Distribution and Optical Properties of the Pulsed Plasma Thruster Plume Deposition

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Abstract. In order to study the characteristics of Pulsed Plasma Thruster plume contamination, the distribution and optical properties of the films deposited by Pulsed Plasma Thruster were studied. The morphology of the deposited film was analyzed by scanning electron microscopy and scanning probe microscope, transmittance and reflectance of the films were tested using UV-vis spectrophotometers. The results showed that, plasma sputtering and neutral large particles deposition existed in the PPT plume disposition process, the deposited films had strong ultraviolet absorption and enhanced reflective properties. Different plasma characteristics in different region of the PPT plume led to different surface morphology and optical characteristics and trends.

Introduction

Pulsed Plasma Thrusters(PPT)is one of the promising propulsion system[1], which operates at low pulsed energy level, PPT has the unique feature of low impulse bit and high specific impulse , it is an attractive propulsion option for orbit maintenance, constellation station-keeping, deorbit and drag compensation purposes for micro spacecraft.

Many types of materials can be used in PPT as propellants; Polytetrafluoroethylene (PTFE) is one of the most attractive fuels because of its outstanding properties [2]. It is easy to manufacture, remain relative stable in vacuum pressures encounter during spaceflight, and it has high thermal stability and excellent electrical insulation. All these properties make PTFE highly attractive for PPT application. However contamination arise from the exhaust plumes of the PPT is very important problem [3-5], the ejected material containing hot plasma and ablated particulates such as carbon atoms, fluorine atoms, fluorocarbons C_xF_y, and their ions dissociated from the PTFE can condense and create carbon film layer on the surface of spacecraft, solar arrays, and on-board optical sensors, which can induce degradation of optical resolution of the optical instruments and power generation of the solar cells by affecting transmittance, reflectivity and signal intensities, raising potential of the spacecraft by electric charges accumulating on the spacecraft surface due to the dielectric properties of the films.

Rudolh et al. [6] and Guman et al. [7] found the plume to be within a cone angle of approximately 40 degrees, beyond that angle with minimal deposition occuring. Arrington et al. [8,9] used an array of quartz witness to collect plume constituents for analysis, results showed a negligible loss of transmittance from the deposition in the backflow region and at 90degree from the thruster axis, and found that measurable changs in transmittance were confined to 30 degrees from the centerline of the thruster.

The purpose of this study is to establish techniques for PPT plume contamination measurements and assess distribution characteristics and optical properties of the films deposited on the PPT cathode side, data acquired from this study were used to assess contamination arised from the exhaust plume of the PPT and help satellite designer eliminate possible interactions between the plume and the spacecraft in understanding its possible effects on spacecraft and integrate PPT into spacecraft.

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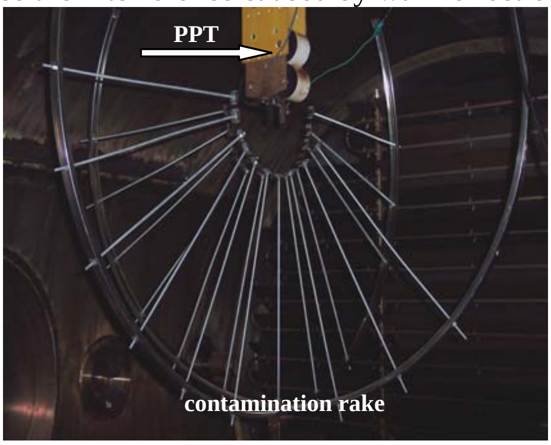
Experimental apparatus

The PPT used in the experiment was a single channel parallel plate electrode PPT, the capacitors were charged to 1500 volts for a discharge energy of 13.5J, the thruster was pulsed 54000 times at a frequency of 1Hz, corresponding to an average power level of 13.5W for every discharge, the two non-oxide copper electrodes with electrode separation of 45mm, length of 35mm, width of 15mm, and thickness of 3mm. A piece of self-made cuboid PTFE was used as propellant of the thruster; the surface exposed to plasma was 45mm in length 15mm width.

As shown in Fig.1, the thruster was placed inside a cylinder-shape vacuum chamber of 2.5m diameter 3.5m long to simulate the space environment. The PPT was mounted at the top of the vacuum chamber and secured downward to reduce the effects of gravity, the chamber base pressure was 4×10^{-4}Pa and pressure during thruster operation was 3×10^{-3}Pa. The chamber was large enough to reduce the interference caused by wall reflections.



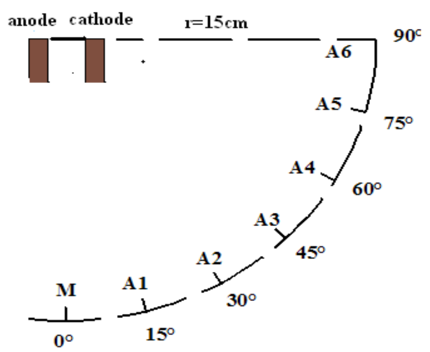


Fig. 1 PPT and contamination rake   Fig. 2 substrate locations relative to PPT

As shown in Fig.2, On the asymmetric plane perpendicular to the electrodes, from the thruster axis to 90 degree on the cathode side of the thruster, every 15 degree a glass slide substrate ($2.5\times2.5\times0.11cm^3$) was located on a contamination rake, the distance between the substrate and the center of the propellant surface was 15cm. Before treatment, all the witness plates and PTFE bar were cleaned in successive ultrasonic baths of acetone for 20 min, ethanol for 20 min, and deionized water for 20 min, and then be dried in an oven at 70^o for 1h.

The morphology of these deposited films was examined by scanning electron microscopy (SEM) (S-4800, Hitachi Co. Ltd.), different magnification levels were tried to better analyze the morphological characterization. The surface morphology of these films was studied by scanning probe microscope (SPM) (TS-150, NT-MDT Co. Ltd,) that operated in the semi contact mode. The root mean square (RMS) deviation of each sample was calculated from the profile data correspondingly. The optical property of these films deposited onto the glass slide substrate was measured with UV-vis spectrophotometers (U-4100, Hitachi Co. Ltd.) in the wavelength between 300 nm and 1500 nm.

Results and discussion

Morphology. The morphology of the A4 sample observed by SEM was shown in Fig 3. As shown in Fig 3(a) the magnification of the micrograph was 500, there were fewer but larger particles 20-100 microns in diameter, and a larger number of small particles less than 10 microns in diameter on the film surface. As shown in Fig 3(b) the magnification of the micrograph was 4000, it showed a dense film formed on glass substrate surface, while on its surface tiny particles of about 3 microns and 30 microns in diameter were still capable of being observed. These particles might come from the ablated unionized neutral PTFE particles, which were expelled and condensed on the substrate during the PPT operation process, or because the glass substrate was sputtered by high speed plasma in PPT plume and formed precipitates substance. Because of the deposited film insulation characteristics,

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greater magnification observation of surface morphology, spraying gold processing must be done, but it may reduce the credibility of the surface morphology.

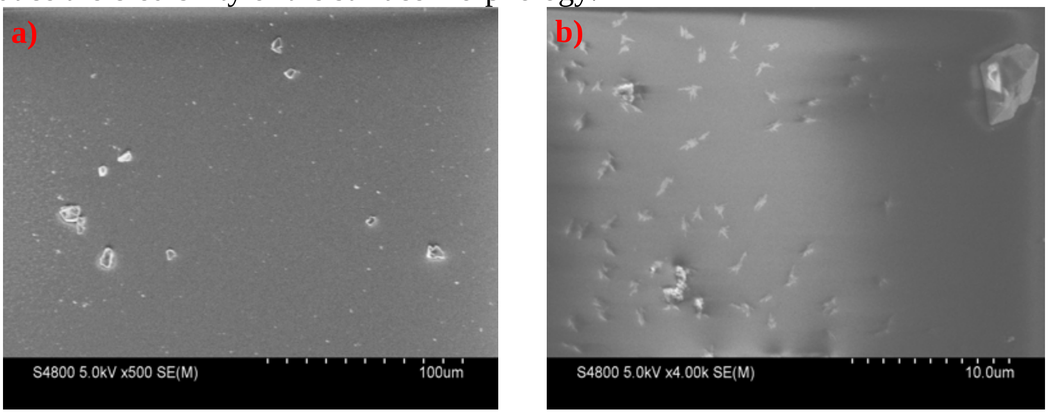
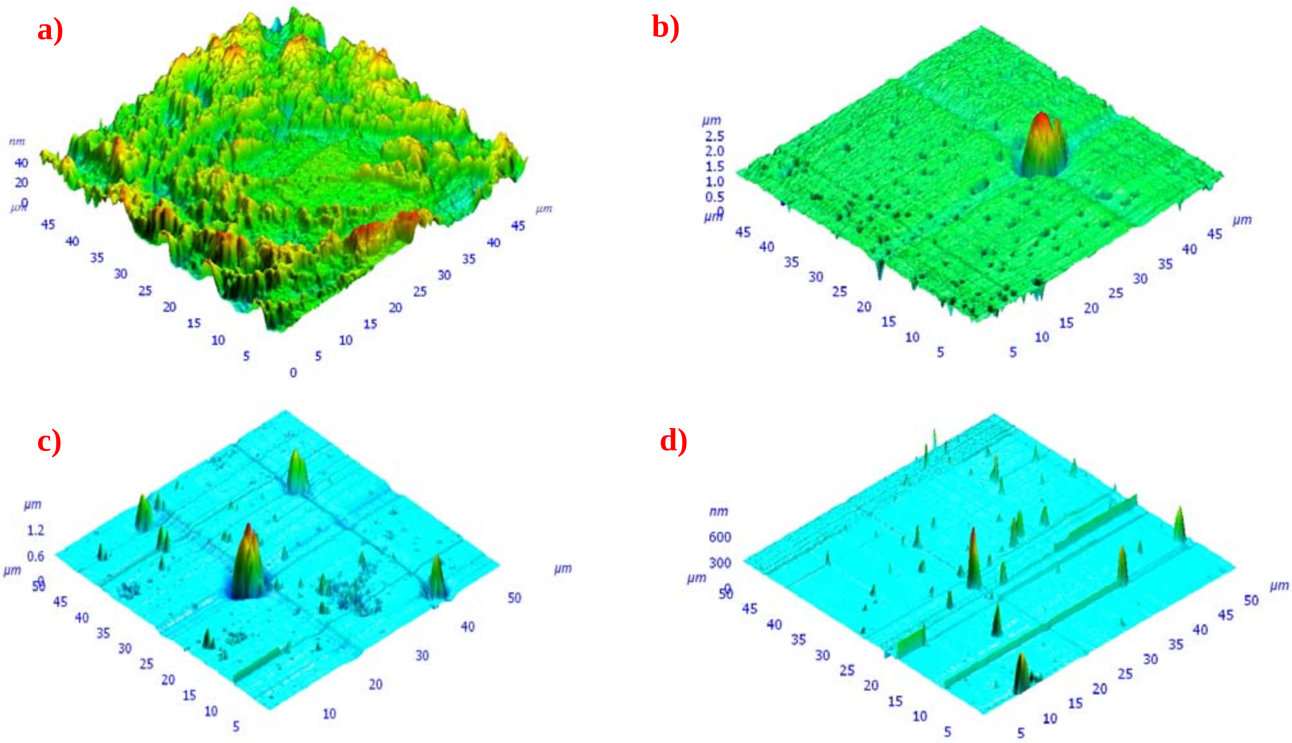


Fig. 3 SEM images of the A4 sample. a) 500magnification; b) 4000magnification

So the surface morphology of these films was observed by scanning probe microscope, the SPM images shown in Fig 4 a) - g) illustrated the surface morphology of M to A6 respectively, many conical granular materials existed on the film surface, density of these particles decreased with the distribution angle increase, and the film surface become smoother gradually. On the surface of M and A1 positioned at 0 degree and 15degree from the thruster axis respectively, existed obvious sputtering pits, previous studies of PPT contamination indicated a plume half angle of approximately 40 degrees, high speed (~ 40km/s) and high density (~$10^{20}m^{-3}$) plasma existed in this region[9], so the plasma etching effect on the substrate is stronger in this region. The surface roughness decreased from the center position R_{rms}=90.9998nm gradually to 45 degrees R_{rms}=46.7307nm, in the range of greater than 45 degrees, Rrms value is basically the same, but due to large particles existing on the surface, the surface roughness is still maintained a higher value than the glass substrate.



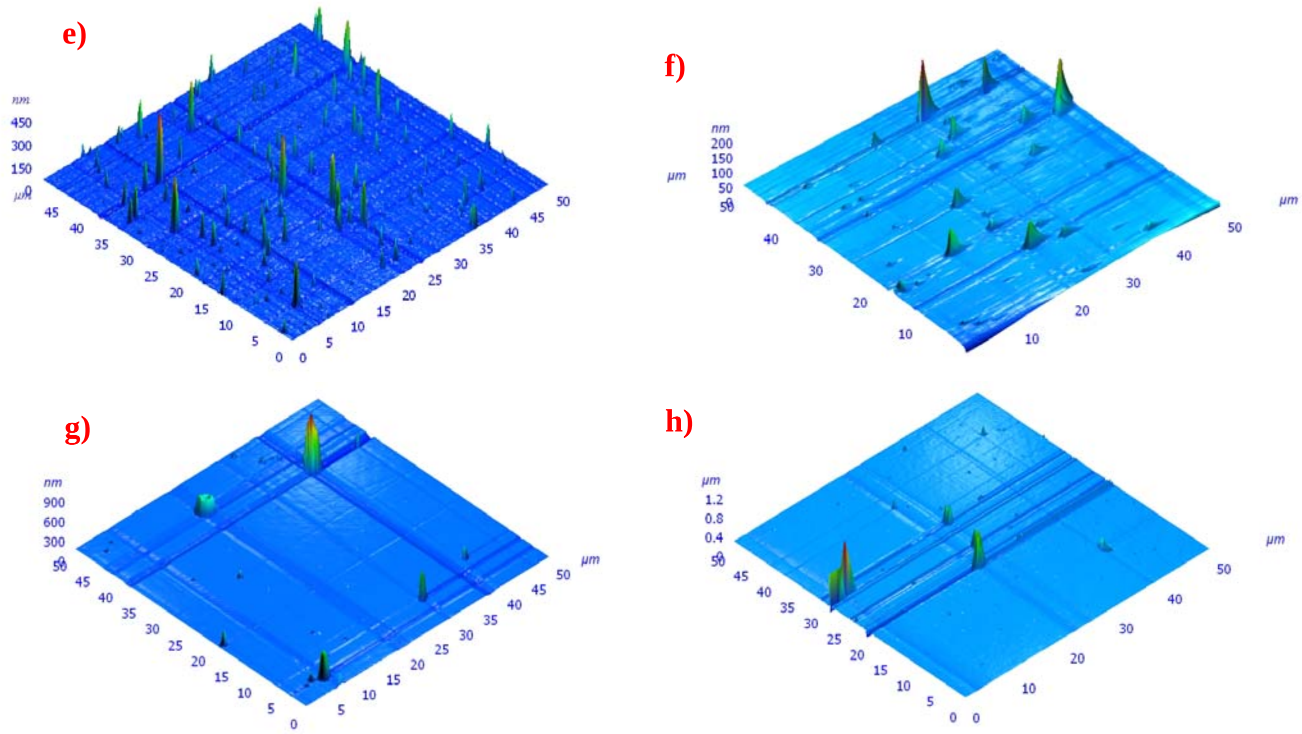


Fig. 4 SPM micrographs of pre-test glass substrate and M to A6: a) glass substrate, Rrms:7.97843 nm; b) M, Rrms: 122.499 nm; c) A1, Rrms: 81.2771nm d) A2, Rrms: 56.4902nm; e) A3, 46.7307 nm; f) A4, Rrms:26.4855 nm; g) A5, Rrms: 23.7297 nm; h) A6, Rrms: 23.84nm.

Optical properties. The transmittance and reflectance spectrum curves of M to A6 were shown in Fig 4. For comparison, the transmission spectrum curve of the pre-test glass substrate was given also, it can be seen from Fig 5 a) that compared to the original substrate, each sample basically showed having a strong absorption properties for wavelength below 600nm, while with relatively weak absorption property for wavelength over 600nm, as expected the largest decrease was in the astronomical V-band. As can be seen in Fig 5 b), the deposited films showed having enhanced reflective characteristics.

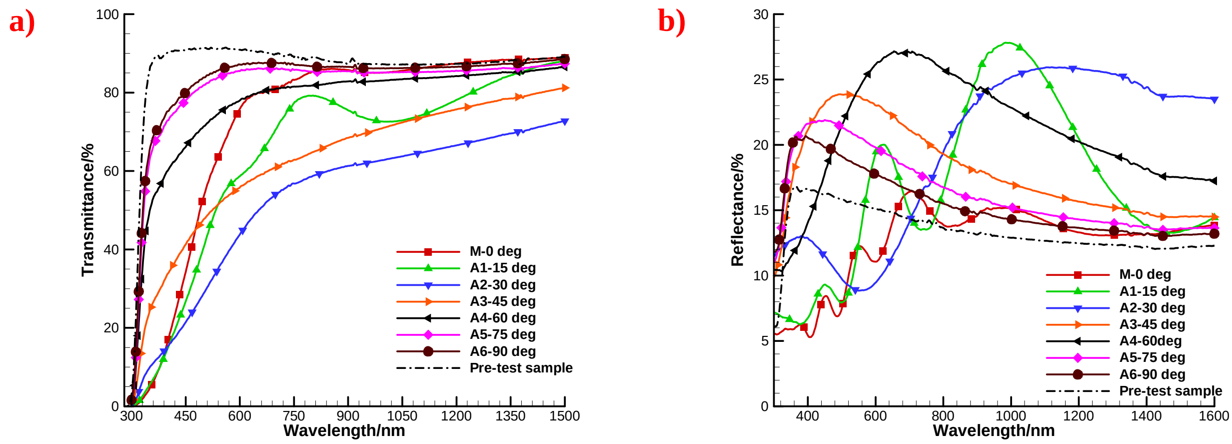


Fig. 5 transmittance and reflectance spectrum curves of M to A6 and pre-test substrate, a) transmittance; b) reflectance

Both from the transimittance and reflectance curves, the angular dependence of the results was quite striking. From 0 degree to 30 degree and from 45 degree to 90 degree, samples located in these two different angle ranges showed different optical properties. The transmittance decreased more for samples between angles of 0 degree and 30degree, not only in the ultraviolet wavelenth but also in the visible and infrared wavelenth range, it showed a significant decrease for sample at 30 degree . While results for sample located over 45 degree showed a smaller decrease in transmittance, the transmittance of the sample increased gradually with the angle increased and reached the maximum at 90 degrees, almost no decrease in visible and infrared wavelength was observed at 75 degree and 90 degree.

Compared to the transmittance, the deposited film seemed to have less impact on reflectance, the largest change in reflctance was about 7% compared to the pre-test glass substrate. Similarly, samples located in the range from 0 degree to 30 degree within main body of the PPT plume showed different reflective characteristics from those samples located beyond 45 degree. The samples located within 0 degree to 30 degree showed more complicated reflective characteristics because of the hign density and hign energy ions in this region. Like the transimitance, impact on reflectance was weakest at the sample at 90 degree.

Summary

The morphology and optical property of the films deposited on the PPT cathode side were studied. Due to different plamsa and neutral particles distribution characterisitics, the morphology and optical properties showed signigicant angular dependence, the deposited films showed having strong UV absorption and enhanced reflection characteristics. Results from the investigation of the optical characteristics showed that deposition of the PPT plume had considerable impact on instrument visibility in the range from 0 degree to 30 degree within main body of the PPT, the effect of the thruster effluents seemd to be negligible when the instrument was located at70 degree and 90 degree from the thruster axis.

Acknowledgments

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References

[1] W.J.Guman: *Journal of Spacecraft and Rockets*, Vol. 7, No. 4, pp. 409-415. (1970)

[2] D.P.Stechmann:*Numerical Analysis of Transient Teflon Ablation in Pulsed Plasma Thrusters*(MS, Worcester polytechnic institute, 2007),p4.

[3] R Eckman, N A Gatsonis, R M Myers: *25th International Electric Propulsion Conference* (Cleveland,Ohio,1997) IEPC-97-126.

[4] R Eckman: AIAA 98-0004.(1998)

[5] N. A.Gatsonis., L.Byrne and R Eckman : *38th AIAA Aerospace Sciences Meeting and Exhibit* (Reno, NV, January 10-13, 2000)AIAA 2000-0464.

[6] L.K.Rudolph, and R.M.Jones:*14th International Electric Propulsion Conference* (Princeton, Oct. 30-Nov, 1979)AIAA paper 79-2106.

[7] W.J.Guman and M. Begun: *14th International Electric Propulsion Conference* (San Diego, California, April 25-27,1978)AFRPL-TR-77-2.

[8] L.A.Arrington:*36th Joint Propulsion Conference* (Huntsville, AL, July 17-19,2000) AIAA-2000-3262.

[9] R.M.Myers and L.A.Arrington:*32nd Joint Propulsion Conference* (Lake Buena Vista, Florida, July 1-3, 1996) AIAA paper 96-9729.