INFLUENCE OF SPACE RADIATION MODEL UNCERTAINTIES ON THE THERMOPHYSICAL PROPERTIES EVALUATION OF ITO/KAPTON/AL FILM

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ABSTRACT

Space radiation model uncertainties may have important influence on the evaluation of thermophysical 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 solar absorptance of ITO/Kapton/Al film in electron or proton radiation environments. After that, the influence of space radiation model uncertainties on the solar absorptance of ITO/Kapton/Al film was analyzed. As the increase of irradiation fluence, the influence of space radiation model uncertainties on the solar absorptance increases firstly and then decrease utile it can be ignored. The influence of space radiation model uncertainties on surface resisitiviyt of ITO/Kapton/Al film increases with the uncertainty factor. When the uncertainty factor lower than 1, the error from space radiation model uncertainty to surface resisitivity of ITO/Kapton/Al film is negative, while the uncertainty factor larger than 1, the error is positive.

INTRODUCTION

During the course of lifetime, spacecraft will be subjected to some space environments such as extreme temperature, energetic particles, plasma, etc, which can cause some effects such as dramatic changes in temperature, charging and discharging. Therefore, the antistatic thermal control coating is usually used on the outer surface of the spacecraft to control the temperature and prevent the charging and discharging effect [1-2]. The ITO/Kapton/Al film as an antistatic thermal control coating with excellent performance is often be used in all kinds of orbit spacecraft.

In the process of ground simulation test to evaluate the thermal control performance especially solar absorptance of the ITO/Kapton/Al film on orbit, the AE8/AP8 models are usually be used to analyze the radiation environments of it will be encounter. Space environmental models used in ground simulation test are based on satellite data. But the models are inaccurate for a consequence of uncertainties in these measures due to instrument calibration and characterization difficulties, extrapolation and interpolation procedures employed in constructing models, representatives of the periods measured, etc. For example, space radiation environmental model AE-8/AP-8 is accurate to within a factor 2, that is, the uncertainty factor of AE-8/AP-8 model is 2.

In order to improve the precision of space environment model, "confidence level" is introduced to evaluate the reliability of the models. For example, AE-9/AP-9 models can supply space radiation model with different confidence level for ground simulation test and analysis.

Although there is a unified understanding of the uncertainty of the space radiation environment model at home and abroad, there is little research on the influence of the space radiation environment model on the ground material simulation test of spacecraft materials. At present, the main space countries are to reduce the impact of uncertainty on space design by increasing the design margin [6-7].

In this paper, we studied the antistatic performance of ITO/Kapton/Al under the action of space electron and proton irradiation firstly, and then we studied the influence of different uncertainties of space radiation models on the performance evaluation of it.

UNCERTAINTY OF SPACE RADIATION ENVIRONMENT MODEL

1.1 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.

1.2 Uncertainty factor

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

$$UF = \frac{F_f}{F_M}$$

Here:

F_f is the the actual fluence of an space environment , its unit is cm^{-2};

F_M is the fluence of the space radiation environment model, its unit is cm^{-2}.

UF is generally related to solar activity. For the functional materials on the surface of the spacecraft, UF are related to the type and energy of the selected particle used in ground simulation tests.

1.3 Relative deviation

Relative deviations can be used to characterize the influence of the uncertainty of the space radiation environment model on the property of the test parts.

$$\frac{\Delta x}{x_0} = \frac{x - x_0}{x_0}$$

Here, Δx is the absolute varaity of the measured performance of samples 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.

EXPERIMENTS AND TESTS

2.1 Sample Preparation

The test samples are ITO/kapton/Al antistatic thermal control film. The thickness of ITO, kapton, Al is 0.1μm, 50μm, 0.1μm separately.

2.2 Exposure Facility

A low-energy combined environment test facility was used to expose the samples at Beijing Institute of Spacecraft Environment Engineering (BISSE), as shown in Fig. 1. This facility is capable of providing a simulated space environment consisting of low-energy electrons, low-energy protons, NUV (near ultraviolet), FUV (far ultraviolet), as well as neutral plasma, thermal cycling, and vacuum. The detailed facility has been described somewhere else. [12] The α_s, spectral reflectance, spectral transmittance, surface resistance, and mechanical properties of test specimens can be measured *in situ*.

Fig.1. Low-energy combined environmental test facility

2.3 Test Parameters

The test samples irradiated by electron generated by electron gun with energy of 40keV, the beam density of it is 8.456nA/cm^2, and the fluencies at which to test their absorptions are 0 、 0.924×10^{15}e/cm^2, 2.097×10^{15}e/cm^2, 3.323×10^{15}e/cm^2, 3.969×10^{15}e/cm^2, 5.113×10^{15}e/cm^2, 6.405×10^{15}e/cm^2, 7.495×10^{15}e/cm^2, 8.725×10^{15}e/cm^2, 9.488×10^{15}e/cm^2 separately. The proton generated by proton sources with energy of 40keV was used as irradiation energy, the beam density of it is 0.8456nA/cm^2, and the fluencies is 0,1.5×10^{14}e/cm^2, 3×10^{14}e/cm^2, 5×10^{14}e/cm^2, 7×10^{14}e/cm^2, 10×10^{14}e/cm^2, 13×10^{14}e/cm^2,

16×10^{14}e/cm^2, 20×10^{14}e/cm^2, 25×10^{14}e/cm^2, 30×10^{14}e/cm^2 separately. The facility was internally surrounded by a cold shroud which was kept at about -35℃ by a (freezer). Because of this, the samples were fixed on a metal sample mount whose temperature was maintained at about 20℃ by a (thermostatically control system) to help keep the sample temperature constantly to be much higher than the shroud. The system was kept at a vacuum better than 3.0×10^{-3}Pa by a turbo-molecular pump backed up by a mechanical pump.

THERMAL PROPERTIES

The solar absorptance and fitting analysis of ITO/Kapton/Al film under different electron irradiation fluencies are shown in Fig.2.

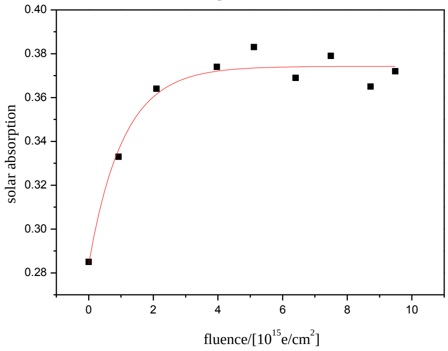

Fig.2. Solar absorptances of ITO/kapton/Al film in different electron fluencies

It is known from Figure 3 that the solar absorptivity of the ITO/Kapton/Al by electron irradiation increase exponentially with the electron fluencies as,

$$y = 0.374 - 0.0901\exp\left(-x/1.070\right)$$

Here，y is solar absorptance, x is electron fluencies, its unit is 10^{15}e/cm^2。

The solar absorptance and fitting analysis of ITO/Kapton/Al film under different proton irradiation fluencies are shown in Fig.3.

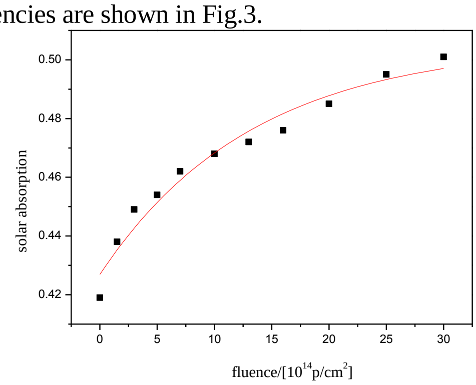

Fig.3. Solar absorptances of ITO/kapton/Al film in different proton fluencies

It is known from Figure 4 that the solar absorptivity of the ITO/Kapton/Al by proton irradiation increase exponentially with the proton fluencies as,

$$y = 1.811 + 1.793/[1 + \exp((x - 7.233)/1.281)]$$

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

INFLUENCE OF THE UNCERTAINTY OF SPACE RADIATION ENVIRONMENT MODEL ON THE PROPERTIES OF SAMPLES

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 evaluation of ITO/Kapton/Al film

According to the formula (1), the solar absorptance variety of ITO/Kapton/Al film in different uncertainties of electron environment model is calculated and analyzed, as shown in Fig.4.

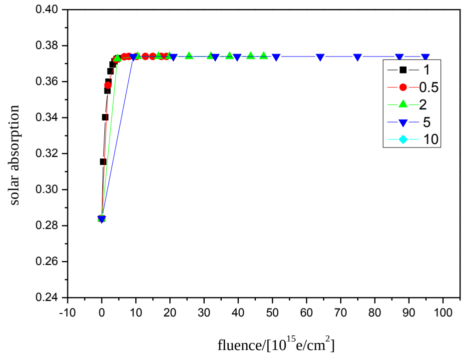

Fig.4. Solar absorptance variety of ITO/Kapton/Al under electron environment with different uncertainties

The error analysis for different uncertainties is shown in Table 1, and the comparison between errors in different uncertainties is shown in Fig.5.

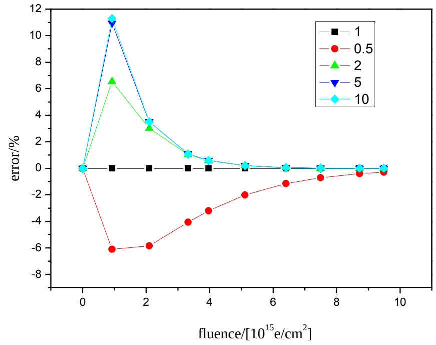

Fig.5. Comparison between errors from uncertainty of electron environment model

Table 1 calculation error caused by different uncertainties (%) [electron fluence/（10^{15} e/cm^2）]

fluence	UF				
	0.5	1	2	5	10
0	0	0	0	0	0
0.924	-6.10555	0	6.539146	10.94935	11.30202
2.097	-5.84683	0	3.018316	3.5119	3.513284
3.323	-4.06358	0	1.042109	1.090977	1.090982
3.969	-3.19913	0	0.579035	0.593574	0.593574
5.113	-2.0106	0	0.201274	0.202981	0.202981
6.405	-1.14799	0	0.060443	0.060595	0.060595
7.495	-0.70407	0	0.021851	0.02187	0.02187
8.725	-0.4016	0	0.006925	0.006927	0.006927
9.488	-0.2826		0.003395	0.003395	0.003395

From table 1 and Fig.6, we can see that the error is less than 1% when the uncertainty factor is 0.5 and the electron flux is 6.5×10^{15} e/cm^2, or the uncertainty factor is 2, 5 or 10, and the electron flux is 3.4╳10^{15} e/cm^2.

4.2 Influence of the uncertainty of proton radiation environment model on the solar absorptance evaluation of ITO/Kapton/Al film

According to the formula (2), the solar absorptance variety of ITO/Kapton/Al film in different uncertainties of proton environment model is calculated and analyzed, as shown in Fig.6.

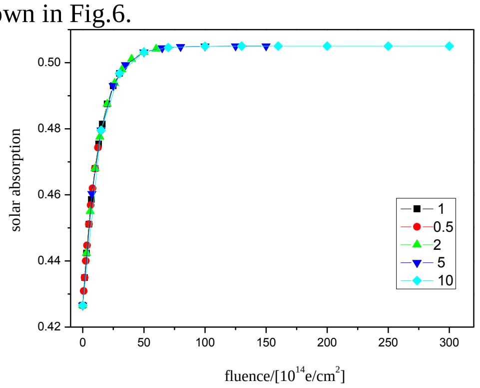

Fig.6. Solar absorptance variety of ITO/Kapton/Al under proton environment with different uncertainties

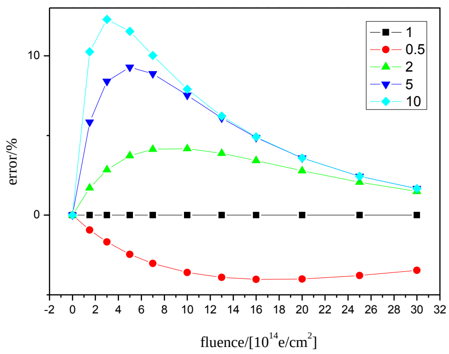

Fig.7. Comparison between errors from uncertainty of proton environment model

The error analysis for different uncertainties is shown in Table 2, and the comparison between errors in different uncertainties is shown in Fig.7.

Table 2 Calculation error caused by different uncertainties (%) [proton fluence/（10^{14} p/cm^2）]

fluence	UF				
	0.5	1	2	5	10
0	0	0	0	0	0
1.5	-0.93191	0	1.7137	5.836402	10.25488
3	-1.68483	0	2.850978	8.397278	12.28311
5	-2.4631	0	3.734975	9.279286	11.53619
7	-3.03531	0	4.130283	8.874434	10.02342
10	-3.6005	0	4.175613	7.520328	7.905242
13	-3.90758	0	3.874112	6.094875	6.219896
16	-4.03273	0	3.428196	4.865709	4.906009
20	-4.00824	0	2.788066	3.580136	3.589034
25	-3.78917	0	2.065259	2.438097	2.439448
30	-3.46074	0	1.48856	1.663787	1.663993

From table 2 and Fig.8, we can see that the error is less than 4% when the uncertainty factor is 0.5 and the proton flux is 20×10^{14} p/cm^2, or the error is less than 2% when the uncertainty factor is 2, 5 or 10, and the electron flux is 30×10^{14} e/cm^2.

CONCLUSIONS

From the study of the solar absorptance variety of ITO/Kapton/Al films 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 ITO/Kapton/Al film. With the increase of the radiation fluencies, the influence of the uncertainty on the solar absorptance of it decreases. When a certain fluency is reached, the influence of UF can be neglected.

(2) The influence of uncertainty on the solar absorptance of ITO/Kapton/Al film 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 ITO/Kapton/Al film is negative. When the UF is larger than 1, it is positive.

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