July 1, 1969 G. L. CANN ET AL 3,453,489

MULTIPLE ANODE ELECTRODE ASSEMBLY

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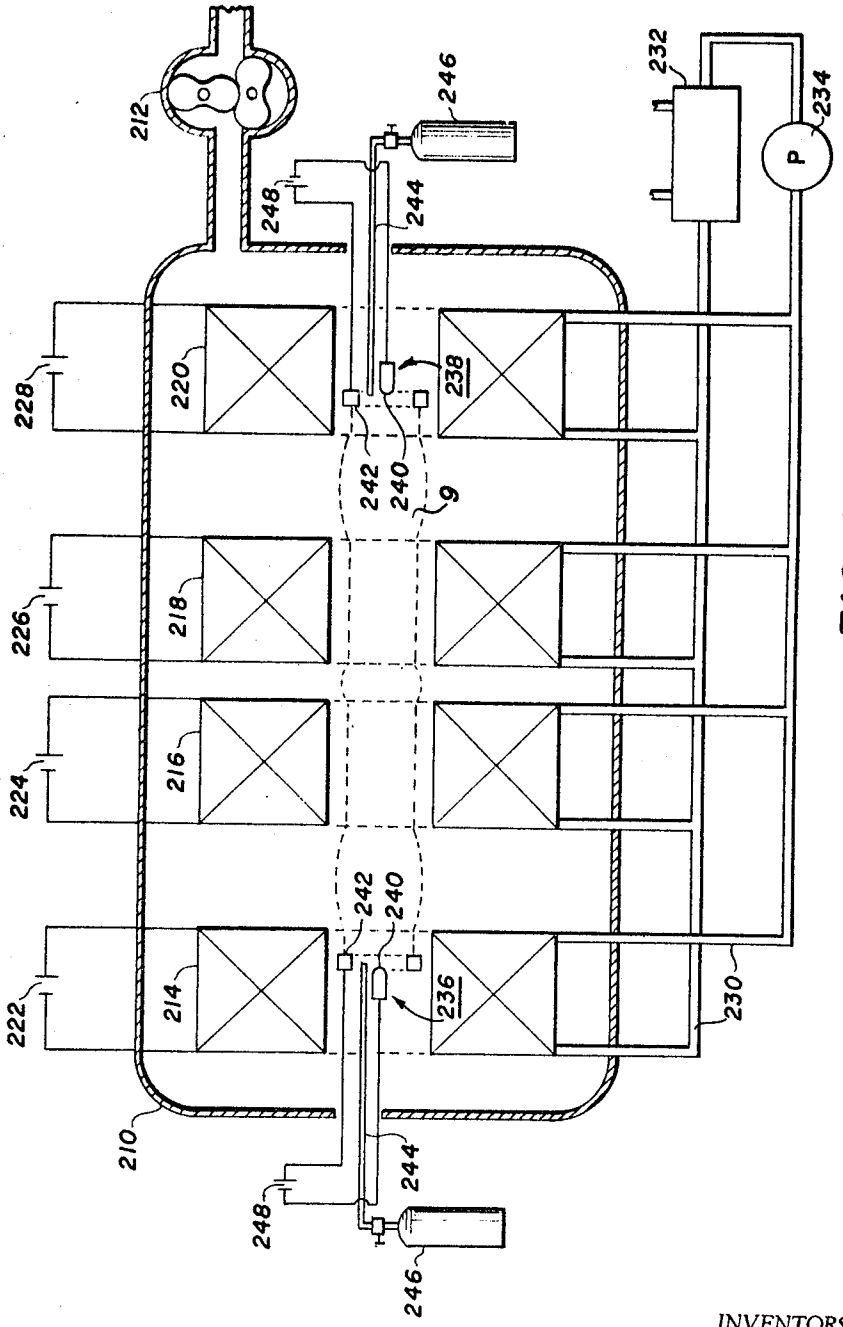


FIG. 1

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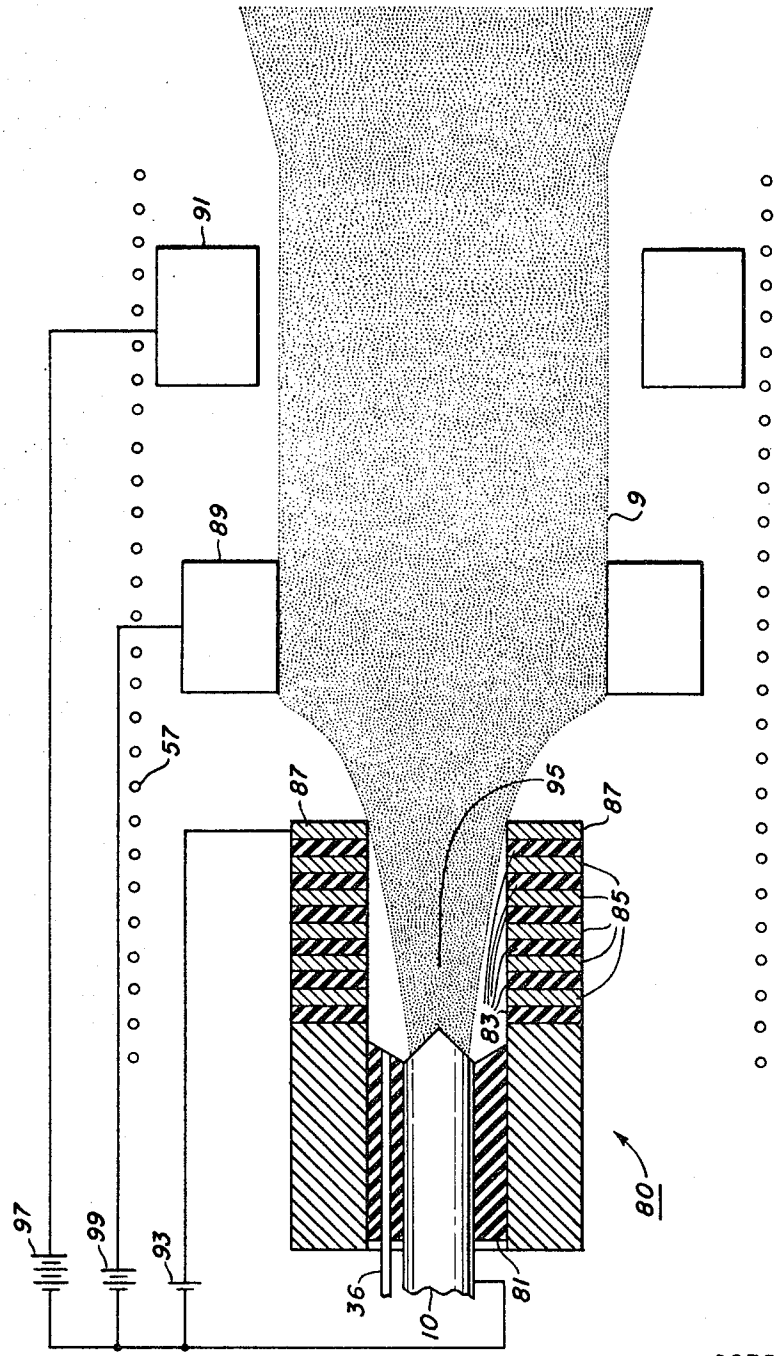


FIG. 2

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MULTIPLE ANODE ELECTRODE ASSEMBLY

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Continuation-in-part of application Ser. No. 458,837, May 20, 1965. This application Apr. 27, 1966, Ser. No. 545,704

Int. Cl. H01j 7/24; H05b 31/26

U.S. Cl. 315—111

3 Claims

ABSTRACT OF THE DISCLOSURE

A high voltage plasma arc electrode assembly including a plurality of anodes with increasing diameters and applied potentials as the anodes are successively removed from the cathode is disclosed. An electrically floating cathode buffer electrode is also disclosed in this assembly.

This application is a continuation-in-part of our copending application bearing Ser. No. 458,837, filed May 20, 1965, and entitled Plasma Arc Electrodes.

This application relates to improved plasma arc electrode assemblies.

Workers in the plasma and other arts have employed electrode assemblies comprising a tapered or pointed cathode electrode surrounded by a concentric annular anode electrode, together with means to introduce a suitable feed gas into the arc region. Such electrode assemblies are useful in connection with plasma torches, plasma containment devices, plasma propulsion devices and the like. An electrode assembly of this general description is described in copending application Ser. No. 457,414 of the present joint applicant, Gordon L. Cann, filed May 20, 1965. Difficulties have been experienced with this type of electrode structure in attempting to increase the size and to extend operation to voltages much in excess of 100 volts or currents much in excess of several hundred amperes. Two major difficulties encountered are unstable and destructive cathode arc attachment and excessive erosion of the anode by high energy electrons. Certain solutions to these problems are disclosed on our copending application Ser. No. 458,837, previously alluded to. A further solution is described in our application entitled Plasma Electrodes With Anode Heat Shield, Ser. No. 545,701 filed Apr. 27, 1966. Reference may be had to these other applications for structural details, operating conditions, and the like and their disclosure is incorporated herein by reference.

Further difficulties arise in that the arc has been formed adjacent to the electrode structure, which holds the arc temperature down, and that the arc is formed in a region where unionized material is being introduced in order to be ionized in the arc. Both factors tend to limit the maximum attainable arc voltage. The latter problem is particularly troublesome because the presence of unionized material in the arc region causes high energy arc electrons to undergo inelastic collisions with neutral atoms whereby the lost electron energy is equally dissipated in ionizing the atoms and heating them. This continuing loss of high energy electrons to the ionization process tends to prevent the arc voltage from exceeding the ionization potential of the particular feed gas by a factor of more than about 6 to 8.

It is accordingly an object of the present invention to provide increased plasma arc voltages through the use of a plurality of anode elements. Further objects will become apparent in conjunction with the following description and figures.

FIG. 1 is a schematic cross sectional view of a plasma containment apparatus in which the electrode assembly of the invention may be employed.

FIG. 2 is a simplified cross sectional view of an electrode assembly according to the invention.

FIGURE 1 shown a form of plasma containment apparatus in which the present invention may be usefully employed. This apparatus is more fully described in copending application 457,746 of the present joint applicant, Gordon L. Cann, filed on Apr. 20, 1965. It includes a chamber **210** which is evacuated by pump **212** and contains hollow magnet coils **214**, **216**, **218** and **220** which are energized in the same direction by power supplies **222**, **224**, **226** and **228**. Water cooling may be provided for the magnet coils as shown by elements **230**, **232** and **234**. Located within coils **214** and **220** are arc electrode assemblies **236** and **238**, each of which includes at least a cathode **240** and an anode **242** which are connected to a power supply **248** as well as a gas supply channel **244**, which is fed from a source **246** of argon, hydrogen or other ionizable gas. The illustrated apparatus is particularly adapted to form a confined rotating column of high temperature plasma **9** extending from electrode assembly **236** to electrode assembly **238** and having an internal radial electric field.

The electrode assembly of FIGURE 2 is particularly suitable for use as electrode assemblies **236** and **238** of FIGURE 1. In the illustrated apparatus, the attainable plasma temperature is related to the electrode arc voltage and the electrode assemblies of the invention therefore result in a desirably higher temperature plasma. The present invention is similarly useful in the containment apparatus described in the copending Cann application 457,414 previously mentioned.

FIGURE 2 depicts an arc electrode assembly according to the invention. A central cathode **10** is preferably surrounded by and recessed within a concentric buffer electrode **80** defining a chamber **95**. The buffer electrode is electrically floating and is insulated from cathode **10** by an insulator **81**. The latter is further provided with one or more gas feed passages **36** for introducing an ionizable gas or vapor. Chamber **95** is extended by a series of alternating insulating and electrically floating conductive segments **83** and **85**, terminating in first anode **87**. Segments **83** and **85** could theoretically be replaced by a single electrical insulator but insulators generally have insufficient thermal conductivity to survive in the vicinity of a high power electrical arc discharge.

Positioned a short distance to the right of the elements thus far described and coaxially spaced therefrom, is an annular second anode **89**. As shown in the diagram, the internal diameter of this second annular anode **89** may be somewhat greater than that of the anode **87**. Spaced somewhat further to the right of this anode **89** is yet a third anode **91** similar to anode **89** but of still somewhat greater internal diameter. Portions of a magnet coil **57** are shown surrounding the overall electrode assembly thus far described. These may be considered as portions of a magnet such as **214** in FIGURE 1. For purposes of simplicity support means for the coil **57** or for the several other elements depicted are not herein shown, nor is it explicitly indicated that insulating supports may be provided between the several anodes and the coil **57** although this will normally be the case. Similarly, it will be understood that the various conductive elements may be provided with internal fluid cooling passages.

In operation coil **57** will be activated in order to provide a generally longitudinal magnet field in the vicinity of the electrode assembly. Power supplies **93**, **95** and **97** are activated to initiate cathode-anode discharges and are adjusted or chosen to be of such magnitude as to establish the first, second and third anodes **87**, **89**

and **91** respectively at successively higher potentials with respect to cathode **10**.

The arc discharge between cathode **10** and first anode **87** is substantially confined within chamber **95** which is a region of relatively high pressure and current density. Since the gas introduced from passages **36** is forced to pass through this same chamber it becomes very highly ionized. However, this ionization process tends to limit the voltage which can be maintained between first anode **87** and cathode **10**, as previously described. The situation with respect to the discharge between cathode **10** and anode **89** is quite different, however. Most of the unionized gas from passages **36** is forced out between anodes **87** and **89**, since it is neutral and not subject to any of the electrostatic or electromagnetic forces which tend to confine the ionized plasma in the central column described in connection with the description of FIGURE 1. Therefore, most of the discharge path between cathode **10** and anode **89** lies in a region of substantially completely ionized plasma and is not subject to the voltage limitations caused by the presence of large numbers of neutral atoms.

A third anode **91**, or even more anodes, can also be provided to further enhance the operation of the invention. Substantially all neutral atoms which succeed in drifting past anode **89** will be expelled between anode **89** and anode **91** so that the discharge path between cathode **10** and anode **91** will be even longer than that between cathode **10** and anode **89** and will include a region of even more completely ionized plasma and lying even further away from the heat dissipating structures of cathode **10**, anode **87**, and associated elements. Thus, an even higher voltage can be maintained between cathode **10** and anode **91**. In this way the plasma energy is successively raised by each subsequent discharge and is not subject to the limitations associated with a need to use a single arc discharge to perform the dual function of ionizing the feed gas and at the same time raising it to a high energy.

While the present invention has been particularly described in terms of specific embodiments thereof it will be understood that in view of the present disclosure numerous modifications thereof and deviations therefrom may now be readily devised by those skilled in the art without yet departing from the present teaching. Accordingly, the present invention is to be broadly construed and limited only by the spirit and scope of the claims now appended hereto.

What is claimed is:

1. A high voltage plasma arc electrode assembly adapted to operate in an evacuated chamber having an axial magnetic field comprising:

(a) a cathode having a downstream-pointing axial tip;
(b) a first anode concentric with said cathode;
(c) means to introduce an ionizable material between said cathode and said first anode;
(d) DC power supply means connected between said cathode and said first anode;
(e) multiple annular anodes concentric with said cathode and positioned downstream from said first anode, the internal diameters of said multiple anodes increasing with distance from said cathode; and
(f) multiple DC power supply means connected between said multiple anodes and said cathode, said multiple power supply means being adapted to deliver successively higher voltages to said anodes successively more removed from said cathode.

2. Plasma containment apparatus comprising:

(a) a chamber;
(b) means to evacuate said chamber;
(c) magnetic means to form a longitudinally continuous magnetic field along an axis of said chamber;
(d) at least one plasma arc generator disposed within said magnetic field on said axis and substantially symmetrical thereabout, said generator comprising:
  (1) a downstream point axial cathode;
  (2) a first anode concentric with said cathode;
  (3) means to introduce an ionizable material between said cathode and said first anode;
  (4) DC power supply means connected between said cathode and said first anode;
  (5) multiple annular anodes concentric with said cathode and positioned downstream from said first anode, the internal radii of said multiple anodes increasing with distance from said cathode; and
  (6) multiple DC power supply means connected between said multiple anodes and said cathode, said DC power supply means being adapted to deliver successively higher voltages to said multiple anodes successively further spaced from said cathode.

3. A high voltage plasma arc electrode assembly adapted to operate in an evacuated chamber having an axial magnetic field comprising:

(a) a cathode having a downstream pointing axial tip;
(b) a cathode ionizing chamber surrounding said cathode and opening downstream, said chamber being defined by an electrically floating cathode buffer electrode surrounding said cathode tip, and a series of alternating electrically conductive, but electrically floating buffer segments and insulating segments defining an extension of the ionization space within said chamber;
(c) a first anode electrode having an internal aperture and terminating said ionization chamber;
(d) means to introduce an ionizable material between said cathode and said first anode;
(e) first DC power supply means connected between said cathode and said first anode;
(f) at least a second annular anode concentric with said cathode and positioned downstream from said first anode; and
(g) at least a second DC power supply connected between said cathode and said second anode and adapted to deliver a higher voltage than said first power supply.

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U.S. Cl. X.R.

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