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(54) Fabrication method for field emission arrays.

(57) Field emitters for displays and vacuum microelectronic devices include a tip (30′), a grid (18) to control electron emission from the tip, and an electrode (22) for focusing the electron emission. The method of fabrication avoids simultaneous evaporation at vastly different angles and replaces simultaneous evaporation with successive evaporations followed by a noncritical lift-off. The metal to form the emitting bodies (30) is deposited over a release layer (26) as well within the field emitter apertures (15′), and forms a layer (28) that seals off the apertures (15′). Most of the layer (28) is etched away to leave only the parts over the apertures (15′), and then the release layer (26) is etched away so that the remaining pieces of the layer (28) are lifted off.

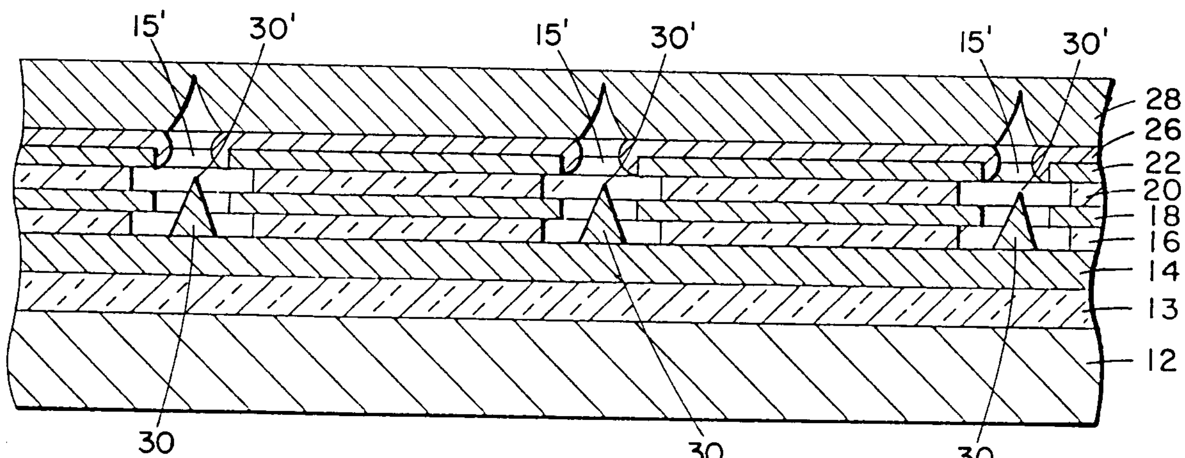

Fig. 5

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Background of the Invention

This invention relates generally to electron emitting structures and, more particularly, to electric field producing electron emitting structures.

As it 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 28, 1973 to C.A. Spindt, et al. As suggested in this patent, a cathode is provide by an electron emitting structure in the shape of a cone having a tip. An electrically conducted gate electrode arrangement is disposed adjacent the tip portion of the cone to produce in response to an applied field between the cone and the tip electron emissions from the tip portion of the cone. An electric field is provided between the electron emitting structure and a spaced apart anode, and by application of a potential therebetween the field emitted electrons are collected by the anode. That is, the electric field is concentrated at the tip portion of the cone with sufficient intensity such that electrons are emitted from the tip and are collected by the anode.

As is also known, such cathode structures can be used in a variety of applications, such as in flat panel displays and vacuum microelectric devices.

To provide the tips of the electron emitting structure, as taught by the Spindt, et al. patent, a highly collimated beam of vaporized metal, illustratively molybdenum, impinges normally onto a substrate having a metal film, the control grid electron, having micron sized apertures disposed over small cavities. A second beam, illustratively aluminum oxide vapor or other dielectric material, impinges simultaneously onto the substrate at a relatively shallow angle compared to the angle of incidence of the vaporized beam of metal. During this co-evaporation process, the substrate is rotated about its central axis. The net affect is that the apertures in the metal film are gradually closed by the deposition of the composite material (i.e. the molybdenum and aluminum oxide) while metal cones are formed as a result of the gradual closing of the aperture by the molybdenum vapor stream. Thus, cathode electrodes are provided within the apertures. Thereafter, the composite material (i.e. molybdenum and aluminum oxide) which surrounds the cones and closes the apertures in the metal film is removed by a subsequent selective chemical etching step which attacks the composite material but generally not the molybdenum metal cones.

To obtain emitters having uniform cone and tip physical geometries over a relatively large area would be useful for a display or microelectric device. In order to try to provide such a characteristic, the co-deposited vapor streams must be highly collimated. In addition, the relative deposition rates of the co-deposited vapor stream must be precisely controlled to provide the desired tip sharpness over a large area. That is, they must be evaporated from a considerable distance, typically of 70 centimeters or greater. This condition requires the use of a relatively large deposition apparatus.

The process described by Spindt is thus complicated and, moreover, the apparatus needed to produce displays would be expensive particularly for usefully sized displays and microelectronic devices.

A further problem with the field emission structure described by Spindt is the absence of an electrode for use in electrostatic focusing. This problem arises in part because of the relative difficulty in initially achieving the emitter tips due to the co-evaporation processing techniques. It would be highly desirable to provide a focusing electrode adjacent said tips since the electrons which emerge from the field emission tips are emitted over a considerable spread of launching angles of typically 30°. To focus these field emitted electrons into a relatively narrow beam would be desirable for many applications, particularly the above-mentioned display applications. A further shortcoming of the described process is the relative difficulty in controlling the height of the cones relative to the gate electrode structures. A high degree of control is desirable since it is generally preferred that the peak or the tip of the cone reach or protrude through the region disposed adjacent the grid electrodes.

Summary of the Invention

In accordance with the present invention, a method of forming field emitter tips for a field emission structure includes the steps of providing over a conductive layer a stack of an insulating layer and a conductive layer and preferable alternating layer pairs of an insulating layer and a conductive layer. Through the stack of layers, a plurality of apertures is provided. Preferably selective portions of the insulating layer or insulating layers exposed by the apertures provided through the stack are etched back to provide the conductive layers overhanging the insulating layers. The substrate is then coated with a release material which is disposed over the stack. A beam of metal is directed towards the stack to provide a layer of said metal over the stack while permitting portions of the beam of metal to deposit onto the portions of the conductive layer exposed through the apertures in said stack while the layer of metal over the stack gradually closes such apertures thus leaving a cone-shaped region of the metal within each of the apertures. With such an arrangement, a plurality of field emission tips are provided in apertures formed in a stack of alternating insulator and conductive layers. This technique thus eliminates the relatively difficult co-evaporation of dielectric and metal to form the cone-shaped field emitters and replaces the co-evaporation with successive evaporations which are more easy to control, partic-

ularly over large surface areas. Furthermore, the geometric relation between the tip of the cone and a conductor which is to be provided as a grid or gate electrode for the field emission structure is easy to control. With a preferred embodiment, a second electrode is provided which can be used for electrostatic focusing.

In accordance with a further aspect of the present invention, the method of forming field emitter tips further comprises the step of masking the apertures provided through the stack of alternating layers while removing portions of the metal layer disposed over the stack and removing the release layer, as well as, the masked portions disposed over the apertures. With this particular arrangement, the combination of the successive evaporations and a relatively non-critical lift-off type of process step may be used to provide the field emitter tips.

Successive evaporations are easier to control than an accurate mixing of simultaneous evaporations as used in the prior techniques. With the present invention, the topographical and etching properties of the two-layer deposited film mainly depend upon the thickness of the layers and not on the relative evaporation rates, that is the final compositions of the layer. For the prior art technique, the topographical and etching properties of the simultaneously evaporated layers are strongly related to the compositions of the two component layers and thus are strongly related to the evaporation rates of the metal and insulating materials. Further, with the present technique, the evaporation sources can now be positioned in the same location in the form of a standard multiple hearth electron beam evaporation furnace. This is a further advantage over the prior approaches since the electron beam evaporation process provides, at relatively high rates, highly collimated depositions of refractory metals. Evaporation becomes very inefficient, however, when the direction of deposition deviates much from a normal to the surface to be deposited on as would be required for one of the beams of metal in the simultaneous evaporation technique of the prior art. The instant method permits the substrate to assume two different positions to allow materials to be consecutively deposited in a multiple hearth source at two different angles.

In accordance with a still further aspect of the present invention, a field emission structure comprises a bottom conductive layer supporting a plurality of field emitters; and a stack of alternating layers of at least two insulating layers interposed with at least two conductive layers disposed over said bottom conductive layer. The stack has apertures disposed therethrough with the field emitters disposed partially through the apertures. With such an arrangement, a field emitting structure having a pair of electrodes disposed over the field emitters is provided. In particular, one of said electrodes can be used as a grid or control electrode to control the rate of the emission from the field emitters, whereas the second one of the electrodes can be used as an electrostatic focusing electrode to collimate a beam of field emitted electrons from each of the field emitters. The field emitters can be any known field emitter structure such as cones having field emitting tips or wedges.

Brief Description of the Drawings

The foregoing features of this invention, as well as the invention itself, may be more fully understood from the following detailed description of the drawings, in which:

FIGs. 1-7 are a series of cross-sectional views showing steps in the fabrication of field emitter tips in accordance with the present invention;

FIG. 8 is a cross-sectional view showing a completed field emitter having a collection electrode disposed over the field emission structure;

FIG. 9 is a plan view taken along line 8-8 of FIG. 8; and

FIG. 10 is a plan view of an alternate arrangement for providing wedge emitters in accordance with a further aspect of the present invention.

Description of the Preferred Embodiments

Referring now to FIG. 1, a substrate 12 is here shown having disposed over a first surface thereof, an optional electrically insulating layer 13 illustratively silicon dioxide which is disposed or grown over substrate 12 using any conventional technique. Layer 13 is illustratively 8,000Å in thickness although other thicknesses may alternatively be used. The substrate 12 is used as a support and it should be appreciated that the substrate is likewise optional. For example, if the arrangement to be described can be supported with other techniques other than the substrate 12, then the substrate 12 can be eliminated. Here the substrate 12 is typically a silicon wafer of the type used in conventional integrated circuit technology. However, alternatively the substrate 12 can be any other material which can support the structure to be described. Further, the substrate 12 may also be electrically conductive and optionally can be electrically insulating.

Disposed over layer 13 is a conductive layer 14 here comprised of a metal, and preferably a tenacious, refractory type of metal such as molybdenum, tungsten, titanium, or tantalum. Such metals are also generally used for subsequent conductive layers to be described. The conductive layer 14, as well as, the other described layers may also comprise a conductive ceramic such as a superconductor type of material. For the purposes of this invention, it is not necessary for the superconductive material to have the properties of superconductivity in the above applica-

tion. It is merely necessary that the ceramic material be conductive at the temperature of operation of the device to be fabricated. Here a preferred example of the metal used for conductive layer 14 and subsequent conductive layers is molybdenum. Conductive layer 14 is annealed at a high temperature at around 1,000°C by any technique such as rapid thermal processing, as well as, other known techniques to improve its conductivity and adhesion to the layer 13. Alternatively, the annealing step can be delayed until all of the conductive layers (as will be described) have been provided in the stack (15 as will be described). Layer 14 may have any desired thickness. A typical range of thicknesses for layer 14 is in the range of 0.3-1.0 microns.

Disposed over layer 14 is a stack 15 here comprised of a first insulating layer 16 of an insulator type of material having a thickness generally in the range of 0.6-1.0 microns, although other thicknesses may alternatively be used. Insulator layer 16 may be any suitable electrically insulating material, for example, here the insulator layer is comprised of chemically vapor deposited or sputtered quartz which has excellent dielectric properties and a relatively low dielectric constant.

Disposed over insulating layer 16 is a second conductive layer 18, here also comprised of a refractory metal and here illustratively being molybdenum although the metals and, in particular, the other refractory metals or ceramics, as mentioned earlier, may alternatively be used. Disposed over conductive layer 18 is a second insulating layer 20 here comprised of quartz although other insulating materials may alternatively be used and disposed over second insulating layer 20 is a third conductive layer 22 here also comprised of molybdenum although other materials may alternatively be used. Layers 16, 18, 20, and 22 provide the stack arrangement 15.

Referring now to FIG. 2, a masking layer 24 is shown disposed over third conductive layer 22 of stack 15. Masking layer 24 is here comprised of a photoresist or any other suitable masking type of material and is patterned to provide apertures 24′ which are here circular although other shapes may alternatively be used. Apertures 24′ are used to expose underlying portions of the stack 15. Here the substrate 12, having the masking layer 24, is brought into contact with a reactive ion etching plasma (not shown) to etch portions of the stack 15 exposed by the aperture 24′ provided in masking layer 24, thus providing apertures 15′ in the stack 15. The reactive ion etching continues until the apertures reach the conductive layer 14.

Since etching through the four layers using the reactive ion etching is a relatively long and tedious process, it might be preferably to provide a more tenacious masking layer 24 rather than conventional photoresist. Thus, if erosion of the resist material becomes a concern, the masking layer 24 may be replaced or supplemented by use of a more durable masking material such as a platinum film which is easily patterned by back sputtering in argon through a photoresist mask (not shown).

Referring now to FIG. 3, portions of the two insulating layers 16 and 20 exposed through apertures 15′, provided in the stack 15, are selectively etched back by use of a relatively noncritical, highly selective chemical etchant such as hydrogen fluoride solution in the case of quartz. This permits etching back of portions of the insulating layers 16 and 20 exposed in aperture 15′ to provide portions of the conductive layers 18 and 22 overhanging the insulating layers 16 and 20. This arrangement is preferable for field emission.

Referring now to FIG. 4, the masking layer 24 (FIGs. 2 and 3) is removed using conventional techniques for the particular masking material used and is replaced by a release layer 26 of a material which is evaporated to a desired thickness typically between 1,000-3,000Å at an angle of approximately 45° while the substrate is rotated about its central axis. The release layer 16 is thus disposed over the third conductive layer 22 and preferable coats inner portions of the third conductive layer 22 exposed within the apertures 15′, as shown. It is also preferred that the release material of the release layer 26 not enter the apertures 15′ other than to coat exposed portions of layer 22, as shown. This arrangement assists in removal of layers which will be disposed over layer 26 in a manner to be described. Examples of suitable materials for release layer 26 include titanium, aluminum, as well as, nickel. In a preferred arrangement, the release layer 26 may be comprised of a composite layer of two of such materials. One example of a composite layer would be to provide a layer of aluminum having a thickness of approximately 2,000Å and followed by a layer of titanium having a thickness of approximately 1,000Å. Other thicknesses, as well as other materials could alternatively be used. In general, the important characteristics of the material for release layer 26 are that it is compatible with the processing to follow and that it be relatively easily etched or removed by any technique that will not attack the underlying layers 16-22, as will be described.

Referring now to FIG. 5, a conductive layer 28 is shown disposed over release layer 26. Here the conductive layer 28 is evaporated molybdenum or other suitable metals or refractory type of metals mentioned above maybe used. Alternatively conductive and superconductive types of ceramic may be used provided they have sufficient conductivity at the temperatures which the device will operate and further that they exhibit field emission of electrons. Here the preferred material for conductive layer 28 is molybdenum and it is evaporated at a normal incidence to the surface of the substrate 12. During the evaporation process, portions of the evaporated molybdenum enter the

apertures 15′ while remaining portions of the molybdenum coat release layer 26 including portions thereof within apertures 15′ and thus provide the conductive layer 28, as shown. As molybdenum is evaporated, the thickness of conductive layer 28 increases, and the conductive layer 28 concomitantly begins to buildup along sidewall portions of release layer 26 to gradually close the apertures 15′ provided in the stack 15. Thus, as the apertures 15′ are closed off by successively increasing the thickness of conductive layer 28, the amount of evaporated molybdenum which enters the apertures 15′ is concomitantly, uniformly reduced. This arrangement provides the cone-shaped emitters 30 disposed within the apertures 15′, as shown. The cone-shaped emitters 30 have tip portions 30′ which are relatively sharp and generally sharper than those provided using the prior techniques. The evaporation process continues until complete closure of the aperture 15′ is provided by conductive layer 28. The evaporation parameters and the aperture 15′ dimensions are chosen such that the apertures 15′ reach complete closure before the tip 30′ grows into it. In addition, for electrical considerations for the field emission tips 30′, it is generally desired that the elevation of the tip 30′ is close to or slightly above the upper surface of the second conductive layer 18 which, as will be described, is generally used to control emission of field emitted electrons from the tips 30′.

Referring now to FIG. 6, a masking layer (not shown) is disposed over conductive layer 28 and is patterned to provide masking regions 34 which generally mask the apertures 15′ in which the cone emitter tips 30′ are provided. These masking regions 34 are used to protect the emitter tips 30′ and a small area adjacent the emitters during subsequent etching processes to remove the conductive layer 28, as well as, release material 26, as will now be described.

The exposed portions of conductive layer 28 are removed by any desired etching step, here by reactive ion etching or alternatively by a wet etching technique. If a wet etching technique is used, it is preferred that the masking regions 34 be relatively large in comparison to the apertures 15′ such that any undercutting of the masking region 34 into layer 28 will avoid the apertures 15′ and thus the emitters 30′. A typical spacing for the emitters is about 5-6 microns, whereas each emitter is typically 1 micron in diameter. Thus, selection of the particular technique principally depends upon convenience and dimensional tolerances available in the ultimately fabricated device. For example, in applications having closely spaced emitter tips and hence masking regions 34, a reactive ion etching technique would be preferred, whereas a wet chemical etch could be used where the masking regions are spaced relatively far apart. After the exposed portions of metal layer 28 are removed, as shown in FIG. 7, the entire release layer 26 is removed by dissolving the release material by using a selective wet etchant. This will remove completely the release layer 26 and concomitantly "lift off" the remainder of the unwanted conductive layer 28, as well as, masking regions 34 as generally shown for the field emission structure 40 of FIG. 8.

Referring, in particular, now to FIG. 8, the field emission structure 40 is shown having the field emitters 30 and field emitter tips 30′ disposed within apertures 15′ provided in stack 15. Here stack 15 includes two insulating layers 16 and 20 spacing two conductive layers 18 and 22, as shown and generally described above. The conductive layer 18 is connected to a control terminal 44 using conventional approaches. Likewise, conductive layer 14 and hence cones 30 are connected to a terminal 42 using conventional approaches. The conductive layer 18 has peripheral portions disposed in the aperture 15′ adjacent tips 30′. Such edge portions of the conductive layer 18 are used to provide an electric field between the edges of the layer 18 and tips 30′ to extract electrons from the tips 30′ of the cone-shaped emitters 30. Thus, a potential V_1 is typically applied between terminals 42 and 44 to permit the extraction of electrons by field emission from the tips 30. Edges of conductive layer 18 exposed by aperture 15′ thus functions here as a control or gate electrode. Typical ranges of potential difference between terminals 42 and 44 are 50-100 volts.

The third optional, and preferred conductive layer 22 is disposed over the second conductive layer 18. The third conductive layer 22 here is provided with a potential V_2 in the range of 0V to 90V with respect to terminal 42 to confine the trajectories of the emitted electrons from tip 30′ and provide a more collimated and focused beam (not shown). Thus, the edges of conductive layer 22 exposed by apertures 15′ thus fonction here as a focusing electrode by the emitted electron beam.

The electrons emitted from tips 30′ are thus accelerated or drawn towards a collection electrode 52 or anode which is coupled to a terminal 58 disposed at a potential V_3 with respect to terminal 42. Here terminal 58 is generally disposed at a much more positive potential than terminal 42. Preferred or typical ranges for V_3 are 200V to 10KV.

Electrode or anode 52 may be any one of a number of arrangements. For example, if apparatus 50 is a display, anode 52 will have a substrate portion 56 here a glass plate which has disposed thereon a very thin conducting layer 53, as well as, one or more electroluminescence layers 54 which when struck by electrons from the field emitter tips 30 emit photons of light energy. In general, when apparatus 50 is a display, the anode 52 will be fabricated using conventional cathode array tube manufacturing technology. The process of fabricating the anode structure 52 and having electroluminescence materials disposed over a

glass substrate is generally conventional. Moreover, it is also to be noted that the apparatus 50 generally has a partially or substantially completely evacuated interior portion which is provided using conventional vacuum sealing techniques which are also well known. For applications other than those pertaining to the use of the cathode in a flat panel display, the exact details of construction would be now apparent to one of ordinary skill in the art.

Referring momentarily to FIG. 9, the field emitter tips 30 are shown in plan view. Here it is to be understood that the field emitter tips 30 may, in general, comprise a large plurality of such tips and further optionally the exposed layer 22, as well as, underlying layer 18 (FIG. 8) may be selectively etched to provide a plurality of substantially parallel strip conductor portions of the layers 18 and 24 connecting groups or individual ones of such field emitting tips 30′ to permit individual addressing of the field emitters 30 as is generally known, as well as, here permit individual focusing of the field emitters 30.

Referring now to FIG. 10, an alternate embodiment of the present invention is shown. Here wedge emitters 130 having sharp raised edges 130′ are shown disposed within an aperture 115′ provided in a stack (not numbered). Here the wedge emitters are fabricated using the same techniques as discussed above in conjunction with FIGs. 1-8, however, the apertures provided in the stack (not shown) are generally rectangular rather than circular as apertures 15′ (FIGs. 1-6.) Alternatively, other aperture shapes may also be used to provide alternative shapes to the emitter electrodes.

Having described preferred embodiments of the invention, it will now become apparent to one of skill in the art that other embodiments incorporating their concepts may be used. It is felt, therefore, that these embodiments should not be limited to disclosed embodiments, but rather should be limited only by the spirit and scope of the appended claims.

Claims

1. A method comprising the steps of:
   providing over a bottom conductive layer a stack of at least one insulating layer and at least one conductive layer;
   forming a plurality of apertures through said stack;
   depositing a release material over said stack; and
   directing a stream of metal toward said stack to permit first portions of the stream of metal to enter the plurality of apertures providing a corresponding plurality of field emitters whereas second portions of said metal coat said release material and gradually build up on said release material closing the apertures disposed in said stack.

2. The method, as recited in Claim 1, further comprising the steps of providing masked regions over the plurality of apertures disposed through said stack;
   removing exposed portions of the layer of metal disposed over the release material; and
   removing the release layer and masked regions disposed over the stack leaving behind the field emitters.

3. The method, as recited in Claim 2, further comprising the step of:
   etching back selective portions of the insulating layer exposed in portions of said plurality of apertures disposed in the stack;

4. The method, as recited in Claim 1, wherein the step of providing the stack further comprises providing a pair of insulating layer alternating with a pair of conductive layer over the bottom conductive layer.

5. The method, as recited in Claim 4, further comprising the steps of providing masked regions over the plurality of apertures disposed through said stacks;
   removing exposed portions of the layer of metal disposed the release material; and
   removing the release layer and masked regions disposed over the stack leaving behind field emitters.

6. The method, of Claim 4, further comprising the step of etching back selective portions of the insulating layers exposed in portions of said plurality of apertures disposed through the stack.

7. The method, as recited in Claim 6, wherein the field emitters are cones having field emitter tips.

8. The method, as recited in Claim 6, wherein said field emitters are wedges having raised edges.

9. The method, as recited in Claim 1, wherein the field emitters are cones having field emitter tips.

10. The method, as recited in Claim 1, wherein said field emitters are wedges having raised edges.

11. A field emission apparatus comprising:
    a conductive layer supporting a plurality of field emitters; and
    a stack of alternating layers of at least two conductive layers and two insulating layers disposed on said conductive layer.

12. The apparatus, as recited in Claim 11, wherein said field emitters are cones having field emitting tips with the tips protruding partially through apertures provided in the first conductive layer and with said first conductive layer providing a control electrode for controlling field emission from said tips.

13. The apparatus, as recited in Claim 12, wherein said second conductive layer is disposed over said first conducting layer and acts as a focusing electrode for field emitted electrons provided from said conducting tips.

14. The apparatus, as recited in Claim 11, wherein said field emitters are wedges having field emitting raised edges with the raised edges protruding partially through apertures provided in the first conductive layer and with said first conductive layer providing a control electrode for controlling field emission from said raised edges.

15. The apparatus, as recited in Claim 12, wherein said second conductive layer is disposed over said first conducting layer and acts as a focusing electrode for field emitted electrons provided from said conducting wedges.

5 10 15 20 25 30 35 40 45 50 55

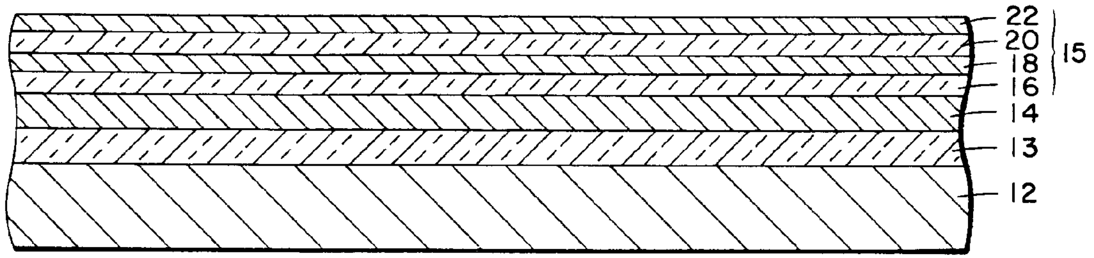

Fig. 1

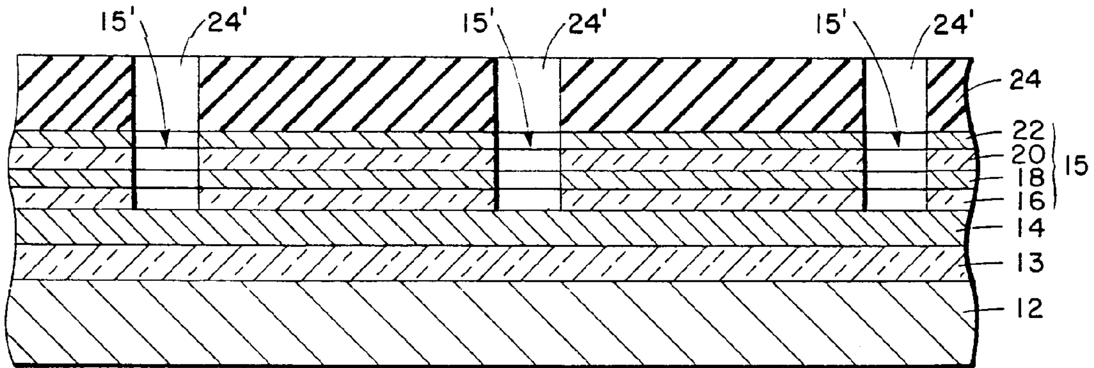

Fig. 2

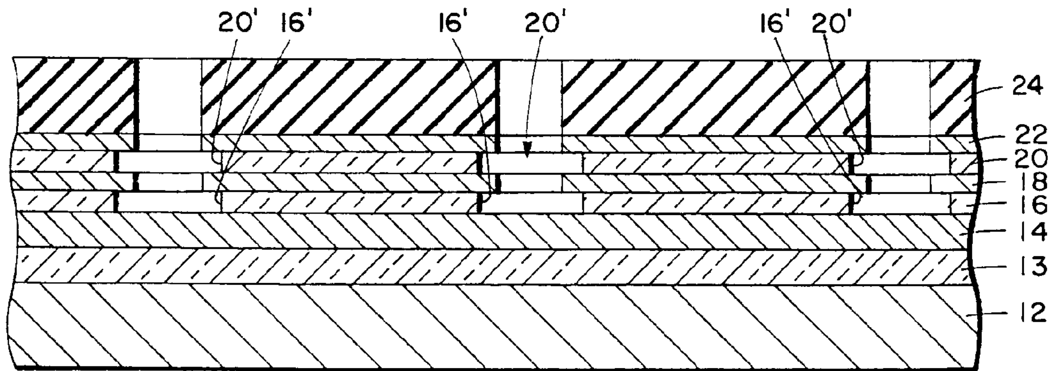

Fig. 3

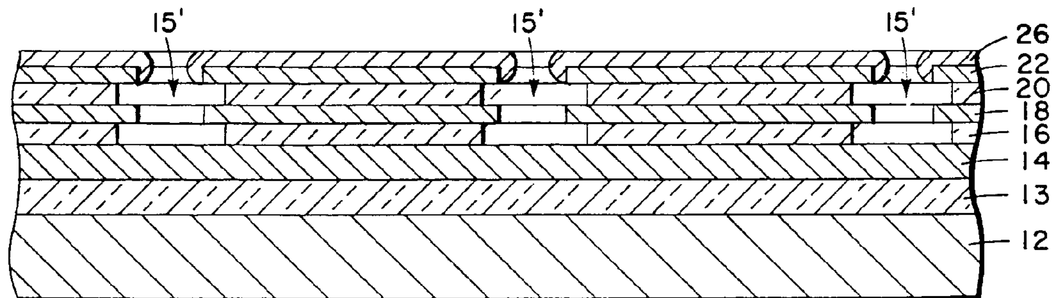

Fig. 4

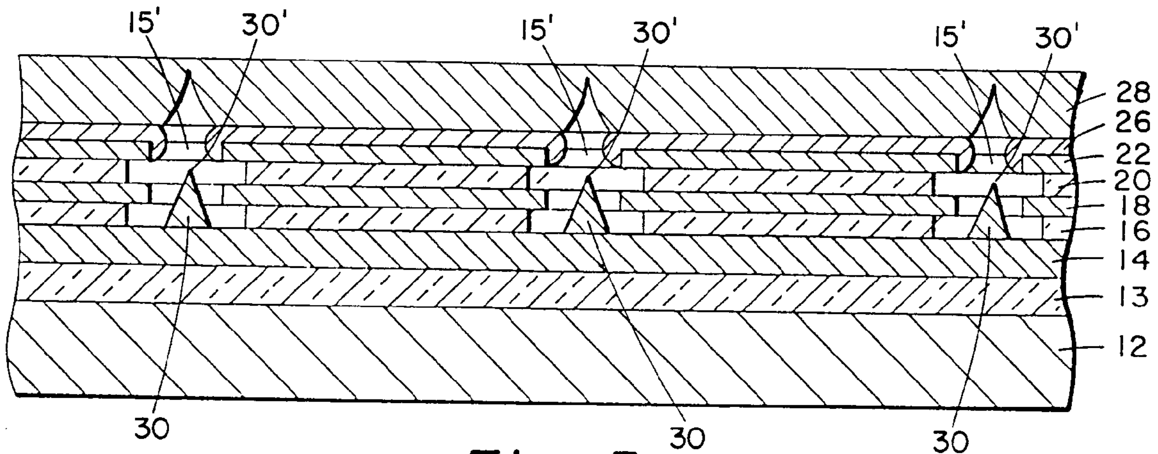

Fig. 5

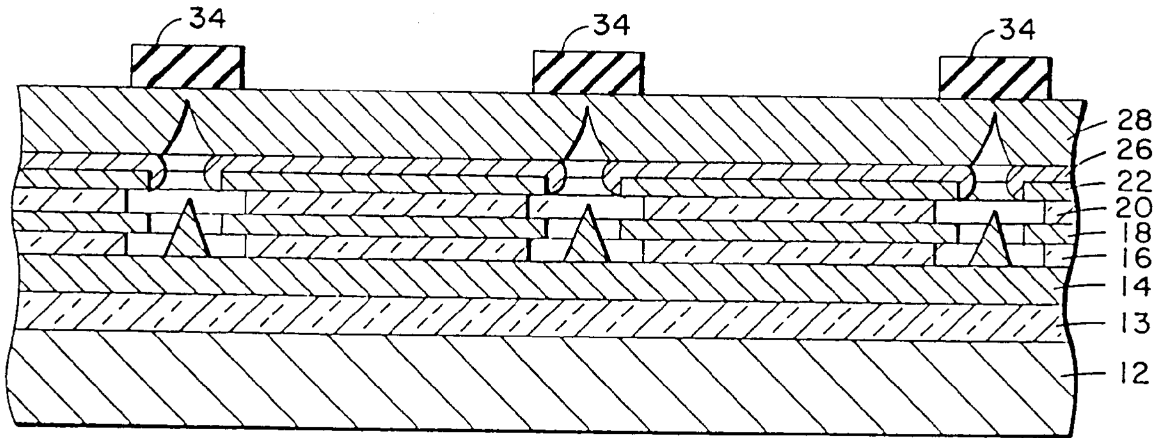

Fig. 6

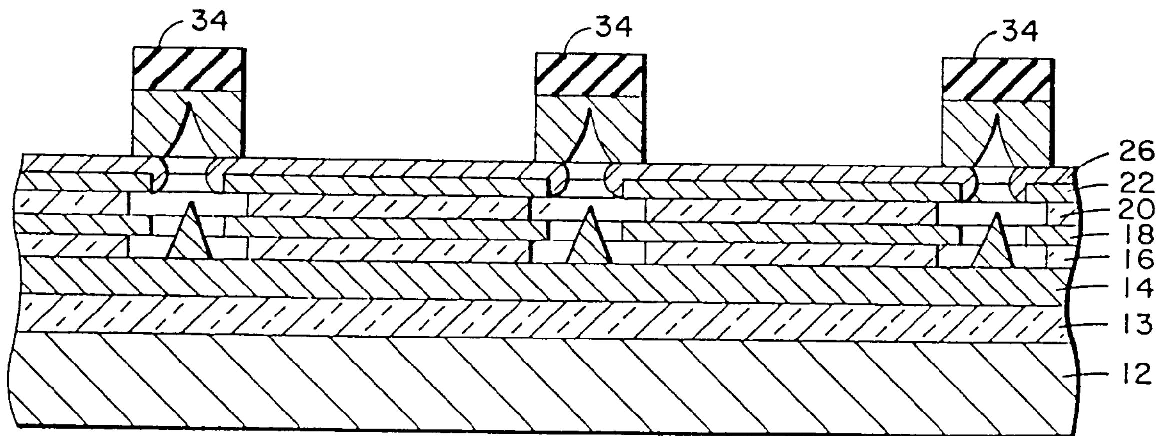

Fig. 7

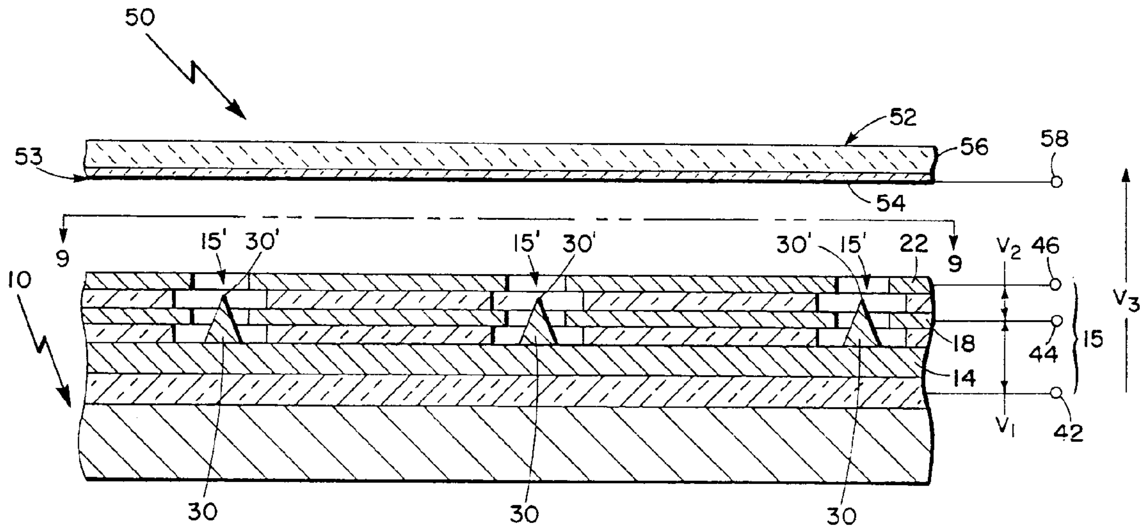

Fig. 8

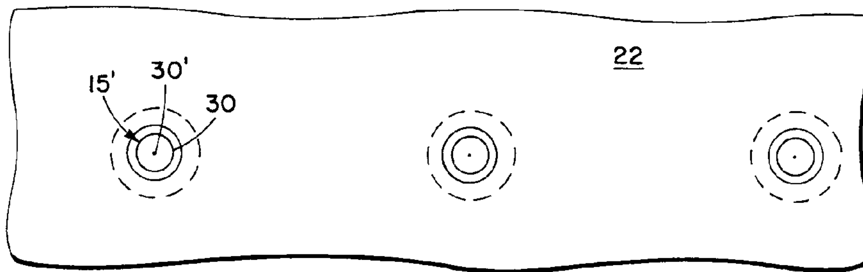

Fig. 9

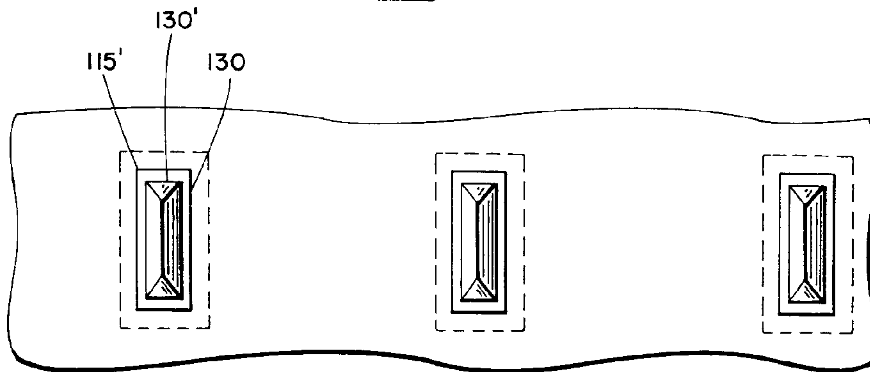

Fig. 10

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 92 30 5824

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X Y	US-A-5 007 873 (H.GORONKIN ET AL.) * Abstract * * Figs. 1A-F, 2A-C * * column 2, line 21 - column 4, line 8 * ---	1,4,6,7, 11,12 3,5,13	H01J9/02 H01J3/02
P,X P,Y	EP-A-0 483 814 (SONY) * Abstract * * column 17, line 7 - column 18, line 15 * * Claims 5,6 * * Figs. 14A-C * ---	1,2,9 3,5	
Y	US-A-3 753 022 (D.L.FRASER JR.) * Abstract * * Figs. 1,3-7 * * Claims 1-3 * ---	13	
X	EP-A-0 234 989 (COMMISARIAT A L'ENERGIE ATOMIQUE) * Abstract * * Claims 1-8 * * Figs. 7-9 * -----	1,9	**TECHNICAL FIELDS SEARCHED (Int. Cl.5)** H01J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	02 OCTOBER 1992	DAMAN M.A.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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D : document cited in the application
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