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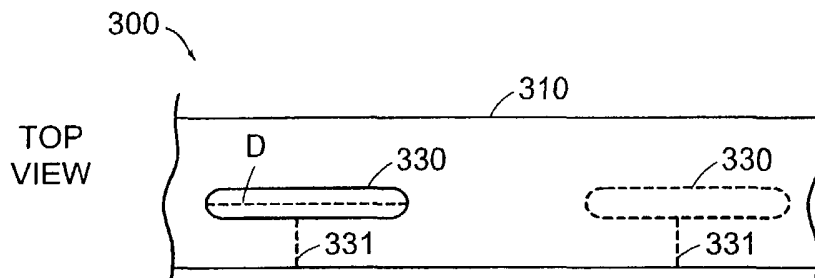
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(54) Title: TOROIDAL LOW-FIELD REACTIVE GAS AND PLASMA SOURCE HAVING A DIELECTRIC VACUUM VESSEL



(57) Abstract: Plasma ignition and cooling apparatus and methods for plasma systems are described. An apparatus (300) includes a vessel (310) and at least one ignition electrode (330) adjacent to the vessel. A total length of a dimension (D) of the at least one ignition electrode is greater than 10% of a length of the vessel's channel. The apparatus can include a dielectric toroidal vessel, a heat sink having multiple segments urged toward the vessel by a spring-loaded mechanism, and a thermal interface between the vessel and the heat sink. A method can include providing a gas having a flow rate and a pressure and directing a portion of the flow rate of the gas into a vessel channel. The gas is ignited in the channel while the remaining portion of the flow rate is directed away from the channel.

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# INTERNATIONAL SEARCH REPORT

International Application No  
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<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC 7 H01J37/32		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
Minimum documentation searched (classification system followed by classification symbols) IPC 7 H01J		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal, WPI Data, PAJ		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 1 534 251 A (SMITH CHARLES G) 21 April 1925 (1925-04-21) page 2, line 15 - line 101; figures 1,2 -----	1-4,6,7, 9,16,18 8
Y	US 5 834 905 A (STATNIC EUGENE ET AL) 10 November 1998 (1998-11-10) column 6, line 12 - line 21; figures 1,2 -----	8
X	US 3 291 715 A (ANDERSON GERALD S) 13 December 1966 (1966-12-13) column 2, line 54 - column 3, line 32; figure 1 -----	1-4,16
X	US 6 167 835 B1 (OOTERA HIROKI ET AL) 2 January 2001 (2001-01-02) column 6, line 61 - column 7, line 30; figure 2 -----	1-3,5-7, 16,19
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<input checked="" type="checkbox"/> Further documents are listed in the continuation of box C.		
<input checked="" type="checkbox"/> Patent family members are listed in annex.		
° Special categories of cited documents :		
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	
"E" earlier document but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.	
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family	
"P" document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search  <p style="text-align: center; font-weight: bold;">24 September 2004</p>	Date of mailing of the international search report  <p style="text-align: center; font-weight: bold;">29. 12. 04</p>	
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer  <p style="text-align: center; font-weight: bold;">Lang, T</p>	

INTERNATIONAL SEARCH REPORT

International Application No  
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 150 628 A (CHEN XING ET AL) 21 November 2000 (2000-11-21) cited in the application column 5, line 53 - column 10, line 6; figures 1,3,5 -----	31,32, 53,54
X	US 6 063 233 A (ASKARINAM ERIC ET AL) 16 May 2000 (2000-05-16) abstract column 10, line 54 - column 12, line 52; figures 4a-4d,5,18-24 column 17, line 54 - column 23, line 15 -----	34,39, 42-48,50

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US2004/011183

## Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.  Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2.  Claims Nos.:  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
  
3.  Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1.  As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2.  As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3.  As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4.  No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-9, 16-19, 31, 32, 34, 39, 42-48, 50, 53, 54

### Remark on Protest

- The additional search fees were accompanied by the applicant's protest.
- No protest accompanied the payment of additional search fees.

## FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-9, 16-19, 31,32,34,39,42-48, 50,53,54

A plasma ignition apparatus comprising:  
a vessel defining an enclosed channel; and  
at least one ignition electrode adjacent to the vessel and having a dimension aligned with an adjacent portion of the channel, a total length of the dimension of the at least one ignition electrode being greater than 10% or 20% of the total length of the channel; wherein the at least one ignition electrode can apply an electric field to a gas in the channel to initiate plasma discharge of the gas; wherein the channel defines a toroidal shape, and the total length of the channel is a length of one circuit around the toroidal shape (claims 1-3);  
wherein the vessel comprises at least one metallic portion, and at least one dielectric portion that fills a gap in the metallic portion (claim 5)

- 1.1. claim: 4

The apparatus of claim 1, wherein the vessel consists of a dielectric material

- 1.2. claims: 6,7,8

The apparatus of claim 1, comprising at least two ignition electrodes spaced from each other

- 1.3. claim: 9

The apparatus of claim 1, further comprising a reference electrode adjacent to the vessel, wherein the at least one ignition electrode and the reference electrode cooperate to apply an electric field to the gas in the channel to initiate plasma discharge of the gas.

- 1.4. claims: 16,17

The apparatus of claim 1, wherein a cross section of the vessel has a curved portion.

- 1.5. claim: 18

The apparatus of claim 1, comprising at least one magnetic core that at least partially surrounds a portion of the vessel to support formation of an oscillatory electric field within the channel.

- 1.6. claim: 19

The apparatus of claim 1, wherein the vessel defines a linear shape, and has a proximate end and a distal end.

## FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

## 1.7. claims: 31,32,53,54

A plasma ignition apparatus or method, comprising:  
a vessel having a gas input port and a gas output port and defining a channel for containing a gas; and an ignition electrode adjacent to the gas input port for application of an electric field to a flowing gas proximate to the input port of the vessel.

## 1.8. claim: 34

A plasma apparatus, comprising:  
a vessel comprising a dielectric material and defining a channel for containing a gas; a heat sink adjacent to the vessel; and a thermal interface disposed between and in mechanical communication with the vessel and the heat sink, wherein the thermal interface defines a space between the heat sink and the vessel that accommodates a movement of at least one of the thermal interface, the heat sink, and the vessel in response to thermally induced dimensional changes.

## 1.9. claims: 39,44,45,50

The apparatus of claim 34, wherein the thermal interface comprises at least one of a composite material, a fibrous material, a laminate material, and a conformal material.

## 1.10. claim: 42

The apparatus of claim 34, wherein the vessel consists of the dielectric material.

## 1.11. claim: 43

The apparatus of claim 34, wherein the thermal interface comprises a plurality of coils.

## 1.12. claims: 46-48

The apparatus of claim 34, wherein the space is filled with a gas for heat transfer from the vessel to the heat sink, and the space has a thickness of less than 100 micrometers.

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## 2. claims: 10,11

## FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

The apparatus of claim 1, further comprising a reference electrode adjacent to the vessel, wherein the at least one ignition electrode and the reference electrode cooperate to apply an electric field to the gas in the channel to initiate plasma discharge of the gas (claim 9); wherein the reference electrode is in thermal communication with the vessel to effectively limit a temperature of the vessel (claim 10); or wherein the vessel has at least four surfaces, the reference electrode covers at least a portion of three of the four surfaces, and the ignition electrode covers at least a portion of a remaining surface of the four surfaces of the vessel (claim 11)

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## 3. claims: 12-15

The apparatus of claim 1, wherein a cross section of the vessel has a straight portion.

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## 4. claim: 20

The apparatus of claim 1, wherein the at least one ignition electrode comprises a ceramic substrate and a conductive film formed on the ceramic substrate.

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## 5. claims: 21-27

A plasma ignition apparatus, comprising:  
a vessel defining an enclosed channel; and at least one ignition electrode adjacent to the vessel for application of an electric field to a gas in the channel, the at least one ignition electrode having an area greater than 1% of a total external surface area of the vessel.

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## 6. claims: 28-30

A plasma ignition apparatus, the apparatus comprising:  
a vessel defining an enclosed channel; and at least three ignition electrodes adjacent to the vessel, wherein the plurality of ignition electrodes can apply an electric field to a gas in the channel to initiate the plasma.

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## 7. claims: 33,55

## FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

A plasma ignition apparatus, comprising:  
a vessel having a gas input port and a gas output port and defining a channel for containing a gas; and an ignition electrode adjacent to the gas input port for application of an electric field to a flowing gas proximate to the input port of the vessel (claims 31,53);  
wherein the ignition electrode is positioned upstream from the gas input port.

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## 8. claims: 35,66-68

A plasma apparatus, comprising:  
a vessel comprising a dielectric material and defining a channel for containing a gas; a heat sink adjacent to the vessel; and a thermal interface disposed between and in mechanical communication with the vessel and the heat sink, wherein the thermal interface defines a space between the heat sink and the vessel that accommodates a movement of at least one of the thermal interface, the heat sink, and the vessel in response to thermally induced dimensional changes (claim 34);  
wherein the channel has a toroidal shape (claim 35).

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## 9. claims: 36-38

The apparatus of claim 34, wherein the heat sink comprises at least two segments that substantially surround the vessel and are joined together by at least one spring-loaded mechanism.

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## 10. claims: 40,41

The apparatus of claim 34, wherein the thermal interface comprises a plurality of cantilevered fingers.

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## 11. claim: 49

The apparatus of claim 34, further comprising an ultraviolet blocking layer disposed between the vessel and the thermal interface.

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## 12. claim: 51

The apparatus of claim 34, further comprising a gas inlet showerhead disposed adjacent to an inlet of the vessel and defining apertures that direct most of an inlet gas flow along an inner surface of the vessel.

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## 13. claims: 52,63-65



FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

A plasma processing apparatus or method, comprising the apparatus of claims 1 and 2; a transformer comprising a magnetic core and a primary winding that surround a portion of the vessel; an AC power supply that supplies power to the primary winding to maintain a plasma in the toroidal vessel; and a process vessel defining a process chamber that receives activated gas species from the vessel.

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14. claims: 56-62

A method for igniting a plasma, the method comprising:  
providing a vessel defining an enclosed channel;  
providing a gas having a flow rate and a pressure outside of the channel;  
directing a portion of the flow rate of the gas into the channel; and  
igniting the gas in the channel while directing a remaining portion of the flow rate away from the channel.

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US2004/011183

Patent document cited in search report	A	Publication date	Patent family member(s)	Publication date
US 1534251	A	21-04-1925	NONE	
<hr style="border-top: 1px dashed black;"/>				
US 5834905	A	10-11-1998	AU 705741 B2	03-06-1999
			DE 69620153 D1	02-05-2002
			DE 69620153 T2	01-08-2002
			WO 9710610 A1	20-03-1997
			EP 0806054 A1	12-11-1997
			HU 9701872 A2	28-09-2000
			AU 6701396 A	01-04-1997
			CA 2185267 A1	16-03-1997
			CN 1165582 A	19-11-1997
			JP 10511806 T	10-11-1998
<hr style="border-top: 1px dashed black;"/>				
US 3291715	A	13-12-1966	NONE	
<hr style="border-top: 1px dashed black;"/>				
US 6167835	B1	02-01-2001	JP 10270430 A	09-10-1998
<hr style="border-top: 1px dashed black;"/>				
US 6150628	A	21-11-2000	DE 69811497 D1	27-03-2003
			DE 69811497 T2	18-12-2003
			EP 1310980 A1	14-05-2003
			EP 1310981 A1	14-05-2003
			EP 1313128 A1	21-05-2003
			EP 1313129 A1	21-05-2003
			EP 1313130 A1	21-05-2003
			EP 1313131 A1	21-05-2003
			EP 1313132 A1	21-05-2003
			EP 0992059 A1	12-04-2000
			JP 2002507315 T	05-03-2002
			WO 9900823 A1	07-01-1999
			US 2002125225 A1	12-09-2002
			US 2002125226 A1	12-09-2002
			US 6388226 B1	14-05-2002
			US 6486431 B1	26-11-2002
			US 2004079287 A1	29-04-2004
			US 6815633 B1	09-11-2004
			US 2002046991 A1	25-04-2002
<hr style="border-top: 1px dashed black;"/>				
US 6063233	A	16-05-2000	US 6165311 A	26-12-2000
			US 5556501 A	17-09-1996
			US 5770099 A	23-06-1998
			US 5477975 A	26-12-1995
			US 6077384 A	20-06-2000
			EP 0837489 A2	22-04-1998
			JP 10154599 A	09-06-1998
			US 2002096259 A1	25-07-2002
			US 2001042594 A1	22-11-2001
			US 2001054483 A1	27-12-2001
			US 6454898 B1	24-09-2002
			US 6095083 A	01-08-2000
			US 6074512 A	13-06-2000
			EP 0807953 A1	19-11-1997
			JP 10092598 A	10-04-1998
			US 2002092826 A1	18-07-2002
			US 6036878 A	14-03-2000
			US 6444084 B1	03-09-2002
			US 6514376 B1	04-02-2003
			US 6524432 B1	25-02-2003
			US 6444085 B1	03-09-2002

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US2004/011183

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6063233	A	US 6238588 B1	29-05-2001
		US 6054013 A	25-04-2000
		US 2004163764 A1	26-08-2004
		US 6095084 A	01-08-2000
		US 2002020499 A1	21-02-2002
		US 5990017 A	23-11-1999
		US 6440866 B1	27-08-2002
		US 6036877 A	14-03-2000
		US 6545420 B1	08-04-2003
		EP 0520519 A1	30-12-1992
		JP 2635267 B2	30-07-1997
		JP 5206072 A	13-08-1993
		KR 255703 B1	01-05-2000
		US 6068784 A	30-05-2000
		US 2002004309 A1	10-01-2002
		US 5574410 A	12-11-1996
		US 6518195 B1	11-02-2003
		US 5572170 A	05-11-1996
		US 6488807 B1	03-12-2002
		US 6399514 B1	04-06-2002
		US 6444137 B1	03-09-2002
		US 6090303 A	18-07-2000
		US 6171974 B1	09-01-2001
		US 5772832 A	30-06-1998
		US 5888414 A	30-03-1999
		US 6251792 B1	26-06-2001
		US 5392018 A	21-02-1995
		US 6083412 A	04-07-2000
		US 5908576 A	01-06-1999

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