SOLID EXPPELLANT PLASMA GENERATOR

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Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 432 days.

Appl. No.: 11/852,007
Filed: Sep. 7, 2007

Prior Publication Data

Int. Cl. H01J 7/24 (2006.01)
U.S. Cl. 315/111.11; 315/111.21
Field of Classification Search 315/111.21, 315/111.31, 111.71, 111.81, 111.91, 111.11; 118/722, 723 VE

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ABSTRACT

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.
Expellant, Neutrals, Ions, and Electrons

FIG. 1
FIG. 3
SOLID EXPPELLANT PLASMA GENERATOR

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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 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; 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.

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 of 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 of a solid expellant plasma generator in accordance with one embodiment of the present invention. As shown, the solid expellant plasma generator comprises: an electrode rod located in the central portion of the support 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 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 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.

Other aspects and advantages of the invention will be apparent from the following description and the appended claims.
order, and fits over the exterior of the support canister 32. This
has the effect of increasing the path length of ionizing elec-
trons before they escape the discharge region. The increased
erator pressure, as a result of the support canister extension 32
and aperture 35, and the increased path length of the elec-
trons, result in improved ionization efficiency of the vapor-
zized expellant and therefore improved expellant mass utiliza-
tion. Also shown in FIG. 2 is the electrode 38 and power
supply wire 40 that are attached by an expellant connector 42.
They are cover by high voltage insulation 46 and high tem-
perature insulation 44. The power supply wire 40 is held in
place by a capture nut 48.

It should be noted that alternative embodiments of the
present invention may utilize different configurations of fea-
tures and different types of materials. For example, the elec-
trode rod may be located in alternative locations other than
the center of the housing. In one embodiment multiple rods
may be used in the housing to provide enhanced current
capacity. Further, the solid expellant may be a variety of
materials such as a wax (e.g., paraffin wax) or a polymeric
material such as: polyethylene; nylon; poly(methyl meth-
acrylate); poly(butyl methacrylate); crosslinked polyethyl-
en; or teflon. One particular material that may be used is poly
(butyl methacrylate) with poly (tetraethylene glycol diacry-
late) crosslinks. It is generally preferred to use polymers that
do not melt and that depolymerize without ashing. The elec-
trode may be made of such materials as: copper-clad carbon;
uncoated carbon; tungsten; copper; or stainless steel. The key
characteristic of the materials of the electrode and the solid
expellant is that they must be matched so that each material
decomposes at the same rate. The materials used for the
housing may be either conductive or non-conductive. Mate-
erials such as aluminum or stainless steel may be used. The key
characteristic of the housing is that it provides structural
support for the solid expellant material, the discharge cham-
ber, etc.

The function of the solid expellant plasma generator is an-
alogous to that of a candle in which the heat of the flame
melts the tallow which, in turn, fuels the flame. The center
electrode is biased sufficiently that an electrical discharge is
initiated between it and the vapor cloud. The heat of the
electrical discharge decomposes additional material from the
surface of the solid expellant block in the immediate vicinity
doing electrode. The expellant maintains the vapor
cloud at a sufficient density to ensure a high collision
rate between the energetic charged particles, accelerated
away from the center electrode, and the neutral vapor par-
ticles in the cloud. Each ionizing collision creates a charged
pair . . . a positive and a negative particle. Some of the
particles that are of opposite polarity to the center electrode
will be accelerated back into the electrode, which is main-
tained at an emissive temperature by the resulting collisions.

As previously mentioned, the center electrode is designed
so that it decomposes at the same rate as the block of solid
expellant is depleted. This maintains the point of discharge at
the interface between the electrode and solid expellant mate-
rial. This is key to achieving a reliable ignition of the genera-
tor. Also, it is critical for maintaining stable and efficient
evaporation/sublimation of the electrode/expellant of the
generator.

In some embodiments, the center electrode is a 0.9 mm
copper-clad carbon rod. In alternative embodiments, the elec-
trode is a 0.9 mm solid tungsten rod. The performance char-
acteristics of the solid expellant plasma generator as shown in
FIG. 3 which shows the discharge current (amps) v. the volt-
age across the generator discharge (volts). The performance of
the generator shows an emission current capacity of more
than 1.8 amps. Above a critical emission current, the oper-
ating voltage of the generator is inversely proportional to
emission current and decreases to less than 100 volts at 1.8
amps. In testing, the critical emission current was approxi-
ately 0.4 amps. Also, the expellant mass utilization of a test
model was 0.00325 kg/amp-hr.

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 semicon-
ductor 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 gen-
eration of a self-sustained, self-fuelled electrical discharge.
Additionally, the expellant material produces multiple vapor
particles per solid particle which are chemically benign. Con-
sequently, 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 dis-
charge.

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;
ablock of solid expellant material made of poly(butyl
methacrylate) with poly(tetraethylene glycol diacry-
late) 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 utiliza-
tion 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 hous-
ing;
ablock of solid expellant material that surrounds the elec-
trorod 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.