

[54] GAS PLASMA DEVICE

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315/344, 348

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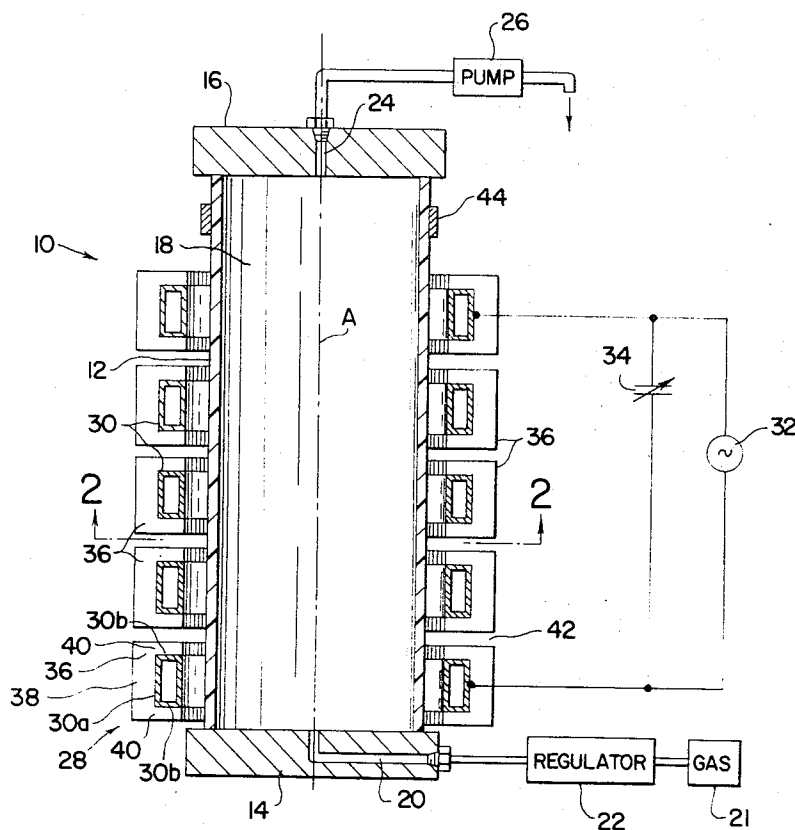
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[57] ABSTRACT

A method and device is disclosed for ionizing gas at the plasma level thereof and comprises a gas chamber having an inlet for gas to be ionized and which inlet is connected to a source of gas so that the chamber can be filled and the gas maintained therein under a vacuum. An induction heating coil surrounds the chamber and the opposite ends of the coil are connected to a source of alternating current for energizing the coil to establish a magnetic field through the chamber. Flux concentrating laminations in the form of C-shaped plates of magnetic material surround the outer and axially opposite sides of the convolutions of the coil to increase the density of the flux field through the chamber to enhance maintenance of gas ionization.

15 Claims, 4 Drawing Figures



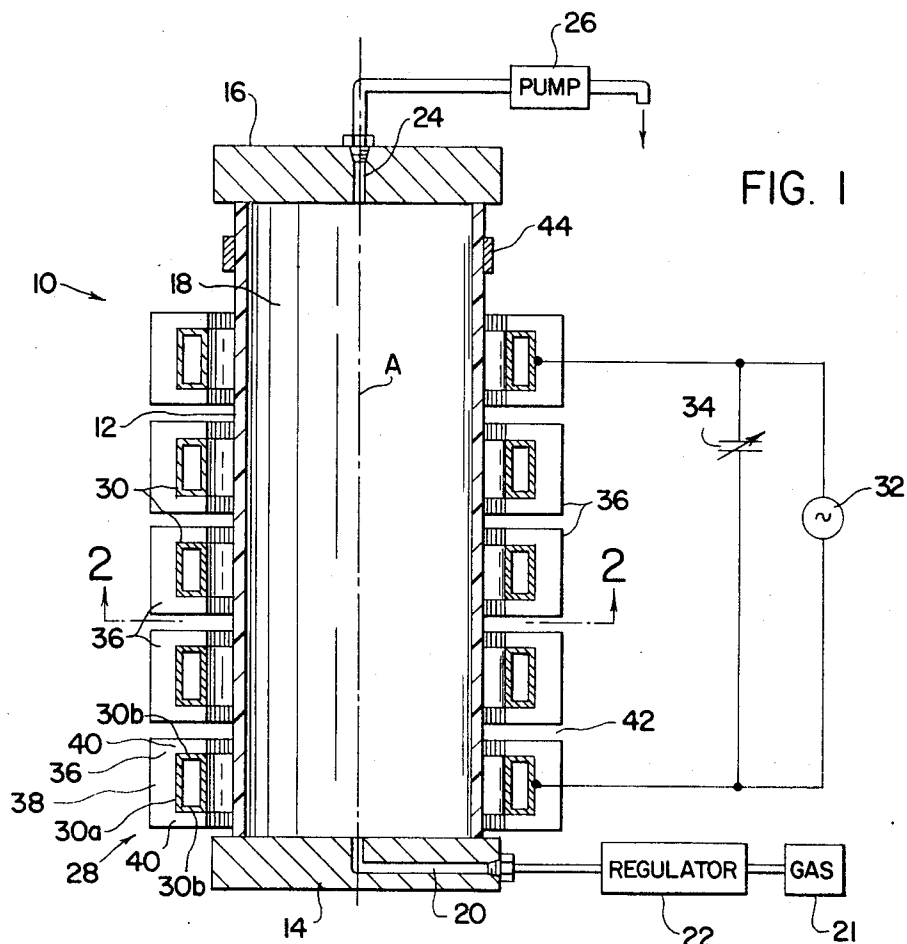


FIG. 1

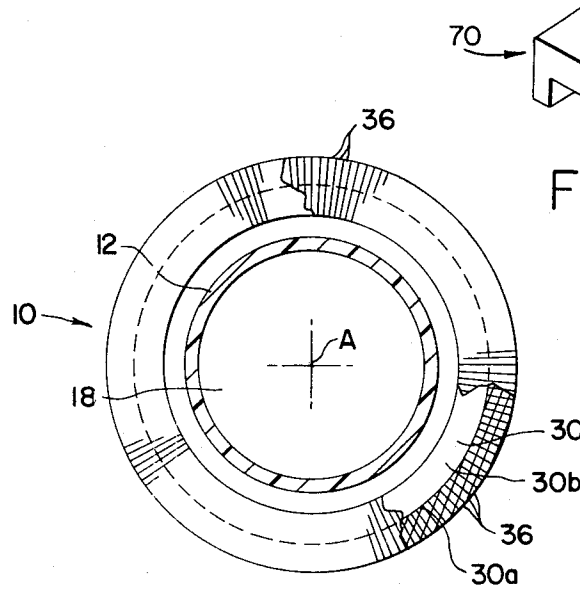


FIG. 2

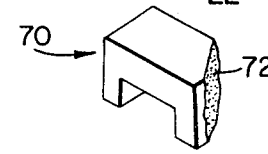


FIG. 4

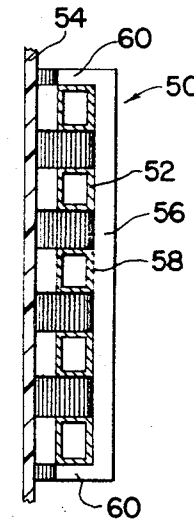


FIG. 3

GAS PLASMA DEVICE

The present invention relates to a method and device for gas ionizing, and more particularly to a method and device for establishing and/or maintaining gas ionization at the plasma level.

In accordance with the present invention, a gas ionizing chamber is surrounded by an induction coil which is energized from a suitable source of alternating current to establish a magnetic field having a portion within the gas chamber to ionize gas therein to obtain and/or maintain ionization at the plasma level. The gas, such as argon, is introduced into the chamber and maintained therein at a desired vacuum during the starting and maintaining of gas ionization. Further, in accordance with the present invention, the efficiency of gas ionization is increased by providing the induction heating coil with flux concentrating means which increases the flux density in the portion of the magnetic field in the gas chamber.

The flux concentrating means is associated with the turns of the coil in a manner whereby the flux path external to the gas chamber is closely confined radially outwardly of the coil convolutions, thus to advantageously increase the flux density in the portion of the magnetic field within the gas chamber and thereby enhance gas ionization. The flux concentrating means is defined by magnetic material disposed adjacent at least radially outer surface portions of the coil and, preferably, is defined by laminations of magnetic metal plates. The laminations are disposed in radial planes coincident generally with the axis of the coil and, preferably, the laminations are disposed in face to face engagement.

In accordance with another aspect of the present invention, the convolutions of the induction heating coil are provided with generally C-shaped laminations of magnetic sheet material. The closed side of the C extends axially adjacent the radially outer surface of a coil convolution and the legs of the C extend radially inwardly from the opposite ends of the side of the C adjacent opposite sides of the corresponding coil convolution. Preferably, the C-shaped laminations are disposed in face to face engagement and extend continuously about the coil from one end thereof to the other. The C-shaped laminations define generally semi-circular paths extending about the coil convolutions to provide a path for magnetic flux which is much closer to the radially outer portion of the coil than it would be if the laminations were not employed. This path advantageously increases the flux density within the gas chamber to increase gas ionizing efficiency.

Accordingly, it is an object of the present invention to provide a method and device for gas employing an induction heating coil to generate a magnetic field for gas to be ionized at the plasma level and which provides for a gas ionizing efficiency greater than heretofore possible.

Yet another object of the present invention is the provision of a gas ionizing device and a method of gas ionization wherein flux concentration is achieved to enhance gas ionizing efficiency.

Still another object of the present invention is the provision of a gas ionizing device of the above character in which an increase in flux density within a gas ionizing chamber is achieved by controlling the path of the magnetic field relative to radially outer portions of the induction heating coil.

A further object of the present invention is the provision of a gas ionizing device of the above character wherein flux concentrating magnetic material is associated with the induction heating coil to control the path of the magnetic field relative to radially outer portions of the coil.

Still a further object of the present invention is the provision of a gas ionizing device of the above character wherein the induction heating coil is provided with laminations of magnetic sheet metal associated with the coil in a manner to control the path of the magnetic field radially outwardly of the coil to increase the flux density in the gas ionizing chamber.

The foregoing objects and others, will in part be obvious and in part more fully pointed out hereinafter in conjunction with the description of the drawing of preferred embodiments of the present invention and in which:

FIG. 1 is a view in longitudinal section, of a gas ionizing device made in accordance with the present invention;

FIG. 2 is an end view in section, of the device illustrated in FIG. 1, the view being along line 2—2 in FIG. 1;

FIG. 3 is a partial longitudinal section of a modified form of flux concentrating laminations for a gas ionizing device made in accordance with the present invention, and

FIG. 4 is a perspective view, partially in section, of a flux concentrator element of powdered ferritic material.

Referring now to the drawing in greater detail wherein the showings are for the purpose of illustrating preferred embodiments of the invention only and not for the purpose of limiting the same, an ionizing device 10 is illustrated which includes a cylindrical housing or envelope 12 of quartz or the like having end wall components 14 and 16 sealingly interconnected with the opposite ends thereof. The sealing can be achieved in any desired manner such as, for example, by gasket means interposed between the housing and end walls. In certain instances, such as if the end walls are metal, it may be desirable to circulate a coolant such as water adjacent to or through the end walls to maintain the temperatures thereof within desired limits. Housing 12 and walls 14 and 16 together define a gas chamber 18 for gas to be ionized. End wall 14 is provided with a passageway 20 which opens into chamber 18 to define a gas inlet thereinto. Passageway 20 is connected to a suitable source 21 of a gas to be ionized, such as argon through a pressure regulator 22. End wall 16 is provided with a passageway 24 defining a chamber outlet, and outlet 24 is connected to a vacuum pump 26. Pump 26 is operable to draw gas from source 21 into and through chamber 18 to initially purge the chamber of air, and regulator 26 is operable to control the pressure of the gas drawn into the chamber from the source and to maintain the gas within the chamber at a desired vacuum for ionization.

The gas chamber is surrounded by induction heating coil 28 which, in the embodiment illustrated, is defined by a continuous coil having a plurality of axially adjacent coil convolutions 30. Opposite ends of the coil are connected across a suitable source of alternating current 32 in parallel with capacitor means 34, and the induction heating coil preferably is defined by a continuous tube of non-magnetic conducting material such as

copper. The tubular structure facilitates the circulation of a coolant such as water, through the coil between the opposite ends thereof to maintain the coil at a desired temperature.

Induction heating coil 28 is provided with flux concentrating means which, in the embodiment illustrated, is defined by a plurality of sheet metal plate elements 36 of magnetic material, preferably iron. Each plate 36 is generally planar and is of substantially C-shaped configuration having a closed side portion 38 and leg portions 40 extending integrally from the longitudinally opposite ends of portion 38. Elements 36 are disposed on the coil convolutions so that the planes of the elements coincide generally with longitudinal axis A of the coil. Further, outer portions 38 of the elements extend longitudinally of the coil axis in engagement with radially outer surface 30a of the corresponding coil convolution, and leg portions 40 extend radially inwardly of the coil and are generally coextensive with and engage the longitudinally opposite sides 30b of the convolution. Leg portions 40 are of a longitudinal width such that a space 42 exists between the legs disposed between longitudinally adjacent coil convolutions. Preferably, flux concentrating elements 36 are disposed in face to face engagement and extend continuously along the coil convolutions from one end of the coil unit to the other.

In operation, energization of coil 28 establishes a magnetic field which longitudinally circumscribes the coil and thus has a portion which extends through the gas chamber in a direction longitudinally thereof and transverse to the axes of the coil convolutions. Without a flux concentrating arrangement, the flux in the portion of the magnetic field radially outside the coil strays or spreads a considerable distance outwardly from the outer surface portions of the coil unit. In accordance with the present invention, however, the flux in the outer portion of the field advantageously is constrained or guided relative to the coil unit to increase the flux density within the gas chamber and thus increase gas ionizing efficiency. More particularly, in the specific embodiment illustrated the magnetic flux is constrained to flow closely adjacent the radially outer surface portions of the coil convolutions. In this respect, the C-shaped laminations define a plurality of individual flux paths bounding the side and outer surface portions of the coil convolutions to guide the flux relative to the gas chamber so as to restrain straying thereof outside the chamber and thus increase the flux density in the portion of the field flowing through the gas chamber.

With an arrangement of the foregoing character, initiation of gas ionization within the chamber can be achieved through energization of the induction coil or through separate starting means such as an RF energy or starting electrode. In any case, once ionization is established it can be maintained by energization of the induction coil. In the particular arrangement illustrated, it has been found that ionization at the plasma level of argon gas can be maintained, after establishment in an argon purged chamber, by energizing the induction coil to provide from 3 to 10 KHz power. Moreover, ionization may be initiated using such power, or by employing RF in the vicinity of 5 MHz. When the latter method for initiating ionization is employed, it has been found most desirable to initiate ionization in a very low pressure environment and then

gradually increase the gas pressure to full atmospheric pressure, at which time transfer to induction coil power takes place to maintain ionization. Pump 26 and regulator 22 facilitate control of gas pressure in this manner. Application of RF for starting can readily be achieved by positioning RF electrode 44 adjacent one end of the gas chamber housing component, in the manner illustrated in FIG. 1. It will be appreciated, of course, that electrode 44 would be connected to a suitable RF source. In the specific ionizing device described hereinabove, the induction heating coil is comprised of one-half inch by one inch rectangular copper tubing. The coil has an inside diameter of about 7¼ inches and an axial length of about 8½ inches and is provided with five turns. The cylindrical housing of the device is quartz, and the gas employed is argon.

While the flux concentrating arrangement in the embodiment described above is defined by C-shaped laminations mounted on the individual coil convolutions, it will be appreciated that other arrangements such as that illustrated in FIG. 3 can be employed to provide for flux concentration. In FIG. 3, laminations 50 are associated with coil convolutions 52 which extend about a housing or envelope 54 in a manner similar to that of coil convolutions 30 in FIG. 1. Laminations 50 are defined by sheet metal plates of magnetic material, preferably iron. Each lamination includes an axially extending outer portion 56 substantially coextensive with the axial length of the coil and disposed in engagement with the radially outer surfaces 58 of the coil convolutions. Further, the laminations preferably include end portions 60 extending radially inwardly from the opposite ends of portions 56 and adjacent the axially outer surfaces of the endmost coil convolutions.

It will be further appreciated that other arrangements of laminations, and forms of magnetic material other than laminations could be provided on or adjacent the radially outer surface portions of the coil convolutions to provide for flux concentration. For example, laminations could be employed which would not include the leg portions extending radially inwardly of the coil as in the embodiments of FIGS. 1 and 3. With further regard to lamination arrangements, it will be appreciated that the flux concentrator laminations could be circumferentially spaced apart from one another as opposed to being disposed in face to face engagement, and that groups of the laminations could be disposed in face to face engagement and adjacent groups of the laminations circumferentially spaced apart. With regard to flux concentrating arrangements defined other than by sheet metal laminations, blocks of such as the block 70 illustrated in FIG. 4 and produced from a powdered ferretic material 72 such as compacted powdered iron could be employed. Such compacted powdered material can be machined or formed to the desired configuration for association with the coil convolutions or the coil unit in a manner similar to the laminations illustrated in FIGS. 1 and 3 or the variations thereof mentioned hereinabove. Such blocks would have a thickness in the circumferential direction relative to the coil convolutions greater than the corresponding dimension of a sheet metal lamination. The actual thickness in this direction can, of course, be varied and will depend in part on the structural integrity necessary to avoid breakage during use or assembly since the material is relatively brittle. It will be further appreciated that solid metal blocks of magnetic material such as iron

could also be employed in a manner similar to blocks of compacted powdered iron, and that combinations of laminations and blocks could be employed to achieve flux concentration. Many flux concentrating arrangements will come to mind upon a reading of the foregoing description which is intended merely to be illustrative of preferred embodiments. It will be further appreciated that the coil convolutions could have a cross sectional configuration other than rectangular and could, for example, be round or square.

As many possible changes may be made in the present invention, and as many possible changes may be made in the embodiment herein described, it is to be distinctly understood that the foregoing description is to be interpreted merely as illustrative of the present invention and not as a limitation.

I claim:

1. A gas ionization device comprising: gas chamber means having a gas inlet, a source of gas connected to said inlet, means to maintain gas in said chamber means under pressure not exceeding atmospheric pressure, induction coil means surrounding said chamber and connectable across a source of alternating current for current to flow through said coil means and establish a magnetic field longitudinally circumscribing said coil means and having a portion extending through said chamber, said induction coil means being tubular to facilitate the circulation of cooling fluid therethrough, and flux concentrating means operatively associated with said coil means to increase the flux density in the portion of the magnetic field extending through said chamber.

2. The device according to claim 1, wherein said coil means has an axis and includes axially spaced apart convolutions, and wherein said flux concentrating means is defined by magnetic material disposed adjacent at least radially outer surface portions of at least some of said convolutions.

3. The device according to claim 2, wherein said magnetic material is powdered ferretic material.

4. The device according to claim 1, wherein said coil means has an axis and includes axially spaced apart coil convolutions, and wherein said flux concentrating means includes a plurality of flux concentrating elements of magnetic material at least portions of which are disposed adjacent radially outer surface portions of at least some of said convolutions.

5. The device according to claim 4, wherein said flux concentrating elements are metal plates each lying in a plane generally coincident with said axis.

6. The device according to claim 5, wherein at least some of said metal plates are disposed in face to face engagement.

7. A gas ionization device comprising: gas chamber means having a gas inlet, a source of gas connected to said inlet, means to maintain gas in said chamber means under pressure not exceeding atmospheric pressure, induction coil means surrounding said chamber and connectable across a source of alternating current for current to flow through said coil means and establish a magnetic field longitudinally circumscribing said coil means and having a portion extending through said chamber, and flux concentrating means operatively associated with said coil means to increase the flux density in the portion of the magnetic field extending

through said chamber, said coil means having an axis and including axially spaced apart coil convolutions, said flux concentrating means including a plurality of flux concentrating elements of magnetic material at least portions of which are disposed adjacent radially outer surface portions of at least some of said convolutions; and at least some of said flux concentrating elements including another portion disposed between the corresponding convolution and an adjacent convolution.

8. The device according to claim 7 wherein said magnetic material is powdered ferritic material.

9. The device according to claim 7, wherein said coil means is tubular to facilitate the circulation of cooling fluid therethrough.

10. A gas ionization device comprising: gas chamber means having a gas inlet, a source of gas connected to said inlet, means to maintain gas in said chamber means under pressure not exceeding atmospheric pressure, induction coil means surrounding said chamber and connectable across a source of alternating current for current to flow through said coil means and establish a magnetic field longitudinally circumscribing said coil means and having a portion extending through said chamber, and flux concentrating means operatively associated with said coil means to increase the flux density in the portion of the magnetic field extending through said chamber, said coil means having an axis and including axially spaced apart coil convolutions, said flux concentrating means including a plurality of flux concentrating elements of magnetic material at least portions of which are disposed adjacent radially outer surface portions of at least some of said convolutions, and at least some of said flux concentrating elements including an outer portion adjacent a radially outer surface portion of a given convolution and side portions extending radially inwardly of said given convolution adjacent axially opposite sides thereof.

11. The device according to claim 10, wherein said elements are metal plates each lying in a plane generally coincident with said axis.

12. The device according to claim 11, wherein at least some of said metal plates are disposed in face to face engagement.

13. A method of ionizing a gas in a chamber surrounded by a tubular induction heating coil connected to a source of alternating current for energizing the coil to establish a magnetic field longitudinally circumscribing the coil and a portion of which field extends through said chamber, comprising: initially maintaining said gas in said chamber at a negative pressure, energizing said coil to produce from 3 to 10 KHz power to establish said field, increasing the flux density in the portion of the field extending through the chamber, increasing said negative pressure to atmospheric pressure after ionization is initiated, and circulating cooling fluid through said tubular coil to maintain the coil at a desired temperature.

14. The method of claim 13, and increasing the flux density by operatively associating laminations of magnetic metal with said coil.

15. The method of claim 14, and energizing said coil to produce 10 KHz power.

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