April 29, 1969 D. VERON 3,441,798

PLASMA GUN UTILIZING SUCCESSIVE ARCS FOR GENERATING AND ACCELERATING THE PLASMA

Filed Aug. 15, 1966 Sheet 1 of 4

Fig. 1

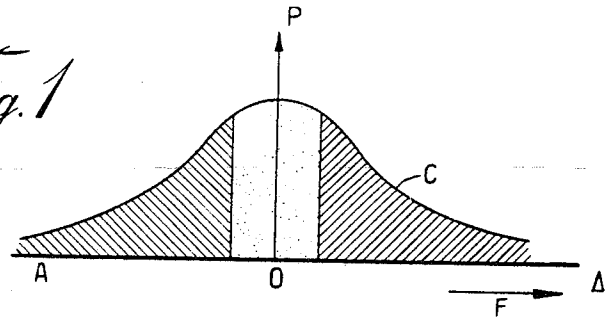
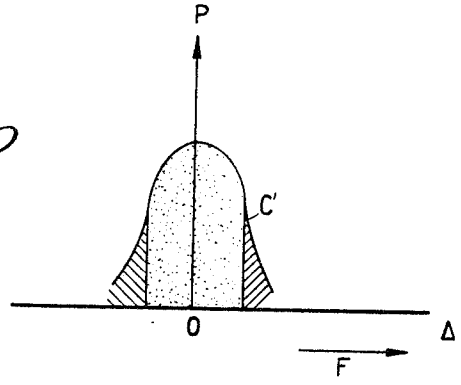


Fig. 2



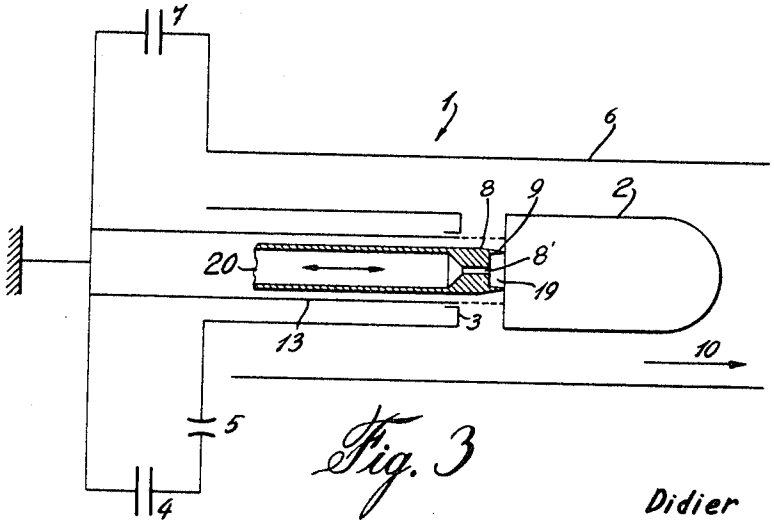


Fig. 3

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Fig. 4a

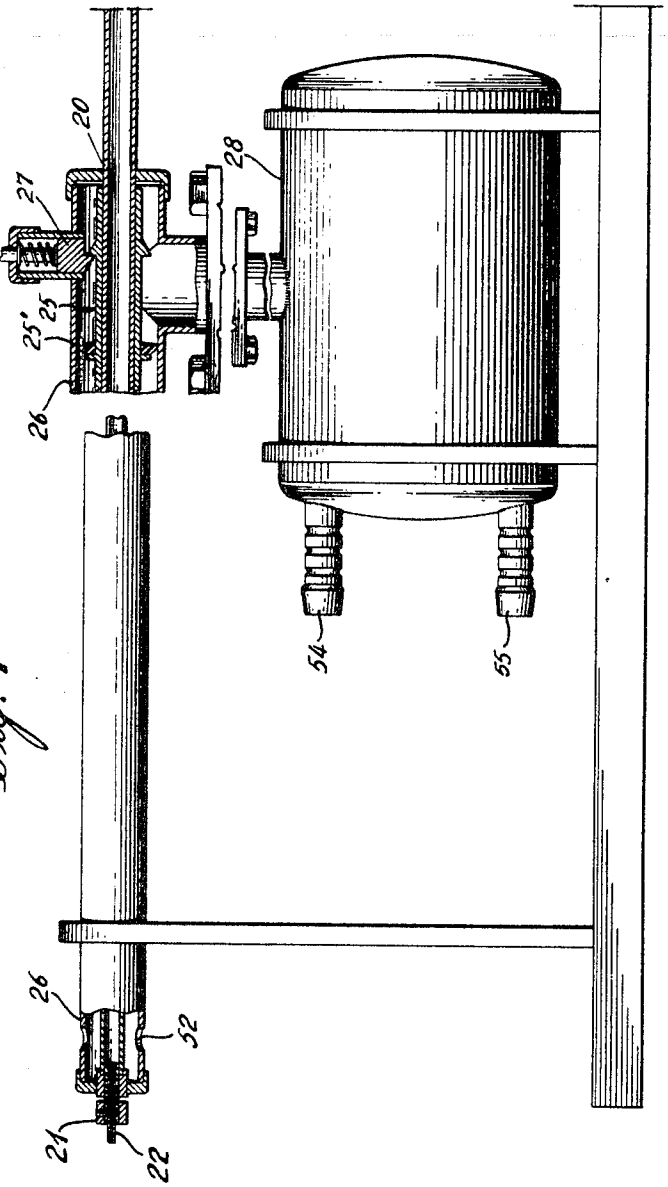


Fig. 4

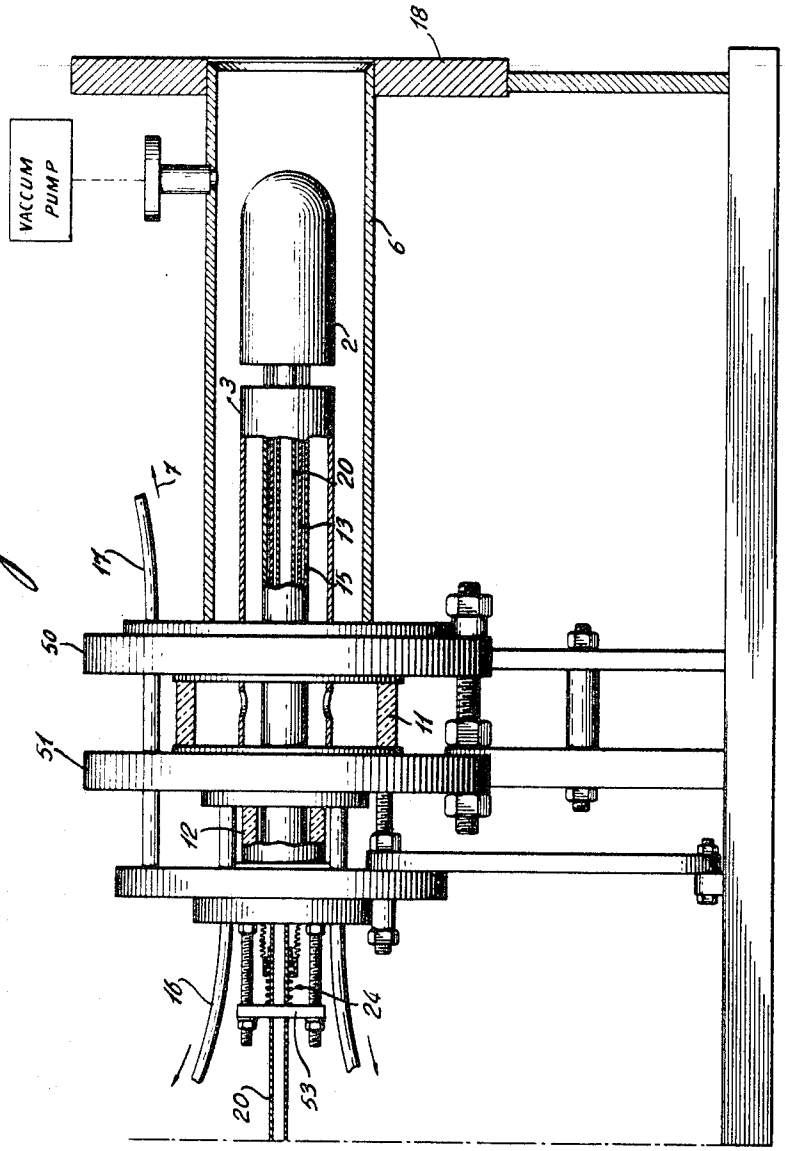
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PLASMA GUN UTILIZING SUCCESSIVE ARCS FOR GENERATING AND ACCELERATING THE PLASMA

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Fig. 5



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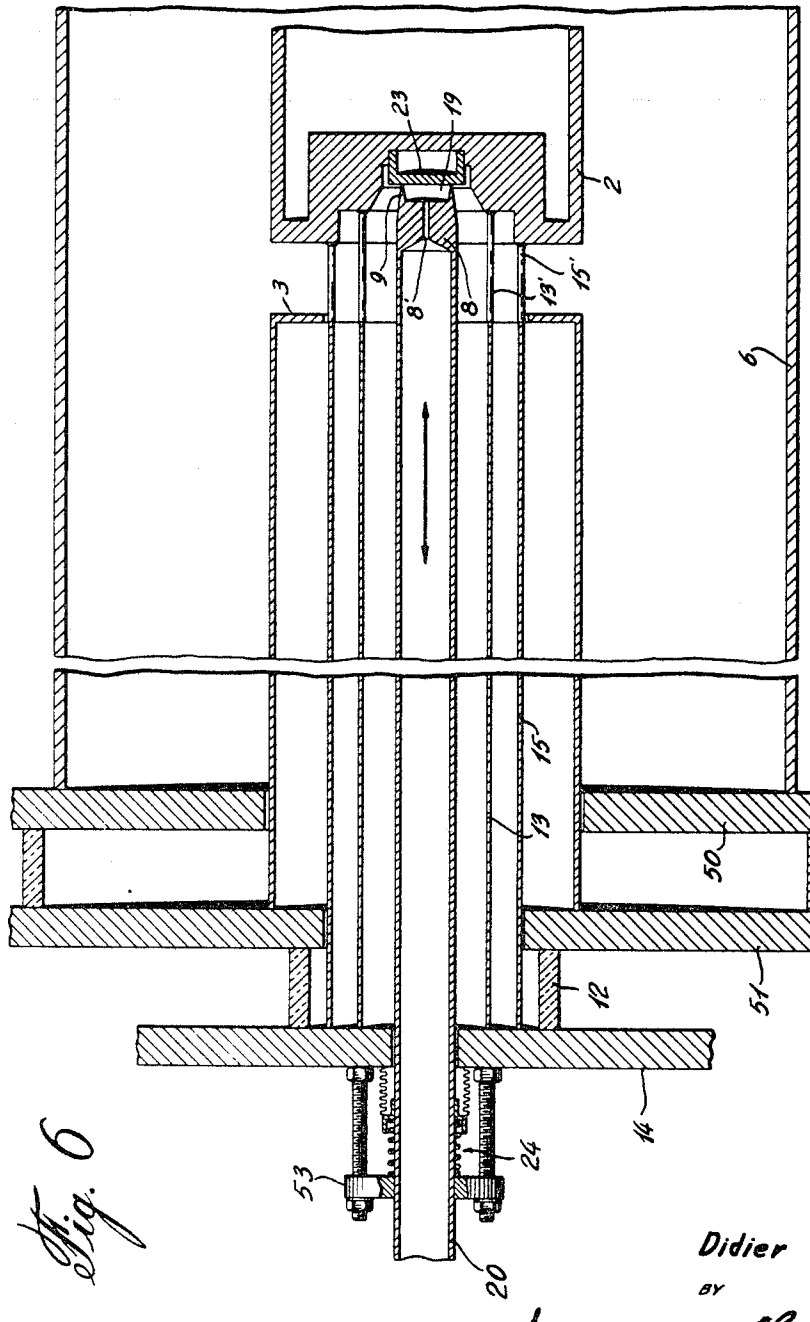


Fig. 6

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PLASMA GUN UTILIZING SUCCESSIVE ARCS FOR GENERATING AND ACCELERATING THE PLASMA

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Continuation-in-part of application Ser. No. 303,567, Aug. 21, 1963. This application Aug. 15, 1966, Ser. No. 572,414

Claims priority, application France, Sept. 19, 1962, 909,899

Int. Cl. H05b *31/26;* H01j *17/26*

U.S. Cl. 315—111 1 Claim

The present invention is a continuation-in-part of my copending application Ser. No. 303,567, filed Aug. 21, 1963, now abandoned.

The present invention relates to a new process for the production and acceleration of a puff of plasma and to a gun for the application of the said process. This gun is used mainly for the production of thermonuclear reactions and for the propulsion by plasma.

It is made to operate under vacuum conditions, that is, either the gun and the enclosure in which the plasma is ejected are placed under vacuum or else the gun is a plasma propeller operating in spatial vacuum.

A presently known process for the production and acceleration of plasma resides in the introduction of a certain amount of gas between two coaxial electrodes, one surrounding the other, and the triggering of a discharge of a battery of condensers between said electrodes by means of a spark gap. The discharge produces an ionized ring and the currents that are created lead to the appearance of Laplace forces which eject the plasma. This process is not entirely satisfactory because all the gas liberated in the space between the electrodes is not ionized. The result is that the plasma is propagated in a zone containing neutral gas.

Such a gun for the production and acceleration of a gas plasma is disclosed in U.S. Patent No. 3,221,212 but in this patent, the plasma in the preliminary ionization is propelled axially of the gun which is thus unsuitable for reducing the presence of neutral gas therein.

The main object of the invention is therefore to provide a process for the production and acceleration of a puff of plasma which would overcome the drawbacks of the known process.

A further object is to provide an apparatus for carrying out the new process.

The process according to the instant invention resides in the injection of a predetermined quantity of gas intended to form the said puff of plasma into an enclosure under vacuum; the subjecting of said gas to a first electrical discharge to cause formation of an ionized electrically conductive expandng plasma ring and then the triggering of a second discharge within said plasma to cause ejection thereof.

As to the plasma gun used for carrying out the process according to the instant invention, it comprises two coaxial and axially offset central ionizing electrodes; means to inject between said electrodes a quantity of gas intended to form a puff of plasma; a spark gap; a first battery of condensers connected to said electrodes through said spark gap; means to cause discharge of said first battery of condensers to ionize said gas which thus forms an expanding ring of plasma; a third ionizing electrode disposed externally of and coaxially with the two central electrodes; said third electrode constructed to form an enclosure under vacuum including said two central electrodes; a second battery of condensers; one of said central electrodes disposed forwardly of the gun and connected to the third electrode through said second battery of condensers, whereby as said ring of plasma expands under the discharge of said first battery of condensers, it comes to contact said third electrode to thus cause discharge of said second battery of condensers to eject said plasma forwardly of said gun.

The ring ionized by the discharge of the first battery of condensers is ejected towards the outer electrode as a result of expansion. The speed of radial displacement of this annular plasma is greater than the speed of diffusion of neutral gas in vacuum. The plasma, therefore, reaches the outer electrode before the neutral gas can notably increase the pressure between the internal ionizing electrode located toward the front of the gun and the outer electrode. The annular plasma then causes the discharge of the second battery of condensers and it is ejected towards the front of the gun.

The invention will now be described in details with reference to the accompanying drawings wherein:

FIGURE 1 is a graphical illustration of a process for the production and acceleration of a puff of plasma in a gun of known type;

FIGURE 2 is a graphical illustration similar to that of FIGURE 1 but relative to the process and gun of the invention;

FIGURE 3 is a diagrammatic illustration of a plasma gun for carrying out the process of the invention;

FIGURES 4 and 5 form, when placed in alignment, a detailed side elevation view, partly in cross-section, of the gun of the invention;

FIGURE 4*a* is a magnified portion of FIGURE 4 and operative in the location shown;

FIGURE 6 is a cross-sectional view of the plasma ejection valve of FIGURE 5, shown on a larger scale.

In the graph of FIGURE 1, the ordinate is the pressure P in the annular space between the electrodes and the abscissa is the distance Δ measured parallel to the axis of the gun, the point of origin O corresponding to the area where the gas is expelled and the electrical discharge takes place. The curve C is therefore an illustration of the variation of the pressure P as a function of the distance from the point of origin O, the curve illustrating the conditions at the time of firing, that is, at the time of the first discharge. It is to be noted that the dotted and hatched zones respectively correspond to the presence of plasma and of neutral gas while the arrow F indicates the direction of plasma propagation. Under these conditions, the properties of the plasma are not satisfactory, as earlier said.

The curve C′ of FIG. 2 illustrates the variation of the pressure P in the gun at the time of the second discharge. The reference characters in this figure are the same as the ones in FIG. 1. It will be noted here that the area in the gun occupied by the neutral gas is considerably reduced and therefore the scavenging of the neutral gas by the plasma becomes of secondary importance. Consequently, the characteristics of the plasma are improved.

In the above curves, the portion to the left of ordinate P represents a state identical to that to the right. The neutral gas located to the left will remain in place, will gradually spread in the gun and eventually be absorbed by the vacuum pumps or dissipate in space.

FIGURES 1 and 2 are mainly intended to show the distribution between the neutral gas and the plasma as a result of experimental observation. They clearly show the advantages to be derived from applicant's device, that is,

they compare the proportion of neutral gas changed into plasma in the prior art and in accordance with the instant invention.

Apart from these main features of the process for the production and formation of a puff of plasma in accordance with the instant invention as well as the essential elements (ionizing electrodes) of the plasma gun used in carrying out the said process, other secondary features of the gun will hereinafter be described. Furthermore, in order to better understand the new process, a specific example thereof will be given with reference to FIGURES 3, 4, 5 and 6 of the drawings although it should be understood that this example should in no way limit the scope of the invention.

The plasma gun generally indicated by reference numeral **1** comprises two coaxial ionizing electrodes **2** and **3** axially offset from one another and mutually electrically insulated by means of insulating tubes **12** and **15** (FIGURE 6). Electrodes **2** and **3** are electrically connected to a battery of condensers **4** through a triggered spark gap **5**. The two electrodes **2** and **3** are surrounded by a third electrode **6** coaxial with and external to the said two electrodes **2** and **3** from which it is electrically insulated by means of tube **11** (FIGURE 6). The electrodes **2** and **6** are electrically connected to a second battery of condensers **7**.

The insulating tubes **11** and **12** may be made of quartz.

The gas intended to form the plasma is introduced through a conduit **20** at the end of which there is provided a valve head **8** defining, centrally thereof, a narrow passage **8'** leading into a space **19** defined by a pointed skirt **9** at the end of the valve head **8** and the seat **23** (FIGURE 6) of electrically insulating material such as polytetrafluoroethylene, the latter seat being integral with the electrode **2**. Valve **8** is biassed towards its seat **23** by valve means generally denoted by numeral **24** acting in cooperation with flange **14**.

The puff of gas intended to form the plasma is introduced annularly between the electrodes **2** and **3** when the quick action valve **8** is open, that is, when pointed skirt **9** is raised off seat **23**. The spark gap **5** is triggered simultaneously with the injection of gas in the space between electrodes **2** and **3**, thus bringing about the discharge of the battery of condensers **4** between the said electrodes and within the liberated gas. A ring of plasma is formed and ejected towards the outer electrode **6** due to the expansion resulting from the electrical discharge. When the ring expands and reaches electrode **6**, it causes the discharge of the battery of condensers **7** through said ring considering that a conducting path exists between electrodes **2** and **6** through said ring. The magnetic field produced in the annular space between electrodes **2** and **6** by the current circulating in the central electrode **2** pushes the plasma in the direction of the arrow **10**, that is towards the open end of the gun. The end of the central electrode **2** preferably has a rounded or generally spherical configuration to avoid the production of arcs that would take place if the edges were sharp.

The capacities of the batteries of condensers can be of the order of several microfarads, the capacity of the battery of condensers **7** being substantially greater than that of battery of condensers **4**. The potential across these batteries of condensers are of the order of several tens of kilovolts.

FIGURES 4 and 5 form, when aligned, a partially sectioned elevation view of a plasma gun used in carrying out the process of the invention and comprises elements analogous to those of gun **1** illustrated in FIGURE 3. The same elements are designated in the two figures as well as in FIGURE 6 by the same reference numerals.

As shown, the coaxial electrodes **2, 3** and **6** are insulated by means of cylindrical sleeves **11, 12** and **15** made of quartz. It is to be noted that the electrode **2** which is supported by the metallic tube **13** fixed to the metallic flange **14** is insulated from electrode **3** by an insulating tube **15** also fixed to flange **14** while electrode **6** is fixed to flange **50**. The cables **16** connect the central ionizing electrodes **2** and **3** to the battery of condensers **4** through spark gap **5**. The cables **17** connect the electrodes **2** and **6** to the battery of condensers **7**. The quick action valve **8** permits the injection of a predetermined quantity of gas between the electrodes **2** and **3**. In the case of experimentations on the plasma, tubular electrode **6** could be connected, through flange **18**, to an enclosure (not shown) wherein the produced and accelerated plasma is injected and wherein a vacuum of 10^{-7} mm. of Hg is maintained, as in electrode **6**. In the case of spatial propulsion, on the other hand, the plasma is ejected directly in vacuum. In such a case, the connection to a vacuum pump is not needed.

The actuating means and operation of valve **8** will now be explained. The valve **8** comprises a narrow passage **8'** joining the space **19** with the conduit **20**. The extreme leftward end of tube **20** (FIGURE 4) has a sleeve **21** provided with a tubing **22** connected to a tank (not shown) filled with gas intended to form the plasma. Therefore, the gas that is to form the plasma flows through tube **20** to the axial space between the electrodes **2** and **3**.

A piston **25** formed as an annular element is slidably mounted over tube **20** and has a piston head **25'** in slidable tight contact with the bore of a cylindrical member **26** coaxial with tube **20**. Piston **25** is normally locked by means of a spring loaded latch **27** which could be solenoid operated in response to signals from other apparatus not parts of the instant invention. Piston **25** serves to control the opening of the valve **8**. When it is released, it moves towards the left along the tube **20**, the tank **28** being then filled with gas, the pressure of which is higher than the atmospheric pressure. It will be noted that the leftward end of cylindrical member **26** has openings **52** connecting with atmosphere. When piston **25** strikes sleeve **21**, slidably mounted at the end of cylindrical member **26**, the impact forces tube **20** to recoil against the spring means **24** (FIGURES 5 and 6) and the valve skirt **9** is then lifted off its seat **23**. At this moment, the gas contained in the space **19** is exhausted or released. This opening of valve **8** will only last a very short time under the impact of piston **25**. Spring means **24** biasses valve skirt **9** back onto seat **23**. Tank **28** has one connection **54** to a source of pressure to drive piston **25** leftward and a connection **55** to a source of subatmospheric pressure to bring piston **25** back to locking position by latch **27**.

The formation and acceleration of a puff of plasma then takes place as described above.

Referring again to FIGURE 6, it will be noted that the outer ends of tubes **13** and **15** are connected to electrode **2** by means of bolts **13', 15'** projecting axially away therefrom and widely spaced around the periphery thereof to allow free passage to the gas ejected from valve **8**.

It will of course be understood that the invention is not limited to the specific embodiments described above and illustrated in the appended drawings but that different modifications and equivalent steps obvious to those skilled in the art may be used without departing from the spirit of the invention or from the scope of the following claim.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In a plasma gun of the coaxial type for the production and acceleration of a plasma obtained from a neutral gas, said gun having a first and a second coaxial cylindrical electrode of different diameters between which a steady potential is applied, said gun also having a device for the preliminary ionization of said gas including a third cylindrical electrode coaxial with said first and second electrodes and a source of electrical impulses connected between said first and third electrodes, the preliminarily ionized gas to serve for the triggering of a high energy discharge between said first and second electrodes to ac-

celerate said plasma and drive it out of said gas, the improvement wherein:

(a) said first and third electrodes are located within said second electrode and are axially offset from one another to define a radially extending preliminary ionization chamber;

(b) means are provided to inject a predetermined quanity of gas for ionization generally centrally of said radially extending preliminary ionization chamber whereby said injected gas expands into a radial ring of plasma in said radially extending chamber under said preliminary ionization and comes in contact with said second electrode whereby triggering said high energy discharge between said first and second electrodes causes ejection of said plasma axially of said electrodes and outwardly of said gun; and

(c) wherein the forward end of said third electrode is rounded.

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U.S. Cl. X.R.

313—231; 219—121