SYNERGISTIC EFFECT OF THE INFLUENCE OF ATOMIC OXYGEN AND ULTRAVIOLET RADIATION ON POLYIMIDES

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Introduction

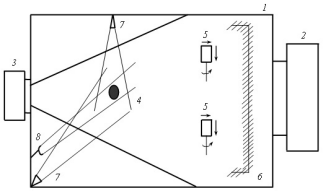
The synergistic effect of accelerated degradation, mass loss, increased sputtering and erosion coefficients of polyimides kapton-H, PM-A, PM-1E – engineering polymers of rocket and space technology products – was experimentally revealed under the simultaneous action of atomic oxygen (AO) flows and vacuum ultraviolet radiation (VUV).

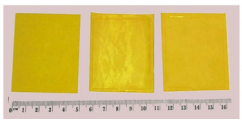
Ensuring the long-term operation of spacecraft in orbit is a pressing issue. To address this, it is necessary to improve the resilience of spacecraft structural materials to the effects of space factors, primarily ionospheric plasma and solar radiation. The dominant chemical factor affecting polymers in the Earth's ionosphere is atomic oxygen. Exposure to ionospheric fluxes leads to the oxidative degradation of polymers, forming volatile oxides such as CO, CO_2, and H_2O. Solar vacuum ultraviolet radiation intensifies the effect of ionospheric oxygen on polymers, promoting the desorption of formed oxide molecules from the surface and greatly increasing polymer erosion. Polymer degradation under the combined effects of ionospheric oxygen and VUV is a synergistic effect.

Experimental Research

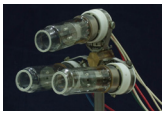
The experimental research was carried out at the plasmaelectrodynamic facility in the Institute of Technical Mechanics. A stationary conditions in vacuum chamber at pressure of ~$1 \cdot 10^{-5}$ Pa were maintained using oil-free pumping. A gas-discharge accelerator with electron impact ionization and electron oscillation in an external magnetic field was used to generate streams of atomic-molecular oxygen ions: a flux of supersonic AO ions with a velocity of $U_{AO} \approx 7.6$ km/s and concentrations of $N_{AO} \approx 5 \cdot 10^{13} – 2 \cdot 10^{16}$ m^{-3} and AO fluence $F_{AO} \approx 10^{16} – 10^{21}$ cm^{-2}. Irradiation was carried out using three VMF-25 hydrogen lamps with a radiation flux density on the polymer sample surface of $\Phi_v \approx 3.9$ mW/cm^2 at wavelengths of $\lambda_v \approx 135 – 165$ nm (VUV) and $\Phi_v \approx 0.45$ mW/cm^2 at $\lambda_v \approx 165 – 380$ nm (UV).

The plasmaelectrodynamic facility and the scheme of the experiment





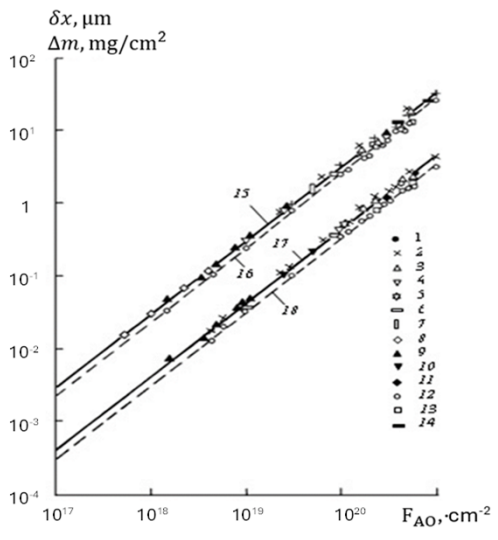
Samples of polyimide film before and after exposure to AO and UV



VUF source

The sample in the AO stream

Destruction of polyimide films under the influence of a supersonic AO flow



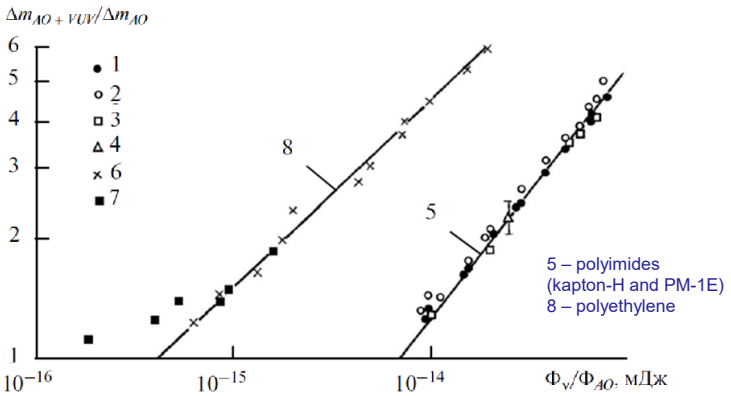
dependencies:
15 – δx for kapton-H
16 – δx for PM-1 E
17 – Δm for kapton-H
18 – Δm for PM-1 E

F_{AK} – fluence of flow
δx – layer thickness
Δm – mass carryover

Synergistic effect of the combined action of AO+VUV flows

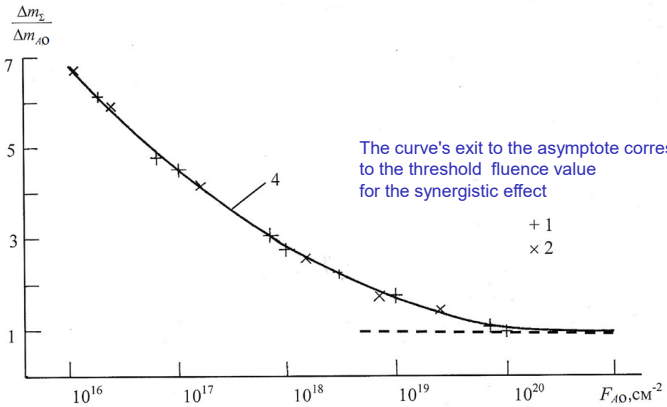
It was established that the ultraviolet radiation alone doesn't cause any noticeable damage to the materials in question. Polyimides are inert to the effects of VUV irradiation. However, when combined with a supersonic flow of atomic oxygen, it significantly enhances the latter's effect: this is a synergistic effect. But for polymer Teflon synergistic effect was not found.

Destruction of polymer films under the influence of AO and VUV



5 – polyimides (kapton-H and PM-1E)
8 – polyethylene

Relative change in the mass loss of the polyimide film when exposed to AO+VUV depending on the AO fluence



The curve's exit to the asymptote corresponds to the threshold fluence value for the synergistic effect

Studies of mass loss Δm_{AO} and the erosion coefficient Y_{AO} in a vacuum chamber with gas leakage and an operating pressure of ~$1 \cdot 10^{-3}$ Pa showed that of the two mechanisms of destruction of polyimides (kinetic sputtering and chemical sputtering), chemical etching with AO ions predominates.

Molecular oxygen does not participate in the destruction of polymers. Under VUV irradiation, the sample surface temperature was $T_W \approx 297$ K; under the influ5ence of simultaneous action AO and VUV fluxes (ΣAK+VUV), $T_W \approx 304$ K. The threshold value of the VUV energy flux Φ_v to the AO flux density Φ_{AO} ratio was determined. For kapton-H, PM-A, and PM-1E polymers, the threshold value Φ_v / Φ_{AO} determining the region of existence of the synergistic effect under the influence of ΣAK+VUV on polyimides is $\Phi_v / \Phi_{AO} \geq 7.1$ 10^{-15} mJ/atomO. In this case, the dependence holds for the mass loss Δm_Σ and the erosion coefficient Y_Σ (the index Σ means ΣAK+VUV) is $\Delta m_\Sigma / \Delta m_{AO} = Y_\Sigma / Y_{AO} \approx 9.891 \cdot 10^8 (\beta \Phi_v / \Phi_{AO})^{0.635}$ here $\beta = 1$ atomO/mJ. At an average level of solar activity, the region of existence of the synergistic effect of ΣAK+VUV on structural polyimides corresponds to an altitude of $h > 460$ km in the Earth's upper atmosphere.

Erosion parameters of polymeric materials

Material	Coefficient of film erosion cm³/atomO	Threshold values of Φ_v / Φ_{AO} mJ/atomO
Kapton-H	$3.03 \cdot 10^{-24}$	$7.1 \cdot 10^{-15}$ (common for polyimides)
PM-1E	$2.37 \cdot 10^{-24}$	
Polyethylene	$3.86 \cdot 10^{-24}$	$4.3 \cdot 10^{-16}$
Teflon FEP-100A	$0.23 \cdot 10^{-24}$	no synergistic effect