Dec. 6, 1966 D. A. LARSON ETAL 3,290,538

LOW-PRESSURE ELECTRIC DISCHARGE LAMP WITH INTERNAL ELONGATED STRUCTURE THAT MODIFIES THE DIFFUSION LENGTH OF THE DISCHARGE AND IMPROVES THE LAMP PERFORMANCE

Filed May 23, 1961 2 Sheets-Sheet 1

FIG. 1.

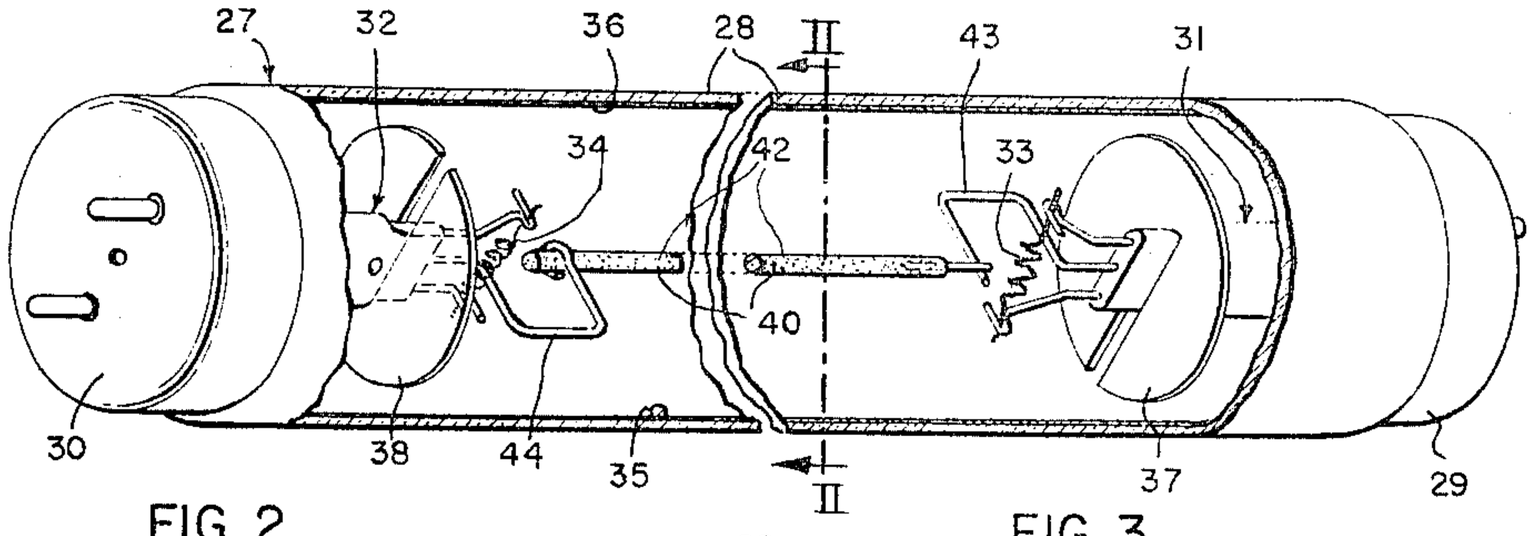


FIG. 2.

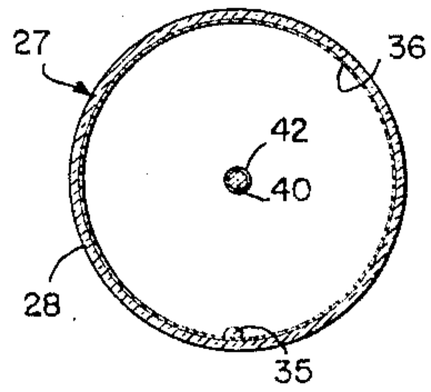


FIG. 3.

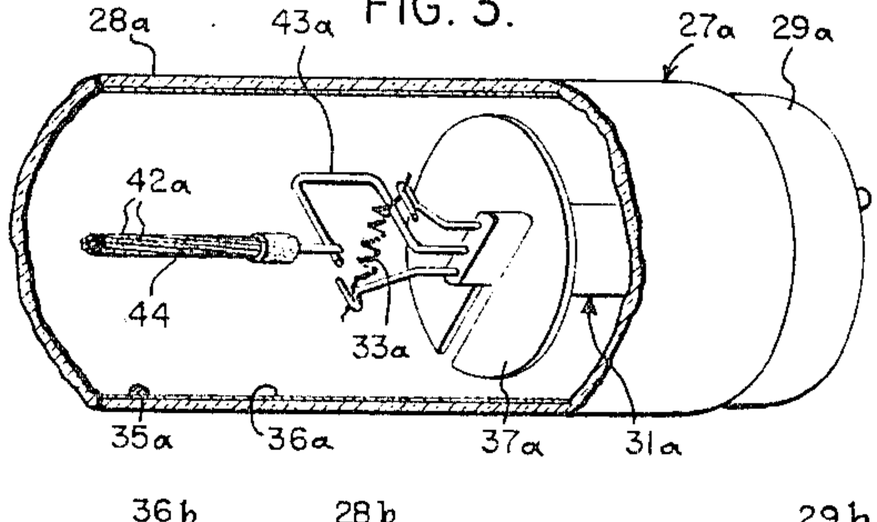


FIG. 4.

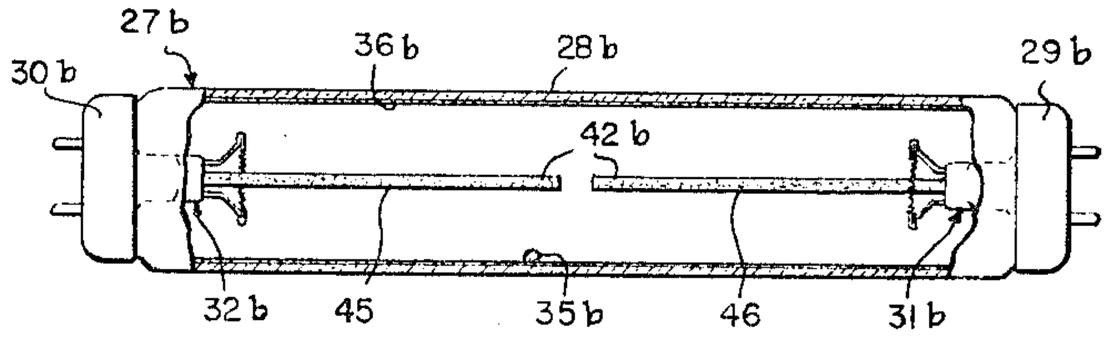


FIG. 5.

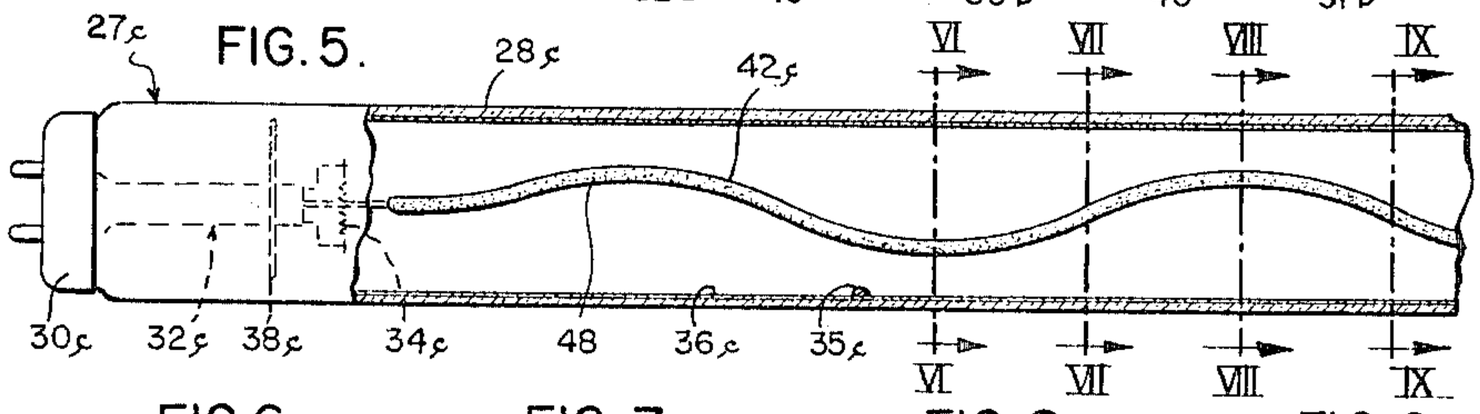


FIG. 6.

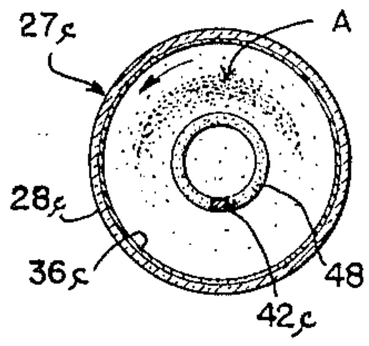


FIG. 7.

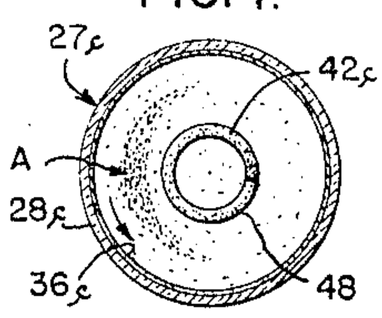


FIG. 8.

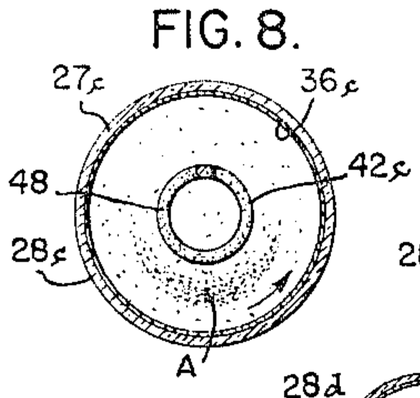


FIG. 9.

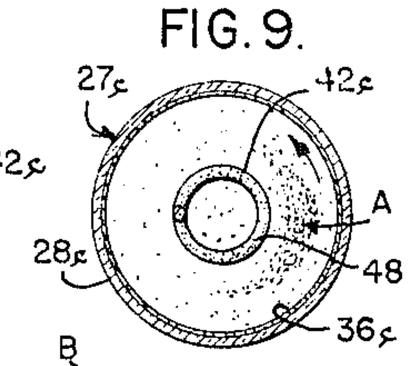


FIG. 10.

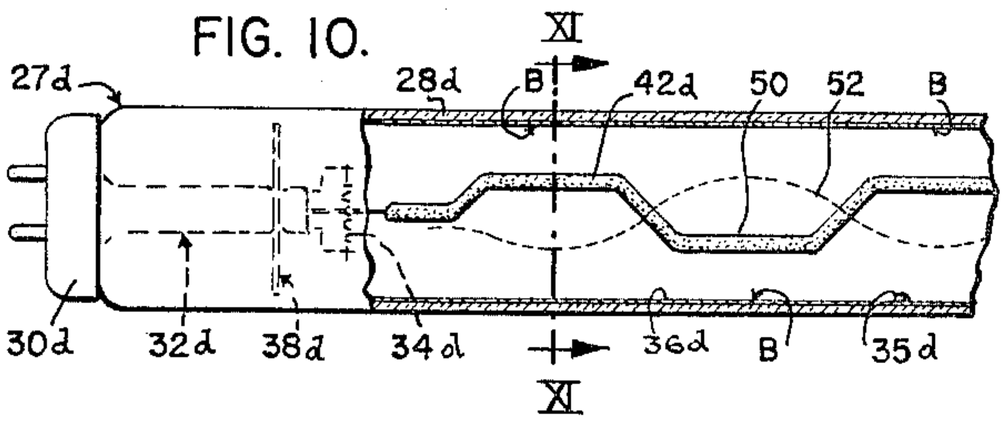
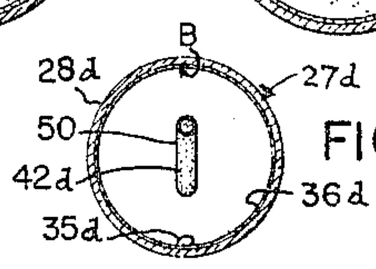


FIG. 11.



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Filed May 23, 1961 2 Sheets-Sheet 2

FIG. 12.

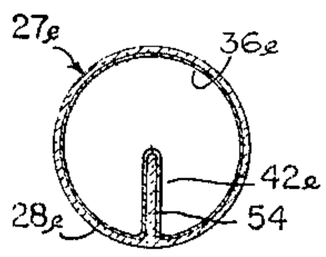


FIG. 13.

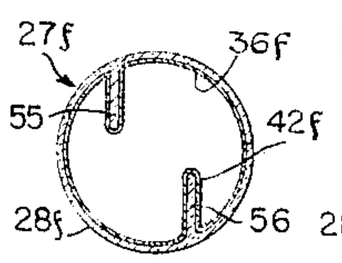


FIG. 14.

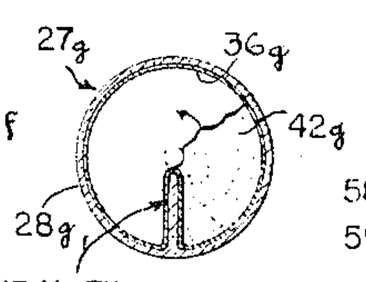


FIG. 15.

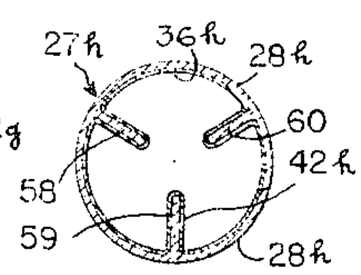


FIG. 16.

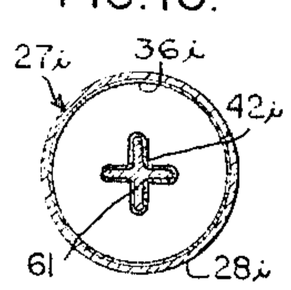
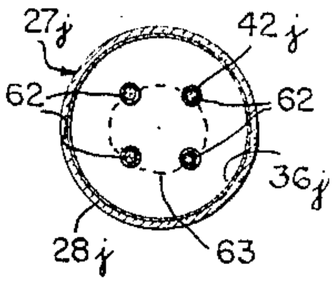


FIG. 17.



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FIG. 18.

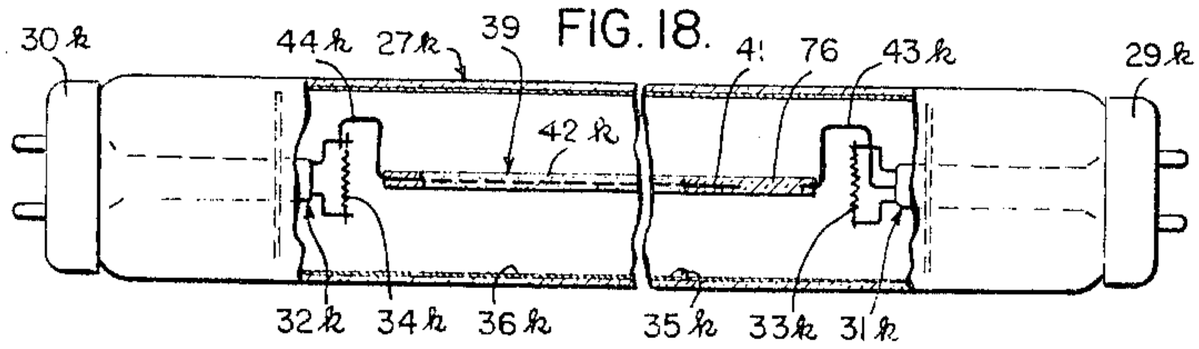


FIG. 19.

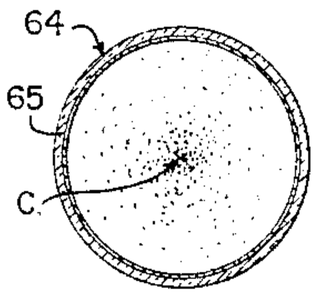


FIG. 20.

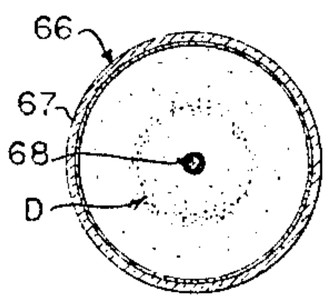


FIG. 21.

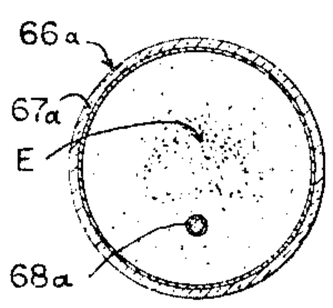


FIG. 22.

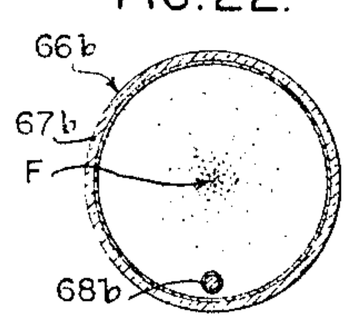


FIG. 23.

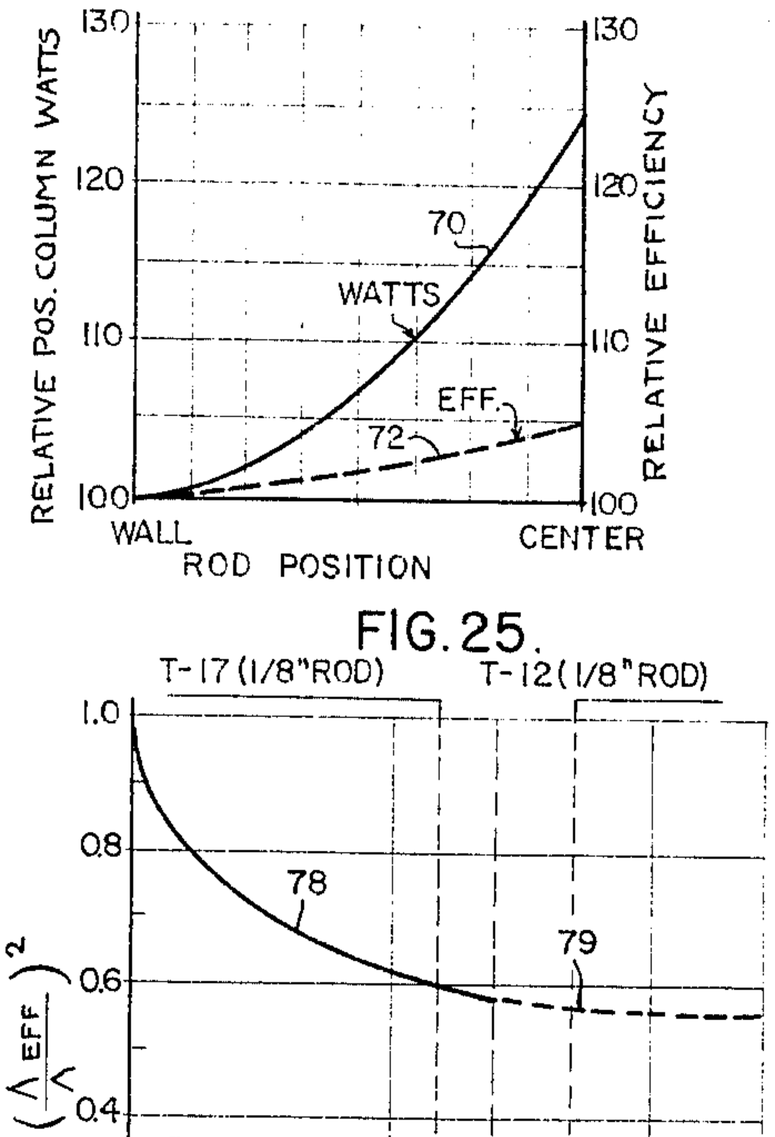


FIG. 24.

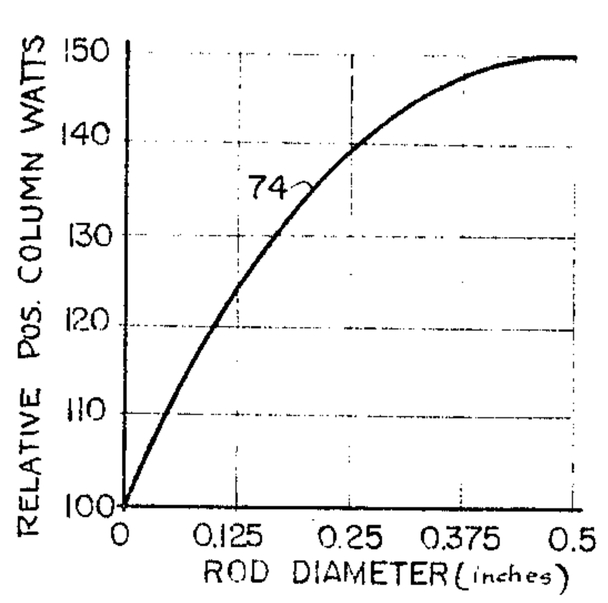
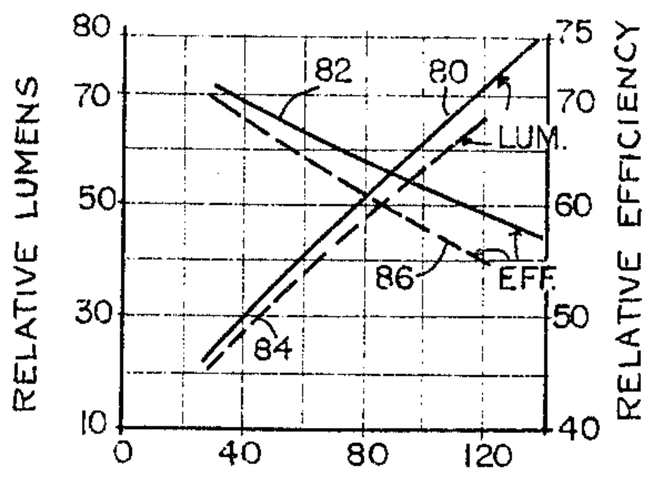


FIG. 25.

FIG. 26.



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United States Patent Office

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LOW-PRESSURE ELECTRIC DISCHARGE LAMP WITH INTERNAL ELONGATED STRUCTURE THAT MODIFIES THE DIFFUSION LENGTH OF THE DISCHARGE AND IMPROVES THE LAMP PERFORMANCE

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Filed May 23, 1961, Ser. No. 112,071
32 Claims. (Cl. 313—109)

This invention relates to electric discharge devices and, more particularly, to radiation-generating devices such as metal-vapor, ultraviolet and fluorescent lamps or the like.

One of the major problems involved in the design of electric discharge devices for generating ultraviolet or visible radiations is the problem of how to increase the power input or loading of the device without decreasing its efficiency. This problem is presently of particular concern in the fluorescent lamp industry in view of the lower installation cost and other commercial advantages afforded by high output lamps of standard diameter and length. However, when the current loading per unit of cross-sectional area of a fluorescent or any type of discharge lamp is increased, the electrode losses are proportionately increased resulting in a decrease in the operating efficiency. More importantly, as the current loading increases the electron temperature decreases resulting, in the case of a fluorescent lamp, in a decrease in the efficiency of generation of 2537A resonance radiation within the discharge and a subsequent drop in the lamp efficiency. Thus, as the power input and current loading are increased the lamp becomes progressively less efficient and thus commercially impractical from an operating cost standpoint.

The electron temperature is critically related to the efficiency with which ultraviolet (UV) radiation is produced by virtue of the fact that the electron temperature is a measure of the average kinetic energy or velocity which the electrons have acquired due to the voltage gradient within and along the discharge. The electron temperature is thus indicative of the fraction of the electrons in the plasma that have sufficient energy to raise the atoms of the gaseous medium with which they collide from their lowest energy level to a higher level from which the excited atoms can emit radiant energy or photons. In the case of a low pressure mercury-rare gas discharge, the atoms which are excited are mercury atoms and they emit principally 2537A resonance radiation. Thus, at the same electron density, the lower the electron temperature the smaller the number of mercury atoms excited by colliding electrons and the fewer the UV radiations generated within the discharge. In the case of a fluorescent lamp, this drop in the UV output results in a proportionate decrease in the number of visible radiations emitted by the phosphor and, thus, in the amount of light produced by the lamp. This same principle applies to non-resonance discharge devices, such as neon lamps for example, and for this reason the present invention can also be advantageously employed in devices of this character.

It is known that the electron temperature can be increased by decreasing the diffusion length of the discharge. The diffusion length is the average distance the electrons and positive ions must travel to reach the walls of the device where they can recombine. The shorter the diffusion length the higher the rate of loss of electrons and ions to the walls. This, in turn, increases the electron velocity or electron temperature and requires an increase in the voltage gradient in the discharge in order to sustain it, which voltage increase raises the wattage and thus the loading of the device.

Various means have heretofore been employed to maintain the electron temperature at a sufficiently high value that will permit a fluorescent lamp to be operated at higher loadings without materially reducing its efficiency. According to one approach a lighter fill gas, such as neon or helium (or mixtures thereof) instead of the usual argon or krypton (or mixtures thereof), and a lower fill pressure are used to increase the mobility of the mercury ions and thus increase the ion losses to the walls. However, because such gases are lighter and have a higher ionizing potential they inherently increase the rate of cathode sputtering resulting in severe end-discoloration, poor lumen maintenance and shorter lamp life.

According to another prior art design the walls of the tubular envelope are indented to form a series of spaced longitudinally-extending grooves which decrease the diffusion length of the discharge and increase the ratio of the perimeter of the envelope to its cross-sectional area. A so-called "grooved" lamp of this type is disclosed in U.S. Patent No. 2,915,664, issued December 1, 1959, to E. Lemmers. While the resultant decrease in diffusion length increases the ion losses and raises the UV output of the discharge, the manufacture of envelopes of such complex configuration constitutes a critical and rather costly operation in that extreme care must be exercised to avoid introducing excessive strains into the glass or otherwise weakening the envelope. More importantly, the reentrant grooves distort the cross-section of the lamp and markedly increase the current density per unit of cross-sectional area in these regions as compared to the ungrooved cylindrical regions. Thus, the increase in efficiency at high loadings is not as great as the decrease in the diffusion length achieved by the grooves would lead one to expect. In addition, dirt naturally tends to accumulate in the grooves, particularly when the lamps are used in a dusty atmosphere, resulting in a more rapid depreciation of the light output at the grooved segments, which is particularly unfortunate since these segments constitute the brightest portions of the lamp.

In another prior art lamp design a series of transverse baffles or discs are mounted inside the lamp along the discharge path to increase the ratio of the effective wall area to the volume of the envelope and thus increase the ion losses. A lamp of this construction is disclosed in U.S. Patent No. 2,363,070, issued November 21, 1944, to E. Lemmers. While this design provides the desired increase in surface area, it is unsatisfactory in that it obstructs the free passage of the discharge through the lamp and constricts it in the regions occupied by the discs. As a result, the current loading per unit cross-section is increased at a plurality of points along the discharge thereby nullifying to a large extent the benefits derived from the additional surface area provided by the discs. Moreover, the transverse partitioning of the discharge space by the discs makes the lamp harder to start and tends to trap the light rays resulting in increased absorption losses.

It is accordingly the general object of this invention to provide an improved electric discharge lamp that obviates the problems and disadvantages associated with the prior art designs.

Another object is the provision of an electric discharge lamp that can be operated at higher wattages without appreciably increasing the current density per unit of cross-sectional area.

Another and more specific object is the provision of a high-output fluorescent lamp of simple inexpensive construction that has a long useful life.

Still another object is the provision of a highly-loaded fluorescent lamp which operates at commercially acceptable efficiency levels and does not require specially shaped envelopes or the use of fill gases that adversely affect lumen maintenance or lamp life.

The aforesaid objects, and others which will become apparent as the description proceeds, are achieved in accordance with this invention by providing an elongated structure within the discharge space that defines a recombination surface for electrons and positive ions and thereby decreases the diffusion length of the discharge. The aforesaid structure extends longitudinally of the discharge space and is so dimensioned that it does not materially diminish the cross-sectional area of the discharge space defined by the envelope or interfere with the free passage of the discharge through the device. Thus, the voltage and wattage of the discharge device are increased without impairing its efficiency or locally increasing the current loading per unit of cross-sectional area. Various device embodiments having recombination surfaces of diverse configurations are provided, including several in which the effective length of the discharge is increased by the recombination surface to effect an additional increase in radiation output.

A better understanding of the invention will be obtained by referring to the accompanying drawings wherein:

FIG. 1 is a perspective view of a high-output fluorescent lamp incorporating this invention, portions of the lamp envelope being broken away for convenience of illustration;

FIG. 2 is a cross-sectional view of the lamp along the line II—II of FIG. 1, in the direction of the arrows;

FIG. 3 is a fragmentary perspective view of one end of an alternative lamp embodiment;

FIG. 4 is a side elevational view on a reduced scale of another lamp embodiment;

FIG. 5 is a fragmentary side elevational view of one end of still another lamp embodiment;

FIGS. 6 through 9 are cross-sectional views along the corresponding lines of FIG. 5, in the direction of the arrows, illustrating the spiraling of the discharge achieved by the helical rod construction of this invention;

FIG. 10 is a fragmentary side elevational view of another lamp embodiment according to this invention;

FIG. 11 is a cross-sectional view along the line XI—XI of FIG. 10, in the direction of the arrows;

FIGS. 12 through 17 are cross-sectional views of additional lamp embodiments;

FIG. 18 is a side elevational view of another form of the invention wherein the elongated structure serves both as a recombination surface and as an auxiliary starting electrode, a central portion of the lamp being broken away for convenience of illustration;

FIG. 19 is a cross-sectional view through a fluorescent lamp of conventional design illustrating the character of the discharge in the positive-column region;

FIGS. 20 through 22 are similar cross-sectional views through lamps incorporating the present invention illustrating the effect on the character of the discharge produced by introducing a rod into the discharge space and varying its location therein;

FIG. 23 is a graph illustrating the marked effect on the wattage and efficiency of a representative lamp produced by varying the position of the rod within the discharge space in the manner shown in FIGS. 20 through 22;

FIG. 24 is a graph illustrating the relationship between the rod diameter and the relative positive column watts of a representative fluorescent lamp incorporating the rod construction of this invention;

FIG. 25 is a graph illustrating the relationship between the diffusion length of the discharge and the ratio of the rod diameter to the bulb diameter; and

FIG. 26 is a graph comparing the lumen and efficiency characteristics versus the overall wattage rating of two different lamp designs illustrating the importance of properly locating the recombination surface within the discharge space.

While the present invention may be advantageously employed to increase the output of various types of low

or medium-pressure discharge devices, such as neon and UV lamps for example, it is particularly useful in conjunction with fluorescent lamps and has accordingly been so illustrated and will be so described.

With specific reference now to the drawings, in FIG. 1 there is shown an improved high-output fluorescent lamp **27** according to the present invention which lamp generally comprises a tubular radiation-transmitting glass envelope **28** of substantially uniform diameter that is sealed at both ends and provided with suitable end caps or bases **29** and **30**. Oppositely disposed mount assemblies **31** and **32** and thermionic electrodes **33** and **34** are sealed into the ends of the envelope in the usual manner. The electrodes are coated with a suitable electron-emitting material such as the well-known mixture of alkaline-earth oxides and are thus adapted to sustain an electric discharge when the lamp is energized. The envelope **28** contains a predetermined charge of mercury **35** and a filling of a suitable inert ionizable starting gas, preferably argon or krypton or the like or a mixture of neon and argon, at a pressure of about 2 mm. of Hg. The inner surface of the envelope **28** is coated with a UV-responsive phosphor **36**, such as a halophosphate type phosphor for example.

In order to maintain the mercury-vapor operating pressure in the range of about 6 to 10 microns required for optimum efficiency of UV generation at high loadings, heat-deflecting discs **37** and **38** of nickel or similar material are attached to the mount assemblies **31** and **32** in transverse relationship with the lamp axis so as to provide cooling chambers at each end of the lamp.

In accordance with this particular form of the invention an elongated rod-like structure or member such as a substantially straight quartz or glass rod **40** is located in the discharge space between the electrodes **33** and **34** and extends for a considerable distance therealong. The rod may consist of a solid or tubular length of glass and is preferably coated with a UV-responsive phosphor **42**. The rod is supported inwardly from the walls of the envelope by suitable means that do not materially obstruct the discharge, as for example by wires **43** and **44** that are anchored in the stems of the respective mount assemblies in the manner illustrated. The rod is thus electrically isolated from both electrodes.

As shown more particularly in FIG. 2, the rod **40** is preferably disposed in substantially coaxial alignment with the envelope **28** and is of circular cross-section. However, rods of noncircular configuration can also be employed if desired, as will become apparent as the description proceeds.

In accordance with this invention, the rod **40** is so dimensioned and located that it provides a recombination surface within the discharge space that decreases the diffusion length of the discharge without substantially diminishing the cross-sectional area of the discharge space defined by the envelope and thus interfering with or obstructing the free passage of the discharge through the lamp. The provision of such a recombination surface near the center of the discharge increases the electron and ion losses which normally take place only at the walls of the envelope, thereby increasing the velocity of the electrons or the electron temperature and both the voltage and wattage loading of the lamp. The desired increase in loading is accordingly effected primarily by increasing the voltage rather than the current so that the drop in efficiency associated with increased current density is avoided.

Since the rod **40** is located at and extends longitudinally along the center of the arc stream, it will naturally operate at a considerably higher temperature than the envelope **28**. In a 4 foot 100 watt T17 (2⅛″ O.D.) lamp for example, this increase in temperature is in the order of 70° C. It may be desirable, therefore, to coat the rod with a suitable UV-responsive phosphor such as tin-activated strontium zince phosphate or the like that

has an efficient output at elevated temperatures, particularly when the wattage loading is such that the temperature differential is in the order of 150° C. or higher.

In FIG. 3 there is shown an alternative lamp embodiment **27***a* of the same general character and construction as the lamp **27** described above except that instead of the vitreous rod a length of fibrous material such as glass-fiber tape or cord **44** is suspended between the electrodes longitudinally of the discharge space to provide the desired recombination surface. Such material is capable of withstanding the higher operating temperature involved and affords the advantage of flexibility which improves the ruggedness of the lamp as a whole. The cord **44** is coated with a UV-responsive phosphor **42***a* and is anchored to the mount assemblies by suitable means such as a support wire **43***a*, as shown. In contrast to the construction employed in the lamp described above, the support wires in this case are desirably terminated by a cup-shaped clamp that is crimped onto the end of the cord.

In FIG. 4 there is shown another embodiment of the present invention that is especially adapted for use in connection with fluorescent lamps of relatively low wattage and short length, such as the well-known 15 watt T12 and 20 watt T12 lamps for example which are 18 inches and 24 inches long, respectively, and have tubular envelopes 1⅜ or 1½″ in diameter. In this case the lamp **27***b* contains two coaxially-extending rods **45** and **46** which are anchored to the mount assemblies **31***b* and **32***b* and protrude inwardly from opposite ends of the envelope **28***b*. The rods are of such length that together they span substantially the entire length of the discharge space and, in the absence of heat-deflecting shields and cool end chambers as in the case here shown, are preferably dimensioned to leave about a ½ or 1 inch spacing between their inner ends which spacing provides the desired cool spot. The lamp **27***b* also contains the usual charge of mercury **35***b*, fill gas, and is provided with bases **29***b* and **30***b*. Both the rods and the inner surface of the envelope also carry a suitable phosphor coating **42***b* and **36***b*, respectively.

In FIG. 5 there is shown another type of high-output fluorescent lamp **27***c* which differs from the embodiments described above in that the recombination surface, in addition to shortening the diffusing length of the discharge, is of such configuration that it controls and determines the discharge path and increases its effective length. This is accomplished by providing a rod **48** of helical configuration that extends longitudinally of the discharge space between the electrodes and spirals about the axis of the envelope **28***c*. When the envelope diameter, fill gas pressure and the dimensions of the rod and helix are properly correlated, the discharge, instead of following its normal straight-line path between the electrodes, will spiral about the rod following the path where the spacing between the rod and the envelope wall is greatest.

The aforesaid spiraling effect is illustrated in FIGS. 6 through 9, which are cross-sections through the lamp **27***c* at points along its axis corresponding to a quarter of a turn of the helical rod **48**. As shown in this series of figures, the region of greatest intensity A of the discharge inherently occupies the region on the opposite side of the lamp axis from the rod **48** so that the arc spirals down the envelope in the same direction as the rod. Since the arc is more or less restricted to only a part of the discharge space, it is constricted in this particular design in much the same manner as in the prior art "grooved" lamp mentioned previously. In contrast to a "grooved" lamp, however, wherein the effective length of the arc is increased and the light output of the lamp is proportionately increased by deforming the envelope and "exteriorly modifying" the discharge space, so as to speak, the same results are achieved in accordance with this invention by introducing an elongated structure into the lamp that "interiorly modifies" the discharge. Thus, the problems associated with complex bulb shapes and large variations in the cross-sectional area of the discharge space and, thus, in the current density are avoided by the "discharge intensifier" principle of the present invention. It has been found that lamps provided with helical rods dimensioned so that the discharge makes about three turns per foot of lamp length have an arc length that is approximately 10% longer than a conventional lamp of the same overall length. It should also be noted that the various design parameters are so correlated that the discharge is stabilized in its spiral path. That is, it does not rotate or wobble about the lamp axis but remains perfectly stationary.

As a specific example of a suitable design, good results have been obtained with a glass rod ⅛″ in diameter formed into a helix ⅝″ in diameter having five turns per foot and mounted in a T17 lamp 4 feet long filled with 60–40 neon-argon mixture at 2 mm. pressure.

In FIGS. 10 and 11 there is shown still another embodiment of the invention comprising a high-output fluorescent lamp **27***d* wherein the elongated structure or member comprises a rod **50** of crenelated configuration that is supported and extends along the discharge space and is substantially symmetrical about the axis of the envelope **28***d*. The rod **50** is coated with a suitable phosphor **42***d* and the envelope is also interiorly coated with phosphor **36***d* and contains a droplet of mercury **35***d* as in the case of the embodiments above described. A heat-deflecting shield **38***d* is also provided at at least one end of the envelope to provide a cooling chamber thereat.

As indicated by the dotted line **52** in FIG. 10, the crenelated configuration of the rod **50** diverts the discharge from its normal straight-line path between the electrodes and causes the arc to swing back and forth across the lamp axis in the same manner but opposite phase as the rod. As in the case of the helical rod, the resultant increase in the effective length of the arc produces a proportionate increase in the UV output of the discharge and in light output of the lamp. By properly correlating the diameters of the rod and envelope and the other design parameters such as the vapor pressure etc., the discharge will remain stabilized in its zig-zag configuration. As will be obvious, the increase in the length of the discharge can be varied by varying the length of the offset segments of the rod. Preferably, the length of these segments is approximately equal to the envelope diameter, as in the case here shown.

The above-described crenelated rod construction affords an additional advantage in that the walls of the envelope **28***d* closest to the offset segments of the rod operate at a lower temperature as compared to the diametrically opposite portions of the envelope that are closer to the discharge. Thus, a series of relatively cool regions B are provided along the envelope which, in conjunction with the cooling end chamber defined by the heat-deflecting shield **38***d*, maintains the operating pressure of the mercury vapor within the desired six to ten micron range.

In FIG. 12 there is shown another lamp embodiment **27***e* wherein the recombination surface constitutes a longitudinally-extending rib or fin **54** of thin cross-section that protrudes radially inward from the inner surface of the envelope **28***e* toward and preferably to the axis of the envelope. As shown, the fin may comprise a vitreous panel that is fused to the inner surface of the envelope and is coated with a suitable phosphor **42***e*.

Various modifications of the aforesaid fin construction are shown in FIGS. 13 through 15. In the lamp **27***f* shown in FIG. 13, a pair of fin-like elements **55** and **56** are attached to the walls of the envelope **28***f* and are disposed in substantially parallel offset relationship so as to protrude toward the envelope axis.

In the lamp **27***g* shown in FIG. 14, a single fin-like member **57** of thin cross-section is attached to the inner

surface of the envelope **28***g* and spirals down the lamp, as indicated by the arrow. The discharge will thus also spiral through the envelope in substantially the same manner as in the case of the helical rod construction described above.

In the lamp **27***h* shown in FIG. 15 three fin-like members **58**, **59** and **60** are attached to the inner surface of the envelope **28***h* at substantially equal distances from each other around the envelope periphery from which they radially extend toward the envelope axis.

It should be noted that in each of the aforesaid embodiments the fin-like elements are of thin cross-section and of such width and length that they provide longitudinally-extending recombination surfaces that are so located that they decrease the diffusion length of the discharge. However, they do not completely span or bridge the discharge space. That is to say, they do not partition the discharge space into a plurality of separate discharge channels or compartments but are so arranged and dimensioned that they do not materially decrease the cross-section of the discharge space or impede or obstruct the free passage of the discharge through the envelope. Thus, the envelope and fins together define a single chamber or channel through which the discharge passes in a stabilized manner.

In FIG. 16 there is shown a modification of the rod design wherein a lamp **27***i* is provided which contains a longitudinally-extending rod-like member **61** of non-circular cross-section that is located in substantially coaxial alignment within the envelope **28***i*. In this particular embodiment, the rod-like member comprises a plurality of thin vanes or ribs that extend radially outward from the envelope axis to provide an integral elongated member the cross-section whereof is X-shaped.

In FIG. 17 there is shown another lamp **27***j* having a plurality of phosphor-coated rods **62** therein that are located in and extend longitudinally of the discharge space. In this particular embodiment the rods are equidistant from each other and from the axis of the envelope **28***j* and are arranged to define a relatively restricted channel or region, indicated by the dotted line **63**, that extends down the center of the envelope. By properly correlating the rod and envelope diameters and the rod spacing it has been found that the discharge can be confined to the aforesaid restricted channel thereby enabling envelopes of rather large diameter to be employed without proportionately increasing the diameter of the discharge space. This particular construction could, accordingly, be advantageously employed in those cases where it is desirable to increase the lumen maintenance of the lamp by increasing the surface area of the phosphor-coated envelope, and thereby decreasing its loading per unit area and its temperature, while retaining the voltage and current characteristics of a much smaller or more concentrated discharge.

The aforesaid rod-like or fin-like members may be fabricated from glass, metal or any material that will not produce conditions harmful to the discharge, such as the release of gaseous impurities for example. In the case of a fluorescent or UV lamp, if the material absorbs UV radiation it should be coated with a UV-reflecting material or with a UV or light-emitting phosphor to prevent the loss of 2537A radiation. Of course, if the elongated member is made of metal it is electrically isolated from at least one of the electrodes.

As shown in FIG. 18, the use of an elongated member that is at least partly electrically conductive affords another lamp embodiment **27***k* wherein the elongated member functions both as a recombination surface and as an auxiliary starting electrode. As shown, the lamp contains a composite axially-extending member **39** that consists of a resistive core **41**, such as a suitable wire that may be insulated throughout substantially its entire length, if desired, by a layer **76** of glass or other vitreous non-conductive material. If the resistance of the wire core **41** is such that it would shunt an undesirable portion of the discharge current, then the wire core is insulated from at least one of the electrodes. This can be accomplished by connecting one end of the wire core **41** to the electrode **34***k* by means of the support wire **44***k* and terminating the other end of the core short of the end of the other support wire **43***k* that is embedded in the glass **76**. The intervening slug of glass thus insulates the wire core **41** from the other electrode **33***k* and prevents the short-circuiting of the lamp through the wire support **43***k*. By virtue of its location within the discharge and its electrically-conductive core, the phosphor-coated composite member **39** not only provides the desired recombination surface but facilitates the initiation of the discharge and thus serves as an auxiliary starting means. If desired, a wire coil could be used as the conductive core as disclosed in U.S. Patent No. 1,935,702.

While the ratio of the surface area to the cross-sectional area of the elongated structure or member is important from the standpoint of providing a recombination surface of sufficiently large size without substantially diminishing the cross-sectional area of the lamp, the location of the structure within the discharge space is of even greater importance insofar as it has a much greater influence on the effectiveness of the recombination surface in decreasing the diffusion length of the discharge. This critical aspect of the invention is illustrated in FIGS. 19 through 22. FIG. 19 represents a cross-section through the positive-column portion of a low-pressure discharge device **64**, such as a conventional fluorescent lamp, that has a diffused discharge. That is, the discharge fills the entire cross-section of the envelope **65** even though the arc is most intense in a circular region C centered around the axis of the lamp. This latter region is, accordingly, also the region where the electron density or concentration is at a maximum.

As shown in FIG. 20, when a rod **68** of even very small cross-section is placed on the axis of an identical discharge device **66** in accordance with this invention, the center or core of the discharge space automatically becomes a region of very low electron concentration. The region of maximum arc intensity and electron density accordingly shifts outwardly toward the envelope **67** and takes the form of an annular region D that is coaxially disposed approximately midway between the rod and the envelope walls. Since the rod in this case is located at the envelope axis where the electron concentration is normally at a maximum, a maximum decrease in diffusion length of the discharge is achieved.

As is indicated in FIG. 21, positioning an identical rod **68***a* at a point midway between the axis and the wall of the envelope **67***a* provides a discharge device **66***a* wherein the region of maximum arc intensity E is more or less crescent-shaped and located on the side of the envelope axis opposite the rod. In this case, since the rod is located in a region where the electron density is somewhat lower, the decrease in the diffusion length is proportionately lower compared to the aforementioned coaxial rod.

The extreme case is shown in FIG. 22 wherein the rod **68***b* is located at the wall of the envelope **67***b*. Since the wall represents a region of zero electron concentration, the rod in this case has practically no effect on the diffusion length, as indicated by the fact that the region of maximum arc intensity F is again symmetrically centered around the envelope axis in the same manner as the region C in the conventional discharge device **64** shown in FIG. 19. It should be noted that the discharge in each of the aforesaid examples remains substantially diffused and fills the entire cross-section of the envelopes despite the fact that the regions of maximum arc intensity in the devices shown in FIGS. 20 and 21 are displaced from the envelope axis.

It will be appreciated from the foregoing that the recombination surface need not be large if it is properly located within the discharge space. In fact, it has been found that a coaxially disposed rod having a diameter

only one-fortieth that of the tubular envelope will produce a significant reduction in the diffusion length. In the case of a fluorescent lamp, the decrease in the cross-sectional area of the lamp by such a rod would obviously not only be negligible but the loss of 2537A radiation by absorption would also be negligible. A rod of this size, accordingly, would probably not have to be coated with a phosphor or a UV-reflecting material since the decrease in the overall efficiency of the lamp would be very small.

The graph shown in FIG. 23 illustrates the marked effect the position of the rod has on the wattage and efficiency of a particular lamp. The lamp in this case was a 4 foot 100 watt T17 (2⅛" O.D.) lamp filled with argon at 1.8 mm. pressure and operated at 1.5 amperes, and the rod had a diameter of ⅛". As shown by the solid-line curve **70**, the relative positive-column watts sharply increased from a value of 100 to 125 as the rod was moved from the wall to the center of the envelope, an increase of 25%. Such a large increase is rather surprising in view of the fact that the rod is only one-seventeenth the diameter of the envelope. As shown by the dotted-line curve **72**, the relative efficiency of the lamp is also increased by about 5% when the rod is placed at the center instead of at the wall. Thus, for optimum wattage loading and efficiency of a given lamp, the recombination surface should be located at and extend substantially along the axis or geometrical center of the discharge space. The effect on these operational parameters can, of course, be varied simply by relocating the recombination surface in regions of lower electron density.

The variation in the relative positive-column watts of the same type of 100 watt T17 lamp produced by different size coaxial rods is illustrated in the graph shown in FIG. 24. As indicated by curve **74**, the relative positive-column watts increases sharply by about 25% when an ⅛" diameter rod is used and by about 50% when a ½" diameter rod is used. Preliminary tests have also shown that a gain of approximately 5% in relative efficiency is obtained with the use of a ⅛" coaxially-located rod.

The effect on the diffusion length of the discharge obtained with various combinations of rod and bulb diameters is shown graphically in FIG. 25. The square of the ratio of the effective diffusion length (Λ_{eff}) when a coaxial rod is present, to the diffusion length (Λ) resulting when no rod is present is plotted along the ordinate, and the ratio of the rod diameter (d) to the bulb diameter (D) is plotted along the abscissa. As indicated by the solid line portion 78 of the curve, for small values of d/D the effective diffusion length Λ_{eff} decreases rather rapidly from a maximum, when an infinitely small recombination surface is present, and then tapers or levels off at higher values of d/D, that is, as the rod gets larger relative to the bulb. As is indicated, at values of d/D below about 0.07 the mode of the discharge is diffused, whereas above this value (the dotted line portion **79** of the curve) it is constricted. A diffuse type discharge is preferred and, as shown in the graph, will prevail if a ⅛" diameter rod is used in a T17 type envelope. If the same rod were used in a T12 bulb, the discharge would be constricted since the resulting value of d/D lies within the constricted mode region of the curve. As indicated by the dotted-line portion **79** of the curve, the rate of decrease in the diffusion length with increasing rod size is much less pronounced when the constricted mode prevails.

Insofar as the discharge is thrown off-center and restricted to a relatively small section of the envelope when constricted, thereby increasing the current density per unit of cross-sectional area in this region and tending to nullify the small additional gains obtained in shortening the diffusion length by using larger diameter rods, it is preferred that a rod and envelope combination be selected wherein the ratio d/D is less than approximately 0.07. In practice, this means that the rod should be limited in size to about 3/32" diameter for a T12 envelope (1½" O.D.) and to approximately ⅛" diameter for a T17

envelope (2⅛" O.D.). The latter combination is shown in FIG. 25. Experience indicates that the diffused mode prevails in each case.

The comparative relative lumen output and relative efficiency of a representative high-output fluorescent lamp having a rod located at the bulb wall and at the center of the envelope is graphically shown in FIG. 26. This graph is based on data obtained from a 4 foot 100 watt T17 lamp containing 1.6 mm. of argon and a ⅛" quartz rod, operated in an ambient of 26° C. As indicated by the solid lines **80** and **82**, both the relative lumen output and relative efficiency, respectively, of the lamp are considerably higher when the rod is located at the center of the envelope than at the wall thereof, which latter construction is represented by the dotted-line curves **84** and **86**. Since the current was necessarily increased to achieve such high loadings, the efficiency in both cases decreased somewhat with increasing wattage. However, loadings as high as 50 watts per foot at commercially acceptable efficiencies are possible with lamps internally modified in accordance with this invention whereas loadings in excess of about 16 watts per foot in conventional fluorescent lamps would have too low an efficiency to be economically practical.

Even higher loadings and efficiencies can, of course, be obtained by combining the "internal recombination surface" principle of this invention and the lighter fill gases and lower fill pressures employed in some of the prior art highly-loaded lamps. Preliminary comparative tests of 48" T17 lamps with and without a coaxial ⅛" phosphor-coated rod embodying the aforesaid combination are given below in Table I and show that extremely high loadings at acceptable efficiencies can be obtained in this manner.

TABLE I

Lamp Construction	Relative Lumen Output (0 hours)			
	100W	150W	200W	250W
10% He–90% Ne at 1.0 mm.—no rod	173	245	298	350
10% He–90% Ne at 1.0 mm.—rod	176	252	323	383
100% Ne at 1.0 mm.—no rod	182	251	307	355
100% Ne at 1.0 mm.—rod	196	277	353	419

From the above data it will be seen that the rod becomes more effective as the loading increases. In the case of the He-Ne filled lamps, the relative output with the rod was 1.7% higher at 100 watts and 8.4% higher at 200 watts than the lamps having no rod. With 100% Ne-filled rod lamps, the increase in output over conventional lamps having the same filling was 7.7% at 100 watts and 15% at 200 watts. The resultant increase in efficiency obtained by using the concentric rod is 11% in the case of the He-Ne filled lamps and 16% in the case of the Ne filled lamps.

From the foregoing it will be seen that the objects of the invention have been achieved by providing a relatively simple and inexpensive means of increasing the wattage loading of a discharge device without impairing its efficiency. Moreover, since the decrease in the diffusion length of the discharge and resultant increase in the electron temperature are achieved by means of an internal elongated structure that is substantially uniform in cross-section, the discharge space is of substantially uniform cross-section throughout its length thereby avoiding the undesirable local constrictions of the discharge and increases in current density inherent in the prior art designs. Hence, the desired higher output is achieved without deforming the envelope or distorting its cross-section in any way so that the disadvantages inherent in this approach to the problem are entirely eliminated.

While several embodiments have been illustrated and described, it will be apparent that various modifications in the configuration, dimensions and combination of parts

may be made without departing from the spirit and scope of this invention.

We claim:

1. A low-pressure electric discharge lamp comprising, a sealed radiation-transmitting envelope that contains an ionizable medium, a pair of spaced electrodes within said envelope adapted when energized to sustain an electric discharge therebetween, and an elongated member within said envelope that extends along the discharge space between said electrodes and is so oriented that at least a portion of said member is located near the center of the discharge space, the cross-sectional dimensions of said member compared to those of said envelope being such that said member does not materially increase the current density per unit of cross-sectional area of the discharge, and substantially all of the exposed surface of said member being non-metallic whereby said member by virtue of its location and relatively small cross-section provides a longitudinally-oriented, non-metallic recombination surface within the discharge space that decreases the diffusion length of the discharge, and thus increases the output of said lamp, without substantially impeding the free passage of the discharge through said envelope.

2. An electric discharge lamp as set forth in claim 1 wherein said elongated member is fabricated from electrically non-conductive material and extends substantially the entire length of the discharge space between said electrodes.

3. An electric discharge lamp as set forth in claim 1 wherein at least a portion of said elongated member is disposed at and extends along the geometrical center of the discharge space.

4. An electric discharge lamp as set forth in claim 1 wherein said elongated member is of rod-like configuration and a major portion thereof is spaced a considerable distance inwardly from the walls of said envelope.

5. An electric discharge lamp as set forth in claim 1 wherein said elongated member comprises a fin-like extension that protrudes from the wall to approximately the axis of said envelope.

6. An electric discharge lamp as set forth in claim 1 wherein said elongated member extends substantially the entire length of the discharge space and is of such configuration and so located that it controls and determines the discharge path and materially increases the length thereof.

7. An electric discharge lamp as set forth in claim 1 wherein said elongated member is electrically isolated from both of said electrodes.

8. An electric discharge lamp as set forth in claim 1 wherein said elongated member has an electrically conductive core and is electrically connected to only one of said electrodes.

9. A low-pressure electric discharge lamp comprising, a sealed elongated radiation-transmitting envelope that contains an ionizable medium, a pair of spaced electrodes within said envelope adapted when energized to sustain an electric discharge therebetween, and a pair of elongated members secured to the respective ends of said envelope and protruding longitudinally into the discharge space toward each other, said members being of such length that together they span only a portion of the discharge space between said electrodes and are thus spaced from one another, the cross-sectional dimensions of said members compared to the corresponding dimension of said envelope being such that said members do not materially increase the current density per unit of cross-sectional area of the discharge, said members by virtue of their location and relatively small cross-section constituting longitudinally-oriented recombination surfaces within the discharge space that decrease the diffusion length of the discharge and thus increase the efficiency and output of said lamp.

10. A low-pressure electric discharge lamp comprising, a sealed elongated radiation-transmitting envelope containing a charge of vaporizable metal and an inert ionizable gaseous medium, an electrode at each end of said envelope, and means for increasing the wattage loading of said lamp without decreasing its efficiency comprising an elongated electrically non-conductive member that is located between said electrodes and extends longitudinally of and is located within the discharge space defined thereby, the dimensions and configuration of said member relative to those of said envelope being so correlated that the discharge space defined by said envelope is of substantially uniform cross-section throughout its length and comprises a single discharge channel, the surface area of said member compared to its cross-sectional dimension being of such magnitude that said member provides a recombination surface within the discharge space that decreases the diffusion length of the discharge without materially increasing the current density per unit of cross-sectional area of the discharge.

11. An electric discharge lamp as set forth in claim 10 wherein said elongated member is of such configuration that it increases the length of the discharge path and provides at least one relatively cool region within said lamp during the operation thereof.

12. An electric discharge lamp as set forth in claim 10 wherein said longitudinally-extending member is substantially centrally located within the discharge space.

13. A low-pressure ultraviolet-generating discharge lamp comprising, a sealed elongated radiation-transmitting envelope of substantially uniform cross-section, a quantity of mercury and an inert ionizable gaseous medium in said envelope, a thermionic electrode sealed into each end of said envelope, and an elongated non-metallic member that extends a considerable distance longitudinally along the discharge space between said electrodes and is so oriented that a portion of said member is substantially centrally located within the discharge space, said elongated member being of such configuration and dimensions that the discharge space is of substantially uniform cross-section and said envelope defines a single substantially unobstructed discharge chamber, the surface of said member being ultraviolet-reflecting and extending over an area such that it provides a non-metallic recombination surface in the discharge space that decreases the diffusion length of the discharge and thus increases the loading and output of said lamp.

14. A fluorescent lamp comprising, a tubular light-transmitting envelope of substantially uniform diameter, a quantity of mercury and an inert ionizable gaseous medium contained by said envelope, a thermionic electrode sealed into each end of said envelope, a phosphor coating on the inner surface of said envelope, and an elongated structure in and extending longitudinally along the discharge space between said electrodes, said structure having an electrically non-conductive surface and being so oriented that at least a portion of the structure extends along substantially the center of the discharge space, the configuration and dimensions of said structure relative to those of said envelope being so correlated that the discharge space is of substantially the same size throughout its length and said envelope defines a single substantially unobstructed discharge chamber, the surface area of said structure being of such magnitude that it provides a non-conductive recombination surface in the discharge space that decreases the diffusion length of the discharge and thus increases the light output of said lamp.

15. A fluorescent lamp as set forth in claim 14 wherein said elongated structure comprises a conductive member that is coated with vitreous material and is electrically connected to only one of said electrodes.

16. A fluorescent lamp as set forth in claim 14 wherein said elongated structure comprises a rod that extends along substantially the entire length of the discharge

space and is coated with an ultraviolet-responsive phosphor.

17. A fluorescent lamp as set forth in claim 14 wherein said elongated structure comprises a rod of vitreous material that extends along substantially the entire length of the discharge space, is coated with an ultraviolet-responsive phosphor, and is substantially coaxial with said envelope.

18. A fluorescent lamp as set forth in claim 14 wherein said elongated structure comprises a length of glass-fiber material that is suspended between said electrodes.

19. A fluorescent lamp as set forth in claim 14 wherein said elongated structure comprises a helical rod that has a predetermined number of turns per foot and spirals about the axis of said envelope.

20. A fluorescent lamp as set forth in claim 14 wherein said elongated structure comprises a rod of crenelated configuration that is substantially symmetrical about the axis of said envelope.

21. A fluorescent lamp as set forth in claim 14 wherein said elongated structure comprises a pair of fin-like elements that protrude from the inner surface toward the center of said envelope and are disposed in offset substantially parallel relationship with one another.

22. A fluorescent lamp as set forth in claim 14 wherein said elongated structure comprises a plurality of rods that are spaced from each other and the walls of said envelope and define a restricted passageway that extends along the discharge space.

23. A fluorescent lamp as set forth in claim 14 wherein said elongated structure comprises a plurality of fin-like elements that are substantially equally spaced around the periphery of said envelope and protrude radially inward therefrom toward the envelope axis.

24. A fluorescent lamp as set forth in claim 14 wherein said elongated structure comprises a rod-like element of noncircular cross section that is spaced inwardly from the walls of said envelope.

25. A fluorescent lamp as set forth in claim 14 wherein said elongated structure comprises a fin-like member that protrudes from the inner surface toward the center of said envelope and spirals about the axis thereof.

26. A fluorescent lamp adapted when normally operated to have a loading in excess of 16 watts per foot comprising, a tubular envelope of substantially uniform diameter having a charge of mercury and an inert ionizable gaseous medium sealed therein, a phosphor coating on the inner surface of said envelope, a mount assembly at each end of said envelope including a thermionic electrode, a vitreous rod-like member located in and extending substantially along the center of the discharge space between said electrodes, and means comprising an integral part of said lamp for controlling the mercury-vapor pressure within said lamp during the operation thereof, said rod-like member being electrically isolated from at least one of said electrodes, and the surface area of said member compared to its cross-section being of such magnitude that said member defines a recombination surface which decreases the diffusion length of the discharge, and thus increases the light output of said lamp, without materially decreasing the current-carrying cross-sectional area of said envelope.

27. A highly-loaded fluorescent lamp as set forth in claim 26 wherein said rod-like member is disposed in substantially coaxial alignment with said envelope and includes an off-set segment that deflects the discharge toward one side of said envelope and is thereby adapted to provide a relatively cool region within said lamp for controlling the operating pressure of the mercury vapor.

28. A highly-loaded fluorescent lamp as set forth in claim 26 wherein, said mercury-vapor pressure control means comprises a heat-deflecting shield mounted on one

of said mount assemblies and positioned to form a cooling chamber at that end of said envelope, and said rod-like member is coated with an ultraviolet-responsive phosphor and comprises a helix that spirals about the axis of said envelope and is of such dimensions that it defines a stabilized spiral discharge path.

29. A fluorescent lamp adapted for operation with a power input such that the loading is in excess of 16 watts per foot comprising, a tubular light-transmitting envelope of substantially uniform diameter, a predetermined amount of mercury and an inert ionizable gaseous medium in said envelope, an ultraviolet-responsive phosphor coating on the inner surface of said envelope, an electrode disposed at each end of said envelope, and a vitreous rod of generally circular cross-section supported in substantially coaxial relation within said envelope and extending along substantially the entire length of the discharge space between said electrodes, the ratio of the diameter of said rod to that of the envelope being less than approximately 0.1.

30. The fluorescent lamp of claim 29 wherein the ratio of the diameter of said rod to that of the envelope is less than about 0.07.

31. A highly-loaded fluorescent lamp comprising, a tubular light-transmitting envelope approximately 2⅛" in diameter and of substantially uniform cross-section, a predetermined amount of mercury and an inert fill gas in said envelope, an electrode sealed into each end of said envelope, a vitreous rod having a diameter no greater than about ⅛" supported in substantially coaxial relation within said envelope and extending along substantially the entire length of the discharge path between said electrodes, an ultraviolet-responsive phosphor coating on said rod and on the inner surface of said envelope, and means integral with said lamp adapted to provide a cool region therein that maintains the mercury vapor pressure within predetermined limits during the operation of said lamp.

32. A highly-loaded fluorescent lamp comprising, a tubular light-transmitting envelope approximately 1½" in diameter and of substantially uniform cross-section, a predetermined amount of mercury and an inert fill gas in said envelope, an electrode sealed into each end of said envelope, a vitreous rod having a diameter no greater than about 3/32 inch supported in substantially coaxial relation within said envelope and extending along substantially the entire length of the discharge path between said electrodes, an ultraviolet-responsive phosphor coating on said rod and on the inner surface of said envelope, and means integral with said lamp adapted to provide a cool region therein that maintains the mercury vapor pressure within a predetermined range during the operation of said lamp.

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