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Degradation of Thermal Control Coatings Under Influence of Proton Irradiation

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Simulation tests of radiation stability of various thermal control coatings under proton irradiation with particle energies 100–500 keV and particle fluences 10^{14}–2×10^{16} cm^{-2} were done in the Skobeltsyn Institute of Nuclear Physics of Moscow State University on a proton accelerator. Experimental data on change of *As* of paint coatings and mirror coatings as a function of proton fluence and energy are presented. Prediction of *As* changes of the coatings under the impact of proton radiation with distributed energy spectrum in space flight based on ground test results with monoenergetic proton beams is discussed. Estimates of coating degradation in geosynchronous orbit are made in terms of the mathematical model of degradation.

Nomenclature

a, b, β, γ	=	parameters of the model
As	=	optical absorption coefficient
$d\varphi/dE$	=	spectrum distribution function, cm^{-2} keV^{-1}
E	=	energy of protons, keV
F	=	fluence of protons, cm^{-2}
F_{eff}	=	effective fluence of protons, cm^{-2}
ΔAs	=	variation of optical absorption coefficient

Introduction

THE effect of protons of the Earth's radiation belts is one of the main reasons for degradation of thermal control coatings. Laboratory tests of the coatings are performed usually using monoenergetic proton beams. A mathematical model enables us to predict the increase of the optical absorption coefficient value for 0.5–10 years for various coating types in terms of the tests.

Experimental Studies

Tests of thermal control coating (TCC) samples under impact of protons with energies up to 500 keV and fluences from 10^{14} to 2×10^{16} cm^{-2} have been carried out on the KG-500 accelerator in the Skobeltsyn Institute of Nuclear Physics of Moscow State University. The accelerator provides energy stability of 0.1%. All TCC had thickness of 100 μm. Ranges of protons with energies 100–500 keV are 1–10 μm.

The beam current of protons was established not above 1 μA. At the maximal energy of protons (0.5 MeV), the power on the TCC sample was less than 0.5 W, and the temperature of the sample during the irradiation did not exceed 100°C. Temperature of the samples was measured by a microthermoresistor. Proton fluence was measured with accuracy not worse than 1%. Registration of the TCC optical absorption coefficient *As* was carried out with the help of the photometer built in the vacuum chamber. The high value of the proton fluence (2×10^{16} cm^{-2}) was chosen with the purpose of determining the parameters in the function $\Delta As = f(F, E)$ used in physical and mathematical models of TCC optical degradation.[1–3]

Test Results

Data on the TCC tested are presented in Table 1. Experimental results of the TCC *As* coefficient change are presented in Fig. 1 as a function of proton fluence with energy 300 keV. These data give information on relative radiation stability of the tested coatings. For definition of the model parameters, it is necessary to ascertain similar dependences for irradiation of the TCC with protons having various energies. These dependences for EKOM-1 and TR-SO-TSM are presented in Figs. 2 and 3.

Model of Radiation Degradation of Thermal Control Coating Optical Properties

In Ref. 3, the following equation is used for description of the radiation degradation of optical properties of TCC:

$$\Delta As = a[1 - \exp(-bE^{\gamma}F^{\beta})] \tag{1}$$

These parameters are determined in terms of the experimental data presented in Figs. 2 and 3. The values of the model parameters are shown in Table 2.

Parameters of the model are used to forecast *As* coefficient change under the impact of corpuscular radiation with continuous energy spectrum in spacecraft orbit.

For definition of the coating damage under the influence of radiation with continuous energy spectrum with distribution function $d\varphi/dE$, Eq. (1) is transformed as[3]

$$\Delta As = \int_0^{\infty} a[1 - \exp(-bE^{\gamma}\Phi^{\beta})]\frac{d\varphi}{dE}\,dE \tag{2}$$

In Table 3, values of ΔAs for the same TCC under the influence of proton radiation in geosynchronous orbit (GEO) calculated using Eq. (2) are presented.

It follows from the results presented that the radiation stability of the TCC varies significantly.

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Table 1 Coating parameters

No.	TCC type	Pigment	Binding	Color
1	EKOM-1	ZnO	Acryl pitch	White
2	TR-SO-TSM	ZrO_2	Liquid glass	White
3	SS-1	ZnO + Al paste	Acryl pitch	Silver gray
4	EKOM-2	Metal oxides + carbon black	Acryl pitch	Black

Table 2 Parameters of the radiation degradation model

TCC type	a	b	β	γ
EKOM-1	0.48	1.8×10^{-14}	0.89	0.74
TR-SO-TSM	0.78	1.7×10^{-11}	0.56	0.46

Table 3 Predicted ΔAs values of TCC under the impact of proton radiation as a function of spacecraft time in GEO

TCC type	0.5 yr	1 yr	3 yr	5 yr	10 yr
EKOM-1	0.01	0.02	0.05	0.08	0.14
TR-SO-TSM	—	—	0.001	0.002	0.003

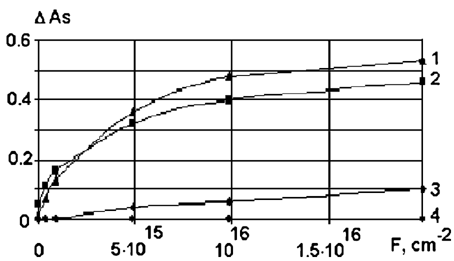

Fig. 1 Change of TCC *As* coefficient after proton irradiation with energy 300 keV: 1, EKOM-1; 2, TR-SO-TSM; 3, SS-1; and 4, EKOM-2.

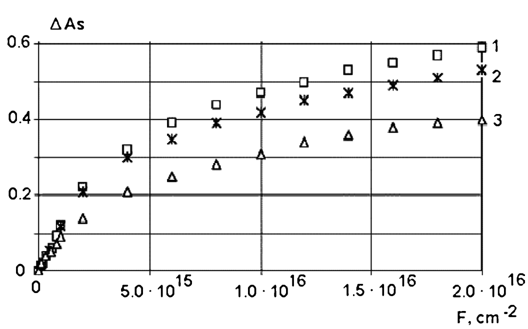

Fig. 2 Change of EKOM-1 coating *As* coefficient as a function of proton fluence with energies 1, 150; 2, 300; and 3, 500 keV.

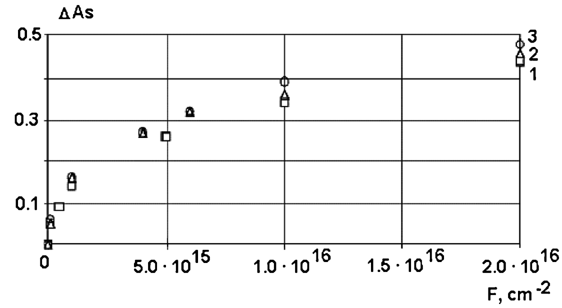

Fig. 3 Change of TR-SO-TSM coating *As* coefficient as a function of proton fluence with energies 1, 150; 2, 500; and 3, 300 keV.

Conclusions

1) Tests of various types of TCC under impact of protons with energies 150–500 keV with fluence up to 2×10^{16} cm^{-2} revealed that the *As* value did not vary for black coating EKOM-2. The ΔAs value is 0.1 for gray SS-1 coating, $\Delta As = 0.4$–0.6 for white coatings TR-SO-TSM and EKOM-1.

2) Radiation stability of the EKOM-1 enamel coating is higher than that of the TR-SO-TSN ceramic coating.

3) The *As* value functions of proton fluence and energy obtained for the EKOM-1 coating and TR-SO-TSN coating were used to predict variations of the *As* value during spacecraft flight in GEO up to 10 years.

4) EKOM-2 and TR-SO-TSM coatings are recommended for use on spacecraft in GEO.

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