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Evaluation of nanoalumina coated germanium black polyimide membrane as sunshield for application on the communication satellite antenna

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Abstract

Alumina thin coatings were grown on Germanium (Ge) coated black polyimide (GBP) or Kapton which has been used as a sunshield membrane on communication satellite antennas to protect it from environmental degradation during ground storage and implementation. The deposited nanoalumina coatings were found to be optically transparent in solar regime in spectral window while RF characteristic revealed negligible losses. Space worthiness of the coating was examined by simulated environments, e.g. humidity, thermal cycling and thermovacuum tests. No degradation was observed in its microstructural, thermo-optical, electrical, chemical state and RF characteristic in particular Ku and Ka bands. The aforesaid study indicates that the alumina thin coating is able to prevent surface degradation of GBP retaining the thermo-optical properties of the Ge coated Kapton and RF transparency which are functional requirements for communication antenna. The thickness of the optimized alumina coating was ~60 nm.

Keywords: Alumina; Ge coated black Kapton; Humidity; Thermal cycling; Thermovacuum

1. Introduction

A parabolic dish type reflector antenna made of carbon fiber reinforced plastics (CFRP) is generally used in communication satellites. However, the fluctuations of solar radiation (i.e., heat load) may cause mechanical damage (i.e., warpage) to its surface leading to the malfunctioning of reflector antenna. To protect the reflector from fluctuating radiations it is covered with sunshield membrane made out of polyimide passive thermal control element i.e., single layer of indium tin oxide (ITO), [1–3] Ge [4–6] and W doped VO_2 [7] or bi/multilayer of semiconductors [6] or combination of ITO/white paint [1] is coated on front (space facing) side of sun shield. The rear side is reinforced by polyester or glass mesh and subsequently coated by white polyurethane paint, [2,3] silicone based paint with primer [2,3] and patterned aluminum consequently coated by cadmium telluride [6]. The following stringent characteristics [1,4,5] of the surface of the membrane/blanket materials at space facing side are devised as (i) high heat emitting surface (i.e. infrared (IR) emittance, $\varepsilon_{ir} > 0.72$), (ii) low solar absorbing surface (solar absorptance, $\alpha_s < 0.6$) surface (iii) transparent to IR wavelength regime, (iv) transparent in radio frequency (RF) region (i.e., less RF loss), (v) essential electrical conductivity (sheet resistance, $R_s < 10^9$ Ω/square) and (vi) long term stability at space environment.

Bowman et al. [1] reported a significant increase in α_s (e.g., from 0.3 to about 0.5 for equivalent 1.3 years) of ITO film on Kapton after exposing simulated UV radiation tests and R_s (from 10^7 to about 10^9 Ω/square for 0.5 equivalent years) of ITO film on Kapton after exposing simulated ultra violet (UV)

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radiation tests [1]. However, RF characteristic was not assessed for both before and after space accelerated environmental tests [1] while Ge coated Kapton with rear side black pigmented sunshield membrane showed lowest RF loss (<0.05 dB) in comparison with other combinations such as Ge coated Kapton with rear side patterned aluminum (~ 0.2 dB), ITO coated Kapton with rare white paint (~ 0.2 dB) and bilayer of ITO/white paint coated Kapton with rear black pigment (0.2–0.3 dB) [5,6]. Further, white paint showed higher degradation in solar absorptance in space environment [7].

However, often degradation is observed in Ge surface during ground storage and implementation time due to instability of Ge in atmospheric environment [8]. The shelf-life of the GBP materials is indicated as only 6 months with a strict and controlled packaging condition in clean room environment [9]. Degraded GBP shows higher α_s (0.92 vs. <0.6), R_s (10^{11} Ω/square vs. $<10^9$ Ω/square) and increase in RF loss. The increased absorbed radiation causes temperature rise leading to thermal distortion of the reflector. Further, data communication can be affected due to high RF loss. Therefore, a protective surface on the top of the Ge layer is required to hide the degradation of Ge during ground storage and implementation. Recently, we have reported that thin alumina (Al_2O_3) coatings can be used to protect the metallic surfaces such as titanium [10] and grade 304 stainless steel [11] for spacecraft application in particular. Thus, in the present study, thin alumina coating is developed on Ge layer of GBP by pulsed RF magnetron sputtering technique. Further, systematic studies of microstructural, thermo-optical, electrical, electronic, and RF characteristics in both Ku and Ka bands of alumina coatings are investigated before and after simulative accelerated tests such as relative humidity (RH), thermal cycling (TC) and thermovacuum (TVAC) performance to understand the space worthiness of the present alumina protective coating.

2. Materials and methods

Alumina thin coatings were deposited on as-received commercial GBP (100CB Black Kapton®, Sheldahl, USA) flexible substrates at room temperature by pulsed RF magnetron sputtering (SD20, Scientific Vacuum Systems, UK) at a constant power of 700 W. The durations of alumina coating deposition were kept in the range of 15–40 min. The deposition rate was kept constant at 2.38 nm min^{-1} [11]. The Al_2O_3 target (diameter-8 in., 99.995%, Soleras Ltd., USA) was utilized to deposit alumina films. Ultra pure argon gas ($\sim$99.9998%, Praxair, India) was used to generate plasma. The coating was carried out at working pressure of 1.5×10^{-2} mbar allowing specific amount of argon gas. The pulse frequency and duty cycle were kept constant at 100 Hz and 57%, respectively. Prior to that, the chamber was evacuated employing subsequently rotary and turbo molecular pumps and base chamber pressure was achieved better than 5.0×10^{-6} mbar.

Morphological characterization and roughness of the coatings were carried out by field emission scanning electron microscopy (FESEM: Supra VP40 Carl Zeiss, Germany) and atomic force microscopy (AFM: Ntegra Prima, NT-MDT, Ireland) in tapping mode. The energy dispersive X-ray (EDX) spectra of the deposited thin films were obtained by a customary unit (Oxford Instruments, UK) attached to the FESEM facility. The X-ray photoelectron spectroscopy (XPS) studies of the coatings were performed by SPECS spectrometer using non-monochromatic AlKα radiation (1486.6 eV) as an X-ray source operated at 150 W (12 kV, 12.5 mA). The binding energies reported in the present case were referenced with C1s peak at 284.6 eV. All the survey spectra were obtained with a pass energy of 70 eV with step increment of 0.5 eV and individual spectra were recorded with a pass energy and step increment of 40 and 0.05 eV, respectively. The experimental data of the desired elements were curve-fitted into several components with Gaussian–Lorentzian peaks after Shirley background subtraction employing CasaXPS program.

Static water contact angles (WCA) were measured by the commercial contact angle analyzer (Phoenix 300 Plus, M/s Surface Electro Optics Co. Ltd., South Korea). The WCA was determined by tangent fitting mode. The water drop volume of $\sim$8 mL was utilized for WCA in the present experiment.

The average α_s in entire solar spectrum regime as per ASTM C1549-09 and total hemispherical ε_{ir} as per ASTM C1371–04a of the deposited coatings were measured at room temperature and ambient humid condition by solar spectrum reflectometer (SSR-E, Devices and Services Co., USA) and emissometer (AE, Devices and Services Co., USA), respectively. The α_s and ε_{ir} data were reported in the present work with an average of at least five readings taken in different places on the samples with an error of 1–3%. The details about the calibration procedure were already discussed elsewhere [12].

Adhesive scotch tape (3M-250, 3M, USA) was utilized for carrying out adhesion test as per the standard test method described in ASTM D903 for peel strength. Finally, the test coating samples and the corresponding scotch tapes were examined visually for removal of the films, if any. R_s was measured using a two probe meter (152- 1 Resistance meter, Trek, USA) as per ASTM D 257-9 both before and after the adhesion test, as any removal of the films or discontinuity of coating material should be reflected in change in R_s data.

The RF losses e.g. insertion loss and return loss of the coatings were evaluated in both Ku band ranges 10.5–14.5 GHz by Agilent Technologies PNA network analyzer (E8362B), USA with Ku adapter (Spectrum C3117) and Ka band ranges 27–40 GHz by Rohde and Schwarz ZVA40 vector network analyzer, Germany with Ka adapter (Space Machine and Engineering Corp.).

Finally, space worthiness of alumina coated GBP and bare GBP were evaluated by accelerated tests. The RH test was conducted to examine the effect of elevated humid environment to assess the stability of the sample to the ambient storage and prelaunch environment. The test was carried out in a thermostatically controlled humid chamber for prolonged time e.g. 48 h. The relative humidity in the chamber was maintained at 75% at a temperature of 50 °C. Next, TC test was carried out to investigate the effect of cycling temperature. Test was