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On aluminum tapes treated for missions at Jupiter

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Abstract

Electrodynamic tethers are effective at Jupiter because of its high magnetic field, the length-averaged tether current lying well below its high *short-circuit* bound for dimensions of interest. Efficiency of Jovian capture of an incoming spacecraft, gauged by the M_{SC}/m_t mass ratio, is then higher for low perijove radius and a thin, long tape [1]. If too long, however, it could result in some attracted electrons hitting it at values of energy with *range (penetration depth)* larger than thickness h. Mission-design depends on keeping electron *range* below tape thickness for all conditions at capture, to ensure current collection; since the electron range decreases with energy, it suffices to set h equal to the *range* for maximum energy of attracted electrons throughout the entire capture operation, which occurs at the anodic end, when the S/C is at the *drag-arc* perijove and the spinning tether is parallel to the *motional* field $\mathbf{E}_m$ driving its current. This is achieved by setting the perijove just hundreds of kilometers above Jupiter, while using short, moderately thin tapes ($L \sim 3$ km, $h \sim 0.02$ mm, say), resulting in a mass ratio about 3 and a S/C of several hundred kg, tape-width being determined by the scaling with M_{SC} [2].

This is down by one order of magnitude from typical mass in studies of Giant Planets, allowing for a *fast/light mission*, with direct S/C launch into a 2.7 years Hohmann transfer to Jupiter, for multiple flybys of moon *Europa*. After a few perijove passes, Lorentz-drag would take the S/C to an orbit with *apojove* about the moon Ganymede — and perijove very near Jupiter —, for a 1:1 resonance orbit with Europa, tether current being kept off through flybys, and radiation dose per orbit reaching 0.1 Mrad under 200 *mils* (about 5 mm) of *Al* shielding [2]. A remaining issue, however, is the strong heating of the tape aluminium, which, in principle, would have very low thermal emissivity, if highly conductive as required from a tether.

With aluminium tethers having thermal emissivity as low as 0.03 at a temperature of 300 K, over the entire spectrum, they present inadequate heat dissipation in the thermal infrared region. A nanostructured coating with high thermal-emissivity and high conductivity, as compared to Al and Al_2O_3 respectively, is being developed in the present work for tethers exposed to the hard conditions at *Jovian* operation. A coating of aluminum oxide is anodically grown on the aluminum tether and treated to make it electrically conductive, in particular to suppress discharges of static electricity, while compatible with emissivity about 0.7. The design objective of this research is to anodically grow an alumina *antidot array* on Al tethers. This anodic aluminum oxide has an intrinsic double-layered structure: a porous external oxide layer and a barrier layer at the bottom of the pores. A

chemical pore-widening technique is used to thin or even remove the barrier layer so as to reduce the transverse electrical resistivity.

The chosen design involves an antidote array coating structure that has a nanoporous size adequate to incorporate conductive material inside. Our approach relies on structures with different pore-size arrays to allow direct metals deposition by electrochemical methods. The electrical conductivity of the coating is tailored to a value between 10^6 and 10^7 S/m. This surface finishing process is made of four main steps: 1) The surface roughness of the aluminum tethers will be increased by etching processes until R_a (average roughness) = 1.6 μm. 2) A nanometric porous aluminum oxide array will be grown on flat and rough Al with a thickness in the order of 100 nm to 10 μm and a pore size in the range 100 - 400 nm. 3) A chemical pore-widening technique will be used to thin the barrier layer at the bottom of the porous aluminum oxide. 4) The nanopores in the aluminum oxide array are filled with T_i or N_i-based materials by chemical methods: electroless and electroplating [3].

Filling the nanopores with electrically conductive material also increases the coating conductivity. This proposed nanoscale patterned metal/dielectric coating also offers the possibility of tuning the local distribution of dielectric surface in a controlled way. That compares favourably with continuous high-resistivity thin oxide films. For space applications, such coating would also provide the required electrical contact with the outer-space plasma. Remarkably, the anodization and electro-deposition processes are compatible with commercial anodizing production lines.

References

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