STUDY OF THE OPTICAL PROPERTIES OF A REFLECTING COATING PREPARED FROM A KAPTON FILM WITH DEPOSITED ALUMINUM

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The effect of the flux density, the flux, and the energy of electrons on the change in reflection spectra and the total solar radiation absorption by the reflecting coating of a space vehicle fabricated from a Kapton film with deposited aluminum in the People’s Republic of China is investigated.

Various types of radiation act on materials of external surfaces of objects in outer space (OS): solar electromagnetic radiation (EMR), including vacuum ultraviolet (VUV), near-ultraviolet (NUV), visible, and near-IR ranges of the spectrum, electron and proton radiation, ionospheric plasma with atomic oxygen, and the plasma of the solar wind (SW). In addition to irradiation, materials are subjected to the action of the intrinsic external atmosphere (IEA), micrometeorites, meteoritic dust, cosmic debris, vacuum, and temperature.

Heat-regulation coatings (HRC) occupy an important place among materials of satellite technology [1]. They cover external surfaces of space vehicles (SV) and are subjected to the action of the above-indicated factors. In an orbital flight, the optical HRC properties are deteriorated, which may lead to a disruption of the SV operation, and its operating characteristics may fall beyond allowable limits. Therefore, to guarantee extended SV operation, HRC are tested under conditions close to field ones. The study of changes in the main SV operating characteristic — the total coefficient of solar radiation absorption $a_s$ determined from diffuse (specular) reflection spectra $p_D$ under the action of OS factors — is of scientific and practical interest.

Electrons and protons with energies $E$ lying in the range from $10^2$ to $10^8$ eV are the main OS charged particles concentrated mostly in the region affected by the Earth’s magnetic field (the Van Allen radiation belt, the plasma layer, etc.). The maximum electron flux density $q_0$, corresponding to an energy of several tens of keV, is $10^8-10^9$ cm$^{-2}$.s$^{-1}$ [2–4].

It is difficult or almost impossible to reproduce electron or proton spectra in the laboratory due to the narrow emission spectra of available sources. Therefore, the integral spectrum is replaced by monochromatic radiation beams, and effective fluxes, modeling the effect of the integral spectrum, are calculated by special methods [5]. The radiation flux density is increased many times in ground-based tests, and the legitimacy of these accelerated tests is an urgent problem.

The necessity of experimental investigations of the joint effect of various radiation types imitating the cosmic radiation has been established in the last few years [5, 6]. This is due to the nonadditivity of joint and separate effects of various radiation types caused by the synergy effects. However, investigations of the effect of a specific radiation type, for example, of electron radiation, on changes in the properties of HRC and other materials are also important. First, they give information on the type and the kinetics of reactions producing an increased concentration of color centers. Second, they are of practical importance, because they allow one to answer the question whether the accelerated tests are feasible and legitimate. Third, they allow one to choose an accelerated regime of joint action of various radiation types imitating OS conditions.

A fairly large number of works studied the optical HRC properties, but only few works considered the effect of the flux density of charged particles, including electrons. In [7] it was concluded that the change in $a_s$ of coatings is independent of the electron parameter $\varphi$, because the experimental values of $\Delta a_s$ obtained for different $\varphi$ fit in the curve of the dependence of $\Delta a_s$ on the electron flux. Investigations of HRC fabricated from TiO$_2$/Al$_2$O$_3$ + acrylic resin, ZnO + polymethylsiloxane, ZnO + polymethylphenylsiloxane, and F4MB-grade fluoroplastic with deposited aluminum performed in [2] demonstrated that the dependence $\Delta a_s = f(\varphi)$ is manifested in the range from $10^{10}$ to $10^{13}$ cm$^{-2}$.s$^{-1}$ and must be considered in ground-based tests.

In the present work, dependences of $p$, $\Delta p$, and $\Delta a_s$ on the flux density, the flux, and the energy of electrons are investigated for HRC fabricated from the most radiation-resistant polymer called Kapton (polyimide) with deposited aluminum.
Fig. 1. Diffuse reflection spectra of the Kapton coating with deposited aluminum made in the People's Republic of China before (1) and after irradiation by electron fluxes of $10^{16}$ (2), $3 \times 10^{16}$ (3), and $5 \times 10^{16}$ cm$^{-2}$ for an electron energy of 50 keV and a flux density of $5 \times 10^{12}$ cm$^{-2}$ s$^{-1}$.

**EXPERIMENTAL PROCEDURE**

Investigations were performed using the Spektr OS imitator [8], which allowed spectra $\rho_{i}$ to be recorded directly (in situ) in a vacuum chamber where the samples were irradiated. The spectra were recorded before irradiation and after separate, simultaneous, and successive irradiation by electrons, protons, and EMR imitating the solar radiation spectrum. A required number of samples of the examined coating were placed into the imitator chamber evacuated to a vacuum of $10^{-7}$ Torr, where the samples were thermostated at room temperature and their spectra before irradiation $\rho_{0}$ were recorded. Then the spectra of the irradiated samples $\rho_{i}$ were recorded. The electron energy varied from 10 to 70 keV, and the electron flux density was changed from $5 \times 10^{12}$ to $10^{13}$ cm$^{-2}$ s$^{-1}$ for fluxes up to $5 \times 10^{16}$ cm$^{-2}$.

The samples of coatings were made in China. They represented a Kapton film 20 μm thick with an aluminum layer approximately 1000 Å thick deposited on the rear side of the film. The film was glued on a substrate prepared from an aluminum alloy thermostated on a copper stage of the facility.

The first batch of samples was irradiated by electrons with energies of 10, 30, 50, and 70 keV and constant $\varphi$ equal to $5 \times 10^{12}$ cm$^{-2}$ s$^{-1}$. The second batch was irradiated by electrons with energy of 50 keV and $\varphi$ lying in the range $5 \times 10^{11}$–$10^{13}$ cm$^{-2}$ s$^{-1}$. Kinetic curves $\Delta \rho = f(t)$ and $\Delta a_i = f(t)$ or curves of dependences of $\Delta \rho$ and $\Delta a_i$ on the electron flux were measured for each sample. Then dependences $\Delta a_i = f(\varphi)$ were drawn for preset values of $\Phi$. The absorption coefficient $a_i$ was then calculated from the spectra $\rho_i$ using 24 points from the Johnson table [9].

**EXPERIMENTAL RESULTS AND THEIR DISCUSSION**

Figure 1 shows the spectra $\rho_{i}$ of the initial and irradiated sample. The sample was irradiated by electrons with energies 50 keV, $\varphi = 5 \times 10^{12}$ cm$^{-2}$ s$^{-1}$, and fluxes $10^{16}$, $3 \times 10^{16}$, and $5 \times 10^{16}$ cm$^{-2}$. It can be seen that the reflection coefficient is approximately 15% near 460 nm. Then the reflection coefficient increases to 89% with $\lambda$. After irradiation, the reflection coefficient decreases in the visible range from 550 to 750 nm.

Figure 2 shows the difference diffuse reflection spectra qualitatively equated to the induced absorption spectra. After irradiation, absorption bands with maxima at 580, 640, and 700 nm appeared. The difference absorption spectrum of a Kapton film 25 μm thick (without deposited aluminum) irradiated for 30 h by electrons with energies varying continuously in the range 2–20 keV [10] are also shown in this figure for comparison. The irradiation induces an absorption band with maximum at 460–480 nm. Longer-wavelength absorption bands characteristic of the coating under study were absent from the spectrum.

To elucidate the reasons for this difference in the spectra, we also investigated coatings fabricated in Russia from polyimide film 50 μm thick with deposited aluminum ($\delta = 0.15–0.2$ μm) and silver ($\delta \leq 0.1$ μm). The coatings were glued with thermally-stable low-molecular siloxane rubber (TLSR) glue on the substrate prepared from the AMG-6 alloy. The samples were irradiated in the Spektr facility by electrons with energies of 20 keV, a flux of $3 \times 10^{16}$ cm$^{-2}$, and a flux density of...