Nov. 22, 1960 E. LEMMERS 2,961,565

LOW-PRESSURE DISCHARGE LAMP

Filed April 9, 1956 2 Sheets-Sheet 1

Fig. 1.

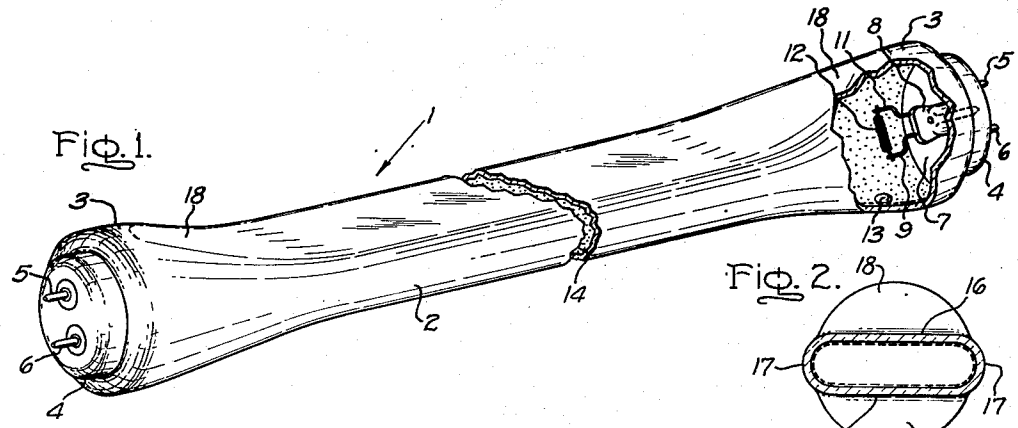


Fig. 2.

Fig. 3.

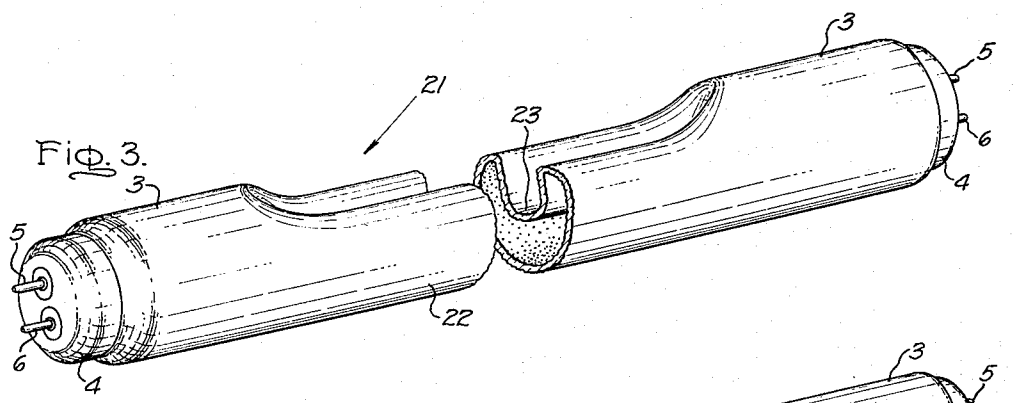


Fig. 4.

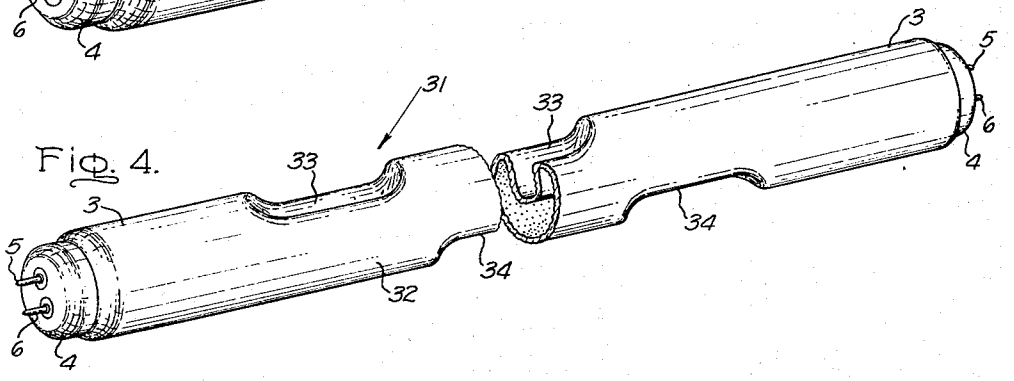
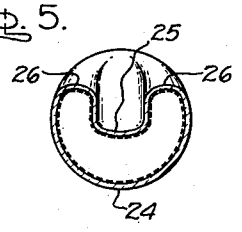


Fig. 5.



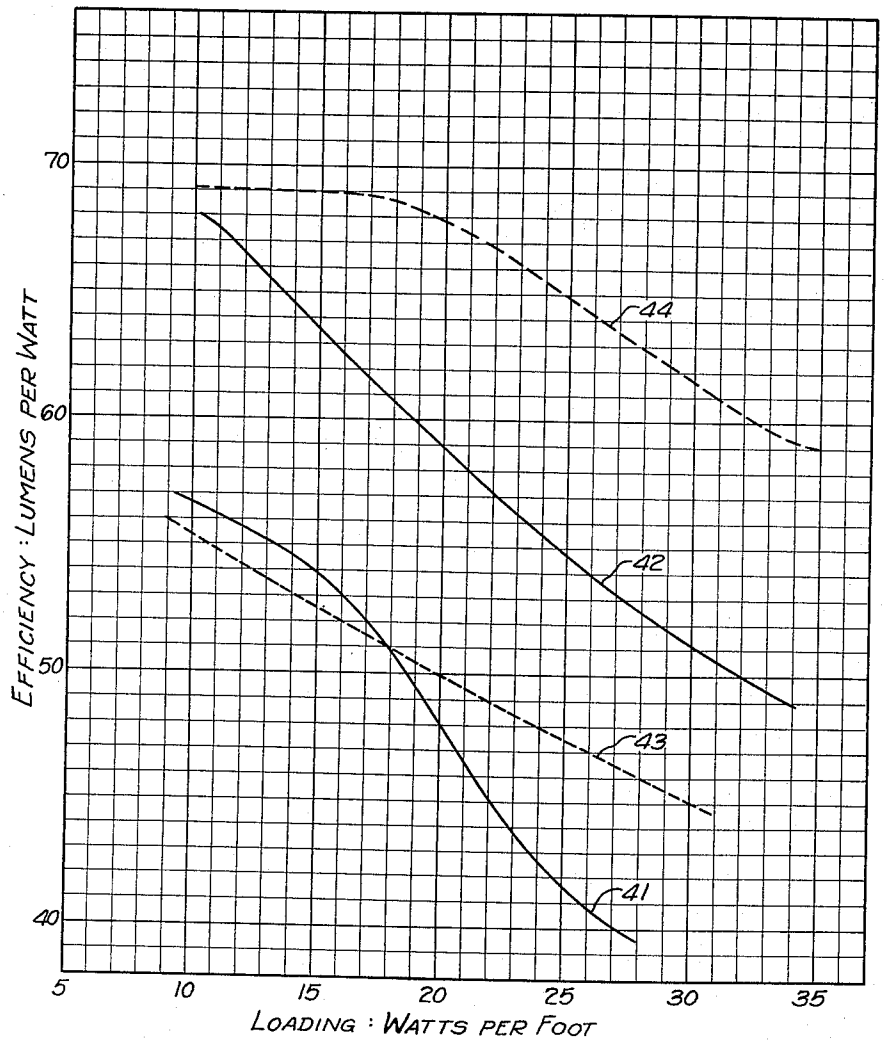
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Filed April 9, 1956 2 Sheets-Sheet 2

Fig. 6.



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2,961,565

LOW-PRESSURE DISCHARGE LAMP

Eugene Lemmers, Cleveland Heights, Ohio, assignor to General Electric Company, a corporation of New York

Filed Apr. 9, 1956, Ser. No. 576,985

8 Claims. (Cl. 313—185)

This invention relates to elongated low-pressure discharge lamps or devices of the resonance radiation type. More particularly, it relates to such lamps wherein the ratio of perimeter to area of the cross section (henceforth abbreviated "*p/a*") is substantially greater than in circular-sectioned lamps of the same perimeter. The instant application is a continuation-in-part of my copending application, Serial No. 475,035, filed December 14, 1954, entitled "Low Pressure Discharge Lamps," assigned to the same assignee as the instant application and now abandoned.

It is known that in low-pressure positive column discharge lamps, for instance, in the usual fluorescent lamps wherein phosphors are excited by the resonance radiation of mercury, it is possible to improve the radiation efficiency at a given loading by increasing the *p/a* ratio. By so doing, there may be achieved either improved efficiency at a given wattage per unit length of lamp, or higher wattage loading per unit length for the same efficiency.

The simplest way of increasing the *p/a* ratio is by flattening a round tube to an oval or loop-like cross section. For the range of commercial fluorescent lamp tube sizes from 1 inch to 2⅛ inches in diameter, flattening to a 2:1 ratio of internal width to internal thickness is about the smallest degree of flattening that is of any real advantage; flattening to a higher ratio, for instance to a 4:1 ratio, is yet more advantageous. Unfortunately, such simple flattened tubes are weak against implosion or inward collapse by external atmospheric pressure when they are evacuated.

One way of improving the implosion resistance of flat-tube lamps is disclosed in my Patent 2,482,421—Flat-Tube Electrical Device, and consists in pre-stressing the narrow longitudinal edges of the flat tube to a state of permanent pre-compression strain. Other lamp shapes of unique form or configuration providing a higher *p/a* ratio and affording marked improvements in implosion resistance along with other highly advantageous characteristics are disclosed and claimed in my copending application No. 475,036 filed December 14, 1954, entitled "Implosion Resistant Lamp Envelopes," and assigned to the same assignee as the present invention but now abandoned in favor of continuation-in-part application Serial No. 577,017, filed April 9, 1956, now U.S. Patent No. 2,915,664, issued December 1, 1959, entitled "Tubular Electric Lamps," and likewise assigned to the same assignee as the present invention. The envelope configurations therein are strengthened by providing additional curvatures as for instance by means of a longitudinally extending groove of re-entrant cross section, either continuous on one side of the tube or in short spaced sections alternating on opposite sides. Tubes of these configurations provide commercially practicable low-pressure fluorescent or discharge lamps in the usual sizes, for instance up to 2⅛ inches in diameter, with thin walls of the usual lime glass and with an advantageous increase in the *p/a* ratio.

The general object of the invention is to provide improved elongated low-pressure electric discharge lamps having higher efficiency under given conditions of loading.

Another object of the invention is to increase the loading of low-pressure discharge lamps for a given efficiency.

A more specific object of the invention is to improve the radiation efficiency or loading capacity of low-pressure elongated discharge lamps of tubular form having a high *p/a* ratio, and particularly of re-entrant groove lamps as disclosed in my aforementioned copending application.

Hereinafter in referring to a lamp or tube of high *p/a* ratio it is intended to signify an elongated lamp or tube whereof the ratio of perimeter to area of the cross section is substantially greater than that of a circular-sectioned tube of the same perimeter. When a circular-sectioned tube is flattened to a 2:1 ratio of internal width to internal thickness to provide substantially flat side walls and semicylindrical edge walls, the increase in *p/a* ratio is approximately 18 percent. Flattening in a 3:1 ratio provides an increase of 42 percent, and flattening in a 4:1 ratio provides an increase of 73 percent in the *p/a* ratio. As previously mentioned, a 2:1 ratio is about the least degree of flattening that is of any real advantage and in referring to a high *p/a* ratio henceforth, a ratio greater by 20 percent or more than that of a circular-sectioned tube of the same perimeter is to be understood. With respect to lamps achieving a high *p/a* ratio by means of a re-entrant groove and wherein the discharge cross section is a sector of an annulus, the degree of equivalent flattening may be considered as the ratio of median curved annular breadth to thickness of the cross section.

In accordance with the invention, I have discovered that in low-pressure electric discharge devices of the resonance radiation type, such as the usual elongated fluorescent lamps, including an inert starting gas or mixture of gases from group 0 of the periodic table, such as argon, at a pressure in the millimeter range and a vaporizable metal filling, such as mercury, a marked increase in lumen output at nominal efficiency may be effected by lowering the pressure of the starting gas. A most striking aspect of this discovery is that the increase in efficiency in the range of conventional or nominal efficiencies, that is, in the range of efficiencies in which a fluorescent lamp must operate in order to be commercially acceptable, is greater with higher *p/a* ratios. In other words reducing the starting gas pressure by a given amount in a lamp of high *p/a* ratio, as in a re-entrant groove lamp, gives a practical and commercially utilizable increase in efficiency, whereas in a circular-sectioned tube, it does not. The percentage increase in efficiency in lamps of high *p/a* ratio is great enough that some reduction in the life of the lamp resulting from increased cathode deterioration may be tolerated and a greater lumen output be provided at reduced cost, when both the cost of the lamp and the cost of the electricity are taken into account.

For further objects and advantages and for a better understanding of the invention, attention is now directed to the following description and accompanying drawings. The features of the invention believed to be novel will be more particularly pointed out in the appended claims.

In the drawings:

Fig. 1 is a pictorial view of a flattened tube discharge lamp in which my invention may be embodied;

Fig. 2 is a cross sectional view through the central portion of the lamp of Fig. 1;

Fig. 3 is a pictorial view of a tubular lamp with a continuous re-entrant portion or groove in which the invention may be embodied;

Fig. 4 is a pictorial view of a tubular lamp with short longitudinally extending indentations or dimples alter-

nating on opposite sides and in which the invention may be embodied;

Fig. 5 is a cross sectional view through the grooved lamp of Fig. 3 and is at the same time a cross sectional view through one of the indentations of the dimpled lamp of Fig. 4;

Fig. 6 is a graph affording a comparison of the radiation efficiency of lamps embodying the invention with that of prior lamps.

Referring to Fig. 1, lamp **1** therein illustrated comprises an elongated envelope **2** having circular or rounded tube ends **3, 3** which are annularly reduced or shouldered and have secured thereto bases **4, 4,** each provided with a pair of insulated contact terminals or pins **5, 6.** As shown at the end of the lamp where a fragment of the envelope wall has been broken out, the electrode mount or stem flare **7** is sealed peripherally into the circular tube end and includes a press **8** through which are sealed current inlead wires **9, 11.** The inward projections of the lead wires support the filamentary cathode **12,** whereas the outward projections are connected to the terminal pins **5, 6.** Cathode **12** may consist of a coiled-coil of tungsten wire provided with an overwind and coated with an activated mixture of alkaline-earth oxides, such as the usual mixture comprising barium and strontium oxides. The other end of the lamp is provided with a similar cathode, and one of the stem flares is provided with an exhaust tube which is sealed or tipped off in the usual fashion. The lamp contains an ionizable atmosphere including a starting gas or mixture of one or more of the inert rare gases of group 0 of the periodic table, such as argon, at a low pressure to be more particularly specified hereinafter. A supply of ionizable and vaporizable metal to provide the discharge atmosphere in operation is indicated at **13** as a droplet of mercury exceeding in amount the quantity vaporized during the operation of the lamp. A phosphor coating is indicated at **14** on the inside of the envelope wall and converts the resonance radiation of the discharge through the mercury vapor into visible light. The lamp may be coated externally with a water-repellent substance to facilitate starting of the lamp under substantially any atmospheric conditions.

As here shown, the lamp envelope or tube **2** is flattened substantially throughout its length between the round ends **3, 3** to an elongated loop-like cross section as illustrated in Fig. 2. The cross section comprises wide substantially flat walls **16, 16** interconnected by semicircular rounded edge walls **17, 17.** The flattened portion may merge into the round tube ends **3, 3** with a wedge-like taper indicated at **18, 18.**

In the usual low-pressure positive column discharge lamps, such as the well-known fluorescent lamps in common use, it has been customary to provide the argon starting gas filling at a pressure of some 2 to 5 millimeters of mercury. The pressure ordinarily used in the common sizes of fluorescent lamps has been 3 to 3.5 millimeters of mercury. In accordance with the invention, the starting gas, in this case argon, is provided at a substantially lower pressure falling in the range from 0.1 to 1.0 millimeters of mercury. Such a filling unexpectedly provides a substantial increase in radiation efficiency or lumen output when the lamp is operated at conventional loadings or higher, for instance, at loadings of 10 watts per lineal foot or higher. In the range of loadings centering about 20 watts per lineal foot in particular, the percentage increase in lumens is much higher than in a conventional circular-sectioned lamp of like perimeter under the same conditions of loading; for instance, the increase may be as much as 25 percent as compared with 0 to 5 percent in the conventional round tube lamp.

Referring to Fig. 3, lamp **21** illustrated therein achieves a high p/a ratio by means of a unique configuration which provides improved implosion resistance along with directional effects in the radiant output and other advantages discussed in my aforementioned copending application. The vitreous envelope **22** is provided with a transversely re-entrant portion of groove **23** extending longitudinally substantially throughout its length between the round ends **3, 3.** The resulting cross section, as shown in Fig. 5, is in general a U shape comprising a convex outer wall **24,** a concave inner wall **25** of greater average curvature than the outer wall, and convex joining or edge walls **26, 26** of slightly greater curvature than the concave inner wall. An alternative way of regarding envelope **22** is to consider it as a flattened tube rolled up into a U shape and providing a discharge cross section which is a sector of an annulus.

Referring to Fig. 4, lamp **31** illustrated therein achieves a high p/a ratio by means of a dimpled or interrupted groove configuration having yet greater implosion resistance than that of lamp **21** shown in Fig. 3. Here the envelope **32** is provided with spaced indentations or re-entrant portions **33, 34** on diametrically opposite sides giving a dimpled or crenelated appearance. The indentations **33, 34** may be considered to be short longitudinally extending transversely re-entrant groove portions alternating on opposite sides of the envelope. A cross section of the envelope through one of the indentations is similar to that of envelope **22** illustrated in Fig. 3 and is likewise shown by the cross sectional view of Fig. 5.

The advantages accruing, in accordance with the invention, from the provision of very low starting gas pressures in elongated tubes of high p/a ratio are graphically illustrated in Fig. 6. The graph compares the lumen characteristics, at argon pressures of 3 millimeters and .5 millimeter, of a conventional round tube 100-watt, 2⅛ inch diameter, 60-inch long fluorescent lamp, designated F100T17, with those of similar lamps reshaped to the dimpled configuration illustrated in Fig. 4. The depth of the groove portions or dimples, by relation to the boundary of the original circularly sectioned tube, was approximately 1⅛ inches. This provided a mean cross sectional area, taking into account the gaps between groove portions, approximately equivalent to that of a tube of the same perimeter flattened in a 3:1 ratio. This configuration provides a percentage increase in the mean p/a ratio of the dimpled tube, over that of the original circular-sectioned tube, of approximately 40 percent.

It will be appreciated that without any change in the argon starting gas pressure and using, for instance, the conventional argon pressure of 3 millimeters of mercury, an increase in the p/a ratio for a given perimeter of lamp will in and of itself bring about a decided increase in efficiency at the same loading. Reference may be made to my earlier-mentioned copending application for theoretical explanations of this increase in efficiency. However, lowering the starting gas pressure provides a further and very noticeable increase in efficiency, especially at loadings above 20 watts per foot.

The curves of Fig. 6 are plotted on the basis of lamp wattage per foot measured in watts as abscissa, and lumens per watt or efficiency as ordinate. Solid line curves **41** and **42** show the lumens per watt or efficiency of conventional round tube T17 lamps and dimpled re-entrant groove T17 lamps, respectively, at the usual argon pressure of 3 millimeters of mercury. The luminous efficiency figures were determined using a halophosphate phosphor coating inside the lamp envelopes producing a standard cool white (4500° K.) color with which the light conversion efficiency is nearly equal to that obtained with a standard warm white (3500° K.) color, being but a few percent (2% to 4%) lower. A phosphor which may be used in achieving these results is a halophosphate phosphor activated with antimony and manganese as per U.S. Patent 2,488,733 McKeag et al. assigned to the same assignee as the present invention. As is well known, in the case of the standard warm white (3500° K.) color, the average luminosity of the spectrum is approximately 47% of the luminosity of the 5540 A. yellow-green line

to which the eye is most sensitive, and the conversion by the phosphor from the 2537 A. ultraviolet line proceeds according to a quantum ratio of approximately 44% at a utilization efficiency of approximately 86%.

The curves of Fig. 6 show that for both round tube (curve **41**) and re-entrant groove (curve **42**) lamps, the efficiency or lumens per watt decreases with increased loading. This fact has limited the loading in ordinary fluorescent lamps. However, it will be observed that the lumens per watt in the dimpled re-entrant groove tube are greater than in the round tube throughout the wattage range which has been plotted. The percentage increase in lumens per watt of the dimpled re-entrant groove tube over the round tube throughout this range averages approximately 20 percent; the novel features of re-entrant groove lamps achieving these results without change in starting gas pressure, are claimed in my aforementioned copending application.

Dotted line curves **43**, **44** illustrate the effect of reducing the argon starting gas pressure to 0.5 millimeter, the former for the round tube and the latter for the dimpled re-entrant groove tube. Curve **43** shows that reducing the argon pressure in the round tube has little effect on the efficiency in the conventional range of loadings from 10 to 20 watts per foot: at a loading of 18 watts per foot, the effect is zero; below 18 watts per foot, the increment is negative; from 18 to 20 watts per foot, it is slightly positive. In the dimpled re-entrant groove tube on the other hand, curve **44** shows that reducing the argon pressure causes a decided increase in efficiency in the aforesaid conventional range of loading, even down to a loading of 10 watts per foot. For instance, at 18 watts per foot in the dimpled tube, the increase in efficiency by reason of the reduction in argon pressure is approximately 13 percent and this is over and above the increase in efficiency which resulted from increasing the p/a ratio by the re-entrant groove configuration.

The curves of Fig. 6 illustrate the reasons why practical and commercially utilizable benefits are realized from reducing the starting gas pressure in non-circular lamps having a high perimeter to area ratio as contradistinguished from ordinary round tube lamps where such benefits are not realized. Comparing curves **41** and **43** for the round tube lamps at argon filling pressures of 3.0 mm. and 0.5 mm. respectively, it is seen that the increase in efficiency with the low-starting gas pressure only begins at loadings in excess of 18 watts per foot: below this loading, the increment is in fact negative. However at the loading of 18 watts per foot which may be regarded as a crossover point, the efficiency of the round tube lamp is approximately 50 lumens per watt, and it is only as the loading is raised further with further reduction in efficiency that any benefit from the use of a reduced filling gas pressure in the round tube lamp begins to make itself felt. However, except for very short lamps generally under two feet in length where the electrode losses become a disproportionately large factor, an efficiency less than 50 lumens per watt is commercially unacceptable, and accordingly there is no practical benefit from lowering the starting gas pressure. (See for instance I.E.S. Lighting Handbook, copyright 1947, by the Illuminating Engineering Society, pages 6–37 to 6–39, particularly Figs. 6–34.) Stated in another way, the reduction in filling gas pressure in a round tube lamp produces either a decrease in efficiency or a negligible increase in the efficiency range above 50 lumens per watt where it is a useful lamp; in the efficiency range below 50 lumens per watt where the reduction in pressure can produce a substantial increase in efficiency, the lamp is no longer acceptable for general lighting. The end result is that reduction in starting gas pressure affords no worthwhile practical advantages for round tube lamps in the usual sizes.

With noncircular lamps of high perimeter to area ratio such as re-entrant groove lamps, on the other hand, it is seen, by reference to curves **42** and **44**, that the increase in efficiency which results from reducing the starting gas pressure occurs, throughout the entire range of loadings from 10 to 35 watts per foot, in the efficiency region exceeding 50 lumens per watt. It can readily be visualized that if curves **42** and **44** were projected to the left in the drawing, the crossover point would be in the region of 69 lumens per watt at a loading of approximately 9 watts per foot. Curve **44** further shows that dimpled re-entrant groove lamp **31**, illustrated in Fig. 4, may be operated at a loading of 35 watts per foot with an efficiency of 59 lumens per watt, a remarkably high efficiency for such a heavy loading. The reduction in starting gas pressure in this case has increased the efficiency from approximately 48.5 lumens per watt to 59 lumens per watt, an increase of 21%, which restores the lamp to an overall efficiency well within commercially acceptable limits. Accordingly it will readily be understood that in lamps of high p/a ratio such as re-entrant groove lamps, the reduction in starting gas pressure produces highly advantageous results of practical utility and not merely of theoretical interest.

Thus, the results graphically illustrated in Fig. 6 demonstrate that the combination of a noncircular lamp of high p/a ratio and a low starting gas pressure produces the unexpected result of a substantial increase in efficiency in a region of efficiency allowing gainful utilization of such increase. Otherwise stated, reduction of starting gas pressure in a noncircular lamp of high p/a ratio such as a re-entrant groove lamp produces an increase in efficiency which is of practical benefit and commercially utilizable, whereas the same reduction in starting gas pressure in lamps of circular section produces either no increase in efficiency, or an increase which is impractical of use because it can only occur at such a low overall efficiency that the lamp ceases to be a source of lighting for commercial applications.

It will be appreciated that the increase in efficiency which is realized from the combination of lamps of high p/a ratio and low starting gas pressure is an outstanding result. It may be utilized either to increase the efficiency of the lamps or to increase the loading at a given efficiency. For instance, the dimpled re-entrant groove lamp shown in Fig. 4 at a pressure of 0.5 millimeter of argon may be loaded up to 35 watts per foot, and, as seen by extrapolation of curve **44**, even up to 40 watts per foot, and the efficiency will still be substantially equal to that of the round lamp at 3 millimeters of argon. (The lamps were not actually tested at loadings of 40 watts per foot, because the cathodes which were used were incapable of withstanding the high currents, and larger cathodes will have to be used for these high loadings.) Translated into practical terms, the above-described results indicate that a single 5 foot long lamp (as that of Fig. 4) may be used to provide approximately the same illumination for the same quantity of electricity as formerly required 5 conventional 4 foot long, 40-watt fluorescent lamps. Or using length as the basis of comparison, 5 feet of lamp may now be used to effect the illumination that formerly required 20 feet: the economic advantage is obvious and needs no elaboration.

Useful beneficial results in accordance with the invention are obtained when the inert starting gas pressure is lowered to 1 millimeter of mercury or less. The lower limit of starting gas pressure is determined by the need for a reasonably low starting voltage for the lamp. It is also necessary to provide some starting gas in order to blanket the cathodes during operation and prevent excessively rapid evaporation of activating material therefrom. The useful range of inert starting gas pressure in accordance with the invention is from 0.1 to 1.0 millimeter of mercury. Besides argon, the other commonly used inert starting gases or starting gas mixtures including krypton and xenon, provide generally similar benefits

through reduction in starting gas pressure. A starting gas mixture consisting of 50 percent argon and 50 percent krypton has been tested and efficiency was found to benefit in like fashion from lowering the pressure in lamps of high p/a ratio in accordance with the invention.

The lowering of inert starting gas pressure to the range of 0.1 to 1.0 millimeter of mercury in accordance with the invention is useful with lamps of high p/a ratio, that is having an equivalent flattening of 2:1 or greater, throughout the linear loading range in excess of 10 watts per foot where acceptable efficiencies (approximately 50 lumens per watt or higher in 3500° K. warm white) are realized. It is particularly useful in the loading range from 20 to 40 watts per foot, corresponding to wall loadings of approximately 0.04 to 0.08 watts per cm.^{2} (0.26 to 0.52 watts per in.^{2}). Re-entrant groove T–17 lamps as illustrated in Figs. 3 and 4, having a maximum diameter of approximately 5.4 cm. (2⅛ in.) and having a perimeter of 16.9 cm. (6.66 in.) and a cross-sectional area of 12.1 cm.^{2} (1.88 in.^{2}), are most effectively operated near the upper end of this preferred range, for instance at 35 watts per linear foot, corresponding to a wall loading of approximately 0.07 watts per cm.^{2} (0.44 watt per in.^{2}), under which conditions, lowering of the starting gas pressure in accordance with the invention will provide an increase of approximately 21% in lumens per watt.

The following may be the explanation for the unexpected and highly useful increase in efficiency in high p/a ratio lamps, such as re-entrant groove lamps, resulting from lowering the starting gas pressure. It has been observed that in a re-entrant groove tube at conventional starting gas pressures such as 3 millimeters of mercury, the discharge decreases slighly in intensity toward the narrow edge walls or rails (**26**, **26** in Fig. 5) of the tube. In other words, the discharge does not fill the cross section of the tube perfectly uniformly but tends to concentrate somewhat near the center. Reducing the argon gas pressure reduces this effect and causes the discharge to fill out the tube more uniformly.

The above described effect is probably due primarily to reduced heating of the gas by reason of the smaller elastic collision losses in the tube of high p/a ratio. At higher starting gas pressures, the elastic collision losses cause development of heat in the body of the gas proportionally more than near the edge walls or rails; this causes displacement of gas towards the edge walls and this in turn further increases the conductivity of the core or central part of the discharge in relation to the conductivity at the rails or edge walls, thereby accentuating the constriction. Reducing the starting gas pressure counters or opposes the foregoing chain of effects, and thus is most effective in lamps of high p/a ratio, such as re-entrant groove lamps.

Another secondary consideration which may have a contributory effect is that the lower gas pressure entails a longer mean free path for the electrons and hence greater diffusibility. A further factor is that the concentration of metastable mercury atoms is lower at the lower gas pressure, as also the electron and ion concentrations. This may result in more single stage ionization (by relation to two stage ionization) which is less constricting than the two stage ionization which is more prevalent at higher pressures. These factors thus result in reducing the tendency to constrict and are accordingly relatively more effective in a lamp of high p/a ratio where constrictive effects are of greater import. Whereas the foregoing theory and explanations are the best which I can offer at the present time, it is to be clearly understood that I do not intend thereby to make this invention subservient thereto.

While certain specific embodiments of the invention have been illustrated and described in detail, various modifications will readily occur to those skilled in the art. The appended claims are therefore intended to cover any such modifications coming within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A low-pressure positive column discharge lamp comprising an elongated generally tubular envelope of equivalent flattened cross section having a ratio of circumference to cross sectional area at least 20 percent greater than a circularly sectioned tube of the same circumference, a pair of electrodes sealed into opposite ends of said envelope, and an ionizable medium contained within said envelope operable at a loading not less than approximately 20 watts per lineal foot of said envelope and comprising an inert starting gas at a pressure in the range from 0.1 to 1.0 millimeters of mercury and a small quantity of mercury in excess of that vaporized during operation at said loading.

2. A low-pressure positive column discharge lamp comprising an elongated generally tubular envelope of equivalent flattened cross section having a ratio of circumference to cross sectional area at least 20 percent greater than a circularly sectioned tube of the same circumference, a pair of electrodes sealed into opposite ends of said envelope, and an ionizable medium contained within said envelope operable at a loading not less than approximately 20 watts per lineal foot of said envelope and comprising argon at a pressure in the range from 0.1 to 1.0 millimeters of mercury and a small quantity of mercury in excess of that vaporized during operation at said loading.

3. A low-pressure positive column resonance radiation discharge lamp comprising an elongated generally tubular envelope of non-circular cross section having an equivalent flattening of at least 2:1, a pair of electrodes sealed into opposite ends of said envelope, and an ionizable medium contained within said envelope operable at a linear loading in the range of approximately 20 to 40 watts per lineal foot and at a wall loading in the range of approximately 0.04 to 0.08 watts per cm.^{2} of said envelope and comprising an inert starting gas at a pressure in the range from 0.1 to 1.0 millimeters of mercury and a small quantity of mercury in excess of that vaporized during operation at said loading.

4. A lamp as in claim 3 wherein the inert starting gas is argon.

5. A low-pressure positive column resonance radiation discharge lamp comprising an elongated generally tubular envelope having a longitudinally extending transversely re-entrant groove defining a discharge space having the general cross section of a sector of an annulus, a pair of electrodes sealed into opposite ends of said envelope, and an ionizable medium contained within said envelope comprising an inert starting gas at a pressure in the range from 0.1 to 1.0 millimeters of mercury and a small quantity of mercury in excess of that vaporized during operation.

6. A low-pressure positive column resonance radiation discharge lamp comprising an elongated generally tubular envelope having a longitudinally extending transversely re-entrant groove defining a discharge space having the general cross section of a sector of an annulus with a degree of equivalent flattening as determined by the ratio of annular breadth to maximum annular wall-to-wall spacing in the discharge space in excess of 2:1, a pair of electrodes sealed into opposite ends of said envelope, and an ionizable medium contained within said envelope operable at a linear loading in the range of approximately 20 to 40 watts per lineal foot and at a wall loading in the range of approximately 0.04 to 0.08 watts per cm.^{2} of said envelope and comprising an inert starting gas at a pressure in the range from 0.1 to 1.0 millimeters of mercury and a small quantity of mercury in excess of that vaporized during operation at said loading.

7. A lamp as in claim 6 wherein the inert starting gas is argon.

8. A lamp as in claim 6 wherein the inert starting gas is argon at a pressure of approximately 0.5 millimeters of mercury.

References Cited in the file of this patent

UNITED STATES PATENTS

2,135,480	Birdseye	Nov. 8, 1938
2,190,009	Boucher	Feb. 13, 1940
2,229,962	DeReamer	Jan. 28, 1941
2,317,265	Foerste	Apr. 20, 1943
2,687,486	Heine	Aug. 24, 1954
2,714,682	Meister	Aug. 2, 1955

FOREIGN PATENTS

861,799	France	Nov. 4, 1940
123,425	Australia	Dec. 1, 1944