

[54] COLOR PLASMA DISPLAY

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[51] Int. Cl. H01j 61/44

[58] Field of Search 313/188, 220, 109, 108 B, 313/185

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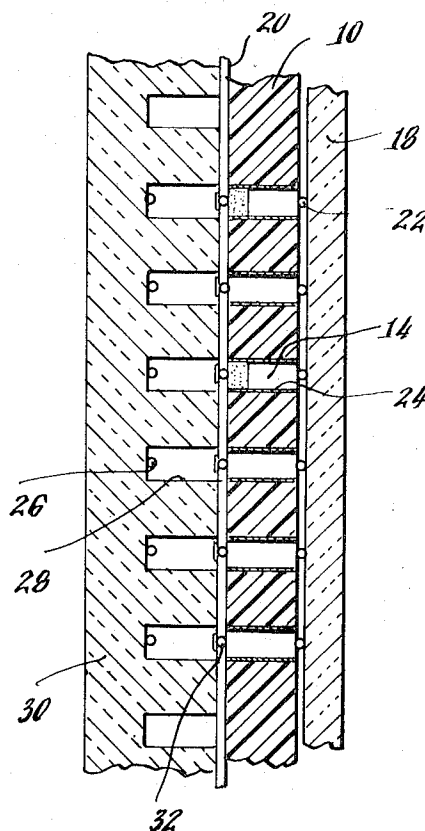
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[57]

ABSTRACT

This invention relates to a plasma display device adapted for generating a display in a color other than the characteristic color of the plasma gas utilized. At least one surface of each cell cavity of the device is formed at least in part of a multi-photon down-conversion phosphor (an anti-Stokes phosphor). For one embodiment of the invention the phosphor is coated on the walls of the cavity. For another embodiment of the invention, the cavity is formed as an opening through a member of an insulating material positioned between a pair of insulating plates, the plates forming the ends of the cavity, and the phosphor is incorporated into the material of at least one of the plates at least in the region thereof forming the end of the cavity.

7 Claims, 5 Drawing Figures



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3,838,307

Fig. 1

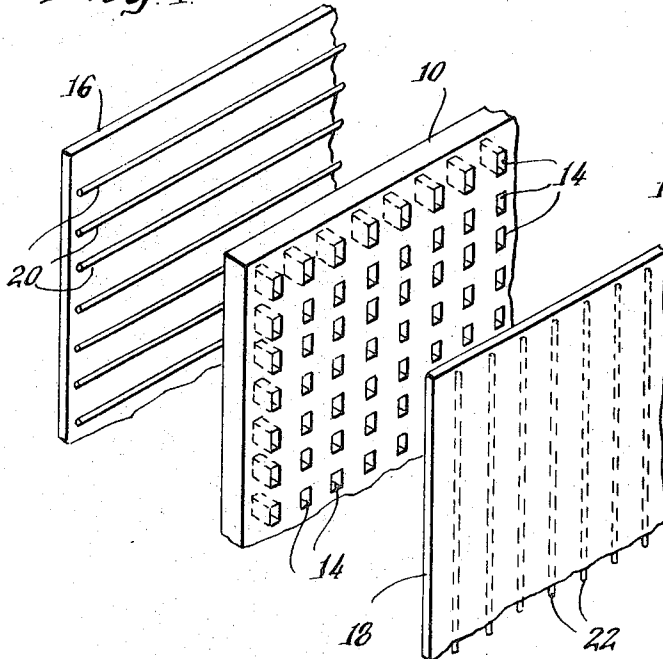


Fig. 2

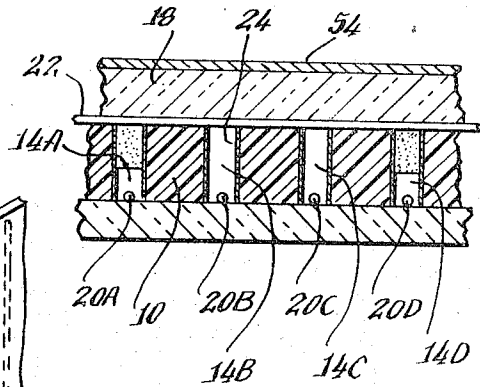


Fig. 3

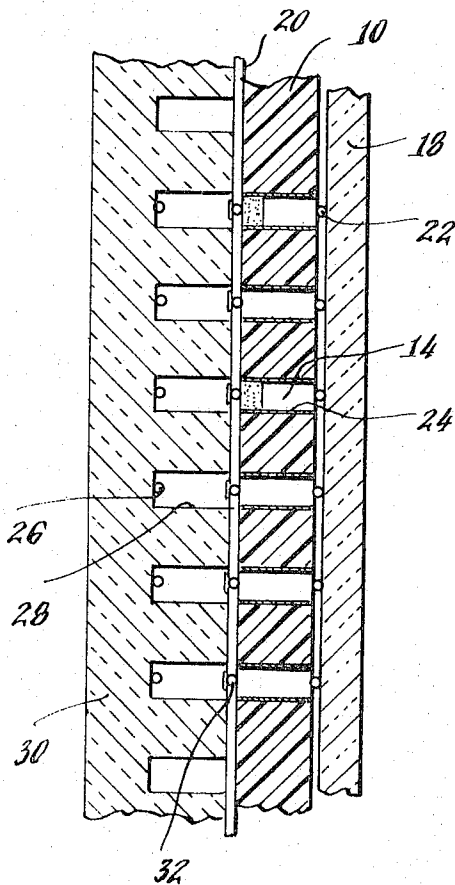


Fig. 4A

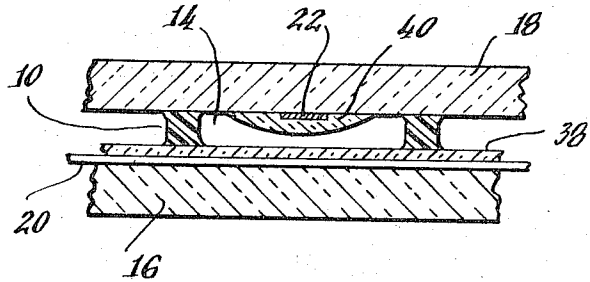
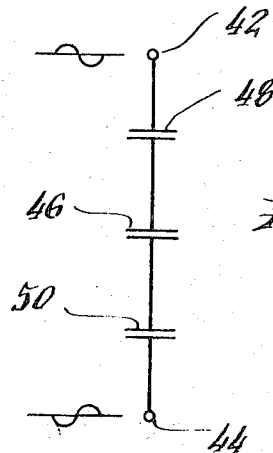


Fig. 4B



COLOR PLASMA DISPLAY

This invention relates to plasma display devices and more particularly to a plasma display device adapted for generating a display in a color other than the characteristic color of the plasma gas utilized in the display device.

BACKGROUND OF THE INVENTION

Presently available plasma display devices have a cell including a cavity, for each bit of information which is to be displayed, a plasma gas being contained within the cavity. A plasma gas is defined as one capable of sustaining a nonchemical reactive electric discharge in which ionized regions exist in which the concentrations of positive and negative ions are approximately equal. The gas normally employed for this purpose is neon with mercury sometimes being added to the neon to provide a uniform low firing potential and improved gas stability. On each side of the cavity is an electrode. For one type of plasma display the electrodes are separated slightly from the cavity by a layer of insulating material and have an AC potential applied to them which is normally sufficient to maintain a discharge in the cavity but not sufficient to initiate the discharge. When a pulse spike is superimposed on the AC input, the gas becomes ionized permitting current to flow through it. A capacitive effect occurs between each electrode and the ionized gas adjacent thereto which charge is operative to supplement the AC input in reinitiating the ionization of the gas during each half cycle of the AC input. With a high frequency AC input, the persistence of the eye provides a substantially flicker-free display. To extinguish the ionization of the cavity, a subtractive input is superimposed on the AC supply during a given cycle.

Various types of DC-excited plasma display devices are also available. These may include a separate DC input line to one electrode of each cavity with the other electrode being common or one of the electrodes may be cyclically excited to effectively scan the cavities with the other electrode being excited when the scanned electrode is excited only if the cell is to be ionized. Again, the scan rate is rapid enough so that the persistence of the eye provides a substantially continuous display. For at least one type of DC-excited plasma display, a scanning and priming cavity is provided for each display cavity to eliminate cell ionization delays, improve brightness, and provide other advantages.

All of the display devices described above suffer, however, from certain significant limitations. First, while the neon or other plasma gas which is ionized generates energy over a wide wave-band, including energy in the ultraviolet region and significant energy in the infrared region, only a small portion of the energy generated is available for display. This energy is generated in the visible region of the spectrum, particularly in the red-orange region. This results in a second limitation of these displays; namely, that they are presently adapted for generating an output only of a red-orange color. It has been found that the red-orange color is not desirable from a human factors standpoint, a softer green color being far preferable. Further, in some applications, it is desirable to be able to display information in more than one color.

For the above reasons, attempts have been made to modify existing plasma displays so as to adapt them for

the generation of various colors. These attempts have normally involved the coating of one surface, such as a wall, of the cavity with an up-conversion or Stokes phosphor. Depending on the phosphor utilized, and on its doping, the phosphor reacts to the ultraviolet energy generated by the ionized plasma gas to emit photons of a desired color.

However, these techniques have not, as yet, been commercially successful for a number of reasons. First, the neon-mercury plasma gas normally utilized does not emit strongly in the ultraviolet region, emitting much more strongly in the infrared region. Therefore, to obtain a strong ultraviolet emission, a percentage of xenon gas, (for example 10 to 15 percent) is added to the plasma gas. The requirement for adding xenon to the plasma gas has certain disadvantages. For one thing, xenon is neither as cheap nor as abundant as neon so that the cost of the display device is increased. Second, neon has clearly established firing and extinguishing potentials while those of the mixed gas are neither as well established nor is certain to remain constant with slight variations in the mixture ratios. Further, the neon molecules are relatively light and thus cause little damage to the cathode associated with the cavity on striking it, while the heavier xenon molecules cause increased wear and thus shorter life for the cathode.

Other problems with attempting to use a Stokes conversion for obtaining colored plasma displays is that the significant amount of energy in the infrared region resulting from the ionized neon is still not utilized. Further, not only is much of the emission in the red region not utilized, but in some instances, this emission is filtered to provide an output only in a desired other color, further reducing the output intensity of the display. In addition, the ultraviolet energy, being of relatively short wavelength, tends to be absorbed in the ionized gas much more readily than the longer wavelength red and infrared energy, further reducing the energy available for generating secondary emission from the phosphor and thus the overall output from the device. Existing color plasma devices thus exhibit poor output intensity and display contrast.

Still another problem with existing color plasma displays is that the phosphor is screened or otherwise deposited on a surface of the cavity. The phosphor is thus exposed to flaking and to deterioration as a result of ion bombardment and thermal cycling. The life expectancy of the display device is of course limited by these factors.

SUMMARY OF THE INVENTION

In order to overcome many of the problems indicated above, this invention provides a plasma display device which includes at least one cavity, a cavity being provided for each bit of information to be displayed, with a gas capable of sustaining a non-chemical reactive electric discharge, (i.e., a plasma gas) contained in each cavity. A means is provided for selectively developing a potential difference across each cavity sufficient to excite the gas therein to form a glow discharge generating photons over a wide wavelength spectrum including a significant number of photons of relatively long wavelength in the visible and infrared region. Such a discharge could, for example, be obtained from a standard neon or neon-mercury plasma gas. The potential developing means includes electrodes formed on

opposite ends of the cavity which electrodes have either an AC or DC potential of proper magnitude applied to them to selectively excite the plasma gas. At least one surface of each cavity is formed at least in part of a multi-photon down-conversion phosphor (an anti-Stokes phosphor), two or more photons of the gas discharge impinging on the phosphor surface being operative to excite the phosphor to generate one photon at and/or near the phosphor characteristic wavelength in the visible region. The term "down-conversion phosphor" thus refers to the capability of the phosphor of converting a plurality of photons to a single photon of lower wavelength, and is intended to have such a meaning in the specification and claims. For one embodiment of the invention, the phosphor is coated on the walls of the cavity. For another embodiment of the invention, the cavity is formed as an opening through a member of an insulating material positioned between a pair of insulating plates, the plates forming the ends of the cavity, and the phosphor is incorporated into the material of at least one of the plates at least in the region thereof forming the end of the cavity.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention as illustrated in the accompanying drawings:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an exploded perspective view of a plasma display device suitable for use with the teachings of this invention.

FIG. 2 is a sectional view showing several cells of a plasma display device employing the teachings of this invention.

FIG. 3 is a sectional view showing several cells of an alternative plasma display device utilizing the teachings of this invention.

FIG. 4A is a sectional view of a single cell of still another alternative plasma display device utilizing the teachings of this invention.

FIG. 4B is a schematic diagram of an electrical equivalent circuit for the cell shown in FIG. 4A.

DETAILED DESCRIPTION

Referring now to FIG. 1, a basic plasma display device is shown. This device consists of a sheet 10 of insulating material having a matrix of cavities 14 formed therethrough. Each cavity 14 is filled with a plasma gas such as neon or a neon-mercury mixture. The sheet 10 is sandwiched between a pair of glass plates 16 and 18, sheet 10 and plates 16 and 18 being sealed together to enclose the plasma gas in each cavity 14. For the embodiment of the invention shown in FIG. 1, one or more cathode electrodes 20 are shown formed on the inside surface of plate 16 for each row of cavities 14 and one or more anode electrodes 22 are shown formed on the inside of plate 18 for each column of cavities. For small panels, the cross-bar arrangement shown in FIG. 1 may be replaced by an individual cathode or anode for each cavity with the other electrode being common for all cavities. Each gas-filled cavity 14 is adapted for the display of a single bit of information and will also be referred to as a cell or display cell in the discussion to follow.

FIG. 2 illustrates a device of the type shown in FIG. 1 which is particularly adapted for DC-excitation. With

this cell, the cathodes 20, for example, are sequentially energized with a negative potential which is insufficient alone to ionize the gas in cavity 14. However, at the same time that each cathode 16 is energized, the anodes 22 for cells in the row corresponding to the excited cathode 20 at which a display is desired, have a positive potential applied to them which, in conjunction with the negative potential applied to the cathode, is sufficient to ionize the gas in the cell. Thus, referring to FIG. 2, assume a display is desired in the two end cells 14A and 14D but not in the two center cells 14B and 14C. Under these conditions, anode 22 would have a positive potential applied to it when a negative potential is applied to cathodes 20A and 20D but not when the negative potential is applied to cathodes 20B and 20C. When the cathode potential passes from electrode 20A to electrode 20B, the gas in cavity 14A deionizes, terminating the display from this cell. However, each cathode 20 is energized at a rate (for example 60 times per second) which is fast enough so that the persistence of the eye provides a continuous flicker-free display.

What has been described so far is a standard DC plasma display. The glow discharge obtained is primarily from the negative or cathode glow and is derived primarily from negative particles attracted to the cathode. The energy from these particles is of relatively short wavelength and the output glow obtained is normally of a red-orange color.

In order to obtain an output in a color other than red-orange and other advantages herein described, the walls of each of the cavities 14 are coated with a multi-photon down-conversion or anti-Stokes phosphor material 24. An example of such a material is lanthanum trifluoride. The phosphor may be doped with various materials in order to obtain an output in a desired color. Thus, for a green output, the phosphor might be doped with terbium. Europium doping could be utilized for a red output and cerium doping for a blue-green display. The phosphor may be coated on the walls of the cavity by use of standard techniques including vacuum deposition and screening.

An anti-Stokes phosphor operates by accepting two or more low energy, long wavelength photons, such as photons in the infrared region, and generating, in response, one photon of shorter length in the visible region of the spectrum. For example, the incoming photons might be at one micron (in the infrared region) while the generated photon might be at 0.52 microns (generally in the green region of the visible spectrum). Physically, the energy from each long wavelength photon striking the phosphor causes an increment in the energy level of an electron in the phosphor molecule from its valence band towards its conduction band. When sufficient energy has been accumulated in the phosphor molecule for it to reach the conduction band or a radiative level near this level, it drops back from this unstable condition to the valence band emitting a high energy (lower wavelength) photon in the process.

Since the anti-Stokes conversion described above is a down-conversion, it is apparent that the anti-Stokes phosphor responds most strongly to high wavelength radiation, particularly radiation in the red and infrared region. Since the neon and neon mercury plasma gas normally utilized in plasma displays generate most of their energy in this region, it is apparent that an anti-Stokes conversion permits optimum utilization of the

discharge from these gases. Further, since a single high energy ultraviolet spectrum photon striking a Stokes phosphor (and possibly also an anti-Stokes phosphor) also raises the energy of the phosphor from its valence to conduction band, a mixed phosphor (and possibly an anti-Stokes phosphor alone) may be utilized to respond to the full range of energy generated by the ionized plasma gas and thus provide significantly higher intensity output with greater contrast ratios than existing color plasma displays.

From the above it is apparent that the greater the quantity of long wavelength photons which are generated, the greater will be the secondary emission from phosphor 24. It is known that the long wavelength photons are generated primarily from the positive column discharge in the ionized plasma cell rather than from the cathode glow. For a color plasma display utilizing secondary emission from a phosphor, it is therefore desirable to optimize the positive column. A positive column discharge is best obtained if the distance between the cathode and anode is greater than the diameter of the discharged cells by at least a factor of two. The length of the positive column depends primarily on the pressure of the gas in the cells and on the current through the cell. Up to a point, the positive glow may be increased by increasing the pressure. With optimized pressure and current, the positive column 28, shown as a shaded area in cavities 14A and 14D of FIG. 2, may be caused to fill more than half of cavity 14, generating abundant long wavelength photons to stimulate the phosphor.

FIG. 3 illustrates an alternative form of DC-excited plasma display device, of a type presently commercially available, showing this device as modified to conform with the teachings of this invention. This display has the transparent front plate 18, parallel display anodes 22, insulating center sheet 10 with cavities 14 formed therein, and parallel cathodes 20, the cathodes and anodes being orthogonal to each other and intersecting at each cavity 14. In addition, the display device of FIG. 3 also has a plurality of aligned scanning anodes 26 each set in a groove 28 formed in a glass back plate 30. Between each groove or cavity 28 and each cavity 14 there is at least one small precision (possibly laser) drilled hole 32 formed in the cathode strip 20. Cavities 28 are also filled with the plasma gas.

In operation, anodes 26 are scanned by having a potential sequentially applied thereto. Anodes 22 are scanned at the same time. For any cell which is being excited, the corresponding cathode 20 has a reduced potential when the anode is scanned, causing a discharge to be initiated in the corresponding slot 28. When this occurs, metastable atoms of the gas diffused from the cathode discharge of the cavity 28 into the corresponding cavity 14. The metastable atoms create ionization in the other cavity which primes the gas in the other cavity into ionization when a potential is applied across it. This arrangement eliminates problems such as variable ionization delay and improves brightness on the display. The structure, operation, and advantages of a plasma display of this type are described in greater detail in U.S. Pat. No. 3,654,507 entitled "Display Panel With Keep Alive Cells" issued Apr. 4, 1972 to Bernard Caras et al. and assigned to Burroughs Corporation.

The display device shown in FIG. 3 may be modified to provide a broad-band color display in the same way

that the display of FIG. 2 was modified by coating the walls of each cavity 14 with an anti-Stokes phosphor 24. Once the gas in cavity 14 is ionized, the phosphor operates in the same manner described above with respect to FIG. 2 to provide the desired display. Again, the parameters of the cavity, the current applied across the cavity, and the pressure on the gas in the cavity are selected to optimize the positive column.

FIG. 4A shows an embodiment of the invention adapted for AC operations. This embodiment of the invention differs in structure from those previously described in that the anode 22 and cathode 20 conductors are each embedded in the corresponding plate. Thus, there is a layer of insulating material 38 (such as glass) between cathode 20 and cavity 14 and there is a layer of insulating material 40 between anode 22 and the cavity. While with this embodiment of the invention the phosphor may be coated on the walls of the cavity or on either end surface utilizing the standard techniques previously mentioned, such a coating, as previously indicated, is subject to flaking and deterioration by ion bombardment. To overcome these problems, the phosphor, which is preferably of the anti-Stokes variety, is incorporated in the material of layer 40 prior to firing. The incorporation of the phosphor in the plate material is in accordance with standard ceramic processes. Assume, for example, that the plate material is glass. The process for making the coating 40 might then include the steps of: (1) mixing the desired quantity of phosphor into a standard glass mixture. Care should be exercised that the resulting mixture still has the required high dielectric properties for the glass. (2) Firing the mixture by standard techniques. (3) Quick chilling the fired glass as by immersion in a water bath. This fractures the glass into a glass frit. (4) Positioning the phosphor glass frit on plate 18 over conductors 22; and (5) firing the plate with the glass frit in place, fusing the glass frit and encapsulating the conductor 22. With this arrangement, the material of the coating 40 is transparent to the high wavelength photons emitted by the ionized gas permitting the phosphor contained therein to be excited to emit photons of the desired color in the manner previously described.

Referring now to FIGS. 4A and 4B, in operation, AC signals which are 180° out of phase with each other, are applied to terminal 42 connected to conductor 22 and terminal 44 connected to conductor 20 respectively. The magnitude of the AC signals is not, in itself, sufficient to ionize the plasma gas in cavity 14. Under these conditions, there is no charge across any of the capacitors shown in FIG. 4B, the capacitor 46 representing the cavity and the capacitors 48 and 50 representing the wall charges, (i.e., layers 38 and 40 being the dielectrics for these capacitors). When an additive signal is superimposed on the AC signal applied to one of the terminals 42, 44 so that the potential applied across these terminals exceeds the firing potential of the gas, the plasma gas becomes ionized, light is emitted, and current flows through the gas cavity charging capacitors 48 and 50. As the wall charge develops, their voltage drop increases at the expense of the voltage drop across the gas in the cavity until there finally is not enough field to keep the gas in ionization. However, the wall charge remains and supplements the voltage drop across terminals 42 and 44 when the AC signals reverse, causing the gas to again be ionized. Thus, once the cell is fired, the wall charges cause it to continue to

fire until a subtractive potential is superimposed on the AC inputs during a half cycle to dissipate the wall charges and extinguish the cell. If the frequency of the AC signal is sufficiently high, the persistence of the eye will give a continuous flicker-free display.

While in the discussion above, a display in only a single color is desired, since the anti-Stokes phosphor utilized responds to most of the energy emitted from the ionized gas, phosphors doped to generate a number of different colors might be utilized (and/or mixed Stokes, anti-Stokes phosphors utilized) and filters (for example, 54 of FIG. 2) placed over all or a portion of the display to permit viewing in only a single color. Thus, one line of the display might be in red, another line in green, and so on, and the color for a given line may be varied by merely varying an external filter. The high intensity obtained from the display permits outputs with adequate intensity and contrast even when the output is filtered.

While the invention has been particularly shown and described above with reference to preferred embodiments thereof, it is apparent that the teachings of this invention could be utilized with other plasma display devices and that various other changes in form and detail may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A plasma display device comprising:
 - means forming a matrix of sealed cavities in a common plane, said cavities being formed as openings through a sheet of an insulating material positioned between a pair of insulating plates, the plates forming the ends of said cavity;
 - a neon gas capable of sustaining a nonchemical reactive electric discharge contained in each said cavity;
 - exciting means including an anode means and cathode means associated with each cavity for selectively developing a potential difference across each cavity sufficient to excite the gas therein to form a discharge generating photons over a wide wavelength spectrum including a significant number of photons of relatively long wavelength in the red and infrared region; and
 - at least one surface of each cavity including a multi-photon down-conversion phosphor which is re-

sponsive to two or more of the red and infrared photons of the gas discharge impinging on the phosphor surface to excite the phosphor to generate one photon at and/or the phosphor's characteristic wavelength in the visible region, said phosphor being incorporated into the material of at least one of said plates at least in the region thereof forming the end of said cavity, the material of the plate into which the phosphor is incorporated being transparent to photons in the red and infrared region.

said anode means and cathode means being located on opposite ends of said cavity and having a potential difference of predetermined energy selectively applied between them, the cavity dimensions, electrical energy, pressure on the gas in the cavity and other factors being such as to form a positive column discharge in the cavity when the gas in the cavity is excited.

2. A device as claimed in claim 1 wherein said anode means and said cathode means include electrodes formed in each of said plates, at least a portion of each of said electrodes intersecting a respective end of said cavity;

and wherein said phosphor incorporation material overlays at least one of the electrodes for the associated plate, embedding the electrode in the plate.

3. A device as claimed in claim 1 wherein the material for the plate having the phosphor incorporated therein is glass.

4. A device as claimed in claim 1 wherein said phosphor is lanthanum trifluoride.

5. A device as claimed in claim 1 wherein said phosphor is doped to emit visible light energy in a desired color when excited.

6. A device as claimed in claim 5 wherein said phosphor is doped to emit visible light energy in a number of different colors when excited; and

including filter means in front of at least a portion of the device to control the color of the display from said portion.

7. A device as claimed in claim 1 wherein said phosphor is mixed with an up-conversion (Stokes) phosphor whereby substantially all the photons of said glow discharge are utilized.

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