INVESTIGATION OF THE NANOSTRUCTURES ON SOLAR CELLS EXPOSED ON ORBITAL SPACE STATION "MIR"

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ABSTRACT

Nanostructures formed on the cover-glass surfaces of the solar cells which worked in space for more than 10 years as component of orbital station "Mir" have been investigated by means of atomic force microscopy. It is found that the nanostructures are present on all vertical scales of visualization: from ~1000 nm up to ~17 nm and on horizontal scales from ~1000 nm up to ~100 nm. Examination of mechanical properties of the exposed cover-glass surface in nanoscale has been carried out by a nanoindentation method with measuring complex NanoTest 600. Under load above ~0,04 mN up to ~10 mN the nanoindentation shows the essential distinction in mechanical properties between the exposed and non-exposed cover-glass surfaces.

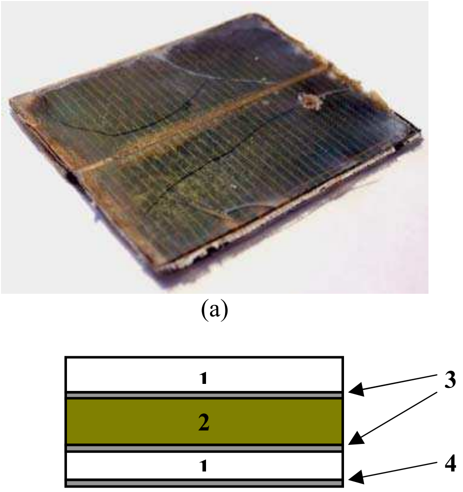
1. INTRODUCTION

During space flight the spacecrafts are in their own external atmosphere (OEA). This OEA is formed due to degasification and sublimation of surface constructional materials, gas outflow from pressurized sections, exhaust products of jet engines and various dust particles. These pollutants together with OEA accompanying spacecraft for a long time can fall out onto optical surfaces and change significantly their physical properties having an influence on their operational characteristics. Solar array nowadays are frequently used as main onboard power supply source. Therefore particular importance is given to investigating surfaces of solar cells which worked in near-Earth space for a long time.

The structure and composition of condensed nanostructures formed on the surfaces of various materials (polymeric composites, aluminum foil, inorganic glass) during long operation at orbital stations "Salut" and "Mir" were examined in study [1]. Methods of electron microscopy and X–ray spectroscopy were used in investigations. It has been also established that the nanostructures are formed on the glass plates' surfaces covering the solar cells which were exposed on orbital station "Mir" more than 10 years. Investigation of the nanostructures on the cover-glass surfaces of the solar cells has been continued in the present study. Images of the surfaces topography were obtained by means of atomic force microscopy [2]. Examination of mechanical properties of these glass surfaces in nanoscale was carried out by a nanoindentation method with measuring complex NanoTest 600.

2. EXPERIMENTAL TECHNIQUES

Three samples (SC–1, SC-2, and SC-3) of solar cells which worked in space for more than 10 years as component of orbital station "Mir", and two cover-glass plates non-exposed in space, were investigated. They had standard size of 43.5 mm × 35.5mm each. View of the solar cell and its cross-section are presented in Fig. 1.



(a)

(b)

Figure 1. (a) View of solar cell; (b) Simplified cross-sectional view of the solar cell:
1 - cover-glass K-208 of thickness 300 μm;
2 - silicon body of thickness 360 μm;
3 - glass cloth, impregnated with glue, of thickness 25 μm; 4 - current receiver.

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Images of surfaces topography were obtained by means of scanning atomic force microscope easyScan (Nanosurf AG) [2]. This microscope works as in a static contact mode (AFM) so in a semicontact dynamic mode (DFM) at room temperature in air. Sensors produced by Nanoworld (Switzerland) which are the micromade cantilever with the integrated tip placed onto the chip of the sensor holder were used. When the sensor tip comes in touch with the sample, the repulsive force acting on the tip increases with decrease in the sample-tip distance. In AFM mode the bend of the cantilever due to force acting on the tip, is measured by a deviation of a laser beam. In DFM mode the cantilever is raised with the help of a piezoelement. The repulsive force acting on a tip increases the cantilever resonant frequency, whereas the amplitude of the console vibrations decreases. The cantilever vibration is also defined by means of a laser beam deviation system. The image of each experiment for AFM and DFM modes contains 128x128 points. Areas of scanning in horizontal plane XY are from 100 microns up to 100 nanometers, in vertical direction Z - from 17 microns up to 17 nanometers. Additional protection of a microscope against external disturbances is realized by means of active vibration isolation system TS-150.

Examination of mechanical properties of the cover-glass surfaces in nanoscale was carried out by a nanoindentation method with MicroMaterials measuring complex NanoTest 600. Experiment was realized by the following technique. The cover-glass plate was separated from the solar cell and then it was fixed on the solid base by the cyanoacrylate glue. Indentation of the cover-glass surfaces was performed in 10 points with an interval 20-30 microns. The load increased with constant speed before achievement of the set maximum load. The loading speed was varied according to magnitude of the maximum load. The loading cycle time occupied 20 seconds. Then the maximum load was fixed for 10 seconds and so-called “creep”- effect was defined, i.e. at the constant load there was a further increase in depth. The unloading speed was the same, as the loading one. Instrument compliance was calibrated on a fused silica. Berkovich indenter with equivalent semi-opening angle of 65,3º and tip radius of 200 nm was used. The indentations were performed in load-controlled mode, with pre-load of 0,02 mN. Scheme of the indentation is shown in Fig.2. From obtained experimental data NanoTest 600 computer system calculates a number of parameters: the maximum depth of indentation, plastic depth, hardness, reduced modulus (comparable with Young’s modulus), elastic recovery, contact compliance, plastic work, elastic work and others. The reduced modulus is calculated by Oliver - Pharr model [3].

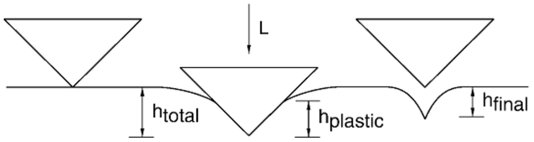


Figure 2. Scheme of indentation, where
h_{total} *is the maximum depth of indentation;*
$h_{plastic}$ *is the plastic deformation;*
h_{final} *is irreversible deformation.*

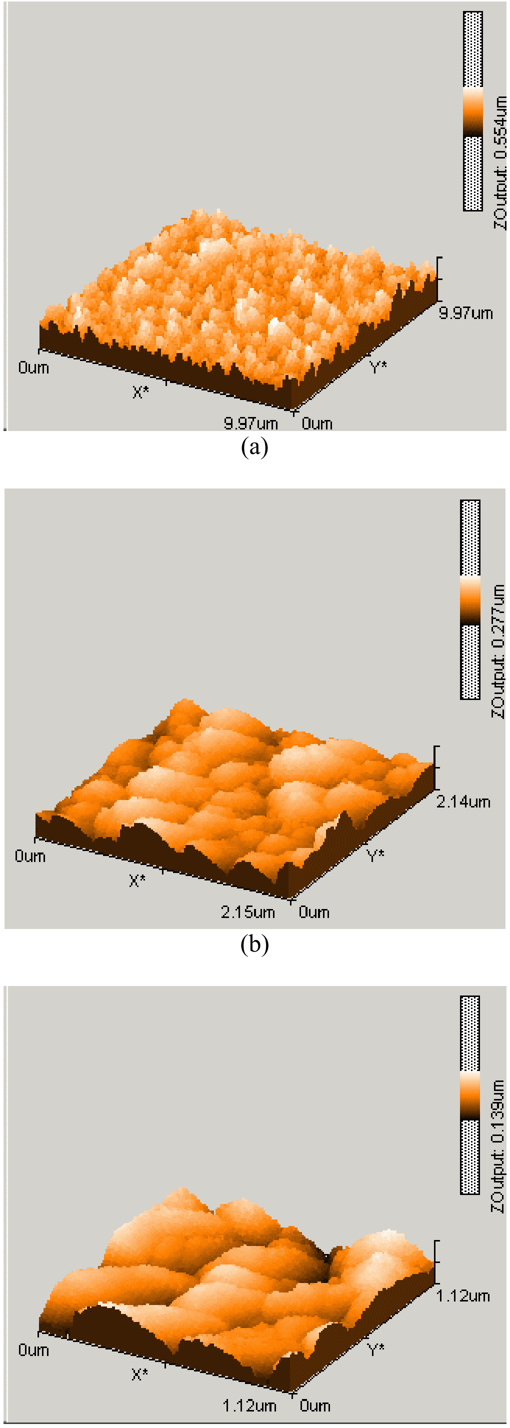
3. EXPERIMENTAL RESULTS

3.1. Experiments with atomic force microscope

Images of the face side surfaces of all solar cells and non-exposed glass plates were obtained for three various areas of each tested surface in AFM and DFM modes. Some of these images obtained in mode AFM are presented in Fig. 3(a-c), 4 (a-c), and 5(a-b). Images show the presence of similar nanostructures on all samples in all investigated areas. Nanostructures are present at vertical scales of visualization: from ~1000 nm up to ~ 17 nm (the low border of admissible vertical measurements) and at horizontal scales from ~1000 nm up to ~100 nm (the low border of admissible horizontal measurements). Thus, it is possible to talk about multi-scale nature of nanostructures, existing in the form of the raised outgrowths on the cover-glass surface of the solar cells.

Two different areas, light and dark, are visually discerned on the back (mirror) side of the solar cell (sample SC-3). DFM images of the back side surface of this solar cell within limits of the light and dark areas were obtained. The nanostructures formed on the light area of this back side are similar to those observed on the SC-3 face side, whereas nanostructures in dark area are strongly blurred. We suppose that the reason for such eroding is in additional influence of OEA on primarily formed nanostructures.

Images of two cover-glass plates non-exposed in space were obtained for various areas of their surfaces. On some of the areas the microscope fixed nanostructures, similar to those observed on the exposed samples. However on non-exposed glass these structures are expressed much more poorly: they have only one vertical scale equal to 17 nanometers, corresponding to limiting accuracy of measurement of the atomic-force microscope. On other areas the microscope did not fix any nanostructures. Apparently, they are expressed even more poorly here, and the vertical scale of these nanostructures cannot be resolved by the atomic-force microscope used for the analysis of the surfaces.



(a)

(b)

(c)

Figure 3. The AFM surface images of solar cell SC–1 (first area). Scan range:

(a) XYZ = 9.97 μm x 9.97 μm x 554 nm

(b) XYZ = 2.15 μm x 2.15 μm x 227 nm

(c) XYZ = 1.12 μm x 1.12 μm x 139 nm

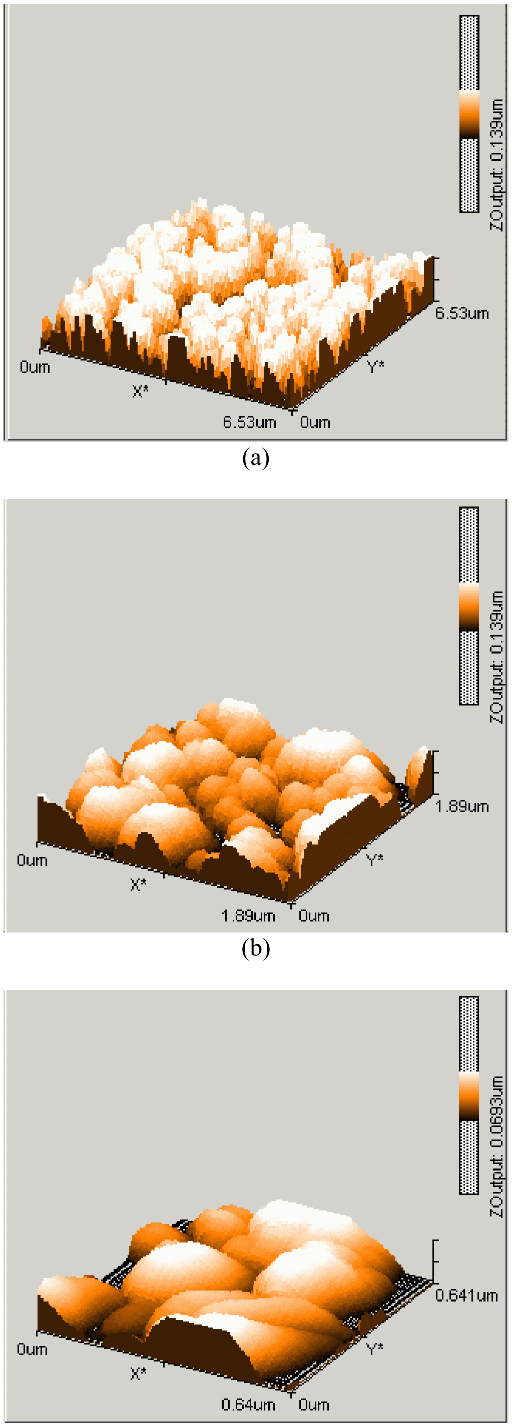


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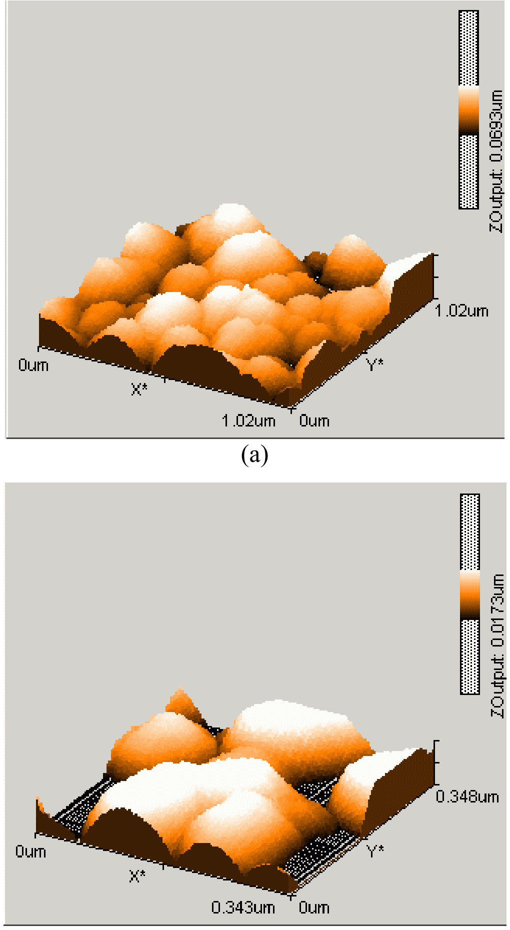
Figure 4. The AFM surface images of solar cell SC–2 (second area). Scan range:

(a) XYZ= 6.53 μm x 6.53 μm x 139 nm

(b) XYZ = 1.89 μm x 1.89 μm x 139 nm

(c) XYZ = 0.64 μm x 0.64 μm x 69 nm



(a)

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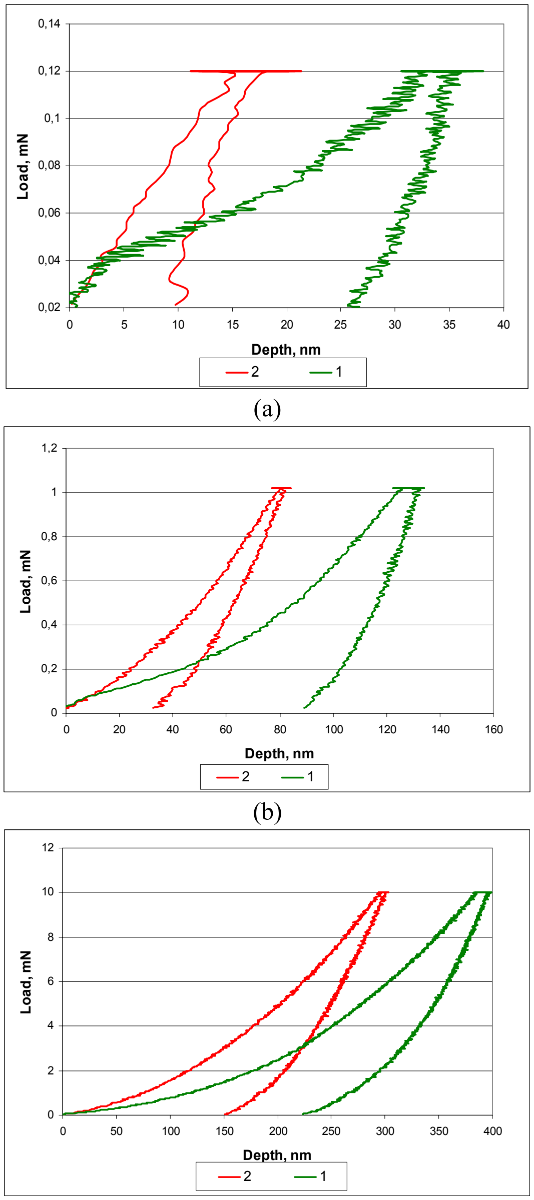
Figure 5. The AFM surface images of solar cell SC–1 (third area). Scan range:
(a) XYZ = 1.02 μm x 1.02 μm x 69 nm
(b) XYZ = 0.343 μm x 0.343 μm x 17 nm

Thus it is possible to conclude that an original structure of the cover-glass surface was able to serve as an effective substrate for epitaxial growth of the observed nanostructures during exposure of the surface in OEA of orbital station "Mir". The multi-scale nature of these structures may be explained by formation of the additional germinal centers formed due to action of various factors in near-Earth space (cyclic change of surface temperature, ultra-violet radiation, influence of atomic oxygen, etc.) on the cover-glass surface.

3.2. Experiments with NanoTest 600

The purpose of the experiments was to reveal differences in mechanical properties of near-surface region of the cover-glass plate before and after exposure in space. Load vs. depth data in ten points of surface for exposed cover-glass plate (SC-1) and non-exposed cover-glass plate were obtained at the maximum loads of 0.1, 0.5, 1.0 and 10 mN. In Fig. 6 average dependences for the exposed and non-exposed samples are presented. Such small loads were chosen to investigate the near-surface region in nanoscale.



(a)

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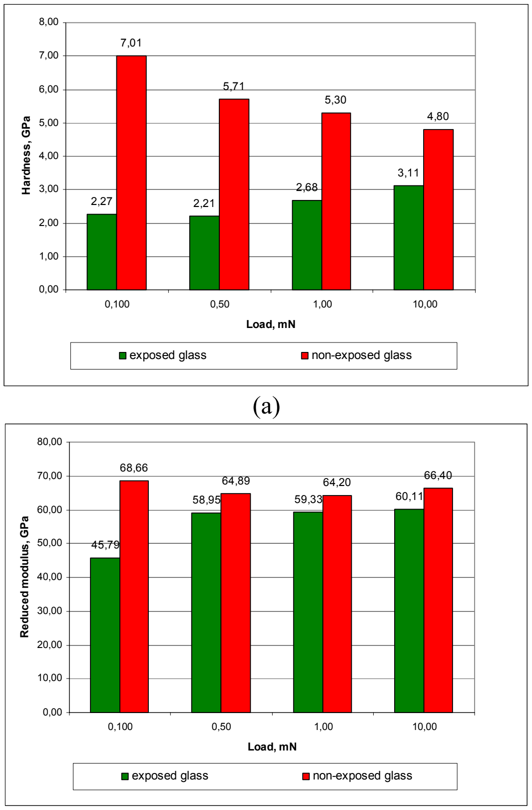
Figure 6. Load vs. depth nanoindentation data for cover-glass plate exposed (1) and not exposed (2) in space with a various maximum load:
a – 0,1 mN, b – 1 mN, c – 10 mN.

From obtained data (Fig. 6) we see that in all range of loads above ~0,04 mN the exposed cover-glass plate (1) shows higher depth of indentation in comparison with non-exposed one (2). However, an initial part of the load vs. depth curve (Fig. 6 a) approximately up to 0,04-0,05 mN goes almost equally for the both exposed and non-exposed cover-glass plate. This shows that their mechanical properties are similar during the initial stage of indentation. In Fig.6a an abrupt deviation of the load curve (curve 1) from linear dependence above 0,04 mN apparently indicates destruction in a near-surface nano-region of the exposed cover-glass plate caused by nanoindentation.



(a)

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Figure 7. Bar graphs of hardness (a) and reduced modulus (b) vs. load for the exposed and non-exposed cover-glass plates.

Processed experimental data showed on higher value of hardness, reduced modulus and elastic work for non-exposed cover-glass in comparison with exposed one (Fig. 7). The reduced modulus for the exposed cover-glass increases with growth of depth. For the non-exposed cover-glass we found practically constant value of reduced modulus (Fig. 7) in all range of the loads and depths that is typical for glass [4]. The exposed cover-glass has higher value of plastic deformation, plastic work and irreversible deformation in comparison with non-exposed one. Here the plastic deformation contains irreversible deformation caused by destruction during nanoindentation. Error level for all these parameters was higher for exposed cover-glass plate. This is attributed to higher heterogeneity of its surface. Also we got relatively high error level for all parameters and for non-exposed cover-glass plate at low loads. The error level decreases with increase in load. This is a sequence of some roughness of the non-exposed glass surface. For exposed glass error level of parameters remained on higher level, than for the non-exposed one, up to load in 10 mN. All it shows on high surface heterogeneity or presence of new nanostructure on the exposed glass surface in comparison with non-exposed one. Influence of this factor remains constant up to depth in 120 nanometers and then become slightly lower.

4. CONCLUSION

Images of surface topography of the cover-glass plates covering the solar cells, which worked in space for more than 10 years as component of orbital station "Mir", and the cover-glass plates, which were not exposed in space, have been obtained by means of the atomic force microscope easyScan. As a result the nanostructures formed on the cover-glass surfaces of the solar cells exposed in space have been visualized. Studying of the obtained images has revealed the multi-scale nature of these nanostructures emerging in the form of the outgrowths on the cover-glass surface. The nanostructures are present on all vertical scales of visualization: from ~1000 nm up to ~ 17 nm and on horizontal scales from ~1000 nm up to ~100 nm. The nanostructures formed on the face side and on the back side (light area) of the solar cell are similar. The supposition is made that an original structure of the cover-glass surface was able to serve as an effective substrate for epitaxial growth of the observed nanostructures during exposure of the surface in OEA of orbital station "Mir".

Examination of mechanical properties of the exposed cover-glass surface in nanoscale has been carried out by a nanoindentation method with measuring complex NanoTest 600. The experiment shows that mechanical properties of the exposed and non-exposed cover-glass surfaces are similar during the initial stage of indentation under load up to ~0,04 mN. Under load above ~0,04 mN the nanoindentation reveals the essential distinction in their mechanical properties. The exposed surface in nanoscale has higher value of irreversible deformation but smaller value of hardness and reduced modulus in comparison with the non-exposed one. The given distinction can be explained by presence of nanostructures on the cover-glass surface exposed in space. The load above ~0,04 mN up to ~10 mN seemingly shows more fast destruction of near-surface nano-region of the exposed glass caused by nanoindentation.

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5. REFERENCES

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