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MacIntyre, Jr.

[11] **3,848,248**

[45] **Nov. 12, 1974**

[54] **GASEOUS DISCHARGE DEVICE**

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[73] Assignee: **Sanders Associates, Inc.,** Nashua, N.H.

[22] Filed: **Apr. 5, 1973**

[21] Appl. No.: **348,413**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 225,249, Feb. 10, 1972, abandoned.

[52] **U.S. Cl.** .... **340/324 M,** 315/169 TV, 316/1, 316/27, 316/32, 340/343

[51] **Int. Cl.** **H05b 37/00**

[58] **Field of Search** ..... 340/324 R, 324 M, 166 EL, 340/343; 315/169 R, 169 TV, 228; 313/54, 108, 188, 201, 220, 223; 316/27, 32, 1, 26

[56] **References Cited**

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2,933,648	4/1960	Bentley	315/169 R
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Primary Examiner—John W. Caldwell
Assistant Examiner—Marshall M. Curtis
Attorney, Agent, or Firm—Louis Etlinger; Robert K. Tendler

[57] **ABSTRACT**

Gaseous discharge display device in which separate and unconnected gas filled enclosures or beads are embedded in a transparent dielectric layer between conductors which are arranged so as to form crosspoint or display volumes. These crosspoint or display volumes are then selected or addressed for ionization or deionization of the gas filled beads contained therein so as to selectively light up different points or areas on a display panel. An X-Y conductor matrix arrangement and a seven segment conductor display arrangement are illustrated.

30 Claims, 12 Drawing Figures

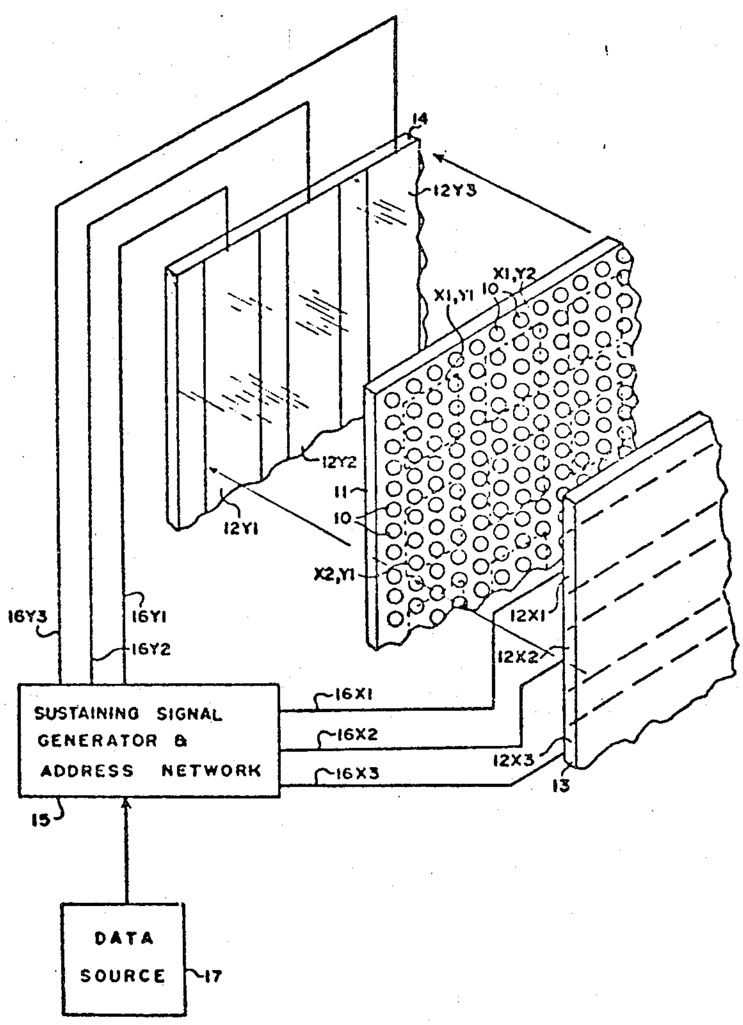
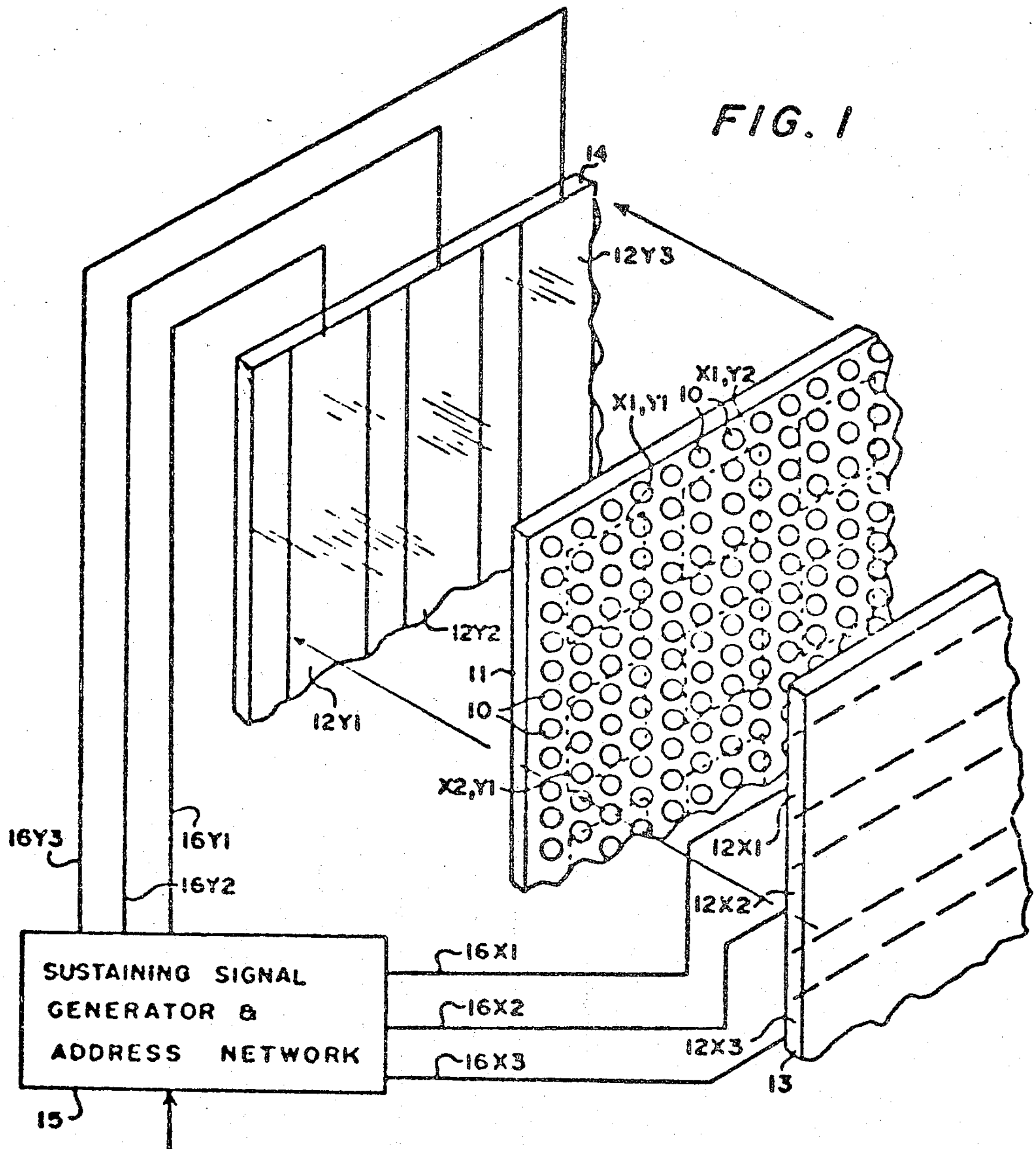


FIG. 1


14
12Y3
X1,Y2
X1,Y1
10
12Y2
11
10
12Y1
X2,Y1
16Y3
16Y1
16Y2
12X1
12X2
SUSTAINING SIGNAL
GENERATOR &
ADDRESS NETWORK
16X1
16X2
16X3
12X3
13
15
DATA
SOURCE
17

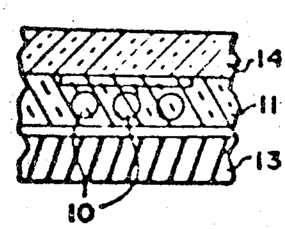

14
11
13
10

FIG. 2

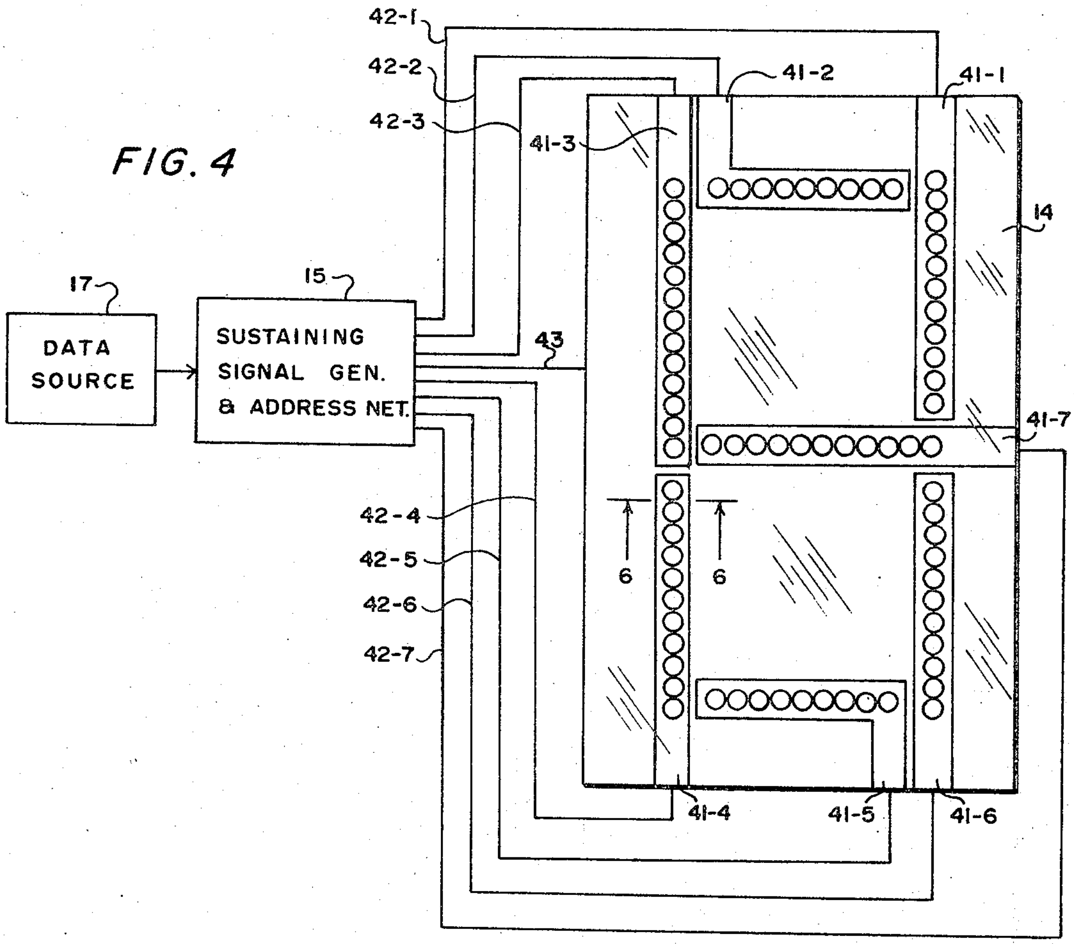


FIG. 4

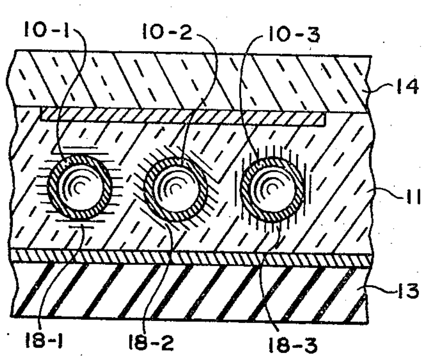


FIG. 3

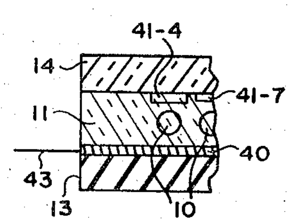


FIG. 6

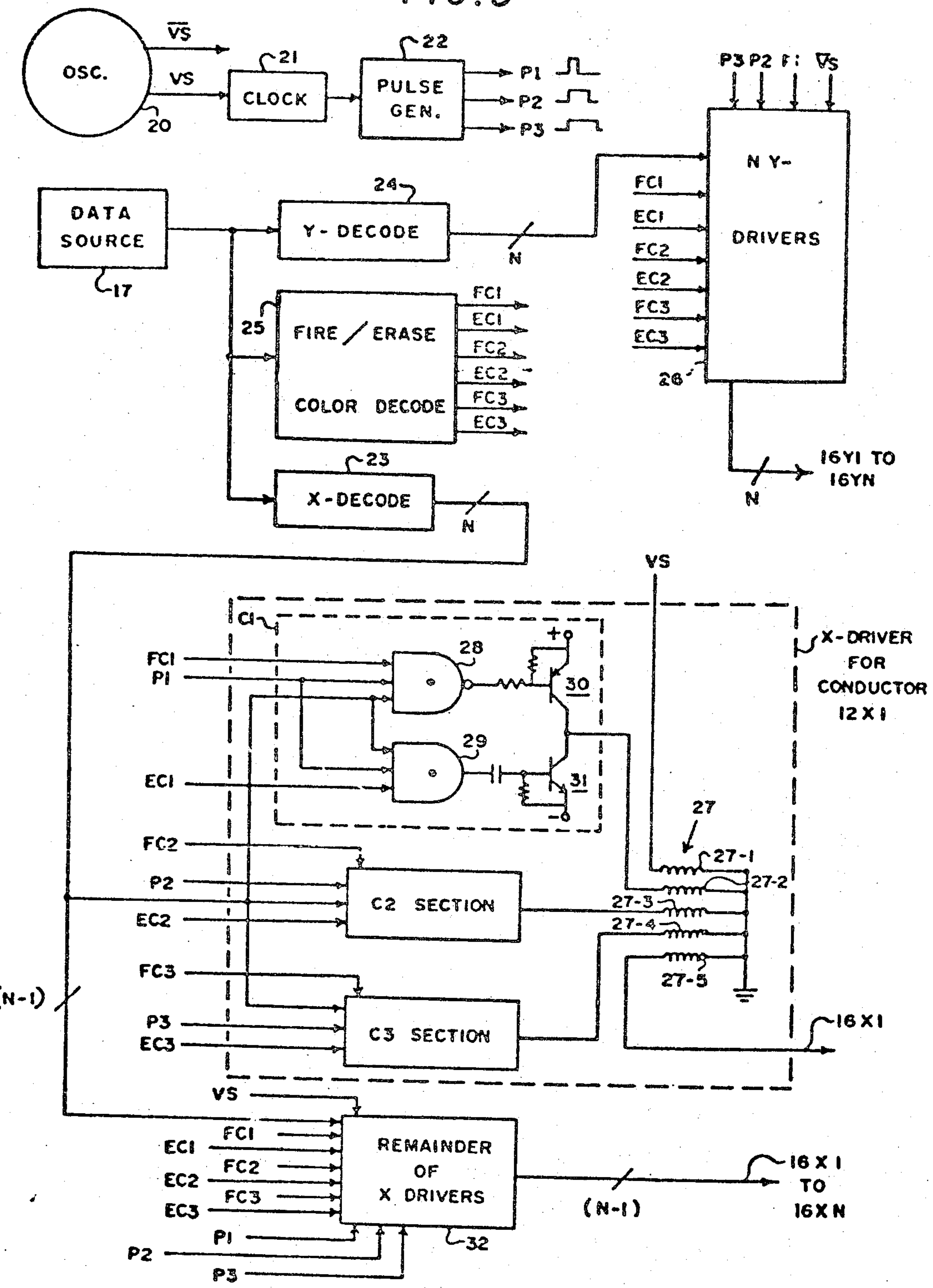

OSC.
20
VS
$\overline{VS}$
CLOCK
21
PULSE GEN.
22
P1
P2
P3
P3 P2 F1 $\overline{VS}$
N Y-DRIVERS
26
DATA SOURCE
17
Y-DECODE
24
N
FC1
EC1
FC2
EC2
FC3
EC3
FIRE / ERASE COLOR DECODE
25
X-DECODE
23
16Y1 TO 16YN
VS
C1
28
29
30
31
27
27-1
27-2
27-3
27-4
27-5
X-DRIVER FOR CONDUCTOR 12X1
C2 SECTION
C3 SECTION
(N-1)
16X1
REMAINDER OF X DRIVERS
32
16X1 TO 16XN

FIG. 5

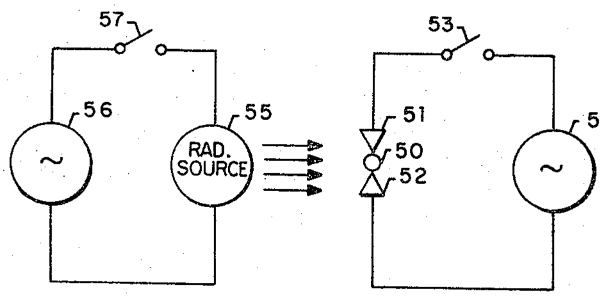


FIG. 7

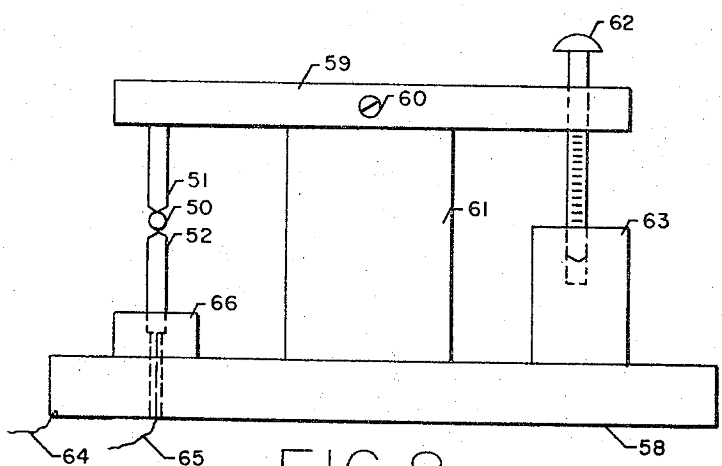


FIG. 8

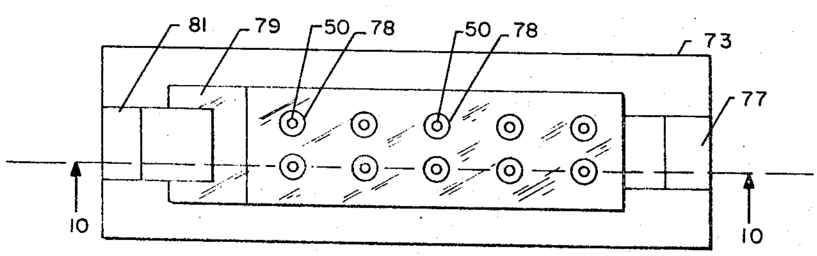


FIG. 9

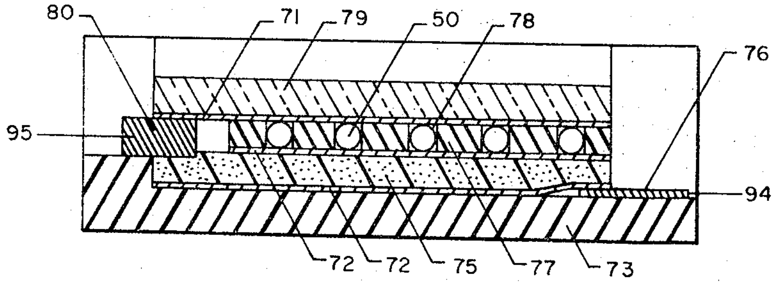


FIG. 10

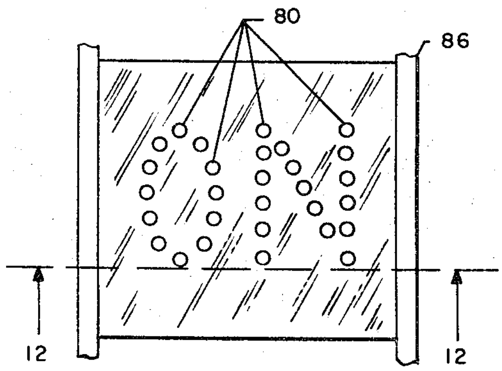

80
86
12
12

FIG.11

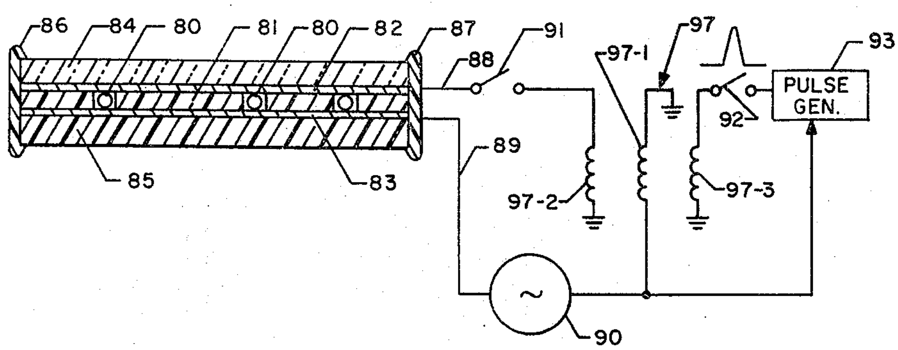

86
84
80
81
80
82
87
91
88
97
97-1
93
PULSE GEN.
92
89
85
83
97-2
97-3
~
90

FIG. 12

GASEOUS DISCHARGE DEVICE

This application is a continuation in part of my copending application also entitled Gaseous Discharge Device, Ser. No. 225,249, filed Feb. 10, 1972 now abandoned.

BACKGROUND OF INVENTION

A. Field of Invention

This invention relates to display and/or memory devices which employ an ionizable gas to visually display and/or store information, and to a method for electroforming or conditioning small hollow beads containing the gas which are used in such devices.

Ionizable gaseous display devices combine the properties of memory and display in a relatively simple and flat structure which is well suited for utility in any application where it is desired to visually display graphics and/or alpha numeric characters. Examples of such applications include television, radar instrumentation and others.

B. Prior Art

In the prior art, display panels have employed an ionizable gas contained in an enclosure formed by a pair of spaced apart and substantially parallel dielectric sheets. In one technique, the enclosure itself is permanently shaped into a desired form such as an alphanumeric character. In another technique, an array of elemental gas volumes is defined within the enclosure by the crossing points of first and second conductor sets which are disposed on different ones of the dielectric sheets. A periodic sustaining voltage is applied continually to all of the conductors. The amplitude of the sustaining voltage is of insufficient value to cause breakdown of any of the gas volumes. A gas volume is addressed or selected for breakdown or ionization by applying rising pulses during the rising part of the sustaining signal waveform to the conductors which define the associated crosspoint. The ions so formed move to the surfaces of the dielectric sheets so as to create a voltage which opposes the applied sustaining voltage which in turn causes the discharge or ionization to quench. When the sustaining voltage changes in sign, the wall or surface charge adds to it so as to cause a breakdown to occur on the falling or negative half cycle without the application of a pulse. This process continues until cancelling pulses, the amplitudes of which oppose the rise or fall of the sustaining voltage waveforms, are applied to the associated crossing conductors. Thus, a selected gas volume emits two pulses of light during each cycle of the sustaining voltage. Since the frequency of the sustaining signals is relatively high (on the order of 50 to 90 kiloherz), the light pulses thus emitted appear as a steady glow. In order to reduce the firing, erase and sustaining voltage values, the plasma panel is usually illuminated by means of a relatively low energy (4 watts or so) source of ultraviolet or near ultraviolet radiation.

In one prior art gaseous or plasma display panel physical isolation of each individual discharge cell or gas volume is required. Such isolation is generally provided by means of a separate center structure having perforations or cells which are in registration with the matrix crosspoints. However, these physically isolated cells are not completely enclosed or isolated from one another since there is a need for free gas passage between all the cells so as to assure uniform gas pressure throughout the panel. This is important since the discharge and memory functions are related to the gas pressure. The manufacture of such plasma panels employing physical isolation has been relatively costly and complex since it is difficult to produce accurate registration of the center piece perforations and the matrix crosspoints.

Attempts have previously been made to reduce the manufacturing cost of plasma displays. In one such attempt, an open cell structure is employed. Rather than using a perforated center sheet, the gas volume or cell isolation is maintained by the geometry of the dielectric sheets and the conductors and by the gas pressure which in the operating range inhibits charge flow.

In both the open cell and the perforated center sheet plasma panels, the dielectric sheets have heretofore been made of glass. The high temperature required to seal and process the glass sheets has resulted in warpage and breakage problems. Since there is free gas passage throughout the enclosure between the glass sheets in both of the aforementioned prior art plasma panels, breakage of the glass or seal results in catastrophic failure of the panel.

In another prior art development, exemplified by U.S. Pat. No. 2,644,113, ionizable gas is placed in ampuls or hollow beads which are placed in a flexible transparent cylinder which can be bent into a desired shape, such as an alpha numeric character, for use on signboards. At column 4, the patentee states that he has employed quartz ampuls having an outer diameter of 3/16 inch, a length of one and one quarter inches and a gas fill of 7mm. helium, argon, mercury. Although the resolution obtained with such ampuls or beads may be adequate for signboard applications, smaller ampuls or beads are required for finer resolution applications.

BRIEF SUMMARY OF THE INVENTION

An object of the present invention is to provide a new and improved display and/or memory device.

Another object is to provide an improved gaseous display device which does not employ a centerpiece perforation and thereby avoids the registration difficulties encountered in the manufacture of prior art devices.

Still another object is to provide a novel and improved plasma panel which can be made of materials other than glass.

Yet another object is to provide an improved display device in which there is no free passage of gas from one point in the panel to another but yet there is substantially uniform gas pressure throughout the entire panel.

A further object is to provide an improved plasma panel display device which employs relatively small hollow beads filled with ionizable gas, but yet has a relatively fine resolution.

Briefly, display devices embodying the present invention employ a plurality of relatively small hollow beads each filled with ionizable gas and all of which have been electroformed or preconditioned. For relatively small bead diameters (on the order of 0.040 inches and smaller) the gas does not initially ionize when subjected to an alternating voltage alone. According to the method of the present invention, initial ionization is achieved by subjecting the gas filled beads both to an alternating voltage having a value greater than the ordinary firing value and to radiation having a wavelength which is equal to or less than that of near ultra-violet radiation. Once the beads have been electroformed or preconditioned in accordance with this process, the gas ionizes in response to a lower firing voltage and lower intensity flood of ultra-violet radiation.

In display devices embodying the invention, the gas filled beads are embedded in a sheet of transparent dielectric material. In accordance with a first embodiment, the beads may be arranged in the dielectric material in any desired design or shape, such as an alphanumeric character. First and second conductors are then arranged on opposite sides of the sheet in sandwich fashion so as to receive a sustaining signal and firing and erase signals.

In another embodiment, the so called X and Y matrix embodiment, first and second sets of conductors are arranged on opposite sides of the dielectric sheet in sandwich fashion and arranged relative to one another to form a plurality of conductor crosspoints. A sustaining voltage signal is applied continuously across all of the crosspoints. An address or selection means then selectively applies firing and erase signals across the crosspoints so as to selectively ionize and deionize the gas contained in the beads sandwiched between the selected crosspoints.

In another embodiment, the selection conductors comprise a continuous conductive sheet disposed on one side of the dielectric sheet and a plurality of separate and unconnected conductors arranged on the other surface of the dielectric sheet so as to form a plurality of display volumes. Again, the sustaining signal is continuously applied across the display volumes and the firing and erase signals are selectively applied thereacross.

In still another embodiment, first and second ones of the beads in each crosspoint or display volume contain first and second gas mixtures having first and second fractional parts of radioactive gas. First and second differently colored phosphors are coated on the first and second beads. The selection means then includes means for applying firing signals across the display volumes or crosspoint volumes, which signals have first and second pulse widths corresponding to the firing times of the first and second gas mixtures to thereby effect a multicolor display.

BRIEF DESCRIPTION OF THE DRAWING

In the drawings like reference characters denote like structural elements; and

FIG. **1** is a perspective view of a portion of a gaseous discharge display device embodying the present invention;

FIG. **2** is a cross section of a selection conductor crosspoint volume of the FIG. **1** display device;

FIG. **3** is an exploded view of a selection conductor crosspoint of the FIG. **1** display for a multicolor display embodiment of the present invention;

FIG. **4** is a plan view of a further display embodiment of the invention having a different arrangement of selection conductors;

FIG. **5** is a block diagram, in part, and a circuit schematic, in part, of an addressing or selection network which can be employed to address the selection conductors for the multicolor display embodiment;

FIG. **6** is a cross section view of the display embodiment of FIG. **4** taken along the lines, **6—6**;

FIG. **7** is a circuit schematic illustrating the electroforming process which embodies the invention;

FIG. **8** is an elevation view of a jig or feature for holding a single gas filled bead during the electroforming process;

FIG. **9** is a plan view of another jig which is attached to hold a plurality of gas filled beads during the electroforming process;

FIG. **10** is a cross section of the FIG. **9** jig taken along the line **10—10**;

FIG. **11** is a plan view of a fixed format or pattern display device embodying the invention; and

FIG. **12** is a cross section of the FIG. **11** display device together with an accompanying circuit diagram.

DESCRIPTION OF PREFERRED EMBODIMENT

It is contemplated that ionizable gas filled ampules, or beads, embodied in the display devices of this invention may assume any suitable shape such as spheroids, teardrops, cylinders or capillaries and will hereinafter be referred to as beads. The beads may be any suitable transparent material, but preferably are made of glass or quartz. The gas may be any suitable ionizable gas or gas mixture having an appropriate gas pressure for selective ionization and deionization. For example, it has been found that a gas pressure in the range of 50 to 350 torr is suitable for an ionizable gas mixture consisting of 97 percent neon and 3 percent nitrogen or of 95 percent neon and 5 percent argon. The bead size can range from relatively large down to the milli-inch range and lower. For example, spheroid beads have been achieved with diameters on the order of 0.005 inches. Spheroid beads useful in the method and devices of the present invention are available from Burrowes Research Co. of Concord, Mass.

The gas filled beads may be made by any suitable process. For example, closed cylinders may be made by circulating the ionizable gas at the chosen pressure in a glass capillary and then forming the cylinders by softening and pinching the capillary at spaced apart points. After cooling, the capillary is then cut or broken at the pinched areas to provide the gas filled cylinders.

When newly manufactured gas filled beads with relatively small diameters, on the order of 0.04 inches, are first subjected to an alternating voltage, the gas does not ionize. This is true even if the voltage is several times higher than the ordinary firing voltage or a like gas mixture and like pressure in a larger enclosure. It has been discovered that ionization of the gas can be initially achieved by employing the electroforming or preconditioning process of the present invention.

Referring now to FIG. **7** the first step in the electroforming process of the present invention is to place an ionizable gas filled bead **50** between a pair of electrodes **51** and **52** which are connected in series with a source of alternating voltage **54** via a switch **53.** The bead **50** is then subjected to radiation having a wavelength which is equal or less than that of near ultraviolet radiation. This is accomplished by positioning a radiation source **55** a short distance away from bead **50** (e.g., 5 to 10 inches). According to one example of the invention, the radiation source **55** takes the form of a Xenon lamp with a power rating on the order of **150** watts which is connected by way of a switch 57 to a 60 Hertz line supply **56.** When the switch **57** is closed, the radiation source **55** is turned on to illuminate the bead **50.** The portion of the emitted spectrum employed is in the near ultra-violet and ultra-violet portion of the spectrum.

At the same time that the bead **50** is subjected to the radiation, the switch **53** is closed so that the alternating voltage from source **54** is applied across the electrodes **51** and **52.** In accordance with the aforementioned example, the alternating voltage **54** has a peak to peak amplitude on the order of 2,000 volts and a frequency on the order of 100 kilohertz. Within a time period of two to five minutes typical, the gas within the bead **50** ionizes so that a visual glow can be observed from the bead. If ionization does not occur within this time period it becomes necessary to open the switch **53** and readjust the voltage of the source **54** to a higher voltage of 3,000 volts peak to peak and repeat the forming process. The lower voltage of 2,000 volts is preferred due to the fact that a higher voltage could cause an arc over between the forming electrodes **51** and **52** which could result in damage to the bead **50.**

The intensity of the radiation emitted by the source **55** is significantly larger than that which is employed for voltage reduction purposes during normal ionization, sustaining and deionization.

For the aforementioned example, the 150 watt Xenon source emits 21 milliwatts of intensity of radiation per sq. cm. at 4,500 A at a distance of 6 inches from the source. The 4 watt ultra-violet light source normally employed emits radiation with an illuminance intensity of 85 microwatts per sq. cm. at 3,660 A at a distance of 6 inches from the source.

After the electroforming process is completed, the gas in the bead **50** will ionize at a lower voltage of 400 volts peak to peak typical (firing voltage) and can be sustained in ionization at 320 volts peak to peak typical at an operating frequency of 100 kiloHertz. These firing and sustaining voltage values prevail for the case where the bead **50** is illuminated by means of a four watt ultra-violet light source. In addition, the typical turn on time after the electroforming process is reduced to about 2 milli-seconds.

It has been further discovered that when the bead **50** is illuminated by radiation of having a wavelength smaller than that of ultra-violet radiation, the peak to peak amplitude value of the voltage source **54** may be reduced. For example, for radiation in the X-ray band, it has been found that a typical peak to peak amplitude value is 500 volts which is still larger than the typical firing voltage of 400 volts peak to peak during normal operating conditions. An X-ray tube made by the Picker Co. operating at **40** kilovolts at 4 milliamperes was used.

With reference now to FIG. **8** a typical fixture for the electrodes **51** and **52** and the bead **50** is shown. In this fixture, the electrode **51** is arranged to move toward and away from the electrode **52** which is stationary so as to facilitate the placement of the bead **50** therebetween. To this end, the electrode **51** is attached to an arm member **59** which is arranged to rotate about a pivot exemplified by a bolt **60** attaching the arm **59** to a vertical support member **61.** Rotation of the arm **59** about the pivot **60** is achieved by means of a screw **62** which engages mating screw threads in a hole through the art **59** and a further hole in a vertical member **63.** The vertical support member **61** and the vertical seat member **63** are attached to a common base member **58.**

All of the elements **58 – 63** are metallic so that a lead **64** attached to the base member **58** serves as the electrical connection to the electrode **51.** On the other hand, the electrical connection **65** to the electrode **52** is made via an aperture through the base plate **58** and a dielectric mounting block **66** which serves to mount the electrode **52** on the common base member **58.**

In FIGS. **9** and **10** there is shown a further fixture which is capable of holding a plurality of beads **50** between a pair of flat spaced apart electrodes **71** and **72.** As best seen in FIG. **10** which is a cross section taken along line **10—10** of the top view of FIG. **9,** the fixture consists of an electrically non-conductive base **73** having a recess **74** in which the electrode **71** and **72** are placed in a sandwich like structure. The electrode **72** takes the form of a metallic foil (e.g., aluminum foil) which is wrapped around a sheet of sponge rubber **75.** Electrical contact is made to the electrode **72** by means of a copper strip **76** which lies in a slot **77** of the base **73** and extends underneath the foil **72.** An electrical lead **94** is connected to the metallic strip **76.**

A perforated sheet **77** of electrically nonconductive material (e.g., plastic) is placed over the electrode **72.** The beads **50** are placed in the perforations **78.** The other electrode **71** takes the form of a thin coating of electrically conductive and transparent material on the underside of a sheet **79** of electrically nonconductive material, such as glass. The coating **71** may be, for example, indium oxide. Electrical contact is made to the electrode **71** by means of a metallic strip **80** which is arranged in another slot **81** of the base **73** so as to extend into the recess **74** in the space between the sponge rubber sheet **75** and the electrode **71.** The conductive strip **80** has an electrical lead **95** attached to it. The strip **80** is given a width which is slightly greater than the combined widths of the foil **72** and the nonconductive perforated sheet **77** so that the sponge rubber sheet **75** acts to bias the strip **80** against the electrode **71.** The strip members **76** and **80** may both be made of copper.

The exact reaction that takes place inside the hollow bead as a result of the electroforming process is not known at this time. However, it is believed that a mechanical altering and conditioning of the inside wall of the glass bead is performed. A conditioning of the gas mixture and metastables contained inside the sphere is created by means of the application high intensity ultraviolet or X-Ray radiation in conjunction with the application of the high voltage across the bead. The result of this altering and conditioning is to provide a permanent change in the glass bead which promotes low voltage ionization of the gas inside the bead.

With reference now to FIGS. **11** and **12** a gaseous discharge display device embodying the invention includes a plurality of ionizable gas filled and electroformed beads **80** arranged in a fixed format display device. The fixed format device takes the form of a sandwich structure in which a spacer sheet **81** is sandwiched between a pair of sheet like conductors **82** and **83** which are coated upon port sheets **84** and **85**, respectively. The conductor coatings **82** and **83**, which may suitably be indium oxide are first coated upon their respective support sheets **84** and **85.** The support sheet **84** is shown to be transparent so as to allow visual observance of the pattern to be displayed. The sheet **84** may suitably be glass, quartz or a transparent plastic. Although the support sheet **85** could also be transparent, if desired, it is here shown as opaque and may be formed of a suitable plastic material. The spacer sheet **81** is of a material having a good electrical insulating quality and in one embodiment takes the form of a sheet of flexible plastic. The fixed format or desired pattern is formed in the spacer sheet **81** by either forming open grooves therein in the desired shape or by punching holes therethrough, one for each bead. The spacer sheet is then placed upon one of the conductor carrying supports and the beads are placed in the grooves or holes, as the case may be. The other conductor carrying support sheet is then placed on the opposite side of the spacer sheet **81.** Circuit leads **88** and **89** are attached to the conductors **82** and **83,** respectively. Finally, clamping elements **86** and **87** are formed on opposite sides of the opposite ends of the sandwich structure so as to securely fasten or clamp the sheets of the sandwich structure together. The clamping elements **86** and **87** may suitably be an epoxy plastic material which when heated and cured seal and hold the structure firmly together.

A source of sustaining voltage **90** is coupled via a transformer **97** to the leads **88** and **89** and a switch **91.** To this end, the transformer primary winding **97–1** is connected in series with the source **90** and the secondary winding **97–2** is in series with the leads **88** and **89.** When the switch **91** is closed, the sustaining signal is applied across the beads **80.** In order to ionize the gas in the beads **80** a pulse generator **93** responds to the output of the sustaining signal generator **90** so as to generate positive going firing pulses in coincidence with the positive going peak of the sustaining signal. To this end the pulse generator is connected in series with the source **90,** a switch **92** and another primary winding **97–3** of the transformer **97.** When it is desired to ionize the gas in the beads **80,** the switch **92** is closed so as to couple the positive going pulses from the generator **93** across primary **97–3.** Once the gas is ionized, the switch **92** is opened. In order to deionize or extinguish the display, the switch **91** is opened to remove all of the signals from the electrodes **88** and **89.** For the purpose of reducing the amplitude values of the firing and sustaining voltages, a low energy source of ultraviolet radiation may be employed to illuminate the beads **80.** For convenience, this source of radiation is not shown in FIGS. **11** and **12** or in any of the other Figures of the drawing. Although the beads **80** are shown in FIG. **11** to be arranged in the fixed format of the alphabetic characters O and N to spell ON, they could be arranged to form any desired pattern, symbol or group of symbols.

With reference now to FIGS. **1** and **2,** a gaseous discharge display device embodying the present invention includes a plurality of ionizable gas filled and electroformed beads **10** embedded in a sheet **11** of dielectric material. The sheet **11** is sandwiched between a first set of conductors **12X1, 12X2,** and **12X3,** and a second set of conductors **12Y1, 12Y2,** and **12Y3.** The first conductor set (the X conductors) are mounted upon the inner surface of an opaque dielectric sheet **13.** The second set of conductors (the Y conductors) are similarly mountd upon a transparent sheet **14** of dielectric material. The first and second set of conductors are arranged relative to one another so as to form a plurality of conductor crosspoints, each of which can be selected or addressed. By way of example, the two sets of conductors have been illustrated in the familiar X-Y matrix arrangement. Each of these conductor crosspoints defines a crosspoint volume in the sheet **11.** Three of these crosspoint volumes are designated by the dashed boxes at the locations **X1, Y1, X1, Y2,** and **X2, Y1.** The widths of the X and the Y conductors are such that each of the crosspoint volumes contains a plurality of the gas filled enclosures **10.**

For the purpose of a clear illustration, the sheets **11, 13** and **14** have been shown in FIG. **1** as disassembled with accompanying arrows which indicate the respective location of the three sheets when in assembled form. These locations are clearly shown in the partial cross section view of FIG. **2,** which illustrates a conductor crosspoint and associated crosspoint volume. In addition, only a portion of the display panel has been shown in FIG. **1,** it being apparent that the total display panel may include more than three X and three Y conductors.

The crosspoint volumes are individually selectable or addressable by means of a sustaining signal generator and address network **15.** The network **15** has first connections **16X1, 16X2,** and **16X3** to the X conductors **12X1, 12X2,** and **12X3,** respectively, and has second connections **16Y1, 16Y2,** and **16Y3,** to the Y conductors **12Y1, 12Y2,** and **12Y3,** respectively.

The network **15** includes any suitable sustaining signal generator (not shown) which produces sustaining signals for application to the X and Y connections and conductors, as well as address circuits (not shown), which respond to address codes or instructions from a data source **17** to superimpose firing and erase signals on the sustaining signals applied to addressed or selected ones of the X and Y conductors. Although the ionization firing, sustaining and erasing operation is well understood in the art, the following brief description is presented here. The sustaining signal has a periodic waveform, for example, a sinusoid, which has a peak amplitude of one-half the peak amplitude required to sustain ionization. The sustaining signal applied to the X conductors is π radians out of phase with the sustaining signal applied to the Y conductors such that the peak amplitude of the sustaining signal across each crosspoint volume is that required to sustain ionization.

The data source **17** may be a computer or any suitable data entry device, such as a keyboard, which is operable to supply address codes to the network **15.** The address circuits (not shown) in network **15** respond to the address codes to select or address an X and a Y conductor for superposition of firing or erasing signals on the sustaining signals. The firing signals are pulses which are additive in an aiding sense to the sustaining signal so as to cause the applied voltage across a selected crosspoint volume to exceed the breakdown potential to thereby cause the gas therein to ionize and emit a visible glow. For instance, the circuit design may be such that the firing signal is applied at a time when the sustaining signal applied to the X conductors is rising and the sustaining signal applied to the Y conductors is falling. For this design, the firing pulse applied to the selected X conductor is positive going (rising). On the other hand, the firing pulse applied to the selected Y conductor is negative going (falling). The amplitude of each of these firing pulses is only one-half the amplitude required to cause the applied voltage across the selected crosspoint volume to exceed the gas breakdown potential. Accordingly, only the gas contained in the volume at the intersection of the selected X and Y conductors ionizes. The breakdown potential of the gas contained in the remainder of the crosspoint volumes associated with the selected X and Y conductors will not be exceeded.

On the other hand, the erase signals are pulses which are additive in an opposing sense to the sustaining signal so as to cause the applied voltage across a selected crosspoint to drop below the gas ionization cutoff potential. Thus, in keeping with the aforementioned design, the erase pulses may be applied during the falling portion of the sustaining signal, as applied to the X conductors and during the rising portion of the sustaining signal, as applied to the Y conductors. In this case the erase pulse applied to the X conductor is negative going (falling), and the erase signal applied to the Y conductor is positive going. Like the firing pulses, the amplitudes of each of these erase pulses is only one-half the amplitude required to cause the applied voltage across a selected crosspoint volume to dip below the gas ionization cutoff potential. Accordingly, only the gas in a selected or addressed crosspoint volume is extinguished, and the ionized conditions of any other crosspoint volumes associated with the selected X and Y conductors are not disturbed.

The dielectric sheets **13** and **14** may be rigid sheets of any suitable dielectric material such as glass, plastic or ceramic, or may be flexible plastic sheets. In any event, conventional printed circuit techniques may be employed to deposit the X and Y conductors on to the respective substrate sheets. Although the X conductors have been shown as opaque, they could just as well be transparent. Indeed, both the X conductors and the sheet **13** could be transparent so as to provide a display panel which can be viewed from either direction.

The dielectric layer **10** is preferably a plastic which is transparent, or at least transparent in a portion of the visible spectrum. The layer **10** may be formed by mixing the transparent plastic in a liquid state with the gas filled beads to form a slurry. The slurry is then spread, as by pasting or painting, upon the conductor carrying surface of one of the sheets **13** or **14.** The preferred method is to place the beads in a layer of one bead thickness, although the display panel will function with a layer of several bead thickness. The pasted slurry is then allowed to solidify. The X or Y conductors and the other sheet **13** or **14,** as the case may be, are then deposited upon the free surface of the layer **10** by conventional printed circuit techniques. A seal may then be accomplished at the outer edges of the resulting structure. According to one exemplary design, where the beam diameter is 0.030 inch, the width of sheet **11** is 0.035 inch and the widths of sheets **13** and **14** can fall in the range from 0.025 inch to 0.062 inch. It should also be noted that the fixed format display device of FIGS. **11** and **12** can be made by spreading the bead containing slurry on one of the conductor carrying supports in a desired pattern.

When the beads are placed very closely together, the display panel structure becomes opaque to the human eye due to the extremely small bead diameter. Although this close spacing or high packing density is desirable for those applications in which extremely high resolution is required, it may be undesirable in other applications where the plasma panel device is intended to be superimposed upon a document containing printed information. In such an application, it is important that the packing density of the beads be such that an observer can see through the panel so as to discern the information on the underlying document but yet have enough resolution to display information in a form readable to the observer. For this application, the beads are placed far enough apart from one another in either a regular ordered array or in a random manner so that the panel becomes transparent enough to allow an observer to discern information contained on an underlying document. Of course, for this application, both of the conductor substrates **13** and **14** as well as both sets of conductors **12**X and **12**Y should be transparent.

Although the light emitted by the ionized gas may be suitable for many applications, it may be desirable for human factor purposes to employ a light of different color. This may be accomplished by employing a suitable photoconversion material such as a photoilluminescent dye or a phosphor which can be either coated to the beads or mixed into the liquid plastic and bead slurry. Use of a green phosphor would produce a conversion of the ultraviolet emission from the gas in the beads to a green light emission due to the photoactivation of the phosphor in the plastic dielectric sheet **10.**

With reference now to FIG. **3,** which is an enlarged cross sectional view of a crosspoint volume of an X-Y matrix panel such as the one shown in FIG. **1,** a multicolor embodiment of the invention will next be described. In this embodiment, advantage is taken of the fact that the firing and/or erase response time of an ionizable gas mixture is proportional to the density of a radioactive gas, such as tritium in the gas mixture. In FIG. **3,** bead **10-1** contains an ionizable gas mixture of neon and nitrogen which is free of any radioactive gas. That is, the gas mixture of bead **10-1** contains zero density of radioactive gas. On the other hand, the beads **10-2** and **10-3** contain ionizable gas mixtures which include radioactive tritium gas of different densities. For example, the tritium gas density in the beads **10-2** and **10-3** may be 5μ ci/cm^3 and 20μ ci/cm^3, respectively, where μ ci is microcuries and cm^3 is cubic centimeters. The beads **10-1, 10-2** and **10-3** are coated with a blue phosphor **18-1,** a green phosphor **18-2** and a red phosphor **18-3,** respectively.

The pulse width of the firing signal will determine which of the three gas mixture will ionize. The narrowest pulse width will ionize the red bead **10-3,** since it has the highest density of tritium. The intermediate width pulse will ionize the gas mixtures in both the red bead **10-3** and the green bead **10-2.** Finally, the widest pulse will ionize the gas mixture in all three of the beads.

With reference to FIG. **5,** an exemplary sustaining signal generator and address network will be described for use with the multicolor embodiment of FIG. **3.** In FIG. **5** the signal leads have in some cases been interrupted and labeled rather than shown as continuous leads so as to avoid cluttering of the drawings. When a signal flow path contains more than a single lead or conductor, a slash mark is made through the path together with an adjacent number or symbol indicating the number of conductors in the path.

The sustaining signal generator is represented in FIG. **5** by an oscillator **20** which produces a sustaining signal V_s and its complement $\overline{V}_s$, which complement is 180° out of phase with V_s. A typical operating frequency for the oscillator **20** is in the range of 50 to 90 kilohertz and a typical voltage range is from 300 to 900 volts peak to peak. The sustaining signal V_s is applied to a clock synchronization network **21** which serves to provide a pulse generator **22** with a control signal at an appropriate time during the sustaining signal cycle. For example, the clock synchronization network **21** could provide a signal to the pulse generator **22** once during each cycle when V_s attains its maximum positive peak. The pulse generator **22** responds to this control signal to provide on its three output leads **P1**, **P2**, and **P3** pulses, the width of which increase from narrow to wide as illustrated by the adjacent pulse waveforms. For example, the pulse width of the pulse on **P1** could be 100 nanoseconds, the pulse on **P2** could be 1 microsecond and the pulse on **P3** could be 10 microseconds. The pulse generator **22** may suitably include three one-shot mulivibrators, one for the generation of each pulse.

An X decoder **23** responds to the address code of the source **17** to provide a select signal on one of its N output leads which are routed to different ones of a group of N X driver circuits the outputs of which are connected to the connections **16X1** through **16XN**. Similarly, a Y decoder **24** responds to the address codes from data source **17** to supply a select signal for each address code on one of its N output leads which are applied to N Y driver circuit **26**, the outputs of which are the Y connections **16y1** through **16YN**. An additional decoder circuit **25** also responds to the address code to decode the firing or erasing and color information contained in each code. For the three color embodiment shown, a three bit field within an address code is sufficient to define a color and whether it is to be fired (written) or erased. The outputs of the decoder **25** are designated FC1, EC1, FC2, EC2, FC3, and EC3 where F and E connote firing and erasing, respectively, and where C1, C2 and C3 connote the colors red, green and blue taken with reference to the aforementioned densities of tritium in the beads **10-3**, **10-2** and **10-1** in FIG. **3**. All of these signals as well as the **P1**, **P2** and **P3** pulses are applied to each of the Y driver circuits and to each of the X driver circuits. In addition, the sustaining signal V_s is applied to all of the X driver circuits and its complement $\overline{V}_s$ is applied to all of the Y driver circuits.

Since all of these driver circuits are similar in circuit structure, only the X driver for conductor **12X1** has been shown in detail. The X driver for conductor **12X1** includes three similar circuit sections **C1**, **C2** and **C3**. The outputs of the **C1**, **C2** and **C3** sections are connected to the primary windings **27-2**, **27-3** and **27-4**, respectively, of transformer **27**. The other primary winding **27-1** is connected to receive the sustaining signal V_s. The secondary winding **27-5** is connected to the conductor **12X1** via the connection **16X1**.

The **C1** section receives the **P1** pulse and applies to its associated primary winding **27-2** a pulse of corresponding width and of a polarity which is determined by which one of the firing and erase signals **FC1** and **EC1** are high. Thus, if the **FC1** signal is high and the **EC1** signal is low, a NAND gate **28** will respond to the **P1** pulse to turn on a PNP transistor **30** for the **P1** pulse duration. This results in a positive going pulse of a width equal to the **P1** pulse being applied to the primary winding **27-2**. On the other hand, if the **EC1** signal is high and the **FC1** signal is low, an AND gate **29** responds to the **P1** pulse to turn on an NPN transistor **31** for the time duration of the **P1** pulse. This causes a negative going pulse of width equal to the **P1** pulse to be applied to the primary winding **27-2**. In either event, the pulse applied to the primary winding **27-2** is added to the sustaining signal V_s so as to appear as a composite signal in secondary winding **27-5**. This composite signal is then applied to the X conductor **12X1** via the connection **16X1**.

The **C2** and **C3** sections in the X driver contain substantially identical circuit elements as the **C1** section. However, the **C2** and **C3** section receives the **FC2**, **P2** and **EC2** and **FC3**, **P3**, and **EC3** signals, respectively, instead of the **FC1**, **P1**, **PC1** signals received by the **C1** section. Thus, the **C2** section responds to the **P2** pulse to apply to the primary winding **27-3** a pulse of like duration and polarity which is determined by the **FC2** and **EC2** signals. Similarly, the **C3** section responds to the **P3** pulse to apply to the primary winding **24-4** a pulse of like duration and of polarity determined by the signals **FC3** and **EC3**. Also, each of the sections **C1**, **C2** and **C3** receives one of the driver select outputs of the X decoder **23**. As shown for the **C1** section, the device select output from the decoder **23** is employed as an enable input to the gates **28** and **29**.

Thus far, it has been described how to select for ionization the red bead **10-3**, the red and the green beads **10-3** and **10-2**, and the red, green and blue beads **10-3**, **10-2** and **10-1**. Other color combinations can be selected by employing a pair of address codes. For example, the blue bead **10-1** can be selected as follows. The first address code would cause the associated **C3** section (FIG. **5**) to apply a firing pulse having a **P3** pulse duration. This would cause the gas in all three of the beads to ionize. The second or next ensuing adress code would cause the associated **C2** section to apply an erasing pulse having a **P2** pulse duration. This would cause the ionization in the beads **10-2** and **10-3** to be extinguished but would not alter the ionization condition of the blue bead **10-1** as the **P2** pulse would terminate too early. In a similar manner, the green bead only or the blue and green beads only can be selected.

Referring now to FIGS. **4** and **6** there is shown another embodiment of the invention which employs the familiar seven conductor segment addressable gaseous discharge display tunnel. In this embodiment transparent dielectric sheet **11**, in which the gas filled beads are embedded, is sandwiched between the opaque conductor carrying dielectric sheet **13** and the transparent conductor carrying dielectric sheet **14**. The conductor **40** which is disposed between the sheet **11** and the sheet **13** is a continuous sheet conductor which covers the entire surfaces of the sheets **11** and **13**. On the other hand, the seven addressable conductor segments **41-1** through **41-7** are distributed in the familiar seven segment pattern at the interface of the sheets **11** and **14** so as to form seven separate and unconnected display volumes in the layer **11**. Although only a single string of gas filled beads **10** is shown in each of these display volumes, it is apparent that the conductor segments **41-1** through **41-7** could be wide enough so as to accommodate more than one string of beads.

The sustaining signal generator and address network **15** responds to the address code provided by the data source **17** to selectively address the seven display volumes for ionization and deionization. To this end, the sustaining signal generator and address network **15** has a single connection **43** to the sheet conductor **40** and address leads **42-1** through **42-7** which are connected to the addressable conductor segments **41-1** through

41-7, respectively. In order to facilitate these connections, the conductor segments **41-1** through **41-7** are shown to have tabs extending from the display volume pattern to the edge of the panel.

As in the X-Y matrix embodiment, the sustaining signals applied continuously at one half the sustaining amplitude to all of the addressable conductors **41-1** through **41-7**. In addition, the sustaining signal with a half sustaining amplitude and a phase displacement of π radians is continuously applied to the common conductor sheet **40**. One or more of the display volumes are selected for ionization by superimposing firing pulses in the aiding sense upon the peaks of the two phase displaced sustaining signal waveforms. For example, if the conductor segments **41-1, 41-3, 41-6** and **41-7** were selected for ionization, the numeral four would be displayed. Ionized ones of the display volumes can be selected for deionization by superimposing erase pulses in an opposing sense on the peaks of the phase display sustaining signal waveforms.

It will thus be seen that the objects set forth above, among those made apparent from the preceding description, are efficiently attained and, since certain changes may be made in the above constructions, without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. Display apparatus comprising,
   a number of electroformed, ionizable gas filled beads supportably mounted as a layer between first and second sets of conductors in sandwich fashion, the conductor sets being arranged in crossing relationship to form in said layer a plurality of conductor crosspoint or volumes, each containing at least one of the beads; and
   means including said conductors for selectively ionizing and deionizing the gas contained in the beads in selected crosspoint volumes.

2. The invention as set forth in claim 1
   wherein there are a plurality of said gas filled beads within each of the crosspoint volumes.

3. The invention as set forth in claim 2
   wherein said ionizable gas contained in said beads includes a fractional part of radioactive gas; and
   wherein said beads are glass beads which are suspended in a plastic dielectric sheet.

4. The invention as set forth in claim 2
   wherein first and second ones of the beads in each crosspoint volume contain first and second gas mixtures having first and second fractional parts of radioactive gas, respectively;
   wherein said first and second ones of the beads in said volumes are associated with first and second phosphors of different colors, respectively;
   wherein said selection means includes means for selectively providing across said crosspoint volumes firing signals having first and second pulse widths which correspond to the firing times of said first and second gas mixtures, respectively; and
   wherein said beads are glass beads which are suspended in a transparent dielectric sheet.

5. The invention as set forth in claim 4
   wherein a third one of the beads in each crosspoint volume contains a third gas mixture having a third fractional part of radioactive gas associated with a third phosphor of another different color; and
   wherein said selective providing means further provides a firing signal having a third pulse width corresponding to the firing time of said third gas mixture.

6. The invention as set forth in clalim **5** and further including first and second substrates upon which said first and second conductor sets are mounted, respectively, said first substrate and said first set of conductors being transparent.

7. The invention as set forth in claim **6**
   wherein said second substrate and said second set of conductors are opaque.

8. The invention as set forth in claim **6**
   wherein said second substrate and said second set of conductors are transparent.

9. The invention as set forth in claim **6**
   wherein said first and second sets of conductors are arranged orthogonally with respect to one another.

10. Display apparatus comprising
    a number of electroformed ionizable gas filled beads suspended in a transparent dielectric sheet, first and second groups of said beads containing first and second ionizable gas mixtures which have first and second fractional parts of radioactive gas, respectively, said first and seocnd groups of beads being associated with first and second photoconversion materials of different colors, respectively;
    first and second conductors mounted on opposite sides of said sheet in crossing relation so as to define in said sheet a crosspoint volume containing at least first and second ones of the beads of the first and second groups, respectively;
    first means connected to said conductors for applying a sustaining signal across said crosspoint volume; and
    second means connected to said conductors for selectively providing across said crosspoint volume firing signals having first and second pulse widths which correspond to the firing times of said first and second gas mixtures so as to ionize the gas mixtures in the first and second beads, respectively.

11. Display apparatus comprising
    a number of electroformed ionizable gas filled beads suspended in a transparent dielectric sheet, first and second groups of said beads containing first and second ionizable gas mixtures which have first and second fractional parts of radioactive gas, respectively, said first and second groups of beads being associated with first and second photoconversion materials of different colors, respectively;
    a first conductor adhered to one side of said transparent dielectric sheet and a second conductor mounted on the opposite side of said dielectric sheet and in overlying relationship to said first conductor so as to define in said sheet a volume containing at least first and second ones of the beads from the first and second groups, respectively;
    first means connected to said first and second conductors for applying a sustaining signal across said volume; and
    second means connected to said first and second conductors for selectively providing across said vol-

ume firing signals having first and second pulse widths which correspond to the firing times of said first and second gas mixtures so as to ionize the gas mixtures in said first and second beads, respectively.

12. Display apparatus comprising

a number of electroformed ionizable gas filled beads supportably mounted as a layer between a first set of conductors and a second conductor in sandwich fashion, the conductors of the first set being arranged relative to one another and to said second conductor so as to form in said layer a plurality of display volumes with each volume containing at least one bead;

first means connected to said first set of conductors and to said second conductor for applying a sustaining signal across all of said display volumes; and

second means connected to said first set of conductors and to said second conductor for selectively applying firing and erase signals across said display volumes so as to selectively ionize and deionize the gas contained in the beads which are located in the selected display volumes.

13. The invention as set forth in claim 12

wherein said beads are glass beads which are embedded in a plastic dielectric sheet; and

wherein said second conductor is a sheet of conductive material which covers one surface of the plastic dielectric sheet.

14. The invention as set forth in claim 13

wherein there are plurality of said gas filled beads within each display volume.

15. The invention as set forth in claim 14 and further including

a first substrate upon which said first set of conductors is mounted, said first substrate and said first set of conductors being transparent.

16. Display apparatus as set forth in claim 1 characterized by said beads being suspended in a sheet of electrically nonconductive material.

17. Display apparatus as set forth in claim 16 wherein said material is plastic.

18. Display apparatus as set forth in claim 17 and further including

first and second substrates upon which the first and second sets of conductors are mounted, respectively.

19. Display apparatus as set forth in claim 18 wherein said selection means further includes

a first circuit coupled to said conductors for applying a sustaining signal across all of said crosspoint volumes; and

a second circuit coupled to said conductors for selectively applying firing and erase signals across said crosspoint volumes so as to selectively ionize and deionize the gas contained in the beads in selected crosspoint volumes.

20. Display apparatus as set forth in claim 19 characterized by

said sheet, one of said substrates and its associated conductor set being transparent to the light emitted by said ionized gas.

21. Display apparatus as set forth in claim 20 characterized by

the conductors in each of said sets being parallel to and spaced apart from one another with the conductors in the first set extending in one direction and the conductors in the second set extending in an orthonogal direction.

22. Display apparatus comprising

a number of electroformed ionizable gas filled beads mounted as a layer between first and second conductors in sandwich fashion, and means including the conductors for ionizing and deionizing the gas contained in the beads.

23. Display apparatus as set forth in claim 22

wherein said beads are arranged in a fixed pattern.

24. Display apparatus as set forth in claim 23 and further characterized by a spacer material which contains one or more apertures for holding said beads and arranged between said first and second conductors.

25. A process of electroforming a hollow glass bead filled with ionizable gas comprising the steps of:

placing the bead between a pair of electrodes;

subjecting the bead to radiation having a wavelength which is equal to or less than that of near ultraviolet radiation; and

applying an alternating voltage across the electrodes until the gas ionizes so as to condition the gas filled bead such that the gas subsequently ionizes when subjected to lower voltage amplitude and radiant intensity.

26. The electroforming process as set forth in claim 25

wherein the subjecting and applying steps are performed concurrently.

27. The electroforming process as set forth in claim 26

wherein said alternating voltage has a frequency in the radio frequency portion of the spectrum.

28. The electroforming process as set forth in claim 27

wherein the radiant intensity during the subjecting step is larger than the radiant intensity subsequently required for ionization by two orders of magnitude.

29. A product for use in display apparatus comprising a hollow glass bead filled with ionizable gas produced by placing the bead between a pair of electrodes, subjecting the bead to radiation having a wavelength which is equal to or less than that of the near ultraviolet region of the electromagnetic spectrum, and applying an alternating voltage across the electrodes until the gas ionizes so as to condition the gas filled bead such that the gas subsequently ionizes when subjected to lower amplitude voltage and lower intensity radiant energy.

30. A product for use in display apparatus comprising a hollow bead filled with ionizable gas produced by subjecting the bead with the gas to both radiation and an alternating current electric field of sufficient intensity and magnitude to ionize the gas.

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