United States Patent

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[54] DISTRIBUTIVE CATHODE FOR FLOWING GAS ELECTRIC DISCHARGE PLASMA

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[52] **U.S. Cl.**.....**313/205**, 313/33, 313/210, 313/211, 313/217, 313/231, 313/346, 315/111, 331/94.5

[51] **Int. Cl.**.....**H01j 17/06**

[58] **Field of Search**.....313/33, 205, 211, 346, 210, 313/217; 315/111; 331/94.5

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[57] **ABSTRACT**

A cathode emitting electrons to form an electric discharge plasma in a flowing gas stream is oriented and disposed to cause a substantially uniform distribution of the emitted electrons throughout the gas stream. A segmented cathode embodiment permits a large surface area, the large area in turn allowing a maximum cooling effect from the flowing gas. The cathode segments are dispersed and interspersed with insulating material to avoid the current concentrations otherwise occurring at the intersections of the individual cathode segments. Also cooling limitations require that the cathode surfaces be substantially parallel to the flowing gas stream. Various configurations are disclosed for providing a proper cathode electron emission area within varying flow cross-sectional areas.

5 Claims, 6 Drawing Figures

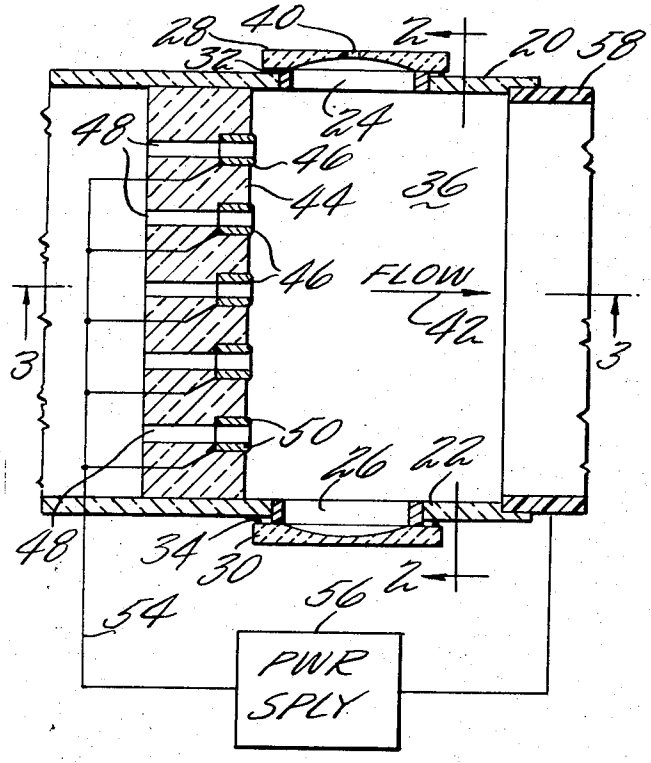


FIG. 1

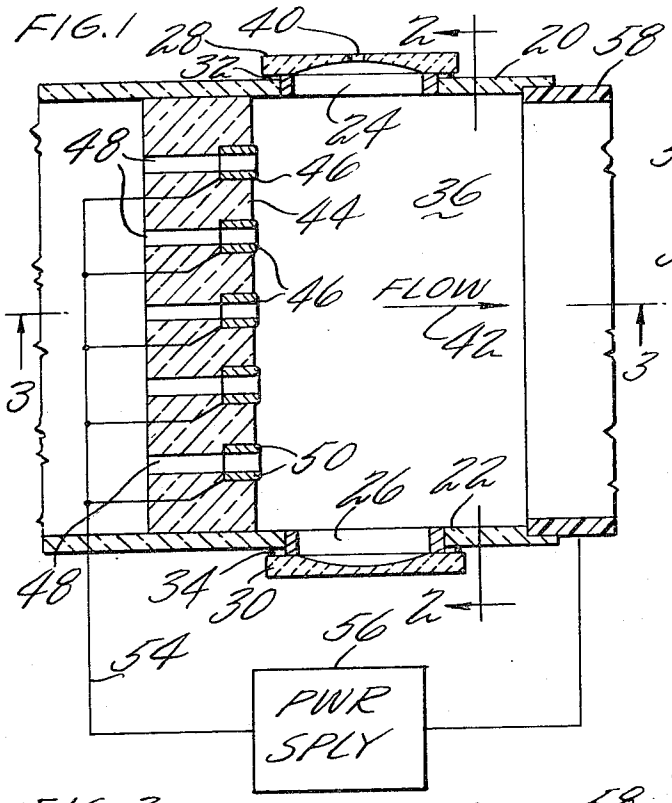


FIG. 2

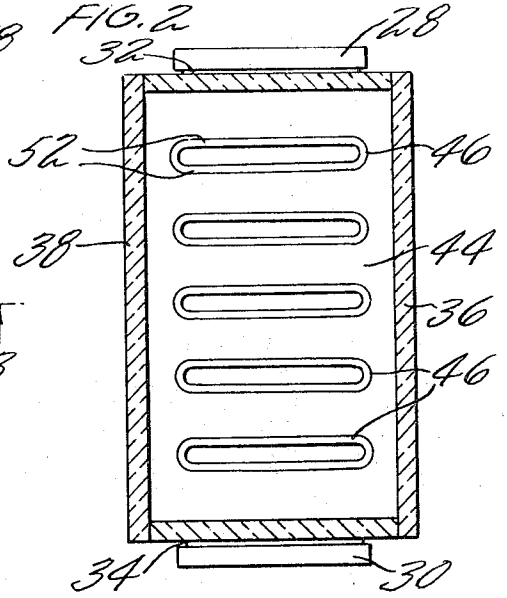


FIG. 3

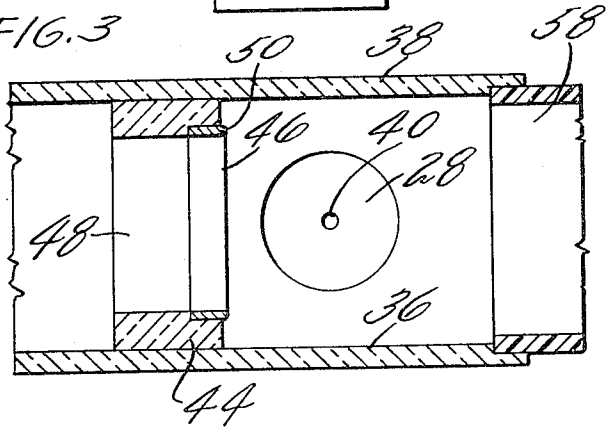


FIG. 5

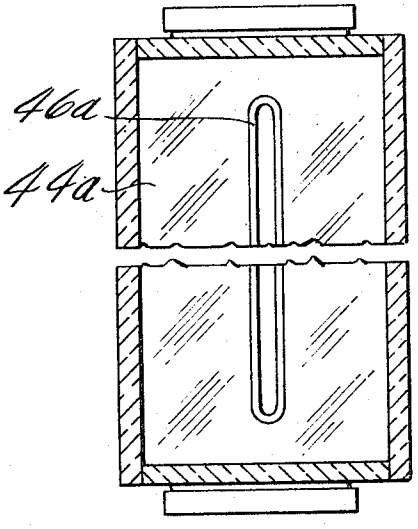


FIG. 6

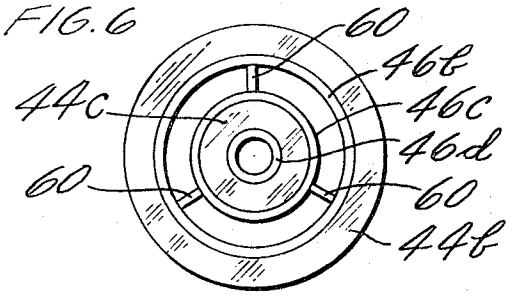
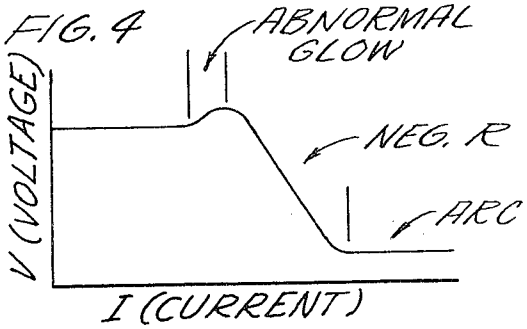


FIG. 4



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DISTRIBUTIVE CATHODE FOR FLOWING GAS ELECTRIC DISCHARGE PLASMA

BACKGROUND OF THE INVENTION

1. Field of Invention

This invention relates to electric discharge plasmas, and more particularly to improved cathodes for use with electric discharge plasmas in flowing gas streams.

2. Description of the Prior Art

The use of electric discharge plasmas, particularly in a stream of flowing gas, is old and well established in the art. However, recent advances in high power gas lasers indicate the need for high velocity flow and high gas pressure to create and extract maximum optical power per unit of volume, weight, cost and gas consumption. In an electric discharge gas laser, the efficiency of production of upper energy states of energizing or lasing gases is directly related to current density, electric field, and number density of un-ionized particles in the gas stream, etc. The sheer power extractable in a given laser configuration increases with pressure since extractable power is a function of the number of participating gas molecules, and the latter increases with pressure. Enhancement of extractable power requires that corresponding changes in other variables of the electric discharge plasma accompanying the increase in pressure.

The control of optimized electric discharge plasmas in small, low pressure flow configurations is relatively simple; however, such control becomes extremely complex as the cross-sectional area of flow and gas pressure are increased. Attempts to increase the amount of the working gas in a flowing gas laser results in a variety of complications in the maintenance of a stable electric discharge plasma suitable for optimum excitation of selected levels of the working gas through electron collisions within the plasma. One such complication is the inability to maintain a proper discharge in a plasma having a cross-sectional area with a least dimension greater than about 3 or 4 inches; multiple electric discharges, each with separate gas flow paths and electrodes have been required to overcome the problem.

The phenomenon of localized arcing or streamering in an electric discharge can also become critical at sufficiently high pressure. Streamering or arcing is actually the result of an electrical short circuit along the path of the streamer or arc with substantially all of the current supplied to the plasma conducted through the relatively small cross-sectional area of the streamer or arc. Streamering reduces the effectiveness of a plasma to provide electron collision excitation of the gas molecules flowing through the electric discharge region because the high current conduction of the streamer short circuits the remainder of the plasma region, the presence of streamering or arcing essentially "puts out" the plasma; furthermore, excitation of the gas molecule to upper energy states through electron collision is accomplished most efficiently in a properly optimized uniform plasma. In addition to the above described localized arcing or streamering, high gas pressure or large cross-sectional flow area interfere with the maintenance of a uniform plasma because a non-uniform "attachment" of the plasma to the cathode can occur. The non-uniform attachment of the plasma and the consequent non-uniform distribution of the plasma relative to the cathode, are caused partially by field concentrations resulting from abrupt discontinuities in cathode surfaces, and partially by variations in the thermal characteristics of the cathode. Sufficient local heating of discrete areas on the cathode surface can result in thermionic emission or vaporization of metal from the cathode surface, the latter causing metal atoms to enter the gas discharge region and thereby tending to induce arcing along the metal atom path.

SUMMARY OF THE INVENTION

The object of the present invention is to provide a cathode capable of sustaining a substantially uniform electric discharge plasma in a flowing gas stream.

The invention is predicted in a significant part on my discovery that heretofore recognized limitations in the maximum cross-sectional area of a flowing gas electric discharge plasma results from the emission of electrons into the boundary layers of the gas flow, such as from a cathode circumscribing substantially the entire wall surface. The invention is further predicted on my discovery that a segmented cathode arranged in a geometry having regions of contiguous segments, tends to develop concentrated currents in such regions, the concentrated current resulting in preferential heating of the electrode, thus tending to support arcing and/or streamering as described hereinbefore. The invention is also predicted on my discovery that in a prior art laser gas discharge plasma, the amount of cathode surface area actually involved in the electron emission process is less than the area which would be involved if the plasma had a uniform distribution at the cathode surface.

According to the present invention, the cathode of an electric discharge plasma generating means is oriented and disposed centrally of a flowing gas stream to allow the electron and ion concentration contained by the flowing gas to follow the streamlines of flow determined by the fluid mechanics involved, the flowing gas thereby being capable of supporting a uniform electric discharge plasma. In further accord with the present invention, substantially all of the electron-emission surface of the cathode is exposed directly to a stream of flowing gas, the gas flow across the cathode surface having a substantial and uniform velocity, in contrast with the low velocity boundary or eddy regions typically found in fluid flow through the main flow channel. In still further accord with the present invention, the surface of the distributive cathode, having maximum cooling through direct contact with the flowing gas, may be segmented and distributed across the cross-sectional area of flow. In accordance further with the present invention, the cathode structure is shaped and configured to avoid acute surface discontinuities, thereby minimizing electric field concentrations and reducing localized thermal heading of cathode surfaces. Still further in accordance with the present invention, in embodiments employing a segmented cathode structure, unwanted current concentrations in the region of the plasma are eliminated by physical separation of the distributed cathode segments although the segments maybe interconnected electrically to facilitate distribution of electric current.

The present invention provides means for extending the cross-sectional area of an electric discharge plasma in a flowing gas. The invention is particularly useful in the design of very high power gas laser systems. This invention extends the operation of electric discharge plasmas utilized for excitation of laser working gases to higher pressures than have heretofore been obtainable without mitigating the uniformity and stability of the resulting electric discharge plasma.

The foregoing and other objects, features and advantages of the present invention will become more apparent in the light of the following detailed description of preferred embodiments thereof, as illustrated in the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a simplified, partially broken away, sectioned, plan view of an exemplary embodiment of the present invention;

FIG. 2 is a sectioned side elevation taken on the line 2—2 of FIG. 1;

FIG. 3 is a sectioned front elevation taken on the line 3—3 of FIG. 1;

FIG. 4 is an illustration of electric discharge plasma characteristics;

FIG. 5 is a sectioned side elevation of an alternative embodiment of the present invention; and

FIG. 6 is a simplified, partial, sectioned side elevation of a circular embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIGS. 1–3, a laser incorporating the present invention comprises a pair of side walls **20, 22** having holes **24, 26** disposed therein respectively, adjacent to which are a pair of concave laser mirrors **28, 30**. The mirrors **28, 30** may be clamped to the walls **20, 22** by clamps (not shown) or other suitable securing modalities, a number of which are well known in the art. To provide a gas tight seal, O-rings or other suitable gaskets **32, 34** may be employed as is known in the art. The wall structure **20, 22** may comprise quartz, compressed mica, or other suitable insulating material. In the embodiment of FIGS. 1–3, the laser chamber is of rectangular configuration including a bottom wall **36** and a top wall **38** (broken away in FIG. 1 for clarity). The mirror **28** may have a hole **40** therein to permit coupling optical power out of the cavity or laser gain area formed between the mirrors **28,30**. The flow of gases in this embodiment is from left to right as viewed in FIGS. **1** and **3**, and as illustrated by an arrow **42**.

The cathode in accordance with the present invention is disposed on an insulating block **44** which may consist of quartz, mica, or other suitable insulating material, within which are disposed a plurality of cathode segments **46**, each of which is comprised of a suitable cathode metal, such as copper. Each of the cathode segments **46** is snugly fit into suitable holes **48** formed within the block **44**, the end of each hole **48** into which the cathode segment **46** is fitted (to the right in FIGS. **1** and **3**) being enlarged to receive the cathode segments **46**, so that the cross-sectional flow area is substantially constant from one side of the block through the holes **48** and segments **46** to the other side of the block. The exposed portions of the cathode segments **46** are designed so as not to present any sharp surface discontinuities which can promote field concentrations. For instance, as seen in FIGS. **1** and **3** the exposed edges **50** of the cathode segments are rounded, and as seen in FIG. **2** each cathode segment **46**, although of a generally rectangular design, is rounded at the corners **52** sufficiently so as to avoid supporting concentrations of electric field.

The cathode segments **46** may be connected by suitable wiring **54** to a proper, ballasted power supply **56**, the other output of which is connected to a suitable anode, which may comprise a portion of metallic duct work **58**. The electrical supply means **54–58** is eliminated from all of the views except FIG. **1** for simplicity, in view of the fact that such means are well known in the art.

The features of the embodiment shown in FIGS. **1–3** all relate to the provision of a uniform electric discharge plasma within a suitable flowing gas. The characteristics of such a plasma include the voltage current characteristic illustrated in simplified form in FIG. **4**. Therein, as the current in an electric discharge plasma is increased from a relatively low value, there is initially no change in voltage. Thereafter, an abnormal glow exists in which there is a positive proportional relationship between voltage and current followed by a negative proportional relationship. Thereafter, a negative resistance region is reached wherein the voltage decreases with increases in current; further increases in current cause the plasma to change into an arc, as described briefly hereinbefore. In the utilization of many plasmas, operation in the negative resistance regime is required; this is particularly true in the case of vibrationally excited molecular gas lasers. Thus, in high power gas laser technology, the desired operation of the electric discharge plasma is in the negative resistance region. However, as described briefly hereinbefore, great care must be taken so as not to cause any portion of the plasma to achieve a non-uniformly high current and thus assume an arc, since this shorts out the entire plasma. It is this, to which the present invention primarily relates.

In the embodiments of FIGS. **1–3**, a main feature of the present invention is that the distributive cathode (comprised of segments **46** suitably isolated from one another the distance between cathode segments being on the same order of magnitude as the least dimension of one of the segments) provides a relatively uniform field across the entire flow of gases. This contrasts with the prior art which typically utilizes a cathode surrounding the periphery of the gas flow which therefore introduces electrons into boundary flow field rather than uniformly across the flow field. Further, because the cathode segments **46** are isolated from one another by suitable insulating material (such as the block **44**) there is no tendency to have high current concentrations at the junction of cathode segments (as would be true in the case of a simple metallic "egg crate" structure). Additionally, since there are no sharp corners in the cathode segments **46** (either as viewed in FIGS. **1** and **3** or as viewed in FIG. **2**) there is no tendency for individual cathode segments to support high field concentrations which would cause abnormally high localized currents resulting in localized arcing or streamering. Thus, the distributive cathode in the embodiment of FIGS. **1–3** provides a fairly uniform electric discharge plasma which can be maintained in the negative resistance region across substantially the entire flow field of the gas. Additionally, the cathode segments **46** include dimensions which are sufficiently small with respect to the flow field so that there is a substantial gas flow immediately adjacent the surfaces of the segments **46**, which tends to cause these segments to be cooled by the gas flowing through the laser or other utilization apparatus. This contrasts with prior art cathodes which surround the periphery of the gas flow area and are thus located in the relatively low velocity boundary layer of flow rather than in the higher velocity, main stream of flow. Thus, the cathode segments in accordance with the present invention are cooled by the gas flowing therethrough and avoid localized heating which can result in arcing and streamering and gross alterations in the electric discharge plasma.

An alternative to the embodiment of FIGS. **1–3** is illustrated in FIG. **5** wherein a single cathode segment **46*a*** is located within an elongated slot formed in the insulating material **44*a***. This embodiment is not comprised of segments, but it is distributive, in that the cathode will be located in the main stream of flow (rather than at the wall) and thus out of the boundary layer of flow adjacent to the walls of the main flow structure. It is therefor a distributive cathode in the sense that it distributes the plasma into the stream of main flow rather than localizing it in the boundary layer of main flow.

Another embodiment of the invention shown in FIG. **6** is illustrative of other configurations in which the present invention may be practiced. Therein, three cathode segments **46*b***, **46*c***, **46*d*** are disposed on related insulating rings **44*b***, **44*c***, the rings being separated by suitable insulating struts **60**. This amounts to no more than a coaxial, circular equivalent of the embodiments of FIGS. **1–3** and **5**. Similarly, other polygonal or curvilinear configurations may be chosen to provide a distributive, and if desired, segmented cathode, having no field concentrations.

If desired, non-electrode gas passages may be provided to facilitate a greater volume of gas flow through the cathode structure. Similarly, although the invention has been shown and described with respect to preferred embodiments thereof, it should be understood by those skilled in the art that the foregoing and various other changes and omissions in the form and detail thereof may be made therein without departing from the spirit and scope of the invention.

Having thus described typical embodiments of my invention, that which I claim as new and desire to secure by Letters Patent of the United States is:

1. Apparatus through which a stream of flowing gas is passed for providing and utilizing an electric discharge plasma having a current voltage characteristic that includes a negative resistance region in which an increase in current causes a decrease in voltage, comprising:

a wall structure adapted to constrain the stream of flowing gas;

a distributive cathode comprising a metallic cathode segment supported inwardly from the walls of said structure

a sufficient distance to dispose said cathode segment in the main stream of flow and out of the flow boundary layer whereby the flow of gas can provide substantial cooling for the cathode, said distributive cathode having cross-sectional configurations without sharp corners or bends which preclude electric field concentrations that are sufficient in strength to initiate electric arcing in the stream of the gas, the distributive cathode providing a substantially uniform electric discharge plasma across substantially the entire stream of gas; and

an anode supported from the walls of said structure and positioned downstream of the cathode.

2. The apparatus according to claim 1 wherein said cathode segment comprises a metallic sleeve disposed in an insulating structure, the volume contained by said sleeve comprising a passageway for the flow of at least a portion of the gas in said wall structure.

3. The apparatus according to claim 2 wherein said metallic sleeve is only partially exposed to the gas flow and wherein the exposed portions of said sleeve are rounded and thereby devoid of sharp discontinuities in the metallic surfaces thereof.

4. The apparatus according to claim 1 including a plurality of said cathode segments; and further comprising:

insulating means holding said cathode segments, each segment being displaced from an adjacent segment by said insulating means, the distance between cathode segments being on the same order of magnitude as the least dimension of one of the segments.

5. Apparatus through which a stream of flowing gas is passed for providing and utilizing an electric discharge plasma having a current voltage characteristic that includes a negative resistance region in which an increase in current causes a decrease in voltage, comprising:

a wall structure of dielectric material adapted to constrain the stream of flowing gas transiting therethrough;

an insulating member which is supported by the wall structure and forms an obstacle to the flowing gas, a member having a hole therein through which the stream of gas is flowable thereby allowing the flowing gas to transit said wall structure;

a distributive cathode comprising a metallic cathode section supported by the insulating member and positioned in the hole, the inner surface of said segment projecting beyond the boundary layer of, and into the stream of, the flowing gas so that it cools the segment and electric discharge plasma in the stream of gas substantially beyond the boundary layer of the flowing gas, said distributive cathode having cross-sectional profiles without sharp corners or bends which preclude electric field concentrations that are sufficient in strength to initiate electric arcing in the stream of the gas, the distributive cathode providing a substantially uniform electric discharge plasma across substantially the entire flow field of the gas; and

an anode supported from the walls of said structure and positioned downstream of the cathode.

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