Evaluation of the EUV emission from the sub-LEO space environmental simulation using carbon dioxide laser: FY2014 report

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1. INTRODUCTION

The environmental factors in space, for example, ultraviolet (including EUV and VUV wavelength), x-rays, ion and electron radiations, thermal cycling, and neutral species such as atomic oxygen (AO), give serious effects on many spacecraft materials [1]. The incompleteness of the ground-based simulation technology arises problems on the accuracy of assessment of the material survivability in real space environment. One of the discrepancies between space and laboratory data is obvious in AO-induced erosion of fluorinated ethylene polymer (FEP) Teflon. It has been reported that FEP Teflon eroded much faster in ground-based facilities than in space. This discrepancy is believed due to the ultraviolet which is a byproduct from the oxygen plasma; and many studies regarding synergistic effect of AO and VUV has been conducted [2]. A laser detonation AO source, which has widely been used as AO environmental simulator, uses high-power CO₂ laser to create laser-sustained oxygen plasma. The basic configuration of laser detonation AO beam source is similar to that of EUV light source using xenon gas cloud. However, EUV from laser-detonation AO beam source has not been evaluated. In FY2008-2010, we have installed a flat-field EUV spectrometer into laser-detonation AO beam source, and confirmed the capability to measure EUV spectra from oxygen plasma. Also, the relationship between EUV spectra from the oxygen plasma and time-of-Flight (TOF) spectra of AO beam has been studied.

In FY2014, a gas mixture system was installed in the laser-detonation system which allows mixing of O₂ and Ar gases in any ratios regarding to the sub-LEO neutral gas simulations. Basic operational conditions of the gas mixing system were investigated.

2. LASER DETONATION SPACE ENVIRONMENTAL SIMULATOR

The laser detonation AO beam source at Kobe University was used in this study [2]. This type of AO beam source is widely used in many space environmental studies in US, Europe and Japan. A pulsed CO₂ laser (5 J/pulse) and a pulsed supersonic valve (PSV) are used in this system. The laser light is focused on the nozzle throat with the concave Au mirror located 50 cm away from the nozzle. The PSV introduces target gas into the nozzle and the laser light is focused on the target gas in the nozzle. Energies for the dissociation and the acceleration are provided by the inverse Bremsstrahlung process. The hyperthermal beam, thus generated, was characterized by a TOF distribution measured by a quadrupole mass spectrometer (QMS) installed in the beam line. Translational energies of the species in the beam were calculated using TOF distributions with the flight length of 235 cm.

3. GAS MIXING SYSTEM

A precise gas mixing system (MAP Mix9000 system, Dan Sensor, Inc., Figure 2) with a reservoir was installed in the target gas supply line connecting to the PSV. The system diagram is shown in Figure 3. This system automatically controls the output pressure of the mixed gases.

Figure 1 Photograph of the laser-detonation hyperthermal beam facility.

Figure 2 Photograph of the MAP Mix9000 system installed in the laser detonation system.
gas to 0.6 MPa and the PSV pressure was tuned by the in-line regulator from 0.1 to 0.5 MPa.

4. RESULTS AND DISCUSSION

Figure 4 shows the O$_2$ fraction in the mixed gas (Ar + O$_2$) in various settings by the gas mixing system. The gas composition was measured by analyzing the thermal beam ejected from the nozzle with the QMS in the beam line. The intensity of the QMS signal was compensated by the relative ionization cross-section of the each atoms/molecule [3]. Note that the result was obtained through the operation process established in this study including evacuation and 5 minutes purging of the gas supply line and 60 minutes warm-up operation of the PSV. It was clearly indicated that the composition of thermal beam (no laser firing) was adjustable from 5 to 95%O$_2$ almost in linear relationship with the mixer setting.

A 6-7 Joule TEA CO$_2$ laser pulse was focused to the gas in the nozzle and hyperthermal atomic beam was formed. The beam composition was analyzed by the QMS. The results are shown in Figure 5. It was clearly indicated that the AO fraction in the beam increased with increasing O$_2$ fraction in the mixed target gas. Undecomposed O$_2$ fraction in the beam was as low as a few percent in case of target gas with the O$_2$ fraction below 60 % (Ar 40% or higher). This is due to the promotion of decomposition reaction of O$_2$ with Ar collision in the plasma [3]. This effect was less obvious in the target gas with high O$_2$ compositions; however, the undecomposed O$_2$ is still less than 15 %. By comparing the upper atmospheric composition of Earth, it was concluded that the gas mixing system used in this study reproduce N$_2$/AO fraction in the altitude of 120-350 km by Ar/AO fraction in the hyperthermal beam facility.

5. CONCLUSIONS

The precision gas mixing system was installed in the laser-detonation atomic beam source and basic operation property of the system was analyzed/established. It was found that the gas mixing system could reproduce N$_2$/AO fraction in the altitude of 120-350 km by Ar/AO fraction in the hyperthermal beam facility.

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