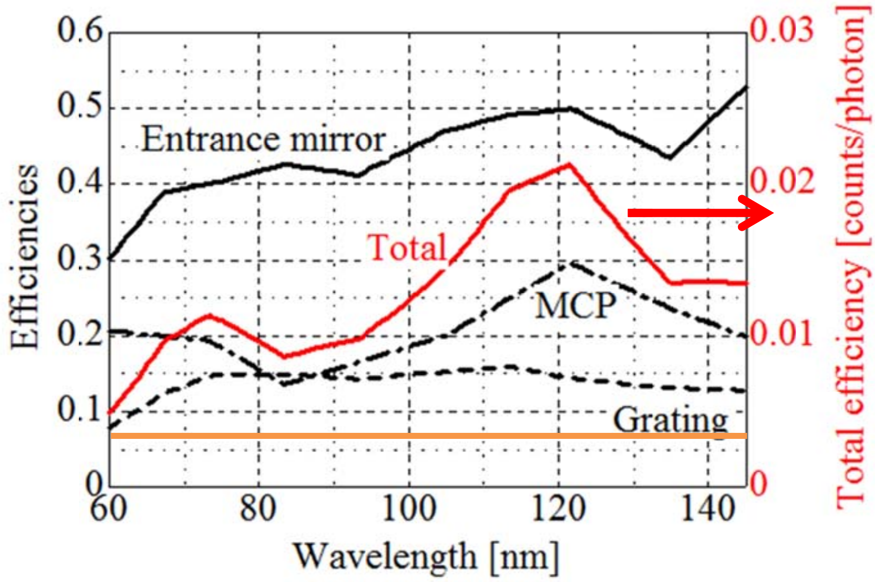

Figure 2. EXCEED component efficiencies and total photon detection efficiency. Total efficiency must be higher than 0.003 [counts/photon] (orange line).

3 Molecular contamination for optics

In the vacuum environment, outgassing from organic materials occur and create contaminant films on optical surfaces. Contaminant film absorbs light energy, resulting in reduced surface reflectance as a function of contamination thickness. Contaminated mirror reflectivity (R^x) is given by,

$$\mathbf{R}^x(\lambda) = \mathbf{R}(\lambda)\exp[-2\alpha_c(\lambda)\mathbf{x}] \qquad \text{Equation 1}$$

where x is contamination thickness, λ is wavelength and α_c is absorption coefficient. The factor of 2 is present in the exponential because a ray of light would have to transverse the contaminant film twice. The equivalent expression for a surface that is designed to be totally transmissive, such as an MCP is,

$$T^x(\lambda) = \mathbf{T}(\lambda)\exp[-\alpha_c(\lambda)\mathbf{x}]. \qquad \text{Equation 2}$$

Using the extinction coefficient k, we obtain

$$\alpha_c(\lambda) = {}^{4\pi k}/_{\lambda}. \qquad \text{Equation 3}$$

As shown by Equation 1, 2 and 3, most contaminants are more absorptive in short wavelength.

Therefore, molecular contamination is a serious problem for EUV optics.

To date, tests to quantify the critical level of contamination have been conducted. A standard test is ASTM E 595 (Material Outgassing Test). In this test, a sample material is held at a temperature of 125℃ for 24 hours at a pressure of less than 7×10^{-3} Pa with a collecting plate held at 25℃. Comparing the initial and final masses of the sample and collecting plate, we obtain the TML (Total Mass Loss) and CVCM (Collected Volatile Condensable Material). The conventional wisdom defines typical pass/fail criteria for most spacecraft materials to be 1% TML and 0.1% CVCM. A more detailed test is ASTM E 1559 (Contamination Generation Characteristics of Spacecraft Materials). The purpose of ASTM E 1559 is to determine outgassing characteristics over a wider temperature range and determine relevant time dependencies.

However, the criteria do not provide complete insight into the effect of molecular contamination on optics.

During the TTM (Thermal Test Model) test (Fig 3) a decline of mirror reflectivity occurred. In the TTM test, the TTM model was put in a vacuum chamber with variable temperature during one week. Molecular contamination appeared to be responsible for the decline of mirror reflectivity. For this reason, a study on the effect of molecular contamination on the EXCEED optics was conducted.

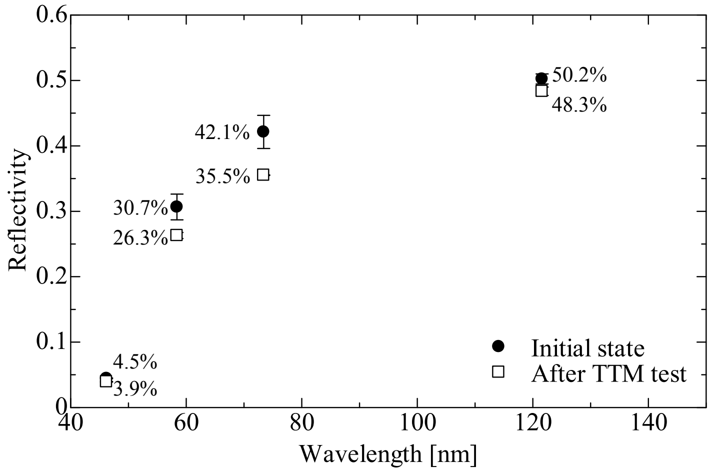

Figure 3. Reflectivity of CVD-SiC mirror before and after the TTM test. Reflectivity was degraded through the TTM test especially in short wavelengths. Incident angle was 10.4° .

4 Experiment & Results

In order to evaluate the effect of molecular contamination on the EXCEED optics, we contaminated SiC mirrors and compared mirror reflectivities in the EUV range before and after contamination. In this test, we contaminated SiC mirrors in the same configuration as ASTM E 595. The test conditions are listed in Table 2. These conditions are comparable to 3 years of the EXCEED mission environment.

Results are shown in Table 3. There are no significant changes in mirror reflectivity. At maximum, reflectivity degradation is 1.9%.

Table 2. Conditions for the test. These conditions are comparable to 3years of the EXCEED mission environment.

Mirror	SiC mirror
Contamination source	Epicoat/Versamid (Epoxy adhesive)
	Cho-therm (Thermally conductive adhesive)
	Scothweld 2216B/A (Fastening screw)
Duration	1day
Temperature	25℃ (Sample mirror)
	30℃ (Contamination source)

Table 3. Results. There are no significant changes in mirror reflectivity.

Contamination source	Reflectivity before the test	Reflectivity after the test	TML	CVCM
Cho-therm	28.6±0.3%	28.9±1.6%	0.030%	0.001%
Scotchweld		29.1±1.5%	0.305%	0.001%
Epicoat/Versamid		28.5±0.4%	0.295%	0.007%

5 Discussion

Within the EXCEED instrument, a light ray would have to transverse contaminant film 5 times (Twice at the entrance mirror, twice at the grating and once at the MCPs). Thus an estimation of the maximum degradation of total efficiency in the EXCEED instrument is given by Equation 1 and 2. It is concluded that the total efficiency would not be less than 86% in 3years. It indicates that the total efficiency will be maintained at acceptable levels after 3 years on orbit.

It is well documented that the presence of UV light can cause contamination to condense on surfaces. Presumably, UV light initiates a polymerization process that either binds the contaminant molecule to the surface or binds several contaminant molecules into a larger molecule with a longer residence time. This photochemical deposition process accelerates the molecular contamination. Furthermore, photodeposited films may be much darker than the 'typical' contaminant films. Thus, strong UV such as solar UV may dramatically degrade the performance of optical instruments. Even though EXCEED will not be exposed to solar UV, the effect of molecular contamination combined with UV illumination on the EXCEED optics has to be evaluated. Additional contamination tests will be carried out under various conditions.