US005831699A

United States Patent [19]

Wright et al.

[11] **Patent Number: 5,831,699**

[45] **Date of Patent: Nov. 3, 1998**

[54] **DISPLAY WITH INACTIVE PORTIONS AND ACTIVE PORTIONS, AND HAVING DRIVERS IN THE INACTIVE PORTIONS**

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[21] Appl. No.: **639,671**

[22] Filed: **Apr. 29, 1996**

[51] **Int. Cl.**[6] **G02F 1/13**; G02F 1/00; H04N 5/74

[52] **U.S. Cl.** **349/73**; 345/32; 345/55; 345/82; 345/84; 345/204; 349/57; 349/149; 349/5; 348/744; 348/750; 348/758; 359/298

[58] **Field of Search** 349/73, 57, 149, 349/5; 345/32, 55, 82, 84, 204; 359/298, 237; 348/744, 750, 758

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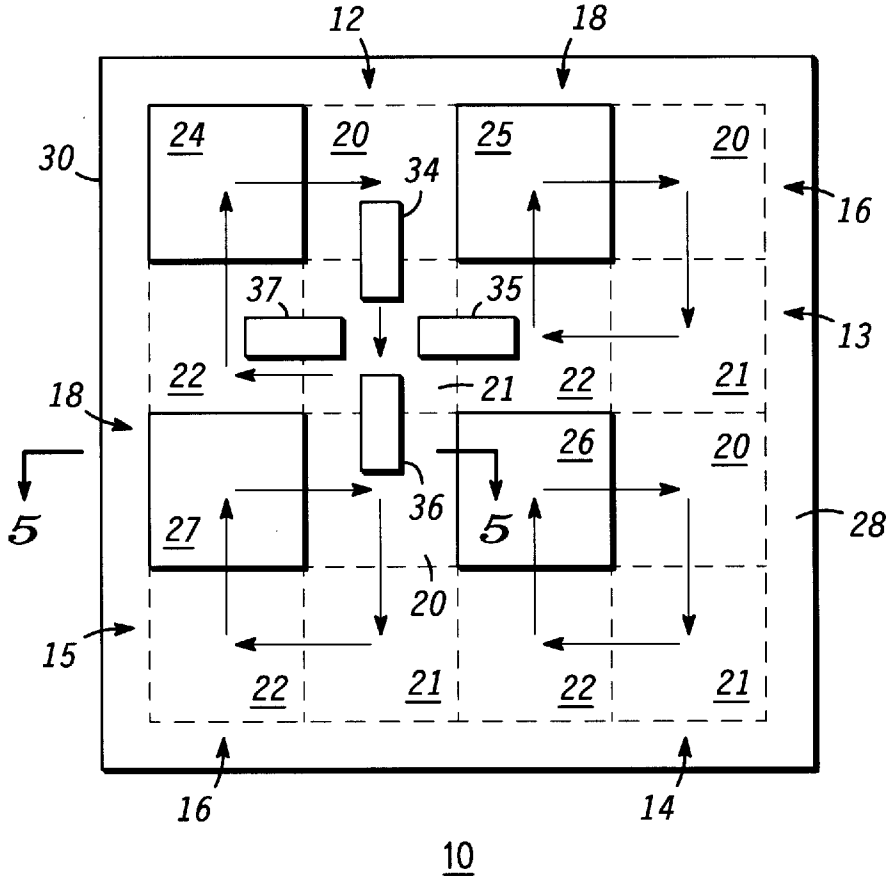
Assistant Examiner—Kenneth Parker
Attorney, Agent, or Firm—Eugene A. Parsons

[57] **ABSTRACT**

An integrated electro-optical package including an array composed of a substrate having defined thereon a plurality of unit cells, composed of active and inactive areas. The substrate having positioned thereon a major surface, a plurality of sub-arrays and driver/control circuits. The sub-arrays, defining the active area formed within each unit cell, and being composed of a plurality of light emitting devices. The driver/control circuits mounted to the substrate within the inactive area of each unit cell. The electro-optical package fabricated to allow for scanning of the active area of each unit cell to create a resultant integrated image of increased resolution, without an increase in the number of pixels formed by the light emitting devices of the sub-arrays.

22 Claims, 6 Drawing Sheets



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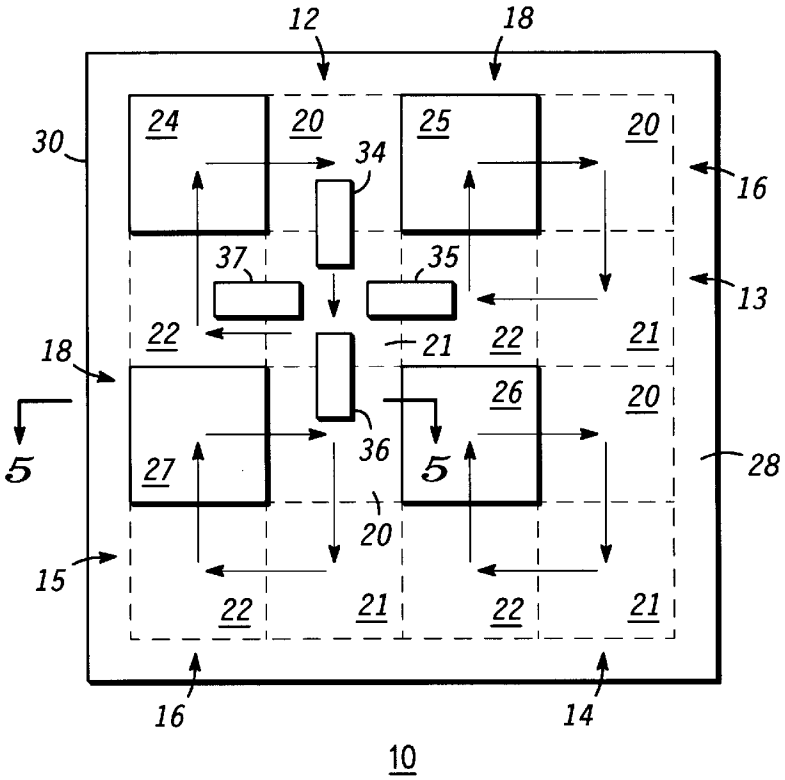
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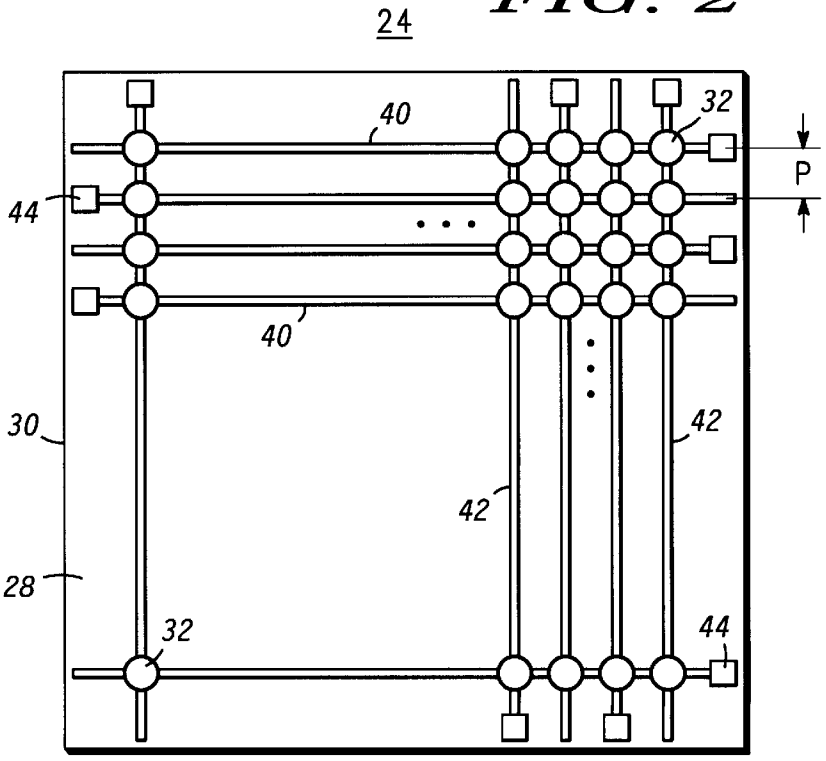
FIG. 1

FIG. 2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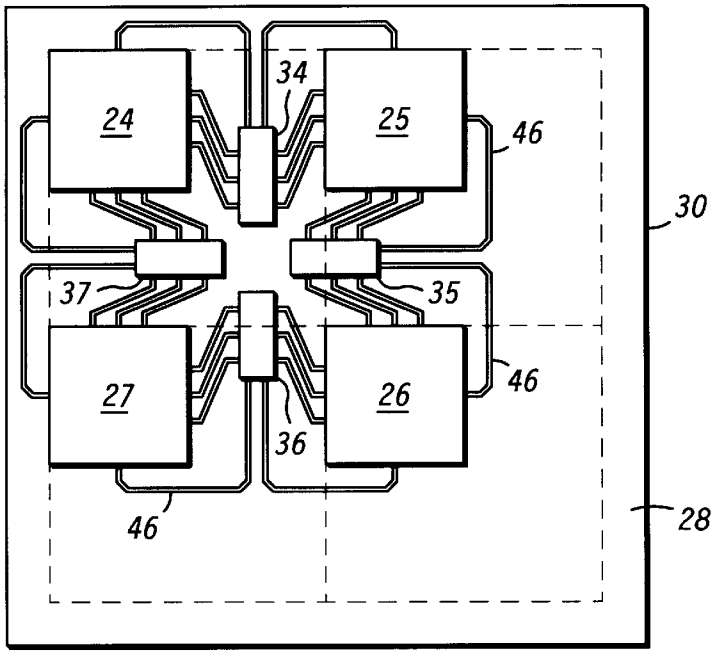
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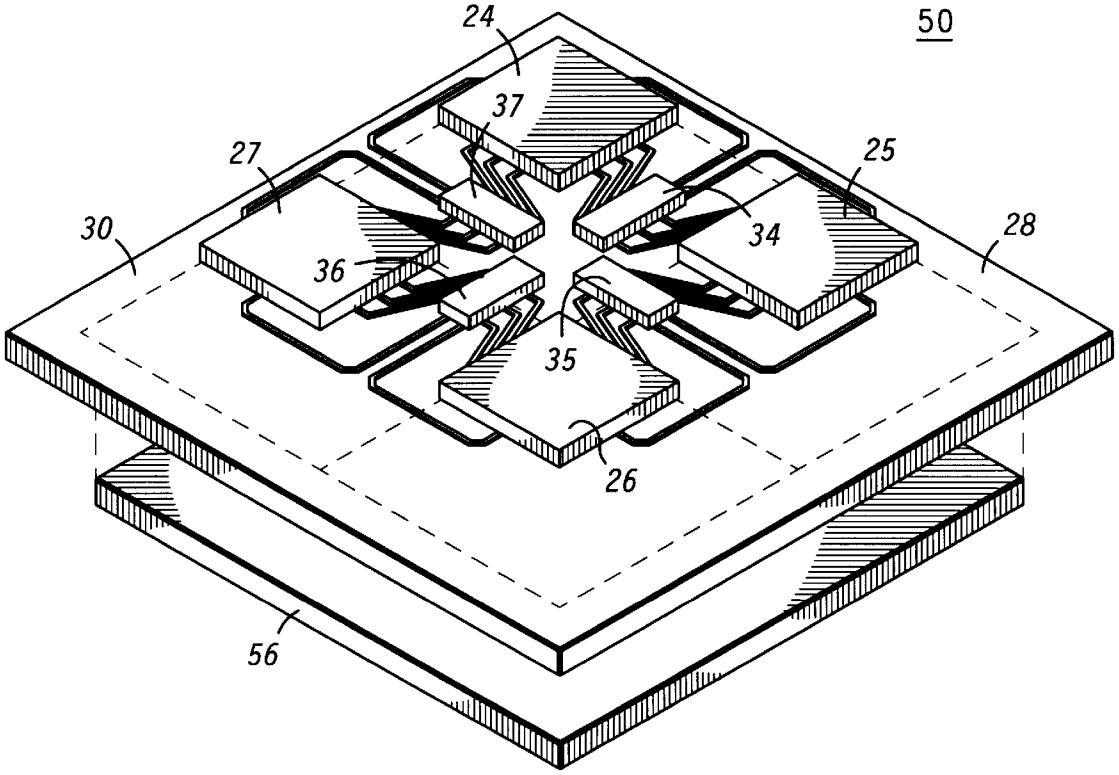
FIG. 3

FIG. 4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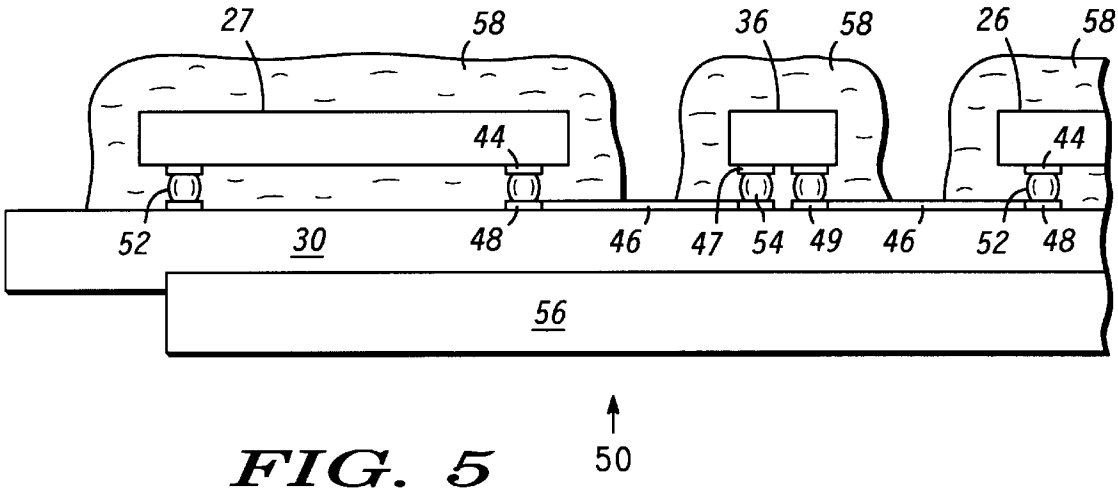


FIG. 5

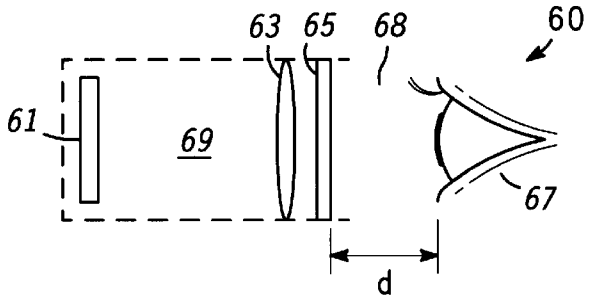
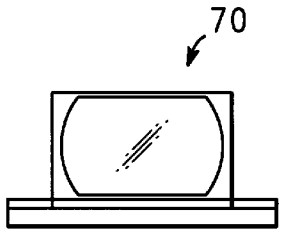


FIG. 6



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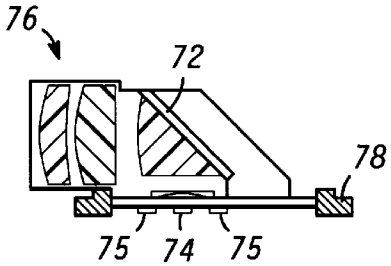

FIG. 8

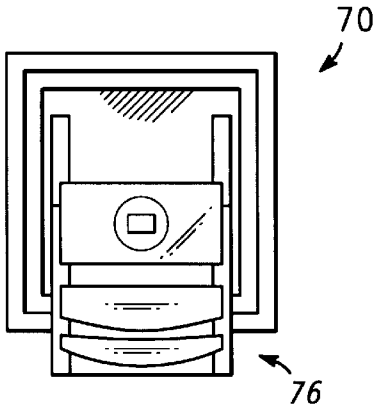

FIG. 9

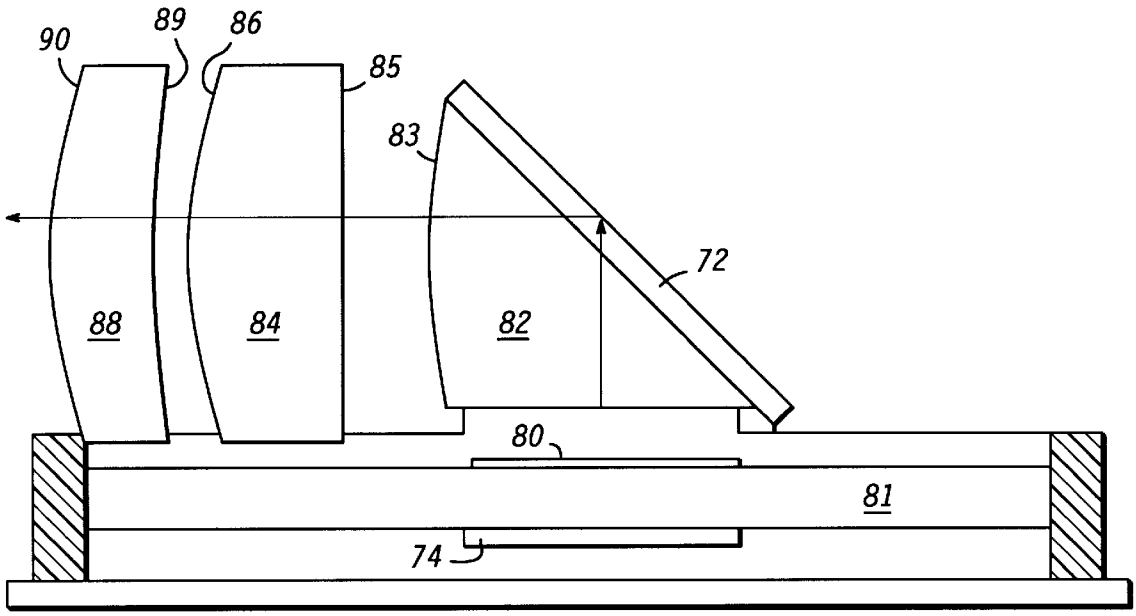

FIG. 10

FIG. 11

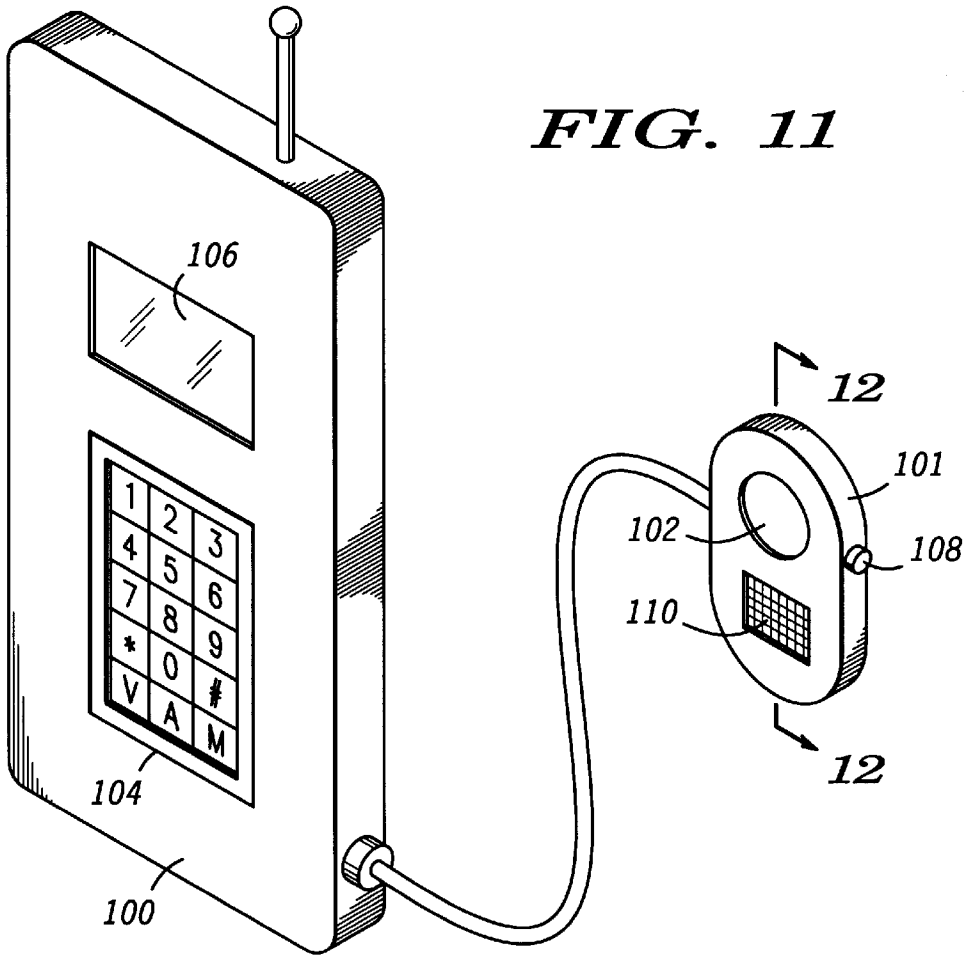
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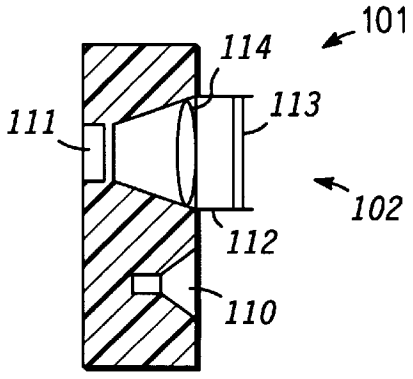
FIG. 12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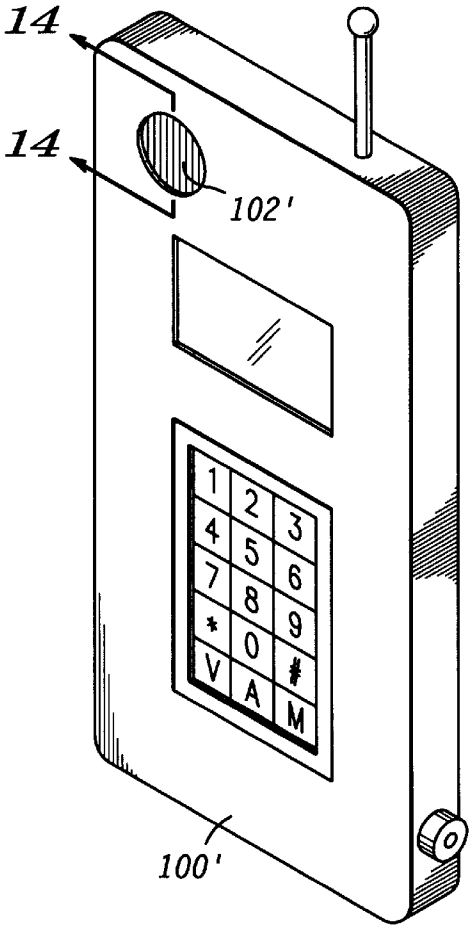


FIG. 13

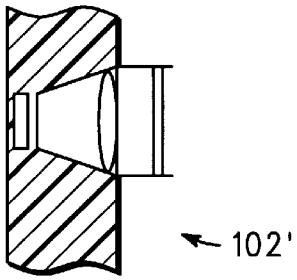
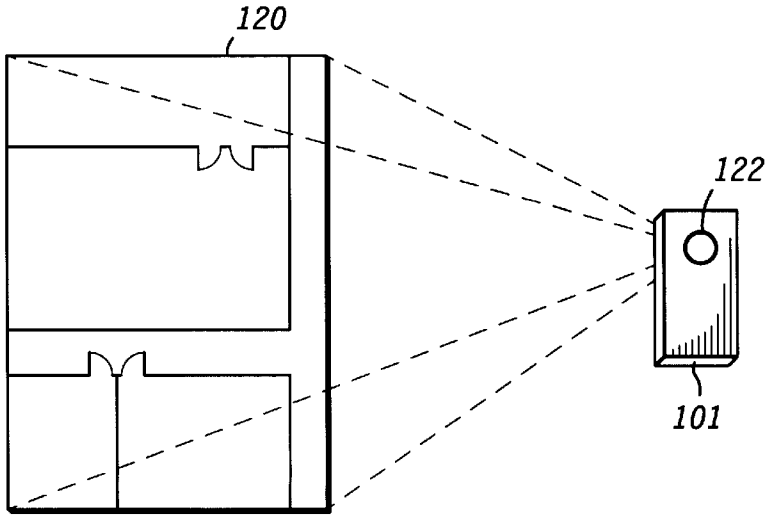


FIG. 14

FIG. 15



DISPLAY WITH INACTIVE PORTIONS AND ACTIVE PORTIONS, AND HAVING DRIVERS IN THE INACTIVE PORTIONS

FIELD OF THE INVENTION

The present invention pertains to the field of miniature visual displays, and more particularly to electro-optical packages that integrate electrical and optical components and utilize scanning techniques to project a fully integrated image within an observer's field of view.

BACKGROUND OF THE INVENTION

The human visual system is a complex system with a great ability to absorb vast amounts of information originating in many varying formats, including visual displays. Visual displays are found in varying sizes and forms in today's world, displaying many types of information, from large visual display screens announcing scheduling information found in airports, to small visual displays, such as those incorporated into pocket calculators. Of concern in the reduction in the size of visual displays, specifically those utilized in portable electronic devices, such as portable communications equipment, or the like, is the number and complexity of electrical interconnects, the display resolution quality and the maintenance of minimal power requirements and low manufacturing costs.

Of relevance in the reduction in size of visual displays, and the maintenance of resolution quality, is the human visual system's ability to process and integrate information, and the speed at which the visual system is able to do so. The human visual system can process information no faster than 60 Hz. Therefore, an image that is projected and scanned within 1/60th of a second to varying positions within a visual display is seen by the eyes of the viewer as one enlarged integrated image. As an example, by moving an image of an "A" to six different locations within a visual display, at a speed of 60 Hz, the viewer will see one integrated image composed of six "A"s. If the image is simultaneously content modulated, for example, the images are of six letters "A", "B", "C", "D", "E" and "F" that are individually and sequentially moved to six varying positions at a speed of 60 Hz., the viewer will see one integrated image composed of the six letters. This process, more commonly known as time-multiplexed imagery, can be utilized in the field of display technology through the use of scanners, and more specifically in the development of electro-optical packages for use in enhanced resolution miniature visual displays.

A vast amount of effort has been expended to develop compact, lightweight, low-power visual displays. As display technology reduced the size of visual displays, the resolution of such displays was difficult to maintain. Of greatest importance in the development of these miniature visual displays is the manufacturing costs. It has been shown that as the active area of a display decreases, pixel size of the image source must decrease to maintain resolution. As higher resolution is desired, the number of pixels of the image source and the cost of materials and manufacturing increases, in part because of the number of electrical interconnects required for the increased number of pixels.

Generally, an image source, more specifically an electro-optical package, composed of electrical and optical components, a semiconductor chip, or integrated circuit, is mounted on a printed circuit board or the like and the accepted method for connecting the chip to external driver/control circuits is to use standard wire bond technology. However, when a semiconductor chip having a relatively large array of electrical components or devices formed thereon is to be connected, standard wire bond techniques can become very difficult.

At the present time wire bond interconnects from bond pads having a pitch of 4.8 milli-inches is the best that is feasible. Thus, in a standard array composed of 100×100 light emitting devices the bond pads on the perimeter of the semiconductor chip would have a minimum pitch of 4.8 milli-inches, with 50 bond pads situated along each edge of the perimeter. As more devices are included in the array, more bond pads are required and the perimeter size to accommodate the additional bond pads increases at an even greater rate. That is, since the minimum pitch of the bonding pads is 4.8 milli-inches, the pitch of the devices in the array can be as large as 2.4 milli-inches, or approximately 61 microns, without effecting the size of the chip. Thus, even if the devices can be fabricated smaller than 61 microns, the minimum pitch of the bonding pads will not allow the perimeter of the chip to be made any smaller. It can quickly be seen that the size of the semiconductor chip is severely limited by the limitations of the wire bonding technology.

Scanning devices known today are used to aid in increasing the resolution of visual displays from a minimal number of pixels of an image source. These scanning devices can be found in many forms, most commonly electro-mechanical scanners incorporating mirrors, such as galvanometric scanners and polygonal scanners. These types of electro-mechanical scanners are commonly quite large in size, therefore not amenable to the incorporation into a display device that is small, lightweight, operates on low power consumption and meant to be portable in nature. In addition, mechanical scanners are expensive to manufacture and utilize great amounts of power.

Thus, there is a need for interconnect and packaging structures and techniques which can substantially reduce the limitation on size of packages by mounting a plurality of sub-arrays directly on a substrate, having a plurality of driver/control devices mounted directly on the substrate between the sub-arrays, thus allowing for the sub-arrays to be scanned to generate a resultant image, thereby utilizing fewer pixels and thus fewer interconnects, leading to increased manufacturing yield, thus decreased manufacturing costs.

Accordingly, it is highly desirable to provide for an electro-optical package that is formed by mounting individual sub-arrays, directly to a substrate and mounting a plurality of driver/control devices between the sub-arrays. The electro-optical package, or image source, in operation utilizes an externally positioned phase spatial light modulator scanner to spatially modulate the phase of the light emitted by the package, thereby providing for scanning of the sub-arrays, thus generating a resultant low-powered miniature visual display with resolution enhancement.

It is a purpose of the present invention to provide a new and improved integrated electro-optical package for display resolution enhancement for use in miniature visual displays.

It is a further purpose of the present invention to provide a new and improved electro-optical package for use in visual display systems for display resolution enhancement which utilizes a plurality of sub-arrays mounted to a substrate, having positioned therebetween each sub-array, a plurality of driver/control devices, that in combination with an externally positioned phase spatial light modulator scanner allows for spatial modulation of the light emitted by the electro-optical package, thereby permitting the use of an electro-optical package having fewer number of pixels and interconnects into a visual display system.

It is another purpose of the present invention to provide for an electro-optical package and method of fabrication that utilizes a plurality of sub-arrays and minimal electrical interconnects to generate a resultant integrated image by scanning these sub-arrays, that can be incorporated into a miniature visual display.

SUMMARY OF THE INVENTION

The above problems and others are substantially solved and the above purposes and others are realized in an integrated electro-optical package that utilizes sub-arrays, mounted on a substrate, having positioned therebetween a plurality of driver/control devices. The electro-optical package is of minimal size, thereby permitting incorporation into a visual display system composed of the electro-optical package, or image source, a phase spatial light modulator scanner, such as a liquid crystal phase spatial light modulator scanner, and optical elements.

The electro-optical package is formed by dividing a whole array, comprised of light emitting devices, into smaller sub-arrays. The sub-arrays are then mounted directly on a substrate, thereby defining an image source having an inactive to active area ratio of any number. There are mounted in between the sub-arrays, a plurality of driver/control devices, for driving and controlling the light emitting devices which form the sub-arrays. In operation, the light emitted by the sub-arrays is scanned by utilizing a phase spatial light modulator scanner to fill in the inactive areas located between the sub-arrays, thereby generating a resultant integrated image having high resolution. In that sub-arrays are used as well as scanning techniques which reduces the number of required light emitting devices, the number and complexity of electrical interconnects extending from the light emitting devices to the driver/control devices is minimal, leading to a an increase in manufacturing yield and thus a reduction in manufacturing costs.

In operation, a phase spatial light modulator scanner is utilized, such as a liquid crystal phase spatial light modulator scanner, in which a liquid crystal material is used to spatially modulate the phase, and therefore the direction, of light generated by the sub-arrays of light emitting devices, most commonly light emitting diodes or vertical cavity surface emitting lasers (VCSELs), thereby generating a resultant integrated image and enhancing the resolution of the integrated image being viewed. It should be understood that alternative light or image generating devices can be utilized such as organic light emitting devices (LEDs), cathode ray tubes (CRTs), field emission displays (FEDs), electroluminescent displays, plasma displays, liquid crystal displays (LCDs), etc., but the general term "light emitting devices" will be utilized throughout this disclosure for the sake of simplicity.

In general, the scanner serves to spatially modulate the phase of the generated light waves to produce a directional change of the light passing therethrough. In the instance where a liquid crystal phase spatial light modulator scanner is utilized, this is accomplished based on the principle that the structural organization of the molecules, which compose the liquid crystal material, is not rigid, meaning that the molecules can be easily reoriented as a direct result of an external stimulus. Under appropriate conditions, this exertion of an external stimulus on the liquid crystal material results in the reorientation of the molecular structure of the liquid crystal, thereby causing the light passing therethrough to undergo a phase change. It should be understood that varying amounts of voltage applied to the liquid crystal, will result in varying phase modulations, thus varying the directional travel of the light passing therethrough.

During the operation of the scanner, a voltage is applied to the scanner, thereby causing a resulting change in optical characteristics, such as double refraction/birefringence effects, optical rotation, dichroism or optical scattering. This response to the applied voltage is converted to a visible change in aperture ratio and/or number of pixels of the generated resultant integrated image when viewed by the observer. More specifically, the phase of the light waves generated by the sub-arrays are spatially modulated, producing the resultant integrated image viewable by the observer. The integrated image appears to have high resolution, and higher aperture ratio, yet the number of active pixels on the image source remains the same.

The scanner operates by scanning the light emitted by the sub-arrays formed in the electro-optical package, thereby generating an integrated image through phase modulation that appears, to the viewer, to fill in the inactive areas, seen as physical gaps, between the sub-arrays. The scanning serves to spatially modulate the phase, or direction of travel, of the light, thereby permitting the light emitted by each individual sub-array scanned to be changed in direction to successively produce missing portions of the integrated image. The number of active pixels on the image source remains the same, in that no additional active area, or pixels, etc. are being utilized, yet the resolution and aperture ratio of the generated integrated image is dramatically increased through the scanning process.

In general, by integrating the driver/control devices on the substrate and positioning them between the sub-arrays of light emitting devices, in conjunction with scanning techniques, the number of pixels used to form the resultant integrated image is decreased, therefore decreasing the number of interconnects. By decreasing the number of pixels and interconnects, the package size is decreased, thereby creating a more cost effective product, in that the manufacturing yield is increased, thereby decreasing the cost of manufacturing.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the claims. The invention itself, however, as well as other features and advantages thereof will be best understood by reference to detailed descriptions which follow, when read in conjunction with the accompanying drawings, wherein:

FIG. **1** is a simplified top view of the major surface of an electro-optical package, or light emitting display device, illustrating positioning of the sub-arrays and driver/control devices according to the present invention, and diagramatically illustrating the directional scanning of the sub-arrays;

FIG. **2** is a greatly enlarged view in top plan of a partial sub-array of light emitting devices mounted to a substrate;

FIG. **3** is a simplified top view of a plurality of sub-arrays of light emitting devices formed on an optically transparent substrate, showing the positioning of the active sub-arrays, the driver/control devices mounted in the inactive areas of the array and electrical conductors extending therebetween;

FIG. **4** is an exploded view in perspective illustrating the relative positions of the components of FIGS. **1–3**;

FIG. **5** is an enlarged view of the components of FIG. **1**, portions thereof broken away, assembled into a complete package generally as seen from line **5—5** of FIG. **1**;

FIG. **6** is a simplified schematic view of a miniature visual image display incorporating the electro-optical package of the present invention;

FIGS. **7**, **8** and **9** illustrate a front view, side elevational view, and a top plan, respectively, of an image manifestation apparatus utilizing the electro-optical package of the present invention;

FIG. **10** is a 4× magnified view in side elevation of the apparatus of FIG. **7** utilizing the electro-optical package of the present invention;

FIG. **11** is a view in perspective of a portable communications receiver incorporating the miniature visual image display of FIG. **7**;

FIG. **12** is a simplified view generally as seen from the line **12**—**12** of FIG. **11**;

FIG. **13** is a view in perspective of another portable communications receiver incorporating the miniature visual image display of FIG. **7**;

FIG. **14** is a simplified view generally as seen from the line **14**—**14** of FIG. **13**; and

FIG. **15** is a view in perspective illustrating a typical view as seen by the operator of the portable communications receiver of FIG. **11**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

During the course of this description, like numbers are used to identify like elements according to the different figures that illustrate the invention. The present invention is based on utilizing individually addressable visible light emitting devices formed in a two-dimensional array, that in combination with driver/control circuitry and optical elements compose a light emitting display device, or an integrated electro-optical package, of the present invention. The integrated electro-optical package of the present invention utilizes sub-arrays, positioned to allow for scanning of the light emitted by the sub-arrays to generate a resultant integrated image, by filling in the inactive areas, or gaps, produced by the separation of the sub-arrays. To increase the resolution for a given number of light emitting devices of the electro-optical package or to reduce the number of light emitting devices needed to achieve a desired resolution, sub-array scanning techniques employing a phase spatial light modulator scanner are utilized. The electro-optical package, or light emitting display device, serves as the image source for a visual display system whereby a resulting integrated image is formed by scanning the light emitted by a plurality of sub-arrays through a light modulating material, thereby modulating the phase of the light emitted by the sub-arrays. This phase modulation serves to change the directional travel and in essence "moves" the light to an inactive area of the display chip. This scanning action generates what appears to the observer to be a high resolution resultant integrated image. Those skilled in the art will appreciate that scanning allows a full page display to be created from a much smaller number of display devices than is necessary to generate the full page display, whether for a direct, projected or virtual image. The electro-optical package. or display chip, which serves as the image source in the present invention, is fabricated based on the principle of reducing the number of pixels, thereby decreasing the number of electrical interconnects extending from the light emitting devices to a plurality of driver/control devices, while permitting the generation of a high resolution resultant integrated image.

As previously stated, the purpose of this disclosure is to provide for an electro-optical package, or light emitting display device, in which a plurality of sub-arrays are mounted to a substrate, having positioned therebetween a plurality of driver/control devices. The use of a miniature phase spatial light modulator scanner to bring about the phase modulation of the light emitted by the display chip, positioned externally the electro-optical package, but within the optical train of the light emitted, allows for the electro-optical package to remain small in size and permits it, as well as the liquid crystal scanner components and additional optical elements, to be incorporated into miniature visual displays such as those found in portable electronics equipment, or the like.

Referring now to the accompanying illustrations, disclosed is an electro-optical package, or a two-dimensional light emitting display device fabricated according to the present invention. Specifically, with regard to FIG. **1**, illustrated in a simplified top view is a portion of whole array **10** which is illustrated as being divided into four equal quadrants, hereinafter referred to as unit cells **12**, **13**, **14**, and **15**. It should be understood that whole array **10** can define any number of replicated unit cells, dependent upon the number of sub-arrays utilized, although array **10** composed of four unit cells will be used through this description for consistency. Each unit cell is composed of an approximate 3:1 ratio of an inactive area **16** to an active area **18**. Each of the inactive areas **16** is further defined by a first inactive area **20**, a second inactive area **21**, and a third inactive area **22**. Each of the active areas **18** is further defined by a plurality of sub-arrays **24**, **25**, **26**, and **27**.

For simplicity of illustration, only a representative portion of array **10** has been completed. Sub-arrays **24**, **25**, **26** and **27** are initially fabricated as part of a larger array, thereafter being subdivided and mounted (discussed presently) to a major surface **28** of a substrate **30**, such as an optically transparent material, namely optically transparent glass, optically transparent plastic, or the like. In addition, substrate **30** can be formed of silicon, or a thin film ceramic with organic dielectric and thin film metallization. It should be understood that in an alternative embodiment, substrate **30** is opaque and the light emitted by sub-arrays **24**, **25**, **26**, and **27** is emitted in a direction opposite the mounting to substrate **30** (discussed presently). Substrate **30** is defined by a first major surface and a second opposed major surface. Sub-arrays **24**, **25**, **26**, and **27** are each composed of a two-dimensional array of light emitting devices. It should be understood that varying sources of light or image generating devices can be utilized such as inorganic or organic light emitting devices (LEDs), cathode ray tubes (CRTs), field emission displays (FEDs), vertical cavity surface emitting lasers (VCSELs), electroluminescent displays, plasma displays, liquid crystal displays (LCDs), etc. The general term light emitting devices will be utilized throughout this disclosure for the sake of simplicity.

As previously stated, each unit cell **12**, **13**, **14**, and **15** of array **10** is fabricated to define inactive area **16** and active area **18** of array **10**. In this specific example the active area **18** of each unit cell **12**, **13**, **14**, and **15**, defined by sub-arrays **24**, **25**, **26**, and **27** appears to be approximately 25% of the total area of each unit cell **12**, **13**, **14**, and **15**.

There is positioned on major surface **28** of substrate **30**, between sub-arrays **24**, **25**, **26** and **27**, a plurality of driver/control circuits **34**, **35**, **36**, and **37**. Driver/control circuits **34**, **35**, **36**, and **37** are generally fabricated as smaller integrated circuits which are bump bonded to electrical contacts (discussed presently) on major surface **28** of substrate **30**. A plurality of electrical conductors, more commonly known as metal-line interconnects, or traces, (discussed presently) form electrical connections between the light emitting devices of sub-arrays **24**, **25**, **26**, and **27** and driver/control circuits **34**, **35**, **36**, and **37**.

During the scanning process of sub-arrays **24**, **25**, **26**, and **27**, varying external voltages are applied to a phase spatial light modulator, such as a liquid crystal phase spatial light modulator scanner, hereinafter referred to as "liquid crystal scanner" (discussed presently), which is incorporated into a visual display system, through which the light emitted by array **10** of the electro-optical package passes, resulting in a scanning action of the active area **18** of each unit cell **12**, **13**, **14**, and **15**, through the inactive areas **20**, **21**, and **22** of each unit cell **12**, **13**, **14**, and **15**, generally as shown by the directional arrows of FIG. **1**. Generally speaking, the active area **18** of each unit cell **12**, **13**, **14**, and **15** is scanned, meaning the light or portion of an image represented by each sub-array **24**, **25**, **26**, and **27** passes through the liquid crystal scanner to which a voltage, or voltages, have been applied, and the resultant light emitted, having undergone a change in phase, changes direction of travel to fill the inactive areas **20**, **21** and **22** of each unit cell **12**, **13**, **14**, and **15** of the whole array **10** with a specific portion of the image. The resulting integrated image will appear to have a higher resolution, in that the resulting integrated image will appear to have four times the number of pixels contained in the sub-arrays **24**, **25**, **26**, and **27** due to the scanning effects, although, there is no actual increase in the number of pixels of the image source.

Referring specifically to FIG. **2**, a greatly enlarged view in top plan of a portion of sub-array **24**, composed of a plurality of light emitting devices **32**, is illustrated. For simplicity of illustration, only a representative portion of sub-array **24** has been completed. It should be understood that the plurality of sub-arrays **24**, **25**, **26**, and **27** of the present invention are similarly formed. As illustrated, each sub-array **24**, **25**, **26** and **27**, defines a plurality of pixels, with light emitting devices **32** positioned in rows and columns and having row/column addressing contacts similar to those used for charged coupled device (CCD) arrays. Contacts to the light emitting devices **32** are formed by conventional deposition and/or etching techniques wherein, for example, common row and column bus contacts are formed to individually address each light emitting device **32**, as is generally known in the art. The plurality of driver/control circuits **34**, **35**, **36**, and **37** have data input terminals and further having control signal output terminals (not shown) connected to the light emitting device sub-arrays **24**, **25**, **26**, and **27** through a plurality of connection/mounting pads and electrical conductors, for activating and controlling each of the light emitting devices **32** of the sub-arrays **24**, **25**, **26**, and **27** to generate an image in accordance with data signals applied to the data input terminals.

As illustrated in FIG. **2**, each light emitting device **32** defines a pixel, with the plurality of light emitting devices **32** positioned in rows and columns as previously stated. Each light emitting device **32** has first and second electrodes (not shown) to provide an activating potential thereto with the first electrodes of each light emitting device **32** being attached to one of a plurality of horizontal electrical conductors **40** and the second electrode of each light emitting device **32** being attached to one of a plurality of vertical electrical conductors **42**. A plurality of external connection/mounting pads **44** are positioned adjacent outer edges thereof. The first electrodes of light emitting devices **32** are connected to a first plurality of external connection/mounting pads **44** by electrical conductors **40**, defining rows of pixels, and the second electrodes of light emitting devices **32** are connected to a second plurality of external connection/mounting pads **44** by electrical conductors **42**, defining columns of pixels. To completely distribute connection/mounting pads **44** around the periphery of each sub-array **24**, **25**, **26**, and **27**, connection/mounting pads **44** are attached to alternate horizontal electrical conductors **40** and alternate vertical electrical conductors **42**. Thus, the space available between adjacent connection/mounting pads **44** is 2P, where P represents the spacing between centers of light emitting devices **32**.

Referring to FIG. **3**, another view array **10**, composed of the plurality of sub-arrays **24**, **25**, **26**, and **27** and the plurality of driver/control circuits **34**, **35**, **36** and **37** is illustrated. In this illustration, a plurality of electrical conductors **46**, commonly referred to as metal-line interconnects or traces, are formed on major surface **28** of substrate **30**. Electrical conductors **46** are fanned out from a plurality of connection/mounting pads (not shown) that align with connection/mounting pads **44** of the sub-arrays **24**, **25**, **26**, and **27**, when sub-arrays **24**, **25**, **26**, and **27** are properly mounted and registered on major surface **28** of substrate **30**. Electrical conductors **46** extend from the plurality of connection/mounting pads to a plurality of connection/mounting pads (not shown) that serve as electrical contacts for driver/control circuits **34**, **35**, **36**, and **37** when driver/control circuits **34**, **35**, **36**, and **37** are properly mounted and registered on major surface **28** of substrate **30**.

In the instance where substrate **30** is formed of glass, standard thin film metallization can be utilized in which layers of metal are deposited by, for example, sputtering. In a typical metallization system, a first layer of chromium is applied by sputtering to operate as an adhesive layer on the glass. A second layer of copper is applied over the chromium to provide the desired electrical conduction and a layer of gold is applied over the copper to provide a barrier and adhesive layer for the bumps or further connections. It should be understood that the metallizations can be either an additive or subtractive method with the patterning and etching being performed by any of the various methods well known in the art to provide the desired final structure.

Further, in the instance where substrate **30** is formed of glass, the glass is selected to have approximately the same thermal coefficient of expansion as the substrate onto which the light emitting devices **32** are formed, so that when the sub-arrays **24**, **25**, **26**, and **27** of light emitting devices **32** are fixedly bonded to substrate **30** changes in ambient temperature produce substantially the same amount of expansion or contraction and the sub-arrays **24**, **25**, **26**, and **27** are not damaged. It will of course be understood that minor differences in the thermal coefficients which produce minor differences in expansion/contraction can be tolerated if the amount of change between sub-arrays **24**, **25**, **26**, and **27** and substrate **30** is not large enough over the operating temperature range of the structure to damage sub-arrays **24**, **25**, **26**, and **27**.

An exploded view in perspective illustrating the relative positions of the components of FIGS. **1–3** and additional components included in an electro-optical package **50**, are illustrated in FIG. **4**. An enlarged view, portions thereof broken away, of the components of FIG. **4** assembled into a complete electro-optical package **50** is illustrated in FIG. **5**. In the assembly process, each sub-array **24**, **25**, **26**, and **27** is inverted and mounted on major surface **28** of substrate **30** so that a light emitting surface of each sub-array is down, thereby causing the light emitted by the plurality of light emitting devices **32** to pass through substrate **30**. In the instance where substrate **30** is opaque, sub-arrays **24**, **25**, **26**, and **27** are mounted so that the light emitting surface of each sub-array **24**, **25**, **26**, and **27** is up, thereby causing the light emitted by the plurality of light emitting devices **32** to emit

in et direction opposite the substrate **30**. The plurality of connection/mounting pads **44** of each sub-array **24**, **25**, **26**, and **27** are positioned to each contact a separate connection/mounting pads **48** on substrate **30** when each sub-array **24**, **25**, **26**, and **27** is properly registered on major surface **28** of substrate **30**. Each sub-array **24**, **25**, **26**, and **27** has bumps **52** of contacting material deposited on connection/mounting pads **48** for electrically and physically connecting sub-arrays **24**, **25**, **26**, and **27** to substrate **30**. Bumps **52** are formed of a material that is a relatively good electrical conductor and which can be at least partially melted and reset to form a good physical connection. Material which can be utilized for this purpose includes gold, copper, solder and especially high temperature solder, conducting epoxy, etc. A bump height of up to 80 microns can be formed on a square or round connection/mounting pad with a 20 micron diameter. Some compatible metal may improve the assembly procedures, e.g., gold metallization or gold plating on connection/mounting pads **48** of optically transparent substrate **30**.

Driver/control circuits **34**, **35**, **36**, and **37** are positioned to allow a plurality of connection/mounting pads **47** of driver/control circuits **34**, **35**, **36**, and **37** to contact a plurality of connection/mounting pads **49** positioned on substrate **30** utilizing bumps **54** of contacting material, similar to bumps **52**. Sub-arrays **24**, **25**, **26**, and **27** are electrically interfaced to driver/control circuits **34**, **35**, **36**, and **37** through connection/mounting pads **44**, **48**, **47** and **49**, bump **52** and **54** of contacting material and the plurality of electrical conductors **46** extending therebetween.

In an alternative fabrication technique, sub-arrays **24**, **25**, **26**, and **27** are thermo compression bonded to substrate **30**. At the point illustrated in FIG. **4** where sub-arrays **24**, **25**, **26**, and **27** and driver/control circuits **34**, **35**, **36**, and **37** are bonded to substrate **30**, sub-arrays **24**, **25**, **26**, and **27** can be easily tested and/or burned in prior to additional assembly of the package. This ability to provide an intermediate test point can be a substantial cost and time saving in the packaging procedure.

In the present invention, fewer electrical conductors, or interconnects, are needed in that there are a fewer number of pixels required to be defined by the sub-arrays **24**, **25**, **26**, and **27**, because of the utilization of scanning. Because of this decreased number of interconnects, the manufacturing yield of electro-optical package **50** is increased, thereby reducing manufacturing cost. Further detailed description of image sources composed of a two-dimensional array of light emitting devices similar to sub-arrays **24**, **25**, **26**, and **27** of the present invention, can be found in U.S. Pat. No. 5,432,358, entitled "Integrated Electro-Optical Package", issued Jul. 11, 1995, assigned to the same assignee and incorporated herein by this reference.

The final additional component in electro-optical package **50** is a lens **56** which is fabricated to overlie substrate **30** on a surface opposite the mounting of sub-arrays **24**, **25**, **26**, and **27** and driver/control circuits **34**, **35**, **36**, and **37**. Lens **56** is designed as one of a plurality of refractive and diffractive lenses, or optical elements, to magnify and/or correct the image generated by the sub-arrays **24**, **25**, **26**, and **27** of light emitting devices **32**. In the illustrated embodiment, lens **56** is affixed to the underside of substrate **30** by some convenient means, such as optically transparent epoxy or the like, and is fabricated so as to simply overlie the portion of substrate **30**, which in this instance if optically transparent, through which the light is emitted. Alternatively, in the instance where substrate **30** is opaque and sub-arrays **24**, **25**, **26**, and **27** are mounted to emit light in a direction opposite substrate **30**, lens **56** would be positioned on a side of substrate **30** to allow the emitted light to pass therethrough.

It should be understood that sub-arrays **24**, **25**, **26**, and **27** and driver/control circuits **34**, **35**, **36**, and **37** in the illustrated embodiment, are generally protected by glob top formations **58**. For best results sub-arrays **24**, **25**, **26**, and **27**, substrate **30** and lens **56** should be constructed with indices of refraction which are as close together as practical. If, for example, the index of refraction of substrate **30** and the lens **56** differs substantially there is a tendency for light to reflect at the interface back into sub-arrays **24**, **25**, **26**, and **27** and the efficiency of electro-optical package **50** is reduced.

As previously stated, the light emitted by sub-arrays **24**, **25**, **26**, and **27** is scanned, thereby "moving" the image to the inactive area **16** of each unit cell **12**, **13**, **14**, and **15**, namely through first inactive area **20**, second inactive area **21**, and third inactive area **22**. The scanning device of the present invention utilizes a phase spatial light modulator scanner, more specifically a liquid crystal scanner, as previously disclosed. Further detailed description of the utilization of a visual display system including a liquid crystal scanner can be found in U.S. Patent Application entitled "VISUAL DISPLAY SYSTEM FOR DISPLAY RESOLUTION ENHANCEMENT", filed of equal date herewith, assigned to the same assignee and incorporated herein by this reference. As previously stated, a visual display system is disclosed incorporating an electro-optical package **50** of the present invention, and a scanner that utilizes liquid crystal material to serve as a light modulating medium, thereby spatially modulating the phase of the light passing therethrough. It should be understood that throughout this disclosure when referring to a liquid crystal scanner, that various liquid crystal and ferroelectric liquid crystal materials can be provided which will operate in different modes in response to different signals or potentials applied thereto. In addition, it should be understood that various other phase spatial light modulator scanners could be utilized, such as an electro-optic scanners an and acousto-optic scanners.

The mode of operation of the liquid crystal scanner and the scanning technique to be utilized is dependent upon the fabrication of the array of light emitting devices of the image source and the configuration of an optical system (discussed presently) that are both incorporated into the visual display system of the present invention. The liquid crystal scanner of the present invention operates in either a reflective or a transmissive mode.

At least one polarization member or element is incorporated into the visual display system of the present invention. The polarization member is positioned to allow light emitted by the image source of like polarization, to pass through the polarization member prior to undergoing a change in phase. If, for example, the polarization member is polarized horizontally all light similarly polarized will pass therethrough and light that is of different polarization will be blocked. If the polarization member is vertically polarized, similar results will occur.

Thus, a new and improved electro-optical package composed of a plurality of sub-arrays and driver/control circuits mounted to a substrate, and having as a component thereof, at least one optical element, is provided. The electro-optical package of the present invention is meant to be incorporated into a visual display system, more specifically an electro-optical system, additionally composed of a phase spatial light modulator scanner, driver/control circuitry and optical elements (discussed presently). The visual display system includes various additional optical components while con-

veniently integrating electrical connections to the components and providing external connections thereto. Light sources, polarizers, diffusers and, if desired, additional optics are conveniently integrated into the system which is easily integrated into portable electronic equipment. It is further disclosed that additional optical elements, such as polarizer plates or layers, refractive elements, diffractive elements, etc. may be easily positioned exterior the visual display system.

It should be understood that the resultant integrated image generated by the visual display system, composed of the electro-optical package, or light emitting display device, the phase spatial light modulator scanner, driver/control circuits and various optical elements, is too small to properly perceive (fully understand) with the human eye and generally requires a magnification of at least 10× for comfortable and complete viewing. Lens **56** can be a single lens with additional optical magnification supplied by an external system or lens **56** can include a complete magnification system. Further, lens **56** can be fabricated from glass, plastic or any other material or method well known to those skilled in the art. Additionally, in an alternative embodiment lens **56**, may be molded integral with substrate **30**. In some applications, lens **56** may be a complete external magnification system and may not be physically attached as a portion of electro-optical package **50**. Accordingly, a visual display system of the present invention is typically formed within a housing, defining an optical magnifier, having integrally formed therein an optical magnification system. The optical magnifier is generally defined by a plurality of sides which compose the housing. Several examples of optical magnifiers with optical magnification systems which may have incorporated therein the electro-optical package **50** of the present invention are illustrated in FIGS. **6** through **10**, explained below.

Referring to FIG. **6**, a miniature visual image display **60** is illustrated in a simplified schematic view. Miniature visual image display **60** includes image generation apparatus **61**, similar to electro-optical package **50** described above, for providing an image. An optical system, represented by lens system **63**, is positioned in spaced relation to image generation apparatus **61** of miniature visual image display **60**. A transmissive phase spatial light modulator scanner **65** is positioned to allow the light emitted by image generation apparatus **61** to pass therethrough and produces an image viewable by an eye **67** spaced from an aperture **68**.

In operation, the light generated by image generation apparatus **61** passes through lens system **63** and scanner **65**. Varying external voltages are applied to scanner **65**, thereby resulting in a scanning effect of the light emitted by a plurality of sub-arrays, generally similar to sub-arrays **24**, **25**, **26**, and **27** described above, of image generation apparatus **61**. The resultant integrated image viewable by the eye **67** of the observer through aperture **68** appears to have a greater number of pixels and an increased aperture ratio, even though the number of pixels of the image generation apparatus **61** remains the same.

Lens system **63**, represented schematically by an optical element mounted in spaced relation from image generation apparatus **61**, receives the image from image generation apparatus **61** and magnifies it an additional predetermined amount. It will of course be understood that the lens system may be adjustable for focus and additional magnification, if desired, or may be fixed in a separate housing for simplicity. It should be noted that additional optical elements can be provided exterior the miniature visual image display **60** for further image magnification and/or correction.

Eye relief is the distance that eye **67** can be positioned from viewing aperture **68** and still properly view the image, which distance is denoted by "d" in FIG. **6**. Because of the size of lens system **63**, eye relief, or the distance d, is sufficient to provide comfortable viewing and in the present embodiment is great enough to allow a viewer to wear normal eyeglasses, if desired.

There is provided a light polarizing member integrally formed with liquid crystal scanner **65** positioned so that all light entering or exiting an optical magnifier **69** defined by miniature visual image display **60** passes through and is polarized. It will of course be understood that the polarizing member can be deposited on the surface of a mounting substrate to which image generation apparatus **61** is mounted, in an alternative embodiment, or positioned external scanner **65** within the optical train formed by miniature visual image display **60**.

Referring now to FIGS. **7**, **8** and **9**, another miniature visual image display **70**, in accordance with the present invention, is illustrated in a front view, side elevational view, and top plan, respectively. FIGS. **7**, **8** and **9** illustrate miniature visual image display **70** approximately the actual size to provide an indication as to the extent of the reduction in size achieved by the present invention. Miniature visual image display **70** includes a reflective phase spatial light modulator scanner **72**, an image generation apparatus **74**, (generally similar to the electro-optical package **50**, described above), a plurality of driver/control circuits **75**, and a plurality of optical elements, which comprise an optical magnification system **76**. Image generation apparatus **74** is mounted in electrical interface with a standard printed circuit board **78**. Reflective phase spatial light modulator scanner **72** is mounted to optical magnification system **76**, thereby allowing the light emitted by image generation apparatus **74** to pass through liquid crystal scanner **72** and be reflected back through scanner **72** when exiting the folded optical magnifier formed by optical magnification system **76**.

Referring specifically to FIG. **10**, a 4× magnified view in side elevation of miniature visual image display **70** of FIG. **7** is illustrated for clarity. From this view it can be seen that a polarizing member **80** is affixed directly to the upper surface of a mounting substrate **81** to which image generation apparatus **74** is mounted. A reflective scanner **72** is mounted on an optical prism **82** so that the image generated by scanner **72** passes through a refractive surface **83**. The image is then directed to an optical lens **84** having a refractive inlet surface **85** and a refractive outlet surface **86**. From optical lens **84** the image is directed to an optical lens **88** having an inlet refractive surface **89** and an outlet refractive surface **90**. Also, in this embodiment at least one diffractive optical element is provided on one of the surfaces, e.g. refractive inlet surface **85**, to correct for chromatic and other aberrations. The operator looks into outlet refractive surface **90** of optical lens **88** and sees a large, easily discernible visual image which appears to be behind miniature visual image display **70**.

It is anticipated by this disclosure that the plurality of optical elements disclosed in FIGS. **6–10**, include reflective elements, refractive elements, diffractive elements, polarizers, diffusers, or holographic lenses that may be mounted in overlying relationship to the image generation apparatus, specifically positioned on an interior aspect of the optical magnifiers. It is further disclosed that a plurality of optical elements, including reflective elements, refractive elements, diffractive elements or diffusers may be mounted in overlying relationship to the surface of the optical mag-

nifier through which the light, or resultant integrated image, is output, specifically positioned on an exterior aspect of a light output surface, to form an image plane for the light which forms the resultant integrated image.

The electro-optical package **50** of the present invention is meant to be incorporated into any number of varying visual image display systems, some of which were previously described. These types of visual image display systems are ultimately intended for use in various types of electronic equipment, namely portable communications equipment, cellular and portable telephones, smart-card reader devices, or the like. It should be understood that while the specific electronic devices described below include miniature virtual images, that electro-optical package **50** of the present invention is intended for use in visual image display systems as part of the means for generating a direct, virtual and/or projected image.

Referring now to FIG. **11**, illustrated is an example of a portable electronic device, namely a portable communications receiver **100** having a hand held microphone **101** with a miniature virtual image display **102**, generally similar to miniature visual image display of FIG. **7**, mounted therein. It will of course be understood that portable communications receiver **100** can be any of the well known portable receivers, such as a cellular or cordless telephone, a two-way radio, a pager, a data bank, etc. In the present embodiment, for purposes of explanation only, portable communications receiver **100** is a portable two-way police radio, generally the type carried by police officers on duty or security guards. Portable communications receiver **100** includes a control panel **104** for initiating calls and a standard visual display **106**, if desired, for indicating the number called or the number calling. Hand held microphone **101** has a push-to-talk switch **108**, a voice pick-up **110** and a miniature virtual image display **102**.

Referring to FIG. **12**, a simplified sectional view of hand held microphone **101**, as seen from the line **12—12** of FIG. **11**, is illustrated. Miniature virtual image display **102** includes an image generation apparatus **111**, generally similar to electro-optical package **50**, described above, for providing an image. The image generated passes through an optical system **112** to a phase spatial light modulator scanner **113**, which in turn produces a virtual image viewable by the operator through an aperture **114**. Fixed optical system **112** is constructed to magnify the entire image from image generation apparatus **111**, without utilizing moving parts, so that the virtual image viewable through aperture **114** is a complete frame, or picture, which appears to be very large (generally the size of a printed page) and is easily discernible by the operator. The entire miniature virtual image display **102** is relatively small and adds virtually no additional space requirements to hand held microphone **101**. Optical system **112** is constructed with no moving parts, other than optional features such as focusing, zoom lenses, etc. Further, image generation apparatus **111**, in conjunction with scanner **113**, requires very little electrical power to generate the image and, therefore, adds very little to the power requirements of portable communications receiver **100**.

Referring specifically to FIGS. **13** and **14**, a second embodiment is illustrated wherein parts similar to those described in relation to FIGS. **11** and **12** are designated with similar numbers with a prime added to the numbers to indicate a different embodiment. In this embodiment a portable communications receiver **100'** has a miniature virtual image display **102'** included in the body thereof, instead of in a hand held microphone. A hand held microphone is optional and this specific embodiment is desirable for instances where a hand held microphone is not utilized or not available or for use in pagers and the like which do not transmit. Miniature virtual image display **102'** is basically similar to miniature virtual image display **102** of FIGS. **11** and **12** and adds very little to the size, weight, or power consumption of portable communications receiver **100'**.

FIG. **15** is a perspective view of hand held microphone **101** illustrating a typical view **120** seen by an operator looking into viewing aperture **122** of miniature virtual image display **102**, described in conjunction with FIGS. **11** and **12**. View **120** could be, for example, a floor plan of a building about to be entered by the operator (a policeman). In operation, the floor plan is on file at the police station and, when assistance is requested by the policeman, the station simply transmits video representative of the previously recorded plan. Similarly, miniature virtual image display **102** might be utilized to transmit pictures of missing persons or wanted criminals, maps, extremely long messages, etc. Many other variations, such as silent receiver operation wherein the message appears on miniature virtual image display **102** instead of audibly, are possible.

It should be noted that in the prior art, pagers and other small receivers in which visual displays are desired, are especially handicapped by the size of the displays. Generally such displays are limited to a single short line of text or several digits, and the size of the display still dictates the size of the receiver. Further, the display is clearer and easier to read and, because it utilizes a virtual display, requires very little power for the operation thereof. In fact, the present display utilizing the electro-optical package of the present invention uses much less power than any of the direct view displays normally utilized in electronic equipment and, as a result, can be fabricated in much smaller sizes.

Thus, a new and improved electro-optical package composed of a plurality of sub-arrays and driver devices mounted to a substrate, and having mounted thereon at least one optical element is disclosed. The electro-optical package is meant for use in a visual display system incorporating a phase spatial light modulator scanner, which serves to spatially modulate the phase of light emitted by the sub-arrays and generate a resultant integrated image viewable as a direct, virtual or projected image. The package disclosed is relatively easy and inexpensive to manufacture. Light sources, polarizers, diffusers and, if desired, additional optics are conveniently integrated into the small visual display system which is easily integrated into a housing, forming an optical magnifier, for use in portable electronic equipment. By using sub-arrays of light emitting devices for the light source, with low aperture ratios, which are scanned by the phase spatial light modulator scanner to generate a resultant integrated image, characterized by high resolution, the size of the system is further reduced and the electrical power required is also minimized.

While we have shown and described specific embodiments of the present invention, further modifications and improvement will occur to those skilled in the art. We desire it to be understood, therefore, that this invention is not limited to the particular forms shown and we intend in the appended claims to cover all modifications that do not depart from the spirit and scope of this invention.

What is claimed is:

1. An integrated electro-optical package comprising:

at least one sub-array of light emitting devices cooperating to generate an image, mounted on a substrate, thereby defining an active area and at least one inactive area of a unit cell, the light emitting devices of each

sub-array being positioned in rows and columns to define a plurality of pixels of the image and operably connected to a plurality of connection/mounting pads adjacent outer edges of each sub-array;

at least one driver/control circuit having a plurality of connection/mounting pads, mounted to the at least one inactive area defined on the substrate, connected to the light emitting devices through a plurality of electrical conductors extending between the plurality of connection/mounting pads of the at least one driver/control circuit to the plurality of connection/mounting pads of the at least one sub-array; and

a lens system mounted to the substrate over the active and inactive areas and on a side of the substrate so as to receive and magnify light emitted by the light emitting devices.

2. An integrated electro-optical package as claimed in claim **1** wherein the substrate is formed of an optically transparent material.

3. An integrated electro-optical package as claimed in claim **2** wherein the optically transparent material includes at least one of optically transparent glass and optically transparent plastic.

4. An integrated electro-optical package as claimed in claim **3** wherein the light emitting devices include devices selected from the group including organic light emitting diodes, inorganic light emitting diodes, vertical cavity surface emitting lasers, field emission devices, and liquid crystal displays.

5. An integrated electro-optical package comprising:

at least one sub-array of light emitting devices cooperating to generate an image composed of a plurality of pixels, each of the light emitting devices having first and second electrodes for activating the light emitting devices, the light emitting devices being positioned in rows and columns to define a plurality of pixels of the image and operably connected to a plurality of external connection/mounting pads adjacent outer edges of the at least one sub-array, with the first electrodes of the light emitting devices being connected to a first plurality of the external connection/mounting pads and the second electrodes of the light emitting devices being connected to a second plurality of the external connection/mounting pads;

at least one driver/control circuit having a data input terminal and further having a control signal output terminal connected to the first and second electrodes of the light emitting devices for activating the light emitting devices to generate an image in accordance with a plurality of data signals applied to the data input terminal; and

a substrate, defining a major surface and having mounted thereon a portion of the manor surface, the at least one sub-array, thereby defining at least one active area and at least one inactive area, the at least one driver/control circuit being mounted to the at least one inactive area defined on the substrate, the substrate further having a plurality of electrical conductors formed therein, each extending and fanning out from a first plurality of mounting pads formed on the substrate, electrically interfaced with the at least one driver/control circuit, to a second plurality of mounting pads formed on the substrate, electrically interfaced with the first and second pluralities of external connection/mounting pads of the at least one sub-array.

6. An integrated electro-optical package as claimed in claim **5** including in addition an optical magnification system positioned to allow the light emitted by the light emitting devices to pass therethrough for magnifying the image generated by the at least one sub-array.

7. An integrated electro-optical package as claimed in claim **6** wherein the optical magnification system is integrally formed in the substrate.

8. An integrated electro-optical package as claimed in claim **6** wherein the optical magnification system is comprised of at least one separately fabricated optical element.

9. An integrated electro-optical package as claimed in claim **6** wherein the at least one driver/control circuit is mounted to the inactive area of the substrate having the control signal output terminal electrically contacting the first plurality of mounting pads of the substrate, the first and second pluralities of connection/mounting pads of the at least one sub-array each electrically contacting the second plurality of mounting pads of the substrate.

10. An integrated electro-optical package as claimed in claim **9** wherein the first plurality of mounting pads formed on the substrate include mounting bumps.

11. An integrated electro-optical package as claimed in claim **10** wherein the mounting bumps are formed from material selected from the group including solder, gold, and conducting epoxy.

12. An integrated electro-optical package as claimed in claim **9** wherein the second plurality of mounting pads formed on the substrate include mounting bumps.

13. An integrated electro-optical package as claimed in claim **12** wherein the mounting bumps are formed from a material selected from the group including solder, gold and conducting epoxy.

14. An integrated electro-optical package as claimed in claim **9** wherein the substrate is formed of a material selected from the group including glass, silicon, thin film ceramic and ceramic with organic dielectric and thin film metallization.

15. A visual image display system comprising:

at least one sub-array of light emitting devices cooperating to generate an image, mounted on a substrate, thereby defining an active area and at least one inactive area of a unit cell, the light emitting devices of each sub-array being positioned in rows and columns to define a plurality of pixels of the image and operably connected to a plurality of connection/mounting pads adjacent outer edges of each sub-array;

at least one driver/control circuit having a plurality of connection/mounting pads, mounted to the at least one inactive area defined on the substrate, connected to the light emitting devices through a plurality of electrical conductors extending between the plurality of connection/mounting pads of the at least one driver/control circuit to the plurality of connection/mounting pads of the at least one sub-array;

a lens system positioned so as to receive and magnify light emitted by the at least one sub-array of light emitting devices; and

a phase spatial light modulator scanner, positioned to allow for the light emitted by the at least one sub-array of light emitting devices to pass therethrough and be spatially modulated, thereby generating a resultant integrated image viewable by an observer as one of direct, virtual and projected image.

16. A visual image display system as claimed in claim **15** wherein the lens system includes at least one optical element.

17. A visual image display system as claimed in claim **16** wherein the at least one optical element is one of a diffractive lens and a refractive lens.

18. A visual image display system as claimed in claim 17 wherein the phase spatial light modulator scanner includes one of a liquid crystal scanner, a electro-optic scanner and an acousto-optic scanner.

19. A portable electronic device with visual display comprising:

a portable electronic device having a data output terminal;

a miniature visual image display having a viewing aperture, the miniature visual image display being operably attached to a receiver and including at least one sub-array of light emitting devices cooperating to generate an image, mounted on a substrate, thereby defining an active area and at least one inactive area of a unit cell, the light emitting devices of each sub-array being positioned in rows and columns to define a plurality of pixels of the image and operably connected to a plurality of connection/mounting pads adjacent outer edges of each sub-array;

at least one driver/control circuit having a plurality of connection/mounting pads, mounted to the at least one inactive area defined on the substrate, connected to the light emitting devices through a plurality of electrical conductors extending between the plurality of connection/mounting pads of the at least one driver/control circuit to the plurality of connection/mounting pads of the at least one sub-array;

a lens system positioned so as to receive and magnify light emitted by the at least one sub-array of light emitting devices; and

a phase spatial light modulator scanner, positioned to allow for the light emitted by the at least one sub-array of light emitting devices to pass therethrough and be spatially modulated, thereby generating a resultant integrated image viewable by an observer as one of direct, virtual and projected image.

20. A portable electronic device with visual display as claimed in claim 19 wherein the lens system is comprised of at least one of a diffractive lens, and a refractive lens, designed to magnify the image generated by the at least one sub-array of light emitting devices.

21. A portable electronic device with visual display as claimed in claim 19 wherein the portable electronic device includes portable communications equipment.

22. A portable electronic device with visual display as claimed in claim 21 wherein the portable communications equipment is one of a cellular telephone, a two-way radio, a data bank, a smart-card reader and a pager.

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