United States Patent

Chaney

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[54] **FLOW-THROUGH HOLLOW CATHODE SPECTRAL LIGHT SOURCE AND METHOD OF OPERATING SAME**

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[52] **U.S. Cl.** **315/111**, 313/209, 313/217, 313/224, 313/231, 356/86

[51] **Int. Cl.**.....**H01j 61/06**, H01j 61/28

[58] **Field of Search**.....313/209, 231, 210, 217, 224; 356/85, 86, 87; 315/111

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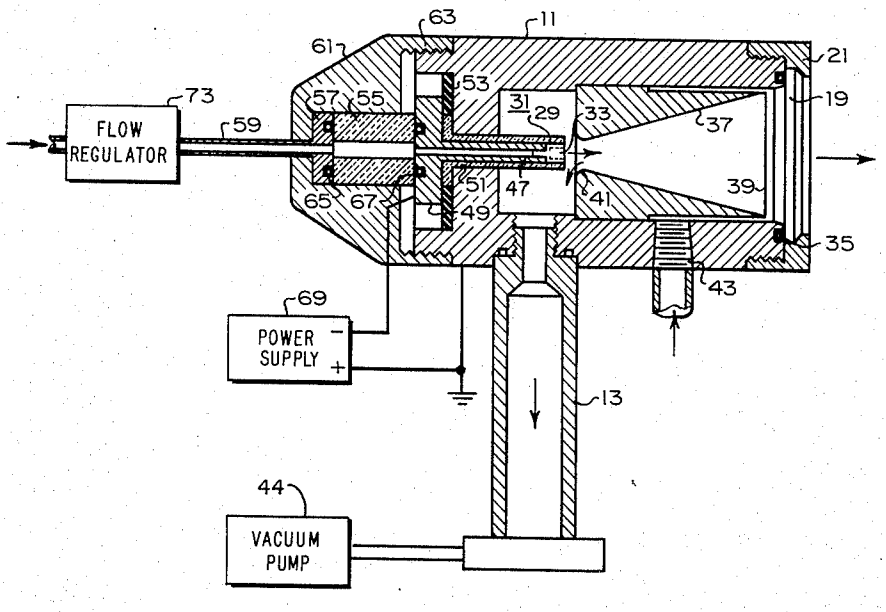
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[57] **ABSTRACT**

An atomic spectral lamp includes a demountable, hollow cathode, and a funnel-shaped anode adjacent to the cathode. A glow discharge plasma is established in the cathode cavity. Counterflow through the funnel-shaped anode prevents self absorption of light by atomic vapor. Gas flow through the hollow cathode at a predetermined velocity increases the intensity of light-emitted from the plasma.

12 Claims, 6 Drawing Figures



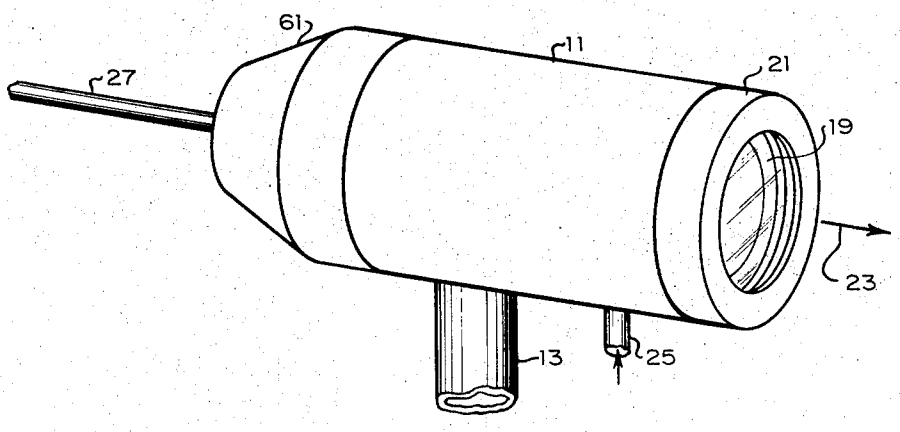


Figure 1

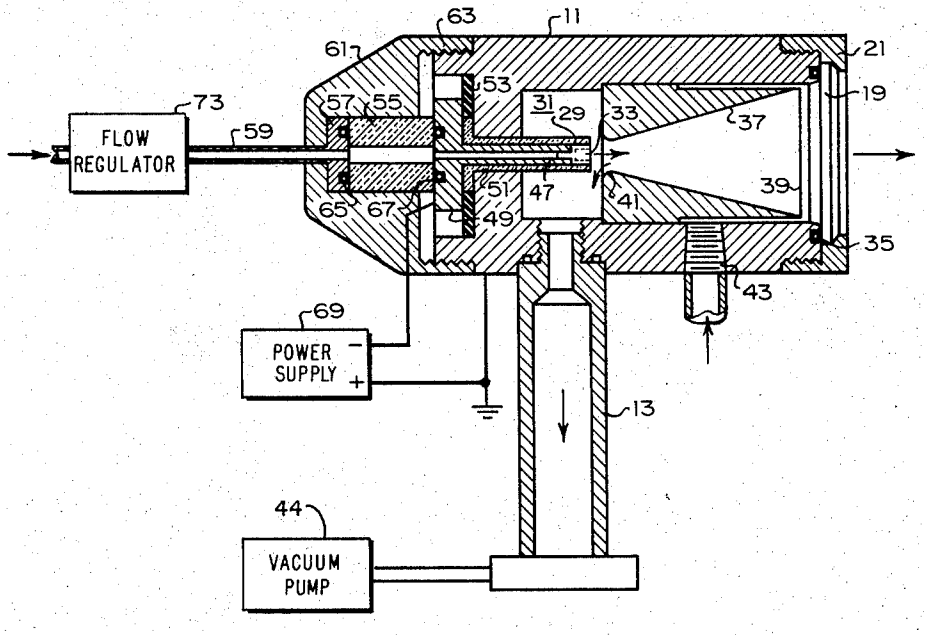


Figure 2

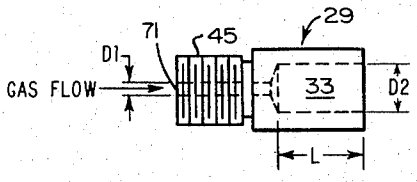


Figure 3

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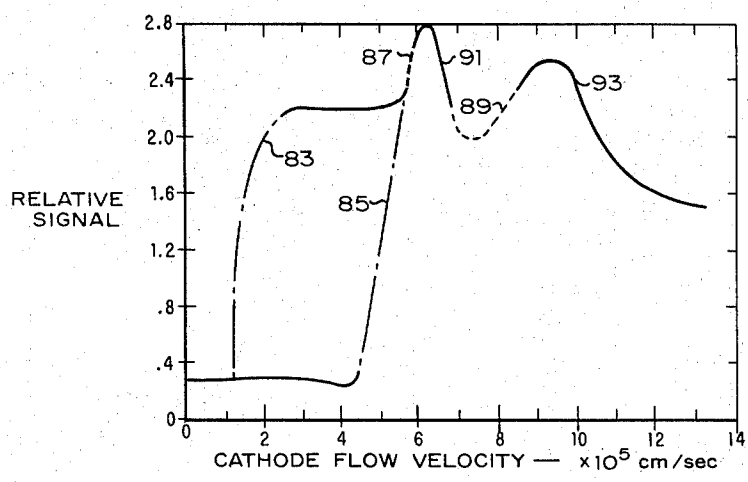


Figure 4c

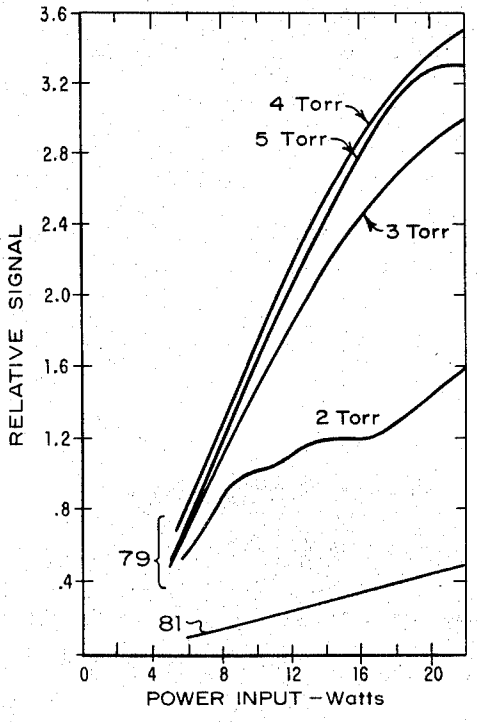


Figure 4b

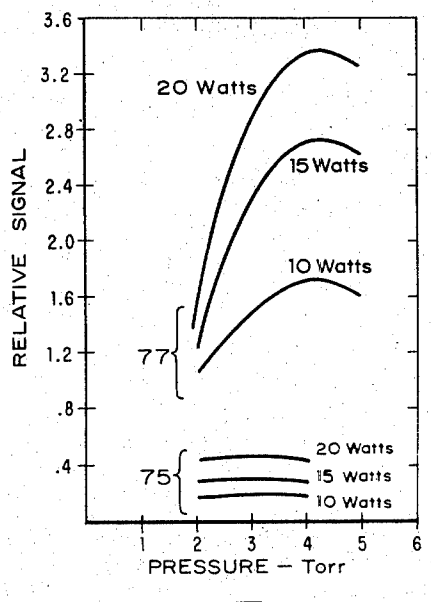


Figure 4a

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FLOW-THROUGH HOLLOW CATHODE SPECTRAL LIGHT SOURCE AND METHOD OF OPERATING SAME

BACKGROUND OF THE INVENTION

This invention relates generally to an improved hollow cathode lamp of the type used, for example, in atomic absorption or atomic fluorescence spectroscopy.

Hollow cathode lamps have found widespread use as sources of high intensity spectral lines. Typically, such a lamp includes a hollow cathode element in an evacuated sealed housing. The cathode is formed of the particular material which provides the spectral lines desired. A d.c. or r.f. glow discharge plasma is used to sputter the cathode material to produce free atoms. These atoms are then excited by the plasma to produce spectral emission.

Recent advances have been made in improving the adaptability and efficiency of hollow cathode lamps. For example, cathode elements have been made demountable to permit cathodes of different materials, and thus different spectral line outputs, to be inserted in the lamp. Also, a flow of inert gas has been provided through the lamp in a direction counter to that of the emitted light. This gas counterflow reduces the concentration of atoms between the light emitting cathode and the light exit window at high discharge currents, which in turn prevents the self-absorption of emitted light. As a result, the intensity of radiation emitted by the lamp is increased and spectral line widths are narrowed.

Continuing efforts have been made to increase the light intensity and narrow the line widths of spectral lines emitted by hollow cathode lamps. Increased intensities have been obtained by increasing the plasma excitation power; however, this approach is limited by the heat dissipating capacity of the lamp.

SUMMARY OF THE INVENTION

The present invention is a hollow cathode spectral light source incorporating a method for greatly increasing the intensity of the spectral line output over that of conventional hollow cathode sources. The illustrated embodiment of the invention includes a demountable hollow cathode element disposed in a vacuum chamber in optical alignment with a light exit window in the chamber. A funnel-shaped anode positioned between the hollow cathode and the window has a narrow open end which terminates in spaced-apart relationship with the cathode. A potential difference applied between the cathode and anode establishes a glow discharge plasma in the open-ended cavity of the hollow cathode. A counterflow of inert gas is directed through the funnel-shaped anode toward the cathode to prevent self-absorption of light by free atoms diffusing toward the window.

A feature of the invention is that the hollow cathode element includes a gas passageway coupled to a gas inlet conduit. The gas passageway directs an inert gas into the cathode cavity from its closed end and out through its open end. The gas flow velocity through the cathode cavity and the vacuum chamber pressure are set to selected values, thereby to permit optimization of the intensity of light emitted from the glow discharge plasma. The intensity of light produced is on the order of ten times greater than that obtained from the most efficient heretofore known hollow cathode light sources, and 100 to 1,000 times greater than that produced by conventional sealed glass lamps.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an external perspective view of the hollow cathode lamp incorporating the present invention.

FIG. 2 is a combined block diagram and longitudinal cross-sectional view of the lamp shown in FIG. 1.

FIG. 3 is an enlarged cross-sectional view of the demountable hollow cathode element shown in FIG. 2.

FIGS. 4*a–c* are graphs illustrating various operating characteristics of the hollow cathode lamp incorporating the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, there is shown the general external configuration of the hollow cathode lamp. A tubular stainless steel cylindrical housing **11** contains a vacuum chamber, hereinafter described, which is evacuated through a vacuum port and exhaust pipe **13**. The exhaust pipe **13** also serves as a suitable mounting member for rigidly holding the lamp in position. A light transparent window or lens **19** is fixed in sealed relation to the housing **11** and held in place by a retainer ring **21** to form one end of the vacuum chamber. Light emitted by the lamp is transmitted through the window **19** in the direction of the arrow **23**. Two gas inlet conduits **25** and **27** direct an inert gas into the vacuum chamber internal of the housing **11**, for purposes hereinafter described.

FIG. 2 shows a vertical, longitudinal cross-sectional view of the lamp illustrating the internal configuration thereof. A cylindrical hollow cathode element **29** is disposed in the vacuum chamber **31** formed by the tubular housing **11**. The cavity **33** in the hollow cathode **29** has an open side facing the window **19**. As described above, the window **19** is secured by the retainer ring **21**. This ring is made of plastic and has a threaded rim portion which screw-mounts onto the end of the housing **11**. A vacuum tight seal is maintained between the window **19** and the housing **11** by a rubber O-ring **35**. Disposed between the cathode element **29** and the window **19** is a cylindrical anode element **37**, constructed of stainless steel, and fitted inside the cylindrical vacuum chamber. The cylindrical anode element **37** has a funnel-shaped internal bore. The wide end of the bore **39** is disposed in spaced-apart relation to the window **19** and the narrow end of the bore **41** is disposed in spaced-apart relation to the cathode element **29**.

The cylindrical anode element **37** is configured so that the external diameter thereof at the end nearest to the window **19** is slightly smaller than the internal diameter of the vacuum chamber **31**, thereby to form an annular open passageway in communication with the wide end of the funnel-shaped bore in the anode electrode. A gas inlet port **43** in the side wall of housing **11** is coupled to the annular gas passageway. As described hereinafter, an inert gas is fed into the port **43**, through the annular passageway, and into the open end of the funnel to produce a gas counterflow through the vacuum chamber and out through the vacuum port and pipe **13** to the vacuum pump **44**.

The hollow cathode element 29 is shown in more detail in FIG. 3. Referring to FIG. 3 in conjunction with FIG. 2, it can be seen that the cathode element has a threaded end portion 45 which is screw-mounted on the internally threaded end of a copper tube 47. This tube extends through an aperture in the end wall of housing 11, and the left end of the tube (as viewed in FIG. 2) terminates in a flanged portion 49. Surrounding the copper tube 47 is another tube 51 which also has a flanged end portion disposed contiguously with the flange 49. The tube 51 is formed of a suitable insulating material, such as alumina. A rubber washer 53 surrounds the flange of the insulating tube 51 and abuts one side of the flanged portion 49. Abutting the other side of flange 49 is a hollow tubular insulating member 55, formed of alumina, for example. Another stainless steel tube 59 having a flanged end portion 57 abuts the other end of the insulating member 55. Member 55 and the flanged portion 57 are set into a bore in a plastic retaining cap 61. As shown, the retaining cap 61 also includes a smaller bore at the left hand end thereof for receiving the stainless steel tube 59. The cap 61 includes a threaded rim portion 63 which is screw-mounted on the end of the cylindrical housing 11.

The above-described cathode mounting structure is assembled by first screwing the cathode element 29 into the end of the copper tube 47, then sliding the insulating tube 51 over the tube 47 and positioning the rubber washer 53 around the flange of tube 51. This assembly is then inserted into the vacuum chamber 31 through the bore at the end of housing 11 into the position shown in FIG. 2. Thereafter, the plastic cap 61 containing the flange 57 and insulating tube 55 is screwed onto the end portion of the housing 11 and securely tightened. This arrangement securely mounts the hollow cathode inside the vacuum chamber in a manner such that the hollow cathode element 29 may easily be demounted, i.e., removed from the lamp. As a result, the cathode element may easily be replaced with another cathode element of a different material when a different spectral line source is desired. The cathode mounting assembly also provides a conduit so that an inert gas may be directed through the inlet pipe 59 to the cathode element 29. The junction points along the components forming the gas conduit are suitably sealed from the external environment by O-rings 65 and 67. The purpose of the gas flow through this conduit is described hereinafter.

The cathode element 29 is electrically coupled through the copper tube 47 and flange 49 to the negative output terminal of a power supply 69. The positive output of the power supply is grounded and coupled to the housing 11. The narrow opening 41 of the funnel in the anode electrode 37 is in electrical contact with the housing 11 and thus is maintained at ground potential. Power supply 69 establishes a potential difference of 150 to 350 volts between the hollow cathode element 29 and the adjacent portion 41 of the anode element. The particular voltage depends on the power input to the lamp during operation. The cathode - anode potential difference causes a glow discharge plasma to be formed. The plasma is made up of free electrons and ions of the inert gas in the vacuum chamber. The plasma causes sputtering of atoms from the cathode element. These atoms are excited by the glow discharge and as a result, they provide spectral line radiation. The radiation is directed outwardly through the lens or exit window 19. Due to the configuration and spacing of the cathode and anode elements, the plasma does not enter the funnel in the anode.

Atoms which have been sputtered from the cathode tend to diffuse toward the exit window and form a cloud of atomic vapor between the cathode and the window. The atomic vapor cloud is undesirable because it absorbs emitted light. The gas counterflow from the wide end to the narrow end of the funnel in the anode element 37 disperses or sweeps away atoms which would otherwise form a vapor cloud between the cathode and the window. As a result, self-absorption of emitted radiation by free atoms is eliminated and the intensity of the light output is increased.

As shown most clearly in FIG. 3, the hollow cathode element 29 includes an axial bore 71 therethrough which acts as a gas passageway to the internal left hand end portion of the cavity 33. This gas passageway is in gas communication with the above-described conduit means formed by the copper tube 47, the tubular insulator 55 and the stainless steel tube 59. An inert gas is directed through a flow regulator 73 and thence through the conduit means and the gas passageway 71 in the cathode element. The gas enters at one end of the cavity 33, and passes through it to emerge at the open end of the cavity. A significant feature of this invention is that the flow of gas through the cathode greatly increases the intensity of radiation emitted from the glow discharge plasma in the cavity 33, as described hereinafter.

As shown, the gas passageway 71 has a cross-sectional area substantially smaller than that of the adjacent upstream portion of the tube 47 on which the cathode element is mounted. This difference in cross-sectional areas serves to create a higher gas pressure in the tube 47 than in the gas passageway 71. The decreasing gas pressure differential along the flow path prevents the glow discharge plasma from moving upstream into the tube 47. Thus, the entire discharge plasma region is maintained in optical alignment with the window 19.

The inert gas directed through the gas passageway 71 may be selected from the group of helium, neon, argon, krypton and xenon. The same inert gas may be used in the gas counterflow through anode 37.

The operation of the flow through hollow cathode lamp can best be understood with reference to the curves illustrated in FIGS. 4*a–c*. These characteristic curves were obtained using a hollow cathode element as shown in FIG. 3 and having a cylindrical gas passageway 71 of diameter D_1 equal to 0.013 inch, a cylindrical cavity of an internal diameter D_2 equal to 0.075 inch, and an internal cavity length L of 0.150 inch. FIG. 4*a* shows the relative signal output, i.e., the intensity of light emitted by the lamp, as a function of the pressure in the vacuum chamber 31 for selected magnitudes of the input power applied to the glow discharge plasma by the power supply 69. The lower three curves in the family of curves 75 correspond to light outputs measured with no gas flow through the cathode element 29; whereas the upper three curves forming the family of curves 77 correspond to light outputs when there is a gas flow through the gas

passageway 71 of the cathode element at a selected velocity of 6.3×10^5 centimeters per second. This flow velocity is achieved when the diameter D_1 of the gas passageway 71 is 0.013 inch in diameter and the gas flow into it is at the rate of 9 cubic centimeters per minute. It can be seen that for the particular cathode configuration described above, the optimum operating pressure in the vacuum chamber is about 4 to 5 Torr (as measured at the exhaust port 13). At this pressure, the light output from the lamp with the gas flow through the cathode is about ten times the light output with no flow through the cathode. It should also be noted that both families of curves 75, 77 were derived from the same lamp having a gas counterflow from the window to the cathode on the order of 11 cubic centimeters per minute. Conventional sealed glass hollow cathode lamps do not have this counterflow feature and the light output therefrom is much lower. The output signals from such lamps are not shown in FIG. 4*a* because they are on the order of 10 to 100 times less than the signals represented by curves 75. Thus, the signal from the lamp having a gas flow through the cathode (curves 77) compared to that from conventional sealed glass hollow cathode lamps is on the order of 100 to 1,000 times greater.

FIG. 4*b* illustrates the relative signal output from the lamp as a function of the power input thereto from the power supply 69 for different pressures in the vacuum chamber 31. The family of curves 79 represent the light output with a gas flow velocity through the cathode passageway 71 of 6.3×10^5 centimeters per second, as described above; whereas the curve 81 represents light output with no gas flow through the cathode. Only one curve 81 is shown for the no cathode flow case because there is no substantial difference in light output for different values of pressure in the vacuum chamber in the range of 2 to 5 Torr. It can be seen in FIG. 4*b*, as in FIG. 4*a*, that relative signal output increases with the power input, and that the optimum pressure in the vacuum chamber is about 4 Torr. Also, as shown in FIG. 4*b*, light radiated in the presence of a gas flow through the cathode is on the order of 10 times greater than a lamp using only a gas counterflow, and thus 100 to 1,000 times better than the conventional sealed glass hollow cathode lamps without a gas counterflow.

FIG. 4*c* illustrates the signal output of the lamp as a function of the gas flow velocity through the gas passageway 71 of the hollow cathode element. The two portions of the curve 83, 85 represent an unstable region of operation of the lamp at cathode flow velocities below about 5.5×10^5 centimeters per second. In this region, the lamp operation may flip back and forth between the two curves 83, 85, thus producing either a high or low intensity light output. Also, in the two portions of the curve 87, 89 represented by the dashed lines, the lamp operation is unstable because the glow discharge plasma oscillates. It has been found that there are two regions of stable lamp operation with the cathode configuration described above. These two stable regions are in the portions of the curve 91, 93 and correspond to gas flow velocities in the range of 6.0 to 6.5×10^5 centimeters per second (region 91) and higher velocities in the range of 8.5 to 10×10^5 centimeters per second (region 93). It is to be noted that the characteristic curves of FIGS. 4*a* and 4*b* were obtained using a gas flow velocity of 6.3×10^5 centimeters per second, which is within the region 91 shown in FIG. 4*c*.

In summary, it can be seen that the provision of gas flow through the hollow cathode greatly increases the light output from the hollow cathode lamp. The radiation emitted by the glow discharge plasma is optimized by setting the gas flow velocity and the vacuum chamber pressure to selected values.

I claim:

1. An atomic spectral light source comprising:
- a vacuum chamber having a window portion and a vacuum port;
- a hollow cathode element having an open cavity therein disposed in said chamber in optical alignment with said window portion, said cathode element also having a gas passageway therethrough communicating with an internal portion of said cavity;
- means for producing a glow discharge plasma in said cavity;
- conduit means coupled to the gas passageway in said cathode element and having a gas inlet for directing a gas flow through the cavity of said cathode element at a predetermined velocity, thereby to permit optimization of the intensity of light emitted by said glow discharge plasma in said cavity;
- a member disposed between said cathode element and the window portion of said vacuum chamber, said member having an internal bore configured in the shape of a funnel having a narrow opening adjacent to said cathode element and a wide opening adjacent to said window portion; and
- gas inlet and conduit means for directing a flow of inert gas into the wide opening of said funnel adjacent to said window portion, thereby to cause gas flow through said funnel in a direction opposite to that of the radiation out of said cavity toward said window portion.

2. The apparatus of claim 1 wherein the cross-sectional area of said gas passageway in said cavity member is less than that of said conduit means to cause a decreasing gas pressure differential from said conduit means to said gas passageway, thereby to prevent formation of a glow discharge plasma in said conduit means.

3. The apparatus of claim 1, further including means for controlling the flow velocity of gas which is passed through said passageway into said cavity.

4. The apparatus of claim 1, wherein the gas flow through said gas passageway is at the velocity of at least 6.0×10^5 centimeters per second.

5. The apparatus of claim 4, wherein the gas flow velocity through said gas passageway is in one of the ranges of 6.0 to 6.5×10^5 and 8.5 to 10×10^5 centimeters per second.

6. The apparatus of claim 4, wherein the gas directed through said cavity is an inert gas selected from the group consisting of helium, neon, argon, krypton and xenon.

7. The apparatus of claim 1, wherein said means for producing a glow discharge plasma in said cavity includes:

an anode element in said vacuum chamber disposed in spaced-apart relation with said cathode element; and

means for applying a positive potential to said anode element and a negative potential to said cathode element.

8. The apparatus of claim 1, wherein said member serves as an anode element and said means for producing a glow discharge plasma in said cavity includes means for applying a positive potential to said member and a negative potential to said cathode element.

9. In an atomic spectral light source including the combination of a vacuum chamber having a window portion and a vacuum port; a hollow cathode element disposed in said chamber so that the open portion of the cavity in said element is optically aligned with said window portion; a member disposed between said cathode element and said window portion having an internal bore configured in the shape of a funnel having a narrow opening adjacent to said cathode element and a wide opening adjacent to said window portion; and means for producing a glow discharge plasma in said cavity; a method for increasing the intensity of light emitted from said glow discharge plasma comprising:

passing an inert gas through a gas passageway in said hollow cathode element into an internal portion of said cavity and out through the open portion of said cavity at a predetermined velocity of flow through said passageway while maintaining a predetermined pressure in said vacuum chamber, and

directing a flow of inert gas into the wide opening of said funnel member, thereby to cause gas flow through said funnel in a direction opposite to that of the radiation out of said cavity toward said window portion.

10. The method of claim 9, wherein said flow velocity in said gas passageway is at least 6.0×10^5 centimeters per second.

11. The method of claim 10, wherein said flow velocity is in one of the ranges of 6.0 to 6.5×10^5 and 8.5 to 10.0×10^5 centimeters per second.

12. The method of claim 9, wherein said inert gas is selected from the group consisting of helium, neon, argon, krypton and xenon.

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