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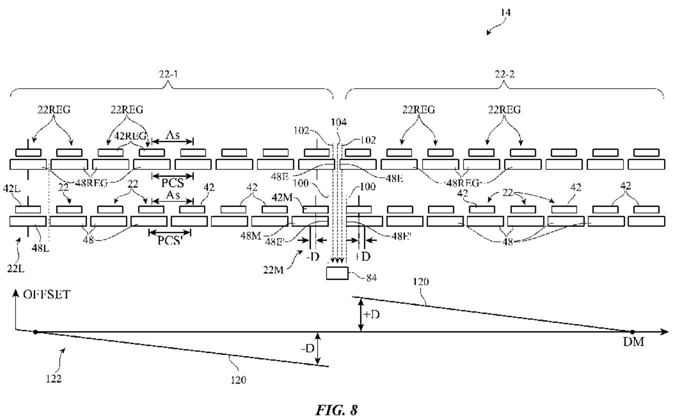

FIG. 8

(57) Abstract: A display may have an array of pixels (22). Each pixel may have a light-emitting diode such as an organic light-emitting diode. The organic light-emitting diodes may each have an anode (42) that is coupled to a thin-film transistor pixel circuit (48) for controlling the anode. The pixels may be arranged in blocks (22-1, 22-2). Within each block, the pixel circuits may be characterized by a center-to-center separation (PCS') that is less than the center-to-center separation (AS) between anodes in the block. The pixel circuits may be shifted by varying amounts as a function of distance across the display, so that the pixel circuits at the corners of adjacent blocks are characterized by enhanced separations. The enlarged spaces between these pixel circuits creates space for light (102, 104) to be received through the display by an array of light detectors (84) or other electrical components that are aligned with the enhanced separations.

Display With Embedded Components

This application claims priority to U.S. provisional patent application No. 62/21 8,347, filed September 14, 2015, which is hereby incorporated by reference herein in its entirety.

Background

[0001] This relates generally to electronic devices, and, more particularly, to electronic devices with displays.

[0002] Electronic devices often include displays. Displays such as organic light-emitting diode displays have pixels with light-emitting diodes. The light emitting diodes each have electrodes (i.e., an anode and a cathode). Emissive material is interposed between the electrodes. During operation, current passes through the emissive material between the electrodes, generating light.

[0003] The electrodes in an organic light-emitting diode display are formed from a photolithographically patterned layer of conductive material. Electrodes are organized in a regularly spaced array. This type of arrangement simplifies the layout of thin-film transistor circuits for the display.

[0004] It may be desirable to incorporate electrical components into a display. If care is not taken, the electrodes and other circuitry in a display may interfere with these components.

[0005] It would therefore be desirable to be able to provide improved display arrangements for accommodating the addition of electrical components.

Summary

[0006] A display may have an array of pixels. Each pixel may have a light-emitting diode such as an organic light-emitting diode. The organic light-emitting diodes may each have an anode that is coupled to an associated pixel circuit. The pixel circuit may include thin-film transistor circuitry for controlling the anode.

[0007] The pixels may be arranged in blocks. Within each block, the pixel circuits may be characterized by a center-to-center separation that is less than the center-to-center separation between anodes in the block. The pixel circuits of the block may be shifted by varying amounts relative to the anodes as a function of distance across the display. As a result, the pixel circuits at the boundaries between adjacent blocks (i.e., the pixel circuits at the comers of adjacent blocks in an array of pixels with pixel circuits shifted in two dimensions) will be characterized by enhanced center-to-center separations.

[0008] The enlarged spaces between these pixel circuits creates additional spaces for light to be received through the display. Transparent windows such as openings that pass partway or fully through a display substrate and which may include transparent material such as transparent polymer may be formed in alignment with the enlarged pixel-circuit center-to-center separations. An array of electrical components such as an array of light detectors or other electrical components may be aligned with the transparent windows and the enhanced center-to-center separations between the pixel circuits at the block boundaries (i.e., at the corners of the blocks).

[0009] Further features will be more apparent from the accompanying drawings and the following detailed description.

Brief Description of the Drawings

[0010] FIG. 1 is a schematic diagram of an illustrative electronic device having a display in accordance with an embodiment.

[0011] FIG. 2 is a top view of an illustrative display in an electronic device in accordance with an embodiment.

[0012] FIG. 3 is a cross-sectional side view of a portion of an illustrative organic light-emitting diode display in accordance with an embodiment.

[0013] FIG. 4 is diagram of an illustrative pixel cell having pixels of different colors in accordance with an embodiment.

[0014] FIG. 5 is a cross-sectional side view of a display with an array of electrical components in accordance with an embodiment.

[0015] FIG. 6 is a top view of an illustrative display with an array of electrical components located at the corners of blocks of pixels in the display in accordance with an embodiment.

[0016] FIGS. 7A and 7B show how the position of a pixel circuit may be shifted relative to an associated anode in a diode as a function of position in a display in accordance with an embodiment.

[0017] FIG. 8 is a diagram showing how pixel circuits may be shifted relative to pixel electrodes within blocks of pixels to create enhanced spaces at the corners of the blocks to accommodate light-transparent windows and associated electrical components in accordance with an embodiment.

Detailed Description

[0018] An illustrative electronic device of the type that may be provided with a display is shown in FIG. 1. As shown in FIG. 1, electronic device 10 may have control circuitry 16. Control circuitry 16 may include storage and processing circuitry for supporting the operation of device 10. The storage and processing circuitry may include storage such as hard disk drive storage, nonvolatile memory (e.g., flash memory or other electrically-programmable-read-only memory configured to form a solid state drive), volatile memory (e.g., static or dynamic random-access-memory), etc. Processing circuitry in control circuitry 16 may be used to control the operation of device 10. The processing circuitry may be based on one or more microprocessors, microcontrollers, digital signal processors, baseband processors, power management units, audio chips, application specific integrated circuits, etc.

[0019] Input-output circuitry in device 10 such as input-output devices 12 may be used to allow data to be supplied to device 10 and to allow data to be provided from device 10 to external devices. Input-output devices 12 may include buttons, j oysticks, scrolling wheels, touch pads, key pads, keyboards, microphones, speakers, tone generators, vibrators, cameras, sensors, light-emitting diodes and other status indicators, data ports, and other electrical components. A user can control the operation of device 10 by supplying commands through input-output devices 12 and may receive status information and other output from device 10 using the output resources of input-output devices 12.

[0020] Input-output devices 12 may include one or more displays such as display 14. Display 14 may be a touch screen display that includes a touch sensor for gathering touch input from a user or display 14 may be insensitive to touch. A touch sensor for display 14 may be based on an array of capacitive touch sensor electrodes, acoustic touch sensor structures, resistive touch components, force-based touch sensor structures, a light-based touch sensor, or other suitable touch sensor arrangements.

[0021] Control circuitry 16 may be used to run software on device 10 such as operating system code and applications. During operation of device 10, the software running on control circuitry 16 may display images on display 14 using an array of pixels in display 14.

[0022] Device 10 may be a tablet computer, laptop computer, a desktop computer, a display, a cellular telephone, a media player, a wristwatch device or other wearable electronic equipment, or other suitable electronic device.

[0023] Display 14 may be an organic light-emitting diode display or may be a display based on other types of display technology. Configurations in which display 14 is an organic light-emitting diode display are sometimes described herein as an example. This is, however, merely illustrative. Any suitable type of display may be used, if desired.

[0024] Display 14 may have a rectangular shape (i.e., display 14 may have a rectangular footprint and a rectangular peripheral edge that runs around the rectangular footprint) or may have other suitable shapes. Display 14 may be planar or may have a curved profile.

[0025] A top view of a portion of display 14 is shown in FIG. 2. As shown in FIG. 2, display 14 may have an array of pixels 22 formed on substrate 36. Substrate 36 may be formed from glass, metal, plastic, ceramic, or other substrate materials. Pixels 22 may receive data signals over signal paths such as data lines D and may receive one or more control signals over control signal paths such as horizontal control lines G (sometimes referred to as gate lines, scan lines, emission control lines, etc.). There may be any suitable number of rows and columns of pixels 22 in display 14 (e.g., tens or more, hundreds or more, or thousands or more). Each pixel 22 may have a light-emitting diode 26 that emits light 24 under the control of a pixel circuit formed from thin-film transistor circuitry such as thin-film transistors 28 and thin-film capacitors). Thin-film transistors 28 may be polysilicon thin-film transistors, semiconducting-oxide thin-film transistors such as indium gallium zinc oxide transistors, or thin-film transistors formed from other semiconductors. Pixels 22 may contain light-emitting diodes of different colors (e.g., red, green, and blue diodes for red, green, and blue pixels, respectively) to provide display 14 with the ability to display color images.

[0026] Display driver circuitry may be used to control the operation of pixels 22. The display driver circuitry may be formed from integrated circuits, thin-film transistor circuits, or other suitable circuitry. Display driver circuitry 30 of FIG. 2 may contain communications circuitry for communicating with system control circuitry such as control circuitry 16 of FIG. 1 over path 32. Path 32 may be formed from traces on a flexible printed circuit or other cable. During operation, the control circuitry (e.g., control circuitry 16 of FIG. 1) may supply circuitry 30 with information on images to be displayed on display 14.

[0027] To display the images on display pixels 22, display driver circuitry 30 may supply image data to data lines D while issuing clock signals and other control signals to supporting display driver circuitry such as gate driver circuitry 34 over path 38. If desired, circuitry 30 may also supply clock signals and other control signals to gate driver circuitry on an opposing edge of display 14.

[0028] Gate driver circuitry 34 (sometimes referred to as horizontal control line control circuitry) may be implemented as part of an integrated circuit and/or may be implemented using thin-film transistor circuitry. Horizontal control lines G in display 14 may carry gate line signals (scan line signals), emission enable control signals, and other horizontal control signals for controlling the pixels of each row. There may be any suitable number of horizontal control signals per row of pixels 22 (e.g., one or more, two or more, three or more, four or more, etc.).

[0029] A cross-sectional side view of a portion of an illustrative organic light-emitting diode display that includes a light-emitting diode (diode 26) and thin-film transistor circuitry for an associated pixel circuit (pixel circuit 48) is shown in FIG 3. As shown in FIG. 3, display 14 may include a substrate layer such as substrate layer 36. Substrate 36 may be a planar layer or a non-planar layer and may be formed from plastic, glass, ceramic, sapphire, metal, or other suitable materials. The surface of substrate 36 may, if desired, be covered with one or more buffer layers (e.g., inorganic buffer layers such as layers of silicon oxide, silicon nitride, etc.).

[0030] Thin-film transistor circuitry for pixel circuit 48 may be formed on substrate 36. The thin film transistor circuitry may include transistors, capacitors, and other thin-film structures. As shown in FIG. 3, a transistor such as thin-film transistor 28 may be formed from thin-film semiconductor layer 60. Semiconductor layer 60 may be a polysilicon layer, a semiconducting-oxide layer such as a layer of indium gallium zinc oxide, or other semiconductor layer. Gate layer 56 may be a conductive layer such as a metal layer that is separated from semiconductor layer 60 by an intervening layer of dielectric such as dielectric 58 (e.g., an inorganic gate insulator layer such as a layer of silicon oxide). Dielectric 62 may also be used to separate semiconductor layer 60 from underlying structures such as shield layer 64 (e.g., a shield layer that helps shield the transistor formed from semiconductor layer 60 from charge in buffer layers on substrate 36).

[0031] Semiconductor layer 60 of transistor 28 may be contacted by source and drain terminals formed from source-drain metal layer 52. Dielectric layer 54 (e.g., an inorganic dielectric layer) may separate gate metal layer 56 from source-drain metal layer 52. Pixel circuit 48 (e.g., source-drain metal layer 52) may be shorted to anode 42 of light-emitting diode 26 using a metal via such as via 53 that passes through dielectric planarization layer 50.

Planarization layer 50 may be formed from an organic dielectric material such as a polymer.

[0032] Light-emitting diode 26 is formed from light-emitting diode layers 40 on the thin-film transistor layers of pixel circuit 48. Each light-emitting diode has a lower electrode and an upper electrode. In a top emission display, the lower electrode may be formed from a reflective conductive material such as pattemed metal to help reflect light that is produced by the light-emitting diode in the upwards direction out of the display. The upper electrode (sometimes referred to as the counter electrode) may be formed from a transparent or semi-transparent conductive layer (e.g., a thin layer of transparent or semitransparent metal and/or a layer of indium tin oxide or other transparent conductive material). This allows the upper electrode to transmit light outwards that has been produced by emissive material in the diode. In a bottom emission display, the lower electrode may be transparent (or semi-transparent) and the upper electrode may be reflective.

[0033] In configurations in which the anode is the lower electrode, layers such as a hole injection layer, hole transport layer, emissive material layer, and electron transport layer may be formed above the anode and below the upper electrode, which serves as the cathode for the diode. In inverted configurations in which the cathode is the lower electrode, layers such as an electron transport layer, emissive material layer, hole transport layer, and hole injection layer may be stacked on top of the cathode and may be covered with an upper layer that serves as the anode for the diode. Both electrodes may reflect light.

[0034] In general, display 14 may use a configuration in which the anode electrode is closer to the display substrate than the cathode electrode or a configuration in which the cathode electrode is closer to the display substrate than the anode electrode. In addition, both bottom emission and top emission arrangements may be used. Top emission display configurations in which the anode is located on the bottom and the cathode is located on the top are sometimes described herein as an example. This is, however, merely illustrative. Any suitable display arrangement may be used, if desired.

[0035] In the illustrative configuration of FIG. 3, display 14 has a top emission configuration and lower electrode 42 is an anode and upper electrode 46 is a cathode. Layers 40 include a patterned metal layer that forms anodes such as anode 42. Anode 42 is formed within an opening in pixel definition layer 66. Pixel definition layer 66 may be formed from a pattemed photoimageable polymer. The photoimageable polymer may be formed from an opaque material and/or a layer of opaque material such as black masking layer 66' may cover other material in layer 66 (e.g., opaque layer 66' may cover a layer of semitransparent polyimide or other polymer).

[0036] In each light-emitting diode, organic emissive material 44 is interposed between a respective anode 42 and cathode 46. Anodes 42 may be patterned from a layer of metal on a planarization layer in the thin-film transistor layers of pixel circuit 48 such as planarization layer 50. Cathode 46 may be formed from a common conductive layer that is deposited on top of pixel definition layer 66. Cathode 46 is transparent so that light 24 may exit light emitting diode 26 as current is flowing through emissive material 44 between anode 42 and cathode 46.

[0037] Display 14 may have an array of pixels 22 of different colors to provide display 14 with the ability to display color images. As shown in FIG. 4, each pixel cell 22P in display 14 may contain a red pixel 22R, a green pixel 22G, and a blue pixel 22B (as an example). These pixels, which may sometimes be referred to as subpixels, may have rectangular emissive areas (e.g., rectangular anode shapes) and/or may have emissive areas of other suitable shapes. White pixels, yellow pixels, and pixels of other colors may also be included in display 14, if desired.

[0038] It may be desirable to incorporate electrical components into display 14 and/or device 10. As shown in FIG. 5, for example, electrical components 84 may be incorporated into device 10 under pixels 22. Components 84 may be discrete components or may be formed as part of a common integrated circuit or other shared component. Components 84 may, as an example, be mounted on a substrate such as substrate 82. Substrate 82 may be, for example, a printed circuit (e.g., a rigid printed circuit board formed from a rigid printed circuit board material such as fiberglass-filled epoxy or a flexible printed circuit formed from a flexible layer of polyimide or other sheet of polymer). Components 84 and/or substrate 82 may be integrated into the layers that make up display 14 and/or may be mounted in alignment with display 14.

[0039] Electrical components 84 may be audio components (e.g., microphones, speakers, etc.), radio-frequency components, haptic components (e.g., piezoelectric structures, vibrators, etc.), may be capacitive touch sensor components or other touch sensor structures, may be temperature sensors, pressure sensors, magnetic sensors, or other sensors, or may be any other suitable type of electrical component. With one suitable arrangement, which may sometimes be described herein as an example, electrical components 84 may be light-based components (e.g., components that emit and/or detect visible light, infrared light, and/or ultraviolet light).

[0040] Light-based components 84 may emit and/or detect light that passes through transparent windows 76 in display 14. Windows 76 may be formed in regions located between pixels 22 and may include transparent materials (e.g., clear plastic, glass, etc.) and/or holes (e.g., air-filled openings or openings filled with transparent material that pass partly or fully through substrate 36 and other display layers 74 of display 14 such as opaque portions of pixel definition layer 66 such as black masking layer 66'). There may be a window 76 between each pair of pixels 22 or, more preferably, blocks of pixels 22 (e.g., blocks of tens, hundreds, or thousands of pixels) may be associated with windows 76 and electrical components 84. For example, additional space may be created between adjacent pixel circuits at the corners of adjacent blocks of pixels to accommodate windows 76 and components 84. If desired, some components may be mounted on the upper surface of display 14 (in which cases windows 76 need not be provided through layers 74 of display 14).

[0041] Examples of light-based components 84 that emit light include light-emitting diodes (e.g., organic light-emitting diodes, discrete crystalline light-emitting diode dies, etc.), lasers, and lamps. Examples of light-based components that detect light include light detectors such as photodiodes and phototransistors. Some components may, if desired, include both light emitters and detectors. For example, components 84 may emit infrared light and may include light detector structures for detecting a portion of the emitted light that has reflected from nearby objects such as object 86. Components of this type may be used to implement a proximity detector, a light-based fingerprint sensor (e.g., when object 86 is the finger of a user), or other light-based sensor. If desired, light-based sensors such as these may be implemented by illuminating object 86 with light 24 from one or more of pixels 22 and/or light 78 from one or more supplemental light sources such as discrete light-emitting diodes 80, while using light-detecting components 84 to gather reflected light from object 86.

[0042] Control circuitry 16 may be used in controlling the emission of light from light sources such as pixels 22, components 84, and/or light sources 80 and may be used in processing corresponding detected light from components 84 (e.g., to generate a proximity sensor signal based on light reflected from object 86, to generate a fingerprint reading based on light reflected from object 86, to process a captured digital image of a far-field object, that is captured using components 84, etc.).

[0043] Components 84 (and windows 76, if used) may be interspersed with pixels 22 using any suitable arrangement. With one illustrative configuration, which is shown in FIG. 6, windows 76 and components 84 are arranged in an array that has a larger pitch than the array of pixels 22 in display 14. There may be, for example, one window 76 and one corresponding component 84 for each set of 10-1 000 pixels 22, for each set of 100-10,000 pixels, for each set of more than 500 pixels, or for each set of less than 5000 pixels (as examples). In configurations such as these, pixels 22 are arranged on display 14 with a finer pitch than windows 76 and components 84. Pixels 22 may, for example, be organized in an array having rows and columns and windows 76 and components 84 may be arranged in an array having a smaller number of rows and columns. Configurations in which windows 76 and components 84 are arranged in patterns other than rectangular arrays may also be used. Arrangements in which windows 76 and components 84 are arranged in rows and columns may sometimes be described herein as an example.

[0044] To make room for components 84 (and for windows 76), it may be desirable to adjust the relative position of the pixel circuit of each pixel relative to the anode of that pixel as a function of lateral distance across the surface of display 14. In this way, the pixel circuits of display 14 can be shifted out of the way to make room for components 84 and windows 76.

[0045] In illustrative pixel 22 of FIG. 7A, anode 42 is centered over pixel circuit 48 and is coupled by a via (via 53) that is centered with respect to anode 42 and pixel circuit 48. At other locations on display 14, pixel circuit 48 can be shifted laterally with respect to anode 42. In illustrative pixel 22 of FIG. 7B, pixel circuit 48 has been shifted to the left by distance D, so that pixel circuit 48 is no longer centered under anode 42 (and so that room is created to the right of pixel circuit 48 through which light can pass). If desired, the position of via 53 may be shifted in conj unction with the shift of pixel circuit 48. For example, the via of FIG. 7B may shift from position 53' (where the via was located in the arrangement of FIG. 7A) to new position 53. When multiple pixel circuits 48 are each shifted in this way, the cumulative amount of space that is created is larger than the space created by a single pixel circuit shift. As a result, additional room may be created for components 84.

[0046] The diagram of FIG. 8 shows how pixel circuits 48 may be progressively shifted to make room for light 90 to reach component 84. Display 14 of FIG. 8 may be characterized by lateral dimensions X and Y and may lie in the X-Y plane. Dimension DM of FIG. 8 may represent lateral dimension X and/or lateral dimension Y.

[0047] Two blocks of pixels 22 are shown in FIG. 8 (e.g., left block 22-1 and right block 22-2). In a display with numerous components 84, numerous blocks of pixels may include progressively shifted pixel circuits (see, e.g., the illustrative arrangement of display 14 of FIG. 6). To accommodate a two-dimensional array of components 84, pixel circuits may be shifted away from the comers of the pixel blocks. The diagram of FIG. 8 shows how pixel circuits may be shifted away from each other at the boundary between a left block of pixels and a right block of pixels as a simplified example.

[0048] As shown in the lower row of FIG. 8, display 14 contains pixels 22. Each pixel 22 contains an anode 42 and a pixel circuit 48, as described in connection with FIG. 3. To accommodate components such as component 84, the locations of pixel circuits 48 are shifted to the left in block 22-1 and are shifted to the right in block 22-2. This creates room for light to reach component 84 at the boundary between blocks 22-1 and 22-2. For comparison, the locations of the anodes and pixel circuits of an illustrative set of unshifted pixels are shown in the upper row of FIG. 8 (see, e.g., pixels 22REG, anodes 42REG, and associated unshifted pixel circuits 48REG).

[0049] In an unshifted set of pixels such as pixels 22REG, each pixel circuit 48REG is centered below a corresponding anode 42REG. As a result, center-to-center separation AS between anodes 42REG does not vary as a function of lateral distance DM across a display and center-to-center separation PCS between pixel circuits 48REG does not vary as a function of lateral distance DM across the display. The center-to-center separation AS is equal to center-to-center separation PCS and there is no increase or decrease in separations AS and PCS when traversing the boundary between blocks 22-1 and 22-2.

[0050] Because pixel circuits 48REG are arranged with a constant pitch, there is relatively little clearance between the adjacent edges of pixel circuits 48REG at the boundary between adjacent pixel blocks 22-1 and 22-2. As a result, although some light (such as light ray 104) may reach component 84 between adjacent pixel circuit edges 48E, other light (such as light rays 102) will be blocked by the portions of pixel circuits 48REGthat are adjacent to edges 48E. Unshifted pixel arrangements of the type shown by pixels 22REG may therefore not allow sufficient light to reach (or exit) component 84.

[0051] With the shifted pixel arrangement of pixels 22, however, each pixel 22 has a pixel circuit 48 that is shifted by a progressively different amount with respect to its associated anode 42. This creates enlarged center-to-center pixel circuit separations at the boundaries between pixel blocks to accommodate aligned components 84 (i.e., at the comers of the blocks of pixels in a two-dimensional display).

[0052] In block 22-1, for example, leftmost pixel circuit 48L in pixel 22L is not shifted with respect to leftmost anode 42L, whereas rightmost pixel circuit 48M in pixel 22M is shifted to the left by offset D with respect to rightmost anode 42M. Pixel circuits 48 in pixels 22 that lie between pixels 22L and 22M are shifted to the left by progressively increasing amounts at increasing distances DM from pixel 22L towards pixel 22M. Curve 120 of graph 122 shows how the offset between pixel circuit and anode is 0 in pixel 42L and increases in magnitude progressively to offset - D at pixel 42M. Pixel circuits 48 are likewise shifted to the right in block 22-2.

[0053] With this type of arrangement, pixel circuits 48 spaced with a finer (smaller) pitch than anodes 42 (i.e., center-to-center pixel circuit separation PCS' is less than center-to-center anode separation AS). Because pixels circuits 48 are spaced closer together than anodes 42 and because of the progressive shifting of pixel circuits 48 away from component 84 toward the outer edges of the pixel blocks, there is an enlarged center-to-center spacing between the pixels 22 at the boundary between blocks 22-1 and 22-2. This creates sufficient room between pixels circuits 48 at the block boundary to allow light 102 to reach component 84 (i.e., the separation between pixel circuit edges 48E' of the centermost pixel circuits 48 in display 14 is sufficiently wide to permit light rays 104 and 102 to reach component 84 without being blocked).

[0054] Each pixel circuit 48 is shifted relative to the anode in the pixel containing that pixel circuit and the pixel circuits have a smaller center-to-center separation than the anodes (except at the block boundaries - i.e., at the corners of the pixel blocks in a two-dimensional array of pixels). This creates an array of enlarged pixel circuit separations at the block boundaries (see, e.g., the enlarged space between pixel circuit edges 48E', which is larger than the space between unshifted pixel circuit edges 48E).

[0055] The array of enlarged center-to-center pixel circuit separations for the pixel circuits at the block boundaries (e.g., at the locations shown by components 84 and windows 76 of FIG. 6) accommodates a corresponding array of electrical components 84. This type of scheme may be replicated for numerous blocks of pixels 22 within display 14, thereby creating a two-dimensional array of enlarged spaces between pixel circuits 48 at the block boundaries (i.e., at comer boundaries between blocks in a display with a two-dimensional array of pixels 22). The two-dimensional array of enlarged spaces will accommodate an array of components 84 (and, if desired, windows 76), as described in connection with FIG. 6.

[0056] Because anode pitch AS is unaltered in pixels 22 relative to unshifted pixels 22REG, display resolution is not diminished due to pixel circuit shifting even though an array of enlarged pixel circuit spaces have been created to accommodate components 84. Within each block of pixels 22 (e.g., within block 22-1 and within block 22-2), center-to-center pixel circuit separation PCS' is constant and smaller than that of unshifted pixel circuit separation PCS, but at the corner boundaries between blocks (e.g., at the boundary between block 22-1 and block 22-2 that is aligned with component 84 in the simplified example of FIG. 8), the center-to-center separation between the edge pixel circuits of the blocks (i.e., the center-to-center separation between pixel circuit 48M of block 22-1 and the adjacent pixel circuit 48 of block 22-2) is larger than PCS' (i.e., the space between edges 48E is enlarged relative to the space between the other adj acent pixel circuits 48). This enlarged space creates additional room to allow light to enter and/or exit component 84 and may also allow non-light-based components 84 to operate satisfactorily.

[0057] In accordance with an embodiment, a display is provided that includes an array of electrical components, and an array of pixels that emit light to form images on the display, each pixel includes an anode and an associated pixel circuit, the pixels are arranged in blocks in which the anodes have a center-to-center anode spacing and the pixel circuits have a center-to-center pixel circuit spacing that is less than the center-to-center anode spacing, adj acent pixel circuits at boundaries between the blocks are characterized by a center-to-center separation that is enlarged relative to the center-to-center spacing of the pixel circuits, and each of the electrical components is aligned with a respective one of the enlarged center-to-center separations.

[0058] In accordance with another embodiment, the electrical components include light-based components.

[0059] In accordance with another embodiment, the electrical components include light detectors.

[0060] In accordance with another embodiment, the light detectors include visible light detectors.

[0061] In accordance with another embodiment, the electrical components include infrared light detectors.

[0062] In accordance with another embodiment, the electrical components include light emitters.

[0063] In accordance with another embodiment, the array of pixels includes an array of organic light-emitting diodes and each anode forms a part of a respective one of the organic light-emitting diodes.

[0064] In accordance with another embodiment, the display includes a substrate, each pixel circuit includes thin-film transistor circuitry on the substrate.

[0065] In accordance with another embodiment, the display includes an array of transparent windows each of which is aligned with a respective one of the electrical components.

[0066] In accordance with another embodiment, the array of pixels includes an opaque masking layer, each transparent window includes an opening that passes through the black masking layer, and each electrical component includes a light detector aligned with a respective one of the openings.

[0067] In accordance with an embodiment, a display is provided that includes a substrate, an array of pixels on the substrate that are organized in blocks, within each block the pixels have pixel circuits characterized by a center-to-center pixel circuit separation that is smaller than an enlarged center-to-center pixel circuit separation that is associated with adjacent pixel circuits from respective adjacent blocks, and electrical components that receive light through the enlarged center-to-center pixel circuit separations.

[0068] In accordance with another embodiment, the electrical components include light detectors.

[0069] In accordance with another embodiment, the display includes transparent window regions, each electrical component receives light through a respective one of the transparent window regions.

[0070] In accordance with another embodiment, each pixel circuit includes thin-film transistor circuitry on the substrate.

[0071] In accordance with another embodiment, each pixel includes a light-emitting diode.

[0072] In accordance with another embodiment, each light-emitting diode includes an organic light-emitting diode having an anode and the anodes are arranged with a center-to-center separation that is larger than the center-to-center pixel circuit separation.

[0073] In accordance with another embodiment, the pixels each include an organic light-emitting diode with an anode associated with one of the pixel circuits and at least some of the pixel circuits are shifted by progressively increasing amounts relative to their associated anodes as a function of distance across the array.

[0074] In accordance with an embodiment, an electronic device is provided that includes a display having an array of pixels, the pixels have anodes with a constant center-to-center separation across the display and the pixels have pixel circuits that are shifted by varying amounts relative to the anodes as a function of distance across the display to create an array of enlarged spaces between some of the pixel circuits, and an array of light detectors aligned with the array of enlarged spaces.

[0075] In accordance with another embodiment, the light detectors each receive light through one of the enlarged spaces and the array of pixels includes and array of organic light-emitting diodes each of which includes a respective one of the anodes.

[0076] In accordance with another embodiment, the pixel circuits include thin-film transistors.

[0077] The foregoing is merely illustrative and various modifications can be made by those skilled in the art without departing from the scope and spirit of the described embodiments. The foregoing embodiments may be implemented individually or in any combination.

Claims

What is Claimed is:

1. A display, comprising:

an array of electrical components; and

an array of pixels that emit light to form images on the display, wherein each pixel includes an anode and an associated pixel circuit, wherein the pixels are arranged in blocks in which the anodes have a center-to-center anode spacing and the pixel circuits have a center-to-center pixel circuit spacing that is less than the center-to-center anode spacing, wherein adjacent pixel circuits at boundaries between the blocks are characterized by a center-to-center separation that is enlarged relative to the center-to-center spacing of the pixel circuits, and wherein each of the electrical components is aligned with a respective one of the enlarged center-to-center separations.

2. The display defined in claim 1 wherein the electrical components comprise light-based components.

3. The display defined in claim 1 wherein the electrical components comprise light detectors.

4. The display defined in claim 3 wherein the light detectors comprise visible light detectors.

5. The display defined in claim 3 wherein the electrical components comprise infrared light detectors.

6. The display defined in claim 1 wherein the electrical components comprise light emitters.

7. The display defined in claim 1 wherein the array of pixels comprises an array of organic light-emitting diodes and wherein each anode forms a part of a respective one of the organic light-emitting diodes.

8. The display defined in claim 1 further comprising a substrate, wherein each pixel circuit includes thin-film transistor circuitry on the substrate.

9. The display defined in claim 8 further comprising an array of transparent windows each of which is aligned with a respective one of the electrical components.

10. The display defined in claim 9 wherein the array of pixels includes an opaque masking layer, wherein each transparent window includes an opening that passes through the black masking layer, and wherein each electrical component comprises a light detector aligned with a respective one of the openings.

11. A display, comprising:

a substrate;

an array of pixels on the substrate that are organized in blocks, wherein within each block the pixels have pixel circuits characterized by a center-to-center pixel circuit separation that is smaller than an enlarged center-to-center pixel circuit separation that is associated with adjacent pixel circuits from respective adjacent blocks; and

electrical components that receive light through the enlarged center-to-center pixel circuit separations.

12. The display defined in claim 11 wherein the electrical components comprise light detectors.

13. The display defined in claim 12 further comprising transparent window regions, wherein each electrical component receives light through a respective one of the transparent window regions.

14. The display defined in claim 13 wherein each pixel circuit comprises thin-film transistor circuitry on the substrate.

15. The display defined in claim 14 wherein each pixel comprises a light-emitting diode.

16. The display defined in claim 15 wherein each light-emitting diode comprises an organic light-emitting diode having an anode and wherein the anodes are arranged with a center-to-center separation that is larger than the center-to-center pixel circuit separation.

17. The display defined in claim 11 wherein the pixels each include an organic light-emitting diode with an anode associated with one of the pixel circuits and wherein at least some of the pixel circuits are shifted by progressively increasing amounts relative to their associated anodes as a function of distance across the array.

18. An electronic device comprising:

a display having an array of pixels, wherein the pixels have anodes with a constant center-to-center separation across the display and wherein the pixels have pixel circuits that are shifted by varying amounts relative to the anodes as a function of distance across the display to create an array of enlarged spaces between some of the pixel circuits; and

an array of light detectors aligned with the array of enlarged spaces.

19. The electronic device defined in claim 18 wherein the light detectors each receive light through one of the enlarged spaces and wherein the array of pixels comprises and array of organic light-emitting diodes each of which includes a respective one of the anodes.

20. The electronic device defined in claim 19 wherein the pixel circuits comprise thin-film transistors.

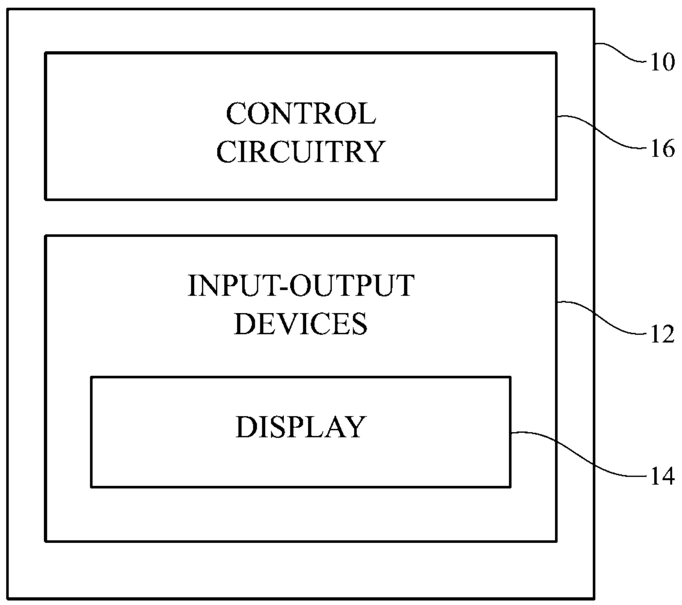

FIG. 1

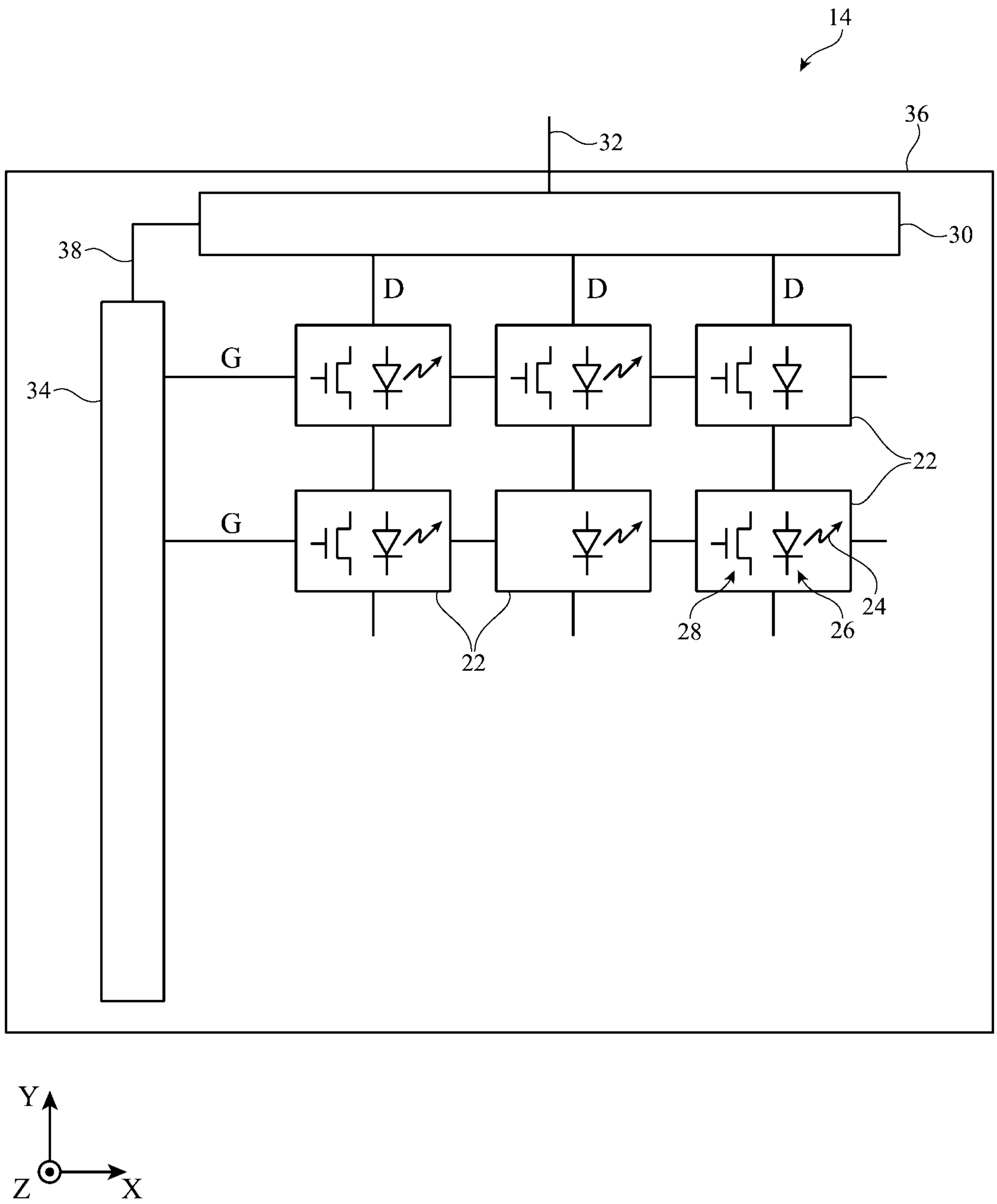

FIG. 2

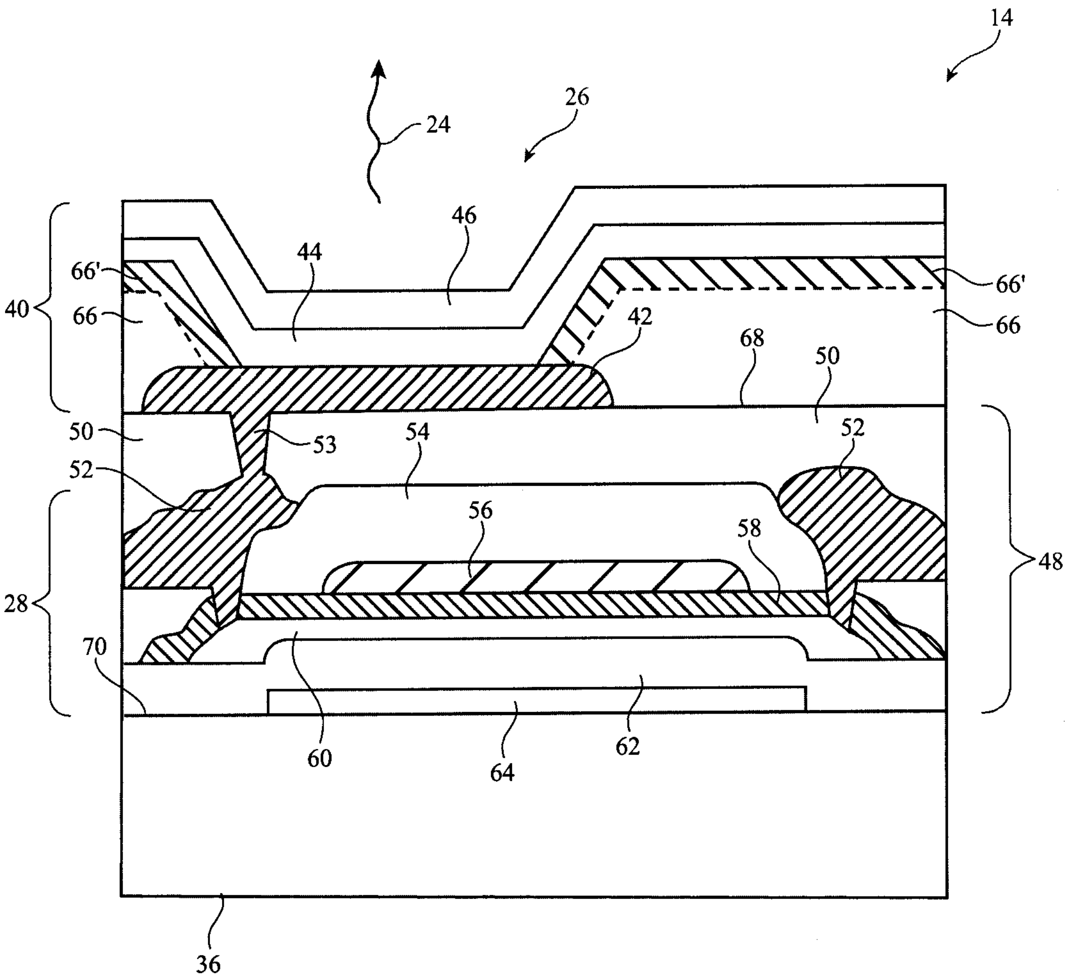
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FIG. 3

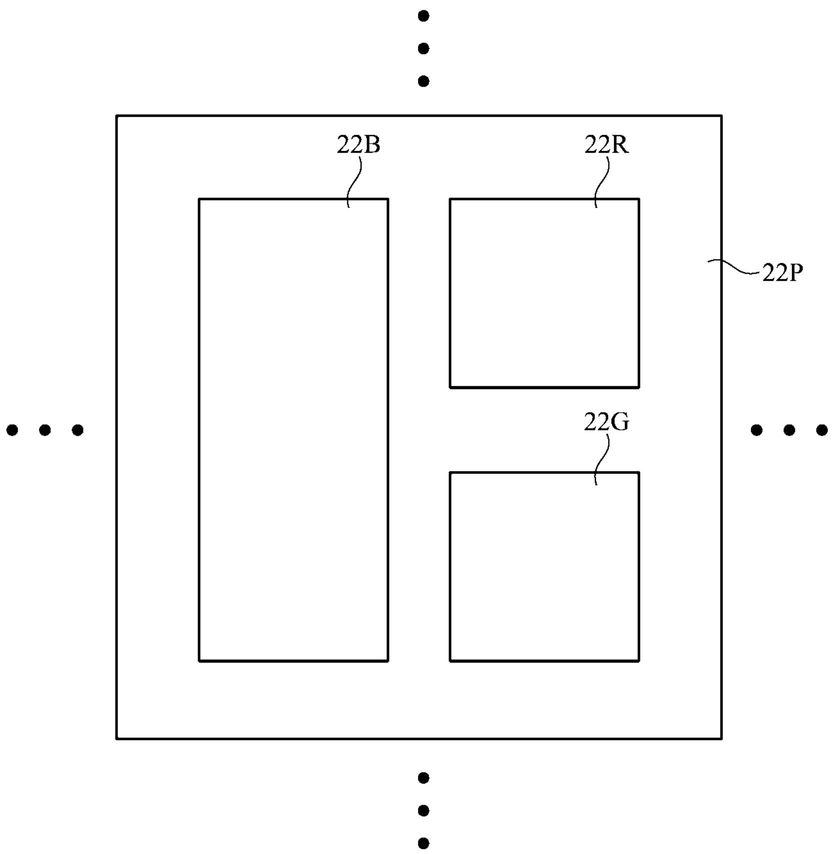


FIG. 4

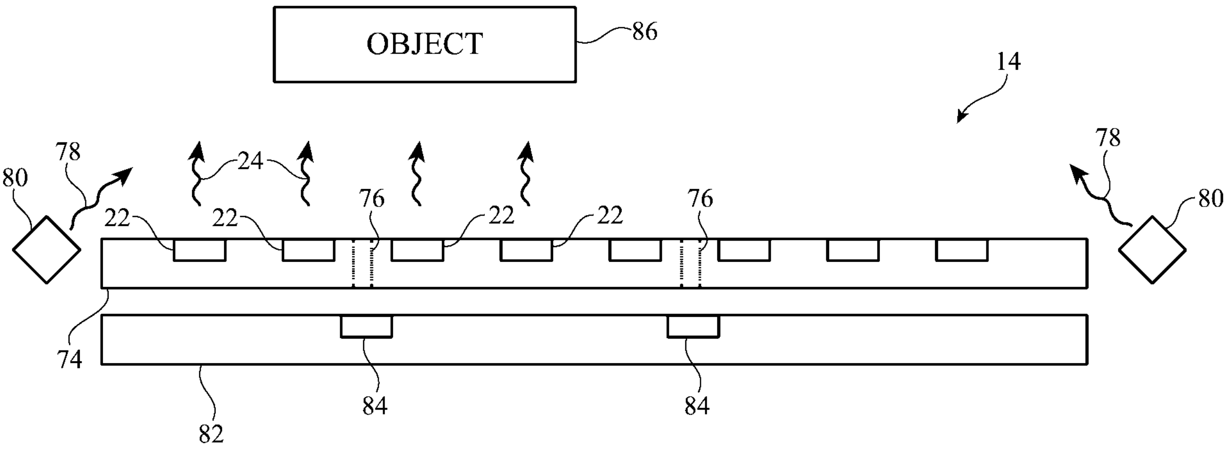


FIG. 5

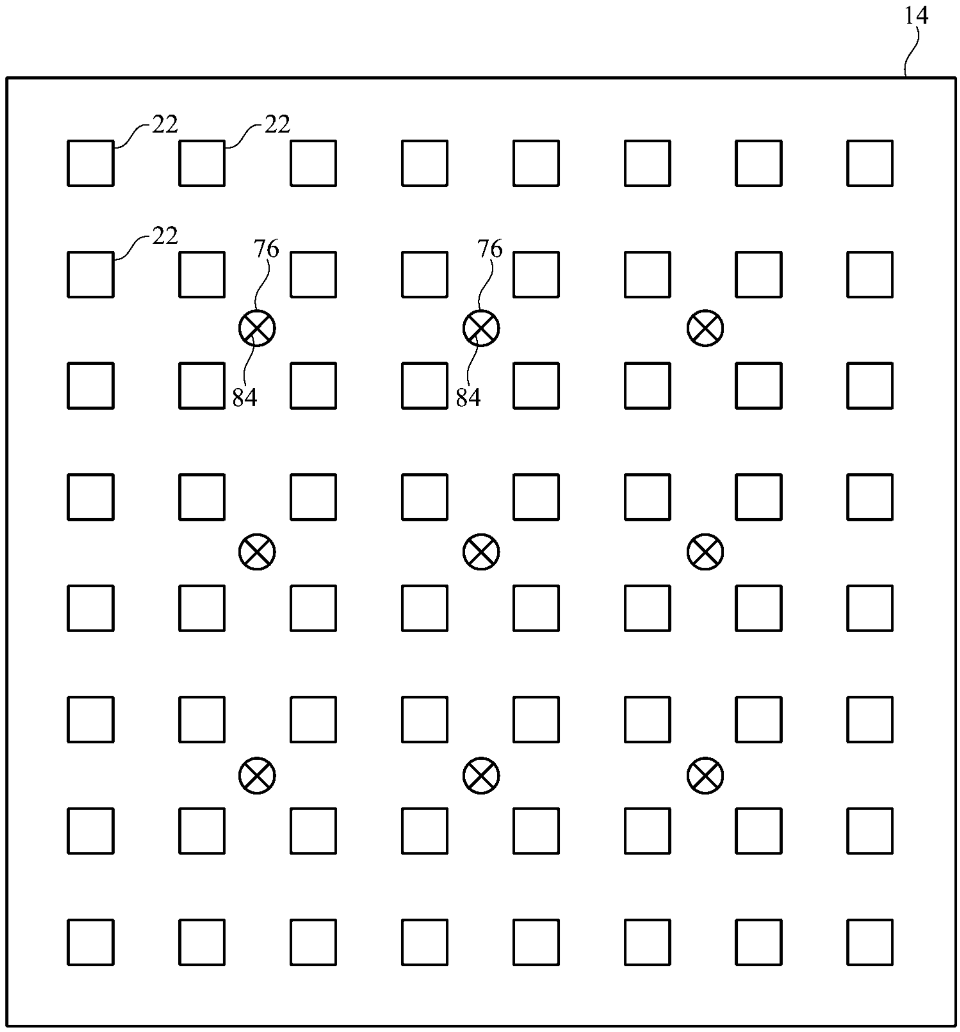


FIG. 6

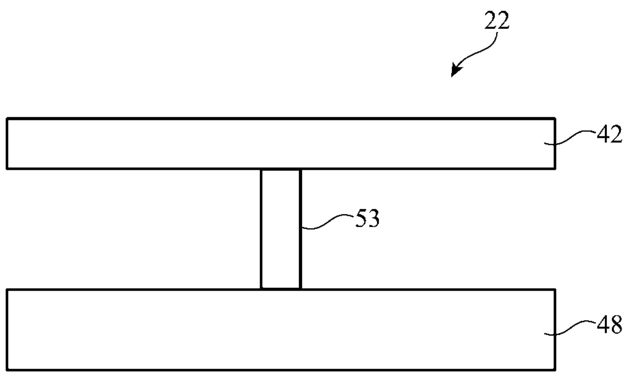


FIG. 7A

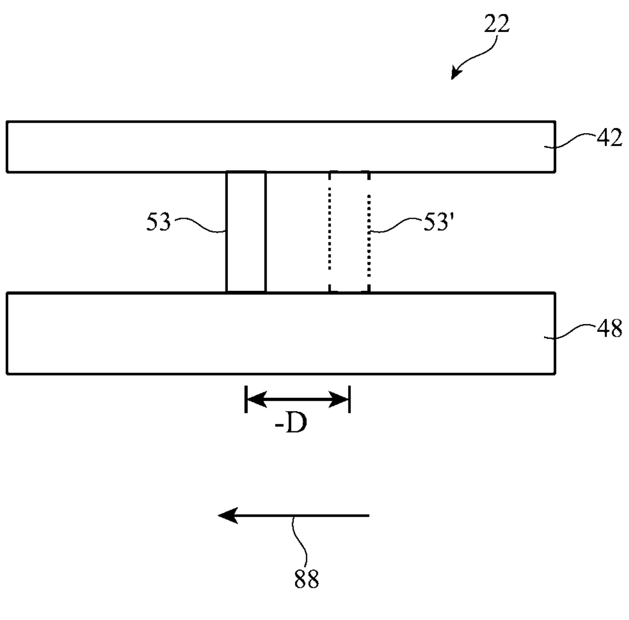
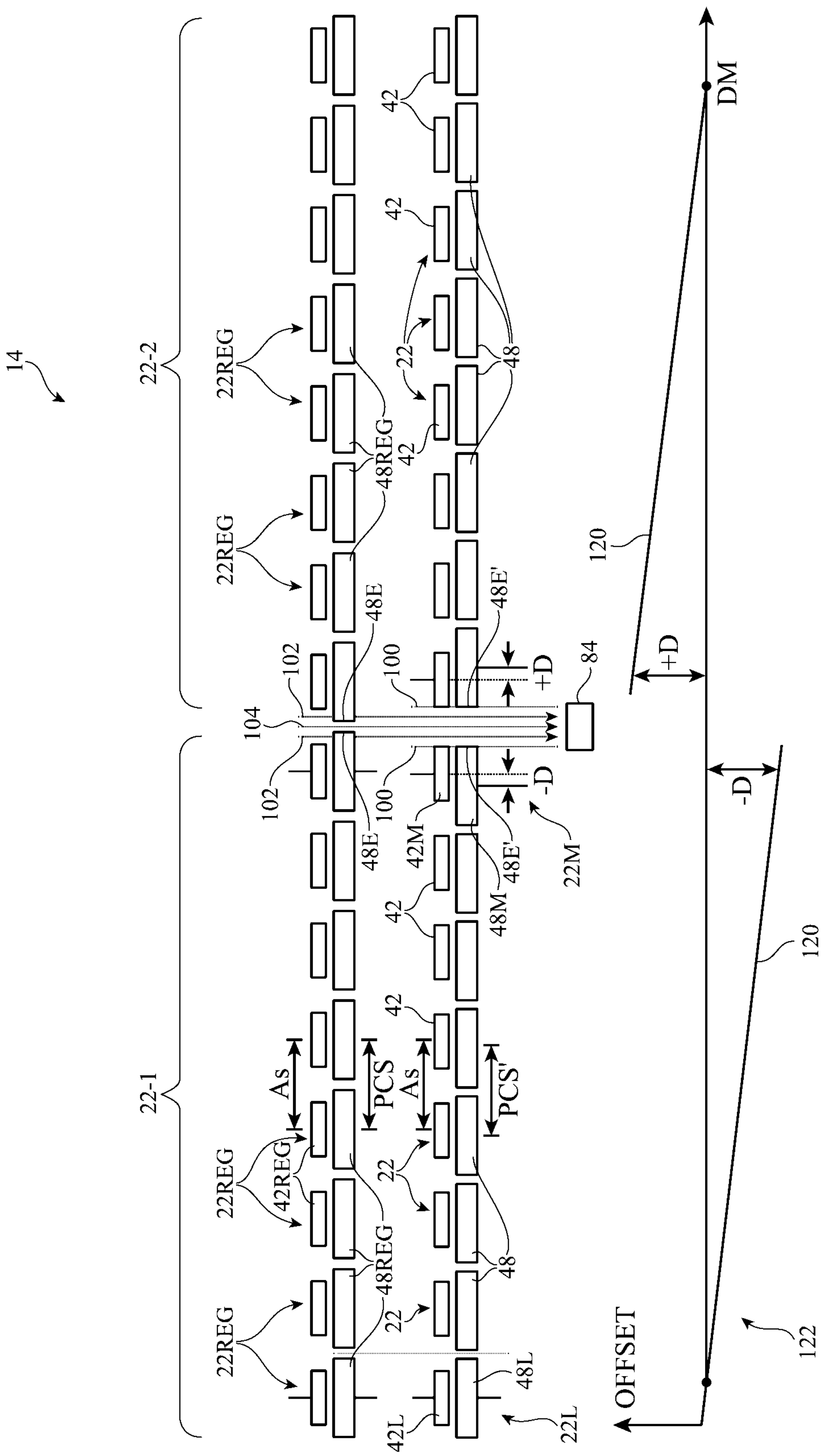


FIG. 7B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-D
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42M
48M
22M
As
PCS
PCS'
42L
48L
22L
OFFSET
DM
120
122

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/048746

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L27/32
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	figure 2 page 4, lines 6-14 page 4, last paragraph page 5, lines 5-14 page 9, lines 9-10 -----	4-6,9, 10,13-16
Y	US 2014/183342 A1 (SHEDLETSKY ANNA-KATRINA [US] ET AL) 3 July 2014 (2014-07-03) paragraphs [0007] - [0009], [0011], [0058] - [0059] -----	4,5,9, 10,13-16
Y	US 2013/094126 A1 (RAPP0P0RT BENJAMIN M [US] ET AL) 18 April 2013 (2013-04-18) figure 3 paragraphs [0050] - [0053], [0067], [0069] -----	4-6,9, 10,13-16

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 November 2016	22/11/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	De Laere, Ann

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2016/048746

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