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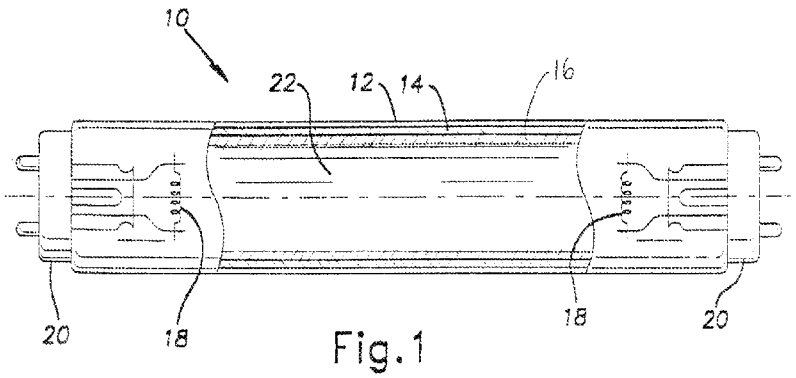


Fig.1

(57) Abstract: A fluorescent lamp includes a glass envelope that is light transmitting. There is means for providing a discharge inside the en velope. A discharge-sustaining fill of mercury and an inert gas is sealed inside the envelope. An underlying phosphor-containing layer is disposed inside the envelope. The underlying layer includes yttrium vanadate phosphor. A protective phosphor-containing layer is disposed over the underlying layer at a location that is more distal from the glass than the underlying layer.

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FLUORESCENT LAMP WITH UNDERLYING YTTRIUM VANADATE PHOSPHOR LAYER AND PROTECTIVE PHOSPHOR LAYER

Field of the Invention:

This disclosure relates to fluorescent lamps and, in particular, to improving lumen maintenance of fluorescent lamps utilizing yttrium vanadate phosphor (e.g., yttrium vanadate activated with Europium or yttrium vanadate phosphate activated with Europium (and/or other activator).

Background of the Invention:

Fluorescent lamps are well known and comprise a tubular hermetically sealed glass envelope including electrodes at ends thereof. Inside the envelope is an arc discharge sustaining medium, usually at a low pressure, including inert gases and a small amount of mercury. The inside of the glass envelope is typically coated with a layer of phosphor, which absorbs ultraviolet electromagnetic radiation of 254nm and 185nm generated by the excited mercury arc and emits in a region of visible light..

Fluorescent lamps usually experience a gradual decrease in light output (measured in lumens) with the increase of lamp usage (measured in hours burned). Ideally, the phosphor should absorb the 254nm and 185nm emission strongly and convert them into visible light efficiently. But in reality, most of the 185 nm wavelength radiation is wasted, which lowers the overall efficiency of the lamp. Moreover, 185nm emission also leads to formation of color center- a type of point defect-in phosphors, which decreases the phosphor conversion efficiency and lumen output of lamps over their life cycle. There are other notable problems associated with phosphors in fluorescent lamps. The phosphor coating is exposed to both ion bombardment and chemical reaction from the mercury discharge which is a reducing medium. In addition, during phosphor synthesis and lamp fabrication process, phosphors are usually exposed to oxygen-rich atmosphere which tend to partially oxidize reactive lower-valence ions in the phosphor lattice. These problems lead to the overall degradation of phosphors and their lumen output over life.

Yttrium vanadate phosphors (e.g., $YVO_4 : Eu^{3+}$, $Y(P,V)O_4 : Eu^{3+}$) strongly emitting in the deep red region, have been widely utilized in high pressure mercury lamps, and have greatly improved color rendering properties of these lamps. However, they have been excluded from current commercial use in fluorescent lamp manufacturing because of their very severe lumen depreciation during lamp operation.

Brief Description of the Invention:

In general, this disclosure features a fluorescent lamp comprising a glass envelope that is light transmitting. There is means for providing a discharge inside the envelope (e.g., electrodes that are spaced apart in inside the envelope). A discharge-sustaining fill of mercury and an inert gas are sealed inside the envelope. An underlying phosphor-containing layer is disposed inside the envelope. The underlying layer comprises yttrium vanadate phosphor (e.g., $Y(P,V)O_4 : Eu^{3+}$and/or $YVO_4 : Eu^{3+}$); this means yttrium vanadate phosphate activated with europium or yttrium vanadate activated with europium, respectively, as is known in the art. A protective phosphor-containing layer is disposed over the underlying layer at a location that is more distal from the glass than the underlying layer. That is, the protective layer is closer to the discharge than the underlying layer is.

Regarding more specific features, the protective layer may inhibit reaction of the underlying layer (i.e., the yttrium vanadate phosphor therein) with the mercury. Other layers could be disposed under the underlying layer, between the underlying and protective layer, and on top of the protective layer. A barrier layer can be disposed between the glass and the underlying layer, wherein the barrier layer comprises alumina or silica.

The protective layer or the underlying layer can comprise a phosphor selected from the group consisting of $Y_2O_3 : Eu^{3+}$ (YEO); $BaMg_2Al_{16}O_{27} : Eu^{2+}$ (BAM); $BaMg_2Al_{16}O_{27} : Eu^{2+}$, Mn^{2+} (BAMn); $GdMgB_5O_{10} : Ce^{3+}$, Mn^{3+} (CBM); $MgAl_{11}O_{19}:Ce^{3+}$, Tb^{3+} (CAT); $GdMgB_5O_{10} : Ce^{3+}$, Tb^{3+} (CBT); $LaPO_4 : Ce^{3+}$, Tb^{3+} (LAP); $(Sr,Ba,Ca)_5(PO_4)_3Cl : Eu^{2+}$ (SECA); $(Ca,Ba,Sr)_5(PO_4)_3(F,Cl):Sb^{3+}$, Mn^{2+} (halophosphate), and combinations thereof. The phosphor of the protective layer can comprise YEO, LAP and SECA. The phosphor of the underlying layer can comprise yttrium vanadate phosphor, LAP and SECA. The phosphor of the protective layer can comprise YEO, LAP and SECA while the phosphor of the underlying layer can comprise yttrium vanadate phosphor, LAP and SECA.

A ratio of a surface density of the protective layer to a surface density of the underlying layer can be at least about 0.5:1, in particular, at least about 1.0:1. A surface density of the underlying layer can be not more than about 2.2 mg/cm^2, in particular not more than about 1.6 mg/cm^2.

A more specific aspect of this disclosure features a fluorescent lamp comprising a glass envelope that is light transmitting. Electrodes are spaced apart in the envelope for providing a discharge inside the envelope. A discharge-sustaining fill of mercury and an inert gas are sealed inside the envelope. An underlying phosphor-containing layer is disposed inside the envelope. The underlying layer comprises at least one of yttrium vanadate activated with europium and yttrium vanadate phosphate activated with europium and/or other activator (e.g., $YVO_4 : Eu^{3+}$, $Y(P,V)O_4 : Eu^{3+}$). A protective phosphor-containing layer is disposed over the underlying layer at a location that is more distal from the glass than the underlying layer. Any of the specific features discussed above with regard to the general embodiment, may be used in any combination in connection with this more specific aspect of the disclosure.

Regarding further specific features of the lamp performance, more desirable is a color rendering index (CRI) of at least 87 or lumens per watt (LPW) of at least 89. A correlated color temperature (CCT) of the lamp, as defined by the x-y chromaticity coordinates as provided on the x-y chromaticity diagram of the ICI system, ranges from 2700 °K to 6500 °K. The x-y chromaticity of the underlying layer could be different than that of the protective layer. Other layers could be disposed under the underlying layer, between the underlying and protective layer, and on top of the protective layer. A barrier layer can be disposed between the glass and the underlying layer. The barrier layer can comprise alumina or silica.

Many additional features, advantages and a fuller understanding of the invention will be had from the accompanying drawings and the Detailed Description of the Invention that follows. It should be understood that the above Brief Description of the Invention describes the invention in broad terms while the following Detailed Description of the Invention describes the invention more narrowly and presents embodiments that should not be construed as necessary limitations of the broad invention as defined in the claims.

Brief Description of the Drawings:

Figure 1 shows diagrammatically, and partially in section, a fluorescent lamp made according to this disclosure;

Figure 2 is a graph of lumen loss between 0 and 100 hours of lamp burning ("lumen % loss") as a function of a ratio of surface density of a protective phosphor layer to a surface density of an underlying phosphor layer; and

Figure 3 is a graph of % lumens maintained at 500 hours of lamp burning compared to at 100 hours lamp burning as a function of a ratio of surface density of a protective phosphor layer to a surface density of an underlying phosphor layer.

Detailed Description of the Invention:

This disclosure features a fluorescent lamp comprising a glass envelope that is light transmitting. There is means for providing a discharge inside the envelope. A discharge-sustaining fill of mercury and an inert gas is sealed inside the envelope. An underlying phosphor-containing layer is disposed inside the envelope. The underlying layer comprises yttrium vanadate phosphor. A protective phosphor-containing layer is disposed over the underlying layer at a location that is more distal from the glass than the underlying layer. Any phosphor can be used in addition to the yttrium vanadate phosphor in the underlying layer. Any phosphor can be used in the protective layer; it may prevent reaction of the yttrium vanadate with mercury of the discharge.

Regarding more specific aspects of this disclosure the yttrium vanadate comprises at least one of yttrium vanadate activated with europium ($YVO_4:Eu^{3+}$) emitting red light with a peak wavelength of 595,620,700 nm and yttrium vanadate phosphate activated with europium ($Y(P,V)O_4 : Eu^{3+}$). The protective layer may inhibit reaction of the underlying layer with the mercury of the discharge-sustaining fill.

The underlying layer or the protective layer comprise a phosphor selected from the group consisting of $Y_2O_3 : Eu^{3+}$ (YEO) emitting red-orange light with a peak wavelength of 611nm; $BaMg_2Al_{16}O_{27} : Eu^{2+}$ (BAM) emitting blue light with a peak wavelength of 450nm; $BaMg_2Al_{16}O_{27} : Eu^{2+}, Mn^{2+}$ (BAMn) emitting blue-green light with a peak wavelength of 450/515nm; $GdMgB_5O_{10} : Ce^{3+}, Mn^{3+}$ (CBM) emitting red light with a peak wavelength of

625nm; $MgAl_{11}O_{19}:Ce^{3+}$, Tb^{3+} (CAT) emitting green light with a peak wavelength of 543nm; $GdMgB_5O_{10}:Ce^{3+}$, Tb^{3+} (CBT) emitting green light with a peak wavelength of 545nm; $LaPO_4:Ce^{3+}$, Tb^{3+} (LAP) emitting green light with a peak wavelength of 544nm; $(Sr,Ba,Ca)_5(PO_4)_3Cl:Eu^{2+}$ (SECA) emitting blue light with a peak wavelength of 445-470nm; $(Ca,Ba,Sr)_5(PO_4)_3(F,Cl):Sb^{3+}$, Mn^{2+} (halophosphor), for example, $Ca_5(PO_4)_3(F,Cl):Sb^{3+}$, Mn^{2+} (calcium halophosphate) emitting white light, and combinations thereof. In particular, the phosphor of the protective layer comprises YEO, LAP and SECA and the phosphor of the underlying layer comprises yttrium vanadate phosphor, LAP and SECA. Alumina or silica may be included in the underlying layer and in the protective layer. The amounts and types of each phosphor in the underlying layer and in the protective layer can be selected to produce the desired CCT of the lamp (2700 °K to 6500 °K) as would be understood by one of ordinary skill in the art in view of this disclosure.

The fluorescent lamp 10 has a light-transmissive glass tube or envelope 12 which has a circular cross-section. The inner surface of the glass envelope is provided with an underlying layer 14. The protective layer 16 is disposed on top of the underlying layer. The protective layer is farther away from the glass than is the underlying layer. Other layers could be disposed under the underlying layer, between the underlying and protective layer and on top of the protective layer. The lamp is hermetically sealed by bases 20 attached at both ends, and a pair of spaced electrode structures 18 at each end of the lamp (which are means for providing a discharge) are respectively mounted on the bases 20. A discharge-sustaining fill 22 of mercury and an inert gas is sealed inside the glass tube. The inert gas is typically argon or a mixture of argon and other noble gases at low pressure which, in combination with a small quantity of mercury, provide the low vapor pressure manner of operation.

The underlying layer 14 and protective layer 16 are preferably utilized in a low pressure mercury vapor discharge lamp, but may also be used in a high pressure mercury vapor discharge lamp. As used herein, a "fluorescent lamp" is any mercury vapor discharge fluorescent lamp as known in the art, including fluorescent lamps having electrodes, and electrodeless fluorescent lamps where the means for providing a discharge include a radio transmitter adapted to excite mercury vapor atoms via transmission of an electromagnetic signal. A "T8 lamp" can be used in this disclosure and is a fluorescent lamp as known in the art, e.g., linear, nominally 48 inches in length, and having a nominal outer diameter of 1 inch (eight times 1/8 inch, which is where the

"8" in "T8" comes from). The T8 fluorescent lamp can also be nominally 2, 3, 6 or 8 feet long, or some other length. T5 and T12 fluorescent lamps known in the art can also utilize the underlying and protective layers of this disclosure. The fluorescent lamp can have a "non-straight glass envelope" which includes (but is not limited to) a glass envelope or tube which is in the shape of an L or a U (such as a 4 foot T8 or T12 lamp bent into a U-shape), a circular glass envelope as is known in the art, the glass envelope of a compact fluorescent lamp (e.g., a helical compact fluorescent lamp), and other glass envelopes which are not a straight cylindrical glass envelope. Compact fluorescent lamps are well known; see U.S. Pat. Nos. 2,279,635; 3,764,844; 3,899,712; 4,503,360; 5,128,590; 5,243,256; 5,451,104; and German Patent Application No. DE 4133077 filed in Germany on Oct. 2, 1991.

The underlying layer 14 and protective layer 16 are provided on the lamp as follows. The underlying layer coating is prepared as codispersion of phosphor particles in an aqueous vehicle containing colloidal alumina or silica. The alumina or silica is about 10 weight% to 50 weight% of the total amount of phosphor used in the underlying layer. The coating formulation is typically kept slightly basic by use of ammonia. Then an acrylic-based thickener, typically, is added together with surfactants. The suspension is then applied as a coating to the inside of the glass tube used to make the fluorescent lamp and heated to dry, as is known in the art. The phosphor-containing underlying layer is applied so that the weight of phosphor in the layer (the "coating weight") is 0.5-3, more specifically, 0.8-2 mg/cm^2.

The phosphor powder of the protective layer is first dispersed in a water vehicle containing colloidal alumina or silica with a dispersing agent such as ammonium polyacrylate and a nonionic surfactant such as nonylphenyl-ethoxylate, though any suitable nonionic surfactant can be used. The alumina or silica is about 0.2-4 weight % of the phosphor used in the protective layer. Then a thickener is added as a viscosity controlling agent, typically polyethylene oxide having a molecular weight in the range of 200,000 to 1,000,000 g/mol, and optionally other dispersing agents, surfactants, and thickeners known in the art may be added. The resulting suspension is typically about 20-40 weight percent phosphor powder, 0.05-2 weight percent dispersing agent, 1-3 weight percent surfactant and 1-5 weight percent thickener, with the balance being water totaling 100% by weight. The suspension is then applied as a coating to the inside of the glass tube which is already coated with the underlying coating as described above, and heated to dry, as is known in the art. The phosphor-containing protective

layer is applied so that the weight of phosphor in the layer (the "coating weight") is 0.5-3, more specifically, 0.8-2, more specifically, 1-1.6 mg/cm^2.

In one aspect, the lamp has no more than two layers inside the glass envelope, these being the described underlying layer and the protective layer. This protective layer faces the arc or is closer to the arc than is the glass envelope. The lamp may have a barrier layer of alumina or silica between the underlying layer 14 and the glass tube 12. In this case the underlying layer is still closer to the arc than the barrier layer.

The disclosure will now be described by reference to the following examples, which should not be used in any way to limit the invention that is described by the following claims.

Example 1

Five T8 lamps with glass envelopes each having a surface area of 972.88 cm^2, a diameter of 25.4 mm and a length of 1219.2 mm were coated with an underlying layer followed by a protective layer each having the following phosphor weight percentage compositions shown in Table 1 and made following the method in the Detailed Description. Each lamp was filled with argon at a fill pressure in the range of 2.0 to 3.5 torr and a dose of mercury in the range of 2.0 to 4.0 mg. The color points of each of the phosphor layers are provided.

protective layer	YEO	61.9%
	LAP	28.7%
	SECA	9.6%
	CCX	0.4122
	CCY	0.3931

underlying layer	Yttrium Vanadate	41.9%
	LAP	42.9%
	SECA	15.2%
	CCX	0.4068
	CCY	0.4070

Table 1

The yttrium vanadate phosphor that was used was yttrium vanadate phosphate $Y(P,V)O_4:Eu^{3+}$.

Each of the layers was coated on the lamps according to the following surface densities in the unit of mg/cm^2 and to have the following ratio of coating surface densities shown in Table 2. Lamps of cell B had no protective layer. A "cell" is a group of similar lamps.

cell	Lamp	Underlying layer surface density (mg/cm^2)	Protective layer surface density (mg/cm^2)	Protective/Underlying layer surface density ratio
A	1	2.61	0.5	0.19
A	2	2.51	0.57	0.23
A	3	2.58	0.54	0.21
A	4	2.58	0.58	0.22
A	5	2.59	0.58	0.22
average		2.57	0.55	0.22
B	1	2.57	0	0.00
B	2	2.61	0	0.00
B	3	2.6	0	0.00
B	4	2.59	0	0.00
B	5	2.6	0	0.00
average		2.59	0.00	0.00
C	1	2.16	1.01	0.47
C	2	2.15	0.97	0.45
C	3	2.12	1.01	0.48
C	4	2.11	1.06	0.50
C	5	2.04	1.06	0.52
average		2.12	1.02	0.48

D	1	1.59	1.48	0.93
D	2	1.47	1.45	0.99
D	4	1.51	1.55	1.03
D	5	1.52	1.5	0.99
average		1.52	1.50	0.98

Table 2

The lamps were burned for 100 hours and the lumen loss between 0 and 100 hours was measured and given on the y axis of Fig. 2 ("lumen % loss"). It can be seen that the lumen % loss decreased at an average surface density ratio of about 0.5 (protective layer surface density/underlying layer surface density) compared to an average surface density of about 0.2. The lumen % loss decreased still further at an average surface density ratio of about 1.0 compared to at the average surface density ratio of about 0.5.

The following Table 3 shows lamp properties after 100 hours of burning.

Cell/ Lamp	Lamp Volts	Total Watts	ccx	ccy	CRI	CCT	Lumens	Lamp LPW
A/1	139.8	32.6	0.4086	0.4067	85.4	3556	2573.5	78.94
A/2	140.1	32.8	0.4087	0.4054	85.6	3544	2597.2	79.18
A/3	142.8	33	0.4075	0.4037	85.5	3556	2588.7	78.45
A/4	142.4	32.9	0.4079	0.4045	85.5	3553	2562	77.87
A/5	142.5	33.2	0.4081	0.4046	85.6	3550	2595.5	78.18
Ave.	**141.5**	**32.9**	**0.4082**	**0.4050**	**85.5**	**3552**	**2583.4**	**78.52**
B/1	142.4	33.1	0.4068	0.4066	80.2	3500	2424.9	73.26
B/2	140	32.7	0.4068	0.4073	80.1	3506	2410.2	73.71
B/3	140.5	32.9	0.4059	0.4077	79.8	3528	2428.4	73.81
B/4	139.6	32.7	0.4061	0.4065	80	3517	2425.7	74.18
B/5	141.1	32.9	0.4084	0.4068	80.6	3565	2412.1	73.32
Ave.	**140.7**	**32.86**	**0.4068**	**0.4070**	**80.1**	**3503**	**2420.3**	**73.66**
C/1	140.3	32.6	0.4203	0.3992	86.8	3262	2681.1	82.24

C/2	146.6	33.3	0.419	0.3988	86.7	3283	2661.6	79.93
C/3	141.9	33	0.4201	0.3989	86.7	3261	2674	81.03
C/4	140.6	32.8	0.421	0.3992	86.7	3247	2682.6	81.79
C/5	141.8	33.1	0.4194	0.3983	86.6	3271	2682.8	81.05
Ave.	**142.2**	**32.96**	**0.4200**	**0.3989**	**86.7**	**3265**	**2676.4**	**81.2**
D/1	143.2	33	0.4222	0.397	86.7	3205	2741.4	83.07
D/2	142.9	33.1	0.4223	0.3964	86.7	3200	2746.8	82.98
D/4	141.4	33	0.4211	0.3952	86.6	3211	2788.1	84.49
D/5	142.5	33.1	0.4226	0.3975	86.7	3202	2747.3	83
Ave.	**142.5**	**33.05**	**0.4221**	**0.3965**	**86.7**	**3205**	**2755.9**	**83.4**

Table 3

These lamps of Table 3 had the phosphor compositions shown in Table 1 and the surface density and surface density ratios shown in Table 2. It can be seen that the lamps having a surface density ratio of about 0.5 and about 1.0 (cells C and D of the invention) favorably had CRI values of about 87 and the highest LPW of all the lamp cells. This is consistent with what one, who is skilled in the art, with knowledge of the present disclosure might expect. With increase of the coating surface density ratio, light emission from the protective layer containing YEO increasingly contributes to the total light emission of the lamp which also includes light emission from the underlying layer containing $Y(P,V)O_4: Eu^{3+}$ red. Therefore , LPW and CRI are both improved. The lamps of cell B which had no protective layer had the lowest CRI of all of the cells. The lamps of cell B also had the highest lumen% loss of any of the other cells (Fig. 2), which highlights the effectiveness of the protective layer in protecting the yttrium vanadate phosphate phosphor of the underlying layer and reducing the lumen% loss.

Example 2

The same lamps described above in Example 1 having the same surface density, protective layer/underlying layer surface density ratio, and phosphor compositions were used to produce 500 hour lamp data.

The percentage of the lumens maintained at 500 hours compared to the lumens at 100 hours on the y axis ("lumen maintenance") was plotted as a function of the protective

layer/underlying layer surface density ratio ("surface density ratio") in Fig. 3. This figure shows that the lumen percentage maintained was at least about 97.5% at a surface density ratio of about 0.2, which is greater than the 95.5% highest lumen % maintained at a surface density ratio of 0 with no protective layer. This shows the effectiveness of the protective layer. The surface density ratios of about 0.5 and about 1.0 produced even better % lumen maintenance of at least about 98.0.

Lamp cells C and D of the invention, which had an average surface density ratio of about 0.50 and about 1.00 favorably had a CRI of about 87 and an average LPW above 80. Lamp cells B that had no protective layer had the lowest CRI and LPW of any of the lamp cells.

Measurements of lamp properties were conducted as known in the art and as described in the "Approved Method Electrical and Photometric Measurements of Fluorescent Lamps," IES LM-9-09, IES Illuminating Engineering Society, which is incorporated herein by reference in its entirety.

Many modifications and variations of the invention will be apparent to those of ordinary skill in the art in light of the foregoing disclosure. Therefore, it is to be understood that, within the scope of the appended claims, the invention can be practiced otherwise than has been specifically shown and described.

What is claimed is:

1. A fluorescent lamp comprising:

a glass envelope that is light transmitting;

means for providing a discharge inside said envelope;

a discharge-sustaining fill of mercury and an inert gas sealed inside said envelope;

an underlying phosphor-containing layer disposed inside said envelope, said underlying layer comprising yttrium vanadate phosphor; and

a protective phosphor-containing layer disposed over said underlying layer at a location that is more distal from said glass than said underlying layer.

2. The fluorescent lamp of claim 1 wherein said yttrium vanadate phosphor comprises at least one of yttrium vanadate activated with europium and yttrium vanadate phosphate activated with europium and/or other activator.

3. The fluorescent lamp of claim 1 wherein said protective layer inhibits reaction of said underlying layer with said mercury.

4. The fluorescent lamp of claim 1 wherein said protective layer or said underlying layer comprise a phosphor selected from the group consisting of $Y_2O_3 : Eu^{3+}$ (YEO); $BaMg_2Al_{16}O_{27} : Eu^{2+}$ (BAM); $BaMg_2Al_{16}O_{27} : Eu^{2+}, Mn^{2+}$ (BAMn); $GdMgB_5O_{10} : Ce^{3+}, Mn^{3+}$ (CBM); $MgAl_{11}O_{19}:Ce^{3+}, Tb^{3+}$ (CAT); $GdMgB_5O_{10} : Ce^{3+}, Tb^{3+}$ (CBT)); $LaPO_4 : Ce^{3+}, Tb^{3+}$ (LAP); $(Sr,Ba,Ca)_5(PO_4)_3Cl : Eu^{2+}$ (SECA); $(Ca,Ba,Sr)_5(PO_4)_3(F,Cl):Sb^{3+}, Mn^{2+}$ (halophosphate), and combinations thereof.

5. The fluorescent lamp of claim 4 wherein said phosphor of said protective layer comprises YEO, LAP and SECA.

6. The fluorescent lamp of claim 4 wherein said phosphor of said underlying layer comprises said yttrium vanadate phosphor, LAP and SECA.

7. The fluorescent lamp of claim 4 wherein said phosphor of said protective layer comprises YEO, LAP and SECA and said phosphor of said underlying layer comprises said yttrium vanadate phosphor, LAP and SECA.

8. The fluorescent lamp of claim 1 wherein said means for providing a discharge inside said envelope comprises electrodes spaced apart inside said envelope.

9. The fluorescent lamp of claim 1 comprising a barrier layer disposed between said glass and said underlying layer, wherein said barrier layer comprises alumina or silica.

10. The fluorescent lamp of claim 1 wherein a ratio of a surface density of said protective layer to a surface density of said underlying layer is at least about 0.5:1.

11. The fluorescent lamp of claim 1 wherein a ratio of a surface density of said protective layer to a surface density of said underlying layer is at least about 1.0:1.

12. The fluorescent lamp of claim 10 wherein a surface density of said underlying layer is not more than about 2.2 $mg/cm^{2.}$

13. The fluorescent lamp of claim 11 wherein a surface density of said underlying layer is not more than about 1.6 mg/cm^{2}.

14. A fluorescent lamp comprising:
a glass envelope that is light transmitting;
electrodes spaced apart in said envelope for providing a discharge inside said envelope;
a discharge-sustaining fill of mercury and an inert gas sealed inside said envelope;

an underlying phosphor-containing layer disposed inside said envelope, said underlying layer comprising at least one of yttrium vanadate activated with europium and yttrium vanadate phosphate activated with europium and/or other activator; and

a protective phosphor-containing layer disposed over said underlying layer at a location that is more distal from said glass than said underlying layer.

15. The fluorescent lamp of claim 14 wherein said protective layer inhibits reaction of said underlying layer with said mercury.

16. The fluorescent lamp of claim 14 wherein said protective layer comprises a phosphor selected from the group consisting of $Y_2O_3 : Eu^{3+}$ (YEO); $BaMg_2Al_{16}O_{27} : Eu^{2+}$ (BAM); $BaMg_2Al_{16}O_{27} : Eu^{2+}, Mn^{2+}$ (BAMn); $GdMgB_5O_{10} : Ce^{3+}, Mn^{3+}$ (CBM); $MgAl_{11}O_{19}:Ce^{3+}, Tb^{3+}$ (CAT); $GdMgB_5O_{10} : Ce^{3+}, Tb^{3+}$ (CBT); $LaPO_4 : Ce^{3+}, Tb^{3+}$ (LAP); $(Sr,Ba,Ca)_5(PO_4)_3Cl : Eu^{2+}$ (SECA); $(Ca,Ba,Sr)_5(PO_4)_3(F,Cl):Sb^{3+}, Mn^{2+}$ (halophosphate), and combinations thereof.

17. The fluorescent lamp of claim 16 wherein said phosphor of said protective layer comprises YEO, LAP and SECA.

18. The fluorescent lamp of claim 16 wherein said phosphor of said underlying layer comprises said yttrium vanadate phosphor, LAP and SECA.

19. The fluorescent lamp of claim 16 wherein said phosphor of said protective layer comprises YEO, LAP and SECA and said phosphor of said underlying layer comprises said yttrium vanadate phosphor, LAP and SECA.

20. The fluorescent lamp of claim 14 wherein a ratio of a surface density of said protective layer to a surface density of said underlying layer is at least about 0.5:1.

21. The fluorescent lamp of claim 14 wherein a ratio of a surface density of said protective layer to a surface density of said underlying layer is at least about 1.0:1.

22. The fluorescent lamp of claim 14 wherein a surface density of said underlying layer is not more than about 2.2 mg/cm^2.

23. The fluorescent lamp of claim 14 wherein a surface density of said underlying layer is not more than about 1.6 mg/cm^2.

24. The fluorescent lamp of claim 14 comprising a barrier layer disposed between said glass and said phosphor containing layer, wherein said barrier layer comprises alumina or silica.

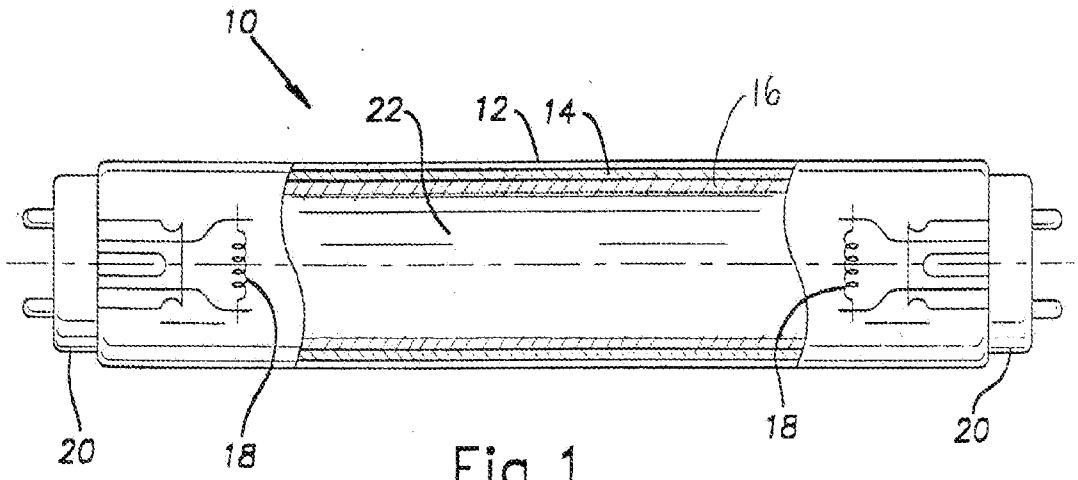


Fig.1

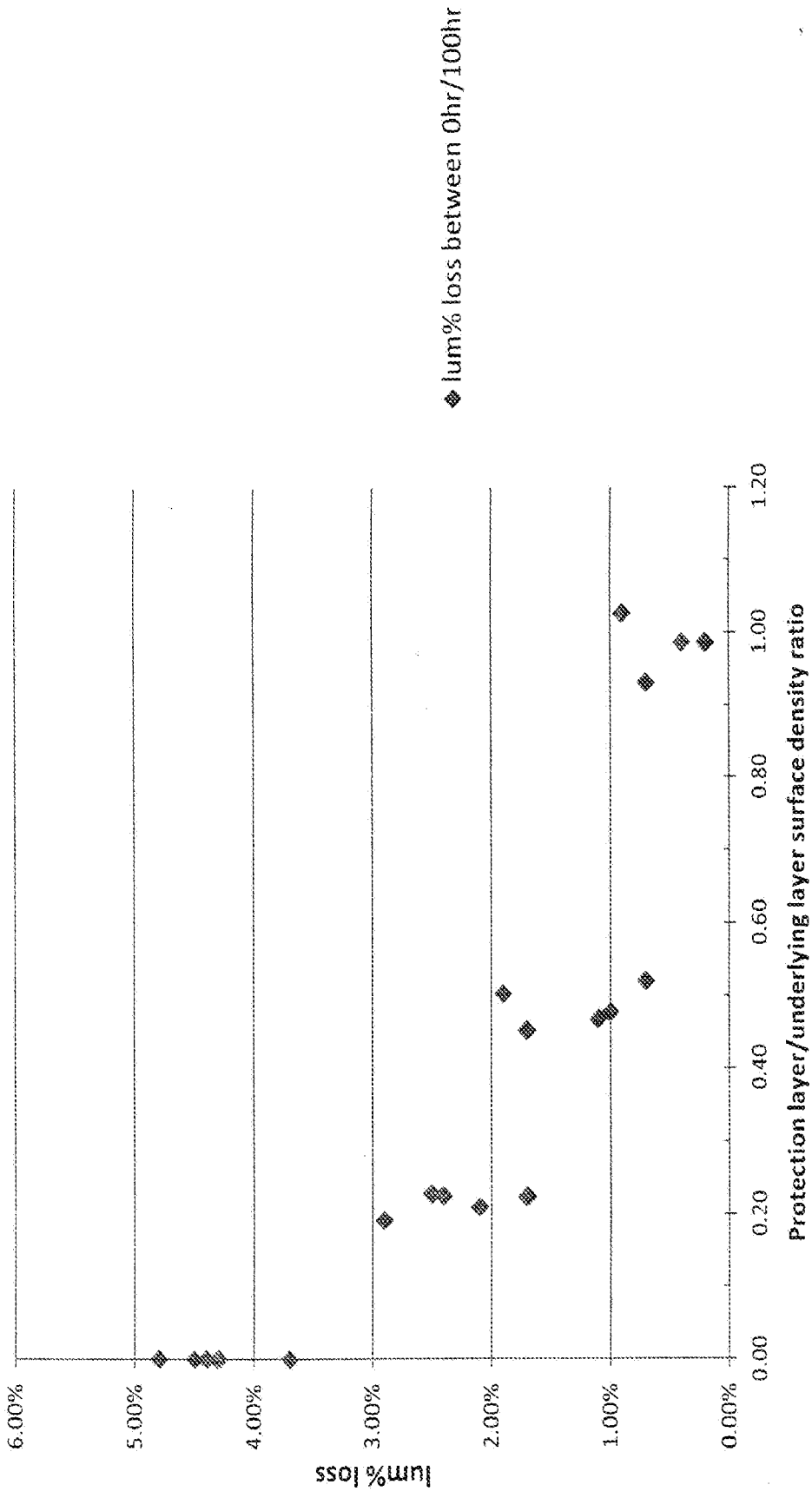

lum% loss between 0hr/100hr
lum% loss
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Protection layer/underlying layer surface density ratio

Fig. 2

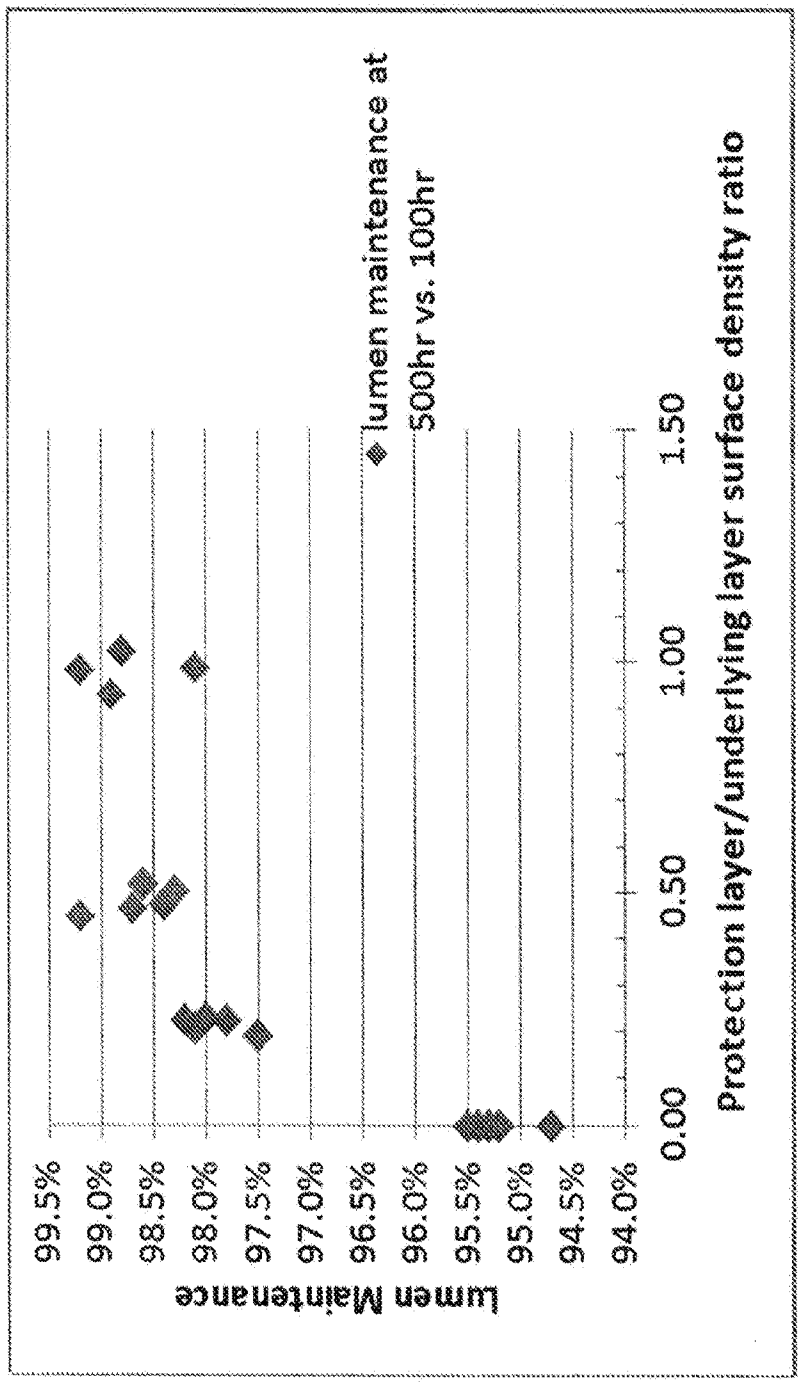

Lumen Maintenance
99.5%
99.0%
98.5%
98.0%
97.5%
97.0%
96.5%
96.0%
95.5%
95.0%
94.5%
94.0%
0.00
0.50
1.00
1.50
Protection layer/underlying layer surface density ratio
Lumen maintenance at 500hr vs. 100hr

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/055480

A. CLASSIFICATION OF SUBJECT MATTER
INV. C09K11/76 C09K11/77 H01J61/44 H01J61/26 H01J61/35 H01J61/48
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C09K H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X Y	US 4 979 893 A (PAPPALARDO ROMANO G [US] ET AL) 25 December 1990 (1990-12-25) figure 1 column 2, line 64 - column 3, line 12 example 2 the whole document ----- -/--	1-8, 10-23 9,24

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 November 2012	22/11/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Ziegler, Jan

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/055480

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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