

[54] **HAFNIUM ACTIVATED METAL HALIDE
ARC DISCHARGE LAMP**

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H01j 17/20

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[56]

References Cited

UNITED STATES PATENTS

2,843,801	7/1958	Kreff	313/184 X
3,384,775	5/1968	Ishler et al.	313/225
3,761,758	9/1973	Bamberg et al.	313/229

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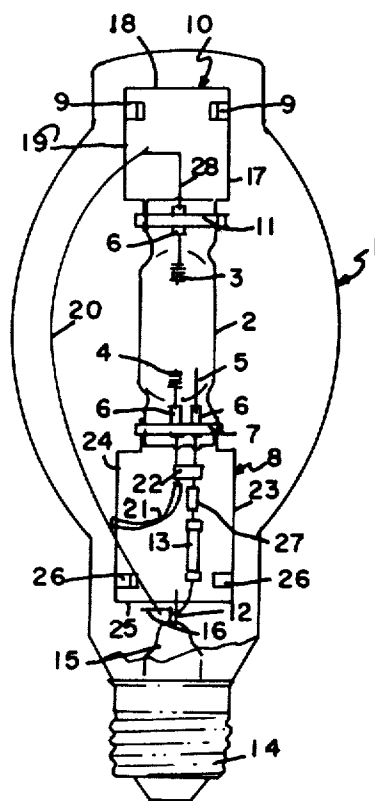
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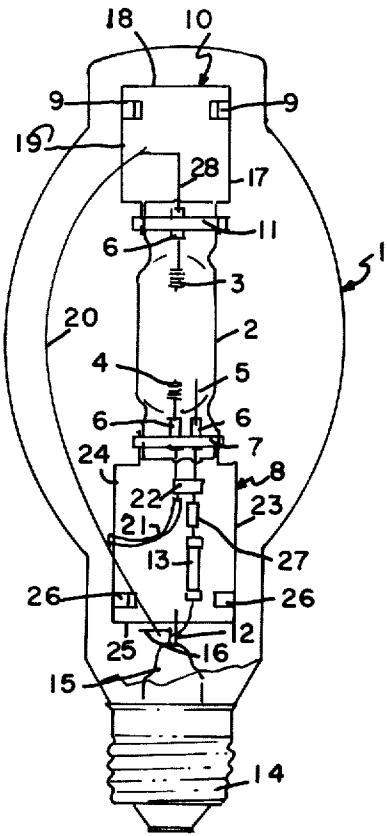
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ABSTRACT

A high intensity arc discharge lamp has a fill including mercury and metal halide and contains hafnium activated electrodes.

3 Claims, 1 Drawing Figure





HAFNIUM ACTIVATED METAL HALIDE ARC DISCHARGE LAMP

BACKGROUND OF THE INVENTION

1. Field Of The Invention

This invention relates to high intensity metal halide arc discharge lamps of the type used for general illumination. Such lamps have a generally cylindrical arc tube having electrodes at each end thereof. The arc tube contains a fill of mercury, metal halide and, for starting purposes, an inert gas. During normal operation, the pressure within the arc tube is between about 1 to 10 atmospheres and the arc tube temperature is between about 450° and 900°C.

2. Description Of The Prior Art

Metal halide arc discharge lamps for general illumination have become commercially useful in the past five to ten years because they are more efficient and yield a whiter light than high pressure mercury vapor lamps. The construction and operation of metal halide lamps are shown in the IES Lighting Handbook, 5th edition, 1972, published by the Illuminating Engineering Society, N.Y., at page 8-34.

The metals generally used in the arc tube fill of such lamps are mercury, sodium, scandium, thorium, gallium, thallium and indium, although the several score metal halide patents that have issued in the past few years suggest the use of 55 different metallic elements, as pointed out in U.S. Pat. No. 3,761,758.

Electrodes for such lamps are generally made of tungsten, and contain, as the electron emissive material, either a metal oxide, such as thorium oxide, or thorium as an activator metal, as shown in U.S. Pat. No. 3,313,974, assigned to the assignee of the instant application. When a dispenser type, that is the metal oxide type, is used, the metal oxide is embedded within the turns of a tungsten coil protected by an outer tungsten coil. And in the case of thorium, a silver thereof is generally attached to the electrode.

During operation, the metal oxide of a dispenser type of electrode is gradually consumed and lamp usefulness ceases when the supply of metal oxide is depleted. In the case of thorium activated cathodes, thorium is, undesirably, an arc constrictor, which can cause early lamp failure if arc-fattening ingredients are not also present in the arc tube.

Accordingly, it is a purpose of this invention to provide a metal halide lamp having improved electrodes which overcome the deficiency of prior art electrodes.

SUMMARY OF THE INVENTION

A metal halide lamp in accordance with this invention comprises an arc tube, usually made of high temperature glass, such as silica, having hafnium activated tungsten electrodes at each end thereof and containing a fill including mercury, a light emitting metal and halogen in the halide form. The hafnium is present on the electrodes in its elemental form as a film and not as an oxide.

Although the prior art does mention this possible use of hafnium as an electron emissive material in electrodes of high intensity arc discharge lamps, previous attempts to so utilize it have been unsuccessful because the operating temperature of such electrodes is so high, that the hafnium is rapidly evaporated therefrom. See, for example, U.S. Pat. No. 2,843,801, at column 1, lines 53-67. In fact, although handbooks on thermionic

properties of elements and compounds do provide the electronic work functions and Richardson constants for eighteen different emissive elements on tungsten, the electronic work functions and Richardson constants for hafnium on tungsten are unknown.

We have found that hafnium can be satisfactorily used as the activating material on the electrodes of metal halide arc discharge lamps provided that the total amount of halogen within the arc tube is controlled in relation to the metals present in the arc tube fill. Also, the hot spot electrode temperature during operation should be such that hafnium from hafnium halide is continuously redeposited on the electrode hot spot at a rate that about equals the rate of hafnium evaporation therefrom, thereby ensuring the presence of hafnium film on the electrodes throughout lamp life.

BRIEF DESCRIPTION OF THE DRAWING

The single FIGURE in the drawing is an elevational view of a metal halide arc discharge lamp in accordance with this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As shown in the drawing, a metal halide lamp in accordance with this invention includes a generally tubular outer bulbous envelope 1 having a bulbous central portion and a conventional base 14 attached to the bottom thereof. Extending inwardly from the base and inside of the envelope 1 is a mount 15 having a pair of stiff lead-in wires 12 and 16 in electrical conducting relation with the base 14. Disposed upon one of the stiff lead-in wires 12 is a lower, U-shaped support 8 welded thereto. U-shaped support 8 comprises a pair of vertical wires 23 and 24 rising from a horizontal base wire 25. The upper ends of lower U-shaped support 8 are welded together with a lower strap 7 which in turn supports an arc tube 2. Preferably, the lower strap includes two sections abutting against either side of arc tube 2 thereby holding it firmly in place. They touch only the press seal of the arc tube and not the body. Generally, both sides of the lower strap 7 can be of identical construction. A pair of bumpers 26 are welded to lower U-shaped support 8 and abut against the tubular portion of the walls of outer bulbous envelope 1, thereby stabilizing the structure within the lamp. Preferably, these bumpers are made of a resilient material so that if the lamp is jarred they will absorb much of the shock.

Since lower U-shaped support 8 is electrically connected to stiff lead-in wire 12, support 8 forms part of the circuit in the device. Current passes from base 14 into lower U-shaped support 8 and thence to lead-in wire 21 which in turn is connected to electrode 4 in the arc tube. It is sometimes desirable to place an insulating shield about lead-in wire 21 to prevent arcing within the lamp and between the various elements. Current passes from lead-in wire 21 to electrode 4 through an intermediary molybdenum foil section 6.

The other side of the circuit is formed through stiff lead-in wire 16 which is preferably bent out of place so that parts on one side of the line are insulated from those on the other side. A resistor 13 is attached to stiff lead-in wire 16 through a lead-in wire associated therewith and thence to a connector 27 which in turn leads through a molybdenum foil section 6 to a starting probe 5. A bimetal 22 is disposed between lead-in wire 21 attached to electrode 4 and connector 27 which is at-

tached to starting probe 5. Bimetal 22 is biased open when the lamp is turned off but when the lamp starts, it biases closed against the lead-in wires to probe 5 thereby establishing the same electrical potential at probe 5 and electrode 4. Such closing prevents electrolysis between the probe and electrode.

At the other end of arc tube 2, an upper support 10 is mounted within the tubular portion of bulbous envelope 1. Support frame 10 includes a horizontal section 18 having vertical supports 17 and 19 depending downwardly therefrom and attached at the free ends to an upper strap 11 which surrounds the press seal of arc tube 2 and rigidly holds it in place. Preferably, the construction and disposition of upper strap 11 is similar to lower strap 7. A pair of upper bumpers 9 are mounted upon vertical sections 17 and 19 of upper support 10 and resiliently abut against the sides of the tubular portion of bulbous envelope 1. Such disposition prevents breakage of the arc tube if the lamp is shaken or dropped.

A lead-in wire 28 extends to the outside of arc tube 2 and is attached at its inner end to a molybdenum foil section 6 and thence to electrode 3. An electrical connection is made between stiff lead-in wire 16 and lead-in wire 28 through a thin conducting lead 20 which may be of any suitable conducting material. Preferably, conducting lead 20 is distantly removed from arc tube 2, generally by bending it close to the perimeter of outer bulbous envelope 1.

Disposed within arc tube 2 is the usual inert starting gas, such as neon, argon, xenon and the like, and a fill which includes mercury, halogen and a light emitting metal. The light emitting metal can be one or more of scandium, sodium, thorium, thallium, indium or any light emitting metal commonly used in metal halide lamps and can be added in element or compound form. The halogen, usually iodine, is generally added as a metal halide. Mercury is present in the usual amount, that is to say, so that under normal operating conditions, the mercury is totally vaporized and produces a pressure within arc tube 2 of about 1 to 10 atmospheres.

Hafnium is present as a film on the hot spot ends of electrodes 3 and 4, which are made of tungsten or thoriated tungsten. The structure of electrodes 3 and 4 is such that their hot spot temperature, during normal lamp operation, is between about 1825°C and 2325°C. This temperature is necessary to ensure that the rate of evaporation of hafnium from the electrodes during operation is about equal to or balances the rate of deposition of hafnium thereon by the dissociation of hafnium iodide. When hafnium is evaporated from the electrodes, it combines with iodine in the arc plasma to form hafnium iodide which, during circulation within the arc tube, is dissociated at the hot spot of the electrodes to deposit hafnium thereat. For this purpose, it is necessary that there be iodine available in the arc plasma to react with the hafnium. Thus, if there are metals present, for example, sodium, whose free energy of formation per iodine atom of the iodide is considerably more negative than that of hafnium iodide, the amount of iodine within the arc tube must exceed the stoichiometric amount needed to completely combine with said metals. Otherwise, iodine will not be available to maintain the regenerative cycle necessary to deposit hafnium on the electrode. However, if there is iodine in excess of the stoichiometric amount equivalent to

the metals having more negative free energy of formation per iodine atom plus the stoichiometric amount equivalent to the hafnium within the arc tube, the equilibrium pressure of the HfI_4 becomes excessive and requires too high a hot spot electrode temperature for satisfactory operation of the lamp.

The optimum hot spot electrode temperature for the hafnium regenerative cycle is determined by the intersection of the curve of HfI_4 equilibrium pressure versus temperature with the curve of hafnium vapor pressure versus temperature. As mentioned before, said optimum temperature is generally between about 1825°C and 2325°C, higher HfI_4 equilibrium pressures requiring higher temperatures. For example, an HfI_4 equilibrium pressure of about 1 millitorr would require a hot spot electrode temperature of about 1825°C, while an equilibrium pressure of about 10 millitorr would require a temperature of about 2100°C.

In one example of a 400 watt lamp in accordance with this invention, arc tube 2 was made of quartz and had an inner diameter of 20 mm and a wall thickness of 1 mm. The arc length, that is, the distance between electrodes 3 and 4 was 45 mm and the arc tube volume was 14.5 cc. Electrodes 3 and 4 were made of 30 mil tungsten rod and had wound thereon a coil of 3½ turns of 28 mil tungsten wire at 100% pitch. Each coil was positioned 109 mils back from the inner end (the hot spot end) of each electrode.

Added to the arc tube, prior to sealing thereof, was a fill consisting of 0.5 mg scandium, 20 mg sodium iodide, 7.3 mg mercury iodide, 0.5 mg hafnium, 51 mg mercury and argon at a room temperature pressure of 35 torr.

Although no hafnium was directly placed on electrodes 3 and 4 during manufacture of arc tube 2, the first operation of the arc tube, that is drawing an arc between electrodes 3 and 4 in sealed arc tube 2, which usually occurs during lamp manufacture, results in the deposition of a hafnium film on the hot spot end of electrodes 3 and 4 as a result of the reaction of hafnium and iodine, and the dissociation of hafnium iodide at the electrodes as previously discussed.

This lamp operated at an efficacy of 96 lumens per watt and had an electrode hot spot temperature of 2230°C, as measured by an infrared radiometric pyrometer.

The iodine for the hafnium-iodine regenerative cycle was supplied by the mercury iodide. The iodine in the sodium iodide was unavailable for this purpose since the free energy of formation per iodine atom of sodium iodide is considerably more negative than that of hafnium iodide; however, the free energy of formation per iodine atom of hafnium iodide is considerably more negative than that of mercury iodide. The free energies of formation per iodine atom for NaI , HfI_4 and HgI_2 are respectively, -56.0, -25.0 and -0.5 kilocalories at 725°C (typical average arc tube wall temperature), and are calculated according to the methods shown in "Thermodynamics", G. N. Lewis and M. Randall as revised by K. S. Pitzer and L. Brewer, 2nd edition, 1961, McGraw-Hill, at pages 169-182, using the reference data in "Thermodynamic Properties of The Halides", L. Brewer et al., in Volume 19B of "National Nuclear Energy Series - Manhattan Project Technical Section", 1st edition, 1950, McGraw-Hill, at pages 76-192.

Examination of the electrodes after 100 hours of operation by means of a scanning electron microscope

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(SEM) revealed that hafnium was present on the electrodes. An SEM topographical scan showed that the hafnium distribution corresponded with the thermal gradient of the operating electrode. That is, the hafnium SEM signal was strongest at the electrode tip, which is the point of highest operating temperature.

In another 400 watt lamp, having the same arc tube size as the previous example, and the same arc tube fill except that the quantity of mercury iodide was reduced from 7.3 mg to 5.0 mg the optimum electrode hot spot temperature was lower than in the previous example, namely, 2150°C. This was obtained by a slight change in the construction of the electrodes, which were made of 36.5 mil tungsten rod and had wound thereon a coil of 3½ turns of 28 mil tungsten wire at 100% pitch. Each coil was positioned 115 mils back from the hot spot end of each electrode. The slight reduction in optimum electrode hot spot temperature required in this example is due to the fact that the equilibrium pressure of HfI_4 is lower than in the previous example because of the reduced quantity of mercury iodide in the arc tube fill.

In a third example, where the mercury iodide was reduced to 3.9 mg, the optimum electrode hot spot temperature was 1980°C. Here, the electrodes were made of 40 mil tungsten rod and had wound thereon a coil of 3½ turns of 28 mil tungsten wire at 100% pitch. Each coil was positioned 119 mils back from the hot spot end of each electrode. Comparison of hafnium activated lamps as per this invention with prior art thorium activated lamps, in 175 watt and 400 watt lamp sizes, show that the hafnium activated lamps consistently yield better efficacy and better maintenance throughout life. This is in large part attributable to the fact that hafnium does not constrict the arc as much as thorium does.

In order to compare the arc construction properties of these two activators, a test was prepared consisting of a group of 400 watt metal halide lamps in which the chemical fill was altered by substituting for the metallic thorium content previously used, various mixture ratios of hafnium and thorium such that the total weight of these two metals was held constant at a value of 0.5 mg. No effect on starting voltage was observed in going from the pure thorium to the pure hafnium system. Photometry at 100 hours indicated some trend to higher lumens with increasing Hf:Th ratio. Visual examination revealed a reduction in the constriction of the arc plasma with increasing Hf:Th ratio. This observation was established using a PAR Vidicon Line Scanner optically filtered for the 5770 Å Hg spectral line. The data was reduced by taking as the arc radius the half-width (in coordinate space) at half-maximum of the 5770 Å radial intensity profile, normalized to the arc tube inner radius, as a function of the Hf:Th ratio. A polynomial regression analysis of this data was carried out, from which the following empirical equation was obtained relating arc construction to Hf:Th ratio:

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$$\frac{\Delta R}{R_T} = 0.135 + 0.152 \left(\frac{\text{Hf}}{\text{Hf} + \text{Th}} \right) - 0.091 \left(\frac{\text{Hf}}{\text{Hf} + \text{Th}} \right)^2$$

The terms Hf and Th are in weight units, R is the arc radius, and R_T is the inner radius of the arc tube. At 0% hafnium - 100 % thorium, the arc is constricted to the extent that its radius is only 13.4% of the arc tube radius. However, at 100% hafnium - 0% thorium, the arc radius is 20% of the arc tube radius. Thus the hafnium arc is about 50% fatter, or less constricted, than the thorium arc.

It has been found that optimum efficacy and maintenance throughout lamp life occur when the amount of hafnium within the arc tube is about equal to 6.2×10^{-7} gram atoms per cm of arc length, at least in arc tubes the primary light emitting metals of which are scandium and sodium. In such lamps activated with hafnium, lamp efficacy was 96.5 LPW, which is higher than the 94.7 LPW efficacy of the thorium activated lamps. Maintenance after 1000 hours operation was 87% for the hafnium activated lamps but only 81.5% for the thorium activated lamps.

We claim:

1. A high intensity metal halide arc discharge lamp comprising: an arc tube having sealed ends and containing a fill including mercury and a metal halide; and hafnium activated electrodes disposed within said arc tube, the size of said electrodes being such that during normal operation of the lamp the rate of evaporation of hafnium from said electrodes is about equal to the rate of deposition of hafnium from hafnium halide thereon, thereby ensuring hafnium activation of said electrodes throughout normal lamp life, and wherein the construction of said electrodes is such that their hot spot temperature during normal lamp operation is between about 1825°C and 2325°C.

2. A high intensity metal halide arc discharge lamp comprising: a sealed arc tube containing hafnium activated electrodes and containing a fill including mercury, sodium halide and a metal halide, the total amount of halogen in said arc tube exceeding the stoichiometric equivalent thereof for all metals in said arc tube having a significantly more negative free energy of formation per iodine atom than hafnium iodide, and wherein said total amount of halogen is less than the sum of the stoichiometric equivalent thereof for the total amount of hafnium in said arc tube plus the stoichiometric equivalent thereof for all metals in the arc tube having a significantly more negative free energy of formation per iodine atom than hafnium iodide.

3. A high intensity metal halide arc discharge lamp comprising an arc tube having sealed ends and electrodes disposed in said ends and containing a fill including mercury, an inert starting gas, sodium iodide, mercury iodide, scandium and hafnium wherein the quantity of hafnium is about 6.2×10^{-7} gram atoms per centimeter of arc length.

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