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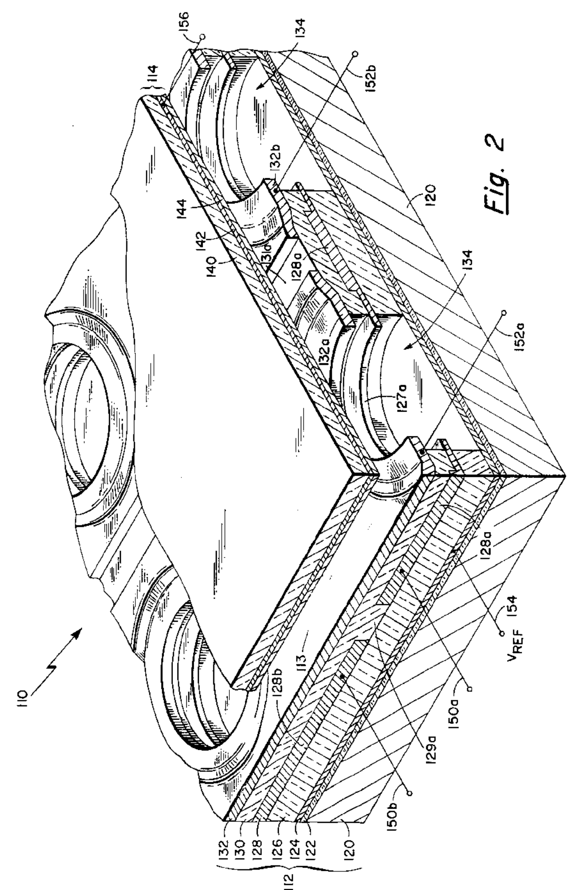
(54) **Electron emitting structure and manufacturing method.**

(57) A field emitter includes an electron emitting structure (112) spaced from an anode structure (114), with the intervening gap (113) being substantially evacuated. The electron emitting structure (112) includes a first electrically conductive layer (128) spaced by an insulating layer (130) from a second conductive layer (132), and a generally circular aperture (134) disposed through the layers (128,132). The anode structure (114) includes an electrically conductive layer (142). Electrostatic forces, provided from a potential applied between the first conductive layer (128) and the anode structure (114), cause an electron beam to be drawn from a cathode provided by a peripheral edge portion (127a) of the first conductive layer (128) within the aperture (134) onto an adjacent surface portion of the anode structure (114). Such field emission occurs under the control of a potential applied between the first and second conductive layers (128,132) of the electron emitting structure with the second conductive layer (132) functioning as a control electrode of the emitting structure. The anode structure (114) has a phosphor layer (144) which converts the electrical energy from the electron bombardment into visible light energy. In one embodiment (Fig. 6), a potential applied to a third conductive layer (360) of the emitting structure (312) serves to focus the electron stream on the anode structure (314). Methods of manufacturing the electron emitting structures employ successive steps of layer deposition and subsequent selective etching.



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Background of the Invention

This invention relates generally to electron emitting structures and manufacturing methods and, more particularly, to electric field-producing electron emitting structures and to methods of fabricating such structures.

As is known in the art, the use of an electric field to produce electron emission has been suggested, as, for example, in U.S. Patent No. 3,755,704, "Field Emission Cathode Structures and Devices Utilizing Such Structures," issued August 2B, 1973, to C.A. Spindt, et al. As suggested in this patent, a cold cathode is formed by providing an electron emitting structure in the shape of a cone having a tip. An electrically conductive gate electrode arrangement is positioned adjacent the tip portion of the cone to generate and control the electron emission from the tip portion. An electric field may be produced between the electron emitting structure and a spaced-apart anode, by the application of a potential therebetween. The electric field is concentrated at the tip portion of the cone with sufficient intensity that electrons are emitted from the tip and are collected by the anode.

As is also known, it has been suggested to form a flat panel display using an array of such tip portions as cathodes. An anode display screen for such a flat panel display may be formed in accordance with conventional cathode-ray tube (CRT) technology, and may comprise a thin, optically transparent electrode affixed to the inside surface of a glass layer. The electrode is coated with luminescing means, illustratively a phosphor material, which emits optical energy such as visible light in response to electron bombardment. Typically, the emitted electrons are accelerated toward the anode by a potential, typically between 500 volts and 10 kilovolts, depending on the maximum brightness required, to illuminate the pixels of the phosphor-coated anode screen, typically mounted in close proximity to the tips.

To provide the tips of the electron emitting structure, a highly collimated beam of vaporized metal, illustratively molybdenum, impinges normally onto a substrate, having a metal film (the control grid electrode) having micron-sized apertures over small cavities. A second beam, illustratively aluminum oxide vapor, impinges simultaneously onto the substrate, but at a very shallow angle. During this evaporation process, the substrate is rotated about its central axis. The net effect is that the apertures are gradually closed by the deposition of composite material (the molybdenum and aluminum oxide) while the metal cones (the cathode electrodes) are formed within the microcavities by the molybdenum vapor beam. The composite material surrounding the cones and closing the apertures is later removed by selective chemical etching.

Clearly, in order to obtain uniform emitters over an area of sufficient size to be useful as a display (e.g., three inches by three inches or larger), the vapor beams must be highly collimated, i.e., they must be evaporated from a considerable distance, typically 70 cm or more. The process described by Spindt et al. is complicated and moreover, the apparatus needed to produce the process would be expensive, particularly for useful-sized displays.

It is also known to fabricate field emission devices as wedge-shaped structures, wherein a sharp edge portions of the wedge structure extends upward from a substrate, adjacent a gate electrode, toward an anode. See, for example, "Self-Aligned Silicon-Strip Field Emitter Array," by J.P. Spallas, et al., and "Simulation and Design of Field Emitters," by R.B. Marcus, et al., both papers presented at the 2d Int. Conf. on Vac. Microelectronics, at Bath, England, in 1989. It is suggested that such wedge emitters may provide certain advantages over comparably sized cone emitters. Firstly, it is suggested that processing techniques described in the literature may permit wedge tips to be made with very high curvature, significantly higher than might be attainable with conical tips. Secondly, in applications where point sources of electron emission are not necessary, such as in vacuum microelectrics applications as, for example, vacuum field transistors and the like, wedge emitters provide the advantage of utilizing a greater fraction of the available substrate surface area for the support of the emitting devices. Thirdly, heat may be dissipated more readily through wedges due to their larger mass or volume, and thus temperature increases are much smaller, than in comparable cone emitters.

Nevertheless, in spite of the potential for superior performance over cone tip emitters, wedge emitters share the same manufacturing problems and technical concerns of cone emitters. That is, with either approach, it is difficult to obtain uniformity among all of the emitting tips or wedges over an array of such emitters. As such, the manufacturing yields of these devices is generally less than satisfactory.

Summary of the Invention

With this background of the invention in mind, it is, therefore, an object of this invention to provide an improved electron emitting structure and manufacturing method.

This and other objects are provided in accordance with the present invention by an electron emitting structure including a sheet of electrically conductive material having an edge. With such an arrangement, electron emission can be provided from the edge of a sheet of conductive material. Such a structure is simpler to fabricate than the prior approaches of wedges and cones having tip portions.

One further problem with the prior approaches is that the maximum current density of electron emission from the tips or wedges is, in general, relatively low. Low current density is a problem for practical application of such an electron emitting structure since field emission and, in particular, current density will influence to a great extent the intensity of a display incorporating such a structure, and the gain, power, and conversion efficiency of a vacuum microelectric device using such structure. With the tip and wedge approaches field emission is low because field emission is very strongly dependent on the electric field intensity and the work function of the emitter which, in turn, are dependent on geometrical details of macroscopic and microscopic dimensions, surface conditions (i.e., surface irregularity, absorbed gases, oxide layers, surface contaminations), and the orientation of crystallites forming the field emission material. The surface conditions and geometrical aspects of the minute field emission tips, for example, are subject to change during their assembly with the anode in a closely fitted, vacuum envelope, and during their activation cycle, which serves to desorb surface contamination and to stabilize the microscopic tip geometry which can change due to field-induced atomic migration. These tips are also subject to change over their operating life because of further atomic migration and ion bombardment. Likewise, the wedges may have similar problems.

With the present invention, the macroscopic and microscopic conditions of the edge of a sheet of conductive material used as an electron emitter are easier to control than the tip or wedge type emitters. Such edges are less susceptible to changes during subsequent manufacturing processes. Moreover, the edges of the sheet of conductive material are less subject to contamination during fabrication of the emission structure.

In accordance with a further aspect of the present invention, an electron emitting structure includes a first layer of electrically conductive material having an aperture disposed therein and a second layer of electrically conductive material spaced from the first layer. With such an arrangement, a voltage potential coupled to the first layer provides a flow of electrons from peripheral edge portions of the aperture in the first layer. A voltage potential is also coupled to the second electrode for controlling the rate of the flow of electrons.

In accordance with a still further aspect of the present invention, the second layer of electron emitting structure has an aperture disposed in alignment with the aperture disposed in the first layer. The potential is disposed between peripheral edges of the aperture in the second layer to control the rate of electron flow. In one embodiment the electron flow is through the first aperture in the second layer in another embodiment flow of electrons occurs beyond the aperture in the second layer.

In accordance with a still further embodiment of the present invention, there is provided a third layer of electrically conductive material spaced from said first and second electrically conductive layers, the third electrically conductive layer having an aperture disposed therein substantially aligned with the apertures disposed in the first and second electrically conductive layers. With such an arrangement, a potential is also applied to the third layer to focus the flow of electrons emitted from the first layer.

With these arrangements, the tip-like and wedge electron emitting structures of the prior art have been replaced with a structure wherein electrons are emitted from a peripheral edge, preferably a peripheral edge of an aperture, thus alleviating fabrication difficulties and changes and degradation associated with a tip-like and generally wedge-shaped electron emitting structures.

In accordance with another feature of the present invention, a method of forming an electron emitting structure comprises the steps of forming a first sheet of electrically conductive material and forming a second sheet of electrically conductive material spaced from the first sheet. With a preferred embodiment, a first one of said sheets has an aperture and a second one of said sheets is disposed to control field emission from peripherial edges of the aperture of said first sheet.

With such an arrangement, a field electron emission structure is produced without forming the cathodes thereof as cones. This arrangement obviates the need for simultaneously co-depositing an insulation material and metal material to provide the tip structures.

Brief Description of the Drawings

The foregoing features of the present invention, and the advantages thereof, may be fully understood from the following detailed description, read in conjunction with the accompanying drawings, wherein:

FIG. 1 is a diagrammatical sketch depicting a partially cutaway isometric view of a portion of an electron emission apparatus according to the principles of the present invention;

FIG. 2 is a variant of the apparatus of FIG. 1 adapted for use in a flat panel display;

FIGs. 3A and 3B are plan and cross-sectional views, respectively, of the electron emitting structure of the apparatus of FIG. 2;

FIG. 4 is a cross-sectional view of a portion of an electron emission apparatus according to a first embodiment;

FIG. 5 is a cross-sectional view of a portion of an electron emission apparatus according to a second embodiment;

FIG. 6 is a cross-sectional view of a portion of an electron emission apparatus according to a third embodiment;

FIG. 7 is a cross-sectional view of a portion of an electron emission apparatus according to a fourth embodiment;

FIG. 8 is a cross-sectional view of a portion of an electron mission apparatus according to a fifth embodiment;

FIG. 9 is a cross-sectional view of a portion of an electron emission apparatus according to a sixth embodiment;

FIG. 9A is a cross-sectional view of a portion of an electron emission apparatus according to a seventh embodiment;

FIG. 9B is a cross-sectional view of a portion of an electron emission apparatus according to a eighth embodiment;

FIG. 9C is a cross-sectional view of a portion of an electron emission apparatus according to a ninth embodiment;

FIGS. 9D-9F are cross-sectional views showing steps in fabricating an alternate embodiment;

FIG. 10 is a sketch in cross section of a flat panel display system including the apparatus of FIG. 2;

FIG. 11 is an isometric view of a cathode structure illustrating field emission of electrons from peripheral edges of an aperture in a conductive layer;

FIG. 11A is an isometric view of an alternate cathode structure illustrating field emission of electrons from an edge of a conductive layer; and

FIGs. 12A-12D are a series of cross-sectional views showing steps in fabricating the electron emission structure of FIG. 6.

Description of the Preferred Embodiment

Referring now to FIG. 1, an electron emission apparatus 10 is shown to include an electron emitting structure 12 spaced from an anode structure 14, with an intervening gap 13 therebetween being substantially evacuated. Electron emitting structure 12 comprises a first electrically conductive layer 28 spaced from a second electrically conductive layer 32, said layers 28, 32 having a generally circular aperture 34 disposed therethrough. Anode structure 14 comprises an electrically conductive material. In response to voltage potentials applied to conductive layers 28, 32 and to anode 14, an electron beam is drawn from a peripheral edge portion of one of the conductive layers 28 and 32 in accordance with the potential differences among conductive layers 28, 32 and anode 14. Thus, one of the peripheral edge portions of the conductive layers 28, 32 within aperture 34 provides a cathode electrode of the electron emitting structure. Optionally, the other one of the peripheral edge portions of conductive layers 28, 32 may be used as a control or grid electrode of emitting structure 12.

Considering the FIG. 1 embodiment in greater detail, emitting structure 12 includes, in addition to electrically conductive layers 24, 28 and 32, electrically insulating layers 22, 26, and 30, and an optional substrate or support layer 20. Here, substrate 20 is typically a silicon wafer, of the type used in conventional integrated circuit technology. Alternatively, substrate 20 can be any other material which can support the structures to be described. If the structures to be described can be supported without the substrate 20 then the substrate 20 can be eliminated. Further, the substrate 20 may also be electrically conductive. Here, an optional electrically insulating layer 22, illustratively silicon dioxide (SiO_2) is disposed over substrate 20 and may be grown or deposited thereon. Layer 22 is illustratively 8000 Å (O.8 μm) in thickness. Electrically conductive layer 24, which may provide a control voltage or a reference voltage, is deposited over layer 22; it is illustratively molybdenum, 3000 Å in thickness. In at least one embodiment of the present invention, conductive layer 24 functions as the control electrode while one of the overlying apertured layers function as the connection to the cathode electrode and the other layer functions as a focusing electrode. A reference voltage (or control signal) may be coupled to layer 24 via signal lead 54.

Electrically insulating layer 26, illustratively SiO_2 having thickness of 8000 Å, is disposed over conductive layer 24. Electrically conductive layer 28, disposed over insulating layer 26, illustratively comprises molybdenum, 3000 Å in thickness, which, in at least one embodiment, provides an electrically conductive plane to connect a voltage potential to peripheral edges of such layer, here, those edges in aperture 34 to provide electron emission. In at least one other embodiment of the present invention, layer 28 functions as the control electrode. Thus, layer 28 is coupled to a signal lead 50 for connection to a cathode or control voltage as desired.

Electrically insulating layer 30, illustratively SiO_2 having a thickness of 8000 Å, overlies conductive layer 28. Electrically conductive layer 32, deposited over insulating layer 30, illustratively comprises molybdenum, 3000 Å in thickness, which, in at least one embodiment, functions as the control electrode in the electron emission apparatus 10 of the present invention. In at least one other embodiment of the present invention, layer 32 functions as the connection to the cathode electrode. Layer 32 is coupled to a signal lead 52 for connection to a control or cathode voltage as desired.

Each of the layers 26, 28, 30, and 32 provided in electron emitting structure 12 have a multiplicity of apertures generally denoted as 34, with each aperture 34 here extending through layers 26, 28, 30, and 32, as shown. Apertures 34 are depicted as circular, and this is the preferred configuration; however, other shapes such as ovals, squares, etc. are possible. Although circular apertures and apertures in general are here preferred to provide electron emission edges, it is also possible to use an edge of a conductive sheet, as will be further described in conjunction with FIG. 11A. Moreover, the conductive layer need not be a continuous sheet, but could alternatively be a loop of conductive material enclosing a region and thus providing a peripheral edge portion of an aperture from which electron emission can occur.

Apertures 34 extend through conductive layers 32 and 28 with a first diameter, illustratively between 1-2 µm, and through insulating layers 30 and 26 with a second, slightly larger, diameter. The extent by which insulating layers 30 and 26 are undercut with respect to conductive layers 32 and 28 is illustratively 0.5 µm. Thus, it is seen that, in at least one embodiment of the present invention, an annular peripheral edge surface of conductive layer 28 extends into aperture 34, providing a relatively sharp edge for the formation of a beam of electrons which flow in a generally uniform distribution upward through aperture 34 to anode structure 14 under the control of the voltage applied to conductive layer 32. Furthermore, it is seen that, in at least one other embodiment of the present invention, an annular peripheral edge surface of conductive layer 32 extends into aperture 34, providing a relatively sharp edge for the formation of a beam of electrons which flow in a generally uniform distribution upward to anode structure 14 under the control of a voltage applied to conductive layer 28.

Electrically conductive layers 24, 28 and 32 have thus far been illustratively described as molybdenum. In fact, these electrically conductive layers may be fabricated from a wide variety of materials. Generally, it is desired that these materials are refractory, and have the properties of high conductivity, relatively low work function and provide satisfactory adhesion to the adjacent layers. Examples of more refractory metals which may be used include molybdenum, tungsten, titanium and tantalum. These metals may be coated with a ceramic material, such as lanthanum hexaboride (LaB_6) to exhibit substantially lowered work function. The material for use as layers 24, 28 and 32 may also comprise a conductive ceramic which may be a super conductor.

Referring now to FIG. 2, there is shown a variant of the apparatus of FIG. 1 adapted for use in a flat panel display. Electron emission apparatus 110 includes an electron emitting structure 112 spaced from an anode structure 114, with an intervening gap 113 being substantially evacuated. Electron emitting structure 112 comprises a first plurality of substantially parallel conductors 128a, 128b, . . ., spaced from a second plurality of substantially parallel conductors 132a, 132b, . . ., and a multiplicity of generally circular apertures 134 formed through conductors 128a, 128b, . . ., and 132a, 132b, ... Anode structure 114 includes an electrically conductive layer 142 which is disposed between a support 140 and a electroluminescent material layer 144 as will be further described.

In at least one embodiment, electrostatic forces, resulting from potentials applied to conductors 128a, 128b, . . ., conductors 132a, 132b, . . ., and conductive layer 142, via signal leads 150a, 150b, . . ., 1521, 152b, . . ., and 154, respectively, cause electron beams to be drawn from here peripheral edge portions 127 of corresponding conductors 128a, 128b, . . ., within apertures 134, onto an adjacent surface portion of anode structure 114, with such electron emission here under the control of signals applied between conductors 132a, 132b, . . ., and 128a, 128b, ... Thus, conductors 132a, 132b here function as control (or grid) electrodes of emitting structure 112, whereas peripheral edges of conductors 128a, 128b, . . ., function as cathodes. Anode structure 114 thus here includes an electroluminescent coating 144 to convert the electrical energy from the electron bombardment into visible light energy. In the above arrangement, a reference voltage is coupled to layer 124 via signal lead 154.

In the embodiments disclosed herein, the gap between the anode structure and the emitting structure is essentially evacuated, preferably at a pressure of approximately 10^{-9} torr. However, for an electron emission apparatus where the anode structure is closely spaced to the emitting structure, such that the path travelled by the electrons is small in comparison to the mean free path through the gas molecules, such vacuum level may not be necessary.

The plurality of electrically conductive stripes 128, 132 are each provided by patterning a layer of material (not shown) or depositing such material as stripes through a patterned region. Each of the plurality of stripes 128, 132 illustratively comprises molybdenum, 3000 Å in thickness, which functions as the connection to the cathode electrode in the electron emission apparatus 110 of the present invention. Individual stripes 128a, 128b . . . are disposed over an insulating layer 126 here of silicon dioxide 8000 Å in thickness. The plurality of stripes 128 is provided as a plurality of parallel stripes, electrically isolated from one another by virtue of spacings 129a, . . ., between them, which extend from the lower-left toward the upper-right in FIG. 2. Each stripe 128a, 128b . . ., of the plurality of stripes 128 is coupled to an individual signal lead 150a, 150b, . . ., respectively, for connections to individually addressable cathode voltages.

Electrically insulating layer 130, illustratively SiO_2 having a thickness of 8000 Å, overlies the plurality of stripes 128, additionally filling the spacings 129a, . . ., between the individual parallel stripes 128a, 128b . . . thereof. The plurality of electrically conductive stripes 132 are disposed as generally mentioned above over insulating layer 130, and such plurality of stripes 132 illustratively comprises molybdenum, 3000 Å in thickness. The plurality of stripes 132 here function as control electrodes in the electron emission apparatus 110 of the present invention. The plurality of parallel stripes 132 are electrically isolated from one another by virtue of the spacings 131a, . . ., between them, as shown. Each stripe 132a, 132b, . . ., of the plurality of stripes 132 is coupled to an individual signal lead 152a, 152b, . . ., respectively, for connections to individually addressable control voltages.

The layers 126 and 130, as well as selective portions of the pluralities of stripes 128, 132 of electron emitting structure 112, have a multiplicity of apertures 134, each extending through such layers 130 and 126 and pluralities of stripes 132, 128. Apertures 134 are positioned at intersections of the parallel stripes 128a, 128b, . . ., with the parallel stripes 132a, 132b, . . ., that is, at the intersections of the individually addressable cathode and control electrodes. Apertures 134 have a first diameter, illustratively between 1-2 μm through the pluralities of stripes 128, 132, and have a second, slightly larger, diameter through insulating layers 130, 126, here 1 μm increase in diameter. Thus, it is seen that here an annular peripheral edge surface 127a of stripes 128a, 128b, extends into aperture 134, providing a sharp edge for the formation of a beam of electrons which flow in a generally uniform distribution upward through the remainder of aperture 134 to anode electrode 142 under the control of the voltage applied to control electrode 132.

Anode structure 114, spaced apart from electron emitting structure 112, illustratively by 0.5-2.0 mm, includes an optically transparent substrate layer 140, illustratively glass, onto which is deposited a layer of electrically conductive material 142. Conductive layer 142 is preferably an optically transparent material such as indium-tin-oxide (ITO); alternatively, layer 142 may comprise a metal such as aluminum, gold, or platinum, sufficiently thin so as to be essentially optically transparent. Layer 144, comprising an electroluminescent material, illustratively a light-emitting phosphor, may be coated over layer 142.

Referring now to FIGS. 3A and 3B, a portion of electron emitting structure 112 useful in visualizing an arrangement of apertures 134 according to the present invention is shown. Although the simplified cutaway section illustrated by FIG. 2 depicts only one aperture 134 at each of the intersections of the stripes 128a, 128b, . . ., with the stripes 132a, 132b, . . ., the views of FIGS. 3A and 3B imply an arrangement comprising a plurality of apertures 134 disposed at each of a corresporiding plurality of intersections of such plurality of stripes 128, 132. While the arrangement of apertures 134 depicted in FIG. 3A may imply a rectangular array, such arrangement is not intended to be a limitation on the invention. The arrangement of apertures 134 at each intersection of the stripes 128a, 128b, . . ., with the stripes 132a, 132b, . . ., will be selected in accordance with the particular application of the cathode structure. For example, a particular arrangement of phosphors on an opposing surface of anode structure (not shown) for use in a display would influence the exact arrangement of the intersecting stripes and positions of apertures 134.

FIGs. 4-11A illustrate various embodiments of the electron emission apparatus of the present invention.

Referring now to FIG. 4, the embodiment of FIG. 4 corresponds in form to that of FIG. 2, and whose electron emission structure 112 is also shown in FIGs. 3A and 3B. The electron emission apparatus of FIG. 4 includes electrically conductive layer 124, and stripes 128a and 132a, electrically insulating layers 122, 126 and 130, and substrate 120, comprising the emitting structure 112. The anode structure 114 includes substrate 140, electrically conductive layer 142 and electroluminescent coating 144. Aperture 134 in emitting structure 112 extends through all layers and stripes down to conductive layer 124.

Conductive stripe 128a, provides the connection to the peripheral edges 127 in aperture 134 of stripe 128a, that is the cathode electrode from which electron emission occurs within aperture 134. The stripe 128a comprises relatively thick sections 128a′ away from apertures 134, illustratively 3000 Å (0.30 μm), and relatively thin sections 128a″ in the vicinity of apertures 134, illustratively 200-1000 Å (0.02-0.10 μm). The portion 128a′ of increased thickness of stripe 128a over the greater portion of its area increases its conductivity and mechanical strength in the contact areas. The thin portion 128a″ of stripe 128a, which may be as thin as possible, such as 200 Å, provides a sharp-edged emitting surface 127 for optimal electron emission density characteristics. Annular surface 127 can be made even sharper by a processing technique, to be discussed later, which would provide a taper, as illustrated, to surface 127.

The embodiment of electron emission apparatus 210, illustrated in FIG. 5, includes electrically conductive layers 224, 228 and 232, electrically insulating layers 222, 226 and 230, and substrate 220, comprising the emitting structure 212. The anode structure 214 includes substrate 240, electrically conductive layer 242 and electroluminescent coating 244. Aperture 234 in electron emission structure 212 extends through all layers down to conductive layer 224.

The structure of the FIG. 5 embodiment differs from the structure of FIG. 4 in that electrically conductive layer 228, functioning as the connection to the cathode electrode, is of uniform thickness throughout. Illustratively, layer 228 is 300 Å (0.03 μm) in thickness. The form of layer 228 in the FIG. 5 embodiment provides the advantage of simplified manufacturing processing over the FIG. 4 embodiment, but it lacks certain performance characteristics of the other. The thin annular surface 227 of conductive layer 228 within aperture 234, functioning as the cathode electrode, may be made even sharper by a processing technique, to be discussed later, which provides a taper to surface 227. Further, it should be appreciated that the conductive layers 228, 232 may also be patterned to provide individually addressable stripes.

The embodiment of electron emission apparatus 310, illustrated in FIG. 6, includes electrically conductive layers 324, 328 and 332, electrically insulating layers 322, 326 and 330, and substrate 320, comprising the emitting structure 312. The anode structure 314 includes substrate 340, electrically conductive layer 342 and electroluminescent coating 344. Aperture 334 in electron emission structure 312 extends through all layers down to conductive layer 324.

The structure of the FIG. 6 embodiment is similar to that of FIG. 4, but it includes an additional conductive layer 360, illustratively a 0.3 rm layer of molybdenum, disposed over conductive layer 332 and spaced therefrom by an electrically insulating layer 362, illustratively a O.8 μm layer of SiO_2. Layers 360 and 362 include apertures which are substantially identical to apertures 334 formed through layers 326, 328, 330 and 332, and aligned therewith. By the appropriate application of a potential on signal lead 358, coupled to conductive layer 360, layer 360 provides improved focusing of the electron beams 336 by attracting those electrons which are directed outward from the cylinder formed by aperture 334.

The embodiment of electron emission apparatus 510, illustrated in FIG. 7, includes electrically conductive layers 524, 528 and 532, electrically insulating layers 522, 526 and 530, and substrate 520, comprising the emitting structure 512. The anode structure 514 includes substrate 540, electrically conductive layer 542 and electroluminescent coating 544. Aperture 534 in electron emission structure 512 extends through all layers down to conductive layer 524.

The structure of the FIG. 7 embodiment differs from the structure of FIG. 4 in that aperture 534 through electrically conductive layer 532, functioning as the control electrode, is greater in diameter than aperture 534 through electrically conductive layer 528, functioning as the cathode electrode. By way of example, aperture 534 through layer 532 may illustratively be one μm greater in diameter than aperture 534 through layer 528. By this arrangement, fewer electrons emitted from the cathode electrode are drawn into the control electrode, and the overall efficiency of the emission system may be improved.

The embodiment of electron emission apparatus 610, illustrated in FIG. 8, includes electrically conductive layers 624, 628 and 632, electrically insulating layers 622, 626 and 630, and substrate 620, comprising the emitting structure 612. The anode structure 614 includes substrate 640, electrically conductive layer 642 and electroluminescent coating 644. Aperture 634 in electron emission structure 612 extends through all layers down to conductive layer 624.

The structure of the FIG. 8 embodiment differs significantly from the embodiments thus far described. In this embodiment, the upper conductive layer 632 functions as the connection to the cathode electrode while the lower conductive layer 628 functions as the control electrode. By the appropriate application of potentials on signals leads 650, 652 and 656, coupled, respectively, to conductive layers 628, 632 and 642, electrons are drawn from the peripheral edge surface 633 of layer 632 within aperture 634 and accelerated toward anode structure 614. In this embodiment, conductive layer 632, the electron emitting layer, is preferably thinner than layer 628; illustratively, layer 632 may be 0.03 μm in thickness and layer 628 may be 0.3 μm in thickness.

The embodiment of electron emission apparatus 710, illustrated in FIG. 9, includes electrically conductive layers 724 and 72B, electrically insulating layers 722 and 726, and substrate 720, comprising the emitting structure 712. The anode structure 714 includes substrate 740, electrically conductive layer 742 and electroluminescent coating 744. Aperture 734 in electron emission structure 712 extends through layers 728 and 726 down to conductive layer 724.

In this embodiment, the apertured conductive layer 728 functions as the connection to the cathode electrode while the unapertured conductive layer 724 functions as the control electrode. By the appropriate application of potentials on signal leads 750, 754 and 756, coupled, respectively, to conductive layers 728, 724 and 742, electrons are drawn from the peripheral edge surface 727 of layer 728 within aperture 734 and accelerated toward anode structure 714. In this embodiment, the thickness of insulating layer 726, separating the cathode and control electrodes, may have to be adjusted from what has been heretofore disclosed, so as to provide the desired electron flow 736 from surface 727 to conductive layer 742.

Referring to FIG. 9A, there is shown an embodiment which is a first variation on the structure of FIG. 9. In this embodiment, the apertures of conductive layer 728′ are greater in diameter than the corresponding apertures 734′ through insulating layer 726′. In the preferred mode of operation of this embodiment, electrons are drawn from peripheral edge 727′ of conductive layer 728′ by virtue of the electric field induced as a result of the potential difference applied at terminals 750 and 754. Thus, it is seen that electric field through insulating layer 726′ is sufficient to cause field emission of electrons. This leads one to the embodiment of FIG. 9B, a second variation on the structure of FIG. 9, in which insulating layer 726″ is unapertured. An electric field through insulating layer 726″, induced by the potential difference applied at terminals 750 and 754, results in field emission of electrons from peripheral edge 727″ of conductive layer 728″.

It will be understood that conductive layers 728, 728′ and 728″, of the embodiments of FIGS. 9, 9A and 9B, respectively, may be stepped in thickness, as shown, for example, in layer 128a of FIG. 4, to provide the advantages described therefor.

Referring to FIG. 9C, there is shown an embodiment which may share the general structure of the FIG. 7 embodiment, but which is similar to the FIG. 9 embodiment in its mode of operation. In the FIG. 9C embodiment, the unapertured conductive layer 824 functions as the control electrode, apertured conductive layer 824 functions as the connection to the cathode electrode, and apertured conductive layer 832 functions as a focusing layer, to improve the pattern of electron flow from peripheral edge 827 toward anode structure 814.

By way of example, the application of potentials to the several electrodes to produce field emission of electrons from the cathode and current flow of the field-emitted electrons to the anode, may be as follows. In a first exemplary embodiment of FIG. 4, wherein control electrode layer 132a is the top layer of emitting structure 112, the conductive layer 142 of anode structure 114 may be set at +1200 volts with respect to emitter layer 128a, and control electrode layer 132a is set between 100-300 volts, illustratively +135 volts with respect to emitter layer 128a. Similarly, in the second exemplary embodiment of FIG. 8, wherein emitter layer 632 is the top layer of emitting structure 612, the conductive layer 642 of anode structure 614 is set at +1200 volts with respect to emitter layer 632, and the potential at control electrode layer 628, with respect to emitter layer 632, may range between +100 and +300 volts, illustratively +135 volts.

It should further be understood that embodiments such as that shown in FIG. 9C having the cathode provided as the intermediate layer, here 828, that the upper layer 832 thereof maybe disposed to provide the anode for the device. That is a relatively high positive potential may be applied between terminals 850 and 852 to draw field emitting electrons towards layer 832 whereas a potential is applied to underlying layer 824 to control emission of electrons from peripheral edge portions 827 of layer 828. Furthermore, layer 832 may be provided as a patterned layer, as shown, having an aperture electrode disposed over layer 832, or alternatively may be provided as continuous nonpattern layer (not shown). This particular structure would be well adapted to vacuum microelectronic microwave type of devices. Furthermore, as also shown in FIG. 9C, structure 814 may also have a dielectric coating (not shown) disposed over layer 844 and structure 814 may then rest directly upon layer 832 to provide a more compact display element (not shown).

Referring now to FIGS. 9D-9F, an alternate structure 712‴ (FIG. 9F) and method of manufacture of a field emission device will now be described. In particular, referring to FIG. 9D, a substrate 720 as generally discussed in conjunction with FIG. 9A and 9B has disposed over a first surface thereof, a layer 722 comprised of, here typically silicon dioxide having a thickness of 3000Å and having disposed thereover, a layer 724 of a refractory conductive material such as molybdenum with layer 724 having a thickness of 3000Å. A layer 726 of silicon dioxide having a thickness of 0.8 microns is disposed over layer 724. An etch-stop layer 770 of a different insulative type of material as layer 722 is disposed over silicon dioxide layer 726. Here etch-stop layer 770 is comprised of a material such as silicon nitride and is deposited to a thickness of 500 to 800Å for example. Disposed over etchstop layer 770 is a second conductive layer 772, here also comprised of molybdenum. A second, here dielectric layer 774, here comprised of the same material as layer 726, that is, silicon dioxide, is disposed over layer 772. It is to be noted that preferably the material of layer 774 is different than the material of layer 770, thus permitting the use of selective etchants for layer 772 and 774 as this having layer 770 act as an etch-stop layer.

A masking layer (not shown), is disposed over layer 774 and is patterned to provide an aperture (not shown) exposing selective underlying portions of layer 774. Layer 774 is then reactively ion etched to provide an aperture 774a having steep vertical sidewalls in layer 774. Exposed portions of underlying layer 772 are also reactive ion etched to provide an aperture 772a having steep vertical sidewalls through layer 772, thus providing the structure, as generally shown, in conjunction with FIG. 9D.

Referring now to FIG. 9E, a third layer 776 of molybdenum is disposed over layer 774 and through the apertures 772a and 774a, provided through layers 772 and 774 respectively. Molybdenum layer 776 has a thickness of, here 3000Å.

Referring now to FIG. 9F, the structure as described above, is placed in a parallel plate, directive ion reactive etching (RIE) system, as are all such steps described herein. Such an etch is used to provide a directional etch to etch away in a vertical direction portions of layer 776. Layer 774 is also removed using hydrofloric acid leaving layer 772 and portions 776′ of layer 776 (FIG. 9E). Since the reactive ion etching technique, preferentially etches in the vertical direction a small ridge or raised edge annulus portion 776′ is left of layer 776 along the peripheral edge portions 772′ of layer 772 in the aperture 772a.

The structure described above is seen as providing a field emission structure which may preferably provide improved field emission characteristics. That is, the structure provides an annulus as in keeping with many of the prior embodiments and here the annulus 772′ has a raised edge portion 776′. Moreover, such a structure may also be fabricated by providing any of the aforementioned structures discussed in conjunction with FIG.9A or FIG. 9B, for example, by placing a sufficient voltage on said structures such that portions of the field emission electrodes are eroded away during normal field emission to a stabilized point in which this small raised-edge or ear shaped portion is provided as a raised annulus surface over the annulus portion of layer 772 provided by aperture 772a.

Referring to FIG. 10, there is shown a sketch, in exaggerated scale, of a cross-sectional view of a flat panel display 400 including an electron emission apparatus which may be of the type shown in FIG. 2. The electron emission apparatus of flat panel display 400 includes emitter structure 112, illustrated in greater detail in FIG. 2 and anode structure 114, also shown in greater detail in FIG. 2.

As shown in FIG. 10, anode structure 114, includes an optically-transparent substrate 140, illustratively made of glass. A thin electrode layer 142, illustratively indium-tin-oxide, is affixed to the inner surface of glass substrate 140, and an electroluminescent material 144, illustratively a light-emitting phosphor, is coated on electrode layer 142. Emitter structure 112 is affixed to the inner surface of base substrate 402, typically fabricated of glass.

Anode structure 114 and base substrate 402 are assembled such that emitter structure 112 is spaced from, and precisely positioned with respect to, anode structure 114 by spacer element 404, which is affixed to the inner surfaces of substrates 140 and 402 by sealing means 406. In the present example, anode structure 114 is illustratively spaced from emitter structure 112 by 0.5-2.0 mm. Spacer element 404 may illustratively be fabricated of glass, ceramic or metal, and sealing means 406 shall be appropriately selected to seal such spacer element 404 to the materials of substrates 140 and 402. The seal provided by spacer element 404 and sealing means 406 between substrates 140 and 402 is sufficient to allow cavity 408 to be effectively evacuated.

Row and column control voltages provided, as seen in FIG. 2, on signal leads 150a, 150b, . . . and 152a, 152b . . ., respectively, as well as the reference voltage applied to substrate conductor 124 on signal lead 154, as seen in FIG. 2, are coupled to emitter structure 112 from controller and power source 410 via a multiplicity of signal leads 412, which pass under spacer element 404 into evacuated cavity 408, and which form electrical contact with emitter structure 112 via contact means 414. Similarly, anode voltage is coupled to anode electrode layer 142 from power source 410 via signal lead 416 which passes around spacer element 404 into cavity 408.

Referring now to FIG. 11, a cathode structure in accordance with the present invention which is generally used as the cathodes in the embodiment of FIGs. 1-10 above, or which can also be used as a cathode in any device which uses such a structure, is shown. The cathode as shown in FIG. 11 can alternatively be used in vacuum microelectric devices such as amplifiers, transistors, tubes, and the like. Here the cathode of the present invention comprises one or more electrically conductive layers 900_1, 900_2, 900_3, . . ., referred to collectively as conductive layers 900, each having one or more apertures 902_1, 902_2, 902_3, . . ., referred to collectively as apertures 902, disposed therein. Electrical potentials V_1, V_2, V_3, . . ., selectively applied to terminal means 904_1, 904_2, 904_3, . . ., and coupled, respectively, to layers 900_1, 900_2, 900_3,. . .. ., cause emission of electrons from the peripheral edge portions of conductive layers 900 within apertures 902, which electrons are accelerated toward a more positive electrical potential +V.

Referring now to FIG. 11A, a sheet 920 comprising an electrically conductive material having here one or alternatively more than one edge 922 adapted for field electron emission is shown disposed on a dielectric layer 926. A potential is coupled to layer 920 via terminal 924. Field-emitted electrons from edge 922 are accelerated towards a more positive potential +V. Edge 922 is preferably a sharp edge as mentioned above to concentrate field emission of electrons therefrom.

The paragraphs which follow disclose a method of fabricating the electron emission apparatus according to the principles of the present invention. The described method applies directly to the most complex structure disclosed herein, i.e., the embodiment of FIG. 6; from this description, it will be obvious to one knowledgeable in the art how to modify the process to obtain the less complex embodiments of FIGs. 4-5 and 7-11A.

The disclosure of the fabrication method will be limited to a description of the process for fabricating emitting structure 312. The process of fabricating anode structure 314, including affixing layers of a conductive material and an electroluminescent material on a glass substrate, follows conventional cathode-ray tube (CRT) manufacturing technology. Furthermore, the process for enclosing emitting structure 312 and anode structure 314 within a chamber capable of evacuation is also deemed to be well known. Further for applications other than those pertaining to the use of the cathode in flat panel displays, the exact details of construction would be apparent to one of skill in the art. For example, a simple expedient would be to replace the conventional tip or wedge cathodes with the sheet or layer of conductive material having an edge or an aperture as in the present invention to provide field electron emission therefrom.

Further, the process to be described is based generally on techniques of patterning by etching selective portions of a metal layer. Alternative techniques such as depositing metal through a patterned resist layer and lifting off the resist to leave the patterned layer could alternatively be used.

Referring now to FIG. 12A, a process of fabricating electron emitting structure 312 (FIG. 6) includes providing a wafer of material for substrate 320, preferably silicon, a semiconducting material, because of its availability and ease of handling. Alternatively, substrate 320 may comprise an insulating material such as glass, ceramic or sapphire. The important characteristic of substrate 320 is that it has an extremely flat and smooth surface for depositions thereon. Substrate 320 is provided to support the remainder of the structure to be fabricated. As such it could also be a metal, or it could be eliminated if the resulting structure had sufficient structural integrity.

A layer 322 of SiO_2, illustratively 0.2-1.0 rm in thickness, is here affixed to the smooth surface of silicon wafer substrate 320. Using standard silicon technology, layer 322 may be grown in a conventional oxidation furnace, or it may be deposited.

A layer 324 of a metal having suitable characteristics including work function, resistivity, and stability particularly for subsequent processing and during operation of the resulting device is deposited using conventional techniques such as evaporation or sputtering, for example. Examples of suitable metals include gold, platinum, and more refractory metals such as molybdenum, tungsten, titanium, tantalum, and so forth. Here a layer 324 of molybdenum, illustratively 0.1-0.3 μm in thickness, is deposited on SiO_2 layer 322. Molybdenum layer 324 may be deposited by evaporation or by sputter deposition; the latter process is preferred for its enhanced adhesion qualities. If it is desired to pattern molybdenum layer 324, to create contact pads or to allow substrate 320 to be used for other circuit functions, a photoresist may be appropriately coated onto the exposed surface of layer 324 and the device etched, typically by standard wet chemical etch or by reactive ion etch. Alternatively, to provide a patterned layer, "lift off" processing could be used. The structure thus far assembled is placed in an oven, illustratively a commercial rapid thermal anneal (RTA) equipment, and heated quickly, typically at an average rate of 50-100°C per second, to approximately 1000°C, held at this temperature for approximately 10 seconds, then allowed to cool. It has been found that this heating step tends to reduce the resistance of an electrically conductive thin film layer, and is preferably repeated in this illustrative process after each subsequent metal deposition, here of a molybdenum layer. Alternatively, the RTA process step may be performed after all layers of molybdenum have been deposited.

Referring now to FIG. 12B, a layer 326 of SiO_2, illustratively 0.8 μm in thickness, is deposited on layer 324, typically by standard low pressure chemical vapor deposition (LPCVD) at approximately 380°C.

Optionally, layer 326 may then be masked and etched to provide windows to access contact pads (not shown) associated with the underlying molybdenum layer 324.

Over layer 326 is deposited layer 328 of a metal, here molybdenum, illustratively 0.1-0.3 μm in thickness. Layer 328 is deposited on SiO_2 layer 326, preferably by sputter deposition, alternatively by evaporation. Layer 328 is masked with a layer 372 of photoresist which is patterned to expose generally circular areas 375 where apertures 334 (FIG. 6) will eventually be located. Here each such exposed circular area 375 has a diameter 2-5 μm greater than the diameter of aperture 334 (FIG. 6).

Referring now to FIG. 12C, molybdenum layer 328 is then etched, using standard wet chemical or reactive ion etch, to remove the molybdenum from these areas. Photoresist layer 372 (FIG. 12B) is removed and an additional layer 328a of molybdenum 0.01-0.03 rm thickness is then sputter deposited to provide a layer portion 328′ slightly increased in thickness and a very thin layer portion 328″ of molybdenum in the previously etched-away areas surrounding the eventual locations of apertures 334. Molybdenum layer 328 is then masked with photoresist (not shown) to pattern the stripes comprising layer 328 (as seen in FIG. 3A) and contact pads (not shown) for each stripe, and etched, using standard wet chemical or reactive ion etch, to create such pattern in the molybdenum.

It will be understood that the process of the previous paragraph does not apply to the embodiments of FIGs. 5, 8, 9, 9A or 9B. In the typical case of the FIG. 5 embodiment, a thin layer 228 of molybdenum, illustratively 0.03 rm in thickness, is deposited on SiO_2 layer 226, preferably by sputter deposition, alternatively by evaporation. Molybdenum layer 228 is then masked with photoresist to pattern the stripes comprising layer 228 (as seen in FIG. 2) and contact pads (not shown) for each stripe, and etched, using wet chemical or reactive ion etch, to create such pattern in the molybdenum.

Returning now to the general process description embodied in the structure of FIG. 6, and, in particular, FIG. 12C, a layer 330 of SiO_2, illustratively 0.8 μm in thickness, is deposited on layer 328, typically by standard low pressure chemical vapor deposition (LPCVD) at approximately 380°C.

Layer 330 may then be masked and etched to provide windows to access the contact pads (not shown) associated with the underlying molybdenum layers 324 and 328.

A layer 332 of molybdenum, illustratively 0.1-0.3 μm in thickness, is deposited on SiO_2 layer 330, preferably by sputter deposition, alternatively by evaporation. Layer 332 is masked (not shown) with photoresist to pattern the stripes comprising layer 332 (as seen in FIG. 2) and contact pads (not shown) for each stripe, and etched, using wet chemical or reactive ion etch, to create such a desired pattern in the molybdenum layer 332.

A layer 362 of SiO_2, illustratively 0.8 μm in thickness, is deposited on layer 332, typically by standard low pressure chemical vapor deposition (LPCVD) at approximately 380°C.

Layer 362 may then be masked and etched to provide windows to access the contact pads (not shown) associated with the underlying molybdenum layers 324, 328 and 332.

A layer 360 of molybdenum, illustratively 0.1-0.3 rm in thickness, is deposited on SiO_2 layer 362, preferably by sputter deposition, alternatively by evaporation. Layer 360 may then be masked with photoresist to pattern the layer and form a contact pad (not shown), and etched, using wet chemical or reactive ion etch, to create such pattern in the molybdenum. Clearly, the steps involving the depositions of layers 362 and 360 are not required for the embodiments of FIGs. 4-5, 7-9, 9A-9C, and 11, 11A.

Referring now to FIG. 12D, aperture 334 (FIG. 6) is provided through layers 360, 362, 332, 330, 328 and 326, down to layer 324 to provide the electron emitting structure 312 (FIG. 6). Here aperture 334 is provided by a series of etching steps. An initial step of this process is to provide a masking layer 374 over layer 360. Here masking layer 354 is a coating of photoresist of sufficient thickness that it can survive the etching process, illustratively a thickness of 2.0-2.2 μm. The masking layer 374 is patterned to provide here an aperture which substantially defines the diameters of apertures 334, illustratively 1-2 μm.

Apertures 334 are provided by removing exposed portions of layers 362, 360, 332, 330, 328 and 326. Here standard reactive ion etch, wherein the etchant gases are provided to selectively etch each layer as it becomes exposed is used. It is desirable to complete the total etch process as quickly as possible so as to avoid etching off the photoresist layer covering the regions of layer 362 which are to be protected from the etchant.

The assembly is placed in a conventional reactive ion etching chamber and the appropriate etchant gases are pumped therethrough. One requirement of the etchant gases is that they are selective, i.e., they provide good etch selectivity of either the molybdenum or the SiO_2, thereby ensuring uniform etching of each layer over its entire area. In the present example, the etchant used for the molybdenum layers is a chlorine-based plasma, illustratively a mixture of chlorine and oxygen gases, and the etchant for the SiO_2 layers is a fluorine-based gas, illustratively CHF_3. During this etching process, as each layer is etched away, the etchant gas fed into the chamber is alternated so as to etch the subsequently exposed layer.

When this step is complete, and apertures 334 have been provided down to molybdenum layer 324, the remaining photoresist over layer 360 is removed, and the assembly is exposed to a wet etch process, typically with hydrofluoric acid (HF), to undercut SiO_2 layers 326, 330 and 362 under molybdenum layers 328, 332 and 360, respectively, typically by 0.5 rm, and thus provide the structure as previously shown in FIG. 6.

In the above-described etching process, particularly the etching of a layer of molybdenum in a generally circular aperture, the etching of the layer is usually fastest at the center of the aperture and proceeds downwardly and outwardly. It is therefore seen that by carefully monitoring the progress of the etch of molybdenum layer 328, tapered surface 327 (FIG. 6), may be created. Such monitoring may be accomplished by a process of end point detection, i.e., by evaluating the intensity of characteristic spectral emissions associated with the reacting gases in the chamber. A second monitoring process may involve laser deflection from an area on layer 328, such area being remote from, but equivalent in thickness to, those portions of layer 328 within functional apertures 334 of structure 312. This laser deflection monitoring evaluates the reflectivity of layer 328, determining the moment at which the etch of layer 328 is to be terminated. Finally, the monitoring of the progress of the etch of molybdenum layer 328 may involve successive visual inspections based on experience and etch time. Still another method for forming a sharp edge on surface 327 involves chemical or electrochemical etching.

While the principles of the present invention have been demonstrated with particular regard to the illustrated structure of the figures, it will be recognized that various departures from such illustrative structure may be undertaken in the practice of the invention. The scope of this invention is not intended to be limited to the structure disclosed herein but should instead be gauged by the breadth of the claims which follow.

Claims

1. A cathode for an electron field emission structure comprising:
a sheet of electrically conductive material having an edge.

2. The cathode of Claim 1 further comprising:
means coupled to said sheet for producing a flow of electrons from said edge.

3. The cathode of Claim 1 wherein said edge is disposed around a region.

4. The cathode of Claim 1 wherein said edge is an edge portion of said sheet of conductive material surrounding an apertured portion of said sheet.

5. In combination:
a layer of electrically conductive material having an edge portion; and

means coupled to said layer for producing an electric field of sufficient strength to provide a flow of electrons from the edge portion of said layer.

6. The combination, according to Claim 5, wherein said layer has an aperture disposed thereon and said edge portion of said layer is a peripheral edge portion of the aperture in said layer.

7. The combination, according to Claim 6, wherein said layer is a first layer and further comprises:
a second layer of electrically conductive material spaced from said first layer.

8. The combination, according to Claim 7, further comprising:
means for controlling the rate of said flow of electrons from said peripheral edge portions of the aperture in said first layer.

9. The combination, according to Claim 8, further including an insulating layer disposed between said first and second electrically conductive layers, said insulating layer having an aperture disposed therein substantially coaxial with the aperture disposed in said first electrically conductive layer.

10. The combination, according to Claim 6, wherein the aperture in said first electrically conductive layer is substantially circular.

11. The combination, according to Claim 6, wherein said first layer of electrically conductive material has a multiplicity of apertures disposed therein; and wherein said producing means provides a multiplicity of individual flows of electrons from peripheral edge portions of the multiplicity of apertures in said first layer.

12. The combination, according to Claim 7, wherein said second electrically conductive layer has an aperture disposed therein.

13. The combination, according to Claim 12, wherein said aperture in said first layer and aperture in said second layer are disposed in coaxial alignment.

14. The combination, according to Claim 13, wherein the apertures in said first and second layers are substantially equal in area.

15. The combination, according to Claim 12, wherein said flow of electrons passes through the aperture in said second layer.

16. The combination, according to Claim 12, further including an insulating layer intermediate said first and second electrically conductive layers and affixed thereto, said insulating layer having an aperture disposed therein substantially coaxial with the apertures disposed in said first and second electrically conductive layers.

17. The combination, according to Claim 8, wherein the means for controlling electron flow is coupled to said second layer.

18. The combination, according to Claim 6, further comprising:
a third layer of electrically conductive material.

19. The combination, accordingly to Claim 18, wherein said third layer has an aperture disposed therein substantially aligned with the aperture disposed in said first electrically conductive layer.

20. The combination, according to Claim 19, further comprising means for controlling the rate of said flow of electrons from peripheral edge portions of the aperture in said first layer.

21. The combination, according to Claim 20, wherein said third layer is disposed between said first layer and second layer.

22. The combination, according to Claim 20, wherein said first layer is disposed between said second and third layers and said means for controlling further comprises:
means coupled to said third layer for focusing said electron flows.

23. The combination, according to Claim 20, wherein said first, second, and third electrically conductive layers are comprised of a metal.

24. The combination, according to Claim 20, wherein said first, second, and third electrically conductive layers are a refractory type of metal.

25. The combination, according to Claim 24, wherein said refractory type metal is selected from the group consisting of molybdenum, tungsten, titanium, and tantalium.

26. The combination, according to Claim 23, wherein said metal is molybdenum.

27. The combination, according to Claim 14, wherein said aperture in said first electrically conductive layer is substantially circular.

28. The combination, according to Claim 14, wherein said peripheral edge portions of the aperture in said first electrically conductive layer have a tapered edge surface.

29. The combination, according to Claim 6, wherein said first layer of electrically conductive material is relatively thin at the portions thereof adjacent the aperture therethrough and relatively thicker at the portions thereof remote from the aperture.

30. The combination, according to Claim 12, wherein said first and second layers of electrically conductive material each have a multiplicity of apertures formed therein, said producing means producing individual flows of electrons from peripheral edge portions of the multiplicity of apertures in said first layer and adjacent peripheral edge portions of the corresponding multiplicity of apertures in said second layer are coupled to said means for controlling the rate of electron flow.

31. The combination, according to Claim 5, further comprising means disposed adjacent said layer for collecting said electron flow provided from said layer.

32. The combination, according to Claim 7, further comprising means for collecting said electron flow.

33. Electron emission apparatus comprising:

a first plurality of substantially parallel conductors; and

a second plurality of substantially parallel conductors spaced from said first plurality of conductors, with said conductors of said first layer having portions in alignment with said conductors of said second layer, and with said first plurality of conductors having apertures disposed through said conductors of said first plurality at the aligned portions of said layers;

means coupled to said conductors of said first layer for producing electron flows from peripheral edge portions of the apertures in said first plurality of conductors; and means coupled to said conductors of said second layer for controlling the rates of said electron flows.

34. The apparatus, according to Claim 33, wherein said first plurality of first conductors are disposed over said second plurality of second conductors.

35. The apparatus, according to Claim 33, where said second plurality of conductors having apertures disposed therein aligned with those of said first plurality and said second plurality of conductors are disposed over said first plurality of conductors.

36. The apparatus, according to Claim 33, further comprising:

means disposed adjacent said first electrode for collecting said electron flows provided from said first electrode.

37. The combination, according to Claim 9, wherein the aperture in said first layer is greater in diameter than the aperture in said insulating layer.

38. The combination, according to Claim 8, further including an insulating layer disposed between said first and second layers.

39. A method of providing an electron emitting structure comprising the steps of:

(a) providing a first layer of electrically conductive material having an aperture; and

(b) providing a second layer of electrically conductive material spaced from said first layer.

40. The method of Claim 39 wherein said second layer has an aperture.

41. The method of Claim 40 where said apertures are formed through said layers.

42. The method according to Claim 41 further comprising the step of:

providing an insulating layer intermediate said first and second electrically conductive layers, and wherein said aperture formed through said first and second layers extends through said insulating layer.

43. The method of Claim 42 wherein the aperture formed in said insulating layer is substantially aligned with and greater in area than the aperture formed in said first and second electrically conductive layers.

44. The method according to Claim 43 further comprising the step of:

providing a third layer of electrically conductive material spaced from said second electrically conductive layer; and

wherein said step of forming an aperture through said first and second layers includes forming an aperture through said third layer.

45. The method according to Claim 44 wherein said first, second and third electrically conductive layers are a refractory the of metal.

46. The method according to Claim 44 wherein said

first, second and third electrically conductive layers comprise molybdenum.

47. The method according to Claim 39 wherein said aperture in said first electrically conductive layer is substantially circular.

48. The method according to Claim 39 wherein said step of providing a first layer includes providing a layer which is relatively thin at the portions thereof adjacent the aperture therethrough, and which is relatively thicker at the portions thereof remote from the aperture.

49. The method according to Claim 48 wherein said step of providing a first layer comprises the substeps of:

(i) providing a relatively thick layer of said electrically conductive material;
(ii) removing said electrically conductive material in a region where the aperture is to be formed, said region of removed material exceeding the area of said aperture; and
(iii) providing a relatively thin layer of said electrically conductive material over said relatively thick layer.

50. The method according to Claim 42 wherein said step of providing the aperture comprises the substeps of:

(i) masking a surface of said second layer with a pattern such as to expose a region where the aperture is to be provided;
(ii) exposing said surface of said second layer to an etchant suitable for selectably etching the material in said unmasked region; and
(iii) repeating said exposing step with a suitable etchant for each layer of said emitting structure until said aperture is provided.

51. The method according to Claim 50 further including the substep of etching said insulating layer so as to enlarge the aperture therethrough to an area greater than the aperture formed in said first and second electrically conductive layers.

52. The method according to Claim 50 wherein said substep of exposing said first layer to a suitable etchant includes the further substep of providing a tapered surface on a peripheral edge portion of said first layer at the aperture.

53. The method according to Claim 52 wherein said substep of providing a tapered surface on a peripheral edge portion of said first layer at the aperture includes a process of endpoint detection during the etching of said first layer.

54. The method according to Claim 39 wherein said step of providing a first layer includes providing said first layer as a first plurality of substantially parallel conductors.

55. The method according to Claim 54 wherein said step of forming a second layer includes providing said second layer as a second plurality of substantially parallel conductors, said conductors of said first layer intersecting said conductors of said second layer, but electrically isolated therefrom; and

wherein said step of forming an aperture includes forming apertures through said first and second layers at the intersections of said conductors of said first and second layers.

56. The method according to Claim 55 wherein said step of forming apertures at the intersections of said conductors of said first and second layers includes forming a multiplicity of apertures at each of the intersections.

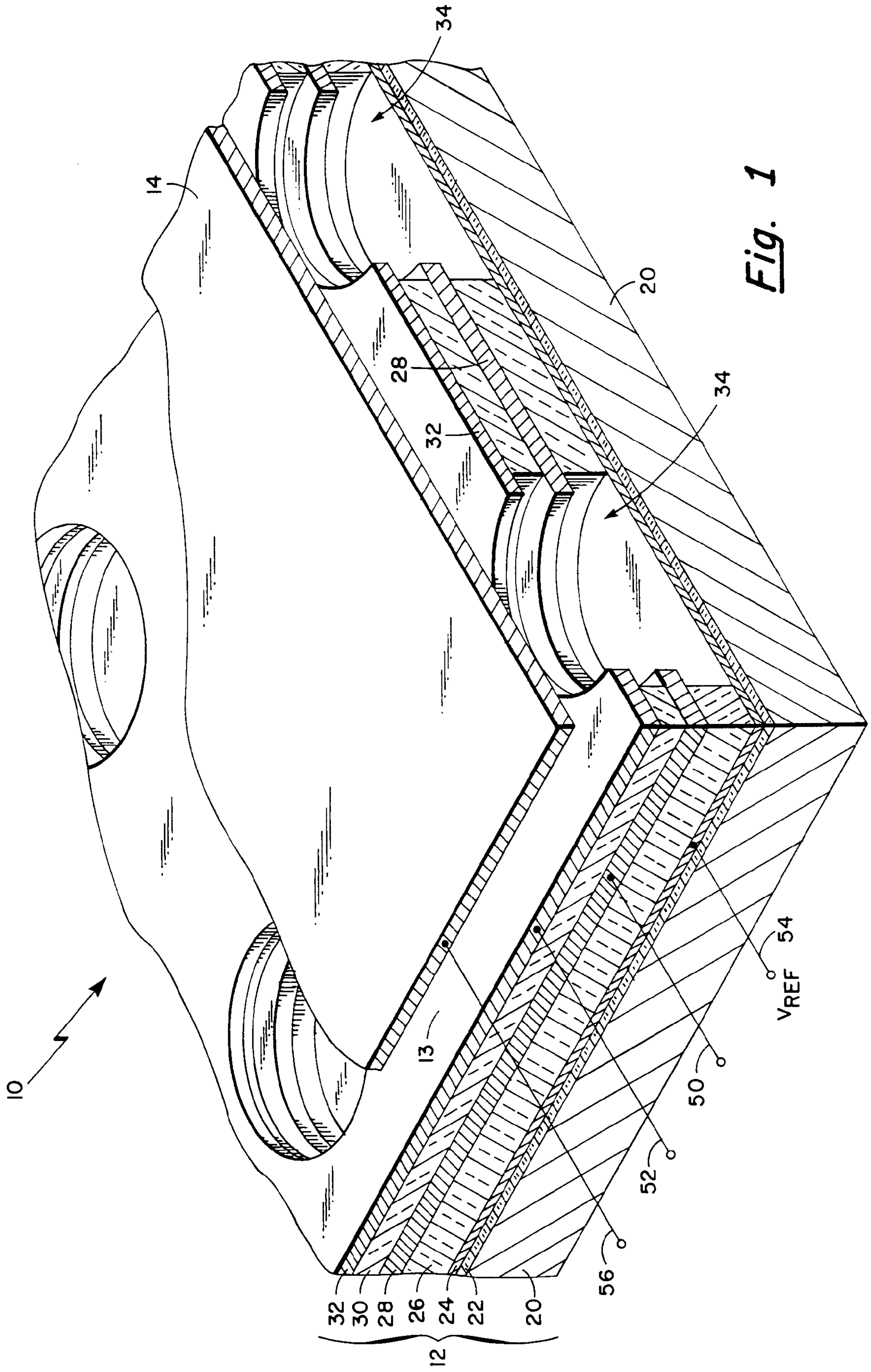
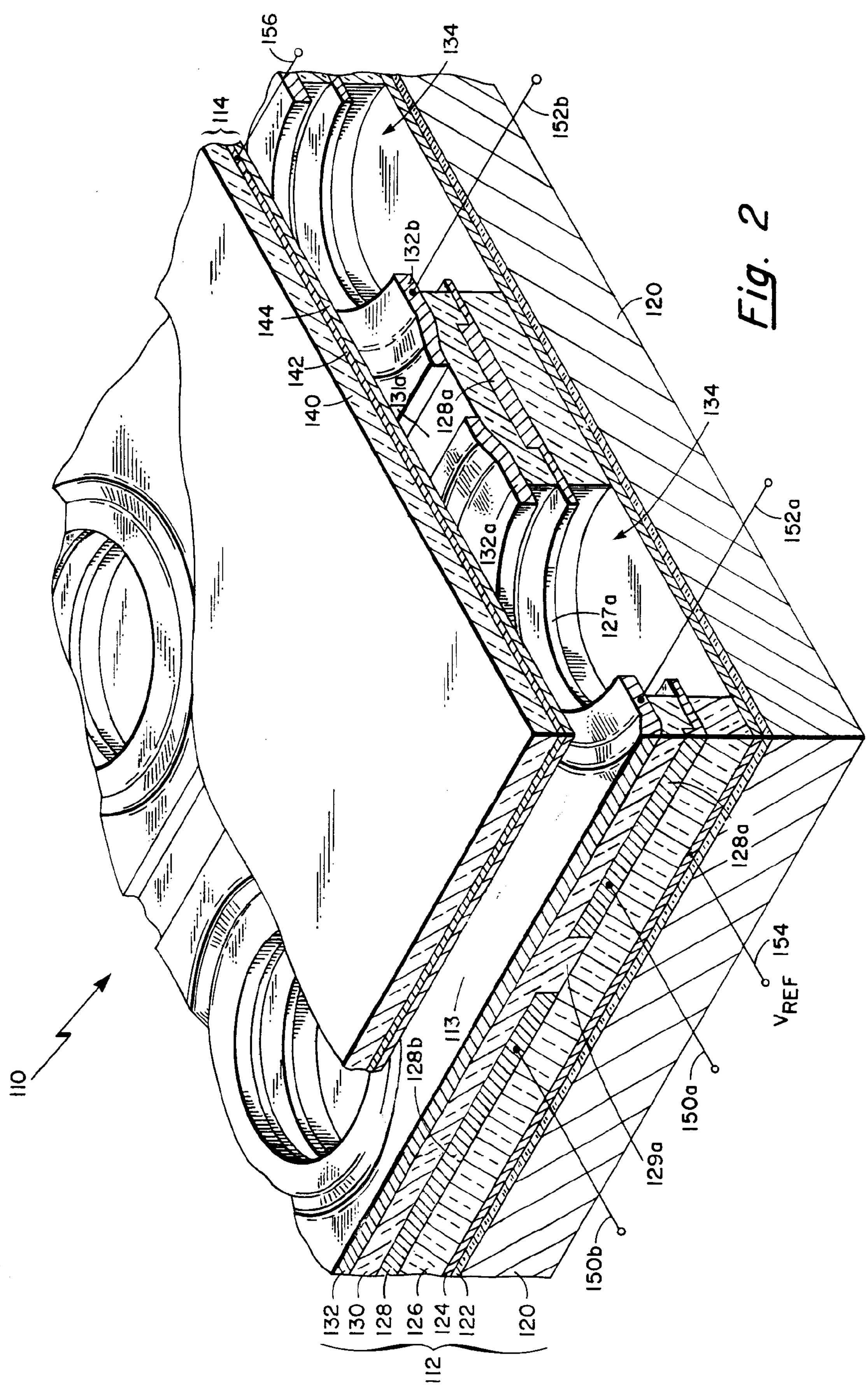


Fig. 1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V_{REF}

Fig. 2

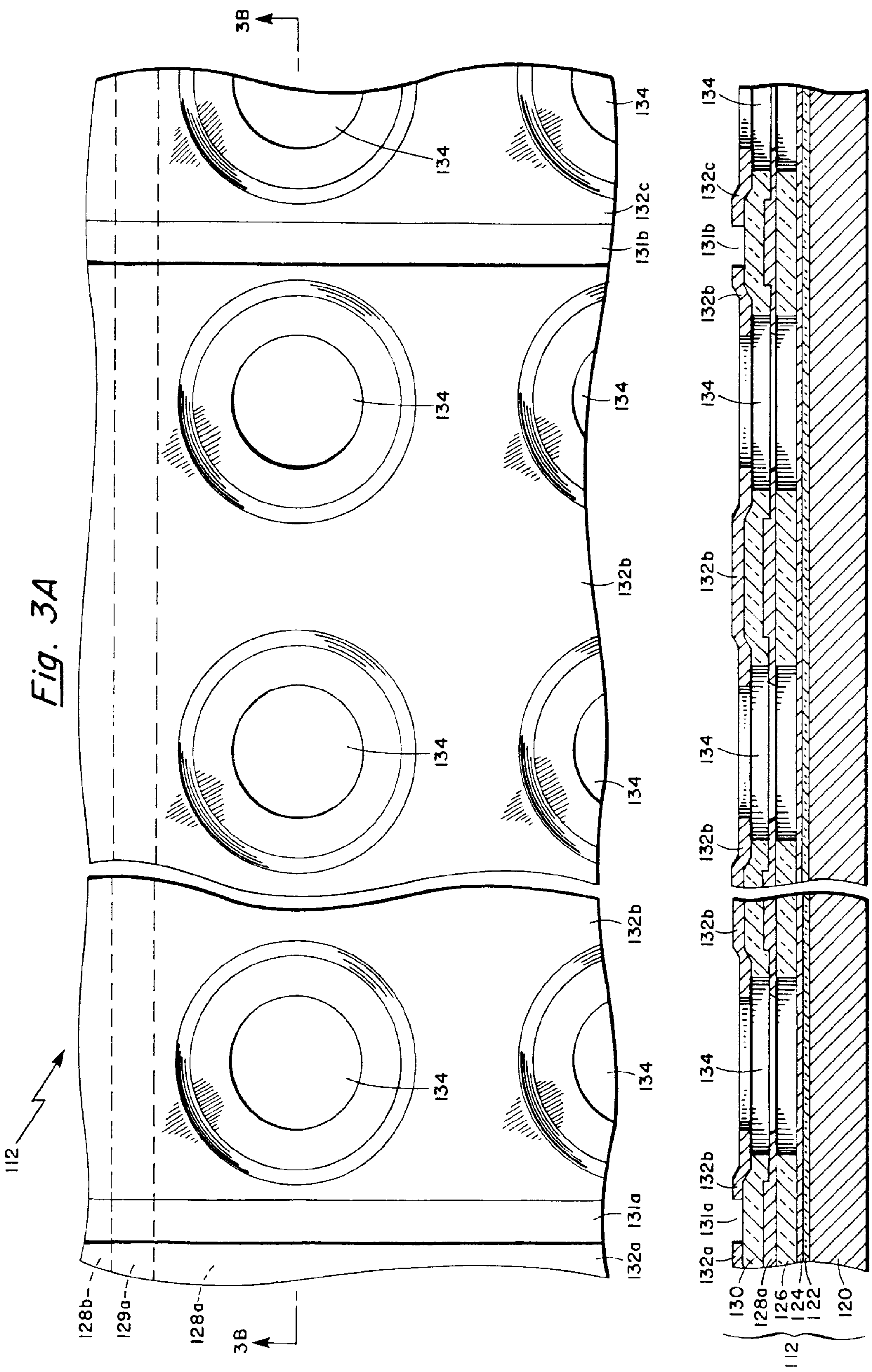
3B
3B
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Fig. 3A

Fig. 3B

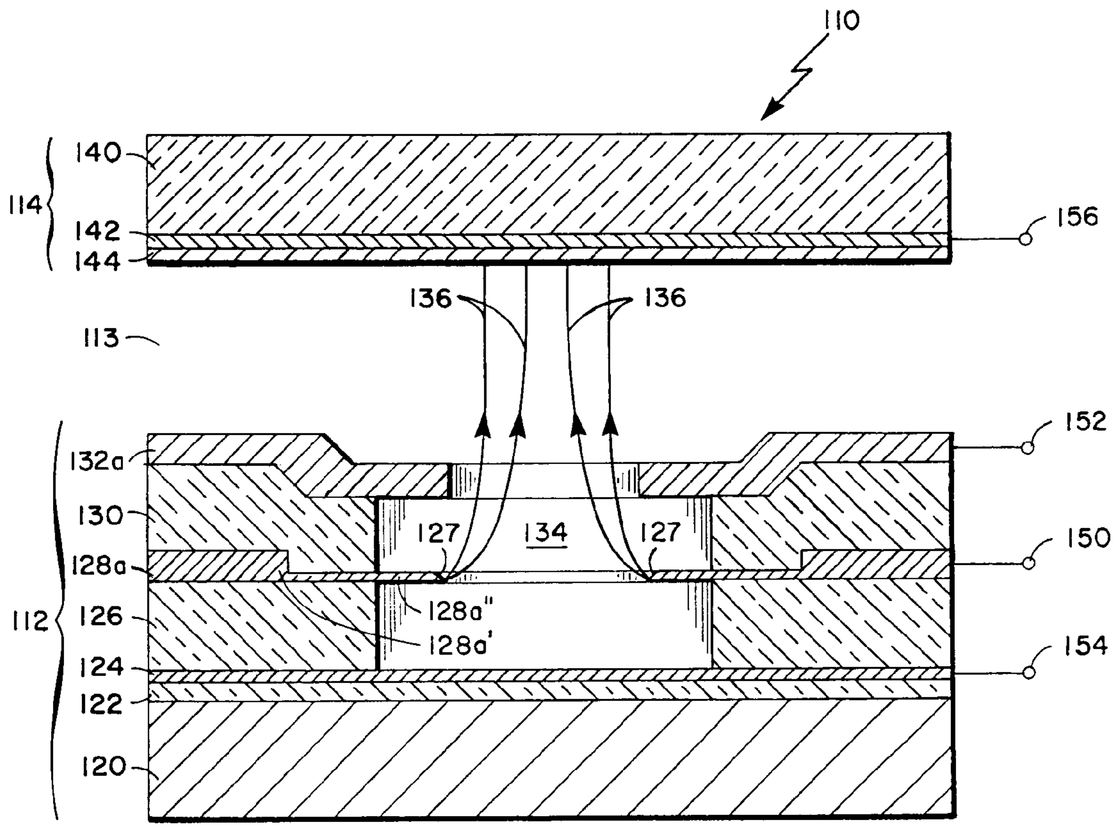
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Fig. 4

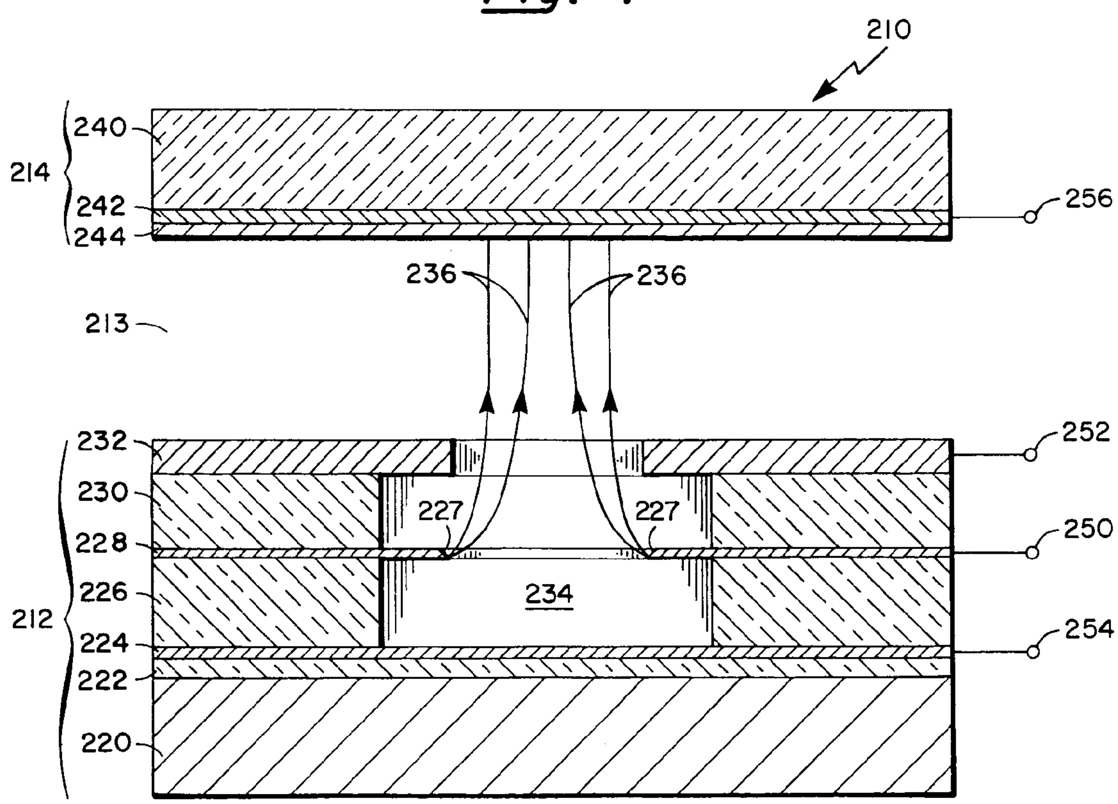
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Fig. 5

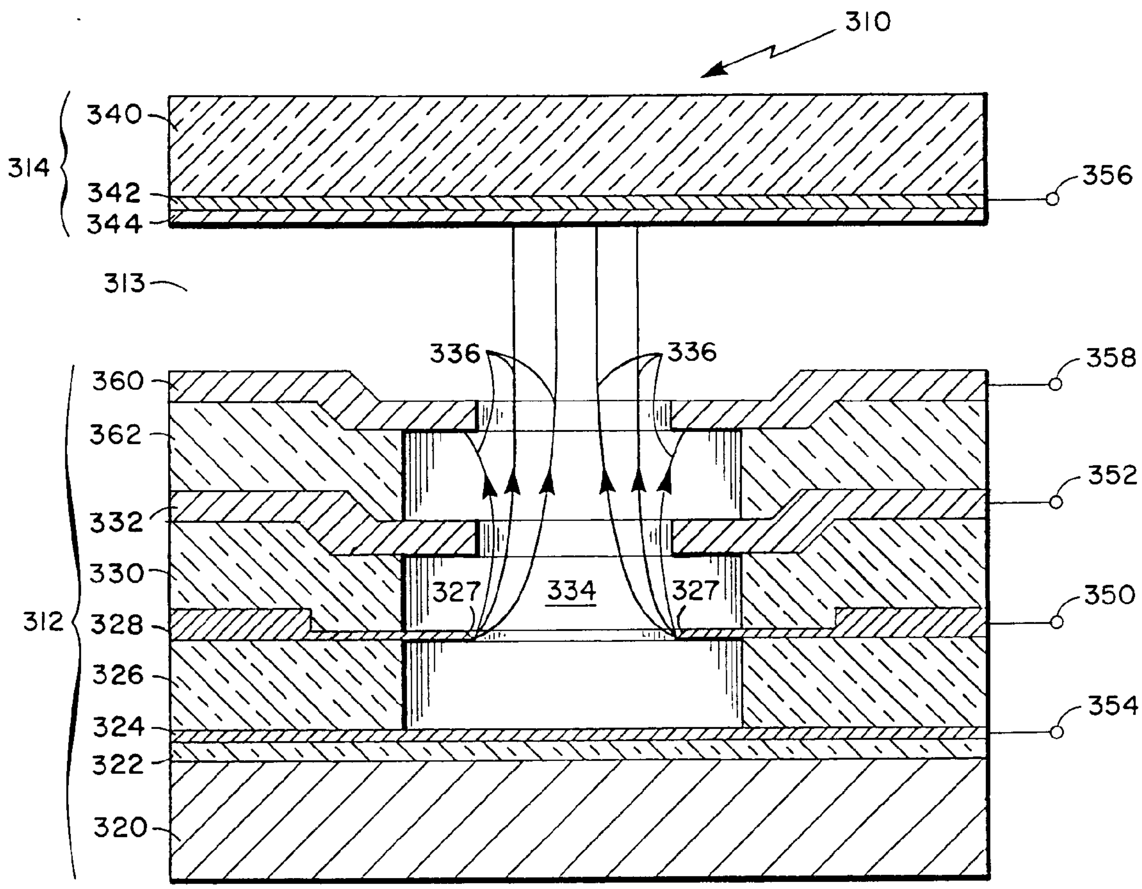
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Fig. 6

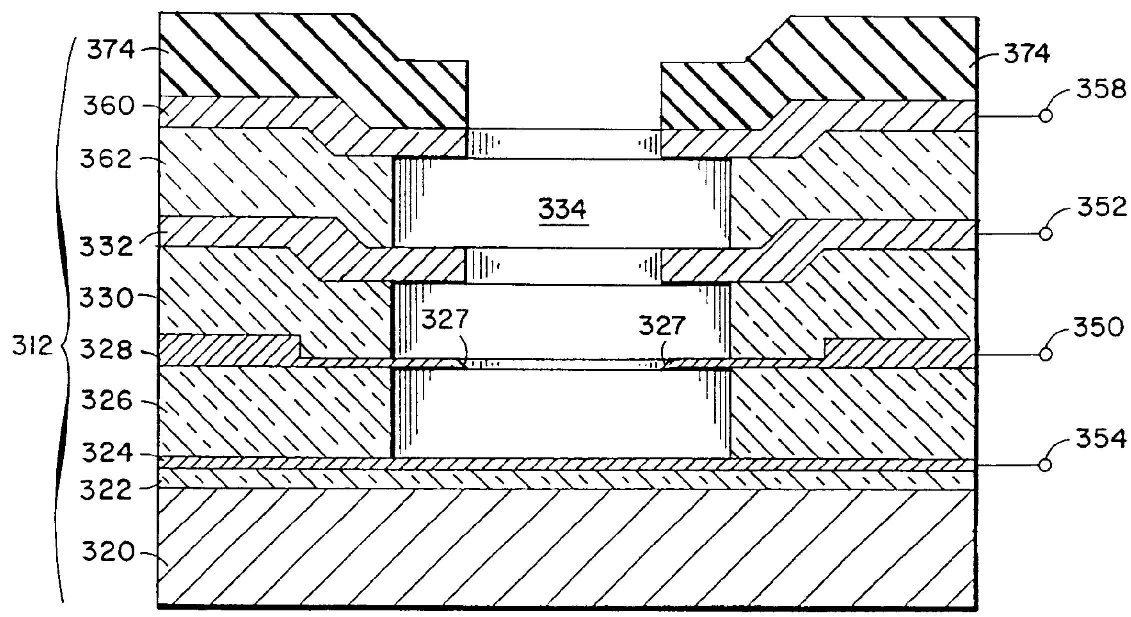
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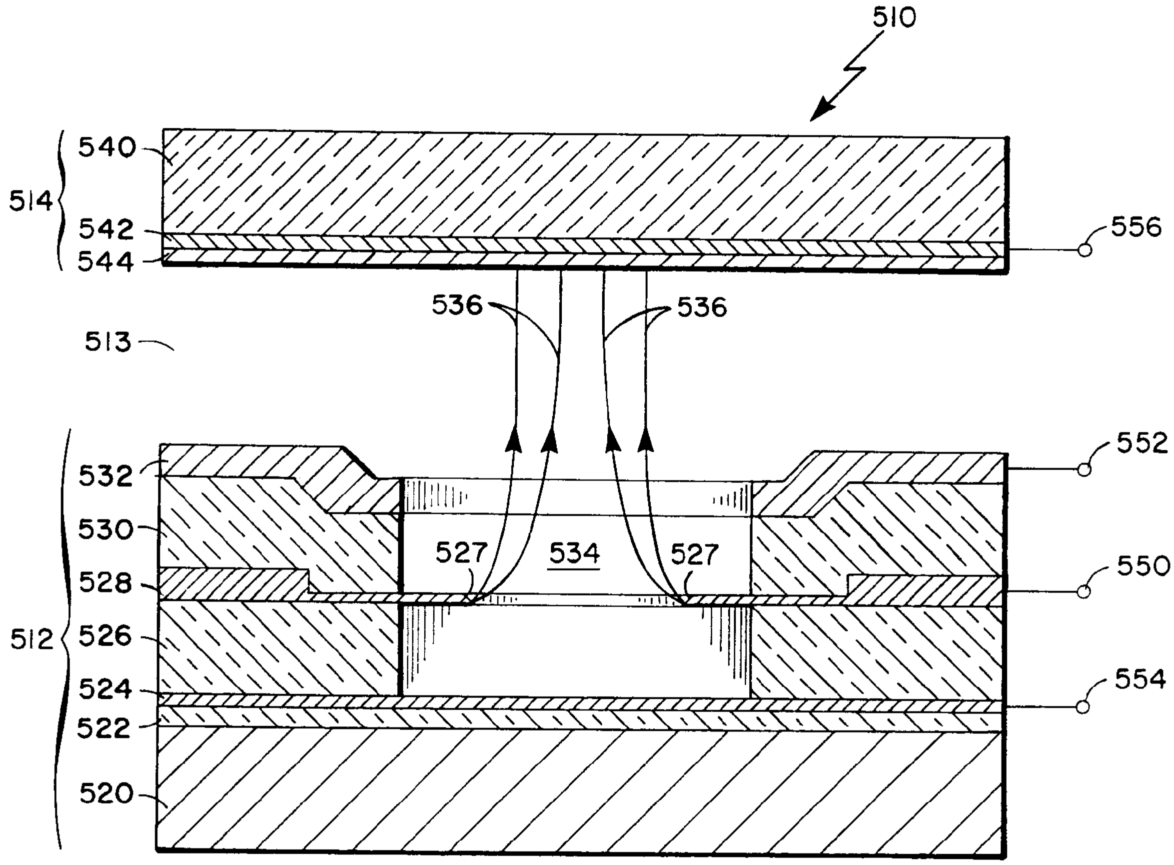
Fig. 12D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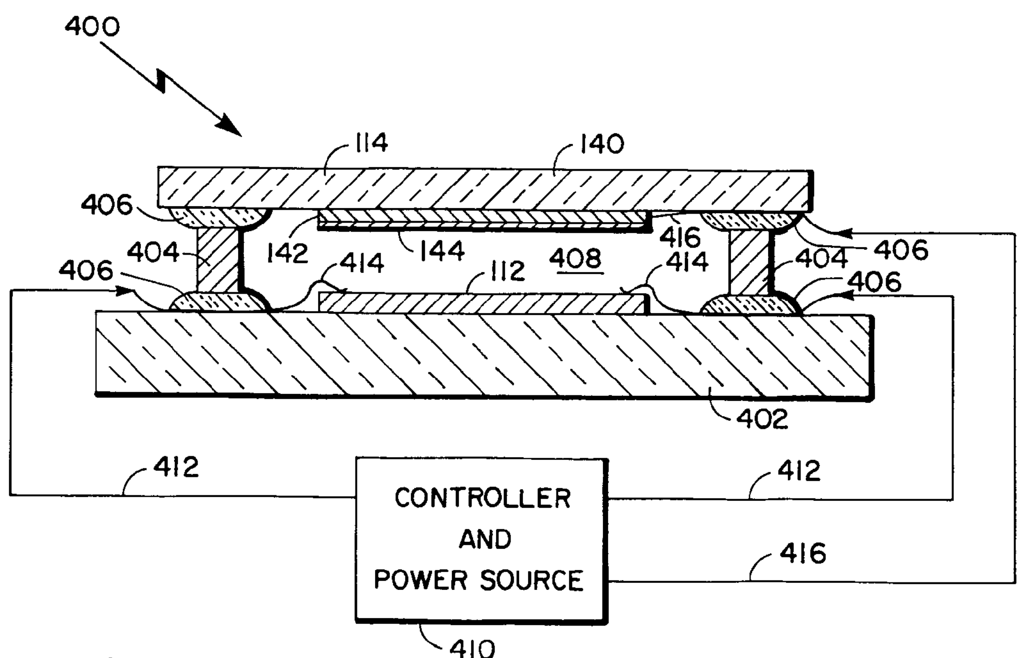
520

Fig. 7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CONTROLLER
AND
POWER SOURCE
416
410

Fig. 10

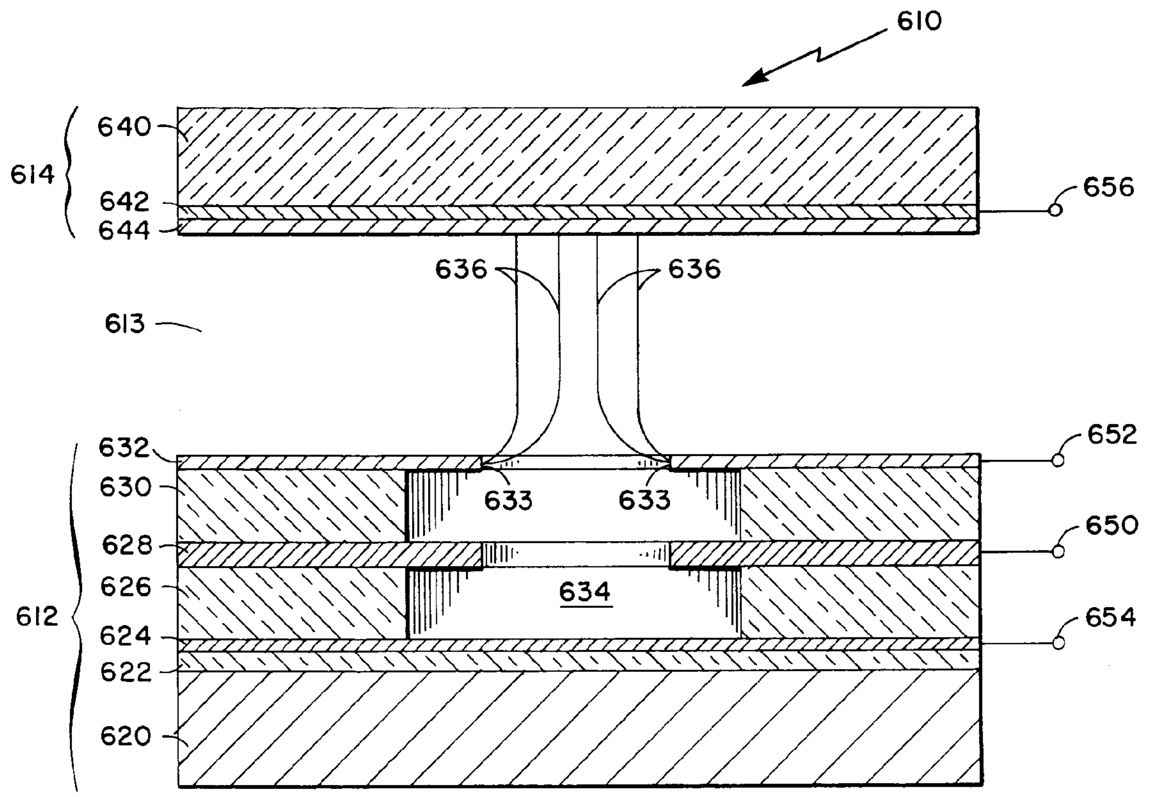
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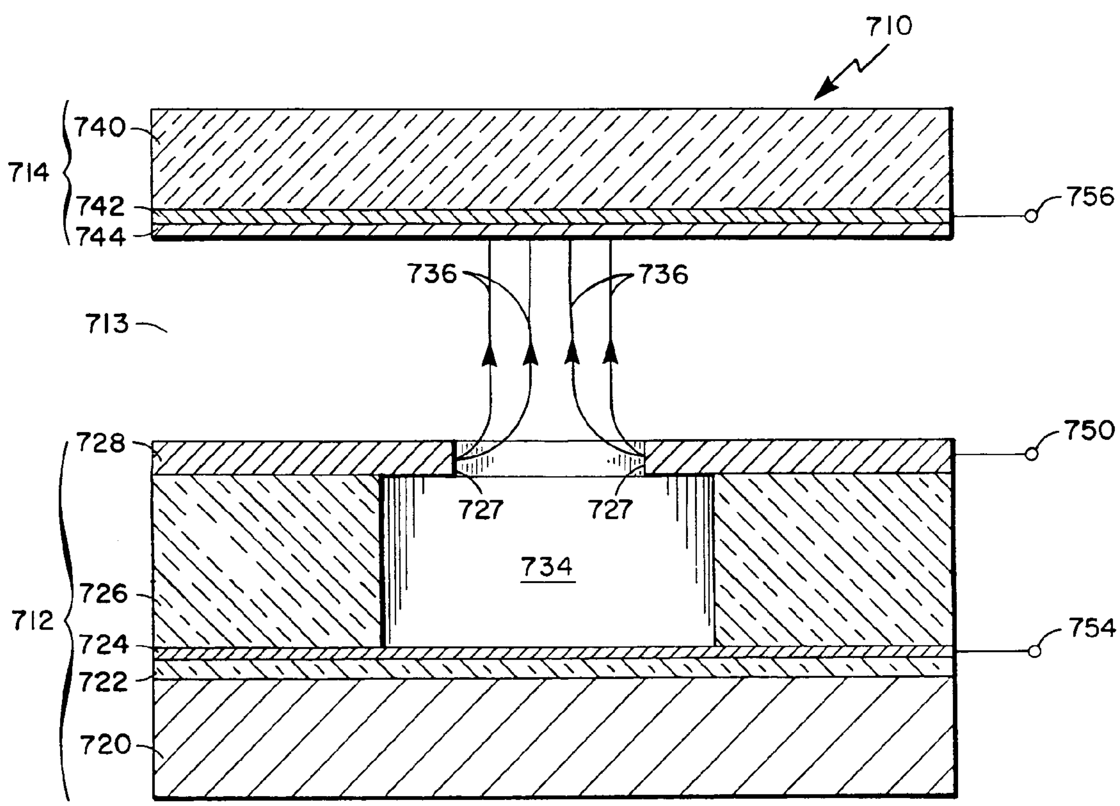
Fig. 8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750
727
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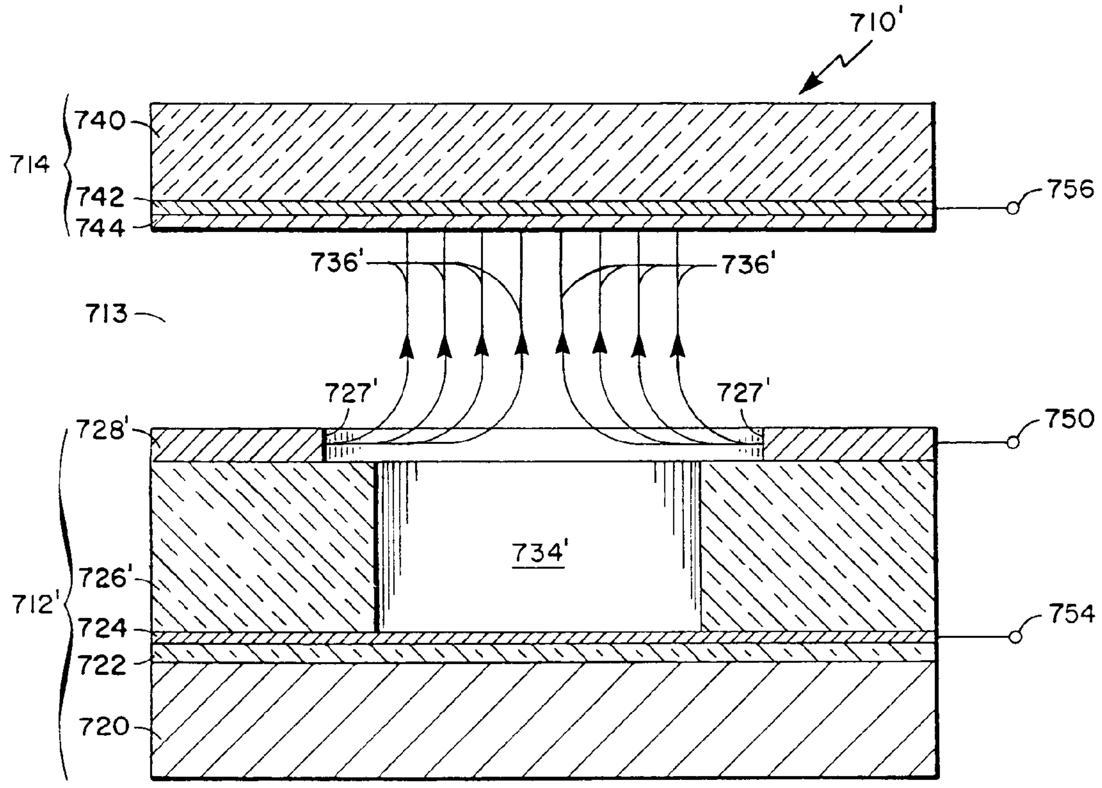
722
720

Fig. 9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744
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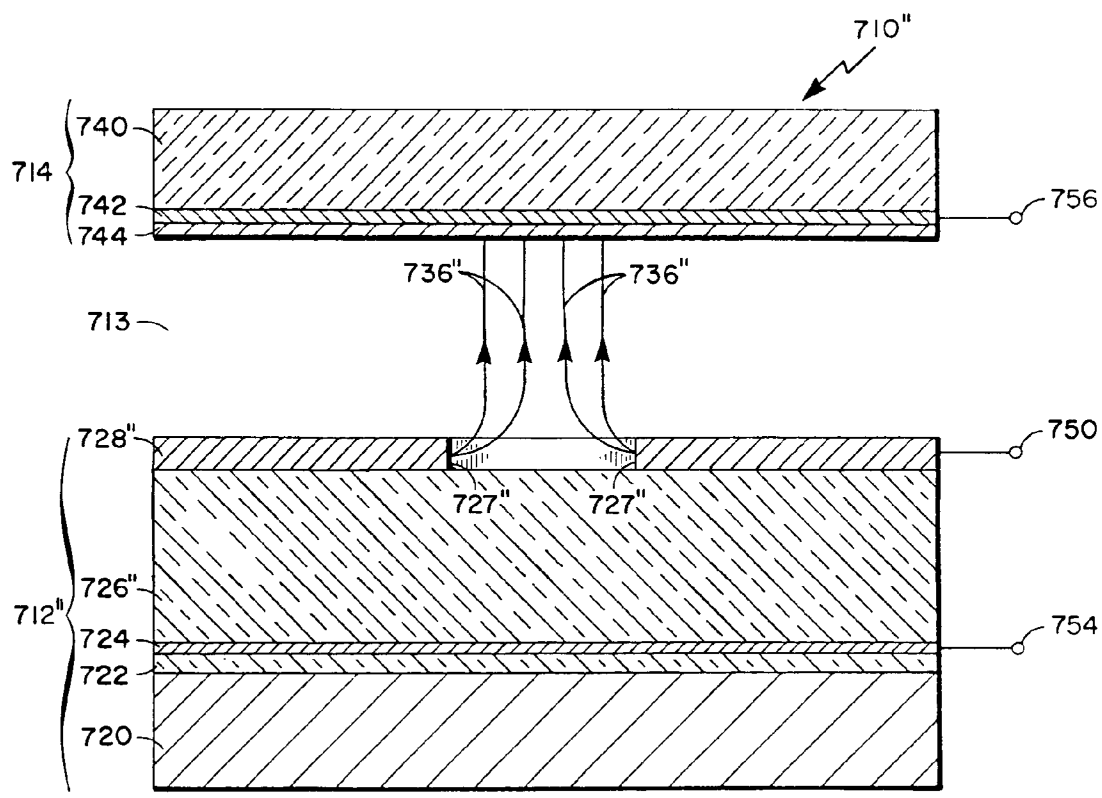
727'
727'
728'
750
734'
726'
712'
724
754
722
720

Fig. 9A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750
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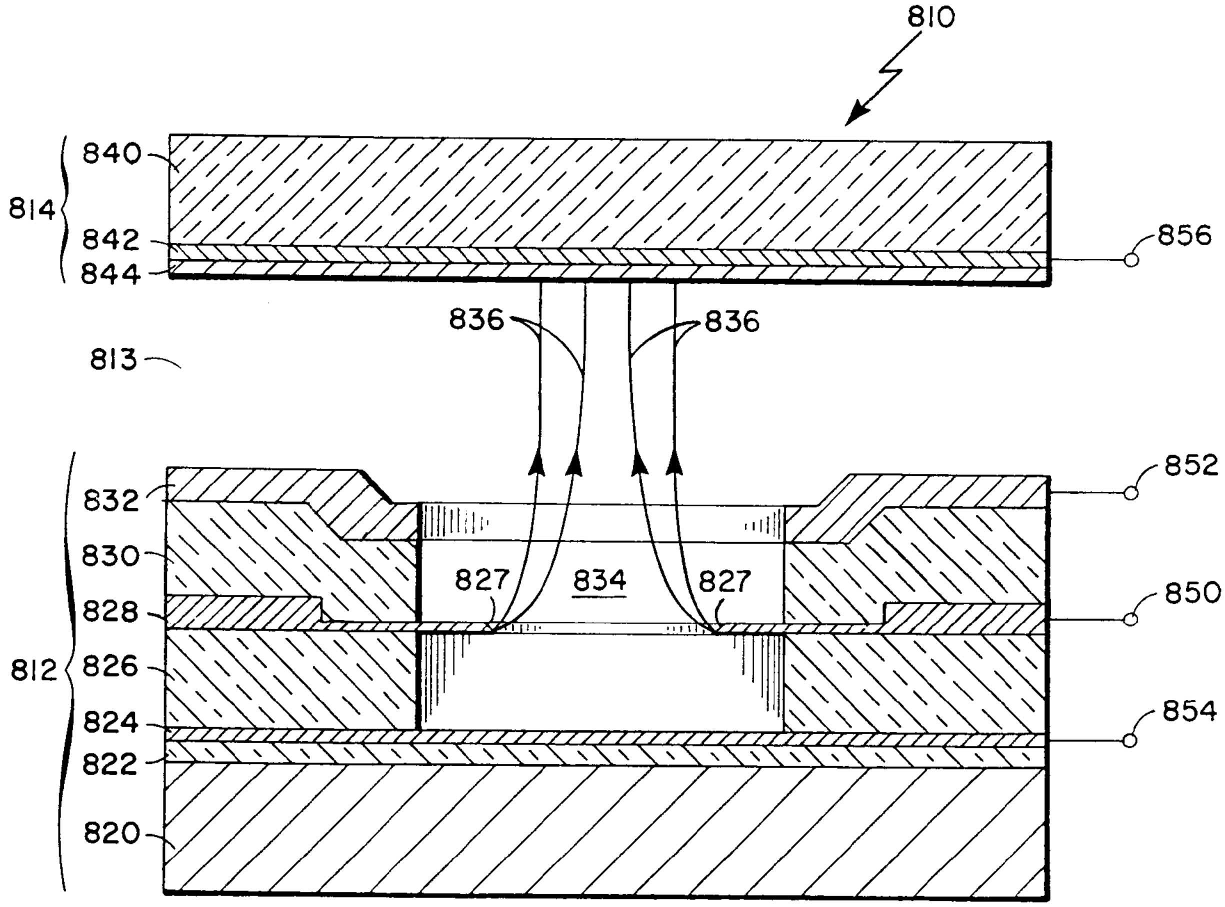
722
720

Fig. 9B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820

Fig. 9C

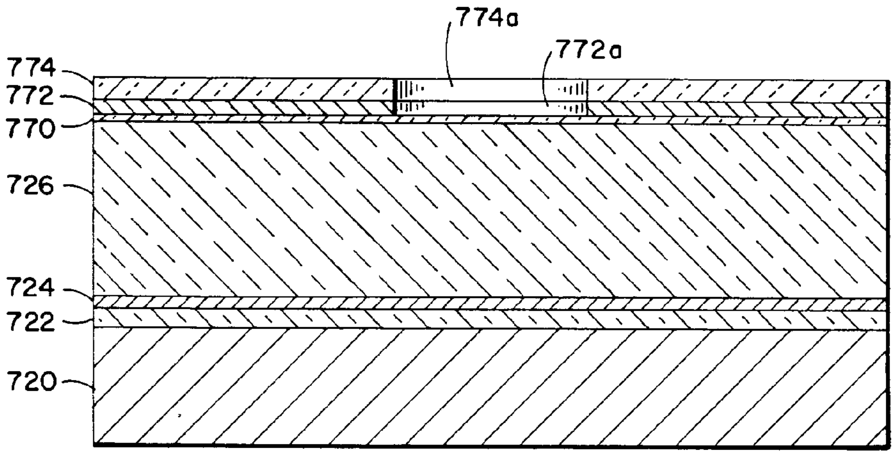

Fig. 9D

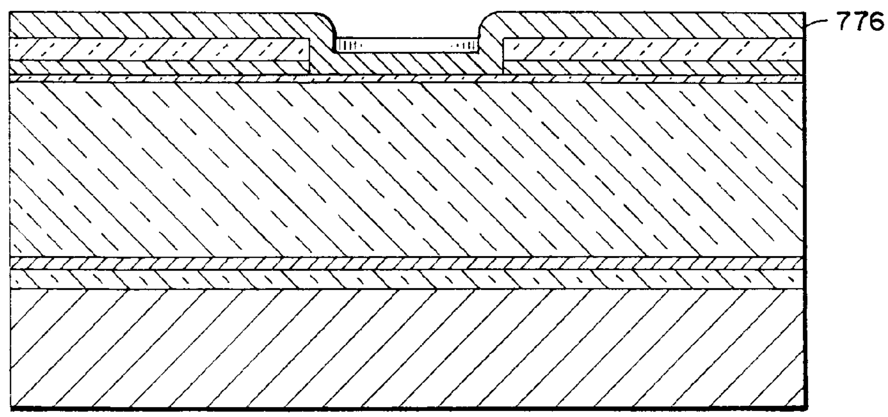

Fig. 9E

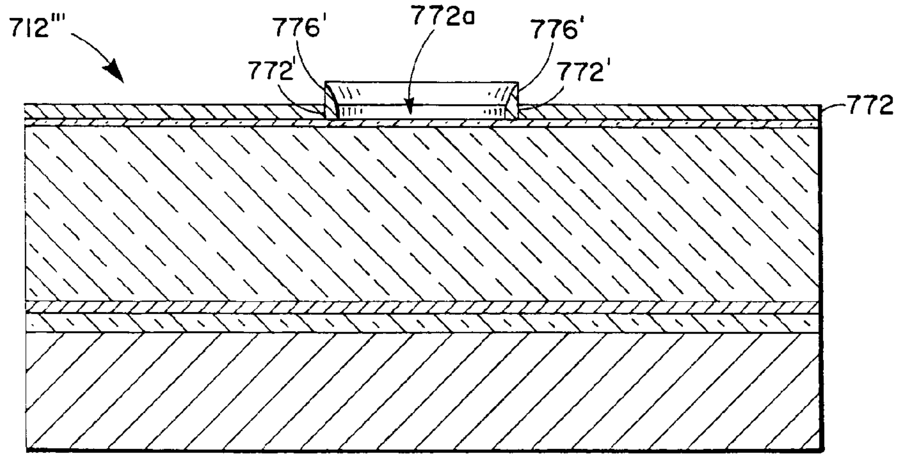

Fig. 9F

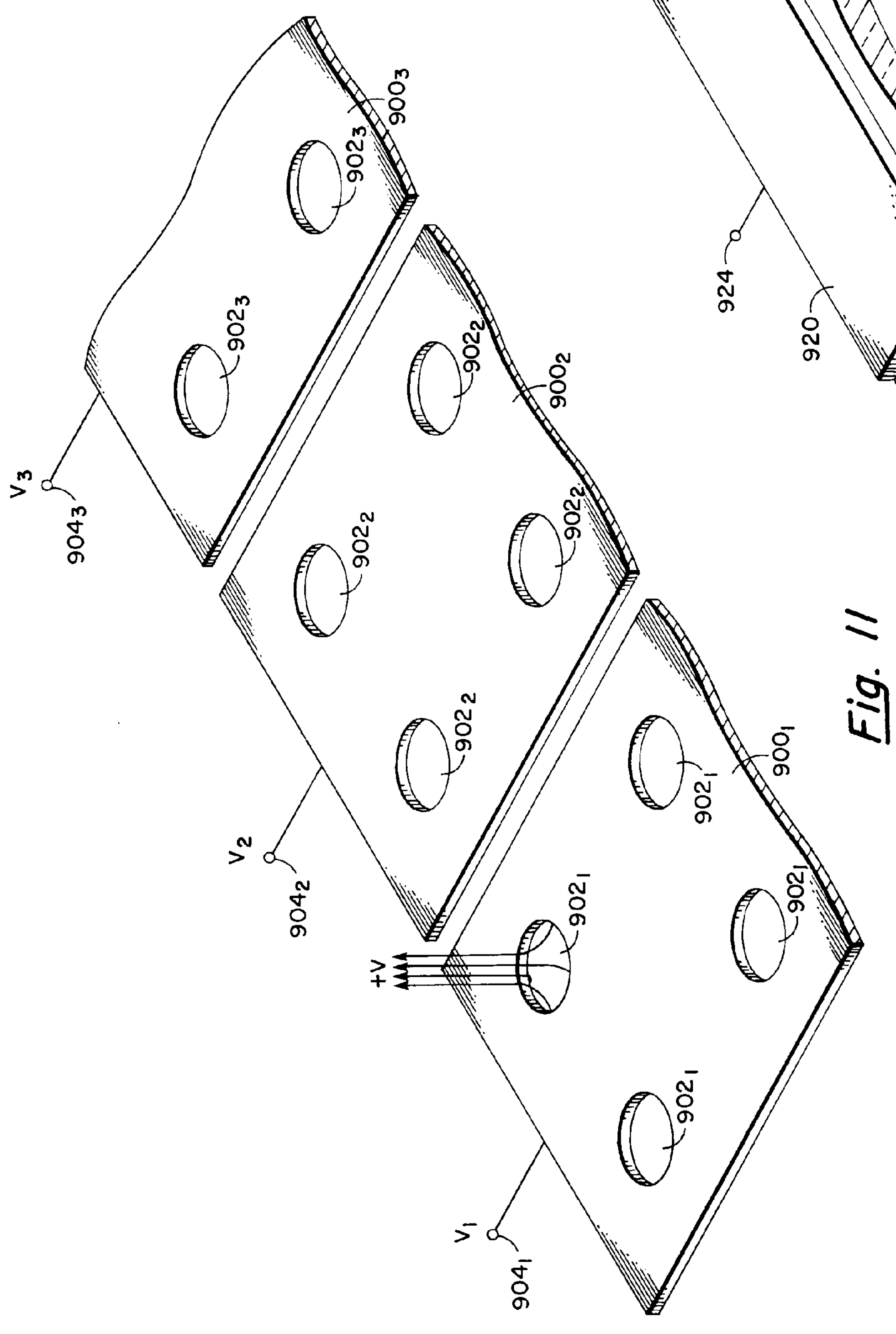

Fig. 11

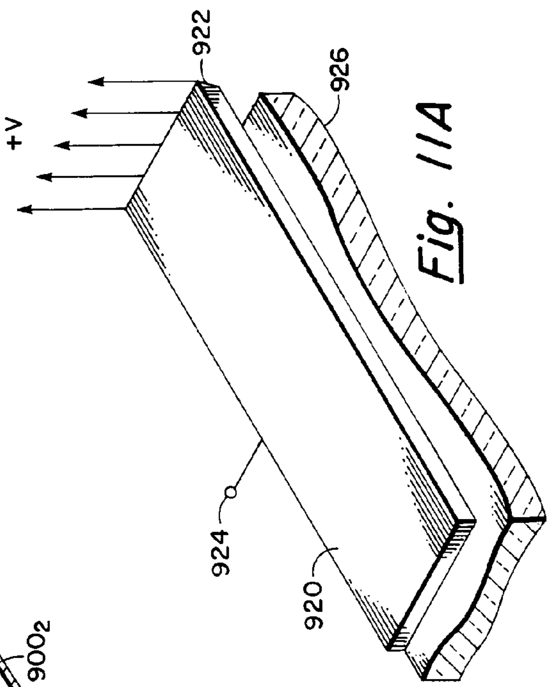

Fig. 11A

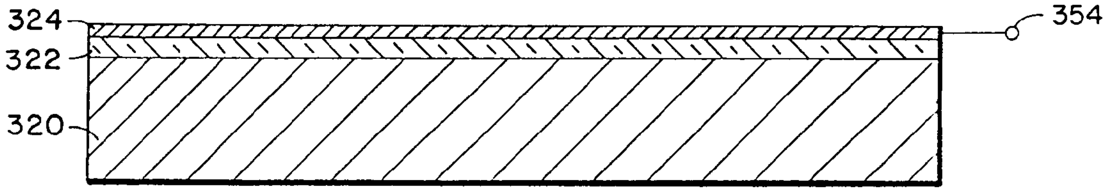

Fig. 12A

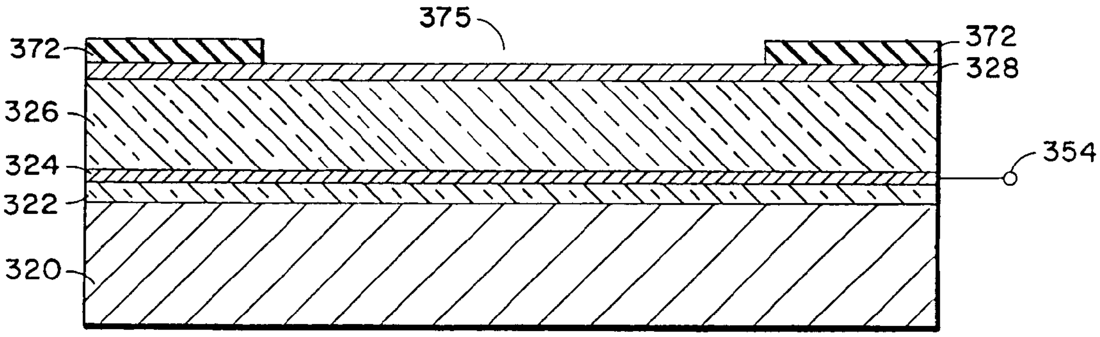

Fig. 12B

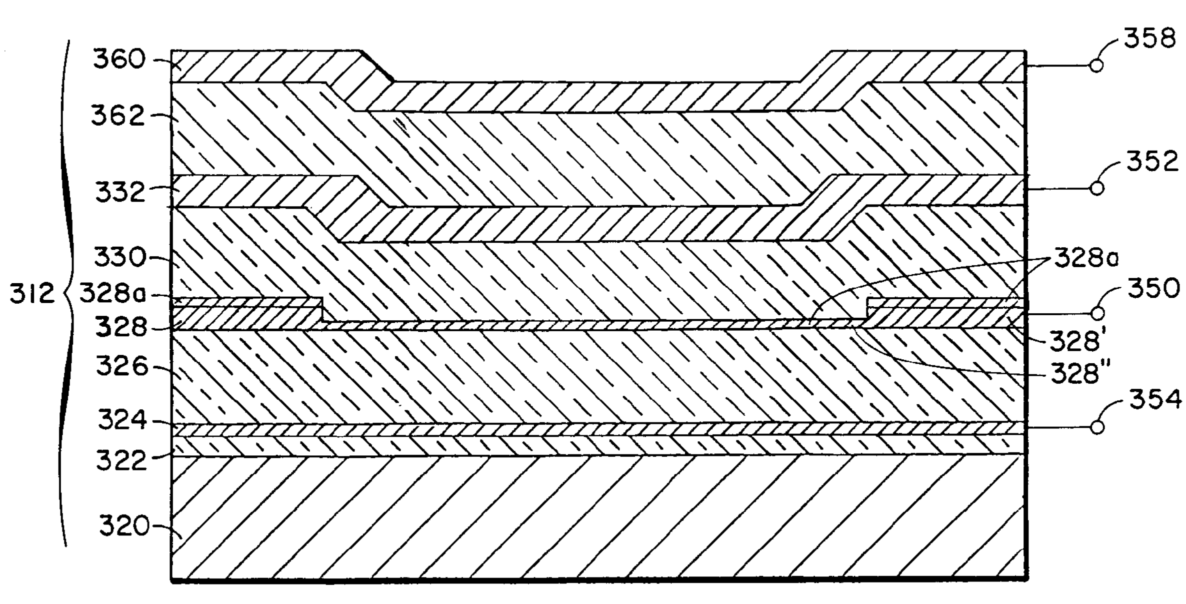

Fig. 12C