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Dorf et al.

[11] **3,916,245**

[45] **Oct. 28, 1975**

[54] **MULTIPLE GASEOUS DISCHARGE DISPLAY/MEMORY PANEL COMPRISING RARE GAS MEDIUM AND PHOTOLUMINESCENT PHOSPHOR**

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[73] Assignee: **Owens-Illinois, Inc.**, Toledo, Ohio

[22] Filed: **Nov. 27, 1973**

[21] Appl. No.: **419,396**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 95,892, Dec. 7, 1970, abandoned.

[52] **U.S. Cl.** **313/486;** 313/185; 313/226

[51] **Int. Cl.**[2] **H01J 1/63**

[58] **Field of Search** ..... 313/108 R, 108 A, 108 B, 313/109, 109.5, 210, 220, 224, 485–487, 490, 491, 493, 185, 226; 315/169 TV; 340/173 PL, 324 M

[56] **References Cited**

UNITED STATES PATENTS

3,334,269	8/1967	L'Heureux	315/169 TV
3,499,167	3/1970	Baker et al.	313/220 X
3,559,190	1/1971	Bitzer et al.	313/210 UX
3,686,686	8/1972	Hall	313/108 R X
3,723,977	3/1973	Schaufele	315/169 TV X

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Attorney, Agent, or Firm—Donald Keith Wedding

[57] **ABSTRACT**

There is disclosed a multiple gaseous discharge display/memory panel having an electrical memory and capable of producing a visual color display, the panel being characterized by an ionizable gaseous medium in a gas chamber formed by a pair of opposed dielectric material charge storage members which are respectively backed by a series of parallel-like conductor (electrode) members, the conductor members behind each dielectric material member being transversely oriented with respect to the conductor members behind the opposing dielectric material member so as to define a plurality of discrete discharge volumes constituting a discharge unit, at least one dielectric material member containing a photoluminescent phosphor which is excited with ultraviolet radiation of a wavelength of about 500 to about 2500 angstrom units such that the phosphor emits visible light of a brightness and intensity sufficient for visual display.

12 Claims, 5 Drawing Figures

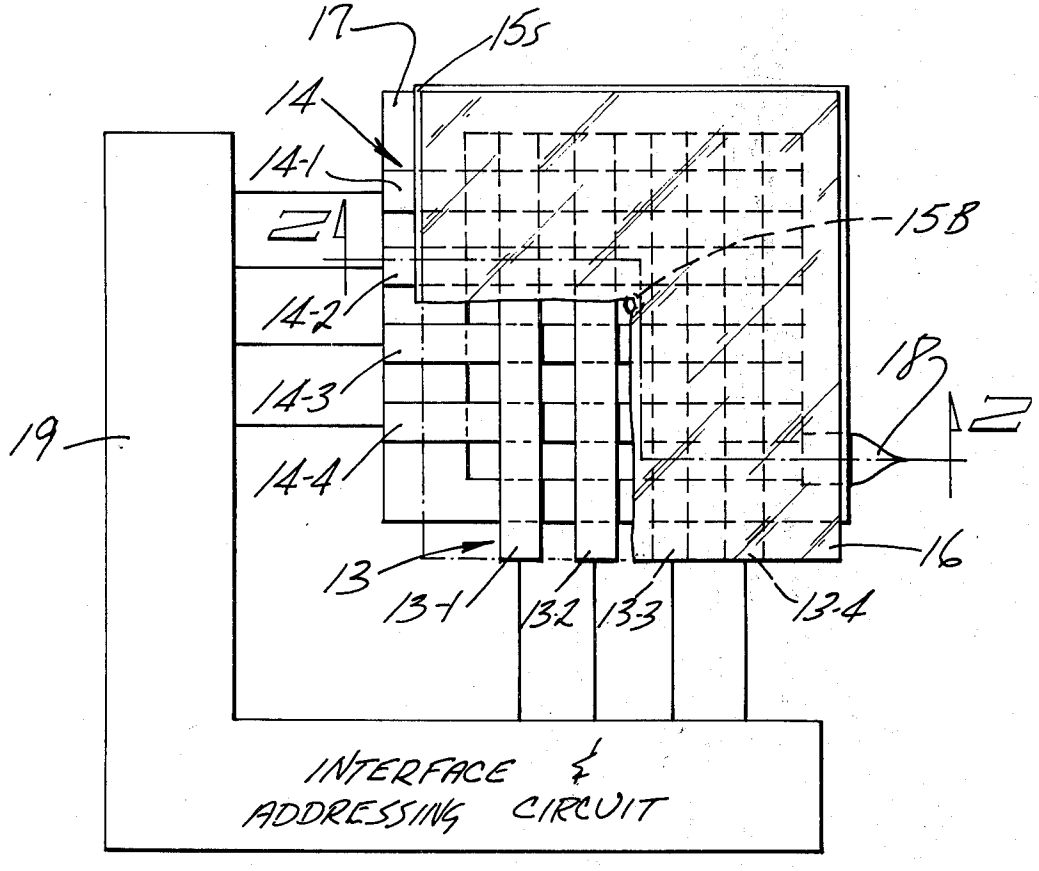


FIG. 2

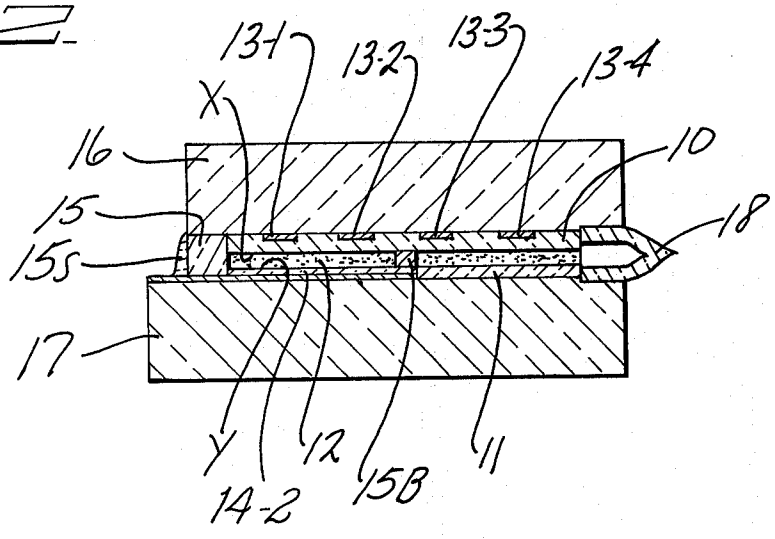

13-1
13-2
13-3
13-4
X
16
10
15
18
15S
17
Y
12
11
14-2
15B

FIG. 1

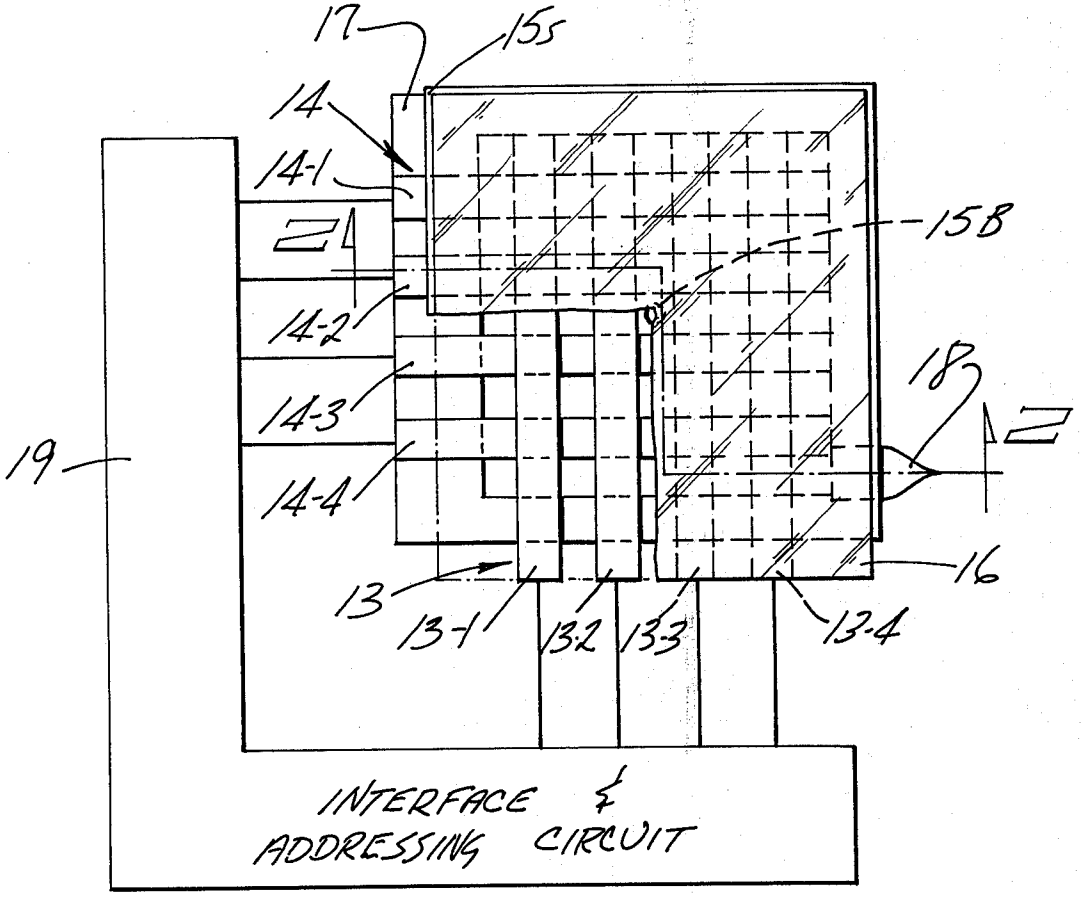

17
15S
14
14-1
Z
15B
14-2
18
14-3
19
14-4
Z
16
13
13-1
13-2
13-3
13-4
INTERFACE & ADDRESSING CIRCUIT

FIG. 3

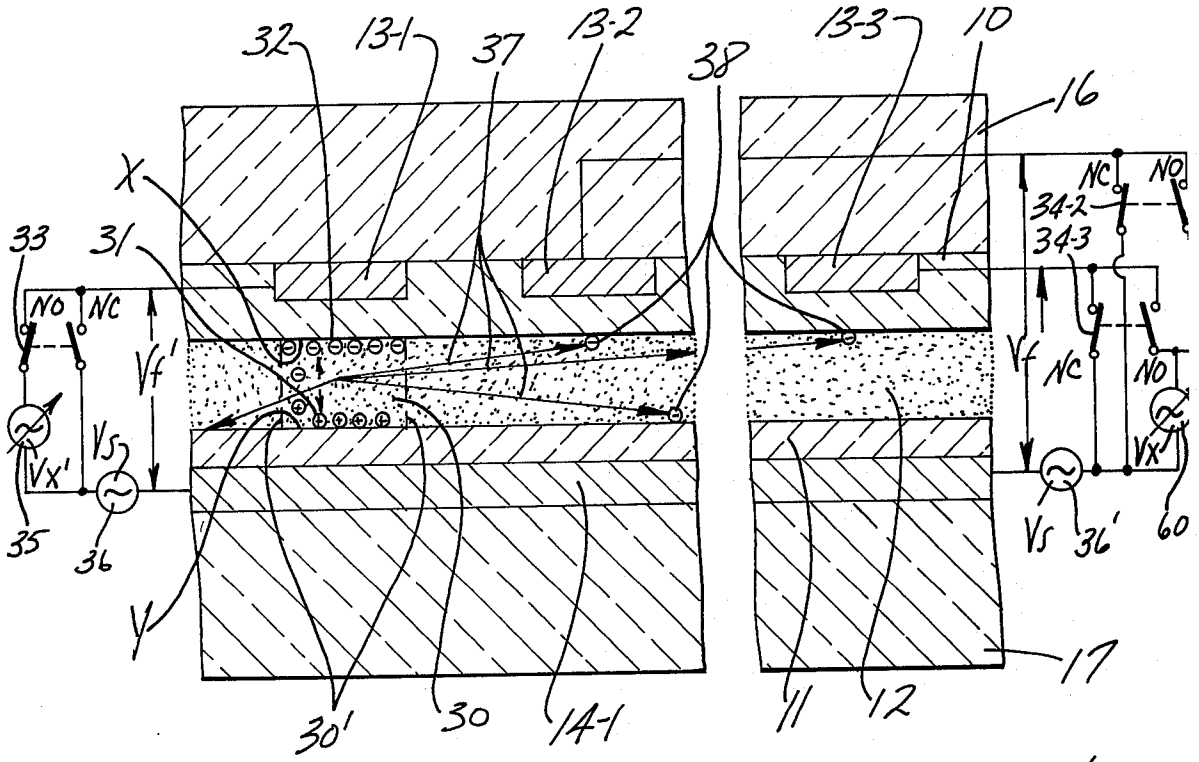

32
13-1
37
13-2
38
13-3
10
16
X
33
31
NO
NC
Vf'
Vx'
Vs
35
36
Y
30'
30
14-1
11
12
17
NC
NO
34-2
34-3
Vf
Vs
36'
60

FIG. 4

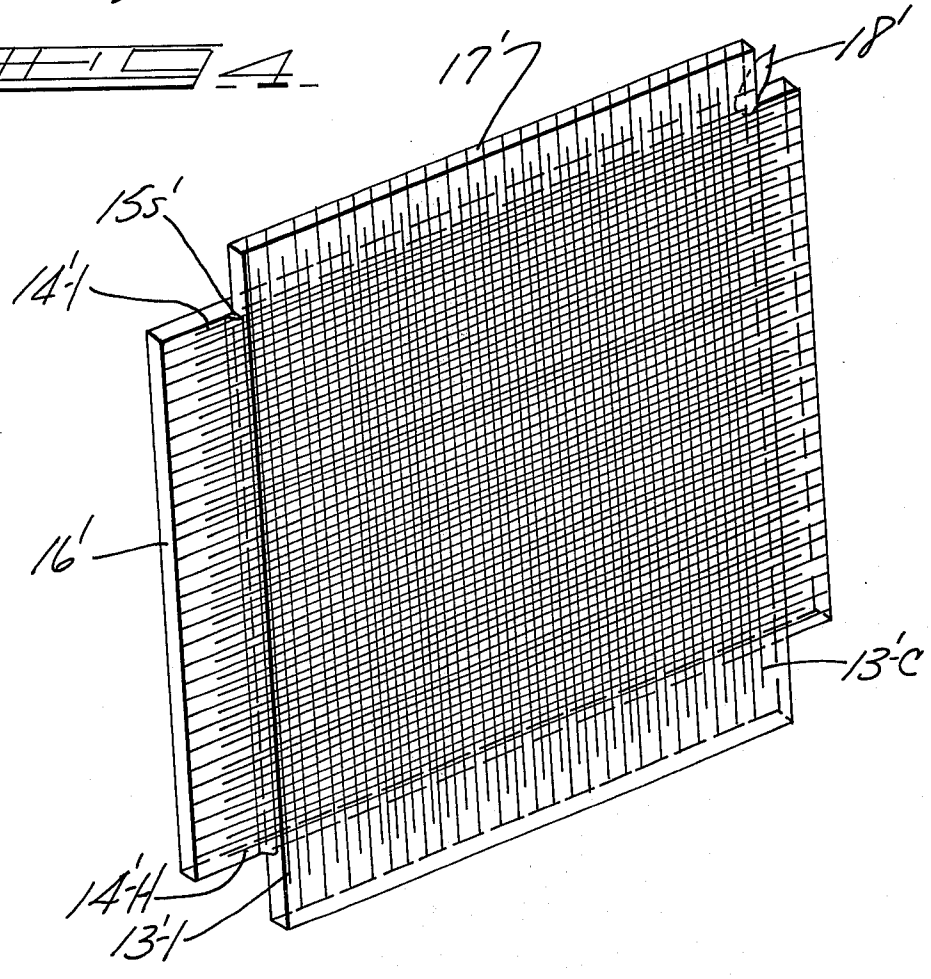
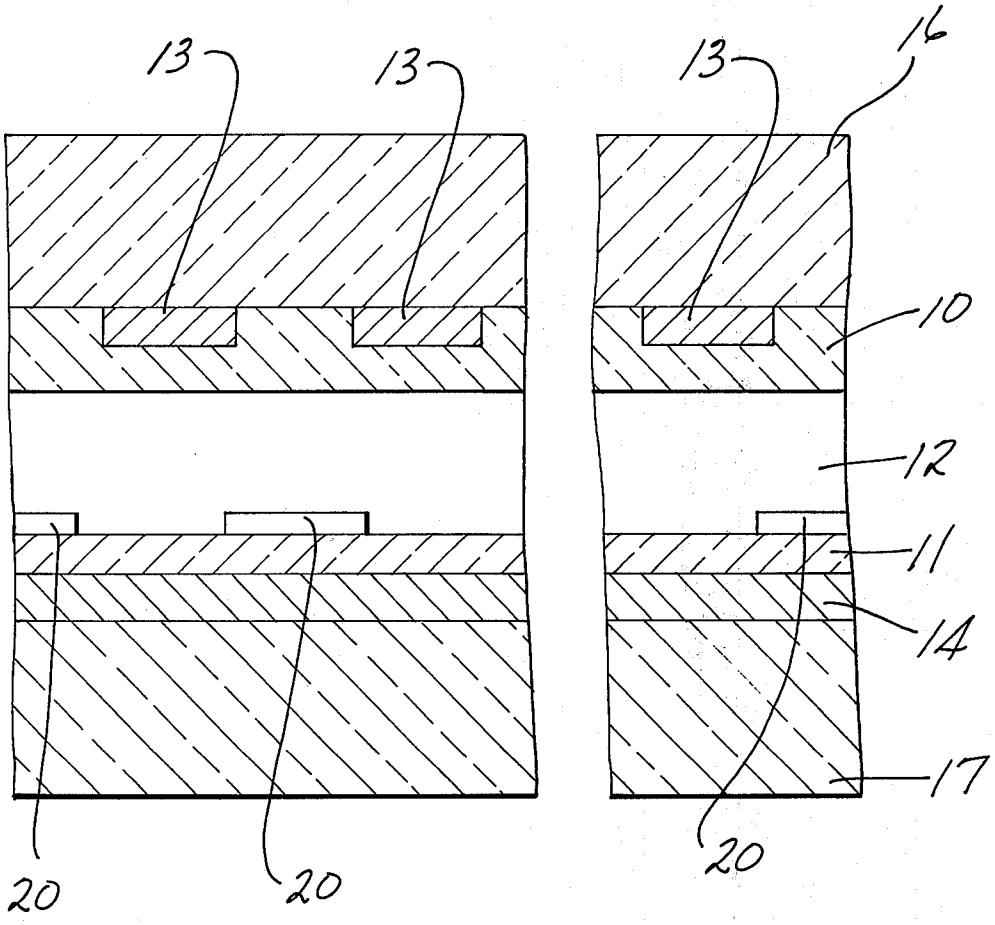

17'
18'
15s'
14'-1
16'
13'-C
14'-H
13'-1

FIG. 5



MULTIPLE GASEOUS DISCHARGE DISPLAY/MEMORY PANEL COMPRISING RARE GAS MEDIUM AND PHOTOLUMINESCENT PHOSPHOR

RELATED APPLICATION

This is a continuation-in-part of copending U.S. Pat. Application Ser. No. 95,892, filed Dec. 7, 1970 now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to novel multiple gas discharge display/memory panels which have an electrical memory and which are capable of producing a visual color display including the representation of data such as numerals, letters, television display, radar displays, binary words, etc. More particularly, this invention relates to multiple gas discharge devices capable of producing a visual color display in a color other than that characteristic of the color exhibited by the particular gaseous medium utilized in the device.

Multiple gas discharge display and/or memory panels of one particular type with which the present invention is concerned are characterized by an ionizable gaseous medium, usually a mixture of at least two gases at an approximate gas pressure, in a thin gas chamber or space between a pair of opposed dielectric charge storage members which are backed by conductor (electrode) members, the conductor members backing each dielectric member typically being appropriately oriented so as to define a plurality of discrete gas discharge units or cells.

In some prior art panels the discharge cells are additionally defined by surrounding or confining physical structure such as apertures in perforated glass plates and the like so as to be physically isolated relative to other cells. In either case, with or without the confining physical structure, charges (electrons, ions) produced upon ionization of the elemental gas volume of a selected discharge cell, when proper alternating operating potentials are applied to selected conductors thereof, are collected upon the surfaces of the dielectric at specifically defined locations and constitute an electrical field opposing the electrical field which created them so as to terminate the discharge for the remainder of the half cycle and aid in the initiation of a discharge on a succeeding opposite half cycle of applied voltage, such charges as are stored constituting an electrical memory.

Thus, the dielectric layers prevent the passage of substantial conductive current from the conductor members to the gaseous medium and also serve as collecting surfaces for ionized gaseous medium charges (electrons, ions) during the alternate half cycles of the A.C. operating potentials, such charges collecting first on one elemental or discrete dielectric surface area and then on an opposing elemental or discrete dielectric surface area on alternate half cycles to constitute an electrical memory.

An example of a panel structure containing non-physically isolated or open discharge cells is disclosed in U.S. Pat. No. 3,499,167 issued to Theodore C. Baker, et al.

An example of a panel containing physically isolated cells is disclosed in the article by D. L. Bitzer and H. G. Slottow entitled "The Plasma Display Panel — A Digitally Addressable Display With Inherent Memory," Proceeding of the Fall Joint Computer Conference, IEEE, San Francisco, Cal., Nov. 1966, pages 541–547. Also reference is made to U.S. Letters Pat. No. 3,559,190.

In the construction of the panel, a continuous volume of ionizable gas is confined between a pair of dielectric surfaces backed by conductor arrays typically forming matrix elements. The two conductor arrays may be orthogonally related sets of parallel lines (but any other configuration of conductor arrays may be used). The two arrays define at their intersections a plurality of opposed pairs of charge storage areas on the surfaces of the dielectric bounding or confining the gas. Thus, for a conductor matrix having H rows and C columns the number of elemental or discrete areas will be twice the number of elemental discharge cells.

In addition, the panel may comprise a so-called monolithic structure in which the conductor arrays are created on a single substrate and wherein two or more arrays are separated from each other and from the gaseous medium by at least one insulating member. In such a device the gas discharge takes place not between two opposing elemental areas on two different substrates, but between two contiguous or adjacent elemental areas on the same substrate; the gas being confined between the substrate and an outer retaining wall.

It is also feasible to have a gas discharge device wherein some of the conductive or electrode members are in direct contact with the gaseous medium and the remaining electrode members are appropriately insulated from such gas, i.e., at least one insulated electrode.

In addition to the matrix configuration, the conductor arrays may be shaped otherwise. Accordingly, while the preferred conductor arrangement is of the crossed grid type as discussed herein, it is likewise apparent that where a maximal variety of two dimensional display patterns is not necessary, as where specific standardized visual shapes (e.g., numerals, letters, words, etc.) are to be formed and image resolution is not critical, the conductors may be shaped accordingly (e.g., a segmented digit display).

The gas is selected to produce visible light and invisible radiation which may be used to stimulate a phosphor (if visual display is an objective) and a copious supply of charges (ions and electrons) during discharge.

In the prior art, a wide variety of gases and gas mixtures have been utilized as the gaseous medium in a number of different gas discharge devices. Typical of such gases include pure gases and mixtures of CO; CO_2; halogens; nitrogen; NH_3; oxygen; water vapor; hydrogen; hydrocarbons; P_2O_5; boron fluoride; acid fumes; $TiCl_4$; air; H_2O_2; vapors of sodium, mercury, thallium, cadmium, rubidium, and cesium; carbon disulfide; H_2S; deoxygenated air; phosphorus vapors; C_2H_2; CH_4; naphthalene vapor; anthracene; freon; ethyl alcohol; methylene bromide; heavy hydrogen; electron attaching gases; sulfur hexafluoride; tritium; radioactive gases; and the so-called rare or inert Group VIII gases.

In an open cell Baker, et al. type panel, the gas pressure and the electric field are sufficient to laterally confine charges generated on discharge within elemental or discrete dielectric areas within the perimeter of such areas, especially in a panel containing non-isolated discharge cells. As described in the Baker, et al. patent, the space between the dielectric surfaces occupied by

the gas is such as to permit photons generated on discharge in a selected discrete or elemental volume of gas to pass freely through the gas space and strike surface areas of dielectric remote from the selected discrete volumes, such remote, photon struck dielectric surface areas thereby emitting electrons so as to condition at least one elemental volume other than the elemental volume in which the photons originated.

With respect to the memory function of a given discharge panel, the allowable distance or spacing between the dielectric surfaces depends, inter alia, on the frequency of the alternating current supply, the distance typically being greater for lower frequencies.

While the prior art does disclose gaseous discharge devices having externally positioned electrodes for initiating a gaseous discharge, sometimes called "electrodeless discharge," such prior art devices utilized frequencies and spacing or discharge volumes and operating pressures such that although discharges are initiated in the gaseous medium, such discharges are ineffective or not utilized for charge generation and storage at higher frequencies; although charge storage may be realized at lower frequencies, such charge storage has not been utilized in a display/memory device in the manner of the Bitzer-Slottow or Baker, et al. invention.

The term "memory margin" is defined herein as

$$\text{M. M.} = \frac{V_f - V_E}{V_f/2}$$

where V_f is the half-of-peak-to-peak amplitude of the smallest sustaining voltage signal which results in a discharge every half cycle, but at which the cell is not bistable and V_E is the half amplitude of the minimum applied voltage sufficient to sustain discharges once initiated.

It will be understood that the basic electrical phenomenon utilized in this invention is the generation of charges (ions and electrons) alternately storable at pairs of opposed or facing discrete points or areas on a pair of dielectric surfaces backed by conductors connected to a source of operating potential. Such stored charges result in an electrical field opposing the field produced by the applied potential that created them and hence operated to terminate ionization in the elemental gas volume between opposed or facing discrete points or areas of dielectric surface. The term "sustain a discharge" means producing a sequence of momentary discharges, at least one discharge for each half cycle of applied alternating sustaining voltage, once the elemental gas volume has been fired, to maintain alternate storing of charges at pairs of opposed discrete areas on the dielectric surfaces.

As used herein, a cell is in the "on state" when a quantity of charge is stored in the cell such that on each half cycle of the sustaining voltage, a gaseous discharge is produced.

In addition to the sustaining voltage, other voltages may be utilized to operate the panel, such as firing, addressing, and writing voltages.

A "firing voltage" is any voltage, regardless of source, required to discharge a cell. Such voltage may be completely external in origin or may be comprised of internal cell wall voltage in combination with externally originated voltages.

An "addressing voltage" is a voltage produced on the panel X - Y electrode coordinates such that at the selected cell or cells, the total voltage applied across the cell is equal to or greater than the firing voltage whereby the cell is discharged.

A "writing voltage" is an addressing voltage of sufficient magnitude to make it probable that on subsequent sustaining voltage half cycles, the cell will be in the "on state."

In the operation of a multiple gaseous discharge device, of the type described hereinbefore, it is necessary to condition the discrete elemental gas volume of each discharge cell by supplying at least one free electron thereto such that a gaseous discharge can be initiated when the cell is addressed with an appropriate voltage signal.

The prior art has disclosed and practiced various means for conditioning gaseous discharge cells.

One such means of panel conditioning comprises a so-called electronic process whereby an electronic conditioning signal or pulse is periodically applied to all of the panel discharge cells, as disclosed for example in British Pat. specification No. 1,161,832, page 8, lines 56 to 76. Reference is also made to U.S. Pat. No. 3,559,190 and "The Device Characteristics of the Plasma Display Element" by Johnson, et al., IEEE Transactions On Electron Devices, Sept., 1971. However, electronic conditioning is self-conditioning and is only effective after a discharge cell has been previously conditioned; that is, electronic conditioning involves periodically discharging a cell and is therefore a way of maintaining the presence of free electrons. Accordingly, one cannot wait too long between the periodically applied conditioning pulses since there must be at least one free electron present in order to discharge and condition a cell.

Another conditioning method comprises the use of external radiation, such as flooding part or all of the gaseous medium of the panel with ultraviolet radiation. This external conditioning method has the obvious disadvantage that it is not always convenient or possible to provide external radiation to a panel, especially if the panel is in a remote position. Likewise, an external UV source requires auxiliary equipment. Accordingly, the use of internal conditioning is generally preferred.

One internal conditioning means comprises using internal radiation, such as by the inclusion of a radioactive material.

Another means of internal conditioning, which we call photon conditioning, comprises using one or more so-called pilot discharge cells in the on-state for the generation of photons. This is particularly effective in a so-called open cell construction (as described in the Baker, et al. patent) wherein the space between the dielectric surfaces occupied by the gas is such as to permit photons generated on discharge in a selected discrete or elemental volume of gas (discharge cell) to pass freely through the panel gas space so as to condition other and more remote elemental volumes of other discharge units. In addition to or in lieu of the pilot cells, one may use other sources of photons internal to the panel.

Internal photon conditioning may be unreliable when a given discharge unit to be addressed is remote in distance relative to the conditioning source, e.g., the pilot cell. Accordingly, a multiplicity of pilot cells may be required for the conditioning of a panel having a large geometric area. In one highly convenient arrangement,

the panel matrix border (perimeter) is comprised of a plurality of such pilot cells.

DRAWINGS ILLUSTRATING GAS DISCHARGE DISPLAY/MEMORY PANEL

Reference is made to the accompanying drawings and the hereinafter discussed FIGS. **1** to **4** shown thereon illustrating a gas discharge display/memory panel of the Baker, et al. type.

FIG. **1** is a partially cut-away plan view of a gaseous discharge display/memory panel as connected to a diagrammatically illustrated source of operating potentials.

FIG. **2** is a cross-sectional view (enlarged, but not to proportional scale since the thickness of the gas volume, dielectic members and conductor arrays have been enlarged for purposes of illustration) taken on lines **2** — **2** of FIG. **1**.

FIG. **3** is an explanatory partial cross-sectional view similar to FIG. **2** (enlarged, but not to proportional scale).

FIG. **4** is an isometric view of a gaseous discharge display/memory panel,

FIG. **5** is a partial cross-sectional view similar to FIG. **3**.

The invention utilizes a pair of dielectric films **10** and **11** separated by a thin layer or volume of a gaseous discharge medium **12**, the medium **12** producing a copious supply of charges (ions and electrons) which are alternately collectable on the surfaces of the dielectric members at opposed or facing elemental or discrete areas X and Y defined by the conductor matrix on non-gas-contacting sides of the dielectric members, each dielectric member presenting large open surface areas, and a plurality of pairs of elemental X and Y areas. While the electrically operative structural members such as the dielectric members **10** and **11** and conductor matrixes **13** and **14** are all relatively thin (being exaggerated in thickness in the drawings) they are formed on and supported by rigid nonconductive support members **16** and **17** respectively.

Preferably, one or both of the nonconductive support members **16** and **17** pass light produced by discharge in the elemental gas volumes. Preferably, they are transparent glass members. These members essentially define the overall thickness and strength of the panel. For example, the thickness of gas layer **12** as determined by spacer **15** is usually under **10** mils and preferably about 3 to 8 mils, dielectric layers **10** and **11** (over the conductors at the elemental or discrete X and Y areas) are usually between 0.1 and 2 mils thick, and conductors **13** and **14** at least about 1,000 angstroms thick. However, support members **16** and **17** are much thicker (particularly in larger panels) so as to provide as much ruggedness as may be desired to compensate for stresses in the panel. Support members **16** and **17** also serve as heat sinks for heat generated by discharges and thus minimize the effect of temperature on operation of the device. If it is desired that only the memory function be utilized, then none of the members need be transparent to light.

The electrical properties of support members **16** and **17** are not critical so long as the electrodes are appropriately insulated from one another. The main function of support members **16** and **17** is to provide mechanical support and strength for the entire panel, particularly with respect to pressure differential acting on the panel. Ordinary ¼ inch commercial grade soda lime plate glasses have been used for this purpose. Other glasses such as low expansion glasses or devitrified glass can be used provided they can withstand processing.

Spacer **15** may be made of the same glass material as dielectric films **10** and **11** and may be an integral rib formed on one of the dielectric members and fused to the other members to form a bakeable hermetic seal enclosing and confining the ionizable gas volume **12**. However, a separate final hermetic seal may be effected by a high strength devitrified glass sealant **15S**. Tubulation **18** is provided for exhausting the space between dielectric members **10** and **11** and filling that space with the volume of ionizable gas. For large panels small beadlike solder glass spacers such as shown at **15B** may be located between conductor intersections and fused to dielectric members **10** and **11** to aid in withstanding stress on the panel and maintain uniformity of thickness of gas volume **12**.

Conductor arrays **13** and **14** may be formed on support members **16** and **17** by a number of well-known processes, such as photoetching, vacuum deposition, stencil screening, etc. In the panel shown in FIG. **4**, the center-to-center spacing of conductors in the respective arrays is about 17 mils for one typical commercial configuration. Transparent or semi-transparent conductive material such as tin oxide, gold, or aluminum can be used to form the conductor arrays and should have a resistance less than 3000 ohms per line. Alternately, narrow opaque electrodes may be used so that discharge light passes the edges of the electrodes to reach the viewer. It is important to select a conductor material that is not attacked during processing by the dielectric material.

It will be appreciated that conductor arrays **13** and **14** may be wires or filaments of copper, gold, silver or aluminum or any other conductive metal or material. For example 1 mil wire filaments are commercially available and may be used in the invention. However, formed in situ conductor arrays are preferred since they may be more easily and uniformly placed on and adhered to the support plates **16** and **17**.

Dielectric layer members **10** and **11** are formed of an inorganic material and are preferably formed in situ as an adherent film or coating which is not chemically or physically affected during bake-out of the panel. One such material is a solder glass such as Kimble SG-**68** manufactured by and commercially available from Owens-Illinois, Inc. of Toledo, Ohio.

This glass has thermal expansion characteristics substantially matching the thermal expansion characteristics of certain soda-lime glasses, and can be used as the dielectric layer when the support members **16** and **17** are soda-lime glass plates. Dielectric layers **10** and **11** should have a dielectric breakdown voltage of about 1,000 v. and be electrically homogeneous on a microscopic scale (e.g., no cracks, bubbles, dirt, surface films, etc.). In addition, the surfaces of dielectric layers **10** and **11** should be good photoemitters of electrons in a baked out condition. Alternately, dielectric layers **10** and **11** may be overcoated with materials designed to produce good electron emission, as in U.S. Pat. No. 3,634,719, issued to Roger E. Ernsthausen. Of course, for an optical display at least one of dielectric layers **10** and **11** should pass light generated on discharge and be transparent or translucent and, preferably, both layers are optically transparent.

The preferred spacing between the facing surfaces of the two dielectric films is about 3 to 8 mils if the conductor arrays **13** and **14** have center-to-center spacing of about 17 mils.

The ends of conductors **14-1 . . . 14-4** and support members **17** extend beyond the enclosed gas volume **12** and are exposed for the purpose of making electrical connection to interface and addressing circuitry **19.** Likewise, the ends of conductors **13-1 . . . 13-4** on support member **16** extend beyond the enclosed gas volume **12** and are exposed for the purpose of making electrical connection to interface and addressing circuitry **19.**

As in known display systems, the interface and addressing circuitry or system **19** may be relatively inexpensive line scan systems or the somewhat more expensive high speed random access systems. In either case, it is to be noted that a lower amplitude of operating potentials helps to reduce problems associated with the interface circuitry between the addressing system and the display/memory panel, per se. In addition, by providing a panel having greater uniformity in discharge characteristics throughout the panel, manufacturing tolerances of the interfacing circuitry can be made less rigid.

One mode of initiating operation of the panel will be described with reference to FIG. **3,** which illustrates the condition of one elemental gas volume **30** having an elemental cross-sectional area and volume which is quite small relative to the entire volume and cross-sectional area of gas **12.** The cross-sectional area of volume **30** is defined by the overlapping common elemental areas of the conductor arrays and the volume is equal to the product of the distance between the dielectric surfaces and the elemental areas. It is apparent that if the conductor arrays are uniform and linear and are orthogonally (at right angles to each other) related each of elemental areas X and Y will be squares and if conductors of one conductor array are wider than conductors of the other conductor arrays, said areas will be rectangles. If the conductor arrays are at transverse angles relative to each other, other than **90°**, the areas will be diamond shaped so that the cross-sectional shape of each volume is determined solely in the first instance by the shape of the common area of overlap between conductors in the conductor arrays **13** and **14.** The dotted lines **30'** are imaginary lines to show a boundary of one elemental volume about the center of which each elemental discharge takes place. It is known that the cross-sectional area of the discharge in a gas is affected by, inter alia, the pressure of the gas, such that, if desired, the discharge may even be constricted to within an area smaller than the area of conductor overlap. By utilization of this phenomena, the light production may be confined or resolved substantially to the area of the elemental cross-sectional area defined by conductor overlap. Moreover, by operating at such pressure charges (ions and electrons) produced on discharge are laterally confined so as to not materially affect operation of adjacent elemental discharge volumes.

In the instance shown in FIG. **3,** a conditioning discharge about the center of elemental volume **30** has been initiated by application to conductor **13-1** and conductor **14-1** firing potential V_x' as derived from a source **35** of variable phase, for example, and source **36** of sustaining potential V_s (which may be a sine wave, for example). The potential V_x' is added to the sustaining potential V_s as sustaining potential V_s increases in magnitude to initiate the conditioning discharge about the center of elemental volume **30** shown in FIG. **3.** There, the phase of the source **35** of potential V_x' has been adjusted into adding relation to the alternating voltage from the source **36** of sustaining voltage V_s to provide a voltage V_f', when switch **33** has been closed, to conductors **13-1** and **14-1** defining elementary gas volume **30** sufficient (in time and/or magnitude) to produce a light generating discharge centered about discrete elemental gas volume **30.** At the instant shown, since conductor **13-1** is positive, electrons **32** have collected on and are moving to an elemental area of dielectric member **10** substantially corresponding to the area of elemental gas volume **30** and the less mobile positive ions **31** are beginning to collect on the opposed elemental area of dielectric member **11** since it is negative. As these charges build up, they constitute a back voltage opposed to the voltage applied to conductors **13-1** and **14-1** and serve to terminate the discharge in elemental gas volume **30** for the remainder of a half cycle.

During the discharge about the center of elemental gas volume **30,** photons are produced which are free to move or pass through gas medium **12,** as indicated by arrows **37,** to strike or impact remote surface areas of photoemissive dielectric members **10** and **11,** causing such remote areas to release electrons **38.** Electrons **38** are created in every other discrete elemental gas volume, and condition these volumes for operation at a firing potential V_f which is lower in magnitude than the firing potential V_f' for the initial discharge.

Thus, elimination of physical obstructions or barriers between discrete elemental volumes permits photons to travel via the space occupied by the gas medium **12** to remote surface areas of dielectric members **10** and **11** and provides a mechanism for supplying free electrons to all elemental gas volumes, thereby conditioning all discrete elemental gas volumes for subsequent discharges, respectively, at a substantially uniform lower applied potential. While in FIG. **3** a single elemental volume **30** is shown, it will be appreciated that a entire row (or column) of elemental gas volumes may be maintained in a "fired" condition during normal operation of the device with the light produced thereby being masked or blocked off from the normal viewing area and not used for display purposes. It can be expected that in some applications there will always be at least one elemental volume in a "fired" condition and producing light in a panel, and in such applications it is not necessary to provide separate discharge or generation of photons for purposes described earlier.

However, as described earlier, the entire gas volume can be conditioned for operation at uniform firing potentials by use of external or internal radiation so that there will be no need for a separate source of higher potential for initiating an initial discharge. Thus, by irradiating the panel with ultraviolet radiation or by including a radioactive material within the glass materials or gas space, all discharge volumes can be operated at uniform potentials from addressing and interface circuit **19.**

Since each discharge is terminated upon a build-up or storage of charges at opposed pairs of elemental areas, the light produced is likewise terminated. In fact, light production lasts for only a small fraction of a half-cycle of applied alternating potential and, depending

on design parameters, is typically in the submicrosecond range.

After the initial firing or discharge of discrete elemental gas volume **30** by a firing potential V_f', switch **33** may be opened so that only the sustaining voltage V_s from source **36** is applied to conductors **13-1** and **14-1.** Due to the storage of charges at the opposed elemental areas X and Y, the elemental gas volume **30** will discharge again at or near the peak of the following half cycle of V_s (which is of opposite polarity) to again produce a momentary pulse of light. At this time, due to reversal of field direction, electrons **32** will collect on and be stored on elemental surface area Y of dielectric member **11** and positive ions **31** will collect and be stored on elemental surface area X of dielectric member **10.** After a few cycles of sustaining voltage V_s, the times of discharges become symmetrically located with respect to the wave form of sustaining voltage V_s. At remote elemental volumes, as for example, the elemental volumes defined by conductor **14-1** with conductors **13-2** and **13-3,** a uniform magnitude or potential V_x from source **60** is selectively added by one or both of switches **34-2** or **34-3** to the sustaining voltage V_s, shown as **36'**, to fire one or both of these elemental discharge volumes. Due to the presence of free electrons produced by photons from the discharge centered about elemental volume **30,** each of these remote discrete elemental volumes have been conditioned for operation at uniform firing potential V_f.

In order to turn "off" an elemental gas volume (i.e., terminate a sequence of discharges representing the "on" state), the sustaining voltage may be removed. However, since this would also turn off other elemental volumes along a row or column, it is preferred that the volumes be selectively turned off by application to selected on elemental volumes a voltage which can neutralize the charges stored at the pairs of opposed elemental areas.

This can be accomplished in a number of ways, as for example, varying the phase or time position of the potential from source **60** to where that voltage combined with the potential from source **36'** falls substantially below the sustaining voltage.

It is apparent that the plates **16-17** need not be flat but may be curved, curvature of facing surfaces of each plate being complementary to each other, so that the gap between plates remains substantially uniform over their entire surfaces. While the preferred conductor arrangement is of the crossed grid type as shown herein, it is likewise apparent that where an infinite variety of two dimensional display patterns are not necessary, as where specific standardized visual shapes (e.g., numerals, letters, words, etc.) are to be formed and image resolution is not critical, the conductors may be shaped accordingly. Reference is made to British Pat. Specification No. 1,302,148 and U.S. Pat. No. 3,711,733 wherein non-grid electrode arrangements are illustrated.

The device shown in FIG. **4** is a panel having a large number of elemental volumes similar to elemental volume **30** (FIG. **3**). In this case more room is provided to make electrical connection to the conductor arrays **13'** and **14'**, respectively, by extending the surfaces of support members **16'** and **17'** beyond seal **15S'**, alternate conductors being extended on alternate sides. Support members **16'** and **17'** are transparent. The dielectric coatings are not shown in FIG. **4** but are likewise transparent so that the panel may be viewed from either side.

THE INVENTION

In accordance with the practice of this invention, there is provided a multiple gaseous discharge display/memory panel capable of producing a visual color display, the panel having at least one dielectric material charge storage member containing a photoluminescent phosphor which is excited with ultraviolet radiation of a wavelength of about 500 to about 2500 angstrom units such that the phosphor emits visible light of a brightness and intensity sufficient for visual display. In one preferred practice hereof, the photoluminescent phosphor is excited with vacuum ultraviolet radiation of about 750 to about 2000 angstrom units.

As used herein, color is broadly intended to include all phosphor electromagnetic output in the visible range as well as various combinations thereof such as white light. Color is also intended as used in the sense of color television.

The term photoluminescent phosphor includes quite generally all solid and liquid, inorganic and organic materials which are able to convert absorbed energy in the form of quanta of radiation (ultraviolet of about 500 to about 2,500 angstrom units) into visible light.

Typical photoluminescent phosphors contemplated include not by way of limitation both activated and non-activated compounds, e.g., the sulfides such as zinc sulfides, zinc-cadmium sulfides, zinc-sulfo-selenides; the silicates such as zinc silicates, zinc beryllo-silicate, magnesium silicates; the tungstates such as calcium tungstates, magnesium tungstates; the phosphates, borates, and arsenates such as calcium phosphates, cadmium borates, zinc borates, magnesium arsenates; and the oxides and halides such as self activated zinc oxide, magnesium fluorides, magnesium fluorogermanate; and the rare earth oxides and oxysulfides such as yttrium vanadate, yttrium oxide, gadolinium oxide, yttrium oxysulfide. Typical activators include not by way of limitation Mn, Eu, Ce, Pb, etc.

The phosphor is applied to and/or combined with the dielectric by any suitable manner or means that the phosphor can be excited by ultraviolet radiation of the prescribed wavelength, e.g., about 500 to about 2,500 angstrom units. If the ionized gaseous medium is the source of the UV radiation, the phosphor may be directly exposed (such as by direct contact) to the gaseous medium. If the phosphor is not directly exposed to the gaseous medium or other source of the UV radiation, then the dielectric material must be transparent to such UV radiation so as to permit excitation of the phosphor. Thus another embodiment of this invention comprises overcoating the photoluminescent phosphor with a dielectric material transparent to the prescribed UV.

Each phosphor is applied to the dielectric surface (or sub-surface) by any convenient means including not by way of limitation vapor deposition; vacuum deposition; chemical vapor deposition; wet spraying or settling upon the dielectric a mixture or solution of the phosphor suspended or dissolved in a liquid followed by evaporation of the liquid (and fusion of the phosphor if needed); dry spraying of the phosphor upon the dielectric; electron beam evaporation; plasma flame and/or arc spraying and/or deposition; and sputtering target techniques.

The phosphor is applied to the dielectric in an amount sufficient for visual display, e.g., it is applied to the dielectric surface as a very thin film or layer of about **100** angstrom units up to about 10 microns or more.

In one particular embodiment, the photoluminescent phosphor material is deposited, with or without a binder, directly onto a portion of the gas exposed charge storage surface of the dielectric so that the phosphor can be directly excited by ultraviolet radiation, e.g., of about 500 to about 2,500 angstrom units, emitted from the ionized gaseous medium during the operation of the panel; that is, ultraviolet radiation from the gaseous discharge.

Another method of application comprises mixing the phosphor with a commercial photobinder, spraying the mixture onto the glass substrate, drying the sprayed mixture, exposing the photobinder to radiation so as to obtain a desired pattern, and then developing, e.g., with a commercial developer.

Other methods of application could be any of those typically used in color cathode ray tubes, e.g., such as a two-step process where a clear photobinder is applied and the dried film is exposed and developed. A phosphor slurry is then applied, dried and redeveloped. This method should result in sharper definition since the exposure is made without the presence of light scattering crystals.

Another method comprises a dusting process where the dry phosphor is dusted on a sticky photobinder. Another method comprises settling the phosphor, drying, coating with a photo-binder, exposing and developing.

Another embodiment of this invention would be in the use of luminescent glass to replace the phosphor and also the dielectric glass which is used to separate the electrodes.

It is further contemplated in the practice hereof that two or more phosphors may be combined so as to produce a multi-color display, each phosphor being excited by the same or different source. In such embodiment, the radiation from one phosphor may be used to excite another phosphor.

As an extension of this embodiment it is possible to produce multicolor displays by the use of two or more phosphors with a different colored phosphor at adjacent electrode intersections. This allows control of the discharge so as to excite only the color desired. In this manner, one could produce red characters on a green background for a more striking visual display.

Another extension is the use of three color dots, as commonly used in cathode ray tubes, to obtain multicolor displays. To get true color pictures a means of controlling the intensity of the light from each color is necessary. Possible ways of doing this are varying the voltage applied to the discharge exciting a particular color; varying duration of discharge; use of multilayers of glass and phosphor, possibly with transparent electrodes; and addressing the various layers independently.

As noted hereinbefore, one preferred embodiment of this invention comprises exciting the photoluminescent phosphor with ultraviolet radiation emitted from the gaseous discharge. In the practice of such embodiment, it is contemplated using any gaseous medium which will emit (upon panel discharge) ultraviolet radiation in the range of about 500 to about 2,500 angstrom units sufficient to excite the photoluminescent phosphor.

In one highly preferred embodiment hereof, the UV emitting gaseous medium is selected from the rare gases of helium, neon, argon, krypton, xenon, and mixtures thereof.

In the practice of such embodiment, it has been discovered that the phosphor exciting effectiveness of such rare gases increases with atomic weight, e.g., from neon to argon to krypton to xenon. With krypton and xenon, practically all of the visible light emitted from the panel comes from the excited phosphors, e.g., relative to color emitted by the gaseous medium during the gaseous discharge.

In the broad practice of this invention, it is contemplated that the UV source for exciting the photoluminescent phospor may be from other than the gaseous discharge. In such broad practice, it is of course feasible to use even a wider variety of gaseous media; that is, gases which do not emit sufficient UV radiation (within the range of about 500 to about 2,500 angstrom units) for exciting phosphor.

The operation of a gaseous discharge display/memory panel comprises consideration of many operating parameters. In the practice of this invention, two important parameters are the gaseous medium pressure and the frequency of the A.C. supply.

The gaseous medium must be at a pressure sufficient to give a panel memory margin, the exact gas pressure being a function of the particular gaseous medium and other parameters of the system. For example, a pressure of about **50** Torr to about 400 Torr is contemplated for 100% xenon. For mixtures of neonargon or neon-argon-xenon, pressures up to about 800 Torr may be utilized. Thus for rare gases and mixtures thereof, an overall pressure of about 50 Torr to about 800 Torr is contemplated.

The frequency of the A.C. supply must be sufficient for both memory margin and display purposes. Typically the higher the frequency, the greater the average light output. However, for optimum memory margin the frequency ranges from about 25 kilohertz to about 300 kilohertz depending upon other parameters, e.g., pressure and wave shape.

In the prior art the color of a display from a gaseous discharge device has been limited to a color characteristic of the particular gas in use, for example red with neon or blue with xenon. The present invention allows other colors to be obtained from the discharge of a particular gas. For example a display using a xenon discharge can be made to appear red, green, blue or almost any other color. This invention also shows that desirable electrical properties, such as memory margin, can be maintained.

The following example is intended to illustrate some of the best embodiments contemplated by the inventors in the practice of this invention.

EXAMPLE

Two pieces of glass (1-inch by 1-½ inches) were prepared with a gold electrode pattern. The pattern was then covered with a low melting glass and fired to produce a smooth dielectric surface. The ends of the glass were left exposed to allow electrical connection. One of these pieces was then coated with Mn activated zinc silicate phosphor via the following procedure.

About 0.40 gram of phosphor were mixed with **10** cc (cubic centimeter) potassium silicate solution (29.5% total solids, mole ration **1** K_2O:3.31 SiO_2) and 20 cc

H_2O. This was first mixed by hand and then ultrasonically for **15** minutes. One of the plates was cleaned and placed in a 10.5 cm (centimeter) diameter dish and covered with 350 ml (milliliters) of a barium acetate solution (0.33 gram barium acetate/1000 cc H_2O) to a depth of 5.07 cm.

The dispersed phosphor was then poured through a multinozzled funnel into the barium acetate solution. The mixture was allowed to stand undisturbed for one hour and the excess liquid was then removed by siphoning and decanting. This gave a phosphor thickness of about 0.001 inch (1 mil) or a density of 0.4 gm/cm^2.

The plate was dried in air for three hours and then at 90°C for 13 hours. The plate was then sealed to the other plate with a glass spacer in between them so as to form a gap which could subsequently be filled with gas.

After sealing the device was evacuated and baked out, then back filled with xenon gas. When an A.C. voltage was applied between the electrodes on the opposite plates, a discharge was initiated in the gas and radiation from this discharge excited the phosphor. The color of the xenon gas discharge is a deep blue, but it is rich in ultraviolet radiation. The color of the excited phosphor was a bright green.

Discharge and excitation was examined over a range of pressures, voltages, and frequencies. The lowest voltage needed for discharge was found to be in the 50 to 75 Torr range with xenon gas and for this particular gap spacing, about 5 mils, but investigations were conducted from 25 to 200 Torr. In this range brightness increased with increasing voltage at a given pressure. Light output, in general, increased with increasing pressure at a given voltage; and increased with increasing frequency for a given voltage and pressure.

In other experiments other phosphors were applied in the same way and other colors were obtained, e.g., red-P-22 yttrium orthovanadate; Europium; blue-magnesium tungstates. It therefore appears that any color can be obtained for which there is a phosphor which can be excited from the radiation from a gaseous discharge.

These devices also exhibited a memory which depends on many things such as the gas used, the purity of this gas, gas pressure, frequency of signal, and materials in contact with the discharge (the gas-solid interface).

The feasibility of scaling up this process was demonstrated by coating a panel with a 4-inches by 4-inches active surface with a phosphor. After sealing, this panel was operational over a range of xenon gas pressures, voltages, and frequencies as defined hereinbefore.

In another series of experiments various phosphors were mixed on the basis of 0.07 gram phosphor + 4.5 ml barium **solution** (0.66 gram barium acetate/1000 ml water) + 0.45 ml potassium silicate solution (29.5% solids, mole ration 1 K_2O:3.31 SiO_2). This was poured into a square borosilicate tube and allowed to settle for 1 hour. The excess water was siphoned off and the tubes dried in air for three hours, 90°C for 13 hours, 400°C for one hour. A number of these tubes were then attached to a manifold which was evacuated and then could be refilled with different gases. Electrodes were painted on the outside of the tube to allow a potential to be applied across the glass and gas. The following phosphors were excited with a xenon or a krypton discharge: $(MgO) \times (As_2O_5)$ y: Mn; $MgWO_4$; zinc magnesium oxide: Zn; zinc oxide: Zn; zinc orthosilicate: Mn; calcium silicate: (Pb, Mn); calcium magnesium silicate: Ti.

The calcium magnesium silicate: *Ti* phosphor was also excited with a discharge from a 99.9% neon – 0.1% argon gas. This test indicates that many phosphors can be excited by a number of discharging gases. This also indicates that a different glass besides a low melting glass can be in contact with the gas. For each gas there is an optimum operating pressure depending upon gas characteristics and electrode spacing.

Although this invention has been primarily described with reference to the rare gases, it is contemplated that other gases may be useful including not by way of limitation nitrogen, hydrogen, oxygen, carbon dioxide, carbon monoxide, etc. as well as mixtures thereof.

FIG. **5** is a partial cross-sectional view similar to FIG. **3.**

FIG. **5** shows a pair of plate glass substrates **16, 17,** transversely oriented electrode arrays **13** and **14** which define a cross point matrix, gaseous medium **12,** the conductor arrays **13** and **14** being insulated from the gaseous medium by dielectric members **10, 11,** respectively, and photoluminescent phosphor **20** adjacent each cross point as shown.

We claim:

1. In a gaseous discharge information display/memory device characterized by an ionizable gaseous medium in a gas chamber formed by a pair of opposed dielectric members, and a pair of transverse electrode arrays, each array being insulated from the gas chamber by said dielectric members and providing firing and sustaining alternating current voltages for initiating and sustaining discharges of said gaseous medium, said opposed dielectric members storing charges during each half cycle of operation, the improvement wherein said dielectric members are spaced under about 10 mils and at least one of said opposed dielectric members contains at least one photoluminescent phosphor sensitive to and excited by ultraviolet radiation of a wavelength within a range of about 500 to about 2,500 angstrom units, said gaseous medium consisting essentially of a gas selected from the rare gases helium, neon, argon, krypton and xenon and mixtures thereof and at a pressure from about 50 torr to about 800 torr, said phosphor in the excited state emitting visible light of a brightness and intensity sufficient for visual display said phosphor being essentially insensitive to said applied voltages whereby the charge storage property of said dielectric members is retained thereby.

2. The invention of claim **1** wherein the photoluminescent phosphor is sensitive to and excited by vacuum ultraviolet radiation of about 750 to about 2,000 angstrom units.

3. The invention of claim **1** wherein said photoluminescent phosphor is a zinc sulfide, zinc-cadmium sulfide, zinc-sulfo-selenide, zinc silicate, zinc-beryllosilicate, magnesium silicate, calcium tungstate, magnesium tungstate, calcium phosphate, cadmium borate, zinc borate, magnesium arsenate, zinc oxide, magnesium fluoride, or magnesium fluorogermanate.

4. The invention of claim **1** wherein said photoluminescent phosphor is a thin film having a thickness between about 100 angstroms and 10 microns.

5. In a gaseous discharge information display/memory panel comprising an ionizable gaseous medium in a gas chamber formed by a pair of opposed dielectric

material members backed by electrode members, the electrode members behind each dielectric material surface being transversely oriented with respect to the electrode members behind the opposing dielectric material surface so as to define a plurality of discharge units, and means providing firing and sustaining alternating current voltages for initiating and sustaining discharges of said gaseous medium, said gaseous medium consisting essentially of a rare gas selected from helium, neon, argon, krypton, xenon and mixtures thereof, said dielectric material surfaces serving to store charges during each half cycle of operation, the improvement wherein the frequency of said sustaining alternating current voltage is in the range of from about 25 KHz to about 300 KHz, and said ionizable gaseous medium is at a pressure in the range from about 50 torr to about 800 torr and sufficient to give said panel a memory margin, at least one dielectric member contains at least one photoluminescent phosphor sensitive to and excited by ultraviolet radiation of a wavelength within a range of about 750 to about 2,000 angstrom units, said phosphor in the excited state emitting visible light of a brightness and intensity sufficient for visual display.

6. The invention of claim **5** wherein the gaseous medium is xenon.

7. The invention of claim **5** wherein said photoluminescent phosphor is a zinc sulfide, zinc-cadmium sulfide, zincsulfo-selenide, zinc silicate, zinc-beryllo-silicate, magnesium silicate, calcium tungstate, magnesium tungstate, calcium phosphate, cadmium borate, zinc borate, magnesium arsenate, zinc oxide, magnesium fluoride, or magnesium fluorogermanate.

8. The invention of claim **5** wherein said photoluminescent phosphor is a thin film having a thickness between about 100 angstroms and 10 microns.

9. In a process for operating a gaseous discharge display/memory device characterized by an ionizable gaseous medium in a gas chamber formed by a pair of dielectric material members having opposed charge storage surfaces, which dielectric material members are respectively backed by a series of parallel-like electrode members, the electrode members behind each dielectric material member being transversely oriented with respect to the electrode members behind the opposing dielectric material member so as to locate a plurality of discrete discharge volumes each constituting a discharge unit having a discharge gap under about 10 mils, and wherein the gas is selectively ionized within each discharge unit by firing and sustaining alternating current voltages applied to the transversely oriented electrode members and charges are stored on said charge storage surfaces during each half cycle of operation, the improvement which comprises applying at least one photoluminescent phosphor to at least one dielectric member and then exciting the phosphor with an ultraviolet radiation of a wavelength of about 750 to about 2000 angstrom units, said alternating current voltages having a frequency in the range of from **25** KHz to about 300 KHz such that the phosphor is excited by pulses of U.V radiation during the discharge and at double the frequency of said alternating current voltage and emits visible light of a brightness and intensity sufficient for color visual display, said gaseous medium consists essentially from the rare gases group and at a pressure between 50 torr and 800 torr sufficient to give the panel a memory margin.

10. The invention of claim **9** wherein said photoluminescent phosphor is a zinc sulfide, zinc-cadmium sulfide, zinc-sulfo-selenide, zinc-silicate, zinc-beryllo-silicate, magnesium silicate, calcium tungstate, magnesium tungstate, calcium phosphate, cadmium borate, zinc borate, magnesium arsenate, zinc oxide, magnesium fluoride, or magnesium fluorogermanate.

11. The invention of claim **9** wherein said photoluminescent phosphor is a thin film having a thickness between about 100 angstroms and 10 microns.

12. A gas discharge display/memory device comprising, in combination, a pair of spaced-apart nonconductive support members, a pair of conductor arrays arranged one on each of the confronting surfaces of said support members, the arrays being in transverse relative orientation so as to provide a series of cross-points therebetween, a thin dielectric material coating on the confronting surfaces of each of the support members and conductor arrays defining therebetween a sealed gas chamber with the discharge gap at each cross-point being between 3 and 8 mils, and means providing firing and sustaining alternating current voltages of a selected frequency for initiating and sustaining discharges of said gaseous medium, said gaseous medium consists essentially of a rare gas selected from helium, neon, argon, krypton, xenon and mixtures thereof, said dielectric material coating serving to store charges during each half cycle of operation, there being at least two discharges per cycle of operation, at least one of said dielectric material coatings containing photoluminescent phosphor means located at each of said cross-points, said phosphor means being sensitive to and excited by ultraviolet radiation of a wavelength within a range of about 500 to about 2,500 angstrom units generated by gaseous discharge at the respective cross-points, said selected frequency being in the range between about 25 KHz and about 300 KHz, said phosphor means in the excited state emitting visible light of a brightness and intensity sufficient for visual display, the pressure of said gas being between 50 torr and 800 torr depending on the gas characteristics and the electrode spacing and at least sufficient to give the panel a memory margin.

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