United States Patent

[11] 3,600,798

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Dallas, Tex.

[54] **PROCESS FOR FABRICATING A PANEL ARRAY OF ELECTROMECHANICAL LIGHT VALVES**
12 Claims, 20 Drawing Figs.

[52] **U.S. Cl.** .... **29/592,** 178/7.3 D
[51] **Int. Cl.** **H01s 4/00**
[50] **Field of Search** 29/592; 178/7.3

[56] **References Cited**

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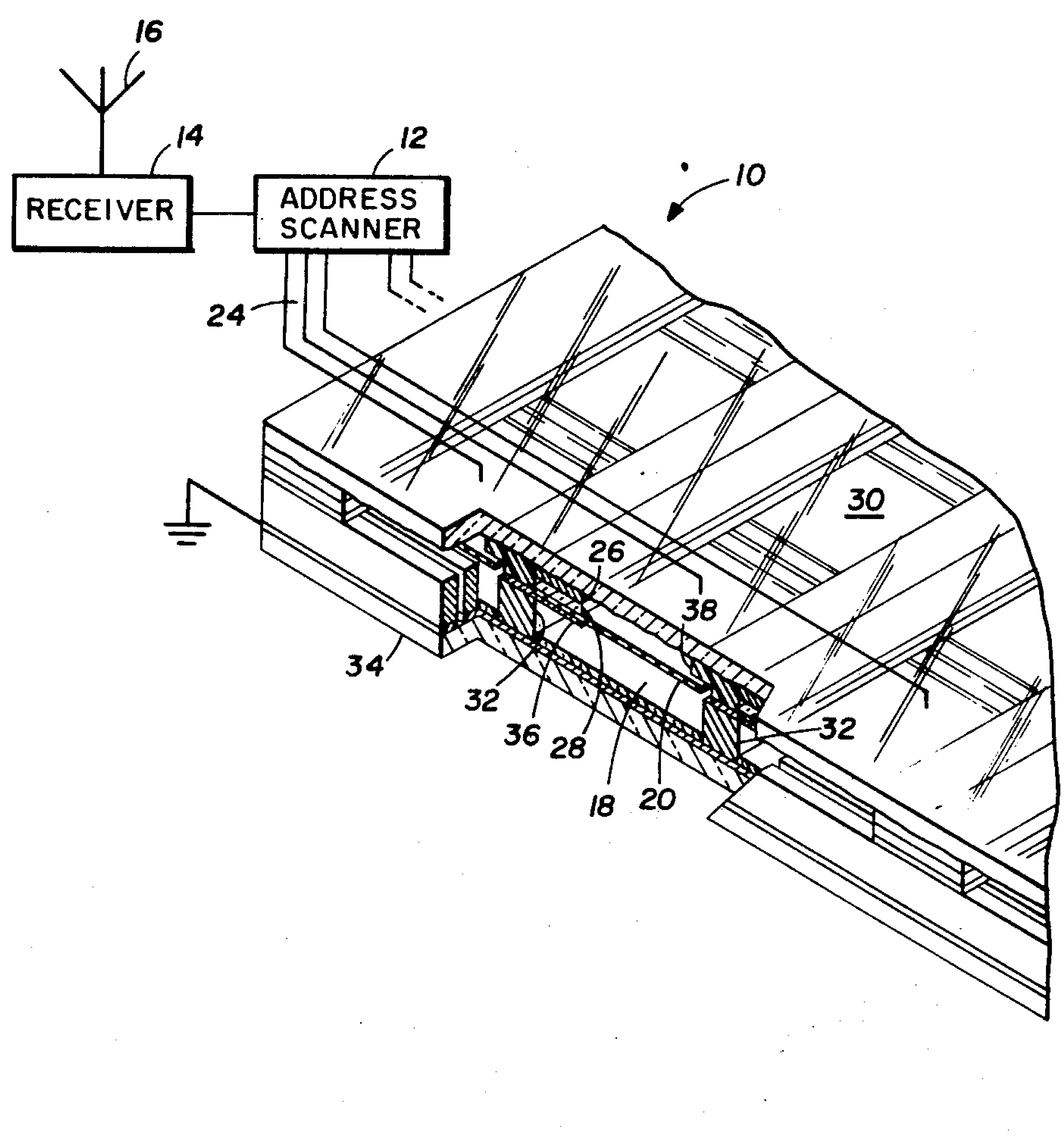
ABSTRACT: Electromechanical light valves in a panel array are fabricated by a process including several metal patterning steps. Each light valve consists of a housing having grounded conducting walls for shielding the interior thereof from external electrostatic forces produced by surrounding valves in the array or from other external electrostatic forces. These walls are formed in a series of processing steps on a light transparent substrate coated with a conductive coating. Light from a source enters one end of the housing through a light transparent substrate to which is mounted an electrostatically controlled leaf shutter for each valve also formed in a series of processing steps. Upon completion of the processing for forming the individual leaf shutters on the one transparent substrate and the valve housings on the other transparent substrate, the two transparent panels are aligned to form an array of electromechanical light valves. The display state of the individual light valves may be modulated by a video signal in a system that makes use of the capacitance of the individual valve as a storage device for transforming the video signal, which is available only during a writing time of short duration to a display signal. Necessary components for each of the light valves required in a display duration modulation system are fabricated in the process for producing the light valve array.



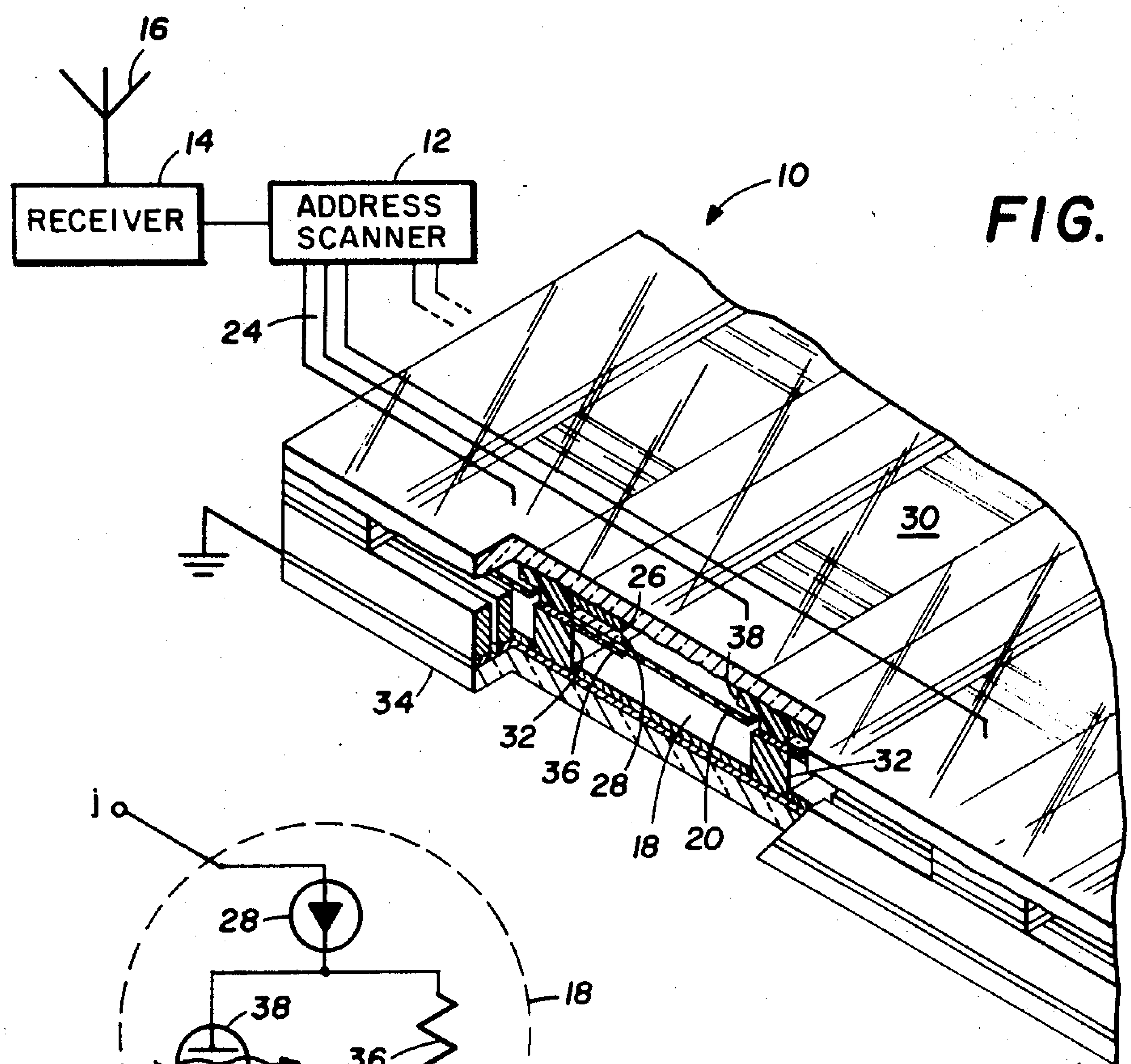


FIG. 1

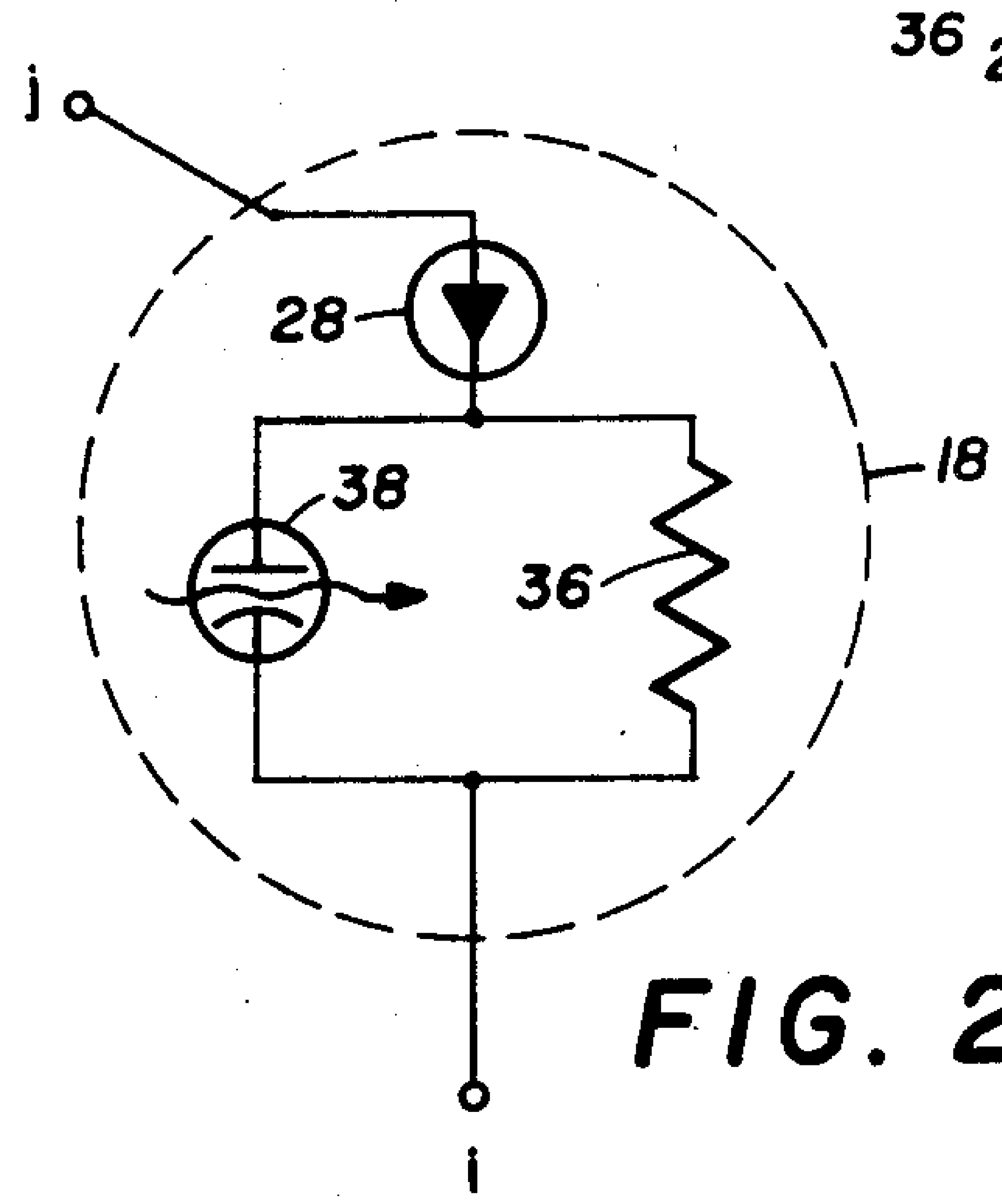


FIG. 2

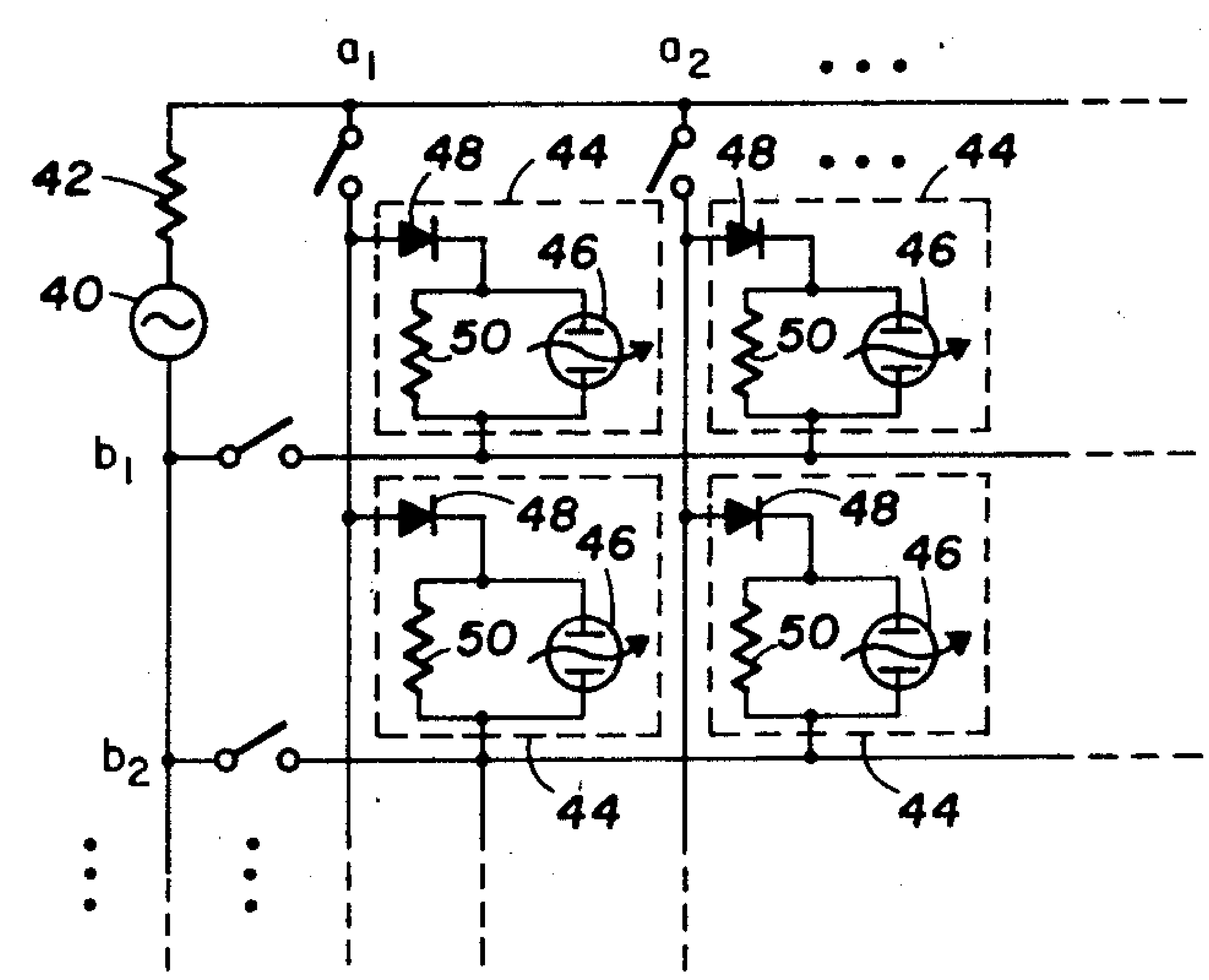


FIG. 3

INVENTOR:

RAY H. LEE

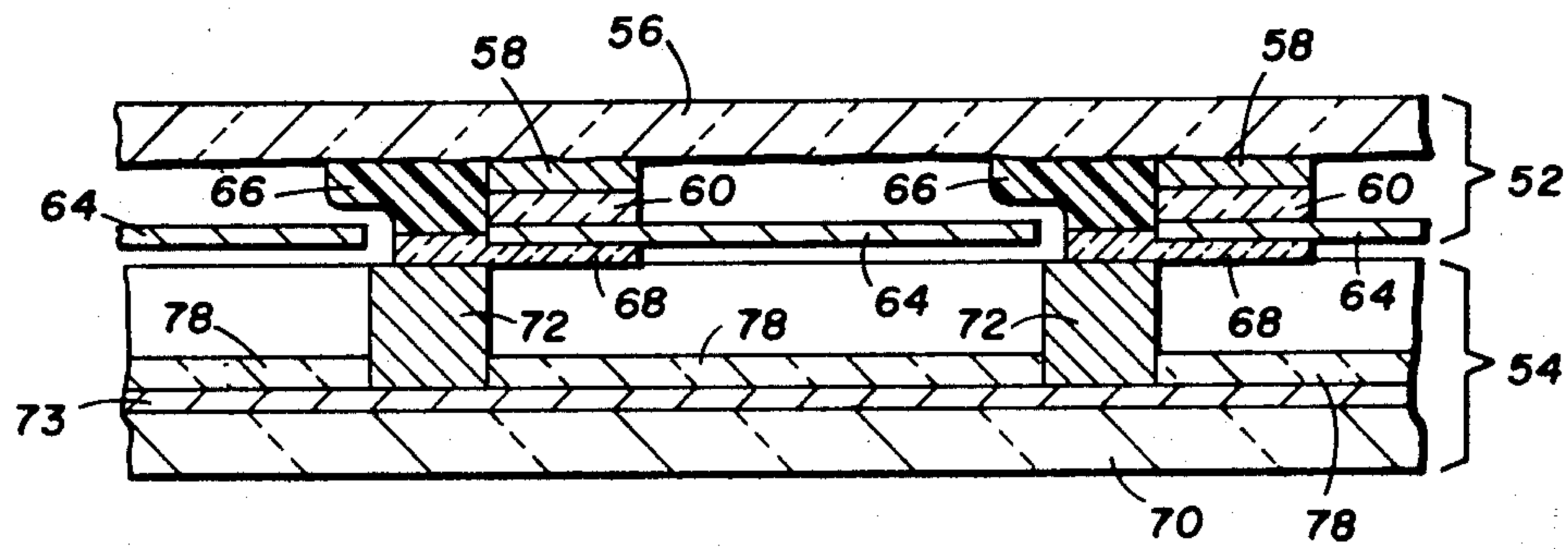


FIG. 4

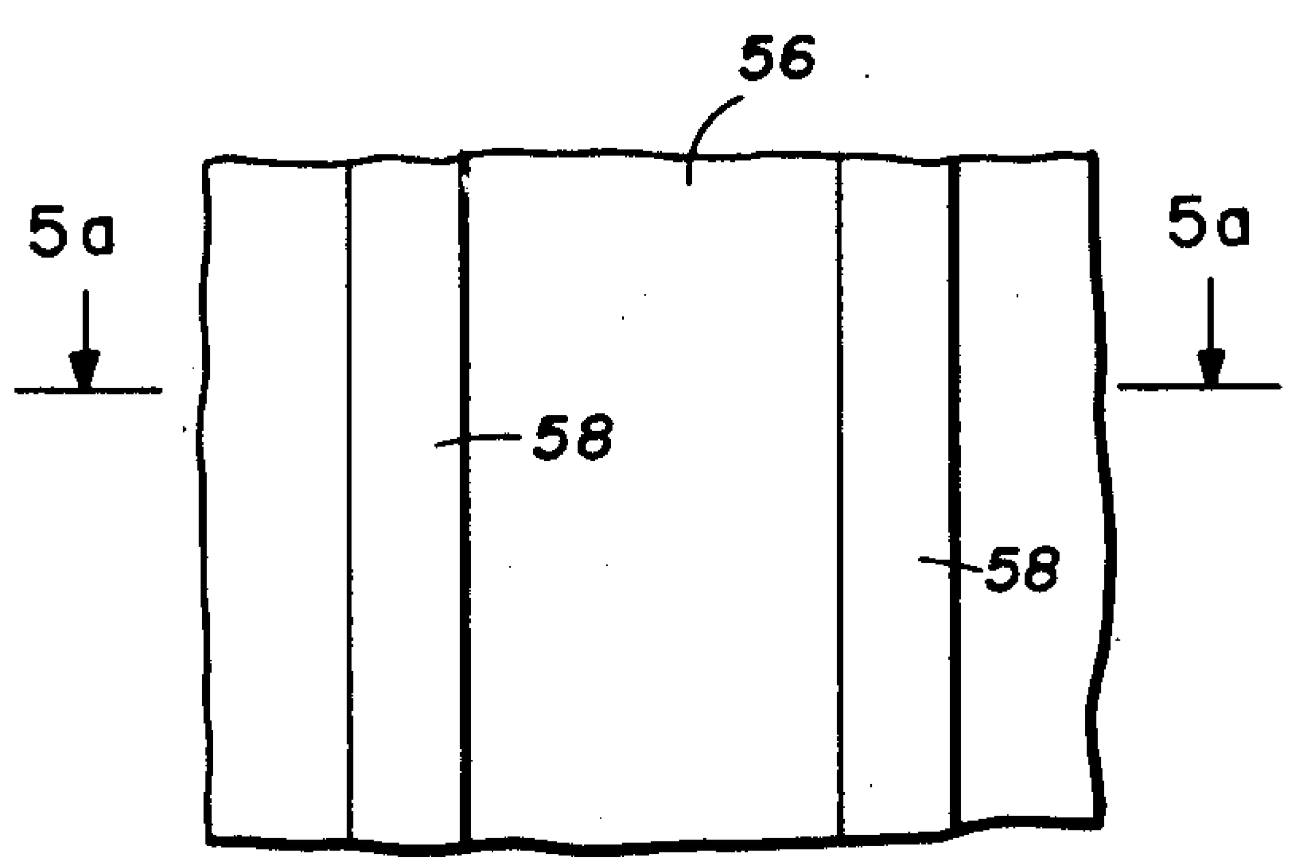


FIG. 5

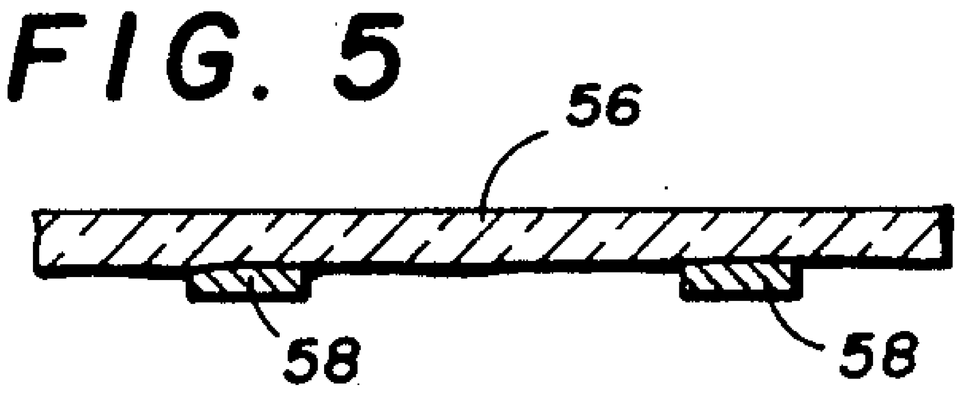


FIG. 5a

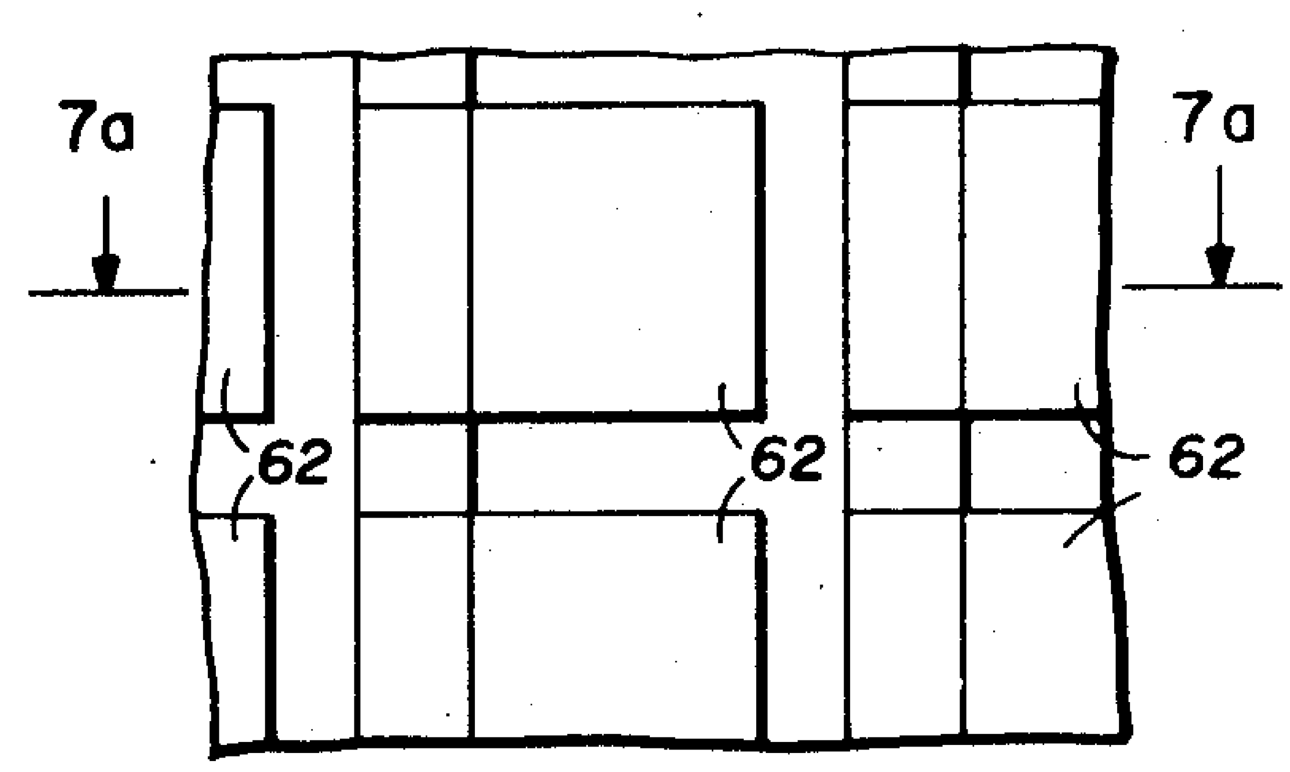


FIG. 7

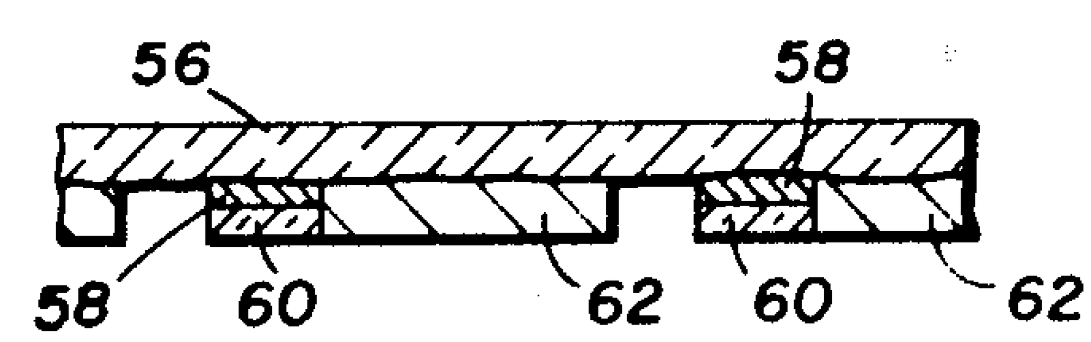


FIG. 7a

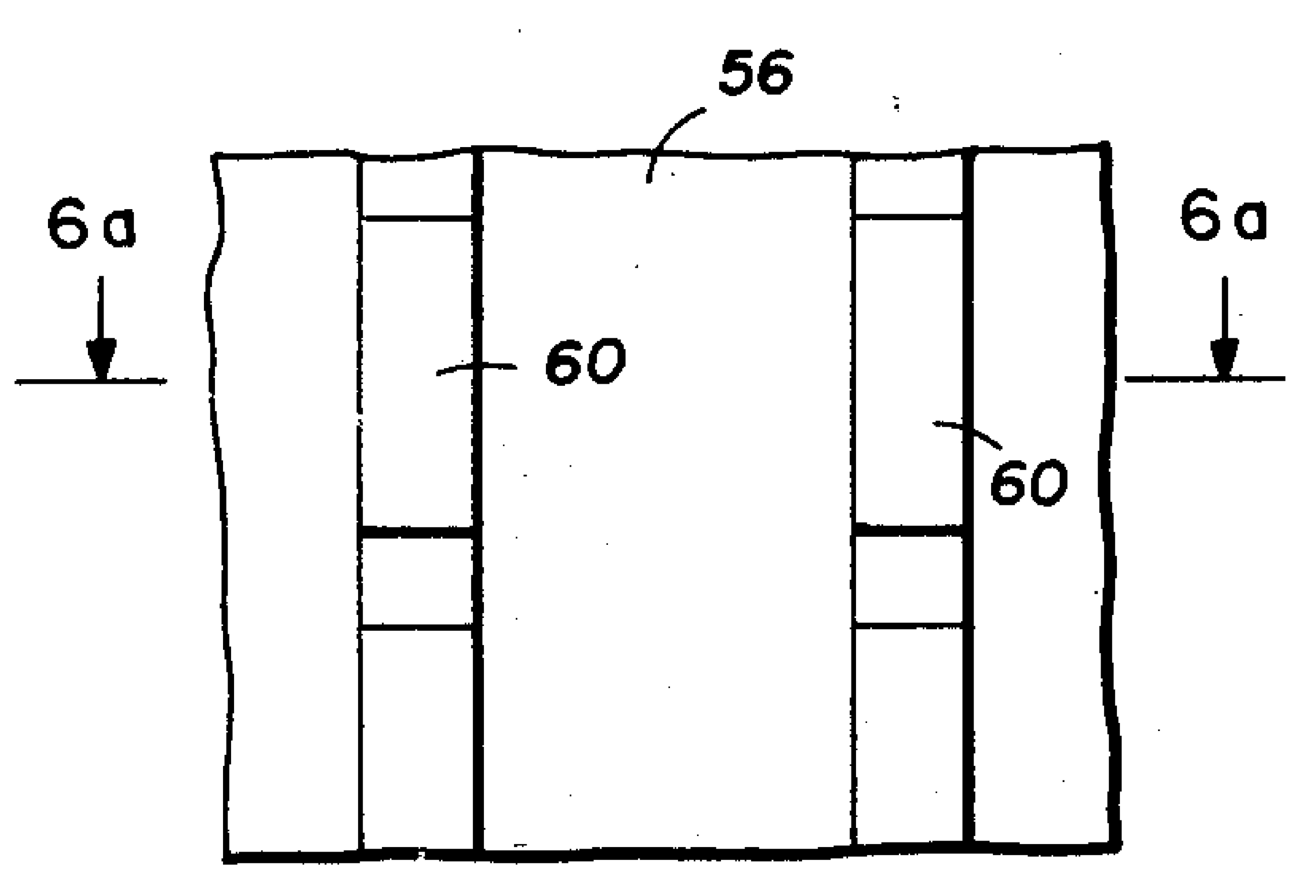


FIG. 6

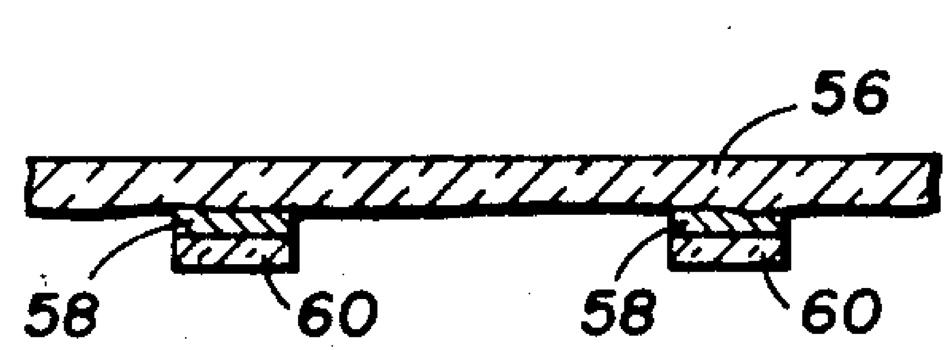


FIG. 6a

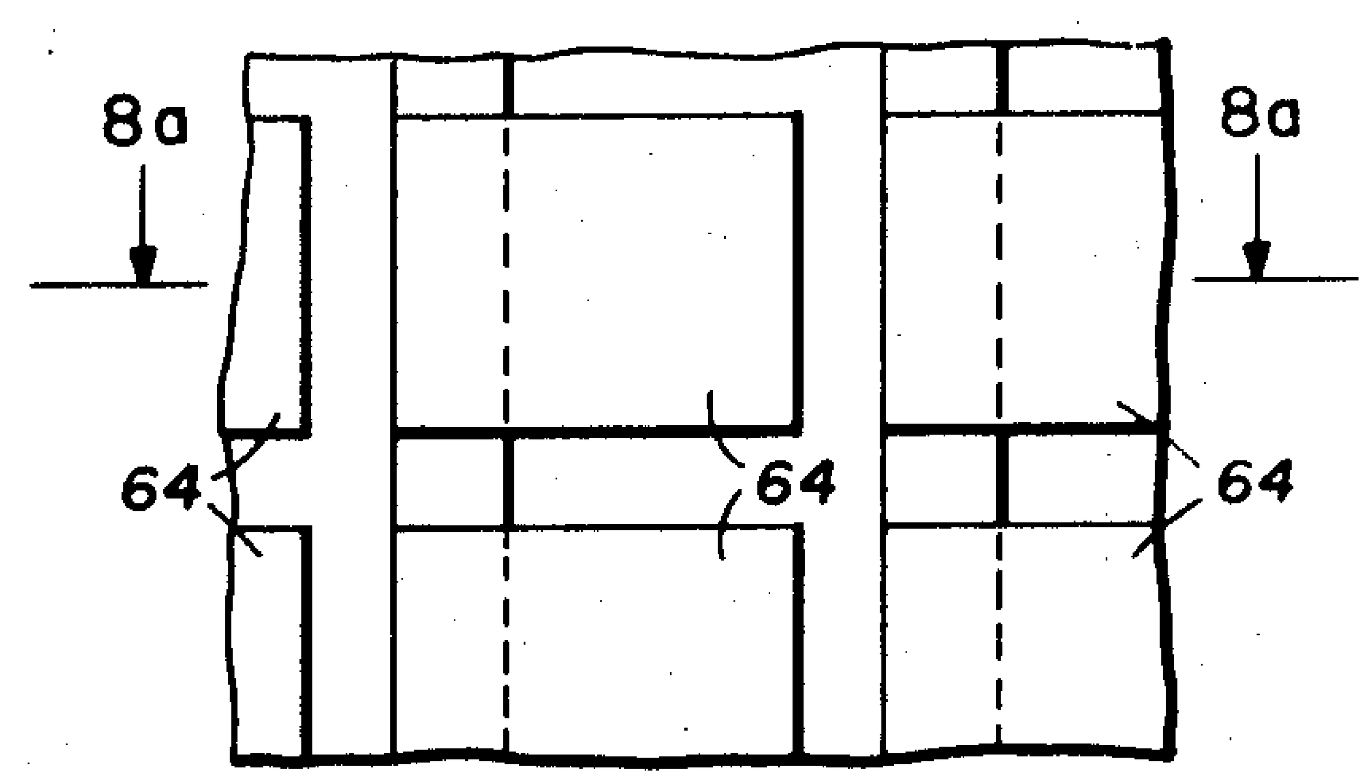


FIG. 8

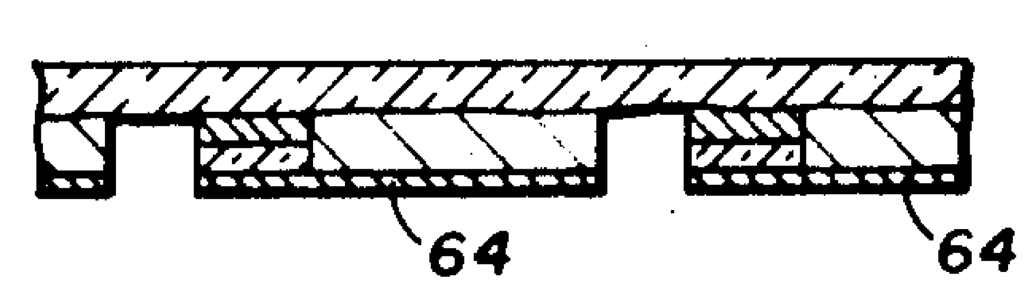


FIG. 8a

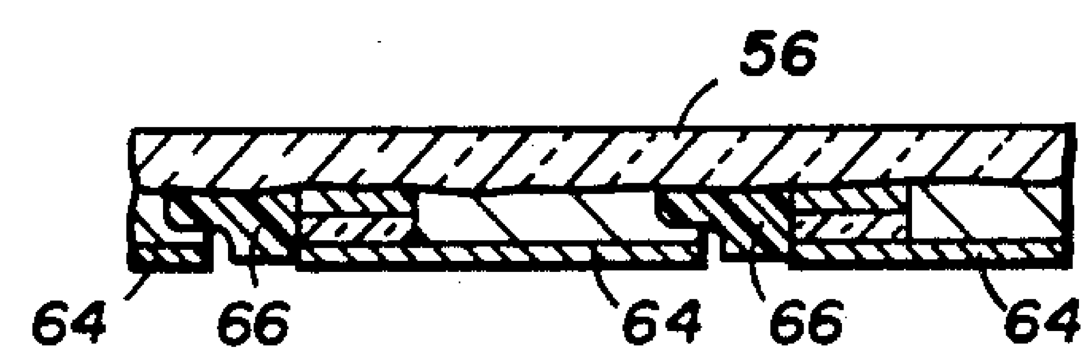


FIG. 9

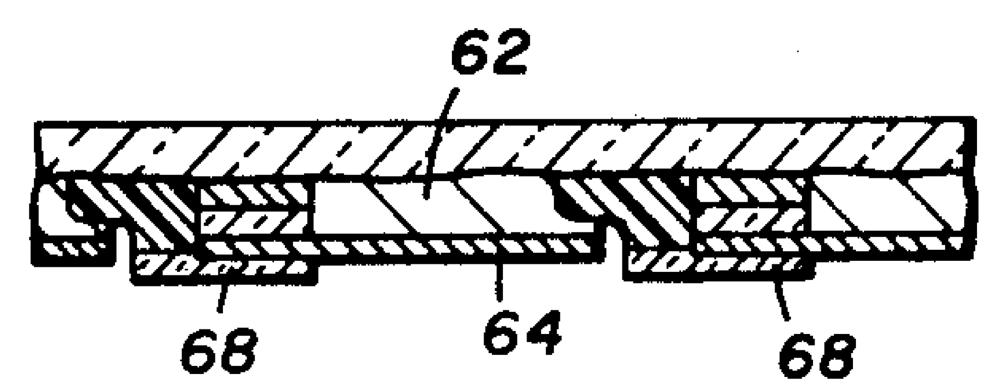


FIG. 10

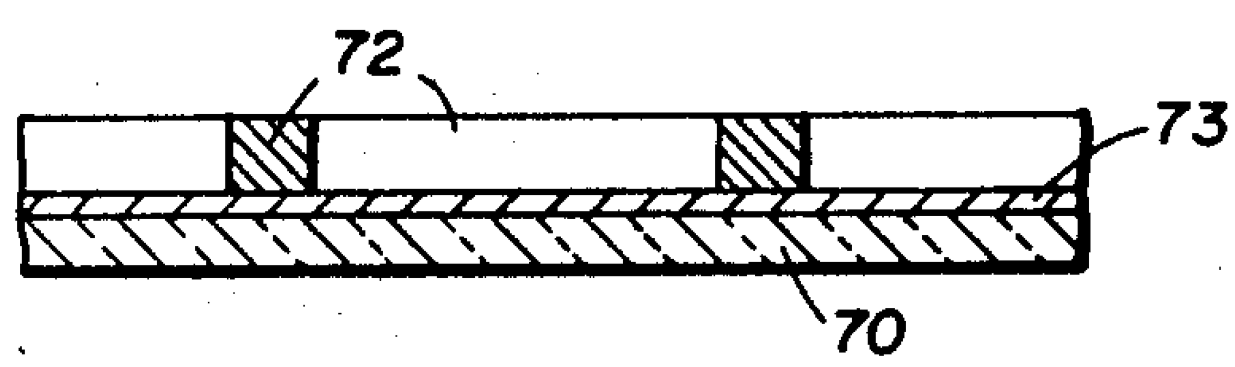


FIG. 11a

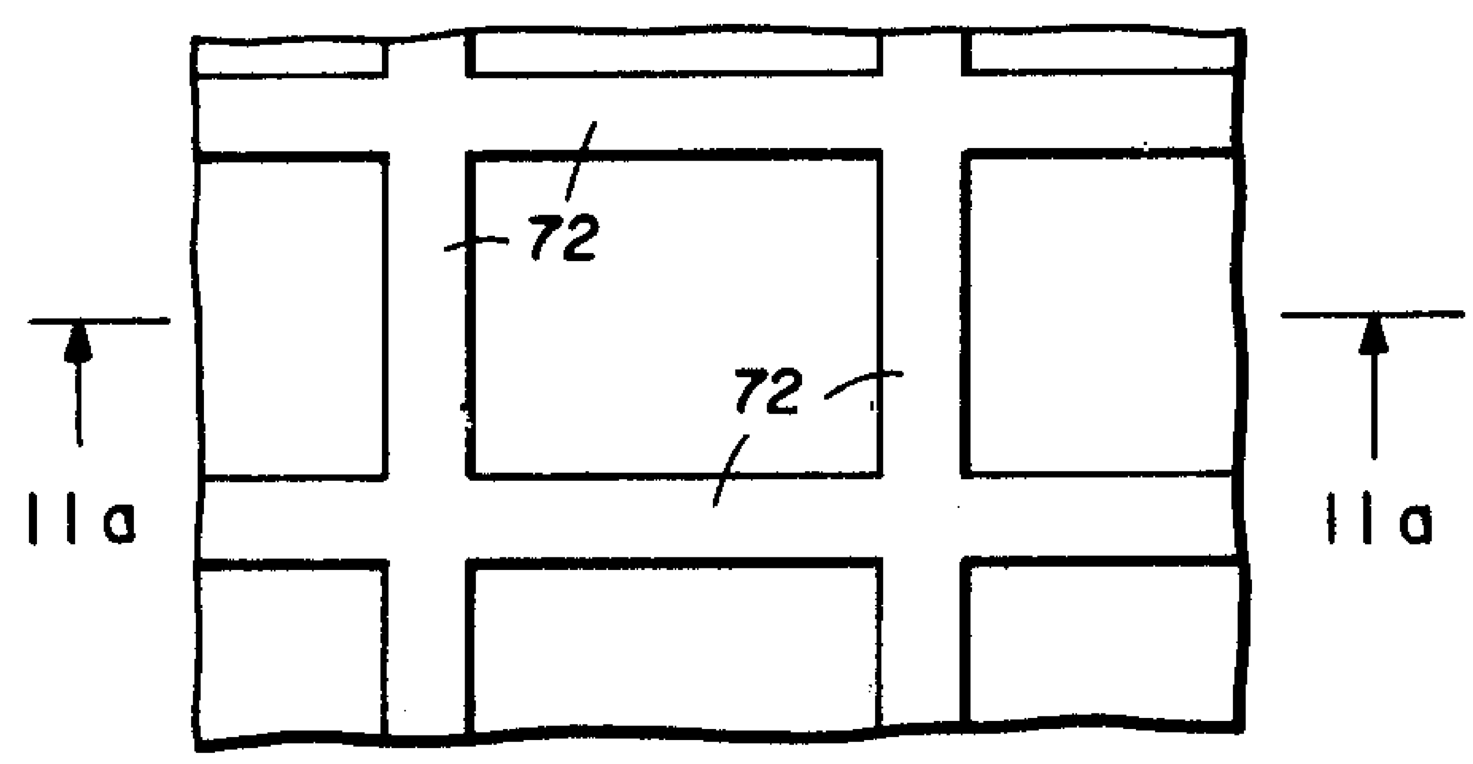


FIG. 11

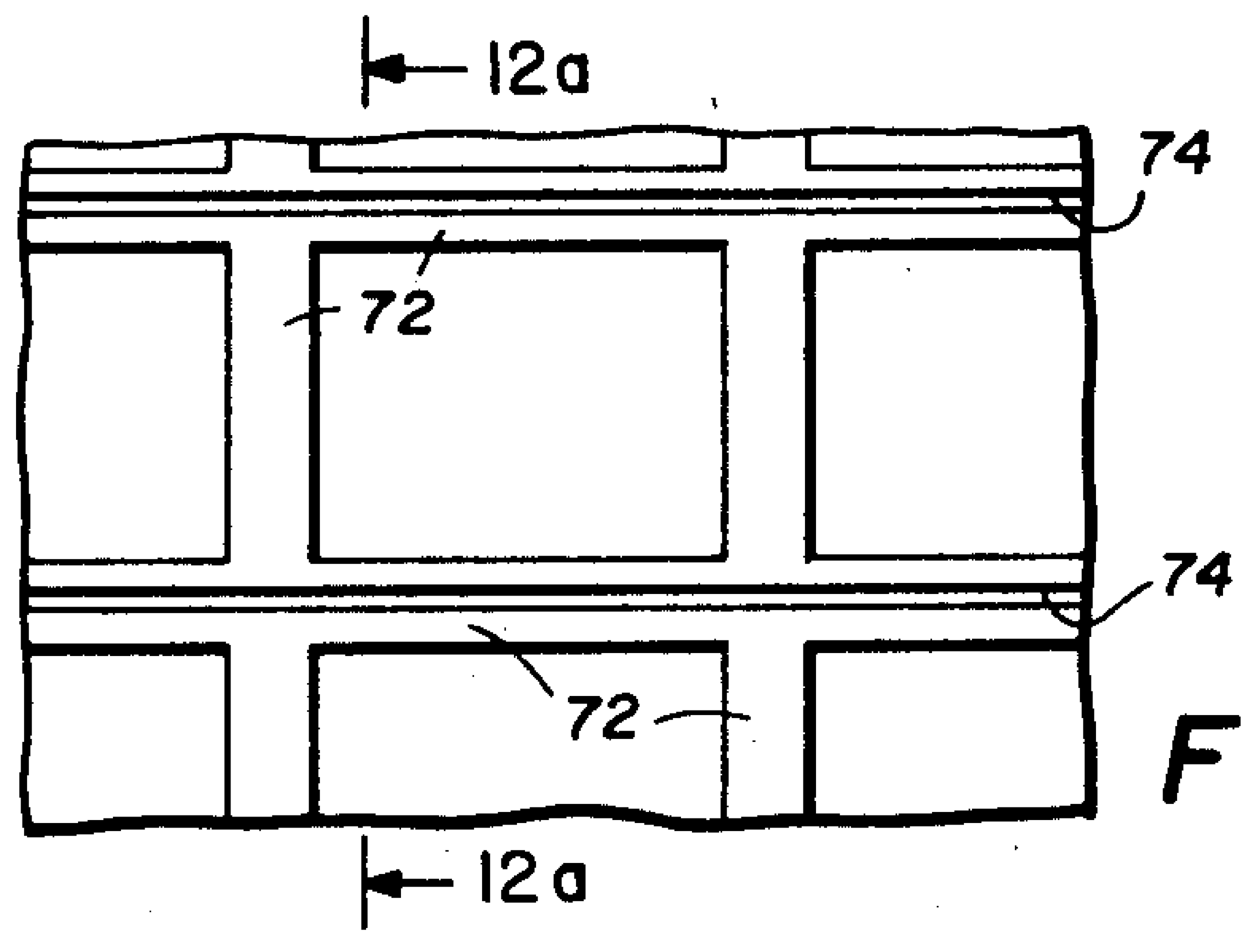


FIG. 12

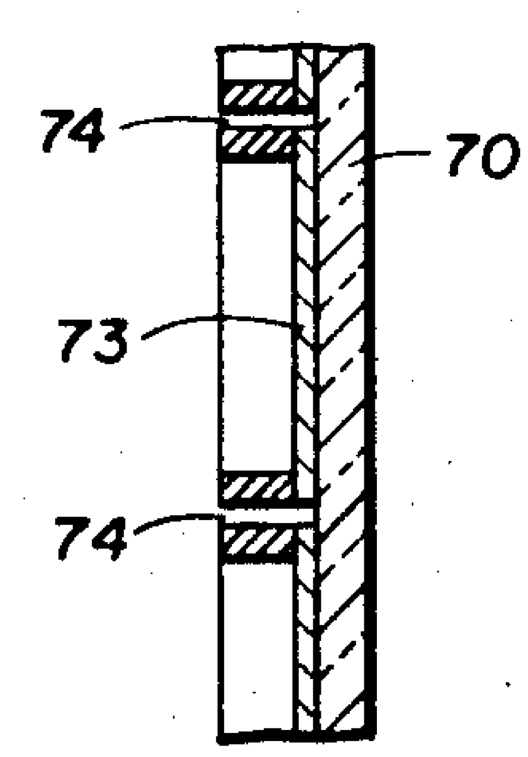


FIG. 12a

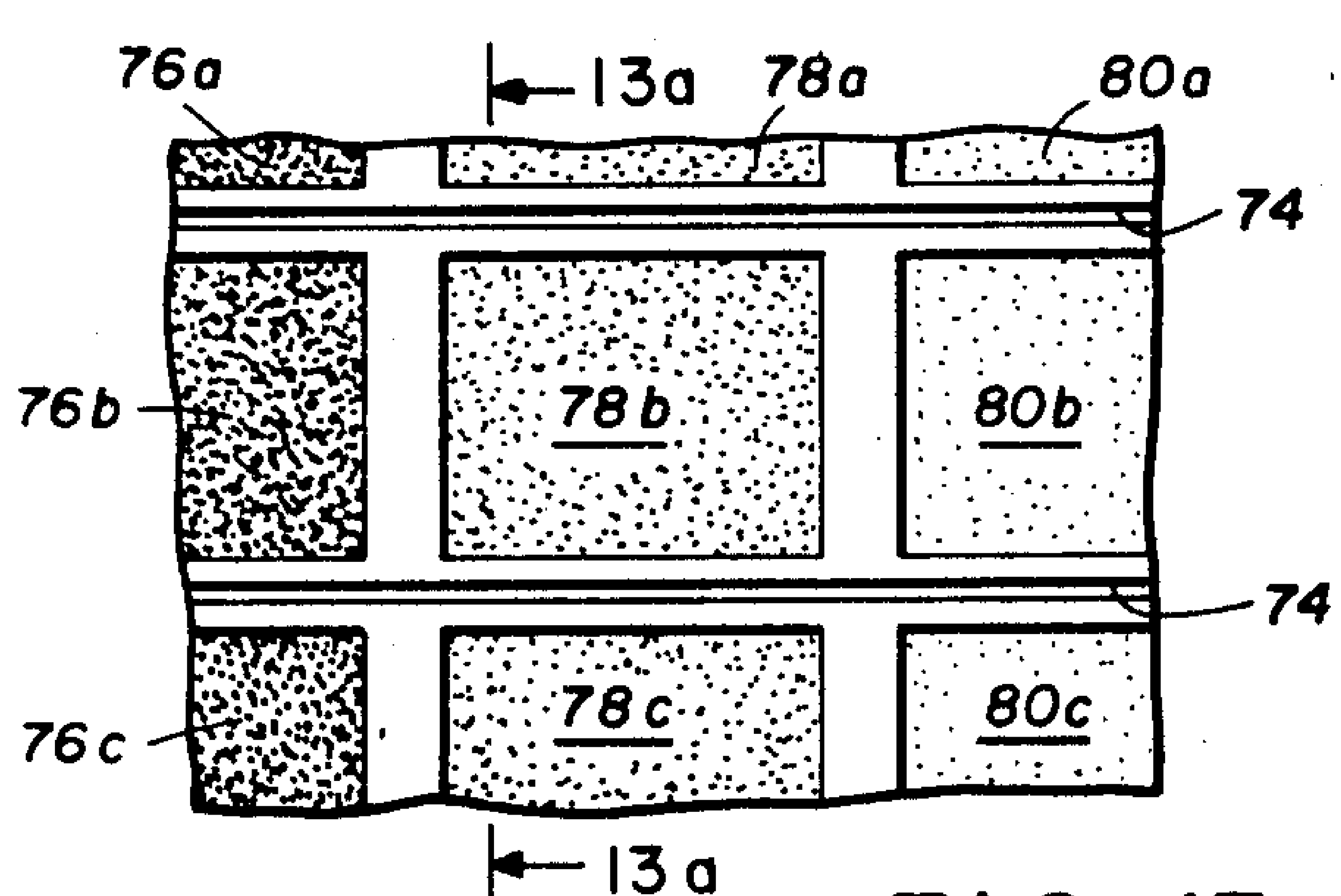


FIG. 13

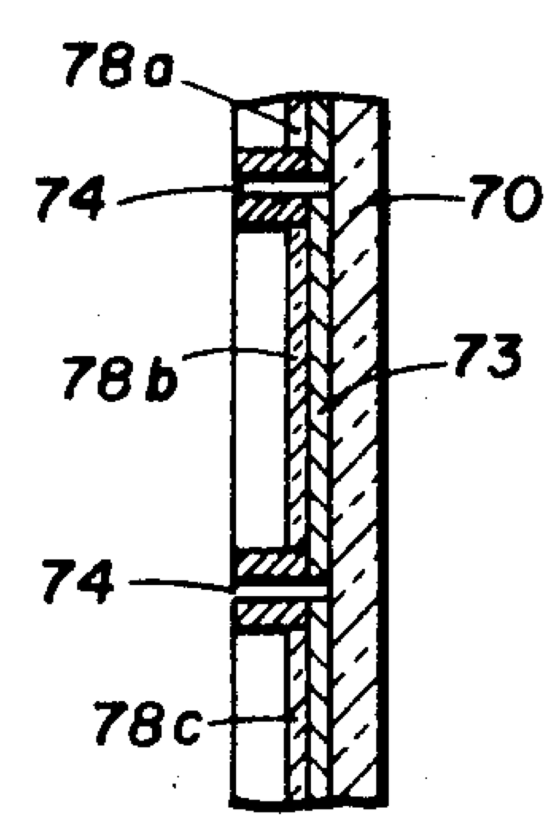


FIG. 13a

PROCESS FOR FABRICATING A PANEL ARRAY OF ELECTROMECHANICAL LIGHT VALVES

This invention relates to a light valve display panel, and more particularly to a process for fabricating a panel array of electromechanical light valves.

During the early development of television in the latter part of the last century, a picture was generated on the retina of the eye of an observer by the rapid movement and intensity fluctuation of a narrow light beam. Because of persistence of vision of the human eye, a picture was in fact generated although of a very low quality. A method in vogue in panel displays, such as television, during the first part of the present century built up a picture by controlling the transmission of a high-intensity light source by means of light valves. Two patents which issued about this time on light valves are U.S. Pat. No. 1,848,888 and U.S. Pat. No. 1,964,062.

Basically, such displays require two matching integral parts: addressing and a light valve. Addressing must be able to perform XY scanning as well as intensity modulation for a particular light element located at any XY location at the proper writing time. The light element, located in any XY position, must be able to respond to the writing and to effect a display.

As a result of inferior picture quality due to an inadequate addressing scheme and an operable light element, earlier efforts for producing a picture by means of light valves were abandoned in favor of its electron counterparts, the cathode ray tube. However, it is now realized that the cathode ray tube displays have their limitations especially when producing color pictures. Screen sizes larger than 25 inch diagonal measurement produce a picture that lacks brightness as well as being difficult to handle (too bulky) and smaller than a 21 inch diagonal measurement suffers in resolution on account of tolerance requirements.

In order to fully utilize the NTSC (National Television System Committee) color information, a display of an array of light valves should have 700 color triads per horizontal line and 525 interlaced horizontal lines per frame. Heretofore, it has been difficult to fabricate a display consisting of such a large number of light valves. An object of this invention is to provide a process for fabricating a large array of light valves for a display panel.

Another object of this invention is to provide a process for fabricating a large array of light valves simultaneously. A further object of this invention is to provide a process for simultaneously fabricating a large array of light valves and addressing circuitry for display duration modulation. Yet another object of this invention is to provide a process for producing color triads in a display of a large array of light valves. Still another object of this invention is to provide a process for producing an array of light valves by joining an upper section and a lower section.

In accordance with the present invention, a process for fabricating an array of light valves includes producing an array of shutter supports of a conductive opaque material on one side of a transparent substrate. Next, a shutter plate for each light valve in the array is deposited over the transparent substrate which has previously been covered with a separating material. The individual shutter plates have one edge thereof supported by a shutter support in a cantilever configuration. Next, an array of housing walls of an opaque conductive material are formed on a conductive coating covering a second transparent substrate. After the processing of both substrates has been completed, they are aligned and joined together to form a display panel of an array of light valves.

In accordance with a more specific embodiment of this invention, the individual shutter plates are deposited by evaporating a metal over the separating material and plating the evaporated metal to the desired thickness. For display duration modulation, an isolating element, such as a diode, is formed on the shutter supports prior to evaporation of the metal shutter plates. After the shutter plates have been developed to the desired thickness, a resistor is deposited on each at the supported edge that functions as a holding circuit with the capacitance of the shutter plate.

A more complete understanding of the invention and its advantages will be apparent from the specification and claims and from the accompanying drawings illustrative of the invention.

Referring to the drawings:

FIG. **1** is a perspective view of a light panel, partially cut away, of a large array of parallel light valves;

FIG. **2** is an equivalent circuit of one light valve in the array of FIG. **1**;

FIG. **3** is a schematic of an addressing scheme for a matrix of light valves arranged in rows and columns;

FIG. **4** is a cross section of one light valve in the array of FIG. **1**; and

FIGS. **5–13**, and FIGS. **5*a*–13*a*** illustrate the various processing steps for producing a display panel of an array of parallel-shutter light valves.

Basically, the system illustrated in FIG. **1** consists of a light panel **10** and an address scanner **12**. The address scanner **12** performs XY scanning of the panel **10** as well as intensity modulation (Z axis control) for each light valve of the panel array. A video receiver **14**, coupled to an antenna **16**, provides a video signal for the operation of the address scanner **12** in the usual manner of present day video-receiving systems. To generate the visual display for an observer on the panel **10**, a light source (not shown) is located on one side thereof. By selectively opening and closing each light valve in the panel **10** in accordance with a video signal received by the antenna **16**, an observer sees a picture display. Light valves that are used to make up the panel **10** may be parallel-shutter valves of the type described in the copending application of Ray H. Lee, Ser. No. 713,503, filed Mar. 15, 1968, and assigned to the assignee of the present invention.

In a typical television system in accordance with present day NTSC regulations, the panel **10** includes **525** scanning lines, a bandwidth chosen for equal area resolution with an aspect ratio of 4:3, and there would be two interlaced fields in one frame having a frame rate of 30 frames per second. Accordingly, in order to fully utilize the NTSC information, the panel **10** has $525\times(4/3\times525)=367{,}500$ light units (one light valve per unit for a monochrome display, two light valves per unit for a bicolor display, and three light valves per unit for a tricolor display). In terms of light units, the video information received at the antenna **16** comes in at a rate of 0.0906 microseconds per unit (roughly 0.1 microsecond). Thus, for sequential addressing each valve in the panel **10** must be able to be addressed within a writing time of 0.1 microsecond and updated once per frame time. Each frame time has a duration of 1/30 second.

Referring specifically to the light valve **18**, with the understanding that the other valves in the panel **10** are similar, a shutter plate **20** of an electrically conductive and opaque material is spaced from a conductive coating **22** of an electrically conductive and light transmissive material. The shutter plate **20** is connected to one output of the address scanner **12** by a line **24**, and the conductive coating **22** is connected to ground. The shutter plate **20** is supported on one edge by a column bar **26** extending along one dimension of the panel **10**. Between the shutter plate **20** and the column bar **26** there is formed an isolating element **28** (which may be either a diode or a nonlinear impedance element) that has a threshold change of impedance, being high at low voltages and low at high voltages. The isolation element **28** provides a means for unintentionally effecting other valves in the array when being addressed from the scanner **12**. The shutter plate **20**, the column bar **26** and the isolating element **28** are formed on a substrate **30** of an electrically insulating and light transmissive material.

Each of the light valves of the panel **10** shares a common wall with adjoining valves. These sidewalls **32** are of an opaque material either electrically conductive or covered with a conductive coating. The walls **32** are formed over the conductive coating **22** on a substrate **34** of an optically transparent and electrically insulating material. Between the top of the sidewalls **32** and the shutter plate **20**, there is formed a resistor **36** as part of a holding circuit, as will be explained.

Operationally, the light valve **18** uses the well known electroscope principle with the shutter plate **20** as one plate of a capacitor and the conductive coating **22** forming the second capacitor plate. A charge will be uniformly distributed, neglecting edge effects, over the facing surfaces resulting in a uniformly distributed load on the shutter and setting it in motion against the inertia and elastic properties of the shutter material. The voltage connected to the valve to deflect the shutter plate **20** is identified as the "pull-in" voltage, V_p. To return the shutter plate **30** to the discharged condition, as shown, the voltage to the valve must be reduced to the release voltage, V_r.

A video modulated voltage from the address scanner **12** charges the shutter plate **20** and the conductive surface **22** thereby generating the force on the shutter. This force causes the shutter **20** to be deflected to any "half-tone" position including in contact with the conductive coating **22**. Halftone positioning is the ability to control the shading of the image display. A charge placed on the shutter **20** and the conductive surface **22** will remain until the next frame time when the scanner **12** again addresses the light valve **18**.

Because the shutter plate **20** cannot be made close fitting with the housing walls **32**, a mask **38** extends along one dimension of the substrate **30** for each of the valves. This mask prevents light from being transmitted around the edge of the shutter plate **20** when in a noncharged condition.

Although the basic valve shown in FIG. **1**, without the isolating element **28** and the resistor **36**, has a measure of storage capability, to produce a halftone display with a plurality of such valves requires additional storage capability. This additional storage capability is provided for by means of an addressing scheme and the address scanner **12**. The addressing scheme includes a writing circuit and a holding circuit which control the display duration of each valve in an array. Referring to FIG. **2**, there is shown schematically an equivalent circuit for the light valve **18** including the isolating element **28**, illustrated as a diode, and the resistor **36**. A capacitor **38** is used to illustrate the shutter plate **20** and the conductive coating **22**. This capacitor stores a drive signal from the address scanner **12** during a writing time to maintain the light valve **18** in one of two light states. To hold the shutter plate **20** in a deflected position for the remainder of one frame time, that is, until the valve **18** is again addressed, the resistor **36** and the capacitor **38** form a holding circuit. This circuit has a time constant long in comparison to one frame time. For a complete description of the operation of the addressing system for a light panel, reference is made to the copending U.S. application of Ray H. Hee, Ser. No. 742,365, filed July 3, 1968, and assigned to the assignee of the present invention.

Referring to FIG. **3**, there is shown an addressing scheme for a matrix of light valves arranged in rows $b_1, b_2 ... b_m$ and columns $a_1, a_2 ... a_n$ to be subsequently coupled to a video signal source **40** through a writing resistor **42** by means of single pole single throw switches. Each valve branch includes a light valve **44** having a capacitor **46**, an isolating element **48**, and a resistor **50**. Assume the switch in column a_1 and the switch in row b_1 are coupled to one side or the other of the source. The diode **48**, however, in all the light valves **44**, except the one coupled to both terminals of the source **40**, will be reversed biased thereby isolating these valves.

In operation, during the writing time for each valve the switches in the appropriate row and column are closed, thereby charging the capacitor **46** to the value of the video signal from the source **40**. At the completion of the writing time for a particular valve, the column switch for that valve will be opened and the next column switch closed. At the completion of one row, both the column and row switch will be opened and the next row switch closed. The first column switch is then closed and all the valves in the second row are subsequently connected to the video signal source **40**. Between subsequent couplings of a particular valve to the video signal source **40**, that valve is considered to be in a holding state and the display condition will be determined by the magnitude of the video signal connected thereto during the writing time, and the component values for the resistor **50** and capacitor **46**.

Referring to FIG. **4**, there is shown a cross section of a light valve fabricated in accordance with the process of the present invention. The valve is fabricated by joining an upper section **52** to a lower section **54**, each of which are processed independently. The substrate **56** for the upper section of the light valve is glass with the outside surface optically ground.

The processing steps for the upper section **52** are sequentially illustrated in FIGS. **5**—**10*a***. Initially, a metal is vacuum evaporated as a thick film on the rough side of the substrate **56**. Vacuum evaporation techniques have been developed over the years and are considered to be sufficiently well understood such that a detailed description will not be necessary. Basically, the substrate to be coated is mounted in a highly evacuated glass (or metal) bell jar in which a filament is brought to a high temperature by passing an electric current through it. The material to be evaporated, which may be in contact with the filament, is heated sufficiently to cause quick vaporization. The evaporated molecules from the source strike the substrate and adhere thereto. This process continues until the desired film thickness has been attained.

By photomasking and etching techniques, the film of metal on the substrate **56** is patterned into column bars **58** as illustrated in FIGS. **5** and **5*a***. These column bars provide a support for one edge of the shutter plate as to be described. If the isolating element **28** is a nonlinear impedance it may be constructed by a layer of appropriate polycrystalline powder in a binder. Using either a silk screening or a photoprocessing technique, the mixture of polycrystalline powder and the binder are deposited on top of the column bars **58**. The results of this step are illustrated in FIGS. **6** and **6*a*** wherein the powder and binder material forms areas **60** over the column bars **58** as mounted to the substrate **56**.

After forming the isolating elements, a second vacuum evaporation step covers the area between the column bars **58** with a material that may be differentially etched for removal in a later step. This second metal evaporation is patterned, such as by photomasking and etching techniques, to form islands **62** precisely in the area to be covered by the shutter plates. These islands are shown in FIGS. **7** and **7*a***. The thickness of the islands **62** will be such that the upper surface thereof is flush with the upper surface of the isolating element areas **60**. Next, a thick film of metal is vacuum evaporated over the islands **62** and the isolating element areas **60**. Although thick film techniques are used in the processes herein described, additional thickness than can be obtained by such techniques is required for the shutter plates. Thus, after evaporating the initial layer for the shutter plates **64**, additional metal is added by controlled plating to the desired thickness.

There are a number of plating techniques that may be employed to develop the initial evaporative film to the desired thickness. Gas plating (including hydrogen reduction and thermal decomposition), electroplating and electroless plating are three methods of adding additional metal for building up the shutter plates **64**.

After the shutter plates **64** have been plated to a desired thickness, as illustrated in FIGS. **8** and **8*a***, the islands **62** are selectively etched and a mask **66** formed in the area between the column bars **58** and the cantilever end of the shutter plates. The mask **66** may be formed by depositing an insulating material to the rough surface of the plate **56** as illustrated in FIG. **9**. Next, resistor areas **68** are formed over the mask **66** and the supported section of the shutter plate **64**, as illustrated in FIG. **10**. These resistor areas may be formed by silk screening or by photoprocessing. The silk-screening process used is an adaptation of that used for years by printers and artists. Resistive elements known as cermets (a combination of the words ceramic and metal) may be deposited by the silk screen method. Photoprocessing techniques for forming the resistors **68** are also well known in the art.

Next, the islands **62** are completely removed from under the shutter plates **64** by an etching operation. The upper half of the light panel is now complete with a row and column array of shutter plates formed on the substrate **56** together with isolation elements and resistors for each light valve.

For the lower section **54** of the panel, the substrate **70** is a lamination of metal (a few mils thick), a conductive and transparent coating, and glass. The steps for processing the lower section **54** are illustrated in FIGS. **7**—**13***a*. Initially, the metal side of the laminated substrate **70** is coated with a negative resist. A pattern outlining the side walls **72** of the individual light valves is placed over the negative resist. Using contact printing techniques, the negative resist is exposed and developed through the pattern. The metal layer in the areas other than the walls **72** is removed by a chemical etch. This etching proceeds to the conductive coating **73**, but does not remove this coating. After the etch has been completed, the negative resist is removed from the upper side of the walls **72**.

Another coating of negative resist is applied to the metal side of the substrate **70**. This resist layer is exposed and developed by contact printing using a photomaster of opaque parallel lines designed to separate the light valves into rows. Another etching step removes the metal and the conductive coating in the parallel line areas down to the glass. This step produces channels **74**, as illustrated in FIGS. **12** and **12***a*, for separating the light valves in one row from those in adjoining rows.

At this point, the upper section **52** and the lower section **54**, as processed through the step illustrated in FIG. **12**, could be joined to form a monochromatic display. To form triads for a color display, additional processing is required. A negative resist colorized by mixing with a dye or pigment is applied to the sections **76***a*, **76***b* and **76***c*. This colorized negative resist is exposed through the glass side and developed to produce one of the desired color filters of the three primary colors, red, blue, or green. This same process is repeated for each of the other two primary colors. Next, sections **78***a*, **79***b* and **78***c* are coated with a colorized negative resist that is exposed through the glass side and developed. Finally, the sections **80***a*, **80***b* and **80***c* are coated with a colorized negative resist. This resist is again exposed through the glass side and developed to form the third color filter for a tricolor display.

The final step in the fabrication of the light panel **10** of an array of light valves is the alignment of the lower section **54** with the upper section **52** as illustrated in FIG. **4**. When properly aligned, the sidewalls **72** are positioned to permit deflection of the shutter plate **64** toward the conductive coating **73** over the substrate **70**. Each light valve in the array is electrically isolated from others in the array by means of the isolating elements defined by the area **60** and the channel **74**. Light striking the panel **10** from the substrate **56** side will be blocked when the shutter plates **64** are parallel to the conductive coating of the substrate **70**. Upon a charge being placed on any one of the shutter plates, that particular plate will be deflected toward the substrate **70**, thereby permitting light to be transmitted through that area as enclosed by the sidewalls **72**. Other shutter plates which have not been deflected, however, will continue to block light from passing through the panel. After the upper section **52** and the lower section **54** have been properly aligned, they are held in place by application of an environmental seal to assure an air-dragfree operation. The light element panel is now complete.

While the invention was described with reference to preferred embodiments, together with modifications thereof, it will be evident that various further modifications are possible without departing from the scope of the invention.

I claim:

1. A process for the fabrication of an array of light valves comprising:

forming an array of shutter supports of a conductive opaque material on one side of a first transparent substrate,

covering the first substrate with a separating material in areas defining the configuration of the light valve array,

depositing a shutter plate for each light valve in the array with one edge thereof supported by a shutter support over the separated material,

forming an array of valve walls of a conductive opaque material on a conductive coating covering a second transparent substrate,

removing the separating material from the first substrate to form an array of cantelevered shutter plates, and

aligning the supports on the first substrate with the valve walls on the second substrate and joining the two substrates to form an array of light valves.

2. A process for fabricating an array of light valves as set forth in claim **1**, wherein the step of depositing the shutter plates includes evaporating a metal over a supporting material covering the first substrate, and plating the evaporated metal to the desired thickness.

3. A process for fabricating an array of light valves as set forth in claim **2**, wherein the step of forming the array of valve walls includes selectively etching a metal film laminated to the conductive coating covering the second transparent substrate.

4. A process for fabricating a column and row array of light valves comprising:

producing an array of support bars in columns of a conductive opaque material on the rough side of an optically ground glass substrate,

covering the glass substrate with a separating material in areas defining the row and column configuration of the light valve array,

depositing a metallic shutter plate for each light valve in the array with one edge thereof supported by a support bar over the separating material,

forming an array of valve walls in a row configuration of a conductive opaque material on a conductive coating covering a second glass substrate,

removing the separating material from the first glass substrate to form a cantilever shutter plate, and

aligning the supports on the first glass substrate with the valve walls on the second substrate and joining the two substrates to form an array of light valves in a row and column.

5. A process for fabricating a column and row array of light valves as set forth in claim **4**, including the step of forming isolation elements for isolating one valve from others in the array on each support bar intermediate the step of producing the support bars and covering the glass substrate with a separating material.

6. A process for fabricating a column and row array of light valves as set forth in claim **5**, including the step of depositing a resistor between the supported edge of the shutter plate and the valve walls intermediate the steps of forming the array of valve walls and removing the separating material.

7. A process for fabricating a column and row array of light valves as set forth in claim **6**, including the step of producing color filters of the three basic colors in a pattern over the entire light valve array after the step of forming the array of valve walls.

8. A process for fabricating a column and row array of light valves as set forth in claim **7** wherein the step of producing the array of support bars includes evaporating a metal over the rough side of the optically ground glass substrate, and selectively etching the metal to form an array of columns.

9. A process for fabricating a column and row array of light valves as set forth in claim **8** wherein the step of depositing the shutter plates includes evaporating a metal over the separating material, and plating the evaporated metal to the desired thickness.

10. A process for fabricating a column and row array of light valves as set forth in claim **9**, wherein the step of forming the array of valve walls includes selectively etching a metal film laminated to the conductive coating covering the second glass substrate.

11. A process for fabricating a column and row array of light valves comprising:

evaporating a metal to the rough side of an optically ground glass substrate,

selectively etching the evaporated metal to form conductive column bars on said glass substrate,

forming an isolation element for isolating one light valve from the others in the array on each conductive column bar,

evaporating a separating material in the space next to the formed isolated element on each column in the area to be covered by a shutter plate,

evaporating shutter plates extending over the isolating elements and the separating material,

plating the shutter plates to a desired thickness to form a metallic shutter plate for each light valve in the array with one edge thereof supported by a column bar,

forming resistors on the shutter plates in the area of the supported edge,

differentially etching the separating material from the first glass substrate to form a cantilever light valve shutter,

patterning a metal film laminated over a conductive coating covering a second glass substrate in a configuration to outline sidewalls for each light valve in the array,

selectively etching the metal film laminate from the second glass substrate to form an array of valve walls,

differentially etching the laminated film and the conductive coating to the glass substrate in a pattern of parallel lines perpendicular to the column bars to separate the light valves into rows, and

aligning the column pattern and shutter plates on the first substrate with the valve walls on the second substrate and joining the two substrates to form an array of light valves in a row and column configuration.

12. A process for fabricating a column and row array of light valves as set forth in claim 11 including:

coating the conductive coating of the second substrate with a negative resist colorized with one of the three primary display colors,

exposing and developing the negative resist to obtain one of the desired color filters, and

repeating the above two steps for the other two primary colors to obtain colored filters of the three primary colors in a pattern over the light valve array.