An improved solid expellant plasma generator has been developed. The plasma generator includes a support housing, an electrode rod located in the central portion of the housing, and a mass of solid expellant material that surrounds the electrode rod within the support housing. The electrode rod and the solid expellant material are made of separate materials that are selected so that the electrode and the solid expellant material decompose at the same rate when the plasma generator is ignited. This maintains a point of discharge of the plasma at the interface between the electrode and the solid expellant material.

25 Claims, 3 Drawing Sheets
Expellant, Neutrals, Ions, and Electrons

FIG. 1
FIG. 3
SOLID EXPELLANT PLASMA GENERATOR

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of Contract Nos. NASS-02105 and NASS-01153 awarded by the National Aeronautics and Space Administration (NASA).

FIELD OF THE INVENTION

The invention relates generally to spacecraft propulsion. More specifically, the present invention relates to a solid expellant plasma generator for spacecraft.

BACKGROUND ART

The application of electrodynamic tethers in space applications is presently limited by the lack of a suitable plasma contactor device. Previously, the NASA Tethered Satellite System used an electron gun to emit electrons back into the conductive ionospheric plasma at the negative pole of the electrodynamic tether. Hollow cathode plasma generators were used on the Plasma Motor-Generator (PMG) tether mission. However, both, the electron gun and the hollow cathode are sensitive to contamination, depend heavily on spacecraft conditioned electrical power, and are complex. In particular, the Hollow Cathode requires a high pressure vessel and the associated plumbing to regulate and handle the gaseous expellant.

Consequently, a plasma device that does not rely heavily on spacecraft resources (mass and conditioned electrical power) is desired. Also, the plasma device should be insensitive to contamination and, therefore, not require special on-orbit pre-operation conditioning or stand-by power and is capable of emitting large, multi-amp currents. In order to create such a plasma device, it is a requirement to emit large currents while minimizing the use of electrical power and expellant mass. Additionally, the device should use the emission of large currents at low power without the use of contamination-sensitive, low work-function materials.

SUMMARY OF THE INVENTION

In some aspects, the invention relates to a solid expellant plasma generator, comprising: a stainless steel support housing; a 0.9 mm diameter copper-clad carbon electrode rod located in the central portion of the support housing; a block of solid expellant material made of poly(butyl) methacrylate with poly(tetraethylene glycol diacrylate) crosslinks that surrounds the electrode rod within the support housing; and where the electrode rod and the solid expellant material comprises separate materials that are selected so that the electrode and the solid expellant material decompose at the same rate in order to maintain a point of discharge of the plasma at the interface between the electrode and the solid expellant material.

Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

It should be noted that identical features in different drawings are shown with the same reference numeral.

FIG. 1 is a conceptual schematic diagram a solid expellant plasma generator in accordance with one embodiment of the present invention.

FIG. 2 shows a cross-sectional diagram of an ionization chamber located above the expellant block in accordance with one embodiment of the present invention.

FIG. 3 is a graph that shows the discharge current (amps) as a function of the voltage across the generator discharge (volts) in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION

The solid expellant plasma generator of the present invention uses a solid expellant to generate a conducting gas (i.e., plasma). The basic principle is that the expellant vapor cloud enables an electrical discharge that ionizes vapor particles. The heat generated by the discharge, in turn, vaporizes additional expellant, which replenishes the expanding cloud and maintains the conditions required for the electrical discharge to function. This device is robust and eliminates the need for high pressure vessels, heaters, pressure regulators, valves and other plumbing components. The generator is also insensitive to contamination, and does not require on-orbit conditioning or regulated power.

The purpose of the solid expellant plasma generator is to provide a suitable plasma contactor device for the operation of electrodynamic tethers in space. The generator requires only a center electrode surrounded by a solid expellant block. The device is powered by unregulated electrical power developed by the electrodynamic tether in the generator mode, or by unregulated solar-electric power in the motor mode.

FIG. 1 is a conceptual schematic diagram a solid expellant plasma generator in accordance with one example of the present invention. As shown, the solid expellant plasma generator includes a cylindrical shaped housing located in the central portion of the support housing; a block of solid expellant material that surrounds the electrode rod within the expellant housing; and where the electrode rod and the solid expellant material comprise separate materials that are selected so that the electrode and the solid expellant material decompose at the same rate in order to maintain a point of discharge of the plasma at the interface between the electrode and the solid expellant material.

In other aspects, the invention relates to a solid expellant plasma generator, comprising: a housing; an electrode rod located in the central portion of the housing; a block of solid expellant material that surrounds the electrode rod within the housing; and where the electrode rod and the solid expellant material comprises separate materials that are selected so that the electrode and the solid expellant material decompose at the same rate in order to maintain a point of discharge of the plasma at the interface between the electrode and the solid expellant material.
The solid expellant plasma generator can be used in any application where a plasma generator is required. Examples of potential applications include: the control of spacecraft charging on commercial satellites placed in synchronous orbit where differential charging is a known problem; and the vapor deposition process used, for example, in the semiconductor industry. In should be clear that the present invention could also be used in any other applications know in the art that require a plasma generator.

Key advantages of the present invention include the generation of a self-sustained, self-fuelled electrical discharge. Additionally, the expellant material produces multiple vapor particles per solid particle which are chemically benign. Consequently, the vapor particles do not react chemically with satellite surfaces or structures. Finally, the unique design of the center electrode, effectively "burns" at the same rate as the expellant block is depleted in order to maintain a stable discharge.

While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed here. Accordingly, the scope of the invention should be limited only by the attached claims.

What is claimed is:

1. A solid expellant plasma generator, comprising:
   - A stainless steel support housing;
   - A 0.9 mm diameter copper-clad carbon electrode rod located in the central portion of the support housing;
   - A block of solid expellant material made of poly(butyl methacrylate) with poly(tetraethylene glycol diacrylate) crosslinks that surrounds the electrode rod within the support housing;
   - Wherein the electrode rod and the solid expellant material decompose at the same rate in order to maintain a point of discharge of the plasma at the interface between the electrode and the solid expellant material upon ignition of the generator;
   - Wherein the generator maintains an expellant mass utilization of 0.00325 kg/amp-hr or greater; and
   - Wherein the operating voltage of the generator is inversely proportional to the emission current once the generator reaches a critical emission current of approximately 0.4 amps.

2. A solid expellant plasma generator, comprising:
   - A housing;
   - An electrode rod located in the central portion of the housing;
   - A block of solid expellant material that surrounds the electrode rod within the housing; and
   - Wherein the electrode rod and the solid expellant material comprises separate materials that are selected so that the electrode and the solid expellant material decompose at the same rate in order to maintain a point of discharge of the plasma at the interface between the electrode and the solid expellant material.

3. The generator of claim 2, wherein the housing is made of a non-conductive material.

4. The generator of claim 2, wherein the housing is made of a conductive material.
5. The generator of claim 2, wherein the housing is made of aluminum.

6. The generator of claim 2, further comprising a plurality of electrodes located in the central housing.

7. The generator of claim 2, wherein the electrode is made of copper clad carbon.

8. The generator of claim 2, wherein the electrode is made of uncoated carbon.

9. The generator of claim 2, wherein the electrode is made of tungsten.

10. The generator of claim 2, wherein the electrode is made of copper.

11. The generator of claim 2, wherein the electrode is made of stainless steel.

12. The generator of claim 2, wherein the solid expellant material is Teflon.

13. The generator of claim 2, wherein the solid expellant material is wax.

14. The generator of claim 2, wherein the solid expellant material is paraffin wax.

15. The generator of claim 2, wherein the solid expellant material is polymeric material.

16. The generator of claim 2, wherein the solid expellant material is polyethylene.

17. The generator of claim 2, wherein the solid expellant material is nylon.

18. The generator of claim 2, wherein the solid expellant material is poly(methyl methacrylate).

19. The generator of claim 2, wherein the solid expellant material is poly(butyl methacrylate).

20. The generator of claim 2, wherein the solid expellant material is crosslinked polyethylene.

21. The generator of claim 2, wherein the solid expellant material is a non-melting polymeric material.

22. The generator of claim 2, wherein the solid expellant material is a non-ashing polymeric material.

23. The generator of claim 2, wherein the generator has a discharge rate of 0.00325 kg/amp-hr or higher.

24. The generator of claim 2, wherein the generator has an emission current capacity of greater than 1.8 amps.

25. The generator of claim 24, wherein the generator has an operating voltage of less than 100 volts when the emission current capacity is greater than 1.8 amps.