Atomic collision-induced etching of polymeric materials in a hyperthermal energy range relevance to material degradation in space

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Synopsis Importance of the atom-surface reaction in hyperthermal energy range (collision energy 5-10eV) on the space environmental effect field is addressed. The laser-detonation beam sources have been used for accelerating electrically neutral atoms/molecules. Required beam properties and recent topics on atom-surface reactions in space environment are discussed.

Materials used in the exterior surfaces of spacecraft orbiting in the low earth orbit (LEO) experienced severe erosion by the hyperthermal collision with atomic oxygen (AO) which is the major atmospheric species in LEO [1, 2]. Due to the high-orbital velocity of spacecraft (8 km/s), the impact energy of AO to the spacecraft surface reaches as high as 5 eV, which is higher than the interatomic bonding energy of many materials. Thus, the chemical reactions occurred at the spacecraft surfaces are under the effect of high-impact energy. Many flight projects have been conducted to clarify the erosion properties of materials in LEO, for example, Materials International Space Station Experiment (MISSE) series (see Figure 1) [3]. On the other hand, much effort has been paid for simulating the materials degradation in a ground-based facility. A microwave or radio frequency oxygen plasma source has been used for material screening test, however, this type of simulation facility does not simulate the collision energy of atomic oxygen in LEO. In order to simulate the impact energy of AO, a laser-detonation method has been applied [4]. In this presentation, a method for accelerating electrically neutral atoms to hyperthermal velocity by laser-induced plasma will be presented and introduced.

The laser-detonation hyperthermal beam source used for accelerating electrically neutral atoms is based on the laser thruster technology. The laser-detonation atomic beam source used in this study is equipped with a custom-built piezoelectric pulsed supersonic valve (PSV) system and a carbon dioxide laser. The PSV introduces the target gas into the nozzle throat through a 1 mm hole. The laser light is focused on the gas cloud in the nozzle throat using a concave Au mirror located 50 cm from the nozzle. Once plasma is formed in the nozzle by the inverse Bremsstrahlung process, the photon energy in the laser pulse is absorbed by the plasma behind the shock. Thus, the detonation wave propagates in the laser incident direction. Moreover, the thermal energy of the high-temperature plasma is converted to kinetic energy up to 15 eV by the nozzle.

Fig. 1. MISSE-1 PEC-1 Pallet attached to the ISS after 1year of exposure (Photo by NASA)

Some recent results will also be presented including dependence on temperatures, angle of attack, and collision-induced desorption. It has been demonstrated that the translational energy of atoms/molecules produced by laser-induced plasma is a key for studying the material degradation on satellites orbiting LEO.

A part of this study was supported by KAKENHI from JSPS under contract Nr. 25289307, 26289322, 15K14252 and 15K14253. Financial support through the Coordination Funds for Promoting Aerospace Utilization from the MEXT was also appreciated.

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