United States Patent

Wiegand, Jr.

[15] **3,657,600**

[45] **Apr. 18, 1972**

[54] AUXILIARY IONIZATION OF DC ELECTRIC DISCHARGE ELECTRODE BOUNDARY SHEATHS

[72] Inventor: **Walter J. Wiegand, Jr.,** Glastonbury, Conn.

[73] Assignee: **United Aircraft Corporation,** East Hartford, Conn.

[22] Filed: **May 18, 1970**

[21] Appl. No.: **38,033**

[52] **U.S. Cl.** **317/4,** 315/330, 313/197

[51] **Int. Cl.** **H01j 61/54**

[58] **Field of Search** .....317/3, 4, 262 R; 315/93, 330; 313/189, 197

[56] **References Cited**

UNITED STATES PATENTS

2,921,236	1/1960	Gawehn	313/197 X
3,275,885	9/1966	Pompfreti	315/330
3,480,820	11/1969	Fehnel	313/189 X
3,465,192	9/1969	Lafferty	315/330 X
2,699,513	1/1955	Watt	313/93 X

Primary Examiner—L. T. Hix

Attorney—Melvin Pearson Williams

[57] **ABSTRACT**

Auxiliary ionization is provided in a DC electric discharge plasma immediately adjacent one or more electrodes, whereby the tendency for streamering or incipient arcing and non uniform attachment of the discharge to electrodes is mitigated. Separate RF electrodes, RF electrodes combined with a DC cathode, separate and combined low voltage DC auxiliary ionization are disclosed. Photon and particle beam ionization are discussed.

5 Claims, 5 Drawing Figures

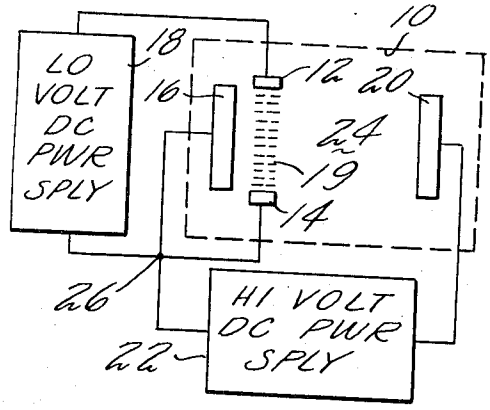


FIG. 1

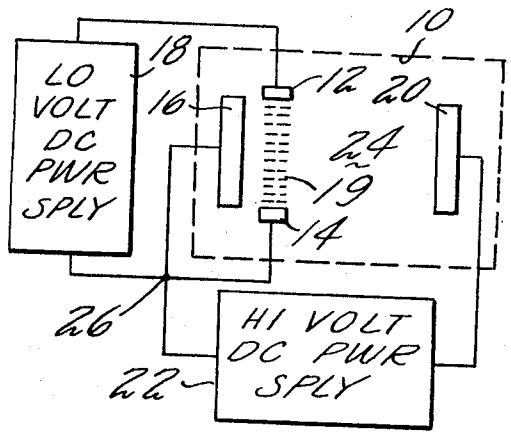


FIG. 2

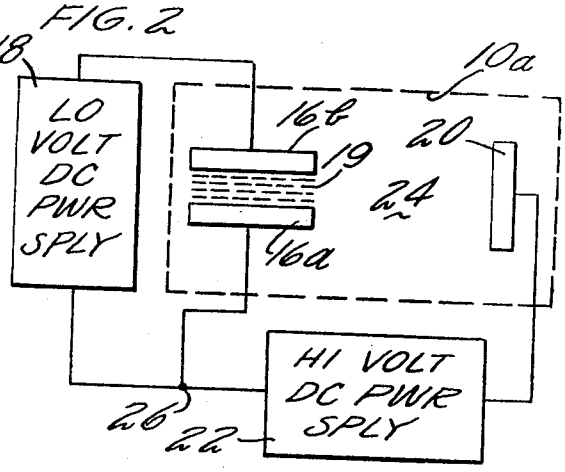


FIG. 3

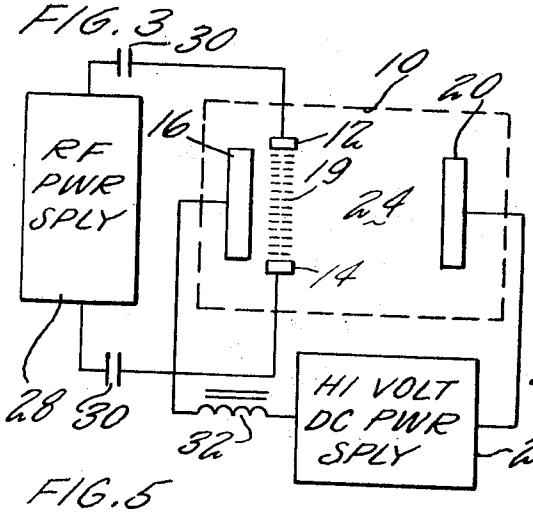


FIG. 4

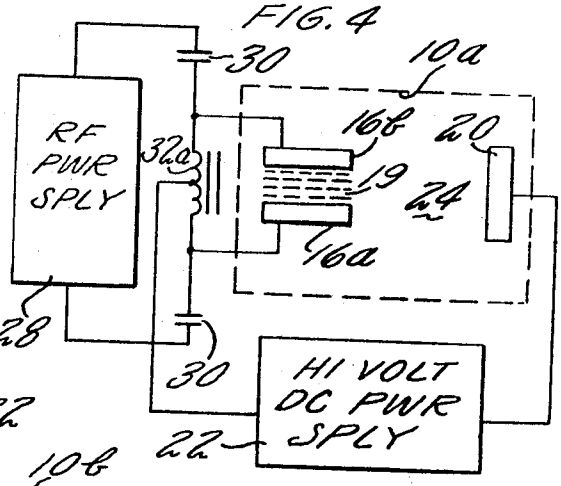
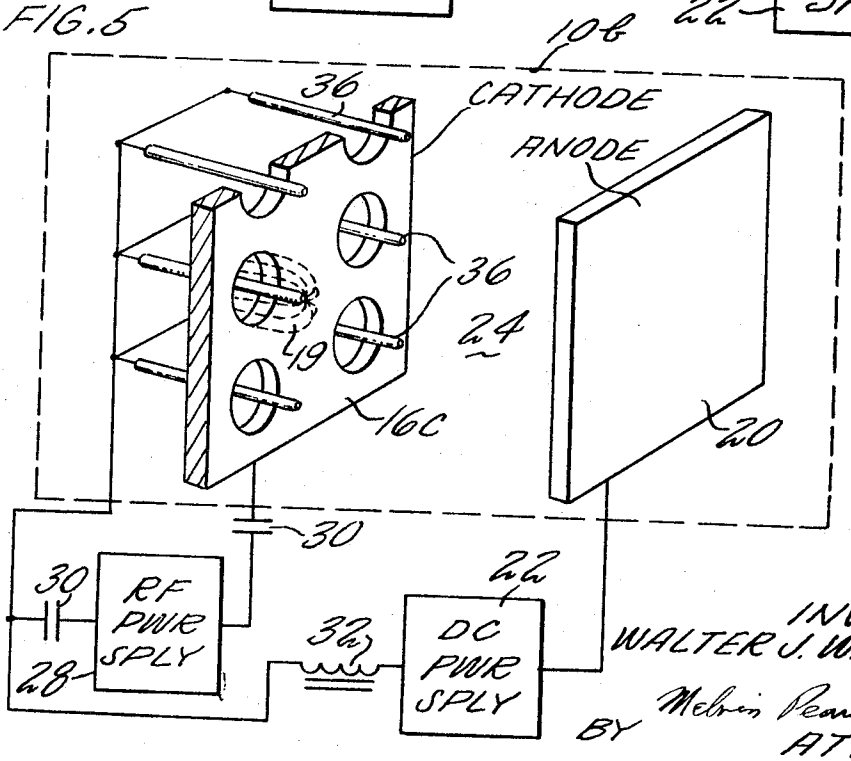


FIG. 5



INVENTOR
WALTER J. WIEGAND, JR.

BY Melvin Pearson Williams
ATTORNEY

AUXILIARY IONIZATION OF DC ELECTRIC DISCHARGE ELECTRODE BOUNDARY SHEATHS

BACKGROUND OF THE INVENTION

1. Field of Invention

This invention relates to DC electric discharge plasmas, and more particularly to auxiliary ionization in the electrode sheaths therein.

2. Description of the Prior Art

In the various electronic arts dealing with DC electric discharge plasmas, the creation and use of such plasmas has long been known. However, the recent advent of the high power gas laser, and particularly the nitrogen/carbon dioxide laser, has revealed certain critical adverse relationships between the useful performance of the discharge and certain of the properties thereof. For instance, in gas lasers, the function of the electric discharge plasma is to excite atoms or molecules of an energizing gas or a lasing gas to higher energy states which are useful in the production of electromagnetic radiation. This function is enhanced by a uniform plasma, having little or no streamering or incipient arcing, and having a uniform attachment of the plasma to the electrodes of the discharge. Streamering or incipient arcing is undesirable since it results in a loss of efficiency and power and in most cases it is necessary that the discharge be operated at a lower than optimum current density to avoid these effects. Another troublesome discharge phenomena is nonuniform attachment of the discharge to the electrodes, particularly in the case of large cathode and anode surface areas. These difficulties are compounded in high power gas laser systems where the gas pressure and current density are set at their upper limits in order to extract maximum power per unit volume.

Discharges of this type consist of a positive column connected through sheaths to a cathode and an anode. The positive column, a region of more or less uniform electric field, comprises a major portion of the discharge length. The cathode fall region at typical operating pressures of a nitrogen/carbon dioxide laser extends a short distance into the discharge, typically from about 0.5 cm to about 10 cm, depending inversely upon pressure; this distance being small compared to the length of the positive column. The magnitude of the electric field in the positive column is determined basically by the requirement that the electrons be distributed in energy in such a way as to make up through ionization the loss of charge particles due to volume recombination and ion neutralization on the tube walls. Furthermore, the electric field E, must, in conjunction with the local electric conductivity of the plasma, give rise to the required discharge current which, in the positive column, is carried almost exclusively by the electrons. The total voltage drop across the positive column may in some discharges represent only a small portion of the total discharge voltage. In gas lasers, it is the positive column that normally contributes most to the laser output. This is true since the positive column is usually much longer than any other region of the discharge and its properties may more easily be controlled by changes in the applied voltage. This has been verified by the fact that when the ratio of electric field to neutral particle gas density (E/N) in the positive column is adjusted by changing the voltage applied across the discharge to optimize the laser output, it is found that the E/N measured in the positive column is consistent with that calculated to be near the optimum for laser operation. The sheaths are the discharge regions at either extreme of the positive column where the boundary conditions on the ends of the column are satisfied. The electric fields in the sheath regions (which are much higher than the field along the positive column), are therefore too high to efficiently produce a laser population inversion. Basically, this indicates that the positive column is the effective laser energizing portion of the discharge and the sheath regions are necessary only to the extent that they permit the positive column to exist.

The boundary conditions near the anode are considerably simpler than the cathode fall conditions. At the anode end of the positive column, an ion current is directed toward the cathode. This ion current is required to make up for the ion current flowing into the cathode sheath at the far end of the positive column. Normally, it is assumed that there are no sources or sinks of current in the positive column, but only enough ionization to make up for ion diffusion to walls and volume recombination losses. An electron accelerating sheath forms at the anode through which the electron current passes. This sheath typically has a voltage drop of approximately the ionization potential of the gas in order that a small ion current source exists through direct electron ionization processes.

The processes taking place near the cathode are considerably more complex than those at the anode. Between the cathode and the positive column there is the cathode fall region which is a high electric field region attached to the cathode followed by a negative glow region nearer to the positive column. The boundary conditions at the cathode end of the positive column must be matched to the electron emission properties of the cathode. In hot cathode discharges and in spray or Malter discharges, copious electron emission takes place at the cathode and only a very small cathode fall exists. Unfortunately, materials problems and/or chemical processes occur on these types of cathodes in some applications, such as nitrogen/carbon dioxide lasers and perhaps other gas lasers such that the small cathode fall associated with a hot cathode cannot be exploited to full advantage. Moreover, these cathodes can be subject to the streamering and nonuniformity problems that the present invention is designed to circumvent.

In cold cathode discharges, used for instance in the current laser art, a large cathode fall usually exists. The high electric field is required to accelerate electrons emitted from the cathode into the cathode fall region where some of the electrons cause ionization and give rise to a region of fairly high ionization rate. Ions from this region are accelerated back through the cathode fall potential, gaining energy, and upon striking the cathode, gives rise to secondary electron emission. These secondary electrons are then accelerated into the cathode fall region, completing the circular process. The shape of the potential profile across the cathode fall, the electron and ion currents and energy distributions, the secondary emission process and losses in this region, must all be internally, mutually consistent.

It is important to note that the cathode fall of a cold cathode discharge must satisfy a number of individual requirements in order to accommodate the boundary conditions of the discharge and the cathode processes. This, of course, has far reaching consequences since it is thought that it is because the discharge is unable to solve the boundary conditions imposed at the electrode that it is forced into a condition of streamering at the cathode. In particular, it appears that, at the currents and pressures encountered in high power lasers, the secondary electron emission process is not adequate to give rise to that ionization rate required in the cathode fall to maintain equilibrium. The only way that the cathode can give rise to the electron current consistent with the external DC power supply and the discharge boundary conditions is to constrict into an arc at the cathode and thereby meet the electron emission requirements through thermionic emission.

SUMMARY OF THE INVENTION

The object of the present invention is to provide improved DC electric discharge plasmas.

According to the present invention, auxiliary ionization of the plasma is provided in a region near at least one of the discharge forming electrodes. According further to the present invention, auxiliary ionization may be provided at both electrodes of a DC electric discharge plasma.

According to the ionization in one form, radio frequency ionization is employed; the ionizatinon may be applied by separate electrodes or may be provided across a segmented DC electrode. In accordance with the invention in another form, low voltage DC ionization may be utilized, it being ap-

plied either by separate electrodes or across a segmented high voltage DC electrode. In accordance still further with the invention, other sources of auxiliary ionization may be employed.

The present invention improves the boundary conditions of a DC electric discharge plasma thereby to minimize streamering and incipient arcing, as well as to provide a more uniform attachment of the plasma to the electrodes. The utility of a plasma incorporating the present invention is enhanced by providing a greater uniformity of electron density throughout the discharge region.

The foregoing and other objects, features and advantages of the present invention will become more apparent in the light of the following detailed description of preferred embodiments thereof, as illustrated in the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified, schematicized diagram of one embodiment of the present invention employing separate primary and auxiliary DC ionization electrodes;

FIG. 2 is a simplified, schematicized diagram of an embodiment of the invention applying low voltage DC auxiliary ionization to a segmented primary high voltage DC cathode;

FIG. 3 is a simplified, schematicized diagram of an embodiment of the invention employing separate auxiliary RF and primary DC electrodes;

FIG. 4 is a simplified, schematicized diagram of an embodiment of the present invention employing the application of RF auxiliary ionization to a segmented high voltage DC cathode; and

FIG. 5 is a simplified, schematicized perspective of an embodiment of the invention applying RF auxiliary ionization between segmented RF electrodes and a DC cathode.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, the primary object of the present invention, which is to improve DC electric discharge boundary conditions by applying auxiliary ionization to the area immediately adjacent one or more of the electrodes **12** and of the DC discharge, is accomplished in an electric discharge apparatus **10** by means of a pair of auxiliary low voltage DC electrodes **14** which are disposed adjacent the main DC cathode **16**. The electrodes **12, 14** are connected across a low voltage DC power supply **18** so as to provide an electric field and produce ionization **19** therebetween. The cathode **16** and an anode **20** are connected across a high voltage, primary DC power supply **22** so as to create the useful electric discharge plasma in the region **24**, the enhancement of which is the purpose of the present invention. In the embodiment of FIG. 1 the low voltage auxiliary ionization potential may be referred to the high voltage primary potential, such as by connecting the electrode **14** to the electrode **16** as at the junction **26**. This connection may be considered ground potential in the system. On the other hand, the junction **26** may be eliminated if desired in certain embodiments, in which case the auxiliary ionization **19**, although apparently floating, is referred to the cathode **16** through conduction within the plasma.

The discharge apparatus **10** is shown in dotted fashion to point out the fact that the present invention may be utilized in a wide variety of different types of discharge apparatus. For instance, the apparatus may be a closed system containing an ionizable gas; on the other hand, the discharge apparatus **10** may comprise an area within a conduit through which suitable gases may flow. For typical configurations, reference may be made to patented and published art relating to industrial, laser and other types of electric discharge plasma apparatus.

In the embodiment of FIG. 2, the discharge apparatus **10***a* includes a segmented cathode **16***a*, **16***b* and the low voltage, auxiliary ionization DC power supply **18** is connected across two segments **16***a*, **16***b*, rather than having the separate electrode shown in FIG. 1. In this embodiment, the junction **26** provides a reference between the two power supplies **18, 22**. Because of the auxiliary ionization **19** between the segments **16***a*, **16***b*, the segment **16***b* will be at substantially the same potential as the segment **16***a*. Thus each of the two segments can act as cathodes with respect to the anode **20** in the formulation of the primary ionization in the region **24**. In this embodiment, the boundary conditions discussed hereinbefore are satisfied between the cathode segments.

Referring now to FIG. 3, the auxiliary ionization **19** may be provided by means of RF excitation, rather than by the low voltage DC excitation illustrated in FIGS. **1** and **2**. Therein, the auxiliary electrodes **12, 14** are connected to an RF power supply **28** through DC isolation capacitors **30**, and the cathode **16** is connected through an RF choke coil **32** to the high voltage DC power supply **22**. The capacitors **30** and the choke **32** provide mutual isolation between the RF and the DC.

In FIG. 4, the RF auxiliary ionization is applied by the capacitors **30** to segments **16***a* and **16***b* of a segmented cathode, the RF choke **32***a* being connected between the segments **16***a*, **16***b*, and the center tap thereof connected to the high voltage DC power supply **22**. This provides DC power to both segments **16***a*, **16***b* while maintaining RF isolation so that the auxiliary ionization **19** may be established between them, while both segments participate with the anode **20** in the formulation of the primary electric discharge plasma in the region **24**.

In another embodiment of the invention as illustrated in FIG. 5, electric discharge apparatus **10b** includes a perforated cathode **16***c* having a plurality of finger electrodes **36** extending therethrough and slightly into the region **24** where the primary electric discharge plasma is to be established. The RF power supply **28** is connected between the finger electrodes **36** and the perforated cathode **16***c*. The DC power supply is connected between the cathode **16***c* and the anode **20** so as to provide the DC field necessary for the creation of the primary electric discharge plasma. In the embodiment of FIG. **5**, the auxiliary ionization **19** exists between each finger electrode **36** and the perforated cathode **16c**. However, this does provide the desired uniformity.

Each of the embodiments of FIGS. **1–5** described herein employs auxiliary ionization only at the cathode. In most cases, application of auxiliary ionization to the cathode is sufficient to provide the enhanced operation of the DC electric discharge plasma which is desired. However, in the event that the particular parameters of a given utilization of the present invention so warrant, auxiliary ionization may also be provided at the anode so as to enhance the boundary conditions in the anode sheath as described hereinbefore. In most cases, a judgement must be made as to the improvement desired for the cost required; the improvement provided by auxiliary ionization at the boundary of the plasma with the cathode will usually be sufficient so that provision of further improvement at the anode boundary will not be worth the cost thereof. The embodiments herein are schematic in nature, and not necessarily illustrative of the specific hardware utilized in performing the present invention. For instance, another method of applying RF preionization between an auxiliary RF electrode and a DC cathode is to employ a well known RF helical resonator electrode; in such case, the RF power **28** is applied across the helix; and the chamber is connected to the DC power supply **22** and serves as the main electric discharge cathode **16**.

Although not disclosed herein, auxiliary ionization **19** may be provided by sources other than electric fields across electrodes. For instance, a source of intense photon flux may be oriented to inject flux adjacent to either or both of the main electrodes of the DC electric discharge. In the case where the present invention is employed in a gas laser, the photon flux should preferably be of a wavelength which does not interfere with laser operation. Similarly, a high energy particle beam source, such as the type employed in electron beam drilling and welding, may be utilized to provide auxiliary ionization. These are not disclosed herein because such complex disclosure does not add to the state of the art in view of the variety

of the configurations which may be employed and the well known nature of such devices in the art.

Thus, although the invention has been shown and described with respect to preferred embodiments thereof, it should be understood by those skilled in the art that the foregoing and various other changes and omissions in the form and detail thereof may be made therein without departing from the spirit and the scope of the invention.

I claim:

Having thus described typical embodiments of my invention, that which I claim as new and desire to secure by Letters Patent of the United States is:

1. An apparatus for producing direct current electric discharge plasma including:

electrode means comprising a pair of electrodes;

means providing a high voltage direct current electric field across said electrode means; and

an ionizable gaseous medium disposed between said electrode means within which the electric discharge plasma is established;

wherein the improvement comprises:

meaNs establishing continuous auxiliary ionization immediately adjacent one of said electrodes which comprises a plurality of segments, the auxiliary ionization being established between said segments to provide better attachment of the plasma to said one of the electrodes and to reduce incipient arcing in the plasma between said pair of electrodes.

2. In direct current electric discharge apparatus including a pair of electrodes for producing a plasma which comprises a positive column of uniform electric field and a sheath region at either end thereof, the method of minimizing streamering and incipient arcing in the plasma and providing a more uniform attachment of the plasma to the electrodes including the steps of:

discharging a high voltage direct current across an ionizable gas which is located between the electrodes to produce a cold cathode type discharge having a large cathode fall potential; and

providing a continuous source of auxiliary ionization to the sheath region to reduce the cathode fall potential.

3. The invention according to claim 9 wherein a low voltage DC power source is connected across said segments of the electrode means.

4. The invention according to claim 1 wherein an RF coupling means connects an RF power source across said segments of the electrode means, and RF isolation means is included in said high voltage DC electric field providing means for connecting said segments of the electrode means to said high voltage DC electric field providing means.

5. The invention according to claim 4 wherein the electrode means is perforated and wherein a plurality of finger electrodes is disposed within the perforations of the electrode means.

* * * * *

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,657,600 Dated April 18, 1972

Inventor(s) WALTER J. WIEGAND, JR.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, Claim 1, line 10 the word "meaNs" should read -- means --

Column 6, Claim 3, line 1 number "9" should read -- 1 --

Signed and sealed this 22nd day of August 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,657,600 Dated April 18, 1972

Inventor(s) WALTER J. WIEGAND, JR.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, Claim 1, line 10 the word "meaNs" should read -- means --

Column 6, Claim 3, line 1 number "9" should read -- 1 --

Signed and sealed this 22nd day of August 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents