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# Structural changes of surfaces of spacecraft solar array protective glasses being irradiated by 20-keV electrons

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## Abstract

When irradiating K-208 and CMG glasses by 20-keV electrons with flux densities of $10^{10} < \varphi_e < 2 \times 10^{11}$ cm$^{-2}$ s$^{-1}$ in vacuum $10^{-4}$ Pa, electrostatic discharges accompanied by plasma emission and destruction of glass surfaces were observed. Examination of glasses by atomic force microscopy (AFM) showed significant difference in structural changes of surfaces of K-208 and CMG samples irradiated by equal flux densities within the range from $2.0 \times 10^{10}$ to $9.0 \times 10^{10}$ cm$^{-2}$ s$^{-1}$ that can be explained by different mechanisms of removal of charge accumulated in glasses. Surface discharges generating channels on surfaces of K-208 and CMG glasses appear when $\varphi \geqslant 7.4 \times 10^{10}$ cm$^{-2}$ s$^{-1}$ and $\varphi \geqslant 8.7 \times 10^{10}$ cm$^{-2}$ s$^{-1}$ respectively. In average, if radiation conditions are the same and $\varphi \geqslant 1.4 \times 10^{11}$ cm$^{-2}$ s$^{-1}$, the channels are 1.5 times deeper in K-208 than in CMG.

*Keywords:* Protective coatings of spacecraft solar arrays; K-208 and CMG glasses; Electron radiation; Electrostatic discharges

## 1. Introduction

Irradiation of low-conductive dielectrics by charged particles results in formation of areas with high density charge (Lackner et al., 1965; Furuta et al., 1966; Gross and Nablo, 1967); its field can initiate the electrostatic discharge (EDS) between the charged area and the surface of dielectric (Fujii et al., 1988; Frederickson et al., 1992; Gross and Wright, 2000; Novikov, 2007). Formation of discharge channels takes place as a result of destruction of dielectric and generation of a conductive phase. Their development is a complicated stochastic process accompanied by ionization, gas formation, heating, etc., which results in the formation of the conductive phase in the glass. Therefore, quantitative theory of formation of conductive channels has not been developed yet.

The study of ESD in dielectrics under radiation is essential both from a scientific point of view and for the solution of applied problems. In particular, interaction of a spacecraft with ambient plasma causes accumulation of electric charges on its surface producing, as a consequence, electric potential between the spacecraft surface and the plasma. For example, potentials on the surface of satellites operating on the geostationary orbit reach up to 20 kV. ESD caused by such potentials can produce not only the considerable electromagnetic interference, but also lead to the destruction of hardware components and structural elements. Electrostatic charging due to electrons from the Earth's radiation belts causes degradation of solar arrays by the surface and internal electrostatic discharges.

In this work, the previous Khasanshin and Novikov (2015a) and Khasanshin et al. (2015) and recent results on generation and development of ESD in K-208 and

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CMG glasses being the protective coatings of spacecraft solar arrays under electron irradiation are analyzed. The surface structure of the samples was investigated by means of AFM.

## 2. Experimental technique

The samples were irradiated in vacuum chamber ($10^{-4}$ Pa) of the “UV-1/2” test facility (Fig. 1) by 20-keV electrons with flux densities from $10^{10}$ to $5 \times 10^{11}$ cm$^{-2}$ s$^{-1}$. An electron beam was directed to square-shaped (40 × 40 mm) CMG and K-208 glass samples of 120 and 170 um thick respectively that have been cleaned in ultrasonic bath. To carry on the tests, the samples are fixed to the polished metal surface of the grounded table by 2-mm wide copper strips. Path length ($R_0$) of 20-keV electrons in glass does not exceed 5 um, therefore discharges between metal substrate and glass do not consider.

Samples of the CMG glass produced by the QIOPTIOQ Company were covered by 110-nm $MgF_2$ film for reducing the glass reflectance in the working spectral range of solar arrays.

Surfaces of the samples before and after irradiation were examined using the AFM Solver P47-Multi-Technique SPM. To study the surface topology the tapping mode that provides high accuracy of measurements and does not destroy the surface was used.

## 3. Experimental results and discussion

Irradiation of the glasses is accompanied by accumulating the thermalized electrons and annealing the structural defects that are especially numerous in the near-surface layer. If the field strength of accumulated charges exceeds a critical value, there occur discharges changing the glass structure (Khasanshin and Novikov, 2015a; Khasanshin et al., 2015). Annealing of the defects is followed by generation of radiation-induced stresses and radiation-induced diffusion encouraging acceleration of transportation processes that cause the substance to transfer to centers of growth of microprojections on the glass surface.

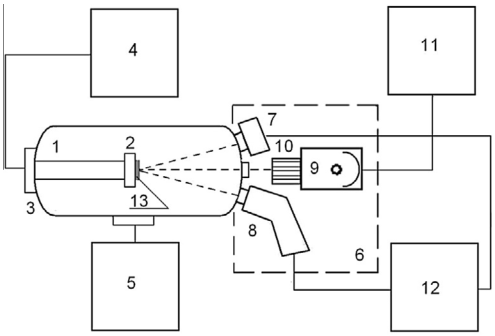

Fig. 1. Schematic diagram of the “UV-1/2” test facility: 1 – vacuum chamber; 2 – table for samples; 3 – thermostat; 4 – pumping and vacuum monitoring system; 5 – measurement unit; 6 – space simulators; 7 – electron accelerator; 8 – proton accelerator; 9 – simulator of solar radiation; 10 – forming optical device; 11 – solar simulator control box; 12 – accelerators control box; 13 – sample.

Test results show that irradiation of K-208 and CMG glasses by 20-keV electrons with flux densities $\varphi$ from $10^{10}$ to $2.0 \times 10^{11}$ cm$^{-2}$ s$^{-1}$ brought about two types of discharges accompanied by plasma ejection and jump-in pressure growth in the vacuum chamber from $10^{-4}$ to $2 \times 10^{-4}$ Pa.

The first type is the ≫glass – ambient residual atmosphere in a vacuum chamber≫ discharge (Fig. 2a). It initiates from a microprojection on the glass surface and is accompanied by quick phase transitions from solid to liquid, gas or plasma state and ended by plasma ejection in surrounding and field depression in the area of discharge. The main acceleration of the substance takes place when it is in the plasma state as a result of gas-dynamic expansion in vacuum and decrease of density of particles. As this takes place, the more speedy electron component fly over the vacuum chamber whereas a part of the positively charged ions or clusters can return to the areas of glass surfaces with negative potential.

We observed in our experiments the surface discharges passing along the glass surface and the metal strip (Fig. 2b) or the peripheral area of glass as well as discharges going between microprojections.

Figs. 3–9 show research data of sample surfaces using the AFM methods. The images of surfaces here are given in line with the increase of flux density from 0 to $2.3 \times 10^{11}$ cm$^{-2}$ s$^{-1}$.

Fig. 3 gives AFM-images of original samples and their surface roughness of CMG (Fig. 3a, b) and K-208 (Fig. 3c, d) glasses. Figs. 4 and 5 give images of samples irradiated by electrons with flux density $\varphi = 3.0 \times 10^{10}$ cm$^{-2}$ s$^{-1}$ showing changes of surface structure for the first type discharge.

One can see from Fig. 4 that 23 microprojections with height from 10 to 30 nm (Fig. 4a, c) arose on squared glass surface 5 × 5 um due to irradiation. According to authors’ opinion, structural changes of the glass surface took place as a result of described above processes and multiple repetitions of the first type discharges enlarging the microprojections through buildup of solidified glass on them.

Between discharges, density of the positive ions increases with the field strength near the surface being irradiated, especially in the vicinity of tops of the microprojections where there are local maximums of the field strength. Indeed, if $h$ and $r$ – microprojection height and radius of its top respectively, then field strength near the microprojection top can be estimated from $E_m(t) \approx E_S(t)\, h/r$, where $E_S(t)$ – field strength near sample surface at moment $t$.

Motion of ions to microprojections cause growth of space-charge density and local increase of electric field strength whereas bombardment of the microprojection