Evaluation and application of the EUV emitted from a laser-detonation atomic oxygen space environmental simulator: FY2012 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 [2]. 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 [3].

A laser detonation atomic oxygen 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 atomic oxygen 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 FY2012, EUV spectra from Ar + AO beams with various compositions was investigated related to the sub-low altitude orbital applications.

2. LASER DETONATION SPACE ENVIRONMENTAL SIMULATOR

The laser detonation AO beam source at Kobe University was used in this study [3]. 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 pure oxygen gas into the nozzle and the laser light is focused on the oxygen gas in the nozzle. Energies for the dissociation of oxygen molecule to oxygen atom and the acceleration of AO are provided by the inverse Bremsstrahlung process. The AO 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. Premix gases of 30%Ar+70%O₂, 50%Ar+50%O₂, and 70%Ar+30%O₂ were used to produce Ar + AO beams with various compositions.

3. EUV SPECTROMETER

A flat-field EUV spectrometer was designed to fit the vacuum chamber of the laser-detonation AO beam source at Kobe University. This spectrometer was designed based on the report by Kita [4] and equips 1400 line/mm grating. It was assembled on a VF250 vacuum flange. In order to measure the TOF distribution of AO and EUV spectra from the plasma simultaneously, the center axis of the AO beamline which uses TOF measurement is 5 degree off from that of the nozzle not to be interrupted by the spectrometer. EUV spectra were recorded on an imaging plate.

4. RESULTS

Figure 1 compares the EUV spectra from laser-sustained plasmas of 100 % O₂, 100% Ar, and 50%Ar+50%O₂. The blue and red lines display EUV spectra from 100 % O₂ and 100% Ar, respectively. In contrast, the black lines show the EUV spectrum from the 50%Ar+50%O₂ plasma. In the experiment with mixed gas target, translational energies of AO and Ar components were 5.0 and 10.8 eV, respectively. It is clearly obvious that EUV emission intensity from Ar plasma is higher than that from O₂ plasma. Surprisingly, Ar emission has not been observed from the laser-sustained plasma consisting of 50%Ar+50%O₂ gas mixture, i.e., EUV lines originated from oxygen are observed. Figure 2 compares three EUV spectra from laser plasmas consisting of 30%Ar+70%O₂, 50%Ar+50%O₂, and 70%Ar+30%O₂. The intensities of emission lines increase with Ar content. Figure 3 shows the detail of EUV spectra from 35 to 43 nm. From the NIST database [5], The emission lines at 35.9, 37.4, and 39.6 nm are labeled according to the
$2s^2 2p^2 - 2s^2 2p(2P)^3s$ transition of O III. Those at 37.7, 39.2 and 40.3 nm are labeled by $2s^2 2p(4S) - 2s^2 2p(3P)5d^4P$, $2s^2 2p(4S) - 2s^2 2p(3P)4d^4P$, and $2s^2 2p(4D) - 2s^2 2p(3D)4d^2D$ transitions of O II. In contrast, the large emissions at 36.8 and 41.6 nm observed in the 100 % Ar are originated from Ar III and Ar VII. Emission intensities originated from O increase with Ar content and disappear in the pure Ar plasma. The EUV emission property is related to the electronic or ionic collision processes in the gas mixture plasma.

Emission properties from an Ar + O$_2$ plasma has been studied with relating to the grow discharge optical emission spectroscopy (GD-OES) [6]. It was reported that the only a few sub-percent oxygen gas is able to make a great alteration in the emission intensities of the Ar plasma [7]. Even though plasma formation method was different, Wagatsuma reported that the O I emission enhanced 40 % by the addition of Ar up to 50 % in the glow discharge, where as O II intensities was hardly affected [7]. This result indicated that an addition of Ar promotes dissociation reaction of O$_2$ to produce more O atoms. On the other hand, Ar emission (both Ar I and Ar II) was drastically decreased by addition of O$_2$ suggesting less population of the excited or ionized Ar. The rate coefficient of Ar + e$^-$ → Ar$^+$ + e$^-$ (in the order of $10^{-7}$ cm$^3$/s) is two orders greater than that of O$_2$ + e$^-$ → O$_2^+$ + 2e$^-$ reaction (in the order of $10^{-9}$ cm$^3$/s). The Ar fraction as high as 50% potentially generates much more electrons in the plasma than 100% O$_2$ target gas. These electrons could be used to produce OII and O III states and prevented the generation of highly ionized states of Ar. However, detail of the mechanism has not been clarified.

5. CONCLUSIONS

The EUV spectrum emitted from the Ar + O$_2$ plasma in the laser detonation AO beam source, which is used in the space environmental effect studies, was measured. EUV emission lines originated from Ar was hardly detected from the laser-sustained Ar + O$_2$ plasma. In contrast, enhancement of O emission was observed with mixed plasma.

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