

PATENT SPECIFICATION

(11) 1 307 394

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DRAWINGS ATTACHED

- (21) Application No. 8521/70 (22) Filed 23 Feb. 1970
 (31) Convention Application Nos. 808 801 and 808 802
 (32) Filed 20 March 1969 in
 (33) United States of America (US)
 (44) Complete Specification published 21 Feb. 1973
 (51) International Classification H01J 61/30 // C03C 3/04
 (52) Index at acceptance
 C4S 66Y 70Y 71S 72O 76Y
 C1M 11B1 11C4 11C6 11C7 11C9 11F1 11F14 11F2
 11F29 11F3 11J3



(54) FLUORESCENT LAMP

(71) We, WESTINGHOUSE ELECTRIC CORPORATION of 3 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 relates to fluorescent lamps. The prime objective in the design and manufacture of fluorescent lamps is the provision of a lamp which has the highest light output and lumen maintenance and the lowest manufacturing cost. Heretofore, it has been the general practice in the fluorescent lamp industry to make the lamp envelopes from soda-lime silicate glass and to coat the inner surface of the envelope with a suitable ultraviolet-responsive phosphor, such as a calcium halophosphate phosphor, to a coating density which will provide optimum light output. It has been found that bulbs fabricated from such conventional glasses are solarized and darken under the influence of the impinging ultraviolet radiations generated within the lamp. In addition, as the lamp burns, a deleterious chemical interaction occurs at the phosphor-glass interface which desensitizes the phosphor and produces a blackening effect in this region. Obviously, all of these reduce the light output of the lamp. As a result, the prior art lamps required a heavy or thick coating of phosphor for optimum light output and lumen maintenance during life. Such heavy coatings, in effect, provided a "barrier" layer of phosphor at the glass surface which inhibited solarization of the bulb and prevented the alkali constituents of the soda-lime glass from chemically reacting with the upper strata of the phosphor coating.

The deleterious darkening effects produced in fluorescent lamps by the alkali constituents present in soda-lime silicate glasses is well

known in the art and various means have been proposed to solve this problem. It has been proposed, for example, that up to 4% by weight of antimony trioxide be included in the soda-lime silicate glass envelope to inhibit the diffusion of alkali ions to the envelope surface and thereby reduce the formation of dark deposits of mercury-alkali amalgam.

Separate transparent barrier layers on the inner surface of the glass envelope have also been proposed. A fluorescent lamp of this type wherein a barrier layer consisting of titanium dioxide or zirconium oxide with additional metal oxides is interposed between the phosphor coating and the inner surface of a soda-lime silicate glass envelope is disclosed in British Patent Specification No. 1,113,133. This patent also discloses that up to 20% less phosphor by weight can be used when such a separately-formed barrier layer is used.

In British Patent Specification No. 1,178,947 there is disclosed a fluorescent lamp having a chemically stabilized and photoresistant soda-lime silicate glass envelope that contains up to 10% by weight TiO_2 and is interiorly coated with an ultraviolet-responsive phosphor such as calcium halophosphate phosphor. However, the phosphor coating is of the same density as that used heretofore and the lamp thus contains the same amount of phosphor as conventional fluorescent lamps now being marketed.

It is accordingly an object of the present invention to provide a fluorescent lamp which is of the same or nearly the same quality as a conventional lamp as regards light output and lumen maintenance but contains significantly less phosphor, viz. 5 to 40% by weight less.

With this object in view, the present invention resides in a fluorescent lamp having a light-transmitting envelope comprising soda-lime silicate glass containing between 0.1 and 10% by weight TiO_2 , means sealed within said envelope adapted to sustain a gaseous dis-

(10)

charge generating ultraviolet radiation when the lamp is energized, and a light-transmitting coating of phosphor on the inner surface of said envelope comprising a substantially uniform layer of finely-divided phosphor particles capable of emitting visible radiation in response to impinging ultraviolet radiation generated by said discharge, the amount of TiO_2 in said soda-lime silicate glass being sufficient to inhibit solarization of the glass and deleterious chemical reaction at the phosphor glass interface, and the total amount of said phosphor within said envelope being from 5% to 40% by weight less than the minimum amount of said phosphor which is required to achieve the same light output after 100 hours burning in an otherwise similar fluorescent lamp that is uniformly coated with said phosphor particles but has a soda-lime silicate glass envelope that is devoid of TiO_2 .

The invention will become more readily apparent from the following description of preferred embodiments thereof shown, by way of example only, in the accompanying drawings, wherein:

Figure 1 is a fragmentary elevational view of a fluorescent lamp embodying the present invention, a portion of the phosphor-coated envelope being shown in enlarged cross section for illustrative purposes;

Fig. 2 is a graph illustrating the light-absorption characteristics of a soda-lime silicate glass that has been modified by the addition of selected amounts of TiO_2 and irradiated with UV;

Fig. 3 is a graph illustrating the percent increase in maximum lumens obtained with fluorescent lamps having bulbs composed of modified soda-lime silicate glasses which contain up to 2% by weight TiO_2 ;

Fig. 4 is a graph illustrating the percent change in lumens, at various phosphor coating densities, exhibited by fluorescent lamps having soda-lime silicate glass bulbs that contain selected amounts of TiO_2 compared to the maximum light output of a conventional fluorescent lamp that has an unmodified soda-lime silicate glass envelope;

Fig. 5 is a graph illustrating the percent change in lumen maintenance of fluorescent lamps that have titania-modified glass bulbs compared to a standard fluorescent lamp having a conventional soda-lime silicate glass envelope;

Fig. 6 is a graph illustrating the lumen maintenance characteristics of a series of fluorescent lamps having various phosphor coating densities and bulbs which contain 1.25% by weight TiO_2 compared to the maintenance of a standard fluorescent lamp having a bulb composed of conventional soda-lime silicate glass;

Fig. 7 is a graph illustrating the correlation between the phosphor coating density and the

total amount of phosphor coated onto the inner surface of the glass bulb for a calcium halophosphate phosphor; and

Fig. 8 is a graph contrasting the reduction in phosphor weight (5% to 40%) achieved by the invention for a phosphor having different average phosphor particle sizes with the amount of the same phosphor required in a conventional lamp of the same size.

In Figure 1 there is shown a fluorescent lamp 10 which embodies the present invention and consists of a tubular light-transmitting bulb or envelope 12 that is composed of TiO_2 -containing soda-lime silicate glass and is interiorly coated with a uniform layer 13 of a suitable ultraviolet-responsive phosphor, such as calcium halophosphate phosphor. The ends of the envelope 12 are sealed to glass stems 14 which support a pair of conventional electrodes or cathodes 16. Each of the cathodes 16 are attached to a pair of lead-in wires 17 that are hermetically sealed through the respective stems 14. These lead wires are electrically connected to terminal pins 18 anchored in suitable base members 20 that are attached to the sealed ends of the bulb 12. The cathodes 16 are coated with an electron-emissive material (such as the usual alkaline-earth carbonates), and, in conjunction with a predetermined amount of mercury and a suitable fill gas such as neon or a mixture of neon and argon at a pressure of approximately 2 millimeters, sustains a gaseous discharge when the lamp 10 is energized. The phosphor is deposited in a substantially uniform layer 13 on the envelope 12, the stems 14 are sealed into the envelope and the latter is exhausted, dosed with mercury, etc. in the usual manner well known to those skilled in the art.

In accordance with the present invention the envelope 12 is fabricated from soda-lime silicate glass that contains selected amounts of TiO_2 between 0.1 and 10% by weight. While the specific composition may vary good results have been obtained with glasses having the following formulation (the various constituents being expressed in percentages by weight as calculated from the batch): 60% to 75% SiO_2 , 3.4% to 18% Na_2O , 4% to 13% MgO or CaO (or a combination thereof), 0.5% to 3.4% Al_2O_3 , 0.1% to 2% K_2O , 0.1% to 10% TiO_2 , up to approximately 0.07% Fe_2O_3 , and from 0.01% to 2% As_2O_3 or Sb_2O_3 . This is the same type of glass as that disclosed in British Patent Specification No. 1,178,947 except that the TiO_2 content is not limited to a range of 0.8 to 10%. As disclosed hereinafter, an appreciable gain in light output can be obtained in accordance with the present invention with amounts of TiO_2 as low as 0.1% by weight. Hence, TiO_2 in the range of 0.1% to 10% by weight can be used.

The addition of selected amounts of TiO_2 to conventional soda-lime silicate glass inhibits the discoloration or "solarization" effect of im-

pinging ultraviolet radiations produced by the gaseous discharge within the lamp, as is disclosed in detail in British Patent Specification No. 1178947. The increase in the photoresistivity of such modified glasses is illustrated by the graph shown in Fig. 2. The data on which this graph is based was obtained by adding from 0.1% to 10% by weight of TiO_2 to a conventional soda-lime silicate glass that contained 0.07% by weight Fe_2O_3 and is used for fluorescent lamp tubing. The samples were irradiated for 30 minutes by placing them against a clear ultraviolet-transmitting quartz section of a low-pressure mercury discharge lamp which was operated at an arc current and at an ambient temperature which simulated those of a standard 40 watt fluorescent lamp. Since the quartz section of the envelope of the discharge lamp was clear and devoid of phosphor coating, the glass samples were subjected to about thirty times the dosage of 2537Å radiation as that which would impinge upon the envelope of a conventional fluorescent lamp that was operated for the same length of time.

As indicated by curve A of Fig. 2, the absorption co-efficient of the TiO_2 -modified glasses in the 4800Å region of the visible spectrum decreases sharply to a value of 0.1 cm^{-1} as the TiO_2 content is increased from 0.1% to 0.8% by weight, reaches a minimum of about 0.06 cm^{-1} at about 2% TiO_2 , and then increases gradually to 0.1 cm^{-1} when the TiO_2 content reaches 10% by weight. Curve B represents the absorption coefficient in the 5800Å region of the visible spectrum and is quite similar to curve A except that it reaches a minimum of 0.02 cm^{-1} at about 3% by weight TiO_2 and then gradually increases to 0.04 cm^{-1} as the TiO_2 content is increased to a value of 10% by weight.

Surprisingly, glasses containing these amounts of TiO_2 do not crystallize and their melt viscosities are about the same as those for similar soda-lime silicate glasses without titania. Their working properties are disclosed in the aforementioned British Patent Specification No. 1178947 and are such that lamps having bulbs made from these TiO_2 -modified soda-lime silicate glasses can be manufactured on the same high-speed lamp-making machines now in use.

In addition to increasing the resistance of the envelope to the solarization effects of ultraviolet radiation, comparative lamp tests have revealed that the addition of selected amounts of titania to the bulb glass has a marked effect on the lumen output of fluorescent lamps made with such bulbs. This effect is illustrated by the graph shown in Fig. 3 wherein the percent increase in lumens at 100 hours burning (compared to a conventional lamp having the same phosphor) is plotted against TiO_2 contents that vary from 0 to 2% by weight as shown by curve C, the light output increases rapidly as

soon as TiO_2 is included in the bulb glass. It increases by about 0.25% with only 0.1% TiO_2 in the glass begins to level off at about TiO_2 by weight TiO_2 and reaches a maximum (about 1.6% gain) when the TiO_2 content reaches 2% by weight. The curve thus shows that significant increases in the light output of a fluorescent lamp can be achieved with very small amounts of TiO_2 in the bulb glass and that practically all of the lumen increase (1.5%) is achieved with about 1.25% by weight TiO_2 . Thus, while up to about 10% by weight TiO_2 can be incorporated in the bulb glass in order to enhance its photoresistivity, from the standpoint of cost versus enhanced light output, the TiO_2 content is maintained below about 2% by weight and 1.25% by weight TiO_2 is preferred.

The data on which Fig. 3 is based was obtained by measuring the light output (after 100 hours burning) of a series of 40 watt T12 fluorescent lamps having bulbs composed of soda-lime silicate glasses that contained the indicated amounts of TiO_2 . The total amount of phosphor (calcium halophosphate) coated onto the inner surface of the respective lamps, that is, the phosphor coating density, was the same as that used in conventional lamps. Curve C thus reveals that for a given phosphor and a given phosphor coating density, the lumen output can be increased 1.6% above the maximum output of a conventional lamp of the same type by including 2% by weight TiO_2 in the bulb glass.

The term "phosphor coating density" as used herein is related to the optical density of the phosphor coating and is a measure of the phosphor weight or total amount of phosphor employed in the lamp. Since the phosphor coating consists of a layer of many finely-divided phosphor particles of varying size, light rays passing through the coating are scattered to a degree which is dependent upon the size of the phosphor particles and the number of such particles that are struck by the light rays as they pass through the layer. As the average particle size increases, the amount of phosphor required to achieve a given optical density also increases since large particles have less scattering effect.

For convenience, the phosphor coating density will be expressed in the description which follows in terms of optical density values. These values, in turn, will be expressed as arbitrary numbers which correspond to the reading of a micro-ammeter which is connected to a Weston Model 594 photocell. The photocell is located 1—1/2 inches from the axis of the lamp envelope in line with a ground glass filter that is positioned 3 inches from the envelope axis and on the other side of the envelope. A light source, such as a 150 watt PAR 38 incandescent lamp, is placed adjacent the filter at a location such that it produces a beam of light which is so directed that it

- passes through the filter and both walls of the coated lamp envelope along a path that is normal to and intersects the envelope axis. The photocell is so calibrated with respect to the intensity of the light beam that a bulb having a phosphor coating of the density or thickness customarily employed in the art produces a reading of 24 on the microammeter when the bulb is placed in the density measuring device.
- As the phosphor weight per lamp is decreased for a given average particle size, the phosphor layer becomes thinner and the scattering of the traversing light beam is reduced so that the microammeter registers a higher reading. Thus, the optical density of the coating as measured by the photocell increases as the amount of phosphor per square centimeter of envelope surface (true coating density) decreases. Hence, higher optical density numbers indicate lower actual phosphor coating densities and phosphor weights. The correlation between these optical density readings or numbers, the phosphor weight per lamp (expressed in percent) for a given phosphor, and the percent increase in the intensity of the light beam which strikes the photocell are set forth in Table I below.

TABLE I

Optical Density	Phosphor Weight (%)	Percent Increase of Light Beam Intensity
22	112	—
23	106	—
24 (standard)	100	0
25	95	4.17
26	91	8.34
27	87	12.51
28	83	16.68
29	79	20.85
30	75	25.02
31	72	29.19
32	69	33.36
33	66	37.53
34	63	41.70
35	30	45.87

- As will be noted, the conventionally coated lamp constitutes the standard and its optical density of 24 corresponds to 100% phosphor weight. This standard optical density is based on a 40 watt, 4 foot T12 fluorescent lamp that is uniformly coated with calcium halophosphate phosphor particles which have an average particle size of 12 microns and contains a total of approximately 7.4 grams of phosphor (equivalent to 6.9 milligrams of phosphor per square centimeter of envelope surface). A lamp of the same size which has an optical density 1 unit higher than the standard will have a thinner phosphor coating density. Measurements have shown that the resultant reduction in phosphor weight is 5% (95% of standard phosphor weight). The intensity of the light beam which traverses the envelope of a lamp having an optical density of 25 is, accordingly, increased by 1/24th or 4.7%. Thus, an optical density of 30 is equivalent to a 25% reduction in phosphor weight and an increase of approximately 25% in the intensity of the transmitted light beam, and an optical density of 35 is equivalent to a 40% reduction in phosphor weight and a 45.87 percent increase in light beam intensity.
- The term "average phosphor particle size" as used herein and in the appended claims means the average diameter of the phosphor particles in microns as measured by a Coulter Counter measuring instrument which is well known in the art and marketed by the Coulter Electronics, Inc., Franklin Park, Illinois. Thus, the weight of the particles having a diameter larger than the average diameter is equal to the weight of the particles which have a diameter smaller than the average diameter.
- We have found that the amount of a given phosphor required in a fluorescent lamp can be significantly reduced with little or no loss of lumens or decrease in lumen maintenance by utilizing an envelope of soda-lime silicate glass that contains a relatively small and selected amount of TiO_2 . This is graphically illustrated in Fig. 4 wherein the lumen output (at 100 hours) of a series of 40 watt T12 fluorescent lamps having bulbs containing various amounts of titania and coated with standard phosphor weights are compared to the maximum lumen output of a conventional lamp of the same size. The percent change in lumens relative to the maximum lumen output of the conventional lamp is plotted along

the ordinate and the variation in the phosphor weight (expressed as a percent of the conventional phosphor weight) are plotted along the abscissa. Curve D represents the conventional lamp (no TiO_2 in the bulb glass, 100% phosphor weight, optical density of 24) and shows that maximum light output requires a certain amount of a given phosphor (7.4 grams of a calcium halophosphate phosphor having an average particle size of 12 microns in the case illustrated). As the phosphor weight is decreased, the lumen output drops and decreases by 4% when the optical density is 34 (63% phosphor weight).

Curve E shows that by adding 0.23% by weight TiO_2 to the bulb glass the resulting increase in lumens (0.5%) with 100% phosphor weight permits the amount of phosphor per lamp to be decreased by 13% (87% phosphor weight and optical density 27) without any sacrifice in output as compared to the conventional lamp which contains 100% phosphor weight.

As shown by curve F, with 0.66% by weight TiO_2 in the bulb or glass the lumen increase is 1% when 100% phosphor weight is used. Lamps with such bulbs can thus be produced which have a light output that is equal to the maximum light output of the conventional lamp and contain only 79% of the phosphor weight (optical density 29). Thus, the use of 0.66% TiO_2 in the bulb glass permits the total amount of phosphor to be reduced by 21% without any sacrifice in lumens.

Curve G shows that the incorporation of 1% by weight TiO_2 in the bulb glass produces a lumen increase such that a light output equivalent to the maximum output of the conventional lamp (curve D) can be achieved with 25% less phosphor (75% phosphor weight and optical density 30).

As indicated by curves H and I (1.25% and 2% TiO_2 , respectively), the rate at which the lumens increase with 100% phosphor weight begins to drop off as the titania content of the bulb glass exceeds about 1% by weight. This agrees with the data shown in Fig. 3. Curve H shows that when the preferred amount of titania (1.25% by weight) is added to the bulb glass, a light output equivalent to that of the conventional lamp can be achieved with approximately 27% less phosphor, (73% phosphor weight and an optical density of about 31). Curve I shows that 2% by weight titania in the bulb glass achieves the same light output with only about 71% of the phosphor weight (an optical density of slightly over 31).

As will be noted from curves F, G, H and I in Fig. 4, it is within the scope of the invention to reduce the amount of phosphor required per lamp by an even greater amount if a small decrease in lumens can be tolerated. Thus, if 2% by weight titania is included in the bulb glass, the corresponding curve I shows that the amount of phosphor per lamp can be

reduced by 35% (optical density of approximately 33 and 65% phosphor weight) with a 1% loss of lumens, and that the amount of phosphor can be reduced by 40% optical density (35 and 60% phosphor weight) with approximately a 2% loss of lumens. Curves H and G show that the loss in lumens with 35% and 40% less phosphor is proportionately greater in lamps having bulbs which contain 1.25% and 1% by weight TiO_2 , respectively. As the titania content is decreased below 1% by weight, curve F (0.66% TiO_2) shows that the drop in lumens with 35% and 40% less phosphor (optical density of 33 to 35) exceeds 2%. Thus, if a lumen output equivalent to the maximum output of a conventional fluorescent lamp is desired, the present invention provides a very convenient and practical way of achieving this with up to 30% less phosphor than was required heretofore. If a small loss of lumens can be tolerated, the invention permits a reduction of up to 40% in the phosphor weight normally employed. Since millions of fluorescent lamps are made each year by the industry and phosphor is one of the most expensive components used in the lamp, the invention represents a major cost reduction and advance in the art.

Tests have shown that the inclusion of selected amounts of TiO_2 in the bulb glass does not impair the lumen maintenance of lamps made with such bulbs. This is evident from Fig. 5 which shows the percent change in lumens during life exhibited by a series of 40 watt T12 lamps having bulbs made of glass with 0.23%, 0.66%, 1.25% and 2% by weight TiO_2 (curves K, L, M, and N respectively), compared with a conventional lamp of the same type having a bulb with no titania (curve J). The lamps in each case where uniformly coated with an identical phosphor (calcium halophosphate) to a conventional optical density of 24. As will be noted, after the lamps burned for 100 hours and became stabilized the lumen output was up to 1.6% greater in the case of the lamps containing titania, with the degree of improvement decreasing with lower titania contents.

After 1500 hours burning the lumen maintenance of the lamps made with TiO_2 -modified bulb glass was higher than that of the conventional lamp as indicated by the slight upward divergence of each of the curves K to N from curve J at 1500 hours life compared to their closer grouping at 100 hours life. The upward divergence of curves M and N (1.25% and 2% titania, respectively) from the adjacent curve L (0.66% titania) indicates that these lamps have a higher lumen maintenance. The curves accordingly show that the lumen maintenance of fluorescent lamps made with bulbs containing selected amounts of titania up to 2% by weight is superior to that of conventional fluorescent lamps and that optimum improvement at the least cost is

(9)

achieved with a titania content of 1.25% by weight.

The light output and lumen maintenance of lamps having TiO_2 -modified bulbs and up to 30% less phosphor is equivalent to or better than that of conventional lamps. This is shown in Fig. 6 where in the lumen maintenance of a standard 40 watt T12 lamp (curve S) is compared to a series of lamps of the same type that have bulbs which contain the preferred 1.25% TiO_2 and are provided with phosphor layers of divergent coating densities. Curve O represents the lumen maintenance characteristic of a lamp that contains the same amount of phosphor as the conventional lamp (optical density 24) but which has 1.25% by weight titania included in the bulb glass. Curves P, Q, R and T show the lumen maintenance of lamps identical with the conventional lamp except that the bulb glass contained 1.25% titania and the amount of phosphor coated onto the bulbs was decreased from 9% to about 30% (as indicated by the optical densities of 26, 28, 30 and 32 for curves P through T, respectively).

Curve U represents the lumen maintenance exhibited by a lamp identical to the other lamps except that it was coated with approximately 63% of the phosphor employed in the conventional lamp S. Thus, the lamp corresponding to curve U contained about 37% less phosphor than that employed in the conventional lamp and had a very thin phosphor coating which had an optical density of only 34. Other tests show that the lumen maintenance is equal to that of a conventional lamp when a phosphor weight which gives an optical density of 35 (40% reduction in phosphor) is used. Similar lamp tests have shown that the lumen maintenance decreases when such thin phosphor coatings are used on soda-lime glass bulbs that contain up to 4% by weight of antimony trioxide.

As will be noted from Fig. 6, the lumen maintenance of the lamps containing the same amount of phosphor as the conventional lamp and up to 75% of this amount (curves O, P, Q and R, respectively) was better than that of the standard lamp (curve S) with the maximum improvement being obtained with the lamp that contained the same amount of phosphor as the standard lamp.

Curves S and T show that the "break even" point with respect to light output with the particular type of phosphor used (calcium halophosphate) and bulb glass that contains 1.25% by weight titania occurs when the phosphor weight is reduced by about 30% (optical density of 32). This is indicated by the fact that curve T shows that a lamp made with these amounts of titania and phosphor have a light output that is slightly lower than the conventional lamp at 100 hours, approximately the same light output as the standard lamp after 1000 hours burning, and a slightly higher out-

put than the standard lamp after 1500 hours burning. Curves S and T thus show that lamps containing only approximately 70% of the phosphor employed in a standard lamp are comparable to conventional prior art lamps as regards lumen maintenance and are even slightly superior in this regard after 1500 hours burning.

Curve U (1.25% by weight TiO_2 and optical density of 34) shows that the phosphor weight per lamp can be reduced up to about 40% with less than a 1% loss in light output (7% drop in lumens at 1500 hours vs. slightly more than a 6% reduction in lumens at the same point in life of the conventional lamp represented by curve S). However, the lumen maintenance is not affected, as is indicated by the fact that curves S and U have substantially the same slope.

Fig. 7 illustrates the correlation between the optical density and the total phosphor weight required in a 40 watt T12 fluorescent lamp. Curve V is based on data obtained with a calcium halophosphate phosphor having an average particle size of about 12 microns. Other types of phosphors would have similar shaped curves. As will be noted, with this particular phosphor a total of 7.4 grams of phosphor per lamp is required to provide the standard coating density (optical density of 24). In contrast, by applying a thinner layer of phosphor on the inner surface of the lamp envelope 12 in accordance with the invention such that the phosphor coating has an optical density of 25 (5% decrease in phosphor weight) reduces the total amount of phosphor per lamp to about 7 grams. Reducing the phosphor coating thickness by an amount such that the coating has an optical density of 35 reduces the phosphor weight per lamp to 4.5 grams, which is equivalent to about a 40% reduction in the total phosphor weight. Hence, in accordance with the invention, a reduction of from 5% to 40% (by weight) of the total amount of this particular type of halophosphate phosphor can be effected (density reading of from 25 to 35 and range R, indicated in Fig. 7) with no impairment of lumen maintenance and only a slight reduction in light output when the very thin phosphor coatings equivalent to an optical density of 34 and 35 are employed.

The actual amount of phosphor required in a fluorescent lamp of a given type will depend, of course, upon the average size of the phosphor particles, the phosphor weight being generally proportional to the average particle size. Hence, as the average particle size increases the total amount of phosphor required to provide a phosphor coating of a given optical density also increases. This relationship is shown by graph depicted in Fig. 8 which is based on data obtained with a calcium halophosphate phosphor of the type generally employed in fluorescent lamps. As indicated by curve W, a conventional 40 watt T12 lamp having a

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bulb devoid of TiO_2 requires 2 grams of such a phosphor when the average particle size is 5 microns and approximately 9.3 grams when the average particle size is 17 microns in order to provide maximum light output (optical density of 24).

In contrast, fluorescent lamps of the same type having soda-lime silicate bulbs containing up to 10% by weight TiO_2 in accordance with the present invention require a smaller amount of such a phosphor, the specific amount varying according to the average particle size within the range of 5 and 17 microns and lying within the area bounded by curves X and Y. Curve X corresponds to an optical density of 25 and 5% reduction in phosphor weight and curve Y to an optical density of 35 and a 40% reduction in phosphor weight. Thus, for a calcium halophosphate phosphor, the phosphor weight required for a 40 watt T12 fluorescent lamp having up to 10% by weight TiO_2 in the bulb glass will be determined by the average size of the phosphor particles and will lie within the hatched area Z shown in the graph of Fig. 8. In the case of a phosphor having an average particle size of 5 microns, approximately 1.2 to 1.9 grams of phosphor will be required per lamp in order to provide a phosphor coating having an optical density of from 25 to 35 (curves X and Y, respectively) in contrast to 2 grams of the same phosphor required in a conventional lamp (curve W) for substantially the same light output and lumen maintenance. In the case of a calcium halophosphate phosphor having an average particle size of 17 microns the total amount of phosphor required per lamp ranges from 5.6 grams to 8.8 grams compared to 9.3 grams for the conventional lamp.

The amount of phosphor required per lamp can also be expressed in terms of the amount of phosphor contained in each square centimeter of coated envelope surface. Expressed in these terms, the reduction in phosphor weight represented by the hatched area Z of Fig. 8 covers a range which has a lower limit of from 1.1 to 1.8 milligrams per square centimeter (the lower limit defined by curves X and Y) for an average particle size of 5 microns) and an upper limit of from 5.3 to 8.3 milligrams per square centimeter (the upper limit defined by curves X and Y for a phosphor having an average particle size of 17 microns). Thus, the reduction in phosphor weight provided by the present invention can be applied to lamps having bulbs of a length and diameter which differ from those of the 4 foot T12 bulb discussed herein by coating the envelopes with a layer of phosphor which contains an amount of phosphor per square centimeter that lies within the milligram per square centimeter range that corresponds to the hatched region Z of Fig. 8.

The phosphor particles are coated onto the inner surface of the bulb in a layer 12 that

is substantially uniform in thickness from one end of the bulb to the other. The coating uniformity, of course, becomes increasingly important at higher optical densities (lower phosphor weights). This can be accomplished by suspending the phosphor in a suitable vaporizable water-based or organic-based solution of a solvent and an organic binder to form a phosphor paint that is uniformly coated onto the bulbs, and then dried and baked.

In co-pending application No. 32797/72 (Serial No. 1,307,394) which has been divided from the present application, we have described and claimed a method of coating the inner surface of a tubular lamp envelope with a substantially uniform layer of finely divided phosphor particles which comprises suspending the phosphor particles in a solution comprising a vaporizable solvent and a volatilizable organic binder to form a phosphor paint, flushing the phosphor paint through said envelope while the latter is held in a vertical position, immediately introducing heated air into the upper end of the vertically-held envelope and subsequently air at a lower velocity to remove the vapors produced within the envelope by the solvent at a rate such that setting and drying of the deposited coating of phosphor paint is accelerated at the top of the envelope and then proceeds at a slower rate to the lower end of the envelope whereby the resulting dried coating of phosphor paint is substantially uniform along the length of the envelope, and then lehring the coated envelope for a time and at a temperature sufficient to volatilize and remove the residual organic binder from the deposited layer of phosphor particles.

WHAT WE CLAIM IS:—

1. A fluorescent lamp having a light-transmitting envelope comprising soda-lime silicate glass containing between 0.1 and 10% by weight TiO_2 , means sealed within said envelope adapted to sustain a gaseous discharge generating ultraviolet radiation when the lamp is energized, and a light-transmitting coating of phosphor on the inner surface of said envelope comprising a substantially uniform layer of finely-divided phosphor particles capable of emitting visible radiation in response to impinging ultraviolet radiation generated by said discharge, the amount of TiO_2 in said soda-lime silicate glass being sufficient to inhibit solarization of the glass and deleterious chemical reaction at the phosphor-glass interface and the total amount of said phosphor within said envelope being from 5% to 40% by weight less than the minimum amount of said phosphor which is required to achieve the same light output after 100 hours burning in an otherwise similar fluorescent lamp uniformly coated with said phosphor particles but having a soda-lime silicate glass envelope devoid of TiO_2 .

2. A lamp according to claim 1, wherein



bulb devoid of TiO_2 requires 2 grams of such a phosphor when the average particle size is 5 microns and approximately 9.3 grams when the average particle size is 17 microns in order to provide maximum light output (optical density of 24).

In contrast, fluorescent lamps of the same type having soda-lime silicate bulbs containing up to 10% by weight TiO_2 in accordance with the present invention require a smaller amount of such a phosphor, the specific amount varying according to the average particle size within the range of 5 and 17 microns and lying within the area bounded by curves X and Y. Curve X corresponds to an optical density of 25 and 5% reduction in phosphor weight and curve Y to an optical density of 35 and a 40% reduction in phosphor weight. Thus, for a calcium halophosphate phosphor, the phosphor weight required for a 40 watt T12 fluorescent lamp having up to 10% by weight TiO_2 in the bulb glass will be determined by the average size of the phosphor particles and will lie within the hatched area Z shown in the graph of Fig. 8. In the case of a phosphor having an average particle size of 5 microns, approximately 1.2 to 1.9 grams of phosphor will be required per lamp in order to provide a phosphor coating having an optical density of from 25 to 35 (curves X and Y, respectively) in contrast to 2 grams of the same phosphor required in a conventional lamp (curve W) for substantially the same light output and lumen maintenance. In the case of a calcium halophosphate phosphor having an average particle size of 17 microns the total amount of phosphor required per lamp ranges from 5.6 grams to 8.8 grams compared to 9.3 grams for the conventional lamp.

The amount of phosphor required per lamp can also be expressed in terms of the amount of phosphor contained in each square centimeter of coated envelope surface. Expressed in these terms, the reduction in phosphor weight represented by the hatched area Z of Fig. 8 covers a range which has a lower limit of from 1.1 to 1.8 milligrams per square centimeter (the lower limit defined by curves X and Y) for an average particle size of 5 microns and an upper limit of from 5.3 to 8.3 milligrams per square centimeter (the upper limit defined by curves X and Y for a phosphor having an average particle size of 17 microns). Thus, the reduction in phosphor weight provided by the present invention can be applied to lamps having bulbs of a length and diameter which differ from those of the 4 foot T12 bulb discussed herein by coating the envelopes with a layer of phosphor which contains an amount of phosphor per square centimeter that lies within the milligram per square centimeter range that corresponds to the hatched region Z of Fig. 8.

The phosphor particles are coated onto the inner surface of the bulb 12 in a layer 13 that

is substantially uniform in thickness from one end of the bulb to the other. The coating uniformity, of course, becomes increasingly important at higher optical densities (lower phosphor weights). This can be accomplished by suspending the phosphor in a suitable vaporizable water-based or organic-based solution of a solvent and an organic binder to form a phosphor paint that is uniformly coated onto the bulbs, and then dried and baked.

In co-pending application No. 32797/72 (Serial No. 1,307,394) which has been divided from the present application, we have described and claimed a method of coating the inner surface of a tubular lamp envelope with a substantially uniform layer of finely divided phosphor particles which comprises suspending the phosphor particles in a solution comprising a vaporizable solvent and a volatilizable organic binder to form a phosphor paint, flushing the phosphor paint through said envelope while the latter is held in a vertical position, immediately introducing heated air into the upper end of the vertically-held envelope and subsequently air at a lower velocity to remove the vapors produced within the envelope by the solvent at a rate such that setting and drying of the deposited coating of phosphor paint is accelerated at the top of the envelope and then proceeds at a slower rate to the lower end of the envelope whereby the resulting dried coating of phosphor paint is substantially uniform along the length of the envelope, and then lehring the coated envelope for a time and at a temperature sufficient to volatilize and remove the residual organic binder from the deposited layer of phosphor particles.

WHAT WE CLAIM IS:—

1. A fluorescent lamp having a light-transmitting envelope comprising soda-lime silicate glass containing between 0.1 and 10% by weight TiO_2 , means sealed within said envelope adapted to sustain a gaseous discharge generating ultraviolet radiation when the lamp is energized, and a light-transmitting coating of phosphor on the inner surface of said envelope comprising a substantially uniform layer of finely-divided phosphor particles capable of emitting visible radiation in response to impinging ultraviolet radiation generated by said discharge, the amount of TiO_2 in said soda-lime silicate glass being sufficient to inhibit solarization of the glass and deleterious chemical reaction at the phosphor-glass interface and the total amount of said phosphor within said envelope being from 5% to 40% by weight less than the minimum amount of said phosphor which is required to achieve the same light output after 100 hours burning in an otherwise similar fluorescent lamp uniformly coated with said phosphor particles but having a soda-lime silicate glass envelope devoid of TiO_2 .

2. A lamp according to claim 1, wherein

(16)



the phosphor particles have an average particle size within a range of from 5 to 17 microns, the amount of phosphor per square centimeter of envelope surface being substantially proportional to the average particle size of said phosphor particles and within a range of from 1.1 milligrams per square centimeter for a phosphor having an average particle size of 5 microns to 8.3 milligrams per square centimeter for a phosphor having an average particle size of 17 microns.

3. A lamp according to claim 2, wherein the envelope is of tubular configuration, approximately 4 feet long and has an outer diameter of approximately 1—1/2 inches, the total amount of phosphor within the envelope for a given average phosphor particle size within the range of from 5 to 17 microns being within the hatched area Z of the graph shown in Fig. 8.

4. A lamp according to claim 1, 2 or 3, wherein the phosphor is a calcium halophosphate phosphor and the soda-lime silicate glass contains less than 2% by weight TiO_2 .

5. A lamp according to claim 4, wherein the soda-lime silicate glass contains 1.25% by weight TiO_2 .

6. A lamp according to any of claims 1 to 5, wherein mercury and an ionizable fill gas is sealed within the envelope, the amount of TiO_2 in the soda-lime silicate glass being sufficient to inhibit solarization of the glass and the formation of blackening deposits at the

phosphor-glass interface due to chemical reaction between the mercury within the envelope and the alkali constituents of the glass.

7. A lamp according to any of claims 1 to 6, wherein the average size of the phosphor particles and the density of the phosphor coating is such that said coating is more light-transmissive than a substantially uniform coating of calcium halophosphate phosphor containing 6.9 milligrams of phosphor per square centimeter of envelope surface and consisting of phosphor particles having an average particle size of 12 microns and disposed on the inner surface of a reference envelope identical to said envelope but composed of soda-lime silicate glass devoid of TiO_2 , the light-transmitting ability of the phosphor layer within said lamp compared to that of the calcium halophosphate phosphor coating on said reference envelope being such that the intensity of a beam of light of predetermined intensity passing through said lamp, when the latter is deenergized, along a path normal to and intersecting the envelope axis is from 4% to 46% higher than the intensity of an identical beam of light passing through said reference envelope along an identical path.

8. Fluorescent lamps according to claim 1 substantially as described herein with particular reference to the accompanying drawings.

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