United States Patent [19]

Ehlers et al.

[11] **3,846,668**

[45] **Nov. 5, 1974**

[54] **PLASMA GENERATING DEVICE**

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[73] Assignee: **The United States of America as represented by the United States Atomic Energy Commission,** Washington, D.C.

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[21] Appl. No.: **334,824**

[52] **U.S. Cl.** **315/111,** 250/423, 313/63, 313/230

[51] **Int. Cl.** **H01j 7/24,** H05h 1/00

[58] **Field of Search** 313/63, 230; 315/111; 250/423, 426

[56] **References Cited**

UNITED STATES PATENTS

3,345,820	10/1967	Dryden	315/111
3,614,440	10/1971	Carr	315/111
3,760,225	9/1973	Ehlers et al.	313/63

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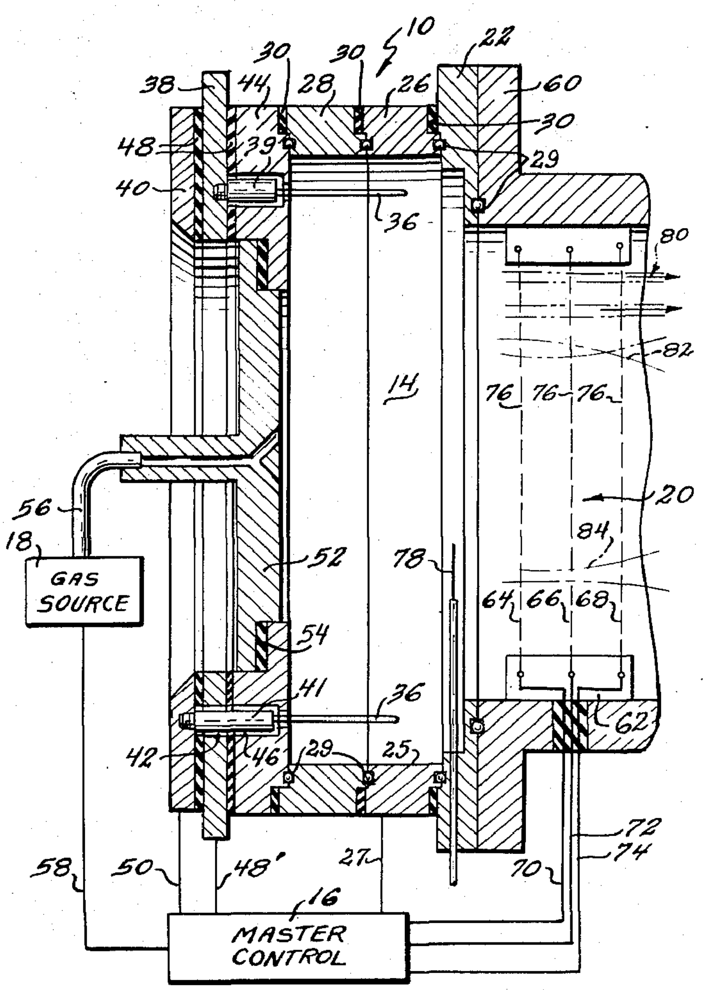
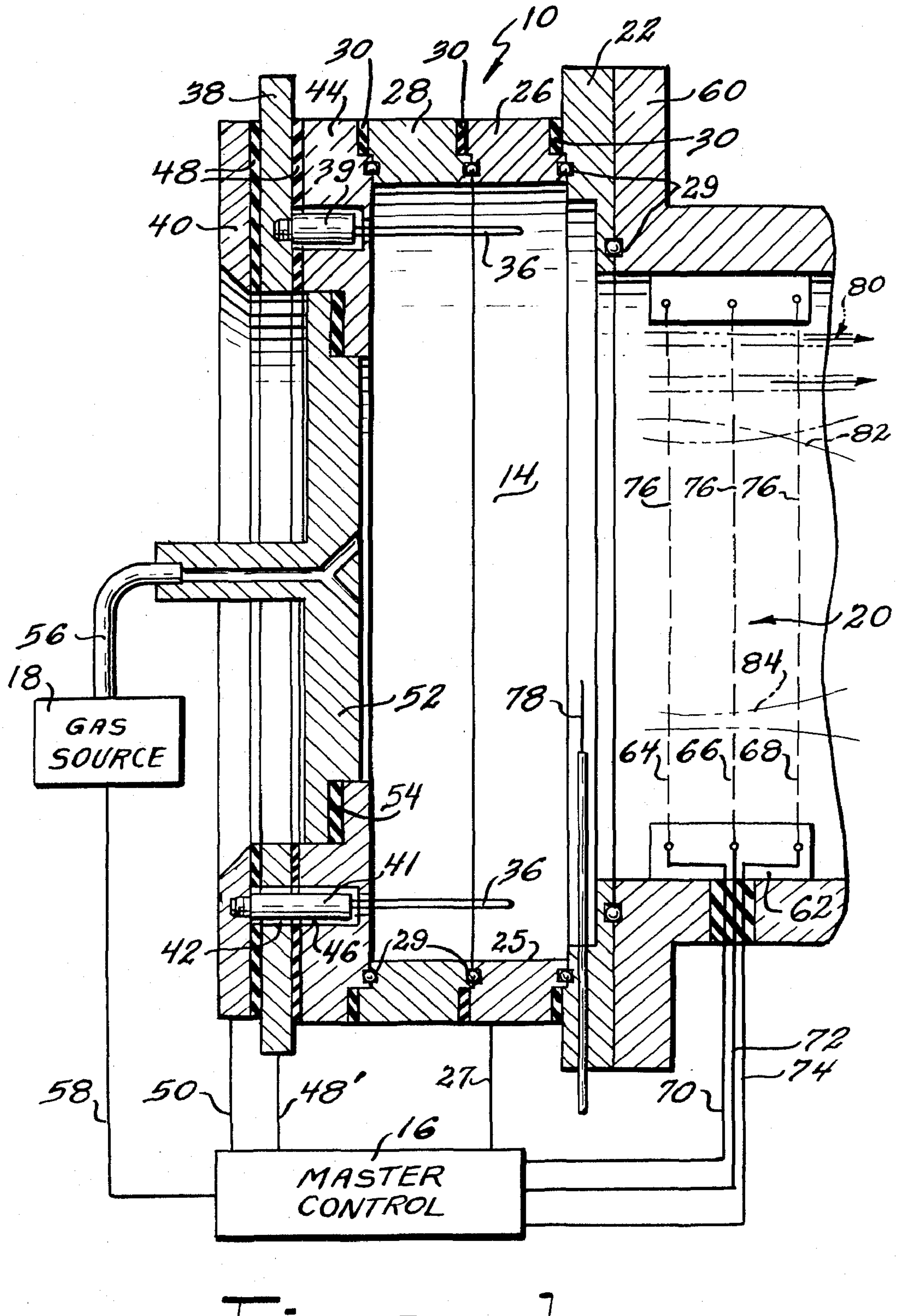
[57] **ABSTRACT**

An improved high current plasma generating device generally comprised of an annular shaped anode means disposed in radially outward and circumjacent spaced relation to a plurality of electron emitter elements so as to cause a gaseous medium upon introduction into the discharge chamber of the device to be progressively formed into a more useful and homogeneous plasma of substantially uniform ion current density in transverse section for enhancing the fueling of a thermonuclear reactor.

6 Claims, 2 Drawing Figures

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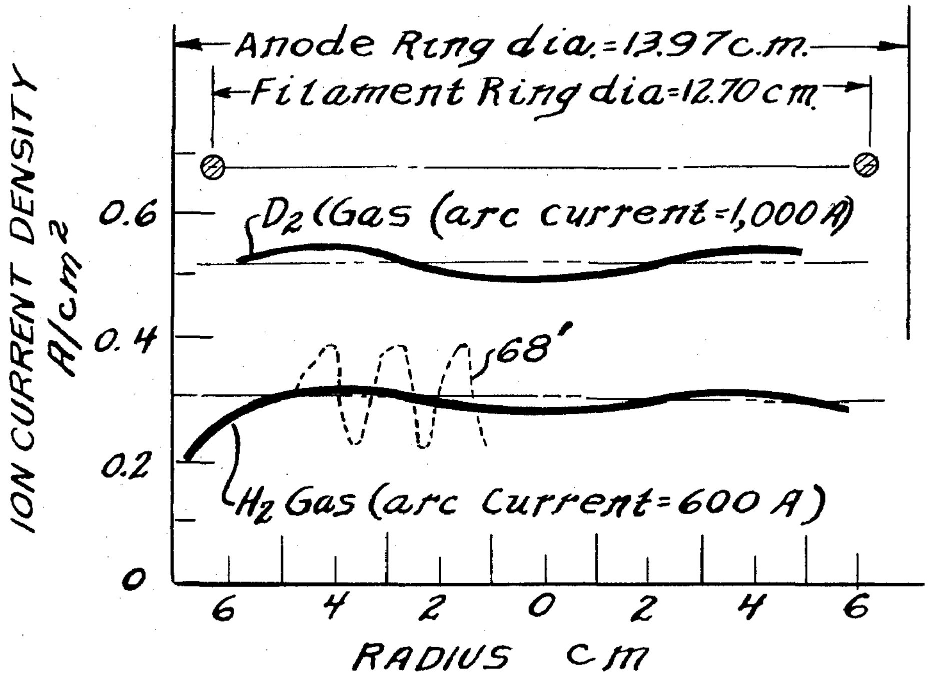
42
46
29
25
72
58
50
48'
27
70
74
16
MASTER CONTROL

Fig — 1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Filament Ring dia=12.70cm
ION CURRENT DENSITY
A/cm²
0.6
0.4
0.2
0
D_2 (Gas (arc current=1,000A)
68'
H_2 Gas (arc Current=600 A)
6
4
2
0
2
4
6
RADIUS cm

Fig—2

PLASMA GENERATING DEVICE

Reference is made to the copending pat. application entitled, "High Current Ion Source" by Kenneth W. Ehlers et al, filed June 6, 1972, and having S.N. 260,236, now U.S. Pat. No. 3,760,225, issued Sept. 18, 1973.

BACKGROUND OF THE INVENTION

The invention was conceived or made in the course of Contract No. W-7405-ENG-48 with the United States Atomic Energy Commission.

This invention relates to a plasma generating device. More particularly, it relates to an improved high current plasma generating device for producing a stable and quiescent plasma of substantially uniform ion current density.

In the past various plasma generating devices have been designed as exemplified by two U.S. Pat. Nos. 2,785,311 to Lawrence and 2,902,614 to Baker and the aforementioned copending U.S. application. Prior ion producing devices were incapable of generating plasmas that would satisfactorily meet the overall fuel requirements for a thermonuclear reactor without encountering various difficulties such as nonhomogeneity of an ion beam as it was extracted from the plasma generating device, excessive optical convergence or divergence of the extracted ion, etc.

This invention relates to an improved plasma generating device generally comprised of a plurality of electron emitter filaments and an annular shaped anode disposed in outwardly spaced and circumjacent relation to the plurality of emitter elements so as to cause a gaseous medium upon introduction into the discharge chamber of the device to be progressively formed into a homogeneous plasma for effecting fueling of the thermonuclear reactor with minimal difficulties.

Accordingly, it is an object of the present invention to provide an improved plasma forming device that will effect the production of a plasma having a stable and substantially uniform ion current density in transverse section upon operating the present device at arc currents up to and on the order of 1000 amperes.

Another object of the instant invention is to provide an improved plasma forming device having an annular-shaped anode surface area for minimizing among other things the adverse effects of an anode sheath build-up having the tendency to cause accelerated wear and overheating of the instant device.

SUMMARY OF THE INSTANT INVENTION

The present invention relates to an improved plasma generating device generally comprised of a plurality of electron emitter elements and a novel annular shaped anode disposed in radially outward and circumjacent spaced relation to the emitter elements for effecting ionization of a gaseous medium made-up of various selected atomic compositions into an ionized plasma of substantially uniform ion current density, such uniform ion density effecting formation of an improved fuel for a thermonuclear reactor.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic and sectional view in dotted and solid lines of a plasma generating device that incorporates a preferred embodiment of the instant invention; and

FIG. **2** is a graphic view of the radial profile of the ion current density of more than one plasma produced by the present inventive device.

With continued reference to the drawings they illustrate a preferred embodiment of an improved plasma generating device **10** for introducing and subjecting a given pulsed volume of a gaseous medium to a relatively high arc current range so as to cause formation of the introduced gaseous medium into a pulse type plasma of substantially uniform ion current density the ions of which can be extracted for fueling a thermonuclear reactor in improved fashion. Although the instant device is preferably operated to produce a plasma in pulse-type fashion it is not intended to be limited thereto. Device **10** is generally comprised of a hollow cylindrical shaped vessel made up of uniquely interconnected elements so as to define a vacuum electron arc discharge and plasma forming chamber **14.** A master control electric pulse and operating circuit **16** and a pressurized gaseous source **18** for timely supplying a selected amount of a gaseous medium to be ionized in chamber **14** are associated with device **10** in the manner shown in FIG. **1.** An ion accel-decel extraction grid **20** is connected to the right or outlet end of decive **10** as illustrated in FIG. **1** for extracting and accelerating a plurality of ions from a plasma formed in chamber **14** to grid **20** while at the same time focussing the extracted and accelerated ions in the configuration of an ion beam of improved collimated shape from grid **20** to the containment zone of a thermonuclear reactor (not shown) such as, e.g., a 2X-II type or Baseball type of thermonuclear reactor all during operation of device **10.** As will become more fully apparent hereinafter because of the device creating a plasma of substantially uniform ion current density as well as forming a improved ion beam from the plasma created, a thermonuclear reactor can be fueled in a more efficient fashion.

In an advantageous embodiment of the present invention, device **10** is comprised of a vessel having an apertured right end cap **22** and a pair of coaxially aligned intermediately disposed annular ring elements **26** and **28.** Since the inner annular surface **25** of ring **26** preferably serves as the anode of the present device, ring **26** is electrically connected to master control **16** by way of electric lead **27.**

As indicated in FIG. **1,** the inner opposed wall portions of end cap **22** and ring **26** and rings **26** and **28,** are provided with opposed and matching **0**-ring receiving grooves. Upon inserting an **0**-ring **29** in an **0**-ring receiving groove of a given vessel element, e.g., ring **26** in conventional fashion, it is to be understood that the **0**-ring has sufficient thickness such that upon assembling the rings **26** and **28** and end cap **22** together to form the right vessel end of device **10,** the opposed inner end faces of rings **26** and **28** and ring **26** and end cap **22** are held in spaced relation to each other. At the same time an **0**-ring is inserted in a groove between rings **26** and **28** and between end cap **22** and ring **26,** the outer opposed and matching stepped and recessed portions of rings **26** and **28** and ring **26** and end cap **22** are provided with an elastomeric seal ring **30** clampingly held therebetween in the manner shown in FIG. **1.** Seal ring **30** is preferably composed of a suitable grade of epoxy material having appropriate heat resistance and dielectric properties.

In another advantageous embodiment of the present invention, vessel **10** includes a plurality of thermionic electron emitter elements **36** mounted at the left end thereof in unique relation to anode ring **26**. Each one of the emitter elements **36** is of corresponding hairpin or U-shaped configuration and is preferably composed of a suitable grade of refractory tungsten material of wire-like configuration that normally has a diameter on the order of a half millimeter.

An inner chuck assembly includes an annular plate **38** and a series of plug-shaped molybdenum chucks **39** only one of the chucks **39** being shown for the sake of brevity in FIG. **1**. Each one of the chucks **39** is threadably connected to one end face of plate **38** is equally spaced circumferential relation to the other chucks. An outer chuck assembly at the left end of device **10** includes an annular plate **40** and a series of plug-shaped molybdenum chucks **41** only one of the chucks **41** being shown for the sake of brevity in FIG. **1**. For reasons apparent hereinafter chuck **41** has a longer length than chuck **39**. As with chucks **39**, each one of the chucks **41** is threadably connected to one end face of plate **40** in equally-spaced and circumferential relation to the other chucks **41**.

Inner chuck plate **38** is provided with a series of apertures **42** interposed between the series of chucks **39** in equally spaced and circumferential relation to each other and the series of chucks **39**. Each one of the apertures **42** in plate **38** freely receives a given chuck **41** upon assembly of plates **38** and **40** together in the manner shown in FIG. **1**. A spacer ring **44** is provided with a series of apertures **46** for freely receiving the outer ends of the alternate series of chucks **39** and **41** upon assembly of spacer ring **44** to previously assembled inner and outer plates **38** and **40**. As with annular rings **26** and **28**, an annular seal **48** of epoxy material is inserted between opposed faces of plates **38** and **40** and plate **38** and ring **44** during assembly of plates **38** and **40** and ring **44** as depicted in FIG. **1**.

Prior to connection of spacer ring **44** to ring **28**, the opposed ends of each one of the hairpin-shaped emitter elements **36** is appropriately connected to its respective chuck **39** or **41**. Upon connecting each one of the emitter elements **36** to its respective chuck **39** or **41**, ring **44** is connected to ring **28** whereby the series of circumferentially spaced emitter elements **36** extend longitudinally of vessel **10** in chamber **14** and are disposed radially inward of vessel rings **26** and **28** in circumjacent spaced relation thereto. Rings **28** and **44** are provided with opposed and matching grooves for receiving an 0-ring **29** as well as opposed and matching stepped and recessed portions for receiving an annular seal **30**. The particular manner, such as bolt nut assemblies, etc., for effecting connection of plates **38** and **40**, rings **26, 28** and **44** and end cap **22** to form vessel **10** have not been shown for the sake of simplicity in FIG. **1**. Electric leads **48'** and **50** extend between plates **38** and **40** and master control **16** thereby electrically connecting elements **36** in parallel fashion across master control **16**.

A stem-shaped cap **52** closes off the left end of vessel **10** upon assembling cap **52** to ring **44**. Prior to assembling cap **52** in the counterbored aperture of ring **44**, an annular seal **54** of epoxy material is inserted between the opposed shoulders of the cap and ring **44**.

Cap **52** and ring **44** as well as cap **22** and ring **28** are structural members only, defining wall and end portions of chamber **14**, and are allowed to float electrically. It is to be understood that these metal elements of vessel **10** may, if it is desired, also be electrically connected to master control **16** for selectively applying a voltage to section **22**, ring **28**, etc. Such selective application of a voltage potential to ring **22**, e.g., effectively minimizes the side capacitance effects that would otherwise normally occur during operation of device **10**. Although master control **16** is schematically shown, it is believed that the various circuits for applying the proper voltages across emitter elements **36**, anode ring **26**, etc., are believed to be within the skill of an electric circuit designer.

A pressurized ionizable gas source **18** is interconnected to the fully-bored-through-stem portion of cap **52** by way of conduit **56**. An electric lead **58** interconnects source **18** and master control **16** whereby a timely signal from the control triggers a valve (not shown) for transmitting a selected amount of ionizable gaseous medium from the source to the electron arc discharge vacuum chamber **14** of device **10** during operation of device **10**. Depending upon the particular fuel requirements for a thermonuclear reactor, source **18** can be filled with various gaseous mediums such as hydrogen, deuterium, tritium and various admixtures thereof.

Another advantageous embodiment of the present invention, device **10** is comprised of an ion accel-decel extraction grid **20** for effecting extraction, acceleration and focussing of ions from a plasma formed in device **10** to the containment zone of a thermonuclear reactor (not shown). Grid **20** is comprised of an outer open-ended sleeve **60**, the left flanged end of which is suitably connected to the apertured end cap **22** of device **10**. The right flanged end of sleeve **60** (not shown) is connected to the fuel inlet port (also not shown) of a thermonuclear reactor. A grid assembly **62** is mounted within the interior of sleeve **60** and is preferably made up of a series of three parallel spaced grid elements **64, 66** and **68**. Each grid element **64, 66** or **68** is separately connected to the master control by way of electric leads **70, 72** and **74**. A given grid **64, 66** or **68** includes a series of longitudinally extending slots **76** across the width thereof disposed in axial alignment with respect to the series of slots of the other grid elements.

Since the inner annular anode surface **25** of ring **26** presents an extended anode surface area each one of the series of electrons emitted from the plurality of emitter elements **36** travels from its respective element to a certain surface portion of anode ring **26** without resulting in an excessive concentration of electrons about the anode ring during operation of the present device. It has been found that reducing the excessive concentration of electrons traveling from emitter elements **36** to anode ring **26** not only reduces the build-up of cathode spots adjacent to anode ring **26** but also effectively minimizes the build-up of an anode sheath or voltage gradient adjacent thereto. Reduction in the adverse effects of cathode spots and anode sheaths assures the formation of a homogeneous plasma as produced from a given pulse of gaseous medium introduced into vacuum chamber **14** when the instant device is operating. Moreover, in reducing the cathode spots the series of electrons in traveling from the plurality of emitters **36** to the anode surface **25** are incapable of forming magnetic fields, commonly known as theta fields, that produce instable plasma hash effects as indicated by the zig-zag dotted line waveform **68'** in FIG. **2.**

Upon forming a plasma in chamber **14** of device **10**, control **16** can apply selective voltage potentials across grids **64, 66** and **68.** For instance grid **64** could have a voltage potential of +20 kilovolts, grid **66** a voltage potential of −5 kilovolts and grid **68** a ground potential. Since the uniquely shaped anode **26** of device **10** effects formation of a substantially homogeneous plasma, for instance, a plasma formed from an H_2 or D_2 (hydrogen or deuterium) gaseous medium as indicated by the relatively flat H_2 and D_2 waveforms in FIG. **2** upon moving plasma ion current sensing probe **78** in FIG. **1**, grid **64** will effect extraction and acceleration of ions from the plasma in the chamber **14** of device **10** to the interior of grid **20.** At the same time grid **20** will also be able to uniformly focus various portions of the extracted and accelerated ions of substantially uniform current density from chamber **14** of device **10** into a plurality of collimated ion beams **80** that are directed through their associated axially aligned slots of grids **64, 66** and **68** as indicated by dotted lines in FIG. **1.** In the absence of device **10** forming a homogeneous plasma as aforedescribed, grid **20** would form an ion beam having convergent and/or divergent shapes **82** and **84** thereby resulting in loss of ions for fueling a thermonuclear reactor. Hence the instant device **10** provides minimal loss of ions thereby assuring a resultant ion beam of maximum density for fueling a thermonuclear reactor.

In an operative embodiment of device **10** the inner surface of anode ring **26** had a diameter on the order of **14** centimeters, a plurality of **20** filaments **36** had an average perimeter diameter on the order of 13.50 centimeters and the grid outlet opening of vessel **10** had a diameter on the order of 13 centimeters. In operating device **10** at pulse line voltages on the order of 40 to 300 volts and arc voltages on the order of 35–100 volts, a stable deuterium plasma was formed having an ion current density of 0.5 amperes per square centimeter, with variations in current density on the order of ±3.0 percent, when the arc current of device **10** was on the order of a **1000** amperes as depicted in FIG. **2.**

Similarly, another plasma essentially composed of hydrogen ions had a homogeneous ion current density on the order of 0.3 amperes per square centimeter, with variations in density on the order of ±5.0 percent, as indicated by the relatively flat waveform in FIG. **2** where the arc current of device **10** was on the order of 600 amperes.

In view of the foregoing embodiments of the instant invention modification may be made therein without departing from the present invention as covered by the appended claims, wherein:

What we claim is:

1. A high current plasma generating device comprising a vessel means having an evacuated electron arc discharge chamber therein, an electron emitter means being made up of a plurality of refractory metal filaments, each one of said plurality of metal filaments being individually mounted at one end of said vessel means so as to project longitudinally into the arc discharge chamber and to be disposed in circumferentially spaced relation to each other as well as inwardly spaced relation to the surrounding outer peripheral wall of said vessel means, reservoir means for selectively introducing a predetermined amount of a gaseous medium to be ionized into the discharge chamber of said vessel means, and an annular shaped anode means provided in the outer wall of said vessel means in outwardly spaced and circumjacent relation to said plurality of electron emitter means for causing a series of electron arc discharges between said plurality of electron emitter means and said anode means so as to effect formation of the introduced amount of gaseous medium into a relatively stable and quiescent high current plasma of substantially uniform ion current density throughout its extent upon simultaneous electric energization of said anode means and said plurality of emitter means when said reservoir means admits a predetermined amount of gaseous medium into the discharge chamber.

2. A plasma generating device as set forth in claim **1** in which a given emitter means is of hairpin shaped configuration.

3. A plasma generating device as set forth in claim **1** in which a given emitter means is essentially composed of a refractory metal material such as a suitable grade of tungsten.

4. A plasma generating device as set forth in claim **1** wherein said vessel means has an outlet opening at the end opposing said one end where filaments are mounted and said plasma generating device includes means connected to said vessel means at said outlet opening for extracting and accelerating the ions of a plasma from the discharge chamber of said vessel means to the inlet port of a thermonuclear reactor while at the same time focusing the extracted and accelerated ions into the shape of a collimated ion beam for injection into the inlet port of a thermonuclear reactor.

5. A plasma generating device as set forth in claim **1** in which said reservoir means includes a gaseous medium selected from the group of hydrogen, deuterium, tritium and various admixtures thereof.

6. In a high current plasma generating device made up of a vessel means and a plurality of electron emitter elements mounted at one end of said vessel means and disposed in the evacuated electron arc discharge chamber therein, each one of said elements being disposed in circumferentially spaced relation to each other and extending longitudinally into the chamber of said vessel means, a reservoir means for introducing a predetermined amount of a gaseous medium into the chamber of said vessel means, and an anode means disposed in electron arc discharge relation to said emitter means, the improvement comprising an annular shaped anode means provided in the outer peripheral wall of said vessel means and disposed in radially outward and circumjacent spaced relation to said plurality of emitter elements so as to cause an introduced amount of gaseous medium in the chamber to be formed into a relatively stable and quiescent high current plasma of substantially uniform ion current density throughout its extent upon simultaneous electric energization of said anode means and said plurality of emitter means when said reservoir means admits a predetermined amount of gaseous medium to be ionized into the discharge chamber.

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