Influence of Space Radiation Model Uncertainties on the Solar Absorptance Evaluation of OSR Second Reflector

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Abstract. Space radiation model uncertainties may have important influence on the evaluation of thermo physical properties of anti-electrostatics thermal control materials. The sources of space radiation model uncertainties are analyzed and the uncertainty factor is defined firstly, then the simulation test was performed on the surface resistivity of OSR in electron or proton radiation environments. After that, the influence of space radiation model uncertainties on the solar absorption of OSR was analyzed. As the increase of irradiation fluence, the influence of space radiation model uncertainties on the solar absorption increases firstly and then decrease utile it can be ignored. The influence of space radiation model uncertainties on surface resistivity of OSR increases with the uncertainty factor. When the uncertainty factor lower than 1, the error from space radiation model uncertainty to surface resistivity of OSR is positive, while the uncertainty factor larger than 1, the error is negative.

1. Introduction

The exterior surface of spacecrafts is supposed to have a low ratio of solar absorption to emissivity. This can be accomplished by applying suitable ‘white’ pigments blended with organic, semi organic or inorganic binders to the exterior surface of the spacecraft [1-2]. Among the common thermal control coatings, optical second reflector (OSR), has excellent properties and is widely used in outer surface of satellites [3].

In the ground simulation test of OSR secondary surface mirror under space energetic particle radiation environments, the mature AE8/AP8 model is usually used to analyze the on-orbit space radiation environment. However, since these models are statistical average models and are limited by the range of detection capabilities and detection data, as well as the effects of solar activity, whether they are homosexual, and the drift of the South Atlantic anomaly region, the difference between space radiation environment models and many on-orbit detection data is 2 to 3 times, and even in some high-orbit regions, there is even a difference of 10 times [3-5].

Although there is a unified understanding of the uncertainty of the space radiation environment model at home and abroad, little research has been done on the influence of the space radiation environment model on the ground material simulation test of aerospace materials. At present, the world's major space powers reduce the impact of uncertainty of radiation environment model on spacecraft design by increasing the design margin [6-7].

In this paper, the antistatic performance of OSR under electron and proton irradiation is studied firstly, and the influence of different uncertainty on its performance is studied.
2. Uncertainty of the Model of Space Radiation Environment

2.1. Source of Uncertainty

Although the new generation of space proton and electron radiation environment models named as AP9 and AE9 separately have been developed and gradually tried, the AP8 and AE8 models are still used in most of the spacecraft development process in China. The uncertainty of these two space radiation environment models mainly comes from the following aspects:

The first is the dependence of the model on the solar activity cycle. The AE/AP model can only provide the flux of space radiation environments in solar activity Valley or the solar activity peak year and its nearby, but cannot provide the change of space radiation environments during the solar activity period.

The second is the transient of space radiation environments. The AE/AP model is a statistical model. They provide the average flux for 6 months or even longer periods, which is more accurate, especially for the high latitude temporary change caused by geomagnetic disturbance.

The third is the directionality of space radiation environments. The AE/AP model provides only omnidirectional fluxes rather than arbitrary angles.

The fourth is the extrapolation of energy. In the case of proton, the proton energy spectrum of the AP8 model below 10MeV is the extrapolation of the flight data, and the accuracy of these extrapolation data remains to be evaluated.

The fifth is the drift of the space radiation environments in the southern Atlantic anomaly (SAA). In the case of proton, proton flux moves westward at 0.3 degrees a year at low latitudes and high intensity SAA regions due to long-term geomagnetic changes. AP8 can not accurately predict the correct geographical location of the flux in the SAA region, but it is possible to forecast the AP8 flux to drift westward to the AP8 database at 0.3 degrees per year. At a height below 800km, the NOAA satellite data combined with the NOAAPRO model can be used to accurately handle the drift of the SAA.

2.2. Uncertainty Factor

The uncertainty of the model of space radiation environment can be characterized by the uncertainty factor (UF). Here, the UF is defined as the ratio deviation between the actual radiation environments to theoretical radiation environment.

\[
UF = \frac{F_f - F_M}{F_M}
\]  

Here:

- \(F_f\) is the actual fluence, its unit is cm\(^{-2}\);
- \(F_M\) is the theoretical fluence, its unit is cm\(^{-2}\);
- UF is generally associated with solar activity. The surface functional materials of the spacecraft are related to the type and energy of the particles selected for the ground simulation test.

2.3. Relative Deviation

Relative deviation can be used to characterize the influence of the uncertainty of the fluence on the performance of the test sample.

\[
\frac{\Delta x}{x_0} = \frac{x - x_0}{x_0}
\]  

Here, \(\Delta x\) is the absolute variation of the measured performance of sample under different uncertainty factors; \(x_0\) is the value of the measured performance when the uncertainty factor is 1; \(x\) is the performance of the sample with a certain uncertainty factor except 1.
3. Test and Results

A combined environment test facility was used to expose the samples at Beijing Institute of Spacecraft Environment Engineering (BISSE). In the experiment, the working pressure was better than $4 \times 10^{-3}$ Pa, and the sample temperature was kept to 30°C.

The energy of simulated electron is 40keV, the flux of electron is 8.456nA/cm², which is $5 \times 10^{10}$ e/cm²·s, the fluence of electron is $5 \times 10^{15}$ e/cm². The solar adsorption of OSR was measured when the irradiation fluence is 0, $0.924 \times 10^{15}$ e/cm², $2.097 \times 10^{15}$ e/cm², $3.323 \times 10^{15}$ e/cm², $3.969 \times 10^{15}$ e/cm², $5.113 \times 10^{15}$ e/cm², $6.405 \times 10^{15}$ e/cm², $7.495 \times 10^{15}$ e/cm², $8.725 \times 10^{15}$ e/cm², $9.488 \times 10^{15}$ e/cm² separately.

The energy of simulated proton is 40keV, the flux of proton is 0.8456nA/cm², which is $5 \times 10^{9}$ e/cm²·s, the fluence of proton is $5 \times 10^{15}$ e/cm². The solar adsorption of OSR was measured when the irradiation fluence is 0, $1.5 \times 10^{14}$ e/cm², $3 \times 10^{14}$ e/cm², $5 \times 10^{14}$ e/cm², $7 \times 10^{14}$ e/cm², $10 \times 10^{14}$ e/cm², $13 \times 10^{14}$ e/cm², $16 \times 10^{14}$ e/cm², $20 \times 10^{14}$ e/cm², $25 \times 10^{14}$ e/cm², $30 \times 10^{14}$ e/cm² separately.

In order to obtain the real space effect, the solar adsorption of OSR was measured in the vacuum chamber by an in-situ measuring system [6].

The solar absorptance and fitting analysis of OSR under different electron irradiation fluencies are shown in Fig.1.

![Figure 1. Solar absorptances of OSR in different electron fluencies](image)

It is known from Fig.1 that the solar absorptivity of the OSR by electron irradiation increase exponentially with the electron fluencies as,

$$y = 0.0976 - 0.0272 \exp \left( -\frac{x}{0.782} \right)$$

(3)

Here, $y$ is solar absorptance, $x$ is electron fluencies and its unit is $10^{15}$ e/cm².

The solar absorptance and fitting analysis of OSR under different proton irradiation fluencies are shown in Fig.2.
It is known from Fig. 2 that the solar absorptivity of the OSR by proton irradiation increase exponentially with the proton fluencies as,

$$y = 0.1325 - 0.0501 \exp\left(-\frac{x}{7.449}\right)$$

Here, $y$ is solar absorptance, $x$ is proton fluencies, its unit is $10^{14}$p/cm$^2$.

4. Influence of the Uncertainty of Space Radiation Environment Model on the Solar Absorptance of OSR

The electronic radiation environment model and the proton radiation environment model are still dominated by AE8 and AP8, and the uncertainty factor is 2. In this study, 0.5, 2, 5 and 10 were selected as uncertainty factors respectively.

4.1. Influence of the Uncertainty of Electron Radiation Environment Model on the Solar Absorptance of OSR

According to the formula (3), the solar absorptance variety of ITO/Kapton/Al film in different uncertainties of electron environment model is calculated and analyzed, as shown in Fig. 3.
From table 1 and Fig.4, we can see that the error is less than 1% when the uncertainty factor is 0.5 and the electron flux is $5.2 \times 10^{15} \text{ e/cm}^2$, or the error is less than 2% when the uncertainty factor is 2, 5 or 10, and the electron flux is $2.0 \times 10^{15} \text{ e/cm}^2$.

### 4.2. Influence of the Uncertainty of Proton Radiation Environment Model on the Solar Absorptance of OSR

According to the formula (4), the solar absorptance variety of OSR in different uncertainties of proton environment model is calculated and analyzed, as shown in Fig.5.

![Figure 5. Solar absorptance variety of OSR under proton environment with different uncertainties](image)

The comparison between errors in different uncertainties is shown in Fig.6.
Figure 6. Comparison between errors from uncertainty of proton environment model

From table 2 and Fig. 6, we can see that the error is less than 5% when the uncertainty factor is 0.5 and the proton flux is $30 \times 10^{14}$ p/cm$^2$, or the error is less than 1% when the uncertainty factor is 2, 5 or 10, and the electron flux is $30 \times 10^{14}$ e/cm$^2$. Then, the error gradually decreases with the fluence, and its influence can be negligible.

5. Conclusions

From the study of the solar absorptance variety of OSR irradiated by electrons and protons, following conclusions can be obtained.

(1) The uncertainty of the space radiation environment model has a great influence on the solar absorptance of OSR. With the increase of the radiation fluencies, the influence of the uncertainty on the solar absorptance of it decreases. When certain fluence is reached, the influence of UF can be neglected.

(2) The influence of uncertainty on the solar absorptance of OSR increases with the UF.

(3) When the UF is less than 1, the influence of the uncertainty of space radiation environment model on the solar absorptance of OSR is negative. When the UF is larger than 1, it is positive.

6. References

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