# LEO Space Environment Simulation

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## 1. INTRODUCTION

Graphite/epoxy composites of a variety of extraordinary mechanical characteristics such as high specific stiffness and strength-to-weight ratio, excellent fatigue resistance, and low coefficient of thermal expansion are widely applied to space structures. Of noticeable concern are hazardous space environmental effects on polymers and polymer-based composite materials in space structures. The low earth orbit (LEO) space environment composed of high vacuum, ultraviolet (UV) radiation, thermal cycles, atomic oxygen (AO), charged particles, electromagnetic radiation, micrometeoroids, and man-made debris significantly degrades the material properties.

In order to investigate synergistic space environmental effects on the composite materials, a decent ground simulation facility is to be constructed. A number of studies on space environmental effects have been conducted through a variety of ground simulation facilities. However, due to a need for more reliable understanding of the synergistic effects of LEO environment on composites and proper selection and development of polymer-based composite materials, the construction of a ground simulation facility of LEO space environment which is characterized by the presence of variable LEO space environment constituents as many as possible is thus required.

In this study, the characteristics of LEO environment simulation facility developed in Smart Structures and Composite Materials Laboratory at Korea Advanced Institute of Science and Technology are briefly introduced and described.

## 2. SPACE ENVIRONMENT SIMULATION FACILITY

A LEO space environment simulation facility characterized by high vacuum ($10^{-5}$-$10^{-6}$Torr), UV radiation (<200nm wavelength), thermal cycling (-70°C-100°C), and atomic oxygen atmosphere (kinetic energy of ~5eV and nominal flux of ~$10^{15}$ atoms/$\text{cm}^2\cdot\text{s}$) were manufactured to study the characteristics of composite materials under LEO space environment. Fig. 1 presents the schematic of the simulation facility.

### *2.1. High Vacuum System*

The vacuum chamber of a size of 500ϕ×400H(mm) was manufactured with stainless steel which has good resistant property to deformation and outgassing caused by thermal cycling and high vacuum. Pumping system is composed of both rotary and diffusion pumps for low and high vacuums, respectively, to produce system pressure on the order of $10^{-6}$ Torr at a gas extraction rate of 10 L/s.

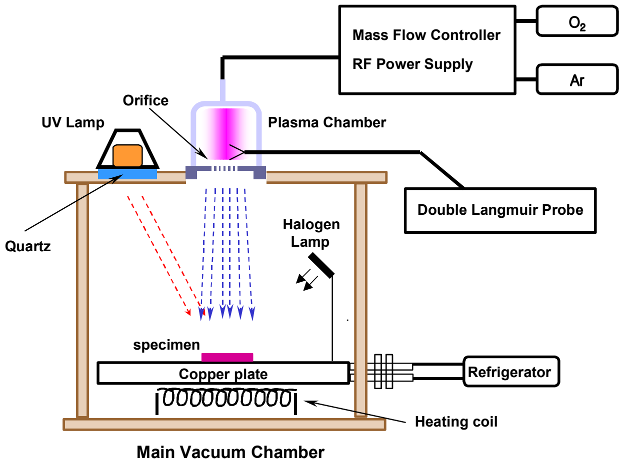

Fig. 1 LEO space environment simulation facility

### *2.2. UV Radiation Source*

UV radiation in LEO environment is of the wavelength of 100-200 nm [1]. UV radiation source in the simulation facility was thus manufactured to have its wavelength of less than 200nm.

### *2.3. Thermal Cycling System*

Thermal cycling of +150°C to -150°C takes place on between sun-facing and shadow-facing of spacecraft operating in LEO [1]. The thermal cycling generates microcracks in matrix of composite materials and thus deteriorates the mechanical properties of composite materials.

The solar radiation temperature in space environment was reproduced using halogen lamp inside the chamber, and temperature cooling was reproduced circulating re-usable coolant. The maximum and minimum operating temperatures were 100°C and -70°C, respectively, and it takes about 90 minutes for a thermal cycle.

### *2.4. Atomic Oxygen Generation System*

In the LEO of altitudes approximately from 200 to 700 km, a major neutral constituent which is very hazardous toward polymers is AO. Surface erosion, degradation in mechanical, thermal and optical properties, and changes in chemical compositions of polymers can be resulted through the collision with AO [1]. At the altitude of about 300 km, the densities of AO during maximum and minimum solar activities are approximately $2\times10^9$ and $8\times10^9$ atoms/cm$^3$, respectively. If a spacecraft orbits at the altitude at a velocity of 8 km/s, it would be encountered with AO particles with kinetic energy of about 5eV and the nominal AO flux range be $10^{14}$–$10^{15}$ atoms/cm$^2$s [1].

Table 2 Sizes of orifices used

| Orifice | Number of holes | Hole diameter (mm) | Total area of holes (mm$^2$) |
|---|---|---|---|
| A | 61 | 2 | 191.64 |
| B | 154 | 1 | 120.95 |
| C | 119 | 1 | 93.46 |
| D | 69 | 1 | 54.19 |
| E | 69 | 1 | 26.55 |

Atomic oxygen generation system equipped in the simulation facility (Fig. 1) generates weakly ionized remote oxygen plasma created with a RF generator. The system is mainly operated through gas ($O_2$ and Ar) supply and 600W, 13.56Mhz RF power supply. Controlling gas flow rate of $O_2$ and Ar, RF power, and orifice size, the optimum AO flux was found for this study. Table 2 shows 5 different orifice sizes used.

Vacuum condition of the main vacuum chamber (Fig. 1) was measured using the 5 different orifices at gas flow rates of $O_2$ and Ar of 2.5 sccm and 0.0 sccm, respectively. The orifices without exception satisfied the vacuum condition for LEO space environment. Since it is recommended that the orifice size used for this system must be as large as possible due to the conductance of plasma from plasma chamber to main chamber, the largest orifice of 2mm diameter, 61 holes, was likely to be used in this system.

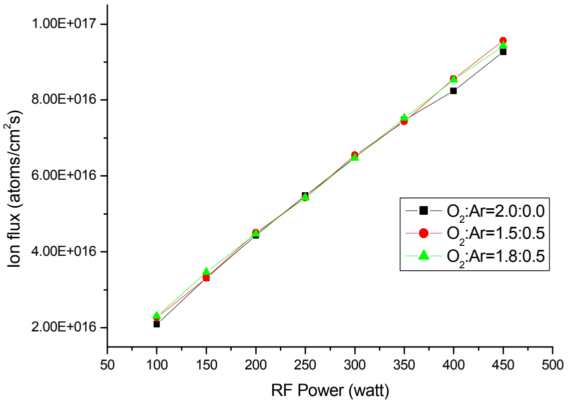

Fig. 3 Ion flux vs. RF power (2mm, 61holes orifice)

AO flux was measured with Double Langmuir Probe (DLP2000-S400$^{TM}$ Plasmart, Inc.). Ion (charged particle) flux measurement rather than neutral radical flux was conducted because it was observed that the density of neutral radicals is higher than that of charged particles in plasma state [2,3].

Figure 3 depicts ion fluxes of few gas flow rate variables as a function of RF power with an orifice of 2mm diameter, 61 holes. Typically, ion flux increases linearly with power, and little Ar flow added to $O_2$ flow generates more AO flux than only $O_2$ gas flow supply because the fraction of O with respect to $O_2$ molecules is enhanced due to the reaction Ar metastables with $O_2$. It was known from the experimental plots shown in Fig. 3 that the ion flux with Ar flow added to $O_2$ flow was not sufficiently higher than that without Ar flow, rather it was less due to too much pressure in plasma chamber through the addition of Ar. Moreover, the ion flux of AO would be less due to the existence of Ar ion in the ion flux. The addition of Ar flow was thus not considered for the optimum gas flow rate in this system.

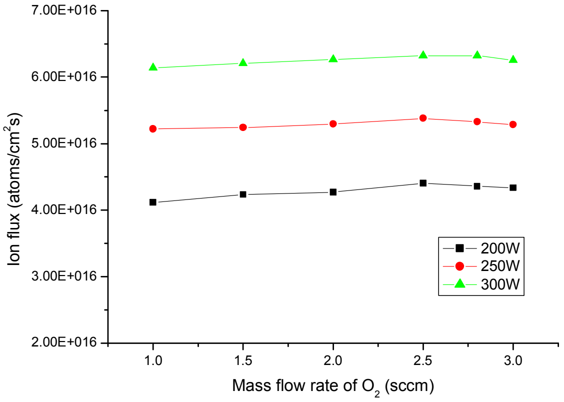

Fig. 4 Ion flux vs. $O_2$ gas flow rate

Using an orifice of 2mm diameter, 61 holes and only $O_2$ gas flow supply, maximum ion flux was measured as shown in Fig. 4. The maximum ion fluxes with RF powers of 200W, 250W and 300W were found to be $4.41\times10^{16}$ atoms/cm$^2$s, $5.38\times10^{16}$ atoms/cm$^2$s, and $6.33\times10^{16}$ atoms/cm$^2$s, respectively, at a gas flow rate of 2.5 sccm.

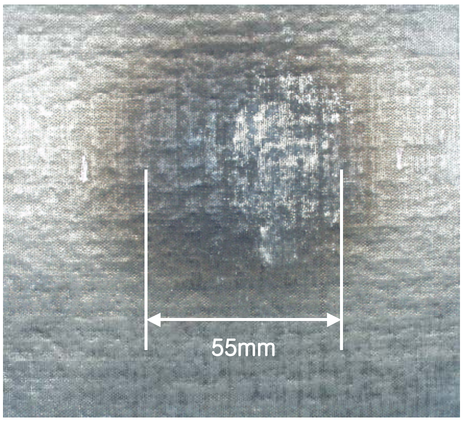

Fig. 7. Sample specimen exposed to AO beam

In this study, only $O_2$ gas flow at a rate of 2.5sccm was supplied; an orifice with 61 holes of 2mm diameter (total area of holes=191.64mm$^2$) was used; and RF power was set at 200W. Under these conditions, atomic oxygen ion flux was approximately $4.4 \times 10^{16}$ atoms/cm$^2$s and ion energy was about 5eV.

The divergence angle was determined by AO beam diameters as a function of distance from orifice to sample specimen, measured through exposing the sample specimen to the beam at 91mm below the orifice. Fig. 7 shows AO beam diameter on the sample specimen exposed to the beam for 24 hours. Obtaining the values of the diameters of orifice and core AO beam and the distance between them, the divergence angle was calculated and was approximately $6.27^{\circ}$.

AO flux encountered upon the specimen in this system, which is placed 341mm below the orifice (Fig. 1), was determined to be approximately $4.46 \times 10^{15}$ atoms/cm$^2$s and plasma energy was about 5eV. Relative to the nominal AO flux in LEO (250 km, $\Phi \approx 3 \times 10^{14}$ atoms/cm$^2$s), the AO flux in this system was determined to have a test acceleration factor of about 15, which is suitable for accelerated testing of AO environment simulation.

## 3.DISCUSSIONS

A LEO space environment simulation facility capable of simulating major LEO conditions have been designed and manufactured. The simulation capability of the facility was tested and qualified.

The investigation of synergistic effects of LEO space environment on composite materials through the LEO space environment simulation facility will be performed afterward.

## REFERENCES

1) Tennyson, R. C., Composites in Space Challenges and Opportunities, Proceedings of ICCM-10, 1995
2) Cvelbar, U., Pejovnik, S., Mozetie, M., Zalar, A., Increased Surface Roughness by Oxygen Plasma Treatment of Graphite/Polymer Composite, Applied Surface Science 210, 255-261, 2003.
3) Hikosaka, Y., et al., Realistic Etch Yield of Fluorocarbon Ions in SiO2 Etch Process, BAPSGEC98, 1998.