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Technical Notes

Space Durable Solar Selective Cermet Coating

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I. Introduction

MINISATELLITES designed for use in high radiation threat orbits will require robust space power systems to achieve mission objectives. One vision for such a robust system is a heat engine powered by thermal energy captured by a small solar collector, and the solar energy must be absorbed by the heat engine efficiently. Engineered coatings made from a mixture of ceramic and metal, a class of coatings known as cermet coatings, offer the combined optical properties of high solar absorptance and low infrared emittance, which are ideal for certain heat engine applications. These solar selective coatings absorb solar energy with minimal loss through radiation.

One testbed on the exterior of International Space Station is the Materials International Space Station Experiment (MISSE). This testbed is used to evaluate the durability of materials and devices in low Earth orbit (LEO). Several MISSEs have been deployed and retrieved over the years [1]. MISSEs 1 and 2 were deployed on the Quest airlock and high-pressure gas tank in August 2001. MISSEs 3 and 4 were deployed on the Quest airlock and high-pressure gas tank in August 2006. MISSE 5 was deployed on the aft P6 trunion pin handrail in August 2005. MISSE 6 was deployed on the Columbus module in March 2008. Retrieved in September 2009, MISSE 6 was host to a number of materials experiments, provided 1.45 years of exposure to LEO, and included one sample of a cermet coating.

Cermet coatings are made in a variety of ways, including ion beam sputter deposition. Coatings range from two- or three-layer coatings to coatings purposely graded through their entire thickness. For ion beam sputter-deposited coatings, the key to making the coating is to gradually vary the percentage of metal and ceramic through the thickness of the coating, with the region adjacent to the underlying substrate being metal rich and the region near the surface being ceramic rich. Previous work identified the mechanism of solar absorption whereby the gradation through the coating creates a labyrinth of metal surfaces locked into place by the ceramic, enabling multiple reflections and subsequent high absorption [2]. A Monte Carlo model showed that atoms of metal adhering to the surface at the time of deposition arrived with sufficient energy and mobility to coalesce into islands, while the oxides arrived at the surface with little mobility and locked the islands of metal in place. Once locked in place, the islands need to remain intact in order for the cermet to maintain its solar selective optical properties.

Different starting materials yield cermet coatings of differing optical properties [3]. Cermet coatings made from titanium and aluminum oxide were identified in ground laboratory space simulation studies as offering the greatest durability to simulated LEO atomic oxygen and vacuum ultraviolet radiation [4]. Additional laboratory studies further identified the durability of the titanium and aluminum oxide cermet coating to high-temperature thermal cycling [5]. Hence, the titanium and aluminum oxide combination was selected for long-term durability evaluation on MISSE 6. Reflectance spectra in the ultraviolet, visible, and infrared were obtained before and after flight. Reflectance data were used to calculate before and after solar absorptance and infrared emittance values. This Note summarizes the reflectance data and optical properties before and after flight in order to evaluate the long-term durability of the cermet coating in LEO. The coating proved to be quite durable over the MISSE 6 mission.

Collecting solar energy with a concentrator can be accomplished over a range of concentrator sizes and concentration ratios. Concentrators with concentration ratios of 1000 or more are best coupled to cavity-type heat receivers where a working fluid is heated in the perimeter of the cavity and the heated working fluid is used to power a heat engine. One example of such a system is a solar dynamic space power system, developed in the early 1990s, capable of producing 2 kW of electricity using a 4.75-m-wide by 4.55-m-tall offset concentrator coupled to a receiver that powered a turboalternator compressor operating on a closed Brayton thermodynamic cycle [6]. Concentrators with concentration ratios on the order of 10 are ideally suited for concentrating sunlight onto photovoltaics. One example of such a system is the stretched lens array developed for solar electric propulsion [7]. The niche for solar selective coatings is in applications where concentrators are small, having concentration ratios on the order of 100, and the heat engine and convertor generates a few 10s of watts using a hot end temperature of up to 600°C. Stirling convertors are ideal for this range. With careful selection of interior convertor components, such as radiation resistant polymers and magnets, the system should prove robust in high radiation threat orbits [8].

MISSE 6 offered the opportunity to fly a sample of a cermet coating where the threats of atomic oxygen, vacuum ultraviolet radiation, and thermal cycling are combined synergistically. Figure 1 shows MISSE 6 on orbit, and the cermet coating is shown in the smallest inset, second from the left.

II. Materials and Methods

The sputter deposition process used for depositing the cermet coating flown on MISSE 6 has been described in detail elsewhere [3]. Briefly, the plume from a 5-cm-diam ion source was allowed to impinge on the surface of a cylindrical target consisting of ceramic juxtaposed with the metal of interest. The ceramic was wedge shaped, so that by slowly rotating the cylinder under the beam, the beam sputtered a varying mixture of metal and ceramic onto a nearby substrate: a 1.27-cm-diam nickel disk. For this work, a total of 11 steps were used to move from depositing all titanium to depositing all aluminum oxide, yielding a coating having a thickness on the order of 200 nm.

The optical properties of the titanium aluminum oxide cermet coating were evaluated in the ultraviolet, visible, and near infrared before flight using a Perkin–Elmer Lambda-19 spectrophotometer equipped with a 15-cm-diam integrating sphere by measuring reflectance over the wavelength range of 250 to 2500 nm. A circuit board in the Perkin–Elmer Lambda-19 burned out beyond repair while the coating was in flight, and a new spectrophotometer was purchased. After flight, a Cary 5000 spectrophotometer equipped with a 15-cm-diam integrating sphere was used to measure reflectance over the same wavelength range. The air mass zero solar

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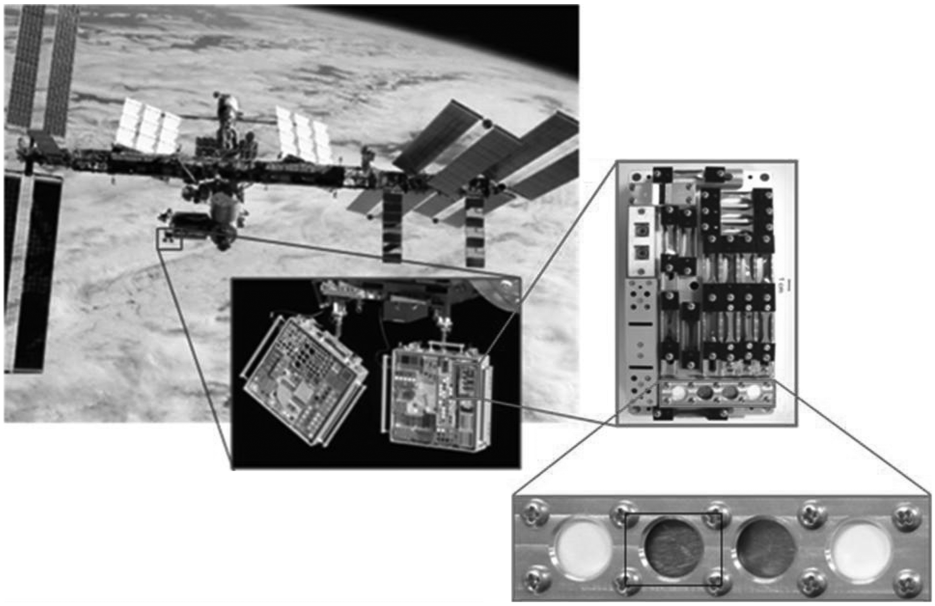

Fig. 1 MISSE 6 on orbit and preflight close-up photograph inset.

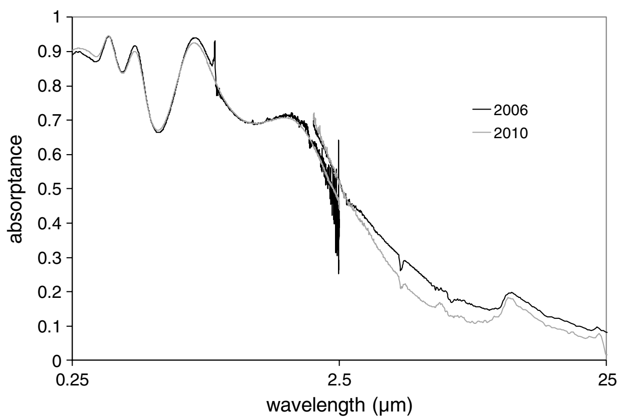

Fig. 2 Spectral data for cermet coating before and after 1.45 years in low Earth orbit.

spectrum was used to convolute the reflectance data into solar absorptance α, and the uncertainty is estimated to be ± 0.005. The optical properties of the titanium aluminum oxide solar selective coating were evaluated in the infrared before and after flight using a Surface Optics Corporation SOC-400t portable infrared reflectometer measuring reflectance in the wavelength range of 2 to 25 μm. A room-temperature blackbody curve was used to convolute the infrared reflectance data into infrared emittance ε at room temperature, and the uncertainty is estimated to be ± 0.01.

III. Results and Discussion

The spectral data of the cermet coating are shown in Fig. 2. The data revealed little change in spectral absorptance over the range observed. Given the estimated uncertainties, the calculated values of α and ε, summarized in Table 1, likewise revealed no change in solar absorptance and little change in infrared emittance.

The significance of these observations is that the cermet coating is shown to be robust to the LEO environment for at least 1.45 years, confirming much of the ground laboratory atomic oxygen, vacuum ultraviolet, and thermal cycling durability testing completed earlier on similar cermet coatings.

Table 1 Cermet coating optical properties, before and after exposure on MISSE 6

	Before flight	After flight
Solar absorptance, α	0.786	0.780
Infrared emittance, ε	0.14	0.11

IV. Conclusions

MISSE 6 hosted the flight of a titanium and aluminum oxide ion beam sputter-deposited cermet coating having the optical properties of high solar absorptance and low infrared emittance. Spectral reflectance data obtained before and after flight revealed essentially no change in the optical properties of solar absorptance and infrared emittance upon low-Earth-orbit exposure, consistent with ground laboratory evaluation of similar cermet coatings.

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