Electrical Properties of ITO/Kapton/Al Anti-Static Thermal Control Coating in Space Radiation Environments

Xiaolin QIU[1], YiRen ZHOU[1], Zicai SHEN[2]

[1] Nanchang Institute of Technology, Nachang 330044, China
[2]Beijing Institute of Spacecraft Environment Engineering, Beijing 100094, China

***Abstract* — ITO/Kapton/Al anti-static thermal control coating has excellent properties and is widely used in satellite surface to adjust the temperature in space. Besides its ability of thermal control, it can mitigate static electricity by depositing with ITO coating. But in space radiation environments, its electrical property can be damaged and even results in the loss of anti-static. In this paper, the electrical property of ITO/Kapton/Al anti-static thermal control coating are tested in simulated space radiation environments including electron, proton, and ultraviolet. Results show that the surface resistivity of ITO/Kapton/Al coating has a sharp decrease in the early irradiation stage, and then decreases slowly as the increase of flux. In the electron and ultraviolet irradiation environments, the surface resistivity of ITO/Kapton/Al coating decreases in second order index with the increases of irradiation flux, but in proton environment, its surface resistivity decreases in Boltzman function with the increases of irradiation flux.**

Keywords - Kapton, coating, irradiation

I. INTRODUCTION

The design of a spacecraft usually requires its exterior surface having a suitable ratio of solar absorption to emittance, this can be accomplished by applying thermal control coating which is important part of spacecraft thermal control system. Among thermal control coatings, Kapton/Al second surface mirror is a major material, and widely used on the surface of satellite.

But during the course of lifetime, satellite in orbit, especially in GEO (Geosynchronous Earth Orbit), will encounter space radiation environments such as electron, proton, and plasma, etc, and results in the severe surface charging and discharging of satellite. So ITO conductive layer was deposited on the surface of Kapton/Al to eliminate ESD (Electrostatic Discharge) threat, which induced by electron and plasma environments.

Under the effect of space radiation environments such as electron, proton, ultraviolet, electrical property of ITO/Kapton/Al thermal control material may be damaged and degradation, so it is essential to evaluate the electrical property change in radiation environments.

In this paper, simulated radiation environments such as electron, proton, ultraviolet was used to irradiate the ITO/Kapton/Al coating, and electrical property of it was tested. At last, damage mechanism of the ITO/Kapton/Al coating in radiation environments was studied.

II. SAMPLE AND MEASUREMENT

The structure of ITO/Kapton/Al materials as Fig.1, and the thickness of ITO is about 0.1μm. Before and after radiation by electron, proton, or ultraviolet, the electrical property of ITO/Kapton/Al materials were in-situ tested by surface resistivity testing apparatus, its key diagram and structure are listed Fig.2 and Fig.3. X ray photoelectron spectroscopy was used to analyze the component and surface topography.

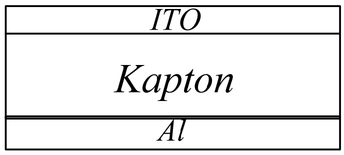

Fig.1. Structure of OSR second surface mirror.

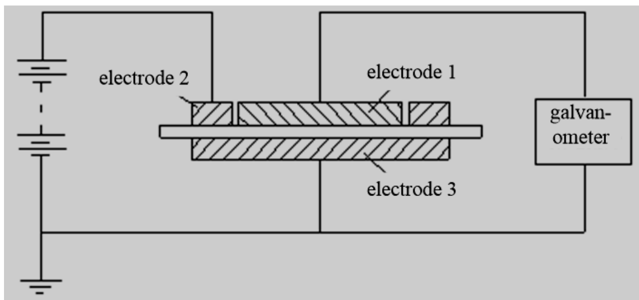

Fig.2. Schematic diagram of surface resistivity testing

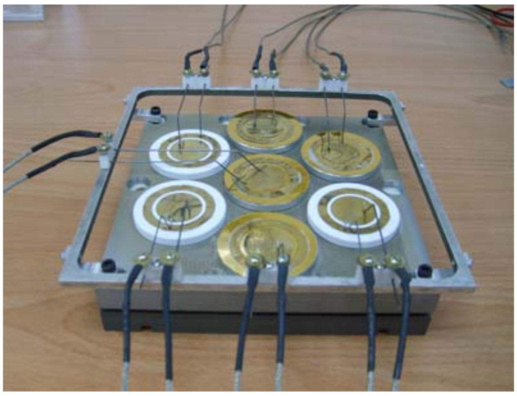

Fig.3. Arrangement of surface resistivity testing.

III. TEST

The test was performed in a low-energy combined environment test facility built by Beijing Institute of Spacecraft Environment Engineering (BISSE), as shown in Fig.4. This facility can provide environments of low-energy electrons, low-energy protons, NUV (near ultraviolet), FUV (far ultraviolet), or neutral plasma, thermal cycling, and vacuum.

Fig.4. Low-energy combined environment test facility.

Main testing parameters listed in Table 1, Table 2 and Table 3.

TABLE 1 TESTING PARAMETERS OF ELECTRON RADIATON

energy	beam current	fluence	vacuum	sample tempret ure
40Kev	8.456nA/cm^2	2.0×10^{16}e /cm^2	<10^{-3}Pa	30℃

TABLE 2 TESTING PARAMETERS OF PROTON RADIATON

energy	beam current	fluence	vacuum	sample tempreture
40Kev	0.8456nA/cm^2	2.5×10^{15} *p/cm^2*	<10^{-3}Pa	30℃

TABLE 3 TESTING PARAMETERS OF VACUUM ULTRAVIOLET RADIATON

energy	Irradiance	Accelerate factor	vacuum	sample tempretu re
1000W	500ESH±10%	4SC	<10^{-3}Pa	30℃

IV. RESULTS

1) Surface resistivity of ITO/Kapton/Al in electron radiation

Surface resistivity of ITO/Kapton/Al in different electron radiation fluencies are listed in Table 4.

TABLE 4 SURFACE RESISTIVITY VARIETY OF ITO/KAPTON/AL IN DIFFERENT ELECTRON RADIATION FLUENCIES

Fluence/10^{14}e/cm^2)	0	1	2	5	10
Surface resistivity /10^4 Ω/□	4.58	1.71	1.31	0.840	0.604
Fluence/10^{14}e/cm^2)	30	50	100	150	200
Surface resistivity /10^4 Ω/□	0.383	0.312	0.258	0.214	0.188

From Table 4, we know that the surface resistivity of ITO/Kapton/Al in electron radiation decreases sharply at the beginning of radiation, and then gradually decrease with electron fluencies. This illustrated electric conduction of ITO/kapton/Al increases with electron radiation.

Fitting the surface resistivity of ITO/Kapton/Al radiated by electron as illustrated in Fig.5.

The surface resistivity of ITO/Kapton/Al exponentially decreases with electron radiation. The fitted expression between surface resistivity of ITO/Kapton/Al and electron radiation fluencies as follows:

$$y = 0.213 + 1.526\exp(-x/2.162) + 0.548\exp(-x/27.792) \quad (x \ge 1)$$

Here, y is surface resistivity, 104 Ω/□; x is electron fluence, 10^{14} e/cm^2.

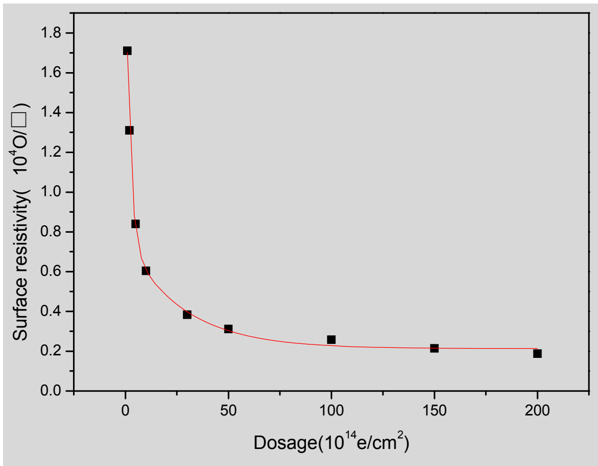

Fig.5. surface resistivity variety of ITO/Kapton/Al in electron radiation

2) Surface resistivity of ITO/Kapton/Al in proton radiation

Surface resistivity of ITO/Kapton/Al in different proton radiation fluencies are listed in Table 5.

TABLE 5 SURFACE RESISTIVITY VARIETY OF ITO/KAPTON/AL IN DIFFERENT PROTON RADIATION FLUENCIES.

Fluence/10^{14}e/cm^2	0	1	2	5	7
Surface resistivity /10^4 Ω/□	3.63	3.62	3.57	3.23	2.88
Fluence/10^{14}e/cm^2)	10	15	20	25	
Surface resistivity /10^4 Ω/□	1.90	1.87	1.83	1.80	

From Table 4, we know that the surface resistivity of ITO/Kapton/Al in proton radiation decreases sharply at the beginning of radiation, and then gradually decrease with proton fluencies. This illustrated electric conduction of ITO/kapton/Al increases with proton radiation.

Fitting the surface resistivity of ITO/Kapton/Al radiated by proton as illustrated in Fig.6.

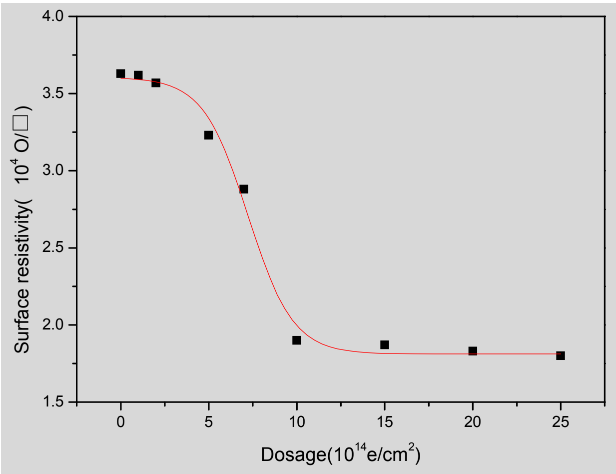

Fig.6. surface resistivity variety of ITO/Kapton/Al in proton radiation.

The surface resistivity of ITO/Kapton/Al exponentially decreases with proton radiation. The fitted expression between surface resistivity of ITO/Kapton/Al and proton radiation fluencies as follows

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

Here, y is surface resistivity, 10^4 Ω/□; x is proton fluence, 10^{14} e/cm^2.

3) Surface resistivity of ITO/Kapton/Al in ultraviolet irradiation

Surface resistivity of ITO/Kapton/Al in different ultraviolet irradiation fluencies are listed in Table 6.

From Table 6, we know that the surface resistivity of ITO/Kapton/Al in ultraviolet irradiation decreases sharply at the beginning of radiation, and then gradually decrease with ultraviolet fluencies. This illustrated electric conduction of ITO/kapton/Al increases with ultraviolet irradiation. Fitting the surface resistivity of ITO/Kapton/Al irradiated by ultraviolet as illustrated in Fig.7.

TABLE 6. SURFACE RESISTIVITY VARIETY OF ITO/KAPTON/AL IN DIFFERENT ULTRAVIOLET IRRADIATION FLUENCIES

Irradiation/ESH)	0	25	50	75	100
Surface resistivity /10^2 Ω/□)	166	7.27	5.03	4.32	4.12
Irradiation/ESH)	150	200	300	400	500
Surface resistivity /10^2 Ω/□)	4.17	4.22	6.36	6.39	6.47

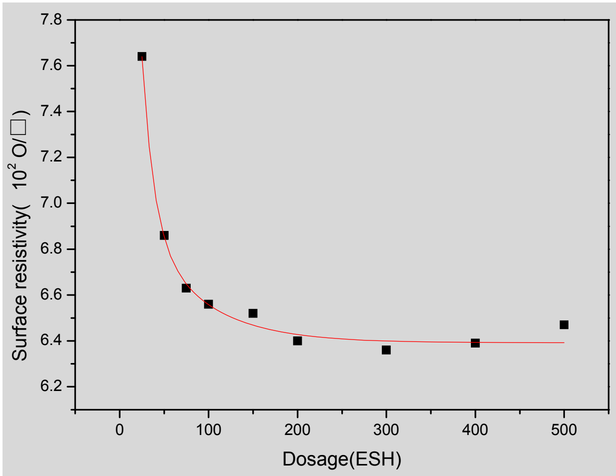

Fig.7. surface resistivity variety of ITO/Kapton/Al in ultraviolet irradiation

The surface resistivity of ITO/Kapton/Al exponentially decreases with ultraviolet irradiation. The fitted expression between surface resistivity of ITO/Kapton/Al and ultraviolet irradiation fluencies as follows:

$$y = 6.391 + 4.778\exp(-x/13.412) + 0.741\exp(-x/66.221) \quad (x \geq 25)$$

Here, y is surface resistivity, 10^2 Ω/□; x is ultraviolet irradiation, ESH.

V. MECHANISM ANALYSIS

XPS was used to analyze the component and energy spectrum of O1s in ITO/Kapton/Al film. Table 7 give the Composition percentage of ITO/kapton/Al before and after near ultraviolet irradiation.

TABLE 7 COMPOSITION PERCENTAGE OF ITO/KAPTON/AL BEFORE AND AFTER NEAR ULTRAVIOLET IRRADIATION

Component percentage	O (At.%)	In (At.%)	Sn (At.%)
before	59.83	36.24	3.93
after	78.97	18.49	2.54

From Table 7, we know that main component of ITO layer which includes In and Sn decrease and this tell us that ITO was damaged by ultraviolet ray.

Further discussion was given to the conductivity property of ITO film. For ITO film is semiconductor, and its

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conductivity of ITO film is current carrier, which from electron from doped Sn and oxygen vacancy. When Sn4+ was plus into lattice of In_2O_3, Sn^{4+} will replace In3+. In order to keep the electrical property is neutral, Sn^{4+} will capture a electron, and turn to $Sn^{3+}(Sn^{4+}+e)$. And the relation between electron and Sn is weak, and the electron become the main source of carrier.

$$SnO_2 \xrightarrow{In_2O_3} 2Sn_{In}^{\square} + 3O_O + O_i^{''}$$

At the same time, another mechanism of conductivity is oxygen vacancy, its mechanism is the escape of oxygen ion (O^{2-}) from crystal lattice.

$$V_O^{2-} \rightarrow V_O + 2e$$

Oxygen vacancy is like a center of positive charge and electron can be bounded. The bound electron was in the place of oxygen vacancy and was shared by nearby In^{3+}, and the energy level is near to conduction band. When the electron obtains energy, it will transit to conduction band, and electrical conductivity of ITO film occurs[6].

Fig.8 and Fig.9 illustrate the Energy spectrum of O in ITO/Kapton/Al before near ultraviolet irradiation and oxygen release from ITO/Kapton/Al radiated by ultraviolet.

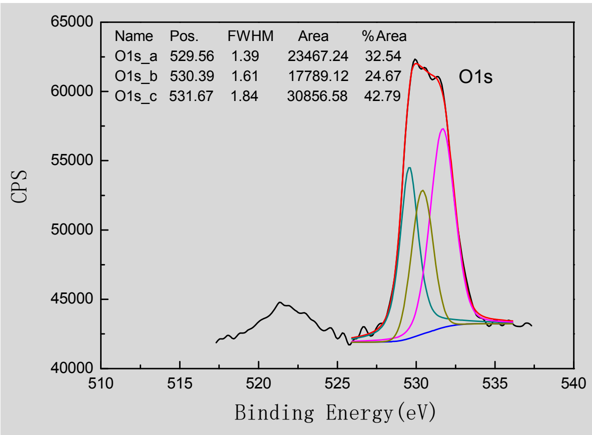

Fig.8. Energy spectrum of O before radiation.

From Fig.9, we know that O1s_a and O1s_c corresponds to oxygen atom and oxygen vacancy in ITO layer, and the oxygen vacancy is relates to carrier.

Mass spectrum testing was performed to test the change of oxygen before and after ultraviolet radiation. Dash line is base vacuum, and solid line is sample in ultraviolet irradiation. Comparing between dash line and solid line, we can see that there was apparent release of oxygen from ITO after ultraviolet irradiation. These illustrated that there was chemical adsorption oxygen release from ITO.

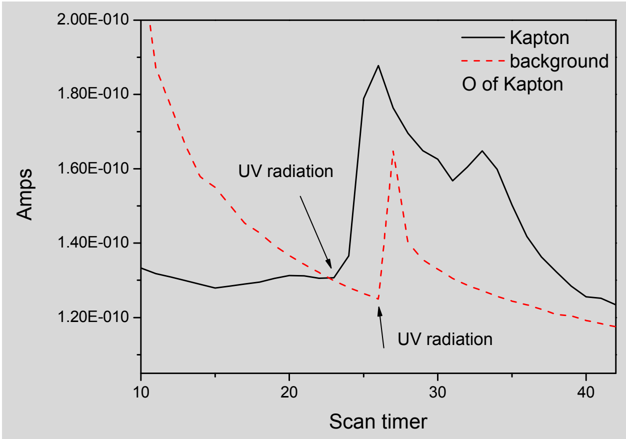

Fig.9. O deflate before and after radiation.

when ultraviolet irradiation was performed, chemical adsorption oxygen was further released. At the same time, bound electrons obtain energy and transit from valence band to conduction band, and resulted in the increase of free electron and conductivity property.

VI. CONCLUSIONS

From above study and discussion, following conclusions can be obtained,

(1) Under radiated by electron, proton, ultraviolet, surface resistivity of ITO/Kapton/Al film exponential decrease sharply and then decreases gradually.

(2) Vacuum has important influence on the surface resistivity of ITO/Kapton/Al film and results in the release of chemical absorption oxygen.

(3) The increase of oxygen vacancy and release of adsorbed oxygen is the origin of decrease of surface resistivity of thermal control film.

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