Design of Smart Coating for Reliability Enhancement and Operation Life Extension of Space Systems

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The topic relevance of project is that the investigations regarding development of scientific foundations and technological approaches of smart coating creation with ability to response on a change of environmental conditions have been begun in all developed countries. Such coatings are called smart or thinking coatings because of their ability to adapt depending on outer energy conditions and at the same time to change their properties in order to operational characteristics remain constant. The international conference dedicated to such coatings was carried out in Germany in 2013.

Thermal stabilizing coatings (TSC), possessing the properties to manage emitted power and to maintain the objects' temperature on a predetermined level, belong to one of the classes of such coatings. Regular thermal control coatings (TCC) are designed for maintenance of spacecraft temperature on predetermined level due to their optical characteristics: integral absorption coefficient of solar radiation and integral emissivity. The ratio of these coefficients determines a temperature of space vehicle at the beginning of flight. During the flight, there are at least three complicated situations:

1) The absorption coefficient a_s increases due to the effects of space radiations while the integral emissivity (ε) has no change that leads to an increase of space vehicle temperature. Such cases practically occur with any spacecraft at any orbits. Instead of 20 ^oC in the beginning-of-life the temperature of spacecraft can increase up to 40-50 ^oC and above in the end-of-life.

2) The temperature of spacecraft decreases in the shadow of the Earth or other planets due to lack of solar energy.

3) The temperature drop of unlit part of spacecraft's body occurs at the rotating of around its axis.

Mentioned problems can be solved if to use the TSC with changeable emissivity within operational temperatures of spacecraft instead of TCC. The dependence of TSC emissivity on temperature has a shape which is close to shape of integral and it changes from values of metals up to values of semiconductors and insulators. With increasing or decreasing thermal load and TSC temperature, the emissivity of such a coating changes and space vehicle's temperature keeps stay the same.

A replacement of all used TCC by TSC on spacecraft's bodies, radiators of thermal control, and on various their parts is possible in a future. The TSC can have an especial importance in spacecraft of open (frame) type and nanosatellite requiring the temperature stabilization of individual units and devices. There are two types of such coatings: with high reflectivity – white reflective coatings and with high absorptivity – black absorptive coatings. The reflective coatings can be fabricated based on barium titanates, the absorptive coatings – based on manganites with rare-earth elements.

Partial substitution of cations by atoms of other elements allows to shift Curie temperature of these compounds toward region of operational temperatures of space vehicle. The coatings with managed phase transitions by partial substitution of cations with atoms of other elements for shifting Curie temperature toward region of operational temperatures are developed. For instance, titanium cations are replaced by zirconium atoms and $BaTi_{(1-x)}Zr_xO_3$ compound can be obtained in result. The Curie temperature of $BaTi_{(1-x)}Zr_xO_3$ compound can place in vicinity of room temperature or even below (in the region of negative temperatures) instead of 120 ˚C which is for unmodified barium titanate $BaTiO_3$. For $La_{(1-x)}Sr_xMnO_3$ compound, where lanthanum cations partially substituted by strontium atoms, the Curie temperature can place in the region of room temperature instead of -145 ˚C for initial lanthanum manganite $LaMnO_3$.

Such coatings are undergone to action of the solar spectrum quanta in terrestrial environment, and the charged particles in addition to solar quanta – in outer space. That is why they should possess high photo- and radiation stability. In order to increase photo- and radiation stability, the coatings are modified with nanoparticles which play a role of defect relaxation centers formed by irradiation. TSCs can be manufactured as ceramic tiles, films, or paints/enamels. Each of these types of coatings have advantages and disadvantages. The tiles are difficult to fabricate, non-technological at applying, have a large weight and price, and have low reliability during exploitation due to small adhesion to the surfaces. The coatings as paints/enamels are more technological in comparison with ceramic coatings at fabrication and applying, possess small weight, have higher reliability in work, but have low stability to effect of irradiations because of polymeric binder presence. The coatings as thin films have no mentioned disadvantages of ceramic tiles, paints/enamels. But films with several microns of width possess low emissivity and it is not possible to manufacture the coatings with properties of emitted thermal flow management and temperature stabilization of objects from them.

Above-mentioned TSC disadvantages as ceramic tiles, thin films, paints/enamels can be eliminated if the coatings are produced as layers applied to metal or insulator surfaces. Such coatings are technological at applying, have small width (up to 100 µm) in terms of weight and price but enough width for providing emissivity, have no polymeric binder that gives high stability to action of irradiation and reliability during exploitation. Such layers can be applied to the surface by several routes: electrochemical, plasma, arc, thermal, and detonation with usage of impact wave energy. The investigations dedicated to an application of coatings to the surfaces by detonation technique, property study, and radiation stability of such coatings have been performed by us.

Thermal stabilizing coatings can be widely utilized in various branches of industry: chemical, pharmaceutical, food, and so on, as well as in construction industry for technological process stabilization.