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VORTEX-STABILIZED RADIATION SOURCE
WITH A HOLLOWED-OUT ELECTRODE
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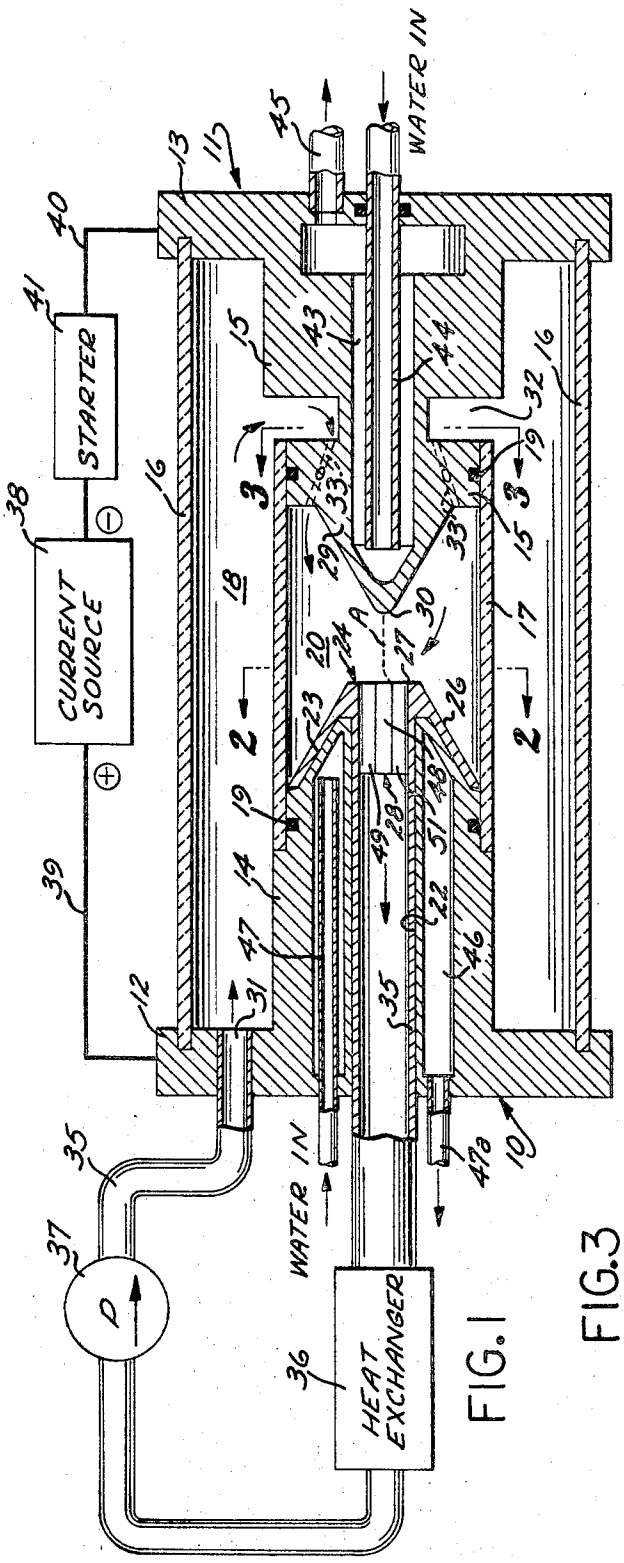


FIG. 1

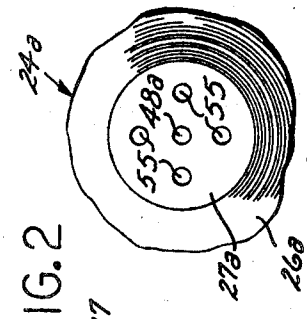


FIG. 2

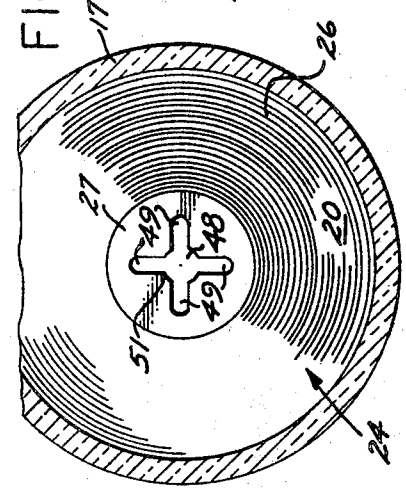


FIG. 3

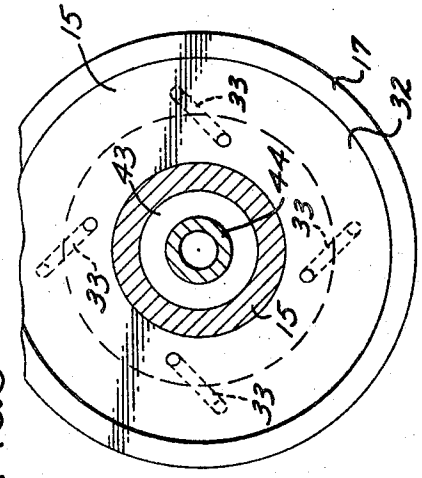


FIG. 4

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VORTEX-STABILIZED RADIATION SOURCE WITH A HOLLOWED-OUT ELECTRODE

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ABSTRACT OF THE DISCLOSURE

A vortex-stabilized radiation source in which at least one of the end portions of the arcing electrodes is hollowed out adjacent the axis. The hollowed-out portion has gas-outlet means communicating directly therewith, being located radially-outwardly from the arcing surfaces of the hollowed-out portion. The gas-outlet means is sufficiently close to the arcing surfaces that the layer of partially-excited gas which surrounds the hot core of the arc discharges directly through the gas-outlet means.

This invention relates to an apparatus and method for generating light, including ultraviolet and infrared light (radiation). More particularly, the invention relates to a radiation source incorporating a novel anode construction.

The generation of light by means of a gas vortex-stabilized electric arc, the gas being contained within an envelope at least part of which is light-transmissive, has proved to be highly important. Reference is made to copending patent application Ser. No. 324,518, filed Nov. 18, 1963, inventors John W. Winzeler, Delbert G. Van Ornum and Arthur C. Miller, for High-Pressure Light Source and Methods. The vortex-stabilized light source and method described in such application are highly successful in many ways but are subject to improvement relative to such important factors as radiation characteristics, efficiency and economy. Stated more definitely, at least four areas or factors relative to the indicated prior-art apparatus and method may be improved, as follows:

(1) The electric arc in such prior-art vortex-stabilized light sources penetrates a substantial distance into the anode, which has only a central gas-discharge opening. The resulting long arc substantially increases the voltage (and thus power) requirements of the system. Not only does the long arc require a relatively high voltage and power, but the portion of the arc which is contained within the anode does not contribute substantially to the useful light transmitted from the source. It is, therefore, highly desirable to provide a light source and method wherein the advantages of a substantially central discharge opening are maintained, yet the arc is relatively short so that a low-voltage, relatively low-power system will generate the same useful radiation as do higher-powered prior-art systems.

(2) The electric arc generated by the indicated prior-art source has two relatively bright or hot portions, one adjacent the cathode and one running down into the anode bore. The latter bright spot is not normally desirable since radiation therefrom is in a large part shielded, and since such radiation adversely affects anode life.

(3) The high cost of the gas, such as xenon, frequently employed in light sources requires that a gas-recirculation system be utilized. In prior-art light sources of the specified type, and of other types, the design of the gas-recirculation system is necessarily dependent upon the power level at which the source is operated. This is because the extreme heat resulting from operation at the higher power levels increases greatly the pressure in the arc chamber, the result being that the recirculation system is required to produce much higher pressures in order to recirculate gas at the necessary rate. It will therefore be understood that it is highly desirable to provide a light source and method, and an anode contained in the source, which are such that a single recirculation system may be employed, without adjustment, for operation at various power levels throughout a relatively wide range.

(4) A major advantage of the source described in the cited application, and in related prior applications, is that there is a relatively thin and sharply defined boundary layer between the cool, vortically-circulating gas and the hot core of the arc. Particularly when a strong emission in the ultraviolet is desired, it is important that such boundary layer be thin in order that the partially-excited gas therein will not screen out excessive amounts of the ultraviolet radiation generated in the hot core. It will thus be understood that it is frequently desirable to effect a further reduction in the indicated boundary layer, with consequent further increase in the amount of light (particularly ultraviolet) transmitted from the hot core of the arc.

In view of the above and other factors relative to prior-art gas vortex-stabilized light sources wherein the light is transmitted directly from the arc radially-outwardly through a transparent envelope, and wherein the gas exhausts near the arc and near the axis of the vortex chamber, it is an object of the present invention to provide an improved radiation source and anode incorporated therein, and an improved method, which provide various advantages including the above-indicated advantages of a greatly shortened arc, improved radiation characteristics, proper gas recirculation at various power levels, and minimized boundary layer of partially-excited gas between the hot arc core and the surrounding cool gas.

Another object is to provide a channeled electrode for use in such apparatus and in other apparatus.

These and other objects will become apparent from the following detailed description taken in connection with the accompanying drawing in which:

FIGURE 1 is a longitudinal sectional view schematically illustrating the light source;

FIGURE 2 is an enlarged transverse sectional view, taken on line 2—2 of FIGURE 1, and showing the channels which surround the axial outlet opening in the anode of the light source shown in FIGURE 1;

FIGURE 3 is a sectional view taken on line 3—3 of FIGURE 1, and illustrating the tangential passages through which gas is introduced into the arc chamber for vortical flow therein and subsequent discharge through the anode; and

FIGURE 4 is a fragmentary view corresponding to the central portion of FIGURE 2, but showing an embodiment wherein the channels are replaced by separate passages.

Referring first to FIGURE 1, the illustrated apparatus comprises first and second metal body elements **10** and **11** formed of flanges **12** and **13** on stems **14** and **15**, respectively. Extended between the flanges **12** and **13** is a relatively large-diameter tubular outer envelope **16** which may be formed of quartz, fused silica, or other suitable transparent material. Extended between the opposed inner end portions of the stems **14** and **15**, in coaxial relationship relative to outer envelope **16**, is a tubular inner envelope **17** which may be formed of the same material. Envelopes **16** and **17** define between them an annular outer chamber **18** into which gas is introduced as will be indicated subsequently, such chamber being maintained sealed from the chamber defined within inner

envelope 17 by suitable O-rings 19 or other seals. The chamber defined within envelope 17, between the opposed ends of stems 14 and 15, is the arc chamber and has been given the reference number 20.

Proceeding to a description of the stem 14 and associated elements, the cylindrical main body of the stem (which is coaxial with both chambers 18 and 20) is provided with a central passage or bore indicated at 22. The inner end of the stem, radially outwardly of bore 22, is shaped as a frustoconical surface 23 adapted to receive the correspondingly frustoconical inner surface of the anode element 24 of the present invention. This anode element is shown to have an exterior frustoconical surface 26 and an end surface 27 which is radial to the common axis of chambers 18 and 20. Furthermore, the anode 24 is provided with an interior central stem portion 28 which fits closely into the passage or bore 22. The anode may be formed of tungsten, for example, and is suitably mounted (as by brazing) to the inner end of stem 14 at the surface 23 and associated surfaces. The anode is formed with channels or passages which provide the advantages of the present invention, and which will be described in detail hereinafter.

Proceeding next to the description of tfhe stem 15 and associated elements, this is shown as having at the inner end thereof a conical portion 29 which is coaxial with chambers 18 and 20 and which has at the inner end thereof an arcing tip or apex 30. Elements 29–30 normally form the cathode of the light source. The spacing between apex 30 and radial surface 27 is relatively small, for reasons stated in the above-cited co-pending patent application.

The gas-flow means for the light source includes the annular outer chamber 18 into which gas is introduced through one or more inlets 31 located radially outwardly of stem 14. The gas flows toward stem 15, or to the right as viewed in FIGURE 1, following which it flows radially-inwardly into an annular channel 32 which is formed in stem 15 adjacent the end of envelope 17. A plurality of passages 33 are provided through stem 15, between channel 32 and the base of conical arcing portion 29, such passages being inclined in such manner as to cause the gas entering arc chamber 20 to flow vortically and helically therein. Stated otherwise, the gas is introduced generally tangentially into the chamber 20, and also somewhat axially, in order that it will follow a spiral path toward anode 24.

After whirling vortically in arc chamber 20, the gas discharges through the outlet means in anode 24 and enters a conduit 35 which is inserted into passage 22. The gas then passes through a heat exchanger 36 for cooling therein, following which it flows through a recirculating pump 37 which communicates with the above-indicated inlet 31 into annulus 18.

Pump 37 is adapted to create the required differential in pressure between inlet passages 33 and conduit 35, so that the gas flow in arc chamber 20 will be strongly vortical, thereby achieving the advantages set forth in the above-cited patent application. The gas pressure should be high in the entire system, on the order of hundreds of p.s.i., also as set forth in such patent application. The gas is a suitable gas adapted to effect the requisite radiation, being normally argon or xenon. It is to be understood that various other gases, such as krypton, etc., may be employed.

A suitable current source is represented schematically at 38, being connected through a lead 39 to flange 12 and thus to the anode 24. The source is also connected through a lead 40 (which may include a starter switch or circuit 41) to flange 13 and thus to cathode 29–30.

The current source 38 is preferably a D.C. source having its positive terminal connected to lead 39 and its negative terminal connected to lead 40, so that element 24 is the anode. It is to be understood, however, that reverse polarity may be various other types, such as an A.C. source, pulse source, etc.

Suitable means are provided to cool the electrodes. Thus, stem 15 is provided with an axially-oriented coolant chamber 43 into which is inserted a conduit 44 through which water is directed against the tip region 30 of the cathode. Chamber 43 communicates with an outlet passage 45 leading to a suitable drain. Similarly, the stem 14 is formed with an annular coolant chamber 46 radially outwardly of passage 22. Water is introduced rapidly into such chamber 46 through inlet conduit 47 which extends to the vicinity of anode 24. Water from chamber 46 discharges through an outlet passage 47*a*.

Description of the anode 24 and of the gas-outlet means

There will next be described the critical portions of the anode 24, including the gas-discharge means and the adjacent areas of the electrode itself. Stated in one manner, the anode comprises one or more electrode portions disposed relatively adjacent the axis of arc chamber 20 in order to provide a footing or seating region for the electric arc, and passage or conduit means disposed radially outwardly of such electrode portions in order to discharge gas from the arc chamber. At least a major part of such passage or conduit means is located sufficiently far from the axis that it will drain from arc chamber 20 the partially-excited gas at the boundary layer between the hot core of the arc and the surrounding cool and vortically-flowing gas. On the other hand, such passage or conduit means is disposed sufficiently close to the axis of chamber 20 that the relatively cool gas which flows vortically in chamber 20 will not be drained therefrom.

It is emphasized that the gas-discharge means in anode 24 is generally axial of the arc chamber 20, so that the distinct advantages of axial discharge, at a region adjacent the arc, are achieved. On the other hand, as will be set forth below, the arcing portion or portions of the anode 24 are sufficiently close to the axis that the arc seats at a region adjacent radial surface 27, and thus does not penetrate excessively toward the conduit 35 leading to heat exchanger 36.

The above-indicated advantages of a short arc, and of reduction in the boundary layer of partially-excited gas which tends to screen out the ultraviolet light emitted by the hot core, are thus achieved. In addition, the resulting arc has been found to be relatively free of the above-mentioned hot or bright region adjacent the anode. Furthermore, as will be stated below, a relatively uniform pressure drop is achieved through the gas-discharge means in anode 24, despite wide variations in the power level at which the apparatus is operated.

In the embodiment of FIGURES 1–3, the anode includes a central discharge opening or passage 48 (FIGURES 1 and 2) which is coaxial with the axis of arc chamber 20, and a plurality of channels 49 located radially-outwardly of the central passage 48 and disposed to drain off the boundary-layer gas between the hot core of the arc and the surrounding cool-gas blanket. The channels communicate with passage 48 throughout the length thereof, the cross-sectional shape being generally cruciform. In the illustrated embodiment there are four channels 49, but it is to be understood that the number may be increased or somewhat reduced.

The cross-sectional area of the gas-discharge means through anode 24 (the combined areas of channels 49 and passage 48) should be at least as great as, or preferably greater than, the combined areas of the gas-inlet passages 33 through stem portion 15. It has been found that the combined cross-sectional areas of channels 49 and passage 48 may be the same as the cross-sectional area of the single cylindrical passage described in the cited patent application.

The apex regions 51, adjacent the areas where the channels 49 communicate with central passage 48, form the above-indicated electrode regions on which the arc foot

point is located (seats). Stated more definitely, the arc (indicated schematically at A in FIGURE 1) seats on one or more apexes **51** and adjacent the radial surface **27**. Thus, the arcing portions or apexes **51** of the anode **24** may be regarded as "screen" or "sieve" portions which catch the electrons and thus prevent the arc from extending toward or into the discharge conduit **35**. With the described construction, essentially all of the light emitted by the arc A is permitted to radiate through the envelopes **17** and **16** to a desired point of use.

The channels **49** not only serve to drain off the partially-excited gas layer between the hot core of the arc and the surrounding cool gas, so that filtering of ultraviolet light is minimized, but they also serve (as noted above) to maintain the pressure drop across the gas-discharge means relatively contsant throughout a substantial range of arc powers. This phenomenon might best be understood by considering the case which would occur if the gas-discharge means were a single cylindrical bore (axially of the arc chamber). A substantial increase of arc power would then cause a very substantial expansion of the gas, which heated gas would then tend to choke in the gas-discharge passage and greatly increase the pressure drop thereacross. Because of this increased pressure drop, the pump **37** would be forced to generate a much higher pressure in order to maintain the necessary pressure differential between the gas-inlet passages **33** and the gas-discharge conduit **35**.

In the present gas-discharge means, on the other hand, an increase in arc power produces a relatively small effect on the pressure drop across the anode, because of the large proportion of relatively cool (boundary layer) gas which flows through the channels **49**. Thus, despite the fact that a power increase tends to provide a choking action in the central passage **48**, this will not greatly increase the pressure drop across the combination of passage **48** and channels **49**. Accordingly, the gas pressure drop is maintained relatively constant, so that the same pump **37** may be employed without any adjustment, regardless of the power level (within a reasonable range) at which the light source is operated.

In summary, therefore, the method of the embodiment of FIGURES 1–3 comprises generating a high-pressure arc between opposed electrodes, locating the footpoints of the arc at points relatively adjacent a common axis extending between the electrodes, effecting a strong vortical flow of gas about such axis to thereby stabilize the arc therealong, and discharging the gas through passage means located adjacent at least one of such electrodes and radially outwardly of the indicated axis and of the corresponding footpoint. Furthermore, the method comprises effecting radiation from substantially the entire arc, including both footpoints thereof, through an envelope means defining the chamber in which the vortical gas flow occurs. The method additionally comprises draining off from the indicated chamber the partially-excited gas between the vortically flowing outer blanket and the hot, highly-excited core of the arc. The filtering action effected by such partially-excited gas is thus maintained at a minimum.

Relative to the appartus shown in FIGS. 1–3, the method comprises filling the apparatus with gas such as argon or xenon, under high pressure, and starting operation of pump **37** to effect a continuous flow of gas into annular chamber **18**, thereafter through inlet passages **33** for vortical flow and arc chamber **20**, and thereafter through passages or conduits **48–49** and conduit **35** for recirculation to pump **37** through the heat exchanger **36**. Current source **38** is then applied, and the arc A is initiated (by the starter **41**) between the conical tip **30** of the cathode and at least one of the apexes **51** of the anode. Such arc is stabilized by the vortically flowing gas, being constricted to cross-sectional area substantially smaller than the arc would normally ocupy in space. The amount of current is relatively high, for example being on the order of one hundred amperes. It is to be understood, however, that relatively low-power operation may also be effected.

Embodiment of FIG. 4

The embodiment of FIG. 4 is identical to that of FIGS. 1–3, except that each of the channels **49** is replaced by a passage or bore **55** which does not communicate with the central passage. Such central passage is numbered **48*a*** in FIG. 4. Other parts in FIG. 4 which correspond to those in FIG. 2 have also been given the same reference numerals except followed by the letter "*a*."

Passages **55** are located and sized similarly to channels **49** of the previous embodiment, being disposed to drain off the boundary layer of partially-excited gas.

The operation (and method) relative to FIG. 4 are similar to that described above. It is to be understood, however, that the wall of the central passage **48*a*** in FIG. 4 affords to the arc a larger footing region than do the apexes **51** of the previous embodiment.

In order to permit a better understanding of the present invention, the following specific example will be given (by way of illustration, not limitation) relative to the embodiment of FIG. 4:

Inner diameter of arc chamber **20**—1 inch
Spacing from tip **30** to radial surface **27**—0.40 inch
Diameter of central passage **48*a***—0.04 inch
Diameter of each passage **55**—0.04 inch
Distance between centers of diametrically-opposite passages **55**—0.20 inch
Diameter of each of the four inlet passages **33**—0.04 inch
Gas pressure in chamber **20**, at the peripheral part thereof, prior to initiation of the arc—200 p.s.i.
Type of gas—argon
Rate of gas recirculation—3 standard c.f.m.
Arc voltage (D.C., element **24*a*** positive)—50 volts
Arc current—100 amperes
Diameter of the arc at a point midway between the electrodes—2.5 mm.
Average brightness—520 candles per mm.^{2}
Efficiency—25%
Uniformity and character of emission—a continuous spectral distribution from 0.2μ to 2.7μ with line radiation peaks around 0.42μ and 0.81μ.

In conclusion, it is emphasized that the exact sizing and locating of bores **55** (or of channels **49** in the previous embodiment) depend on factors such as arc current and power, chamber diameter, gas pressure, etc. The bores **55** (and the channels **49**) are located at substantially the same radial point or region as is the above-mentioned boundary layer of partially-excited gas. Such radial point or region varies with the above-mentioned, and other, factors.

It is pointed out that, in the embodiment of FIGS. 1–3, the electrode (anode) is hollowed out to form the gas-outlet means. In the hollowed-out anode, there is an arcing region (apexes **51**) relatively adjacent the axis, and gas-discharge regions (channels **49**) more remote from the axis (in addition to the gas-discharge regions, namely pasage **48**, at the axis). The embodiment of FIG. **4** is not hollowed out in this manner.

The foregoing detailed description is to be clearly understood as given by way of illustration and example only, the spirit and scope of this invention being limited solely by the appended claims.

We claim:

1. A vortex-stabilzed radiation source, which comprises:

wall means to define an arc chamber,

at least a portion of said wall means being formed of a light-transmissive material,

first and second electrodes having end portions disposed in said chamber,

said end portions being oriented in opposed spaced

relationship from each other along a predetermined axis,

one of said end portions having an arcing region located relatively adjacent said axis,

said one end portion also having gas-outlet means therein,

at least major portions of said gas-outlet means being located radially outwardly from said arcing region,

means to maintain an electric arc in said chamber between said arcing region of said one end portion and an arcing region of the other of said end portions, and

means to introduce gas into said chamber in such manner as to effect vortical flow of said gas therein about said axis to thereby stabilize said arc along said axis,

the characteristics of said gas flow, the power of said arc, and the radial spacing between said axis and said major portions of said gas-outlet means being so correlated to each other that the boundary layer of partially-excited gas between the hot core of said arc and the surrounding relatively cool gas blanket discharges directly through said major portions of said gas-outlet means.

2. Apparatus for generating high-intensity radiation in an efficient manner, which comprises:

means to define an arc chamber having a light-transmissive wall portion.

first and second spaced electrode elements provided in said chamber,

means to effect a strong vortical flow of gas in said chamber about a straight-line axis which extends between said electrode elements and passes at least adjacent arcing regions thereof,

means to effect a high-current electric discharge between said arcing regions along said axis, and

means to drain at least a major part of said gas from said chamber through gas-outlet means located radially outwardly, relative to said axis, from said arcing region of at least one of said electrode elements,

said gas-outlet means being so oriented relative to said electric discharge that the boundary layer of partially-excited gas surrounding the hot core of said discharge drains from said chamber directly through said gas-outlet means,

said gas-outlet means also being so oriented relative to said discharge that the relatively cool gas blanket surrounding said partially-excited gas layer is prevented from draining directly through said gas-outlet means.

3. A vortex-stabilized radiation source, which comprises:

wall means to define an arc chamber,

at least a portion of said wall means being formed of a light-transmissive material,

first and second electrodes having end portions disposed in said chamber,

said end portions being oriented in opposed spaced relationship from each other along a predetermined axis,

one of said end portions being hollowed out around said axis,

the wall of said hollowed-out end portion having an arcing region located relatively adjacent said axis,

said hollowed-out end portion having gas-outlet means at least major portions of which are located radially outwardly from said arcing region,

means to maintain an electric arc in said chamber between said arcing region of said one end portion and an arcing region of the other of said end portions, and

means to introduce gas into said chamber in such manner as to effect vortical flow of gas therein about said axis to thereby stabilize said arc along said axis,

the characteristics of said gas flow, the power of said arc, and the radial spacing between said axis and said major portions of said gas-outlet means being so correlated to each other that the layer of partially-excited gas between the hot core of said arc and the surrounding relatively cool gas blanket discharges directly through said major portions of said gas-outlet means.

4. A vortex-stabilized radiation source, which comprises:

a generally tubular envelope formed of light-transmissive material,

first and second electrodes having end portions disposed in opposed, spaced relationship,

one of said end portions having an arcing region coaxially of said envelope,

the other of said end portions having an arcing region therein relatively adjacent the axis of the arc chamber defined within said envelope,

said other end portion also having gas-outlet means at least major portions of which are disposed radially outwardly of said second-mentioned arcing region,

said at least major portions of gas-outlet means being sufficiently close to said second-mentioned arcing region to prevent drainage therethrough of relatively cool gas from said chamber,

means to maintain a high-current electric arc in said arc chamber between said arcing regions of said one end portion and said other end portion, and

means to drain gas from said arc chamber through said gas-outlet means, and to pump such gas into said arc chamber tangentially thereof whereby said gas flows vortically in said arc chamber and stabilizes said arc along said axis.

5. The invention as claimed in claim 4, in which said last-named means includes means to effect introduction of recirculated gas radially outwardly of said one end portion through a plurality of inlet passages.

6. A vortex-stabilized radiation source, which comprises:

a generally tubular envelope formed of light-transmissive material,

first and second electrodes having end portions disposed in opposed, spaced relationship,

one of said end portions having an arcing region coaxially of said envelope,

the other of said end portions having an arcing region therein relatively adjacent the axis of the arc chamber defined within said envelope,

said other end portion also having gas-outlet means at least major portions of which are disposed radially outwardly of said second-mentioned arcing region,

said gas-outlet means being sufficiently close to said second-mentioned arcing region to prevent drainage of relatively cool gas from said chamber,

said gas-outlet means being shaped generally as a cross in a plane perpendicular to the axis of said arc chamber,

said second-mentioned arcing region comprising the apex portions adjacent said cross,

said major portions of said gas-outlet means comprising the portions of said cross remote from said axis,

means to maintain a high-current electric arc in said

arc chamber between said arcing regions of said one end portion and said other end portion, and

means to drain gas from said arc chamber through said gas-outlet means, and to pump such gas into said arc chamber tangentially thereof whereby said gas flows vortically in said arc chamber and stabilizes said arc along said axis.

7. A vortex-stabilized radiation source, which comprises:

a generally tubular envelope formed of light-transmissive material,

first and second electrodes having end portions disposed in opposed, spaced relationship,

one of said end portions having an arcing region coaxially of said envelope,

the other of said end portions having an arcing region therein relatively adjacent the axis of the arc chamber defined within said envelope,

said other end portion also having gas-outlet means at least major portions of which are disposed radially outwardly of said second-mentioned arcing region,

at least major portions of said gas-outlet means being sufficiently close to said second-mentioned arcing region to prevent drainage therethrough of relatively cool gas from said chamber,

said second-mentioned major portions of said gas-outlet means comprising a plurality of separate bores formed in said other end portion and all located closely adjacent said arcing region thereof,

said gas-outlet means further including a bore formed in said other end portion axially of said chamber,

means to maintain a high-current electric arc in said arc chamber between said arcing regions of said one end portion and said other end portion, and

means to drain gas from said arc chamber through said gas-outlet means, and to pump such gas into said arc chamber tangentially thereof whereby said gas flows vortically in said arc chamber and stabilizes said arc along said axis.

8. A vortex-stabilized radiation source, which comprises:

a generally tubular envelope formed of light-transmissive material,

first and second electrodes having end portions disposed in opposed, spaced relationship,

one of said end portions having an arcing region coaxially of said envelope,

the other of said end portions having an arcing region therein relatively adjacent the axis of the arc chamber defined within said envelope,

said other end portion also having gas-outlet means at least major portions of which are disposed radially outwardly of said second-mentioned arcing region,

at least major portions of said gas-outlet means being sufficiently close to said second-mentioned arcing region to prevent drainage therethrough of relatively cool gas from said chamber,

means to maintain a high-current electric arc in said arc chamber between said arcing regions of said one end portion and said other end portion,

said means to maintain said arc comprising a D.C. power source the positive terminal of which is connected to said other end portion, and the negative terminal of which is connected to said one end portion, and

means to drain gas from said arc chamber through said gas-outlet means, and to pump such gas into said arc chamber tangentially thereof whereby said gas flows vortically in said arc chamber and stabilizes said arc along said axis.

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