GAS DISCHARGE DISPLAY APPARATUS UTILIZING HOLLOW CATHODE LIGHT SOURCES

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Abstract
Gas discharge display apparatus comprising a plurality of hollow cathodes and associated anodes enclosed in a gastight envelope with an ionizable gas. The hollow cathodes are arranged in a predetermined pattern in order that ignition of gas discharges in the hollow portions of selected cathodes provides the desired display. The anodes are proximate to the hollow portions of the cathodes and the hollow portions have a depth such that only cathode glow discharges substantially confined thereto may occur. Thus, sputtered cathodic material is substantially confined to the interiors of the hollow portions. The anodes are disposed adjacent the hollow portions of the cathodes but exterior thereof for minimizing interelectrode short-circuiting due to sputtering. An individual display light source having a hollow cathode member and a transparent member sealed to the cathode member enclosing the hollow portion thereof and an associated anode with an ionizable gas is also disclosed.

33 Claims, 7 Drawing Figures
FIG. 5.

FIG. 6.

FIG. 7.

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GAS DISCHARGE DISPLAY APPARATUS UTILIZING HOLLOW CATHODE LIGHT SOURCES

BACKGROUND OF THE INVENTION

1. Field of the Invention
The present invention pertains to visual display apparatus particularly of the gas discharge variety.

2. Description of the Prior Art
Visual displays are known that utilize light emitting semiconductor elements such as gallium arsenide diodes arranged in matrix configurations. Selective energization of the elements of the matrix produces visual displays of desired symbols. Apparatus of this character tends to be expensive because of the high cost of the semiconductor elements utilized. Additionally, presently available light emitting semiconductor elements are not capable of generating high intensity light outputs thus limiting the environments in which such displays may effectively be used.

Gas discharge display devices are known that require A.C. excitation across the electrodes of the elements comprising the display to ignite and sustain electrical discharges through the gas. Such displays tend to radiate r.f. interference signals possibly obstructing the operation of electronic equipment in the vicinity thereof. Displays utilizing A.C. excitation require complex addressing and energizing circuits to preferentially ignite discharges at selected elements of the device in order to form desired symbols. Such apparatus tends to be excessively expensive. Additionally, A.C. excited displays often require excessively large energizing voltages hence aggravating the problems previously discussed.

D.C. excited gas discharge displays are known that remedy several of the deficiencies of the A.C. excited displays discussed. For example, D.C. devices do not radiate r.f. interference signals, do not require complex addressing circuits and do not require excessively large energizing voltages as do the A.C. devices. D.C. excited displays often utilize orthogonally oriented sets of conductors immersed in an ionizable gas or individually energizable gas cells. Applying a suitable D.C. potential between selected conductors of the device ignites gas discharges in the gas cells thereof. Because of metal sputtering that often occurs at the cathode electrodes of such devices, apparatus of this character is often subject to failure and degradation of operating characteristics because of cathode erosion, shorting between electrodes and obscuration of the transparent viewing envelope because of deposition of cathodic material thereon. In order to obtain a bright display, high currents must be utilized between the electrodes of the elements hence aggravating the sputtering problem and further shortening the operating life of the device. Cathodes with large surface areas may be utilized to reduce the erosion effects of sputtering. This, however, results in poorly defined glow discharges that spread over the increased cathode surface hence providing a display with inadequate resolution.

Although several of the prior art devices have cathode elements with hollow portions, the glow is often not confined to the hollow portions thus aggravating the problems discussed above. In addition, these prior devices often have the anode electrodes protruding into the hollow portions of the cathodes thus precipitating interelectrode short-circuiting due to sputtered cathodic metal. The cathode glow discharges provided by these prior devices are often viewed through narrow apertures thus decreasing the light output efficiency thereof.

Devices of the type described above may be utilized, for example, for large panel computer operated information displays, or smaller alphanumeric readout indicators or for bright outdoor display panels such as may be utilized in commercial advertising. The disadvantages discussed above such as inadequate resolution, short life, insufficient light output, obstructed glow discharges and high cost tend to limit the usefulness of such devices for applications of the type described.

SUMMARY OF THE INVENTION

The present invention provides a D.C. excited gas discharge display comprising a plurality of hollow cathodes arranged in a predetermined pattern. The hollow portions or holes in the cathodes and the associated anodes are enclosed in a gas-tight envelope with an ionizable gas. Energization of selected cathodes and anodes by suitable D.C. potentials applied therebetween ignites gas discharges in the holes of the selected cathodes thereby providing the desired display.

Since the gas discharges are confined substantially to the holes in the cathodes because of the geometry of the hollow cathode light cells utilized, the resolution of the device is limited only by the dimensions of the hollow cathodes that may practically be constructed. Since the area utilized to generate the gas discharge at each cathode may extend into the interior surface of the cathode hole, a relatively large cathodic surface area is provided for each gas discharge cell. Hence relatively high currents can be utilized in a cell providing a high intensity output without excessively large current densities at the cathode. Thus the sputtering of the cathodic metal is reduced. The undesirable effects of sputtering are further reduced because the sputtered cathodic material should be symmetrically redistributed within the interior of the cathode hole. Hence, the operating life of displays embodied in accordance with the present invention should be increased and the problems associated therewith decreased with respect to the prior configurations previously discussed.

Since the structure of the present invention is relatively uncomplicated and the device may be addressed and energized utilizing simple D.C. potentials, the cost of the present apparatus is reduced with respect to the prior devices.

Since the present invention is energized with D.C. potentials, the anodes thereof may be of a small and unobstructive construction thus not obstructing the glow discharges from view as in prior configurations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an exploded perspective view, partially in section, of a display device constructed in accordance with the present invention utilizing individual addressing of the elements of the display and including a block schematic diagram of the addressing circuits.

FIG. 2 is an exploded perspective view, partially in section, of another embodiment of the present invention utilizing individual addressing of the elements of the display and including a block schematic diagram of the addressing circuits.

FIG. 3 is an exploded perspective view of a display device constructed in accordance with the present invention utilizing coordinate select addressing of the elements of the display and including a block schematic diagram of the addressing circuits.

FIG. 4 is an exploded perspective view of another embodiment of the present invention utilizing coordinate select addressing of the elements of the display and including a block schematic diagram of the addressing circuits.

FIG. 5 is an exploded perspective view, partially in section, illustrating a modification to the device of FIGS. 1-4 providing a multicolored display capability.

FIG. 6 is a side elevational view, partially in section, of an individual hollow cathode light source constructed in accordance with the present invention, and

FIG. 7 is a waveform diagram illustrating potentials useful in energizing the elements of the displays illustrated in FIGS. 3 and 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, an embodiment of the present invention is illustrated and will be described in terms of an alphanumeric or symbol readout indicator 10 of a type that may be utilized, for example, in electronic calculators.
A dielectric member 11, which may be composed of a suitable material such as glass or ceramic, has a plurality of holes formed therein in a predetermined pattern. For the purposes of explanation, a 5 x 7 rectangular array of holes is disclosed, a typical one of which is hole 12. It can be appreciated that other patterns of holes may be utilized, such as the conventional numeric or alphanumeric patterns, depending on the purpose for which the indicator is intended. In addition, a hole 13 and holes 14 are included to provide a decimal point and a comma, respectively. A hollow cathode 16 is sealed in the hole 12 and a plurality of identical hollow cathodes are sealed in the remaining holes in the member 11 respectively. The hollow cathode 16 may comprise a metal rod with an axial hole 17 formed therein. An electrical conductor 20 connects the hollow cathode 16 to addressing circuits 21 and a plurality of identical electrical conductors connect the remaining cathodes respectively thereto for reasons to be explained.

A source of potential 22 provides D.C. voltages to the addressing circuits 21 in a manner and for reasons to be discussed. A transparent dielectric member 23, which may be composed of glass, is sealed to the dielectric member 11 with a shim 24 disposed therebetween. The sealed together members 11 and 23, spaced apart by the shim 24, form a gas-tight envelope enclosing the hole 17 of the cathode 16 and the holes in the remaining cathodes respectively. It may be appreciated that the dielectric member 11 may be formed with the shim 24 as an integral part thereof or alternatively the shim may be formed as part of the transparent dielectric member 23. Any convenient method known in the vacuum tube art may be utilized to hermetically seal together the members 11 and 23. It is to be understood that the cathode 16 is hermetically sealed in the hole 12 and the remaining cathodes are similarly sealed in the remaining respective holes in the member 11.

A metal anode 25 disposed on the surface 26 of the member 23 is positioned adjacent the holes of the cathodes and spaced therefrom. The anode 25 may be a transparent metal film, such as tin-oxide, deposited on the surface 26. It may be appreciated that other metallic coatings, as well as a fine metal mesh, may equivalently be utilized. A conductive tab 27 is included to make electrical contact from the exterior of the gas-tight envelope to the anode film 25. The tab 27 is connected to the addressing circuits 21 via an electrical conductor 30 for reasons to be explained.

It may be appreciated that one of the cathodes, such as cathode 31, may be utilized as the full-tube for the gas-tight envelope formed by the members 11 and 23. The fill-tube 31 may be a metal tube through which the envelope may be evacuated. The envelope may then be filled with an ionizable gas such as neon, argon or Penning mixture (99.5 percent neon, + 0.5 percent argon) to a reduced pressure such as 75 torr. The tube 31 may then be sealed off by any conventional method known in the art of vacuum tube construction. Alternatively, a conventional fill tube may be utilized for these purposes.

The operation of the display device 10 may be appreciated from an understanding of the operation of an individual hollow cathode light source thereof. A positive D.C. potential of sufficient amplitude applied between the anode 25 and the cathode 16 ignites an electrical discharge in the hole 17. This potential is often referred to as the ignition or firing potential. A potential of sufficiently smaller amplitude than that of the ignition potential applied theretobe extinguishes any discharge sustained in the hole 17. This potential is referred to as the extinction potential.

The operating potentials for a hollow cathode gas discharge cell are dependent on the ionizable gas utilized and on its pressure as well as on the geometry and spacing of the electrodes. Utilizing cathode holes of approximately 0.04 inch diameter and 0.06 inch depth and an anode to cathode spacing of approximately 0.025 of an inch in a Penning mixture (99.5 percent neon + 0.5 percent argon) at a pressure of 75 torr, proper operation has been obtained with ignition and extinction potentials of approximately 160 and 130 volts respectively. It is to be appreciated that the operating parameters given are not critical and that departures therefrom may be made in practicing the invention.

In operation, ground potential may be applied to the anode 25 by the source of potential 22 via the addressing circuits 21 and the lead 30. Cathodes selected by the addressing circuits 21 may have ~160 volts applied thereto from the source of potential 22. Non-selected cathodes may be grounded by means of the addressing circuits 21. Thus, electrical discharges are ignited in the holes of the selected cathodes hence displaying a desired symbol or character. For example, applying the ignition potential to the cathodes 32 and the extinction potential to the remaining cathodes causes the numeral 4 to be displayed.

It may be appreciated that the addressing circuits 21 may comprise conventional logic circuits for applying the ignition and extinction potentials provided by the source 22 selectively to cathodes of the display 10 in response to data inputs at a terminal 33. Hence a large variety of characters and symbols may selectively be displayed by the 5 x 7 matrix of hollow cathodes as well as an associated decimal point and comma as provided by the cathodes sealed in the holes 13 and 14 respectively.

As previously discussed, the display device 10 may be employed as an alphanumeric readout indicator of the type utilized in electronic calculators. It may be appreciated that substantially the same design may be used in outdoor display panels by suitably increasing the dimensions of the component parts of the device and by utilizing a larger matrix of cathodes. The cathode rods may be further lengthened and the holes therein deepened so that high intensity displays may be generated by large currents drawn through the extended interior surface area of the cathode. Adequate cooling for such high intensity displays may conveniently be obtained by convective or forced air flow over the cathode rods extending from the back of the member 11. Electrical contact to the individual cathodes is conveniently made at these exposed portions of the cathode rods.

It may be appreciated that the top surface of the cathode rods may be mounted flush with the top surface of the member 11. It may further be appreciated that the top surface of the rods may alternatively be recessed into the holes in the member 11 to reduce the effect of any residual sputtering of cathodic material onto adjacent electrodes.

The device 10 has been described in terms of the holes in the member 11 being formed therethrough with the cathode rod sealed therewith and exposed at the back surface 34. It may be appreciated that the holes in the member 11 need not extend completely therethrough and that hollow cylinders inserted into the holes may be utilized as the cathodic electrodes. With such an arrangement, the member 11 may comprise a transparent dielectric block through the back surface 34 of which the cathodic discharges may be viewed. The transparent dielectric member 23 may then be replaced by a metallic member sealed to the dielectric member 11 to form the gas-tight envelope, the metallic member functioning as the anode of the device.

It may further be appreciated that the cathodes may be formed in the holes of the member 11 by conventional plating techniques.

Referring now to FIG. 2, in which like reference numerals refer to like components with respect to FIG. 1, another embodiment 40 of the present invention is illustrated which may be utilized for the same purposes as those described with respect to the embodiment 10. The device 40, however, incorporates design features that render the manufacturing thereof more economical than that of the device 10.

An electrically conductive cathode member 41, which may be composed of any suitable metal, has a plurality of holes formed therein in a predetermined pattern. The holes may be arranged in accordance with any of the patterns discussed.
with respect to FIG. 1 and are each extending only partially through the member 41. The interior surface of each hole forms the hollow cathode electrode of a light cell of the display 40 in a manner to be explained. An electrical conductor 42 connects the conductive cathode member 41 to the addressing circuits 21 for reasons to be discussed.

A transparent dielectric member 43, which may be composed of glass, is sealed to the cathode member 41 with a shim 44 disposed therebetween. The sealed together members 41 and 43, spaced apart by the shim 44, form a gas-tight envelope enclosing the holes in the cathode member 41 in a manner similar to that described with respect to FIG. 1. The shim 44 may be formed as an integral part of either member 41 or 43 in the manner discussed with respect to FIG. 1. The gas-tight envelope thus formed may be evacuated and filled with an ionizable gas, such as neon, argon or Penning mixture at reduced pressure, in any convenient manner known in the art of vacuum tube construction.

The anode electrodes for the device 40 are comprised of electrical conductors 45 disposed on the surface 46 of the member 43 internal to the gas-tight envelope. The anodes 45 may comprise transparent metal film strips, such as tin-oxide, deposited on the surface 46. It may be appreciated that unobtrusive anode strips of other metals not necessarily transparent, as well as other anode constructions, may equivalently be utilized. The anode strips are arranged adjacent the respective holes of the cathode member 41, each strip and its associated hole forming a hollow cathode gas discharge light source of the display 40 in a manner to be described. Electrically conductive tabs 47, connected to the respective anode strips 45, are included to make electrical contact thereto from the exterior of the gas-tight envelope. The tabs 47 are connected, via respective leads 50, to the addressing circuits 21 for reasons to be explained.

It is understood that the strips 45 must be electrically insulated from the conductive cathode member 41. This may be achieved in any convenient manner known to the art. For example, the shim 44 may be composed of a dielectric material and may be positioned between the anode strips 45 and the cathode member 41 thus preventing electrical contact theretwixt.

The operation of the display device 40 is similar to that described with respect to the device 10 of FIG. 1. Ground potential may be applied to the cathode member 41 by a source of potential 48 via the addressing circuits 21 and the lead 42. Anode strips 45, selected by the addressing circuits 21, may have the positive ignition potential applied thereto from the source of potential 48. Non-selected anode strips may be grounded by means of the addressing circuits 21. Electrical gas discharges are thereby ignited preferentially in the cathode holes adjacent the energized anode strips. Thus it may be appreciated that desired symbols or characters are displayed by the device 10 in response to data inputs at the terminal 33 in a manner similar to that described with respect to FIG. 1.

It should be understood that an anode strip 45 must be disposed adjacent only those cathode holes to be energized thereby. The pattern of anode strips on the surface 45 must be arranged so that no strip is adjacent a hole with which it is not associated. This is required so that discharges are not ignited in holes that are not associated with energized strips thus preserving the fidelity of the display patterns. As an alternative, electrically insulating material 51, such as glass frit, may be utilized to cover the respective surfaces of the strips except at those portions thereof that are adjacent the associated holes.

It may be appreciated that more than one cathode hole may be associated with each anode strip if discharges in these holes are always ignited and extinguished concurrently with respect to each other.

It may further be appreciated that the display apparatus 40 may be employed for uses similar to those discussed with respect to FIG. 1 and may be more economical to manufacture than the device 10 because of its less complex constructional design. The operating parameters for the device 40 may differ from those of the device 10, previously discussed with respect to FIG. 1, because of the constructional differences therebetween.

It may be understood that although the cathode member 41 has been described in terms of holes that are formed partially therethrough, the apparatus 40 may be constructed with holes formed completely through the member 41. A transparent member (not shown) may then be utilized to seal the back surface 52 of the member 41 to complete the gas-tight envelope. The gas discharges may then be viewed through the transparent member.

It may further be appreciated that light intensity from the devices illustrated in FIGS. 1 and 2 may be varied over wide ranges by adjusting the operating currents thereof to accommodate different viewing environments.

Referring now to FIG. 3, in which like reference numerals refer to like elements with respect to FIG. 1, another embodiment 60 of the present invention is illustrated particularly suitable for use as a large panel display. The apparatus 60 may, for example, be operatively associated with a computer or used for outdoor commercial advertising. The elements of the display 60 are energized by a coordinate selection technique to be described.

A dielectric member 61, which may be composed of a suitable material such as glass or ceramic, has a plurality of holes formed therein which are arranged in a matrix 62 of rows and columns. For purposes of explanation a 5 × 5 matrix of holes is disclosed. It is understood, however, that in a practical display, thousands or tens of thousands of holes may be utilized in matrix configuration.

A plurality of hollow cathodes 63 similar to those described with respect to FIG. 1 are sealed in the respective holes of the member 61 in a manner similar to that previously described with respect to FIG. 1. The cathodes of each row of the matrix 62 are connected together by electrical row conductors 64–68 respectively, which in turn are connected to addressing circuits 71 for reasons to be explained.

A source of potential 72 provides D.C. voltages to the addressing circuits 71 in a manner and for reasons to be discussed.

A transparent dielectric member 73, which may be composed of glass, is sealed to the dielectric member 61 with a shim 74 disposed therebetween. The sealed together members 61 and 73, spaced apart by the shim 74, form a gas-tight envelope enclosing the holes in the hollow cathodes 63 in a manner similar to that described with respect to FIG. 1. The shim 74 may be formed as an integral part of either member 61 or 73 in the manner discussed with respect to FIG. 1. The gas-tight envelope thus formed may be evacuated and filled with an ionizable gas as previously described with respect to FIG. 1. It may be appreciated that one of the cathodes, for example cathode 75, may be utilized as the fill tube for the gas-tight envelope in the manner previously explained.

The anode electrodes for the device 60 are comprised of electrical conductors 76–80 disposed on the surface 83 of the member 73 internal to the gas-tight envelope. The anodes 76–80 may comprise respective transparent metal film strips, such as tin-oxide, disposed on the surface 83. It may be appreciated that anode strips of other metals, as well as other anode constructions such as fine wires, may equivalently be utilized. The anode strips 76–80 are arranged in columns adjacent the holes of the columns of cathodes of the matrix 62 respectively. Electrically conductive tabs 84, connected to the respective anode strips 76–80, are included to make electrical contact thereto from the exterior of the gas-tight envelope. The tabs 84 are connected, via respective leads 85–89, to the addressing circuits 71 for reasons to be explained.

The operation of an individual hollow cathode light source of the display 60 is similar to that described with respect to an individual cell of the device 10 of FIG. 1. Ignition and extinction potentials are required for the reasons given with respect
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It may therefore be appreciated that by appropriate ener-
gization of the row conductors 64-68 and the anode strips
76-80, selected cathodes of the matrix 62 may be ignited
and extinguished thus displaying a desired information pattern
on the device 60.

It may further be appreciated that the addressing circuits 71
may comprise conventional logic circuits for applying the igni-
tion, sustaining and extinction potentials provided by the
source 72 selectively to the row conductors 64-68 and to the
anode strips 76-80 in response to data inputs at the terminal
33. Hence a large variety of display patterns may selectively
be generated by the matrix 62 of hollow cathode light cells.

The potentials selectively provided by the addressing cir-
cuits 71 are illustrated in FIG. 7. It may be appreciated that
it is not necessary to symmetrically increase and decrease the
sustaining voltages as hereinabove explained in order to
generate the ignition and extinction potentials. An applied
voltage scheme different from the one specified may be
chosen requiring an asymmetrical increase and decrease of
the sustaining voltage to generate the ignition and extinction
potentials.

It may be appreciated that the display 60 is suitable for ap-
lications requiring a high intensity display for the reasons
given with respect to FIG. 1.

It is further understood that the transparent member 73
should be disposed close to the front surface of the dielectric
member 61 so that the migration of ions and electrons
between the various cathodes of the display is prevented. This
is necessary to avoid the improper ignition of discharges in
non-selected holes. The top surface of the rods 63 are
recessed into the holes in the member 61 to maintain an
anode-cathode spacing appropriate for optimum performance
of the device.

The device 60 has been described in terms of the holes in
the member 61 being formed therethrough with the cathode
rods 63 sealed therein and exposed at the back surface of
the member 61. It may be appreciated that the holes in the
member 61 need not extend completely therethrough and that
hollow cylinders inserted into the holes may be utilized as the
cathodic electrodes. With such an arrangement, the member
61 may comprise a transparent dielectric block through the
back surface of which the cathodic discharges may be viewed.
It may further be appreciated that the cathodes may be
formed in the holes of the member 61 by conventional plating
methods.

Referring now to FIG. 4, in which like reference numerals
refer to like components with respect to FIG. 3, another em-
bodiment 100 of the present invention is illustrated which may
be utilized for the same purposes as those described with respect
to the embodiment 60. The device 100, however, in-
corporates a hollow cathode structure 101 that may be
mechanically stronger and more economical to manufacture
than that of the device 60.

The hollow cathode structure 101 comprises a plurality of
electrically conductive cathode members 102-106 having
rows of holes formed therein respectively. The holes may ex-
tend only partially through the members 102-106, the interior
surface of each hole forming the hollow cathode electrode of
a light cell in a manner similar to that described with respect to
FIG. 2. The members 102-106 may be composed of any suita-
able metal and are aligned with respect to each other so that the
respective rows of holes form columns of holes. It may thus be
appreciated that the holes in the cathode members 102-106
form a matrix of rows and columns. For purposes of explana-
tion a 5 x 5 matrix of holes is disclosed. However, it is un-
derstood that practical displays may utilize larger matrices as
previously explained with respect to FIG. 3. The electrically
conductively cathode members 102-106 are connected to the
addressing circuits 71 via leads 107-111 respectively for
reasons previously discussed with respect to FIG. 3. The
source of potential 72 provides D.C. voltages to the addressing
circuits 71 in the manner and for the reasons explained with
respect to FIG. 3.

to FIG. 1 and, in addition, a voltage intermediate in amplitude
thereof is required to sustain discharges that have been
ignited. This voltage may be referred to as the sustaining poten-
tial. It may be appreciated that the sustaining potential is insuffi-
cient to ignite a discharge in a cell and that a discharge ig-
nited in a cell is sustained by application of the sustaining
potential thereacross.

The operating potentials for a hollow cathode gas discharge
cell are dependent on the ionizable gas utilized and on its pres-
sure as well as on the geometry and spacing of the electrodes.
Utilizing cathode holes of approximately 0.062 inch diameter
and 0.2 inch depth and an anode to cathode spacing of ap-
proximately 0.05 inch in a neon atmosphere at a pressure of
12 torr, proper operation has been obtained with ignition,
sustaining and extinction potentials of 330, 230 and 130 volts
respectively. It is to be appreciated that these operating
parameters are not critical and that departures therefrom may
be made in practicing the invention.

In operation, ground potential may be applied to the row
conductors 64-68 by the source of potential 72 via the ad-
ressing circuits 71. The sustaining potential of 230 volts may
be applied to the anode strips 76-80 by the source of potential
72 via the addressing circuits 71 and the leads 85-89 respec-
tively. Thereby it may be appreciated that the sustaining potential
of 230 volts is applied across each hollow cathode cell of the
matrix 62.

In order to ignite a discharge in a hole of a selected cathode
of the matrix 62, the addressing circuits 71 increase the poten-
tial applied to the anode strip associated with the selected
cathode and decrease the potential applied to the row conduc-
tor associated therewith so that the potential across the
selected cell is equal to the ignition potential. The increased
and decreased potentials are chosen so that the potential
across the non-selected cells of the matrix 62 remain lower than
the ignition potential. When the increased and decreased
potentials are removed from the selected conductors, the
sustaining potential applied to all of the cells of the matrix 62
sustains the discharge ignited in the hole of the selected
cathode.

In order to extinguish discharge in a hole of a selected
cathode of the matrix 62 the addressing circuits 71 decrease
the potential applied to the anode strip associated with the
selected cathode and increase the potential applied to the row
conductor associated therewith so that the potential across the
selected cell is equal to the extinction potential. The
decreased and increased potentials are chosen so that the
potential across the non-selected cells of the matrix 62 remain
greater than the extinction potential. Hence, only the
discharge in the hole of the selected cathode is extinguished.
For example, if it is desired to ignite a discharge in the hole
93 of the cathode 92, the sustaining potential of 230 volts ap-
plied to the anode strip 76 may be increased by 50 volts to a
potential of 280 volts. Simultaneously, the ground potential
applied to the row conductor 64 may be decreased by 50 volts
to a potential of -50 volts. Thus a difference of potential of
330 volts is applied between the anode 76 and the cathode 92
hence igniting a discharge in the hole 93 thereof. It may be ap-
preciated that the cells in the row and column of the matrix 62
associated with the cathode 92 have 280 volts applied thereacross which is insufficient to extinguish discharges sustained therein.

As a further example, if it is desired to extinguish a
discharge in the hole 93 of the cathode 92, the sustaining
potential of 230 volts applied to the anode strip 76 may be
decreased by 50 volts to a potential of 180 volts. Simultane-
ously, the ground potential applied to the row conductors 64
may be increased to 50 volts. Thus a difference of potential of
130 volts is applied between the anode 76 and the cathode 92
hence extinguishing any discharge sustained in the hole 93
thereof. It may be appreciated that the cells in the row and
column of the matrix 62 associated with the cathode 92 have
180 volts applied thereacross which is insufficient to extin-
guish discharges sustained therein.
The cathode members 102-106 include ridges 114 positioned respectively between adjacent holes thereof for reasons to be explained. The cathode members 102-106 are sealed respectively therewith. The top surfaces of the insulators 115-118 are in alignment with the top surfaces of the ridges 114 for reasons to be clarified.

A transparent dielectric member 121, similar to the member 75 of Fig. 3, is sealed to the cathode structure 101 around the edges thereof forming a gas-tight envelope enclosing the holes in the cathode members 102-106 in a manner similar to that described with respect to Fig. 3. The members 101 and 121 may be sealed together at the edges by any conventional means (not shown for clarity) known in the art of vacuum tube construction. The surface 122 of the member 121 is disposed abutting the top surfaces of the ridges 114 and the insulators 115-118 for reasons to be explained. The gas-tight envelope formed between the members 101 and 121 may be evacuated and filled with an ionizable gas, such as neon, argon or Penning mixture at reduced pressure, in any convenient manner known to the art of vacuum tube construction.

The anode electrodes 123-127 are disposed and arranged on the surface 122 of the member 121 in a manner identical to that described with respect to the member 73 of Fig. 3. The electrodes 123-127 therefore form columnar anodes adjacent the respective columns of holes in the member 101 in the manner described with respect to Fig. 3. Electrically conductive tabs 130, connected to the respective anode strips 123-127, are included to make electrical contact thereto from the exterior of the gas-tight envelope. The tabs 130 are connected to the addressing circuits 71 in the manner and for the reasons discussed with respect to Fig. 3.

The operation of an individual hollow cathode light source of the display 100 is similar to that described with respect to an individual cell of the device 40 of Fig. 2. The operation of the display device 100 where electrical discharges are selectively ignited and extinguished in the holes of the cathode structure 101 by appropriate energization of the leads 107-111 and the anode strips 123-127, thereby displaying desired information patterns, is identical to the operation of the device 60 described with respect to Fig. 3. For example, applying the ignition and extinction potentials to the electrically conductive cathode member 102 via the lead 107 and to the anode strip 125 selectively ignites and extinguishes electrical discharges in the hole 131 respectively.

In order to prevent the improper ignition of discharges in non-selected holes due to the migration of ionized gas and electrons between cathodes, barriers may be required around each hole of the matrix. The ridges 114 and the insulators 115-118, the top surfaces of which abut the surface 122 of the member 121, may form the required barriers.

It may be understood that although the cathode structure 101 has been described in terms of holes that are formed partially therethrough, the apparatus 100 may be constructed with holes formed completely through the cathode members 102-106. A transparent member (not shown) may then be utilized to seal the back surface 132 of the structure 101 to complete the gas-tight envelope. The gas discharges may then be viewed through the transparent member.

Referring now to Fig. 5, a modification of the devices depicted in Figs. 1-4 is illustrated that provides a multi-colored display capability. A broken-out portion of a display is shown illustrating the operating principles of the modified embodiment.

Sections 140 and 141 are representative of, for example, portions of displays such as the display 40 of Fig. 2 where the holes in the cathode members 142 and 143 are formed completely therethrough. The pattern of holes in the member 142 may be identical to the pattern of holes in the member 143. The members 142 and 143 are aligned relative to each other so that corresponding holes therethrough are in axial alignment with respect to each other. Transparent members 144 and 145 are sealed, respectively, to the members 142 and 143 forming respective gas-tight envelopes in the manner described with respect to Fig. 2. The gas-tight envelopes associated with the sections 140 and 141 may be filled with different ionizable gases with respect to each other. For example, the envelope associated with section 140 may be filled with neon and the envelope associated with section 141 may be filled with argon in the manner described with respect to Fig. 2.

The members 142 and 143 are sealed to the opposite surfaces of a transparent member 146. The member 146 may be utilized to complete the gas-tight envelopes associated with the sections 140 and 141 respectively.

Electrical discharges may selectively be ignited and extinguished in the cathode holes of the members 142 and 143 utilizing any of the techniques described with respect to Figs. 1-4. For example, an electrical discharge may be ignited or extinguished in the hole 150 and similarly an electrical discharge may be ignited or extinguished in the hole 151 which is in axial alignment therewith.

Electrical discharges through the neon gas in the gas-tight envelope associated with the section 140 emit a red colored light and electrical discharges through the argon gas in the gas-tight envelope associated with the section 141 emit a blue colored light. It may be appreciated that because of internal reflections within the holes of the members 142 and 143, light emanating from a hole in the member 143 is transmitted not only through the transparent member 145 but also through the transparent member 146 into the corresponding hole in the member 142 and consequently through the member 144. Conversely, light emanating from a hole in the member 142 may be viewed through the transparent member 145. Furthermore, because of internal reflections within the holes, color fidelity is obtained over large viewing angles since light from the rear cells is visible over large angles after reflections at the inside surfaces of the front cells.

In operation when an electrical discharge is sustained in the hole 150, for example, and there is no electrical discharge in the hole 151, red light can be viewed through both the members 144 and 145 at the location of the holes 150 and 151. Conversely, if an electrical discharge in the hole 151 and there is no electrical discharge in the hole 150, the color blue light may be viewed at this location of the display. If electrical discharges are sustained in both the holes 150 and 151, the red and blue light generated respectively therein appears at the location of the holes 150 and 151 as a pink color.

It may be appreciated that by appropriate choices of ionizable gases a variety of colors may selectively be displayed by apparatus configured in accordance with the present invention.

Referring now to Fig. 6, an individual hollow cathode light source constructed in accordance with the present invention is illustrated. A gas-tight envelope 160 is formed by a hollow cathode 161 and a transparent member 162 hermetically sealed thereto. The transparent member 162 may be composed of glass. The transparent member 162 may be sealed to the cathode member 161 by any conventional technique known in the art of vacuum tube construction. An electrically conductive anode 163 is disposed on the surface of the member 162 internal to the gas-tight envelope 160. The anode 163 may, for example, be any suitable transparent metal film deposited on the inner surface of the member 162. The envelope 160 may be evacuated and filled with an ionizable gas at a reduced pressure by means of a conventional fill tube 164. Leads 165 and 166, connected to the cathode 161 and the anode 163, respectively, may be utilized for applying suitable potentials to the light source.

In operation the application of suitable ignition and extinction potentials between the leads 165 and 166 may selectively ignite or extinguish an electrical discharge within the hole 167, respectively.

A plurality of individual hollow cathode light sources, of the type illustrated in Fig. 6, may be utilized in combination to form a variety of display configurations.
It may be appreciated that the display devices described hereinabove with respect to FIGS. 1-4 incorporate constructional features that provide rugged devices which are economical to manufacture.

It may further be appreciated that the devices described with respect to FIGS. 1 and 2 are particularly suited to applications where a reasonably small number of hollow cathode light cells are required, for example, in an alphanumeric readout indicator. Since each light cell of the devices of FIGS. 1 and 2 requires a separate lead for energization thereof, a display with a large number of light cells, and consequently a large number of leads, may be prohibitively cumbersome.

The display devices illustrated in FIGS. 3 and 4 are particularly suitable for applications where a large number of light cells are required. Such applications occur, for example, in computer controlled information display panels and in outdoor commercial advertising displays. Since the cells of the apparatus illustrated in FIGS. 3 and 4 are energized by a coordinate selection technique, a smaller number of leads are required relative to the number of cells in the display.

It may be appreciated that prior art hollow cathode light sources are often constructed with the anode spaced an extended distance from the cathode hence providing the capability of columnar type discharges through the gas. Such discharges are unsuited to the applications hereinabove, for which the present invention is designed, because of the exceedingly inferior resolution that such devices would provide and the detrimental sputtering problems precipitated thereby. In the present invention the anodes are disposed adjacent the holes of the hollow cathodes in such proximity thereto that columnar discharges are precluded. Only cathode glow discharges are permitted to occur in the present invention. The discharges are confined substantially to the interior of the holes in the cathodes because of the geometry of the cells utilized hence providing superior display resolution compared to the prior devices previously discussed.

In addition, the sputtering problems are reduced compared to the prior devices since the sputtered cathodic metal is substantially confined to the cathode holes and is symmetrically redistributed around the interior surfaces thereof. Hence a long-lived bright display is provided since the glass viewing plate thereof is not readily obscured by the sputtered cathodic metal as in the prior devices. Additionally, the interelectrode short-circuiting problem due to sputtered cathodic metal is substantially reduced, particularly since the anode electrodes are located external to the cathode holes.

Since in the present invention the entire glow discharges sustained within the cathode holes contribute to the viewed display, in contrast to prior devices where the glow discharges may be viewed through narrow apertures, the light output efficiency of the present device is superior to that of such prior configurations.

While the invention has been described in its preferred embodiment it is to be understood that the words which have been used are words of description rather than limitation and that changes may be made within the purview of the appended claims without departing from the true scope and spirit of the invention.

1. Gas discharge display apparatus comprising cathode means having a plurality of hollow cathode portions arranged in a predetermined pattern, anode means spaced from said cathode means and disposed adjacent said hollow portions but exterior thereof for minimizing interelectrode short-circuiting due to sputtering, gas-tight envelope means enclosing said hollow portions and said anode means with an ionizable gas, said envelope means having a transparent portion for viewing said hollow cathode portions, and connection means included in said cathode and anode means adapted for connection to a source of electrical potential to selectively apply suitable potentials between said anode and cathode means for providing electrical discharges in selected hollow cathode portions, said anode means being in such proximity to said hollow portions and said hollow portions having a depth such that only cathode glow discharges substantially confined thereto may occur thereby substantially confining sputtered cathodic material to the interiors of said hollow portions and defining sharply demarcated glow discharges, each said hollow cathode portion having side wall surfaces providing the primary electron emitting surfaces thereof, said side wall surfaces having low resistivity and said connecting means associated therewith providing a high conductance path from said side wall surfaces to said source of potential.

2. The apparatus recited in claim 1 in which said potentials comprise positive potentials at said anode means with respect to said cathode means.

3. The apparatus recited in claim 1 in which said cathode means comprises a first dielectric member having a plurality of holes arranged therein in a predetermined pattern, and a plurality of electrically conductive hollow cathodes having respective hollow portions therein, said cathodes being disposed in said holes in said first dielectric member respectively.

4. The apparatus recited in claim 3 further including a second member sealed to said first dielectric member thereby forming said envelope means.

5. The apparatus recited in claim 4 in which said second member comprises a transparent dielectric member for viewing said cathodes, and said anode means comprises a transparent electrically conductive film disposed on the surface of said transparent dielectric member internal to said envelope means.

6. The apparatus recited in claim 3 in which said cathodes comprise, respectively, electrically conductive rods having respective axil holes formed therein.

7. The apparatus recited in claim 6 in which said holes in said first dielectric member extend therethrough, and said rods are hermetically sealed in said holes whereby portions thereof are exposed to the exterior of said envelope means for making electrical connection thereto and for efficient cooling thereof.

8. The apparatus recited in claim 6 further including, a source of positive electrical potential sufficient to ignite electrical discharges through said ionizable gas, and addressing means coupling said connection means to said source of electrical potential for applying said positive potential to said anode means with respect to selected ones of said plurality of rods thereby producing electrical discharges in selected holes of said rods.

9. The apparatus recited in claim 7 in which one of said rods comprises the sealed fill tube for said envelope means.

10. The apparatus recited in claim 1 in which said cathode means comprises an electrically conductive cathode member having a plurality of holes therein arranged in a predetermined pattern, and said anode means comprises a plurality of electrical conductors disposed adjacent said holes, respectively.

11. The apparatus recited in claim 10 further including a dielectric member sealed to said cathode member thereby forming said envelope means.

12. The apparatus recited in claim 11 in which said dielectric member comprises a transparent member for viewing said cathode member, and said electrical conductors comprise respectively electrically conductive strips disposed on the surface of said transparent dielectric member internal to said envelope means.

13. The apparatus recited in claim 12 in which said strips are covered along their respective surfaces with a dielectric material except at those portions thereof adjacent said holes.

14. The apparatus recited in claim 12 further including
a source of positive electrical potential sufficient to ignite
electrical discharges through said ionizable gas, and
addressing means coupling said connection means to said source of electrical potential for applying said positive potential to selected ones of said plurality of strips with respect to said conductive cathode member thereby producing electrical discharges in selected holes of said cathode member;
15. The apparatus recited in claim 1 in which said cathode means comprises
a first dielectric member having a plurality of holes ar-
anged therein in a matrix of rows and columns, and
a plurality of electrically conductive hollow cathodes having respective hollow portions therein,
said cathodes being disposed in said holes in said first
dielectric member respectively.
16. The apparatus recited in claim 15 in which
said anode means comprises a plurality of first electrical
conductors each disposed adjacent the hollow portions of
a respective column of said cathodes, and
said cathode means includes a plurality of electrical row
conductors each connecting the cathodes of a respective row.
17. The apparatus recited in claim 16 further including a second
dielectric member sealed to said first dielectric
member thereby forming said envelope means,
said first electrical conductors comprise respective electrically
conductive strips disposed on the surface of said transparent
dielectric member internal to said envelope means.
18. The apparatus recited in claim 17 in which
said second dielectric member comprises a transparent
member for viewing said cathodes, and
said first electrical conductors comprise respective electrically
conductive strips disposed on the surface of said transparent
dielectric member internal to said envelope means.
19. The apparatus recited in claim 16 in which said
cathodes comprise, respectively, electrically conductive rods
having respective axial holes formed therein.
20. The apparatus recited in claim 19 in which
said holes in said first dielectric member extend therethrough,
said rods are hermetically sealed in said holes whereby por-
tions thereof are exposed to the exterior of said envelope
means, and
said plurality of electrical row conductors are connected to
said exposed portions.
21. The apparatus recited in claim 19 further including
means for applying a positive potential to all of said first electrical conductors with respect to all of said row conductors sufficient to sustain electrical discharges through said ionizable gas,
means for increasing the potential at a selected one of said first electrical conductors and for decreasing the potential at a selected one of said row conductors thereby producing a potential therebetween sufficient to ignite an electrical discharge in the hole associated with the intersection of said selected conductors, and
means for decreasing the potential at a selected one of said first electrical conductors and for increasing the potential at a selected one of said row conductors thereby produc-
ing a potential therebetween sufficient to extinguish any
electrical discharge sustained in the hole associated with the intersection of said selected conductors.
22. The apparatus recited in claim 20 in which said rods comprises the sealed fill tube for said envelope means.
23. The apparatus recited in claim 1 in which
said cathode means comprises a plurality of electrically con-
ductive cathode members each having a row of holes therein, said rows being aligned to form columns of holes, and
said anode means comprises a plurality of first electrical conductors each disposed adjacent a respective column of said holes.
24. The apparatus recited in claim 23 in which said cathode members are sealed together with electrical insulator means disposed therethrough.
25. The apparatus recited in claim 24 further including a dielectric member sealed to said cathode members thereby forming said envelope means.
26. The apparatus recited in claim 25 in which said dielectric member comprises a transparent member for viewing said cathode members, and
said first electrical conductors comprise respective electrically
conductive strips disposed on the surface of said transparent member internal to said envelope means.
27. The apparatus recited in claim 26 in which
said cathode member includes a ridge between each pair of adjacent holes disposed therein,
said ridges and said electrical insulator means extending to said surface of said transparent member internal to said envelope means thereby forming a barrier around each of said holes.
28. The apparatus recited in claim 26 further including
means for applying a positive potential to all of said strips with respect to all of said cathode members sufficient to sustain electrical discharges through said ionizable gas,
means for increasing the potential at a selected one of said strips and for decreasing the potential at a selected one of said cathode members thereby producing a potential between said selected strip and said selected cathode member sufficient to ignite an electrical discharge in the hole therein associated with said selected strip, and
means for decreasing the potential at selected one of said strips and for increasing the potential at a selected one of said cathode members thereby producing a potential between said selected strip and said selected cathode member sufficient to extinguish any electrical discharge sustained in the hole therein associated with said selected strip.
29. Gas discharge display apparatus comprising
first cathode means having a plurality of first hollow cathode portions therein having first and second openings thereinto respectively,
first anode means spaced from said first cathode means and disposed adjacent said first hollow portions,
first gas-tight envelope means enclosing said first hollow portions and said first anode means with a first ionizable gas,
said first envelope means including transparent portions adjacent said first and second openings respectively,
second cathode means having a plurality of second hollow cathode portions therein having third and fourth openings thereinto respectively,
second anode means spaced from said second cathode means and disposed adjacent said second hollow portions,
second gas-tight envelope means enclosing said second hollow portions and said second anode means with a second ionizable gas,
said second envelope means including transparent portions adjacent said third and fourth openings respectively, and
connection means included in said cathode and anode means adapted for connection to a source of electrical potential to selectively apply suitable potentials between said anode and cathode means to produce electrical discharges in selected hollow cathode portions,
said first and second cathode means being disposed adjacent each other with said first and second hollow portions being aligned whereby light emanating from said second and fourth openings enters said associated fourth and second openings respectively after transmission through said associated transparent portions disposed therethrough.
30. A gas discharge display element comprising
an electrically conductive hollow cathode having a hollow
portion therein,
an electrically conductive anode spaced from said cathode and disposed adjacent said hollow portion,
a transparent member hermetically sealed to said cathode forming a gas-tight envelope enclosing said hollow portion and said anode with an ionizable gas, and connection means adapted for connection to a source of electrical potential to selectively apply a suitable potential between said anode and cathode to produce an electrical discharge in said hollow portion, said hollow portion having side wall surfaces providing the primary electron emitting surfaces thereof, said side wall surfaces having low resistivity and said connecting means associated there-with providing a high conductance path from said side wall surfaces to said source of potential.

31. The apparatus recited in claim 30 in which said anode comprises a transparent electrically conductive film disposed on the surface of said transparent member internal to said envelope.

32. The apparatus recited in claim 30 in which said potential comprises a positive potential at said anode with respect to said cathode sufficient to ignite electrical discharge through said ionizable gas.

33. The apparatus recited in claim 30 in which said anode is in such proximity to said hollow portion that only cathode glow discharges substantially confined to said hollow portion may occur.