

PATENT SPECIFICATION

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(54) IMPROVED ARC-DISCHARGE LAMP

(71) We, WESTINGHOUSE ELECTRIC CORPORATION, of Westinghouse Building, Gateway, Center, Pittsburgh, Pennsylvania, United States of America, a company organised and existing under the laws of the Commonwealth of Pennsylvania, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention generally relates to arc-discharge lamps and, more particularly, to so-called metal halide discharge lamps wherein predetermined amounts of selected discharge-sustaining materials are utilized in order to improve the performance of the device.

An aim of the present invention is to provide a discharge-sustaining filling for an arc-discharge lamp whereby, in addition to an efficient discharge, optimum efficiency is realized at a relatively low envelope temperature.

According to the present invention an arc-discharge lamp comprises a sealed elongated light-transmitting envelope which encloses a predetermined volume, electrical lead-in conductors sealed through said envelope and electrically connected to electrodes which are operatively spaced apart a predetermined distance within said envelope, a discharge-sustaining filling enclosed by said envelope and including a small charge of rare ionizable starting gas; mercury in a predetermined amount as required which when fully vaporized as the sole discharge-sustaining constituent is capable of providing an operating mercury-vapor pressure of from 3 to 15 atmospheres as calculated on the basis of an average mercury vapor temperature of 2000°K; at least one of praseodymium halide, neodymium halide and cerium halide, excluding the fluoride, in total amount of from 1.4×10^{-6} to 5.4×10^{-5} gm mole/cm of spacing between said electrodes; cesium halide, excluding the fluoride, in amount of from

3.5×10^{-7} to 5.4×10^{-5} gm mole/cm of spacing between said electrodes; and the molar ratio of said praseodymium halide, neodymium halide and cerium halide to said cesium halide being from 4/1 to 1/2.5.

As a supplemental discharge-sustaining filling the envelope also includes at least one halide, excluding the fluoride, of sodium halide, dysprosium halide, and samarium halide, the molar ratio of said dysprosium halide and said samarium halide to the at least one praseodymium, neodymium and cerium halide being less than 5/1, and the molar ratio of said sodium halide to the cesium halide being less than 5/1.

Additional supplemental discharge-sustaining filling to be included can be at least one halide, excluding the fluoride, of holmium halide, scandium halide, gadolinium halide and indium halide, the molar ratio of said holmium and scandium and gadolinium halides to the at least one praseodymium, neodymium and cerium halide is less than 5/1, and the molar ratio of said indium halide to the at least one praseodymium, neodymium and cerium halide being less than 1/1.

In order that the invention can be more clearly understood, convenient embodiments thereof will now be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a discharge lamp, shown partly in section, which incorporates a quartz inner envelope and a discharge-sustaining filling in accordance with the present invention;

Figure 2 is a modified form of discharge lamp showing only a sectional view of the inner arc tube which is formed of polycrystalline alumina or similar refractory envelope material and which incorporates a discharge-sustaining filling in accordance with the present invention; and

Figure 3 is a graph of relative efficiency versus minimum envelope temperature illustrating the lower envelope temperatures which are required to achieve optimum efficiency

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when utilizing a discharge-sustaining filling in accordance with the present invention.

Referring to Fig. 1, the discharge lamp 10 is generally similar in construction to the usual high-pressure, mercury-vapor lamp and comprises a radiation-transmitting sealed inner envelope or arc tube 12 having electrodes 14 operatively disposed proximate either end thereof and operable to sustain a vapor discharge therebetween. A charge of mercury 16 and a small charge of rare ionizable starting gas such as 20 torrs of argon are contained within the inner envelope 12. The charge of mercury 16 is present in predetermined amount as required, when fully vaporized as the sole discharge-sustaining constituent, to provide an operating mercury-vapor pressure of from 3 to 15 atmospheres as calculated on the basis of an average temperature for the vaporized mercury of 2000°K. This average temperature may vary somewhat depending upon the various discharge-sustaining constituents which are used and the lamp operating conditions, but this indicated figure is a representative average temperature for the vaporized mercury. Since the envelope volume is always known, the required amount of mercury to provide the proper operating conditions can readily be calculated. During operation of the lamp, the other discharge-sustaining materials may interact with the mercury to affect the actual operating pressure of the mercury and, in addition, the extreme temperature gradients from the actual arc to the envelope wall may have an effect on the actual pressure within the operating device. For this reason, it is more accurate to express the required amount of mercury as if that material, per se, were the sole discharge-sustaining constituent, since the amounts of mercury placed into the arc tube are known and the resulting pressure, as determined by the foregoing mercury vapor temperature, can readily be ascertained.

At least one of praseodymium halide, neodymium halide and cerium halide 18, excluding the fluoride, is included within the arc tube 12 in total amount of from 1.4×10^{-6} to 5.4×10^{-8} gram mol/centimeter of spacing between the electrodes 14, and as a specific example, the electrodes are spaced from each other by a distance of 7 centimeters and the arc tube 12 encloses a volume of 20 cubic centimeters. Also included within the arc tube is cesium halide 20, excluding the fluoride, in amount of from 3.5×10^{-7} to 5.4×10^{-5} gram mol/centimeter of spacing between the electrodes 14. In accordance with the present invention, the molar ratio of total praseodymium halide, neodymium halide and cerium halide to cesium halide is from 4/1 to 1/2.5.

A radiation-transmitting, sealed outer envelope 24 is spaced from and surrounds the arc tube and preferably the space between the arc tube 12 and the outer envelope 24

is evacuated. Electrical lead-in conductors 26 are sealed through both the inner arc tube 12 and the outer envelope 24 and serve to electrically connect the operating electrodes 14 to a conventional power source (not shown).

A starting electrode 30 is also included within the arc tube 12 and connects through a starting resistor 32 to one end of the electrical lead-in conductors 26. The arc tube 12 is maintained in spaced relationship from the outer envelope 24 by means of a conventional supporting frame 34. Ribbon conductors 36 serve to facilitate hermetically sealing the lead-in conductors through the ends of the arc tube. The lead-in conductors are sealed through the outer envelope 24 by means of a conventional re-entrant stem press 38 and connect to a standard mogul base 40 to facilitate electrical connection to the power source. As a specific example, the lamp 10 as shown is designed to operate with the power input of 500 watts.

In the alternative embodiment 42, as shown in Fig. 2, the arc tube or envelope 44 is a high density sintered polycrystalline alumina body which has alumina end caps 46 sealed thereto. The electrodes 48 are operatively positioned proximate the envelope ends. At the ends of the arc tube 44 there are provided exhaust and fill tubulations 50 which also serve the function of supporting the electrodes 48. In accordance with the present invention, the mercury 16, at least one of praseodymium iodide, neodymium iodide and cerium iodide 18 and also cesium iodide 20 are included within the arc tube 44 in predetermined amount as specified for the previous embodiment, along with the small charge of inert ionizable starting gas. To complete this embodiment as an operative device, the arc tube 44 would normally be included within an outer envelope as in the embodiment shown in Fig. 1, and the general construction of such a device is well known.

As outlined hereinbefore, the essential constituents which comprise the discharge-sustaining filling are the small charge of rare ionizable starting gas, mercury as required to provide an operating vapor pressure of mercury per se of from 3 to 15 atmospheres, at least one of praseodymium halide, neodymium halide and cerium halide, excluding the fluoride, in predetermined amount and cesium halide, excluding the fluoride, in predetermined amount, with a specified relative molar ratio of these rare-earth metal halides to cesium halide. The functioning of the mercury is to provide adequate voltage drop or loading between the electrodes and in conjunction with the cesium halide, the relatively high mercury vapor pressure and cesium halide function to lower the minimum envelope temperature or so-called "cold-spot" temperature at which optimum lamp operat-

ing efficiency is obtained. The specified rare-earth metal halides function to produce an extremely efficient discharge, and cerium halide is preferred. As a specific example, for an arc tube which encloses a volume of approximately 20 cubic centimeters and an electrode spacing of 7 centimeters, mercury included in amount of approximately 200 mg. will provide a mercury operating pressure of approximately 8 atmospheres. Along with the mercury filling are included cerium triiodide in amount of 20 milligrams and cesium iodide in amount of 10 milligrams. Alternatively, praseodymium triiodide in amount of 20 milligrams of neodymium triiodide in amount of 20 milligrams can be used to replace the cerium iodide in the foregoing example. These rare-earth metal iodides can be mixed, if desired.

In order to improve the color appearance and color rendering properties which are obtained from a discharge-sustaining filling as described hereinbefore, it is highly desirable to include one or more of the following halides, excluding the fluorides: sodium halide, dysprosium halide and/or samarium halide. The sodium halide provides radiations in the yellow-orange region of the visible spectrum, dysprosium halide provides a red and blue emission and samarium halide provides a bluish-white emission. The supplemental rare-earth halides may be regarded as a partial substitute for the praseodymium, neodymium and/or cerium halides, although preferably these supplemental halides are present in a total amount of at least 1.4×10^{-6} gram mol/centimeter of electrode spacing. The sodium halide may be regarded as a partial substitute for the cesium halide, although the cesium halide should always be present in amount of at least 3.5×10^{-7} gram mol/centimeter of electrode spacing. It is preferred that the sodium halide be present in an amount of at least 3.5×10^{-7} gram mol/cm of electrode spacing. Preferably, the supplemental rare-earth halides, as outlined hereinbefore, namely dysprosium halide and samarium halide, are present in approximately equal gram mol amount with respect to the praseodymium, neodymium and/or cerium halides and the mol ratio of supplemental rare-earth halide to these required halides should not exceed 5/1. Preferably the sodium halide is present in approximately equal gram mol amount with respect to the cesium halide and the mol ratio of sodium halide to cesium halide should not be greater than 5/1.

In Fig. 3, is shown a graph of relative efficiency versus minimum envelope temperature for two embodiments of discharge lamps (curves D and E) fabricated in accordance with the present invention, and equivalent performances for prior art lamps are also shown (curves A, B and C). The curve design-

ated "A" illustrates luminous efficiency versus minimum envelope temperature for an arc tube dosed with 20 milligrams cerium triiodide, 20 milligrams of dysprosium triiodide, 0.4 milligram of thallium metal, and 50 milligrams of mercury which as the sole discharging-sustaining material would provide an operating mercury vapor pressure of approximately 2 atmospheres. The arc tube had an electrode spacing of 7 centimeters and an arc tube volume of 20 cc. As shown, the graph of efficiency versus temperature is essentially a straight line relationship. Since, as a practical matter, the maximum practical envelope temperatures are limited, the efficiency which is obtainable from such a lamp is likewise limited.

In the curve designated "B", 15 milligrams of cesium iodide was used to replace the thallium and, as shown, with an operating mercury pressure of approximately 2 atmospheres, a peak of efficiency is realized at a somewhat reduced minimum envelope temperature, with the optimum efficiency being realized at a minimum envelope temperature of approximately 910° centigrade. Such a temperature is still unduly high, however, for use as a practical lamp embodiment.

In the curve designated "C", the lamp envelope which had an electrode spacing of 7 cm. and a volume of 8 cc. was dosed with 10 milligrams of cerium triiodide and 10 milligrams of dysprosium triiodide along with 150 milligrams of mercury. This would provide an operating pressure for the mercury per se of approximately 15 atmospheres. As shown, the graph of efficiency versus minimum envelope temperature again is a straight line relationship.

In the curve designated "D", the arc tube, which had an electrode spacing of 7 cm. and a volume of 8 cc., was dosed with 10 milligrams cerium triiodide, 10 milligrams dysprosium triiodide, 10 milligrams of cesium iodide, and 100 milligrams of mercury which if used as the sole discharge-sustaining material would provide an operating mercury vapor pressure of approximately 10 atmospheres. Optimum efficiency of approximately 155 lumens per watt was achieved with a minimum envelope temperature of approximately 665°C, which temperature can readily be achieved with a quartz arc tube. As the mercury pressure is increased over that mercury pressure present in the lamp used in taking curve "D", the minimum envelope temperature required for optimum efficiency is further decreased and the curve designated "E" represents the performance of a similar arc tube dosed with approximately 10 milligrams cesium iodide, 10 milligrams dysprosium iodide, 10 milligrams cerium triiodide, and 150 milligrams mercury which when utilized as the sole discharge-sustaining constituent would provide an operating

mercury vapor pressure of approximately 15 atmospheres. Optimum efficiency with this embodiment was achieved with a minimum envelope temperature of approximately 520°C, which temperature is readily obtainable with a standard lamp construction. While cerium iodide is preferred in combination with the cesium iodide and high mercury loading in order to obtain optimum efficiency with a relatively low minimum envelope temperature, as shown in the curves "D" and "E" of Fig. 3, the cerium iodide can be replaced by an equivalent gram mol amount of praseodymium iodide or neodymium iodide. This will provide a high optimum efficiency with a lowering of the minimum envelope temperature.

As stated hereinbefore, in order to achieve a usable minimum envelope temperature, the pressure of the mercury vapor should be present in such an amount that if used alone as the discharge-sustaining filling, the mercury vapor pressure in an operating device would be from 3 to 15 atmospheres. For an arc tube having a volume of approximately 20 cc as described in the preferred embodiment, the mercury dosing or loading should be from 75 milligrams to 375 milligrams. Preferably, the mercury vapor pressure during operation of the device should be from 4 atmospheres to 10 atmospheres which will require a mercury dose of from 100 mg. to 250 mg. for the preferred embodiment as described hereinbefore. At a mercury vapor pressure of 4 atmospheres, the minimum envelope temperature as required to obtain optimum efficiency is relatively low. At greater than about 10 atmospheres mercury vapor pressure, the arc tends to be unstable.

In summary, the combination of the cesium halide plus the relatively high mercury loading, along with the praseodymium, neodymium and/or cerium iodide provides an efficient discharge and permits optimum efficiency to be realized with a relatively low envelope temperature. The mechanism by which this is achieved is not completely understood, but it appears that the increased mercury pressure in combination with the cesium halide increases the amount of the desired radiating species in the arc, and provides a more diffuse discharge mode which has a lower, more nearly optimum arc temperature. The resulting broader arc has less tendency to bow during operation and even when it does, this broader arc is less destructive to the envelope because it has a lower temperature and is less concentrated.

Other additional supplemental discharge-sustaining fillings can be used, if desired, further to modify the discharge. Examples of such additional halides, excluding the fluoride of course, are holmium halide, scandium halide, gadolinium halide and indium halide. The holmium provides red and blue supple-

mental radiations, the scandium provides strong blue and supplemental other radiations, the gadolinium provides a blue supplemental radiation and the indium provides blue supplemental radiation. If these additional additives are used, the molar ratio of the holmium, scandium and the gadolinium halides with respect to the praseodymium neodymium and/or cerium halide should be less than about 5/1 and the molar ratio of the indium halide to the rare-earth metal halide should be less than about 1/1. As a matter of practicability, any of these additives should be present in amount of at least about 1.4×10^{-6} gram mol/centimeter of spacing between the arc tube electrodes, although lesser amounts can be used if desired.

While the foregoing examples have considered the iodides, it should be understood that the bromides or the chlorides in equivalent gram mol amount can be substituted therefor. Alternatively, any mixture of iodide, bromide and/or chloride can be utilized if desired. While the specific performance curves as shown in Fig. 3 are directed to a mixture of cesium iodide and cerium iodide with supplemental dysprosium iodide, any of the other supplemental halide additives will provide similar results, although the color of the discharge and color rendering properties thereof will vary depending upon the supplemental additive and the amount which is utilized. Preferably, the supplemental additives are generally used in approximately equal gram mol amount with respect to the praseodymium, neodymium and/or cerium halides, except for the sodium halide supplemental additive which desirably is used in approximately equal gram mol amount as the cesium halide.

A particularly attractive combination of discharge-sustaining fillings is a combination of cerium halide, sodium halide, samarium as the dihalide, and cesium halide. As a specific example, for an arc tube having an electrode spacing of 7 cm. and enclosing a volume of 20 cc, the arc tube is dosed with 200 mg. mercury, 8 mg. cerium triiodide, 5 mg. sodium iodide, 15 mg. samarium diiodide and 5 mg. cesium iodide. Argon starting gas is used at a pressure of 20 torrs. Such an embodiment operates with an efficiency of 140 lumens per watt when operated with a minimum envelope temperature of 560°C. The foregoing so-called dosing will provide a mercury vapor pressure of about 8 atmospheres, the cerium iodide and cesium iodide are present in amount of about 2 to 3×10^{-6} gram mol/cm of electrode spacing, and the samarium iodide and sodium iodide are present in amount of about 5×10^{-6} gram mol/cm of electrode spacing. The color of the discharge approximates a white color and the color rendition of illuminated objects is good.

WHAT WE CLAIM IS:—

1. An arc-discharge lamp comprising a sealed elongated light-transmitting envelope which encloses a predetermined volume, electrical lead-in conductors sealed through said envelope and electrically connected to electrodes which are operatively spaced apart a predetermined distance within said envelope, a discharge-sustaining filling enclosed by said envelope and including a small charge of rare ionizable starting gas; mercury in a predetermined amount as required which when fully vaporized as the sole discharge-sustaining constituent is capable of providing an operating mercury-vapor pressure of from 3 to 15 atmospheres as calculated on the basis of an average mercury vapor temperature of 2000°K; at least one of praseodymium halide, neodymium halide and cerium halide, excluding the fluoride, in total amount of from 1.4×10^{-6} to 5.4×10^{-5} gm mole/cm of spacing between said electrodes, cesium halide, excluding the fluoride, in amount of from 3.5×10^{-7} to 5.4×10^{-5} gm/mole of spacing between said electrodes; and the molar ratio of said praseodymium halide, neodymium halide and cerium halide to said cesium halide being from 4/1 to 1/2.5.

2. A lamp according to claim 1, wherein said mercury is present in predetermined amount as required when fully vaporized to produce an operating mercury vapor pressure of from about 4 to about 10 atmospheres.

3. A lamp according to claim 1 or 2, wherein said halides are the iodides.

4. A lamp according to claim 1, 2 or 3, wherein the mercury is present in amount of from 5 to 12.5 mg/cc of the predetermined volume of said envelope.

5. A lamp according to any of claims 1 to 4, wherein there is also included within said envelope as supplemental discharge-sustaining filling at least one halide, excluding the fluoride, of sodium halide, dysprosium halide, and samarium halide, the molar ratio of said dysprosium halide and said samarium halide to that at least one praseodymium, neodymium and cerium halide being less than 5/1, and the molar ratio of said sodium halide to the cesium halide being less than 5/1.

6. A lamp according to claim 5, wherein the dysprosium halide and the samarium halide are present in amount of at least

1.4×10^{-6} gm mole/cm of spacing between the electrodes, and the sodium halide is present in amount of at least 3.5×10^{-7} gm mole/cm of spacing between the electrodes.

7. A lamp according to claim 5 or 6, wherein the halides are the iodides.

8. A lamp according to claim 5, 6 or 7 wherein the supplemental discharge-sustaining filling is samarium dihalide and sodium halide.

9. A lamp according to claim 8, wherein the mercury vapor pressure attainable is of the order of 8 atmospheres, cerium is present as the triiodide in an amount of about 2 to 3×10^{-6} gram mole/cm of spacing between said electrodes, cesium is present as the iodide in amount of 2 to 3×10^{-6} gram mole/cm of spacing between said electrodes, samarium is present as the diiodide in amount of approximately 5×10^{-6} gram mole/cm of spacing between said electrodes, and sodium is present as the iodide in amount of approximately 5×10^{-6} gram mole/cm of spacing between said electrodes.

10. A lamp according to any of claims 5 to 9, wherein there is also included within said envelope an additional supplemental discharge-sustaining filling of at least one halide, excluding the fluoride, of holmium halide, scandium halide, gadolinium halide and indium halide, the molar ratio of said holmium and scandium and gadolinium halides to the at least one praseodymium, neodymium and cerium halide is less than 5/1, and the molar ratio of said indium halide to the at least one praseodymium, neodymium and cerium halide being less than 1/1.

11. A lamp according to claim 10, wherein scandium halide, holmium halide, gadolinium halide and indium iodide are present in an amount of at least 1.4×10^{-6} gm mole/cm of spacing between said electrodes.

12. A lamp according to claim 11, wherein said halides are the iodides.

13. Arc-discharge lamps constructed, arranged and adapted for use substantially as described herein with particular reference to the Figures 1, 2 or 3 of the accompanying drawings.

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