July 1, 1969 R. E. HANNEMAN ETAL 3,453,477

ALUMINA-CERAMIC SODIUM VAPOR LAMP

Filed Feb. 16, 1967 Sheet 1 of 2

Fig. 1.

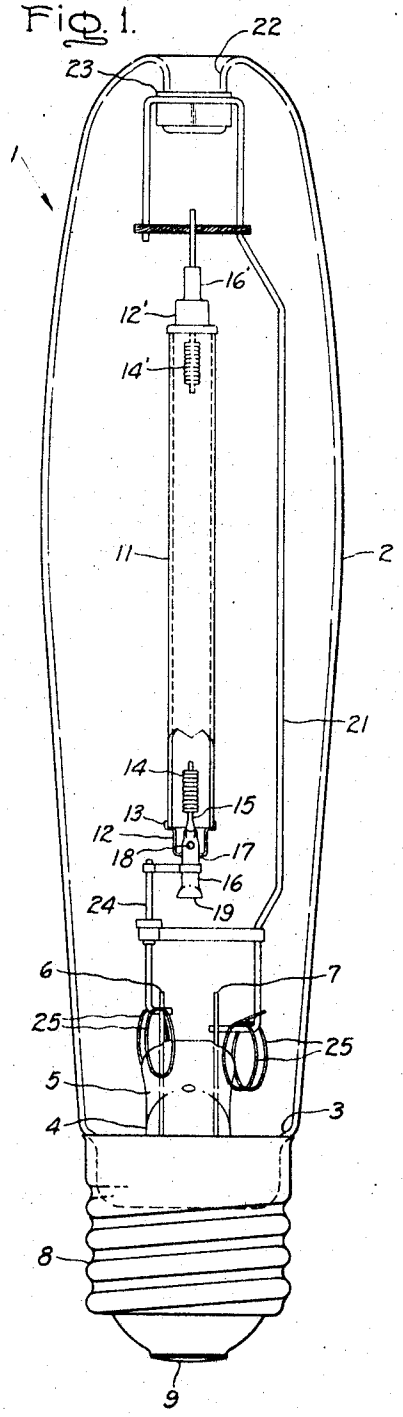
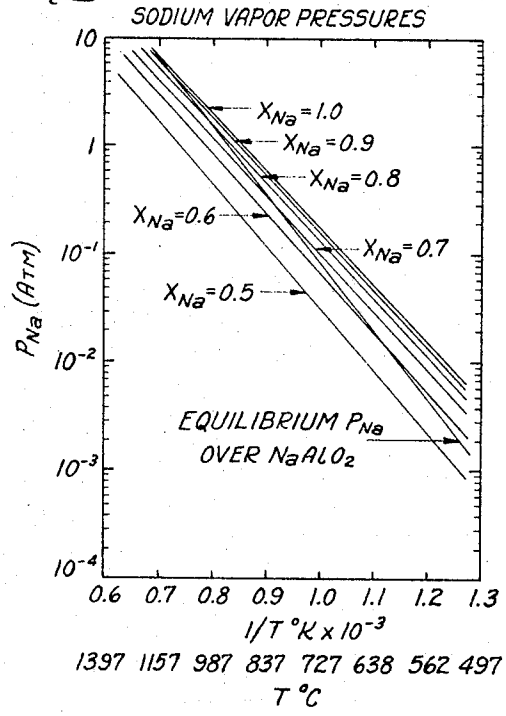


Fig. 2.



Inventors:
Rodney E. Hanneman
Paul J. Jorgensen
Dimitrios M. Speros
by Ernest W. Legner
Their Attorney

Fig. 3.

AMOUNT LIMITED

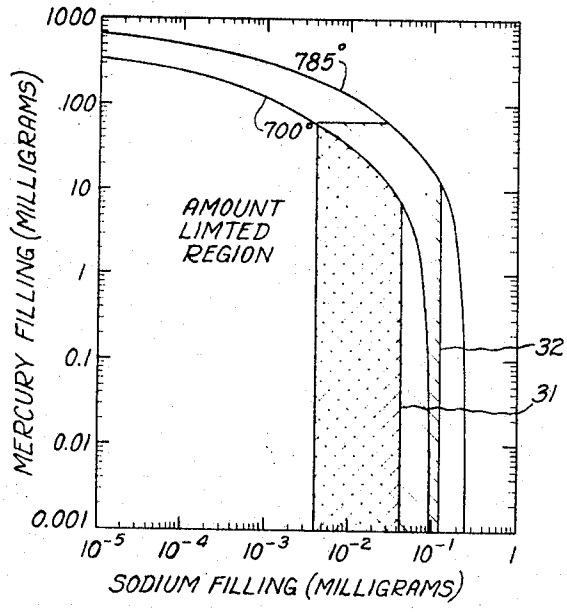
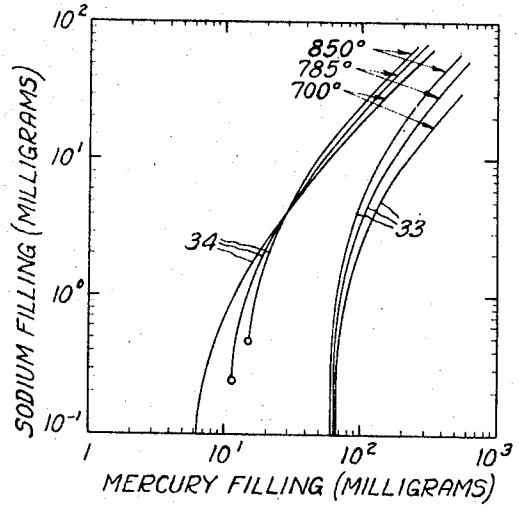


Fig. 4.

EXCESS LIMITED



Inventors:
Rodney E. Hanneman
Paul J. Jorgensen
Dimitrios M. Speros
by Ernest W. Legree
Their Attorney

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3,453,477

ALUMINA-CERAMIC SODIUM VAPOR LAMP

Rodney E. Hanneman, Burnt Hills, and Paul J. Jorgensen, Scotia, N.Y., and Dimitrios M. Speros, Painesville, Ohio, assignors to General Electric Company, a corporation of New York

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Int. Cl. H01j 17/20, 61/18
U.S. Cl. 313—184 7 Claims

ABSTRACT OF THE DISCLOSURE

In a sodium vapor lamp where the enclosing envelope is alumina ceramic, sodium can react with alumina to produce sodium aluminate, resulting in cleanup of sodium. This is prevented by causing the equilibrium vapor pressure of sodium over $NaAlO_2$ to exceed the vapor pressure of sodium in the envelope. Equilibrium vapor pressure of sodium over $NaAlO_2$ depends upon temperature where formed; when an amalgam of sodium and mercury is used for the filling, vapor pressure of sodium in envelope depends on quantity, temperature and atomic fraction of sodium in the amalgam; one or more of these factors can be varied to meet the requirement.

Cross-reference to related applications

Ser. No. 388,567, filed Aug. 10, 1964, by Paul J. Jorgensen, "Ceramic Bonding," same assignee.

Ser. No. 616,538, filed concurrently by Rodney E. Hanneman, Paul J. Jorgensen and Richard J. Charles, "High Pressure Sodium Vapor Lamp," same assignee.

Background of invention

The invention relates to high-pressure sodium vapor lamps utilizing envelopes of alumina ceramic. The invention is particularly concerned with preventing so-called sodium cleanup or reduction in the effective amount of sodium during the life of the lamp.

The high pressure sodium vapor lamp with which the invention is more particularly concerned generally comprises an outer vitreous envelope or jacket within which is mounted a slender tubular arc tube of high density polycrystalline alumina. The basic lamp type is described and claimed in U.S. Patent No. 3,248,590, issued Apr. 26, 1966, to Kurt Schmidt. The arc tube encloses a charge of sodium, preferably a filling of sodium-mercury amalgam, and an inert gas such as xenon. It operates with sodium vapor pressure sufficient to cause appreciable broadening and self-reversal of the resonance lines, the range from 30 to 500 torr being preferred. A large percentage of the total radiation is emitted on either side of the yellow resonance D lines of sodium at 5890 and 5896 A. resulting in a golden white light having a relatively large amount of energy in the red. The xenon is a starter gas for the lamp and the mercury is a buffer gas producing the proper temperature distribution in the plasma and at the envelope walls. The presence of the mercury increases the voltage gradient of the arc resulting in a lamp operating at a higher voltage and lower current for a given wattage and this makes for a more efficient lamp and permits savings in ballast costs. Even though the partial pressure of mercury in the lamp may be several times greater than that of sodium, little radiation of mercury lines is apparent in the visible spectrum and it is essentially only the sodium atoms that are excited to produce light.

In the development of this lamp, it was early found that over a prolonged period of use, the voltage drop across the lamp increased and the proportion of red in the radiation decreased, the light becoming more purple;

the latter phenomenon is generally referred to as decrease in the red factor. At the same time the mercury vapor pressure increased and, if operation were continued notwithstanding the deterioration in light output, the rising mercury vapor pressure would cause the voltage drop across the lamp to increase to the point where the lamp extinguished. It was determined that these happenings were associated with a sodium loss and a reduction in the proportion or atom fraction of sodium in the excess liquid sodium-mercury amalgam present in the reservoir during operation. Such loss or cleanup of sodium could be reduced by lowering the amalgam reservoir temperature; however, this also lowers both lamp efficacy and the red factor and is at best only a compromise. A practical solution utilized in the lamps manufactured for public sale consists in increasing the quantity or loading of amalgam at the chosen composition to the point where, notwithstanding the cleanup occurring, the change in composition occurring remains within acceptable limits during the intended lamp life. This has permitted the increase in voltage, decrease in red factor, and increase in mercury vapor pressure to be slowed down and held within acceptable limits over the full life of the lamp. Such lamps represent a major advance in lamp technology and have been available on the market under the designation Lucalox, a trademark of the assignee herein.

One object of the present invention is to provide a better solution to the problem of sodium cleanup in lamps of the present kind of preventing the responsible sodium-absorbing reaction from taking place so that a lesser quantity of sodium-mercury amalgam will suffice for the lamp's requirements throughout life.

The high-pressure sodium lamps presently available on the market contain a quantity of sodium mercury-amalgam greatly in excess of the amount vaporized and may be described as saturated vapor or excess-limited lamps. The operating pressure in such lamps is determined by the pressure of the vapor over the liquid phase which collects at the coolest spot in the lamp. As a result, such lamps are quite temperature sensitive and in general this is a disadvantage. By limiting the quantity of sodium-mercury amalgam filling to an amount less than the maximum that could be vaporized in the lamp volume at the operating temperature, an unsaturated vapor or amount-limited lamp results. Such a lamp construction avoids the temperature sensitiveness of the excess-limited lamp but requires that the quantity of amalgam remain very constant throughout life and substantially no sodium cleanup at all can be tolerated. Another object of this invention is prevention of sodium cleanup thorough enough that an unsaturated vapor or amount-limited high pressure sodium vapor lamp with a long operating life becomes feasible.

Summary of the invention

An important cause of sodium cleanup in high intensity alumina ceramic lamps operating with relatively high partial pressure of sodium in the range from 10 to 1000 torr is direct reaction of sodium with the aluminum oxide of the arc tube or envelope to produce sodium aluminate and aluminum. If allowed to continue, such reaction will decrease the concentration of sodium in the amalgam or the partial pressure of sodium in the envelope with the ultimate results previously pointed out. In accordance with our invention, we prevent cleanup of sodium by this aluminate producing reaction through a choice of structure and operating parameters such that the equilibrium vapor pressure of sodium over the aluminate is greater than the partial vapor pressure of sodium over the aluminate or existing within the envelope. When this is the case, the aluminate forming reaction will not take place and sodium cleanup is prevented.

The equilibrium vapor pressure of sodium over the aluminate is determined by the temperature of the envelope where the aluminate deposits. In the excess-limited case, the partial vapor pressure of sodium over the amalgam depends upon the composition of the amalgam and the temperature of the amalgam reservoir. In the amount-limited case, the vapor pressure of sodium is determined by the amount of the filling and the volume-temperature relationships in the arc tube. These are the factors which may be varied in accordance with the invention to achieve the desired condition of equilibrium sodium vapor pressure over the aluminate being more than the actual sodium vapor pressure in the arc tube or envelope in order to prevent cleanup of sodium.

For a better understanding of the invention and its advantages, attention is now directed to the following detailed description to be taken in conjunction with the accompanying drawing. The features of the invention believed to be novel will be more particularly pointed out in the appended claims.

Brief description of drawing

FIG. 1 illustrates a jacketed high pressure sodium vapor lamp embodying the invention.

FIG. 2 is a chart showing the equilibrium vapor pressure of sodium over sodium aluminate through a temperature range, along with the vapor pressure of sodium over various sodium-mercury amalgam compositions through the same temperature range.

FIG. 3 is a chart illustrating the range of feasible loadings of sodium and mercury at two selected temperatures under amount-limited operation such that cleanup will not occur.

FIG. 4 is a chart illustrating feasible loadings of sodium and mercury at selected temperatures for excess-limited operation such that cleanup will not occur.

Referring to FIG. 1, the illustrated high pressure sodium vapor lamp **1** comprises an outer vitreous envelope or jacket **2** of elongated ovoid shape. The neck **3** of the jacket is closed by a re-entrant stem **4** having a press **5** through which extend stiff inlead wires **6, 7** connected at their outer ends to the threaded shell **8** and center contact **9** of a conventional screw base.

The inner envelope or arc tube **11** which forms a discharge lamp proper is made of sintered high density polycrystalline alumina ceramic such as disclosed in U.S. Patent No. 3,026,210, Coble, Transparent Alumina and Method of Preparation. The ends of the tube are closed by thimble-like niobium metal end caps **12, 12'** hermetically sealed to the alumina by means of a sealing composition comprising aluminum oxide, calcium oxide, and optionally magnesium oxide, a preferred composition being described and claimed in copending application Ser. No. 388,567, filed Aug. 10, 1964, by Paul J. Jorgensen, entitled "Ceramic Bonding" and assigned to the same assignee as the present invention. The sealing composition is present as a thin layer between the expanded shoulder portion **13** of the end cap and the side and end of the ceramic tube. Electrodes **14, 14'** are mounted in the ends of the arc tube, each consisting of a double-wound tungsten wire coil with the interstices filled with activating material, suitably alkaline earth oxides including barium oxide. The electrode coil is wound over a tungsten shank **15** which is brazed in the crimped inner end of a niobium tube **16** penetrating into the thimble and brazed or welded to the reduced diameter collar portion **17**. Tube **16** is pierced through at **18** and is used as an exhaust tube during manufacture and to introduce the gas filling and sodium-mercury amalgam dose into the arc tube, being thereafter pinched off by a cold weld indicated at **19**. During operation of the lamp, the projecting end of exhaust tube **16** is the lowest temperature spot in the arc tube and may serve as a reservoir where the excess sodium mercury amalgam collects. The other tube **16'** is a dummy and is not pierced through into the arc tube so that it need not be pinched off.

The arc tube is supported within the outer envelope by means of a single side rod frame **21** which extends from inlead **7** at the stem to a dimple **22** at the dome end to which it is anchored by a resilient clamp **23**. Rod **21** electrically connects electrode **14'** to inlead **7** and a short length of rod **24** connects electrode **14** to inlead **6**. The inter-envelope space is evacuated in order to prevent oxidation of the end caps and to conserve heat; this is done prior to sealing off the outer envelope and a getter, suitably barium metal powder pressed into the channeled rings **25**, is flashed after sealing in order to assure a good vacuum. By way of example, a commercial version of the illustrated lamp in a 400-watt size has an arc tube approximately 7.4 millimeters in internal diameter, 9.3 centimeters in length, and has a 7 centimeter arc gap between the electrode tips.

In seeking to cure the problem of sodium cleanup in an alumina ceramic lamp, it is necessary to inquire under what conditions is such a system inherently unstable. The important reaction here of concern is the direct reaction of sodium upon aluminum oxide to produce sodium aluminate, as follows:

$$Na(l)+\tfrac{2}{3}Al_2O_3(s)\rightleftarrows NaAlO_2(s)+\tfrac{1}{3}Al(l)$$

wherein the letters (l) and (s) refer to liquid and solid states respectively. The foregoing is of course a reversible reaction and the criterion for thermodynamic stability is that the free energy of the reaction be negative. From the free energy of reaction, one may calculate the equilibrium pressure of sodium over $NaAlO_2$ involving various possible choices of standard states. The physically most meaningful choice is to take $Na(l)$, $Al(l)$, $Al_2O_3(s)$ and $NaAlO_2(s)$ as the standard states throughout the temperature range of interest from 800 to 1600° K. corresponding to 527 to 1327° C. The result of our calculations is given in the chart of FIG. 2 which shows the equilibrium value of sodium vapor pressure P_{Na} over $NaAlO_2$ versus the reciprocal of absolute temperature; the temperature in ° C. is also given over the range of interest. The values of P_{Na} over various sodium-mercury amalgams wherein the atom fraction of sodium X_{Na} varies from 1.0 to 0.5 are also given over the same temperature range.

Comparing the equilibrium value of P_{Na} over $NaAlO_2$ with the various values of P_{Na} over the several Na-Hg amalgams, the curve of the former is seen to cross over the various curves of the latter as the temperature is increased. With rising temperature, the vapor pressures of progressively higher sodium atom fractions are exceeded; thus P_{Na} of $X_{Na}=0.6$ is crossed over at about 600° C., and P_{Na} of $X_{Na}=0.8$ (80 atom percent sodium) is crossed over at about 1000° C. The foregoing suggests the solution to the problem of sodium cleanup. For a given set of conditions of temperature and amalgam compositions, if equilibrium P_{Na} over the sodium aluminate is less than P_{Na} over the sodium-mercury amalgam composition chosen, then the reaction earlier given will proceed to the right burning up more and more sodium. On the other hand, if equilibrium P_{Na} over the aluminate is greater than P_{Na} over the amalgam, then the sodium aluminate will be unstable, the reaction will not proceed, and sodium will not be burned up. Therefore the latter must be the existing condition in order to prevent sodium cleanup according to our invention, and this condition may be achieved under both amount-limited and excess-limited operation.

Amount-limited case—Unsaturated vapor

In this case the end cap or exhaust tube appendix temperatures and the amounts of both sodium and mercury in the fill are adjusted so that in operation all the sodium and mercury are vaporized. This mode has the distinct advantage that the control of end cap tempera-

ture is not nearly so critical and the lamp is much less temperature-sensitive. However, since all the sodium is vaporized, if any cleanup should take place, the values of efficacy and red factor will drop precipitously. Therefore in this case the prevention of any cleanup is essential in order to have an acceptable lamp.

By way of example, in the chart of FIG. 3 the areas under the two curves represent possible quantities of sodium and mercury in the filling for amount-limited operation with end cap temperatures of 700° and 785° C. for the lamp illustrated in FIG. 1 having an arc tube volume of 4.2 cc. Assuming a maximum permissible pressure in the lamp of approximately 10 atmospheres, and a lower limit of sodium pressure in view of the red factor desired of approximately 5.6×10^{-3} atmospheres (corresponding to 4×10^{-3} milligrams of sodium in the illustrated lamp), the crosshatched zone indicates the range of feasible fillings without cleanup for a 700° C. end cap temperature, and the singly hatched zone for a 785° C. end cap temperature. The upper limits of sodium filling for amount-limit operation wherein $NaAlO_2$ is unstable and cleanup is prevented are indicated by the right-hand vertical edges of the hatched zones, that is, by line **31** for 700° C. end cap temperature, and by line **32** for 785° C. end cap temperature.

The preferred region for stable amount-limited operation for the same lamp example from the point of view of optimum lamp performance characteristics is bracketed by the following fillings or loads for the indicated seal temperatures:

Seal temperature (° C.)	Mercury filling (mg.)	Sodium filling (mg.)
750	6–15	0.07–0.11
775	5–22	.07–.11
800	4–40	.07–.20

Excess-limited case—Saturated vapor

In this case, the invention is very useful to prevent the rise in voltage and decrease in red factor with life without resorting to the expedient of providing a large excess of sodium mercury amalgam in the arc tube. By the use of the invention, a small excess becomes suffiicient because the proportion of sodium in the liquid excess remains constant. Also the invention is valuable in this case to extend the life of the lamp by preventing attack and eventual destruction of the seals.

The chart of FIG. 4 shows the feasible range of conditions for the excess-limited case for end cap temperatures of 700, 785 and 850° C. for the lamp illustrated in FIG. 1. The three right-hand isotherms **33** are given where the total pressure of the system has reached 10 atmospheres which constitutes in practice an upper safe limit of operation. The three left-hand isotherms **34** define the maximum permissible Na load or filling as a function of Hg load where $NaAlO_2$ is just unstable at 700, 785 and 850°, respectively. The range of sodium and mercury fillings for stable saturated vapor or excess-limited operation without sodium cleanup in accordance with the invention is the region between the right and left-hand sets of isotherms of like temperature. The preferred conditions for stable lamp operation lie in a narrow band extending along and just to the right of the left-hand set of isotherms **34**. In general, practical lamp designs use sodium-mercury amalgams wherein the atom fraction of sodium is between 0.6 and 0.8, and such lamps can meet the requirements of the invention for avoidance of cleanup by minimum alumina surface temperatures in the range of 600 to 1000° C.

The foregoing examples illustrate typical fillings for lamps utilizing seals of the type in current use consisting of a niobium end cap sealed to the alumina with a calcia-magnesia-alumina sealing composition. In order to have acceptable life, such seals are limited to operating temperatures not much over 800° C., and this imposes a limitation in connection with meeting the cleanup requirements. In general this means that the sodium vapor pressure must be limited and, for a given operating temperature, a ceiling is imposed on the permissible atom fraction of sodium in the amalgam. By going to seals capable of withstanding higher temperatures, this ceiling is lifted or removed.

The equilibrium pressure of sodium over the aluminate is governed by the temperature of the coolest alumina surface in the envelope. With a niobium end cap **12** and a projecting niobium exhaust tube **19** as illustrated in FIG. 1, the excess sodium-mercury amalgam gathers in the exhaust tube. The exhaust tube is at an appreciably lower temperature than the coolest alumina surface in the envelope which is the alumina where the end of the tube is sealed to the niobium end cap at **13**. In the illustrated lamp, a difference of as much as 50° may exist, 20° being typical. In such cases, the equilibrium vapor pressure of sodium over the aluminate is determined by the temperature at the end **13** of the alumina envelope which is higher than the temperature of the excess sodium-mercury amalgam in the appendix. This provides an additional margin in meeting the requirement of equilibrium P_{Na} over the aluminate greater than P_{Na} over the amalgam for avoidance of cleanup. Such margin, makes feasible a higher atom fraction of sodium than could otherwise be permitted for cleanup free operation.

Prevention of cleanup can also be achieved by providing in combination with the arc tube an agent which will remove one or more of the elements participating in the sodium absorbing reaction. For instance, as described and claimed in copending application of Rodney E. Hanneman, Paul J. Jorgensen and Richard J. Charles, Ser. No. 616,538, filed, Feb. 16, 1967, entitled "High Pressure Sodium Vapor Lamp" and assigned to the same assignee herein, one may provide an oxygen-absorbing metal such as yttrium to destabilize sodium aluminate and prevent cleanup of sodium. The present invention and the above Hanneman, Jorgensen and Charles invention may be used alternatively to achieve the same end. However, if desired, both may be embodied in the same lamp structure and cleanup of sodium prevented more effectively and over a longer life span by meeting the conditions necessary to prevent the sodium aluminate-forming reaction from proceeding, and simultaneously providing an oxygen-absorbing agent such as yttrium to destabilize sodium aluminate.

At end cap temperatures in the range of 600 to 800° C. as in the present lamp, niobium absorbs oxygen readily and is permeable to it. Therefore, a practical lamp using niobium end caps must enclose the arc tube in a protective outer jacket which has been thoroughly outgassed and cleaned of oxygen. Preferably the interenvelope space should be highly exhausted in order to protect the arc tube from oxygen and at the same time reduce the heat loss. The measures prescribed by the present invention for preventing sodium cleanup presuppose a lamp construction in which oxygen is effectively eliminated from the arc tube.

The details of construction of the preferred embodiment which has been illustrated and described are intended as exemplary and not in order to limit the invention thereto except insofar as included in the following claims.

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

1. A high intensity sodium vapor discharge lamp comprising an envelope of light-transmitting alumina having a pair of electrodes sealed into opposite ends and containing a filling of sodium-mercury amalgam wherein sodium exerting a partial pressure in the range of 10 to 1000 torr is the principal discharge supporting element and source of radiant emission, the quantity of amalgam and the atom fraction of sodium therein being so chosen that the vapor pressure of sodium at the operating temperature in said envelope is lower than the equilibrium

vapor pressure of sodium over sodium aluminate tending to condense at the coolest alumina surface in said envelope as represented by the equilibrium curve in FIG. 2, whereby to prevent cleanup of sodium by the reaction between sodium and alumina in said envelope.

2. A lamp as in claim 1 containing a quantity of amalgam which is totally vaporized in operation so that the sodium vapor pressure is amount-limited.

3. A lamp as in claim 1 containing a quantity of amalgam exceeding that vaporized in operation so that the sodium vapor pressure is excess-limited.

4. A high intensity sodium vapor discharge lamp comprising an inner arc tube of light-transmitting alumina ceramic and an outer vitreous envelope surrounding said arc tube, end caps closing the ends of said arc tube, a pair of electrodes sealed into opposite ends, a filling of sodium-mercury amalgam within said arc tube in excess of that vaporized in operation, the atom fraction of sodium in the excess amalgam being at least 0.5 in order that a partial pressure of sodium may be developed in the range of 30 to 500 torr along with a partial pressure of mercury less than 10 atmospheres when the excess amalgam in said arc tube is maintained in liquid form at a temperature in the range of 600 to 1000° C. within one of the end caps, the atom fraction of sodium relative to mercury in the amalgam further being chosen such that

the partial vapor pressure of sodium at the operating temperature is below the equilibrium vapor pressure of sodium from sodium aluminate determined at the coolest alumina surface within said arc tube as represented by the equilibrium curve in FIG. 2 whereby cleanup of sodium by reaction between sodium and alumina will be prevented.

5. A lamp as in claim 4 wherein the atom fraction of sodium in the excess amalgam is between 0.6 and 0.8.

6. A lamp as in claim 4 wherein the end caps are of niobium and the interenvelope space is highly exhausted.

7. A lamp as in claim 4 wherein the atom fraction of sodium in the excess amalgam is between 0.6 and 0.8, the end caps are of niobium and the interenvelope space is highly exhausted.

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JAMES W. LAWRENCE, *Primary Examiner.*

R. F. HOSSFELD, *Assistant Examiner.*

U.S. Cl. X.R.

313—221, 229