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DU GRAND-DUCHÉ DE LUXEMBOURG
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(73) Titulaire(s):
GRADEL, S.À.R.L. – 5691 ELLANGE (Luxembourg)

(72) Inventeur(s):
PETKOW Dejan – 66763 Dillingen (Allemagne),
ROUWETTE Sander – 57480 Rettel (France)

(74) Mandataire(s):
OFFICE FREYLINGER S.A. –
8001 STRASSEN (Luxembourg)

(54) **Apparatus for generating a plasma jet, in particular for space propulsion.**

(57) An apparatus for generating a plasma jet comprising: a gas containment vessel (12) having a cylindrical wall (14) extending along a central axis (A) and made from electrically conductive material, said gas containment vessel forming an outer electrode; an internal electrode (20) arranged inside said gas containment vessel, said internal electrode being a grid-like member made from electrically conductive material and preferably highly transparent to flowing ions and electrons; means for flowing at a controlled rate a gas into said gas containment vessel (12); a power source (24) to create a sufficient difference of potential between said gas containment vessel (12) and said internal electrode (20) to create a plasma; wherein an outlet port (18) is arranged in said cylindrical wall (14) of said gas containment vessel and said apparatus is configured to allow said plasma formed within said vessel (12) to emerge, through said outlet port (18), from the vessel as a plasma jet, preferably in a direction substantially perpendicular to said central axis (A).

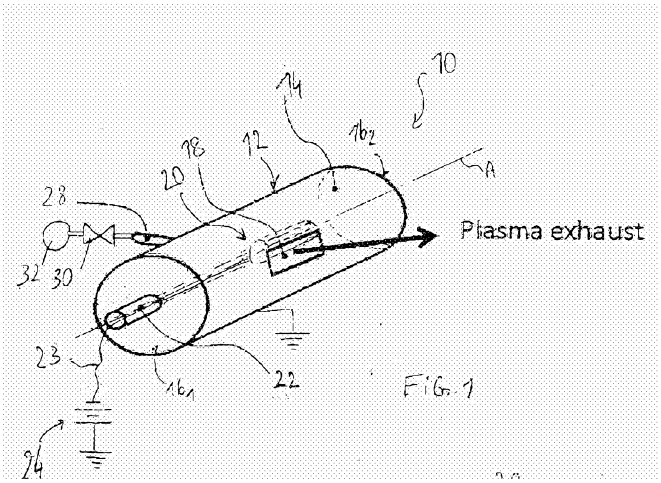


Fig. 1

APPARATUS FOR GENERATING A PLASMA JET, IN PARTICULAR FOR SPACE PROPULSION

FIELD OF THE INVENTION

The present invention generally relates to the field of plasma generation. More specifically, the invention concerns an apparatus for generating a plasma jet providing a thrust force to be used in an electric space propulsion device.

BACKGROUND OF THE INVENTION

The efficiency of any space propulsion thruster is commonly expressed as specific impulse which is proportional to the plasma or ion jet exhaust velocity at the thruster exit. However, a high specific impulse implies a low thrust level and vice versa: Chemical propulsion systems provide high thrust and are therefore used for lift-off. Correspondingly, their specific impulse is very low. Electric propulsion (EP) systems are significantly more efficient which is why practically all scientific mid- and long-term missions rely on EP systems. Nowadays more and more telecommunication satellites use EP systems for station keeping and increasingly quickly reaching the final orbit (Geostationary Orbit – GEO). All big satellite integrators are working on the development of so-called all-electric platforms for future telecommunication satellites which will also use EP systems for reaching the final orbit, not just for station keeping.

Another field of application refers to plasma sources applied to terrestrial applications. For example, plasma sources are used in vacuum based surface treatment processes, e.g. to coat surfaces by melting and accelerating tiny powder particles which form the coating upon impact.

The most prominent EP system is currently based on Hall Electric Thruster technology, followed by the Gridded Ion Engine technology. In both cases, Xenon ions are generated inside a discharge chamber and accelerated by electrostatic fields. Outside the thruster, the ion cloud is neutralized by the electrons which have been created in the ionization process. Those electrons

are emitted using an emitter outside the thruster which points towards the thruster plume.

There are various other EP technologies, some of them have been flown before, others have never left the laboratory stage.

In recent years, an alternative plasma confinement principle called Inertial Electrostatic Confinement (IEC) got in the focus of the EP community. An IEC thruster uses a spherical configuration, wherein ions are generated and accelerated towards the center of a spherical vacuum chamber defined by a conductive vessel acting as anode. A wire grid cathode is arranged inside the vessel, concentrically. A virtual cathode forms in the high-density central core region, combined with a locally distorted cathode grid potential field, extracts accelerated ions into an intense quasi-neutral ion jet. A cylindrical guide is used as extraction guide to convey the plasma jet from the center of the vessel to an outlet port in the vessel.

However, the cylindrical extraction guide renders the system very complex and heavy. Moreover, plasma confinement quality requires accurately manufactured electrode grids. It is very difficult to manufacture complex spherical grids with a sufficient quality and geometric accuracy which are able to sustain both the mechanical loads during lift-off from ground (including shocks due to stage separation) and thermal loads during operation.

OBJECT OF THE INVENTION

The object of the present invention is to provide an alternative design of IEC-based apparatus for generating a plasma jet, which is easier to manufacture and more robust, in order to withstand the constraints for spacecraft applications.

This object is achieved by an apparatus for generating a plasma jet as claimed in claim 1.

SUMMARY OF THE INVENTION

The present invention concerns a device that uses ions or neutrally charged gas to provide a thrust force or stream of matter. The invention has been particularly designed for spacecraft application and therefore concerns a device that can provide a propulsive thrust force for spacecraft propulsion, particularly a plasma jet thruster, which uses an inertial electrostatic confinement design having a discharge plasma for generating ions that provide thrust when accelerated and expelled from the device in the plasma jet. The invention also concerns a device that ejects matter with a jet form for use as an industrial plasma spray, industrial material processing, waste treatment, welding or cutting materials, or for plasma vapor deposition.

According to the invention, an apparatus for generating a plasma jet comprises:

a gas containment vessel having a cylindrical wall extending along a central axis and made from electrically conductive material, said gas containment vessel forming an outer electrode;

an internal electrode arranged inside said gas containment vessel, said internal electrode being a grid-like member made from electrically conductive material and preferably highly transparent to flowing ions and electrons;

means for flowing at a controlled rate a gas into said gas containment vessel;

a power source to create a sufficient difference of potential between said gas containment vessel and said internal electrode to create a plasma;

wherein said cylindrical wall of said gas containment vessel comprises an outlet port in said cylindrical wall and said apparatus is configured to allow said plasma formed within said vessel to emerge, through said outlet port, from the vessel as a plasma jet in a direction substantially perpendicular to said central axis.

Embodiments of the invention are recited in the appended dependent claims 2 to 12.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1: is a principle diagram of an embodiment of the present apparatus;

Figure 2: is a principle perspective view of the cathode grid;

Figure 3: is a detail, front view of the feed-through assembly;

Figure 4: is a principle cross-section view of the cathode grid.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

One embodiment of the present apparatus 10 for generating a plasma jet is shown in Fig.1, that is specifically designed for spacecraft applications – and may thus also be referred to as thruster or electric space propulsion device. The thruster 10 is an inertial electrostatic confinement device with cylindrical design. The thruster 10 comprises a housing formed by a cylindrical gas containment vessel 12. The vessel has a cylindrical wall 14 extending along a central or length axis A and is closed at both ends by end plates 16_1 and 16_2. The containment vessel 12 may be made from electrically conductive material, such as e.g. stainless steel or aluminum alloy.

Reference sign 18 designate a lateral outlet port in the vessel wall 14 through which, in use, a propulsive plasma jet emerges, as will be explained below. In this embodiment, the outlet port 18 is a rectangular orifice; however it could have other shapes, e.g. circular.

Located inside the containment vessel is a grid-like internal electrode designated 20. Reference sign 22 indicates a feedthrough that allows passing electrical power at a predetermined voltage from a power supply 24. In fig.1, components and component parts located inside vessel 12 are represented in dashed lines. The feedthrough 22 may be composed of a small diameter tube 25 defining an internal passage for a conductive wire 23 connecting the power supply 24 to the internal electrode 20. The small diameter tube passes in a sealed and insulated manner through end plate 16_1. The internal electrode 20

comprises a support bracket or a threaded rod 26 engaging the inner end of the tube 25, as can be seen in Fig 3. The feedthrough 22 system also provides for insulation between the vessel and the internal electrode.

A gas or a gas mixture is introduced into the vessel 12 by means of a gas supply interface 28 comprising one or more small orifices provided in cylindrical wall 14. The gas supply interface is connected by piping to a gas source comprising flow control means, e.g. a valve 30, coupled to a pressurized gas cylinder 32 containing here propellant gas. This allows delivering a controlled flow rate of gas, in particular of propellant gas, into the containment vessel. The propellant gas may e.g. be Xenon or a noble gas. Other gases can also be used depending on the application.

It shall be appreciated that the inner electrode 20 is a cylindrical grid-like element. The cylindrical grid electrode 20 is formed by a plurality of wire or vanes 36 joined together to form a general cylinder shape with a pattern of openings or windows that provides a thin profile when viewed in a radial direction in order to achieve a high geometric transparency. "Effective transparency" is conventionally defined as a measure of the probability of ions passing through a grid in the case where the flowing ion beam profile is non-uniform.

The grid electrode 20 serves to define a central volume that allows radial flow of species, confines a plasma formed of generated ions and electrons, and provides a plasma flow stream that becomes the plasma jet.

The grid openings of the inner electrode 20 typically are all of same dimension, except for one opening having a larger dimension through which the plasma jet escapes due to distortion of the electric potential surface at this enlarged grid opening, as is known in the art. (in some application, one could use more than one enlarged grip opening). The cathode 20 may be made from a variety of metals having appropriate properties, in particular high temperature, high electron emissive material such as tungsten, tantalum or molybdenum.

An exemplary embodiment of the cylindrical inner electrode 20 is shown in Figures 2 and 4. The cylindrical electrode 20 is designed as a cylindrical cage: a

set of parallel wires 36 extend between two disk-shaped end plates 38 (i.e. electrode 20 is closed in axial direction). The wires are circumferentially distributed at the periphery of the disks 38, in an equidistant manner, except for two neighboring wires that are separated by a slightly larger distance. Hence, the electrode has grid openings 40 that are all of same dimension, except for one enlarged grid opening designated 42.

The electrode inner 20 is arranged concentrically inside the vessel and axially centered. The inner electrode 20 is further oriented so that the larger opening 42 is radially aligned with outlet port 18. It may be further noted that outlet port is a rectangular orifice having its length oriented along central axis A. The length of electrode 20, i.e. the distance between end plates 38, is about the same length as that of outlet port 18. In general, their length may vary by up to +/-20 to 30%.

The present thruster 10 may be operated similarly to a convention spherical IEC device, as it will appear from the below description. In operation, the vessel 12 defines a containment enclosure having conductive walls held at ground potential and the cylindrical grid-like electrode 20, which is radially and axially centered (i.e. globally symmetrically aligned), acts as a cathode. The cathode 20 is connected to power source 24 to provide a high negative potential, while the vessel 12 itself is maintained at a ground potential. A propellant gas is introduced into the vessel. A voltage is applied to the cathode electrode 20 and, once the voltage difference between the electrodes is high enough, a glow discharge is induced, leading to a generation of electrons and ions. All charges are accelerated by radial electric fields. The electrons created in the inter-electrode space move towards the anode where they get absorbed while the ions created between the electrodes move towards the center of the device. On their way to the center some of them collide with the cathode, thereby getting either neutralized at the surface, or implanted. Some of them trigger the emission of secondary electrons. Other processes that can happen are ion bombardment induced erosion. The dominance of certain processes depends on the ion type, energy of impact, angle of impact, and cathode material. Other processes of relevance are ion induced ionization of background neutrals, and

energy losses due to charge exchange with background neutrals. The latter is a significant loss term as it translates a fast ion into a slow ion. The former process happens preferably inside the cathode area where a slow ion and a slow electron are produced. The slow ions in the plasma core preferably get lost to the cathode (where they neutralize) while the slow electrons preferably get rejected by the cathode's potential until they escape into the inter-electrode space by passing between the cathode vanes. Former research confirms that the effective grid transparency, i.e. the quantity which expresses the probability of an ion to avoid collision with the cathode, can be greatly enhanced under certain operational conditions, thereby reaching values up to 95-99%. A high grid transparency is equivalent to a high cathode life time, both can be further increased by e.g. even more grids with well-defined potentials.

As is known with IEC devices, the enlarged grid opening will create a very intense, tightly coupled space-charge neutralized plasma jet, that is directed outward from the central core plasma region. The jet formation is the result of a large distortion of the electric potential surface at the enlarged grid opening. The resulting local potential gradient initiates electron flow which triggers ions to follow them out across the surface. The result is the formation of an intense space charge neutralized beam at that location. Since grid opening 42[PD1] is radially aligned with outlet port 18, the plasma jet will exit there though and provide a thrust in a direction perpendicular to the central axis A, i.e. perpendicular to the length axis of the cylindrical containment vessel 12.

The present invention brings a number of benefits.

Compared to the state of the art thruster technologies, the cylindrical configuration allows linear scaling by increasing the length of the electrodes without changing the plasma state. Doubling the electrode lengths doubles the power consumption by doubling the current whereas voltage and plasma state remain the same.

The use of cylindrical geometry is also of advantage in terms of manufacturing technologies. Cylindrical shapes can be produced with good quality and geometric accuracy, improving robustness and rendering the device more prone

to sustain both the mechanical loads during lift-off from and thermal loads during operation.

Compared to the state of the art non-IEC thruster technology the grid transparency is very high, reaching even 95-99% depending on proper operational and configurational conditions.

Combined with an EPPM (Electric Propulsion Pointing Mechanism, ESA terminology) allows a significantly larger change of thrust direction by rotating the device around its length axis A compared to the state of the art thruster technology. The strongly reduced angular momentum that is generated and to be conserved if operated in combination with an EPPM is another strong benefit compared to the art. The lower the angular momentum that is to be conserved (using the satellite's control mechanisms), the lower the system wide impact of the change of thrust vector.

P-GRADEL-007/LU

REVENDICATIONS

1. Appareil pour générer un jet de plasma comprenant :
un récipient de confinement de gaz (12) ayant une paroi cylindrique (14) s'étendant le long d'un axe central (A) et constitué d'un matériau électro-conducteur, ledit récipient de confinement de gaz formant une électrode extérieure ;
une électrode interne (20) agencée à l'intérieur dudit récipient de confinement de gaz, ladite électrode interne étant un élément en forme de grille constitué d'un matériau électro-conducteur et préférablement hautement transparent aux ions et électrons en circulation ;
un moyen faire pénétrer à un débit contrôlé un gaz dans ledit récipient de confinement de gaz (12) ;
une source d'énergie (24) pour créer une différence suffisante de potentiel entre ledit récipient de confinement de gaz (12) et ladite électrode interne (20) pour créer un plasma ;
dans lequel un orifice de sortie (18) est agencé dans ladite paroi cylindrique (14) dudit récipient de confinement de gaz et ledit appareil est configuré pour permettre que ledit plasma formé à l'intérieur dudit récipient (12) émerge, à travers ledit orifice de sortie (18), depuis le récipient comme un jet de plasma, préférablement dans une direction sensiblement perpendiculaire audit axe central (A).

2. Appareil selon la revendication 1, comprenant un système d'isolateur à orifice d'amenée, qui est configuré pour amener une énergie électrique à une tension prédéterminée depuis ladite source d'énergie jusqu'à ladite grille d'électrode interne à une valeur suffisante pour créer une décharge de plasma, préférablement une haute tension négative pour faire fonctionner ladite grille d'électrode interne comme une cathode.

3. Appareil selon la revendication 2, dans lequel ledit orifice d'amenée est en outre configuré pour fournir une isolation entre ledit récipient de confinement de gaz et ladite électrode interne.

4. Appareil selon la revendication 1, 2 ou 3, dans lequel ladite électrode interne est formée comme un élément en forme de grille cylindrique ayant son axe longitudinal aligné avec celui dudit récipient de confinement.

5. Appareil selon la revendication 4, dans lequel ladite électrode interne a une longueur plus courte que ledit récipient de confinement et est axialement centrée dans celui-ci.

6. Appareil selon la revendication 4 ou 5, dans lequel ladite cathode interne en forme de grille est formée par un fil parallèle ou des ailettes, agencés circulairement pour définir des ouvertures en forme de grille rectangulaires parallèles audit axe central.

7. Appareil selon la revendication 6, dans lequel lesdites ouvertures en forme de grille rectangulaires (40) sont de la même dimension, à l'exception d'une ouverture en forme de grille agrandie (42) qui est alignée avec ledit orifice de sortie (18) dans ladite paroi de récipient.

8. Appareil selon la revendication 4, 5, 6 ou 7, dans lequel ladite cathode cylindrique en forme de grille (20) a ses extrémités axiales fermées.

9. Appareil selon l'une quelconque des revendications précédentes, dans lequel le récipient comprend des barrettes de refroidissement qui transportent le gaz jusqu'à des points d'entrée bien définis dans la chambre de décharge.

10. Appareil selon l'une quelconque des revendications précédentes, comprenant un mécanisme de pointage mécanique configuré pour faire sélectivement tourner le récipient autour de son axe de la longueur.

11. Dispositif électrique de propulsion spatiale comprenant un appareil pour générer un jet de plasma selon l'une quelconque des revendications 1 à 10, dans lequel ledit gaz est un gaz propulseur afin de former un jet de plasma propulsif, en particulier ayant une densité d'énergie et une poussée.

12. Source d'ions comprenant un appareil pour générer un jet de plasma selon l'une quelconque des revendications 1 à 10.

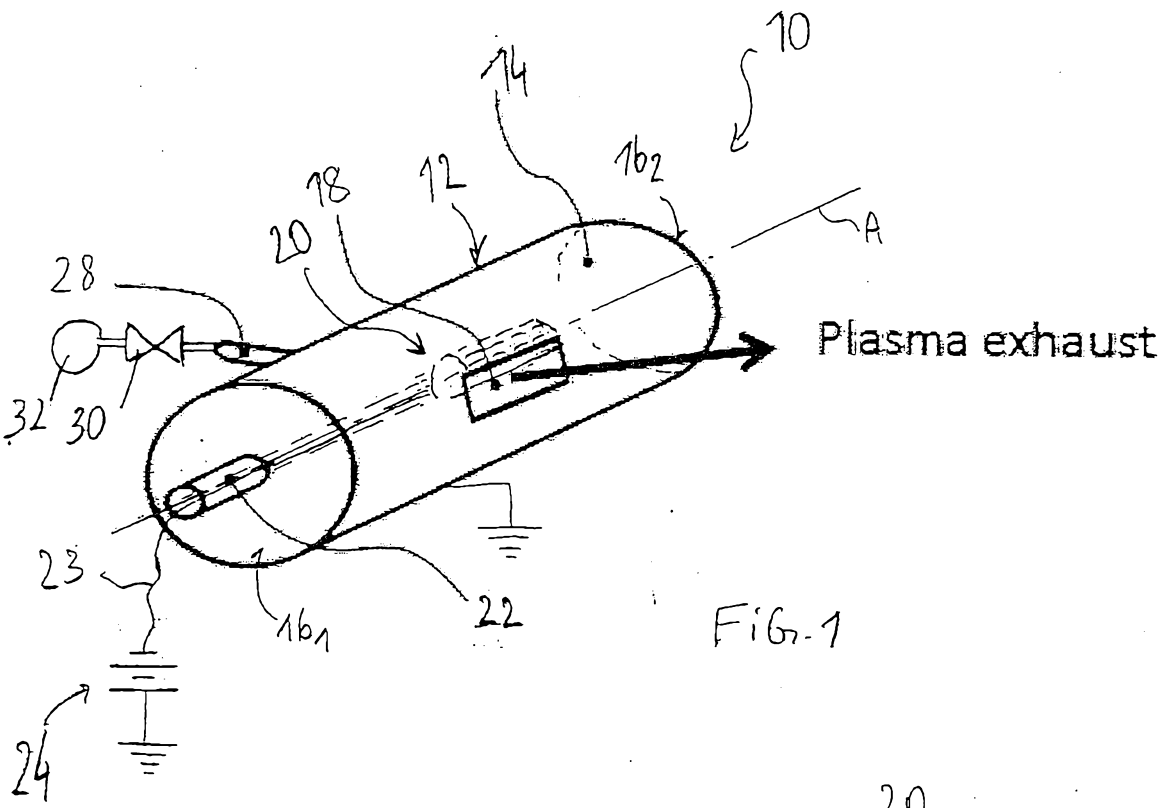

10
14
18
12
16₂
20
A
28
Plasma exhaust
32
30
23
16₁
22
24

FiG.1

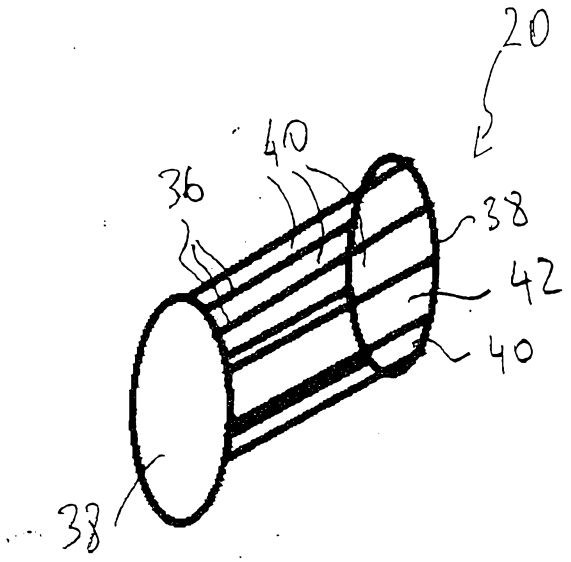

20
40
36
38
42
40
38

FiG.2

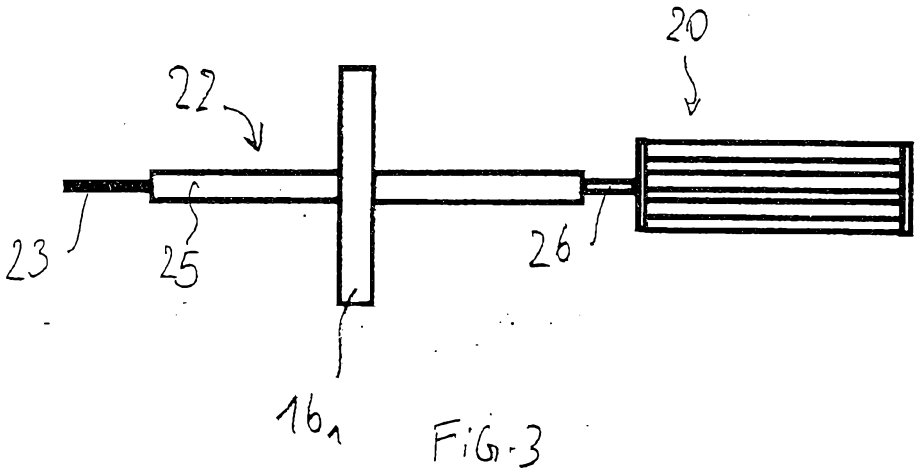


FiG-3

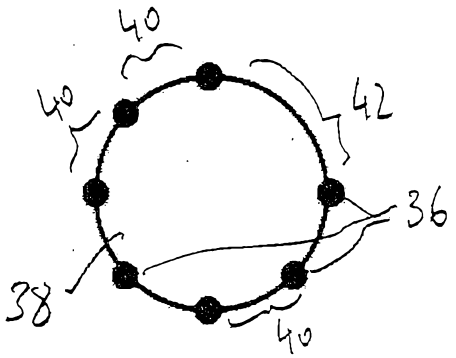


FiG4

Abstract

An apparatus for generating a plasma jet comprising:

a gas containment vessel (12) having a cylindrical wall (14) extending along a central axis (A) and made from electrically conductive material, said gas containment vessel forming an outer electrode;

an internal electrode (20) arranged inside said gas containment vessel, said internal electrode being a grid-like member made from electrically conductive material and preferably highly transparent to flowing ions and electrons;

means for flowing at a controlled rate a gas into said gas containment vessel (12);

a power source (24) to create a sufficient difference of potential between said gas containment vessel (12) and said internal electrode (20) to create a plasma;

wherein an outlet port (18) is arranged in said cylindrical wall (14) of said gas containment vessel and said apparatus is configured to allow said plasma formed within said vessel (12) to emerge, through said outlet port (18), from the vessel as a plasma jet, preferably in a direction substantially perpendicular to said central axis (A).

(Fig.1)

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Ministère de l'Économie
et du Commerce extérieur

SEARCH REPORT

in accordance with Article 35.1 a)
of the Luxembourg law on patents
dated 20 July 1992

National Application Number

LO 1369
LU 93056

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	DE 10 2006 061435 A1 (LEONI AG [DE]) 26 June 2008 (2008-06-26)	1-10,12	INV. H05H1/34
A	* paragraphs [0043], [0046], [0047], [0050] - [0051]; figure 1 * * abstract *	11	

X	DE 20 2013 007063 U1 (PAOLIS MARCO DE [DE]; GEIST DIETER [DE]; STALLWITZ MARKUS [DE]; SUES W) 3 September 2013 (2013-09-03)	1-10,12	
A	* paragraphs [0001], [0002], [0012], [0013], [0018] - [0020]; figure 1 *	11	

X	US 5 485 721 A (STEENBORG MANFRED [DE]) 23 January 1996 (1996-01-23) * abstract; figure 1 *	11	

A	WO 2004/098743 A2 (JEOL USA INC [US]; CODY ROBERT B [US]; LARAMEE JAMES A [US]) 18 November 2004 (2004-11-18) * abstract; figure 6 *	1-12	

TECHNICAL FIELDS SEARCHED (IPC)
H05H

The present search report has been drawn up for all claims

	Date of completion of the search	Examiner
	11 January 2017	de Ruijter-Noordman

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C55)

ANNEX TO THE SEARCH REPORT ON LUXEMBOURG PATENT APPLICATION NO.

LO 1369
LU 93056

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

11-01-2017

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		EP 2104750 A2	30-09-2009
		JP 5193225 B2	08-05-2013
		JP 2010514919 A	06-05-2010
		US 2009314520 A1	24-12-2009
		WO 2008077608 A2	03-07-2008
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		JP H07133757 A	23-05-1995
		US 5485721 A	23-01-1996
WO 2004098743 A2	18-11-2004	CA 2520967 A1	18-11-2004
		EP 1611596 A2	04-01-2006
		JP 4673841 B2	20-04-2011
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		US RE44603 E	19-11-2013
		US 2005056775 A1	17-03-2005
		WO 2004098743 A2	18-11-2004

LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de l'Économie
et du Commerce extérieur

WRITTEN OPINION

File No.	Filing date *(day/month/year)*	Priority date *(day/month/year)*	Application No.
LO1369	04.05.2016		LU93056

International Patent Classification (IPC)
INV. H05H1/34

Applicant
GRADEL, S.A.R.L.

This report contains indications relating to the following items:

- ☒ Box No. I Basis of the opinion
- ☐ Box No. II Priority
- ☐ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV Lack of unity of invention
- ☒ Box No. V Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI Certain documents cited
- ☒ Box No. VII Certain defects in the application
- ☒ Box No. VIII Certain observations on the application

Examiner
de Ruijter-Noordman

Application No.
LU93056

WRITTEN OPINION

Box No. I Basis of the opinion

1. This opinion has been established on the basis of the latest set of claims filed before the start of the search.

2. With regard to any **nucleotide and/or amino acid sequence** disclosed in the application and necessary to the claimed invention, this opinion has been established on the basis of:

   a. type of material:

   ☐ a sequence listing

   ☐ table(s) related to the sequence listing

   b. format of material:

   ☐ on paper

   ☐ in electronic form

   c. time of filing/furnishing:

   ☐ contained in the application as filed.

   ☐ filed together with the application in electronic form.

   ☐ furnished subsequently.

3. ☐ In addition, in the case that more than one version or copy of a sequence listing and/or table relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

4. Additional comments:

Box No. V Reasoned statement with regard to novelty, inventive step and industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty	Yes:	Claims	1-12
	No:	Claims	
Inventive step	Yes:	Claims	
	No:	Claims	1-12
Industrial applicability	Yes:	Claims	1-12
	No:	Claims	

2. Citations and explanations

see separate sheet

Application No.
LU93056

WRITTEN OPINION

Box No. VII Certain defects in the application

The following defects in the form or contents of the application have been noted:

see separate sheet

Box No. VIII Certain observations on the application

see separate sheet

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1 PRIOR ART

Reference is made to the following documents:

D1 DE 10 2006 061435 A1 (LEONI AG [DE]) 26 June 2008 (2008-06-26)

D2 DE 20 2013 007063 U1 (PAOLIS MARCO DE [DE]; GEIST DIETER [DE]; STALLWITZ MARKUS [DE]; SUES W) 3 September 2013 (2013-09-03)

D3 US 5 485 721 A (STEENBORG MANFRED [DE]) 23 January 1996 (1996-01-23)

D4 WO 2004/098743 A2 (JEOL USA INC [US]; CODY ROBERT B [US]; LARAMEE JAMES A [US]) 18 November 2004 (2004-11-18)

D1 - D4 were cited in the Luxembourgh search report.

2 INDEPENDENT CLAIMS 1, 11 AND 12

2.1 CLAIM 1

2.1.1 The present application does not meet the criteria of patentability because the subject-matter of claim 1 does not involve an inventive step.

D1 is considered to be the prior art closest to the subject-matter of claim 1 and discloses all the features of claim 1 except that an internal electrode is a grid-like member. In particular D1 discloses (the references in parentheses applying to this document):

An apparatus *(cf. Figure 1)* for generating a plasma jet *(cf. Abstract)* comprising a gas containment vessel *(6; cf. Figure 1, paragraph [0043])* having a cylindrical wall *(cf. Figure 1, paragraph [0046])*, made from electrically conductive material *(implicit in the embodiment of Figure 1 in order to form an outer electrode)*, forming *(cf. paragraph [0050])* an outer electrode, an internal electrode *(12)* from electrically conductive material *(implicit in the embodiment of Figure 1 in order to form an internal electrode)*, means *(14)* for flowing a gas into said gas containment vessel *(6)*, a power source *(cf. paragraph [0050])* to create a potential between *(cf. paragraph [0050])* said

gas containment vessel *(6)* and said internal electrode *(12)* to create a plasma *(cf. paragraph [0050])* and an outlet port *(16)* in said cylindrical wall *(6)* to allow said plasma to emerge through *(cf. Figure 1)* said outlet port *(16)* from the vessel *(6)* as a plasma jet *(cf. Figure 1)*.

The apparatus of claim 1 therefore differs from the apparatus according to D1 in that the internal electrode is a grid-like member.

However, it is noted that in claim 1 a slight constructional change in the material of the internal electrode of D1 is suggested which comes within the scope of the customary practice followed by persons skilled in the art, especially as the advantages thus achieved can be readily contemplated in advance *(see for example D4 (D4: Abstract))*. Consequently, the subject-matter of claim 1 appears to lack an inventive step over D1.

2.1.2 An alternative inventive step objection to claim 1 could be based on D2.

2.2 CLAIM 11

The present application does not meet the criteria of patentability because the subject-matter of claim 11 does not involve an inventive step.

D3 is considered to be the prior art closest to the subject-matter of claim 11 and discloses an electric space propulsion device comprising an apparatus for generating a plasma jet similar to the one of D2 *(cf. D3: Abstract, Figure 1)*.

In view of paragraph 2.1 above and paragraph 3 below, the persons skilled in the art would regard it a normal design procedure to combine all the features set out in claim 11.

Consequently, the subject-matter of claim 11 appears to lack an inventive step over D3.

2.3 CLAIM 12

The same reasoning as in paragraph 2.1 applies, *mutatis mutandis*, to the subject-matter of corresponding apparatus claim 12, which therefore is also considered to lack an inventive step over D1 or D2.

3 DEPENDENT CLAIMS 2 - 10

Dependent claims 2 - 10 do not appear to contain any additional features which, in combination with the features of any claim to which they refer, meet the requirements of patentability in respect of inventive step. In particular, it is

noted that the additional features of these claims are either disclosed by D1 (claims 4 and 5) or D2 (claims 4 and 8) or represent merely obvious design options (claims 2 - 3, 6 - 7 and 9 - 10) which come within the scope of the customary practice followed by persons skilled in the art, especially as the advantages thus achieved can be readily contemplated in advance.

Claims 2 - 10 do not therefore involve an inventive step over D1 or D2.

Re Item VII

Certain defects in the international application

1 Contrary to the criteria of patentability, the relevant background art disclosed in D1 and D3 is not mentioned in the description, nor are these documents identified therein.

2 Independent claims 1, 11 and 12 are not in the two-part form in accordance with the rules for patentability, which in the present case would be appropriate, with those features known in combination from the prior art D1 (claims 1 and 12) or D3 (claim 11) being placed in the preamble and the remaining features being included in the characterising part.

Re Item VIII

Certain observations on the international application

The application does not meet the criteria of patentability, because claims 2, 3, 6 and 8 are not clear.

1 Claim 2: Claim 2 refers to an "internal electrode grid". However, an internal electrode grid is not introduced before. Claim 2 is therefore not clear.

2 Claim 3: From the wording in claim 3 it is not clear whether the feed-through insulator system introduced in claim 2 is meant by "said feed-through". Claim 3 is therefore not clear.

3 Claim 6: Claim 6 refers to a "grid-like internal cathode". However, a grid-like internal cathode is not introduced before. Claim 6 is therefore not clear.

4 Claim 8: Claim 8 refers to a "grid-like cylindrical cathode". However, a grid-like cylindrical cathode is not introduced before. Claim 8 is therefore not clear.