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(54) **DUAL-MODE MICRO-LED DISPLAY**

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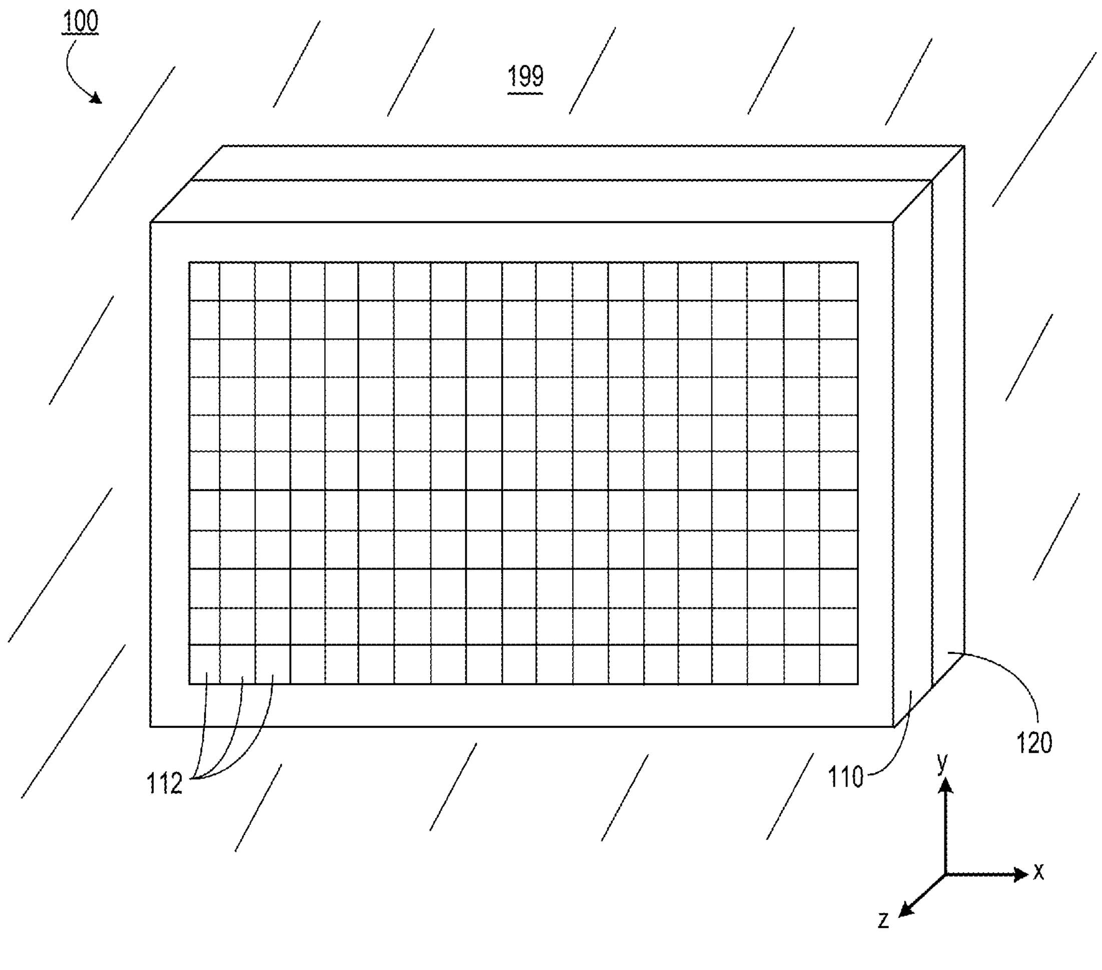
(57) **ABSTRACT**

An electronic display includes a first array of pixels each including a light-emitting element each having a maximum lateral dimension, P_d, in a plane of the display and each being separated from the light-emitting element in each adjacent pixel by a distance, D, wherein $D \geq 5P_d$, the light-emitting elements emitting light of a first color. The electronic display also includes a panel supporting the light-emitting elements. Portions of the panel between the light-emitting elements are visible from a viewing side of the display. The panel includes a second array of pixels each switchable between different optical states. The electronic display further includes a controller programmed to selectively activate the first array of pixels to display a first image and the second array of pixels to display a second image.



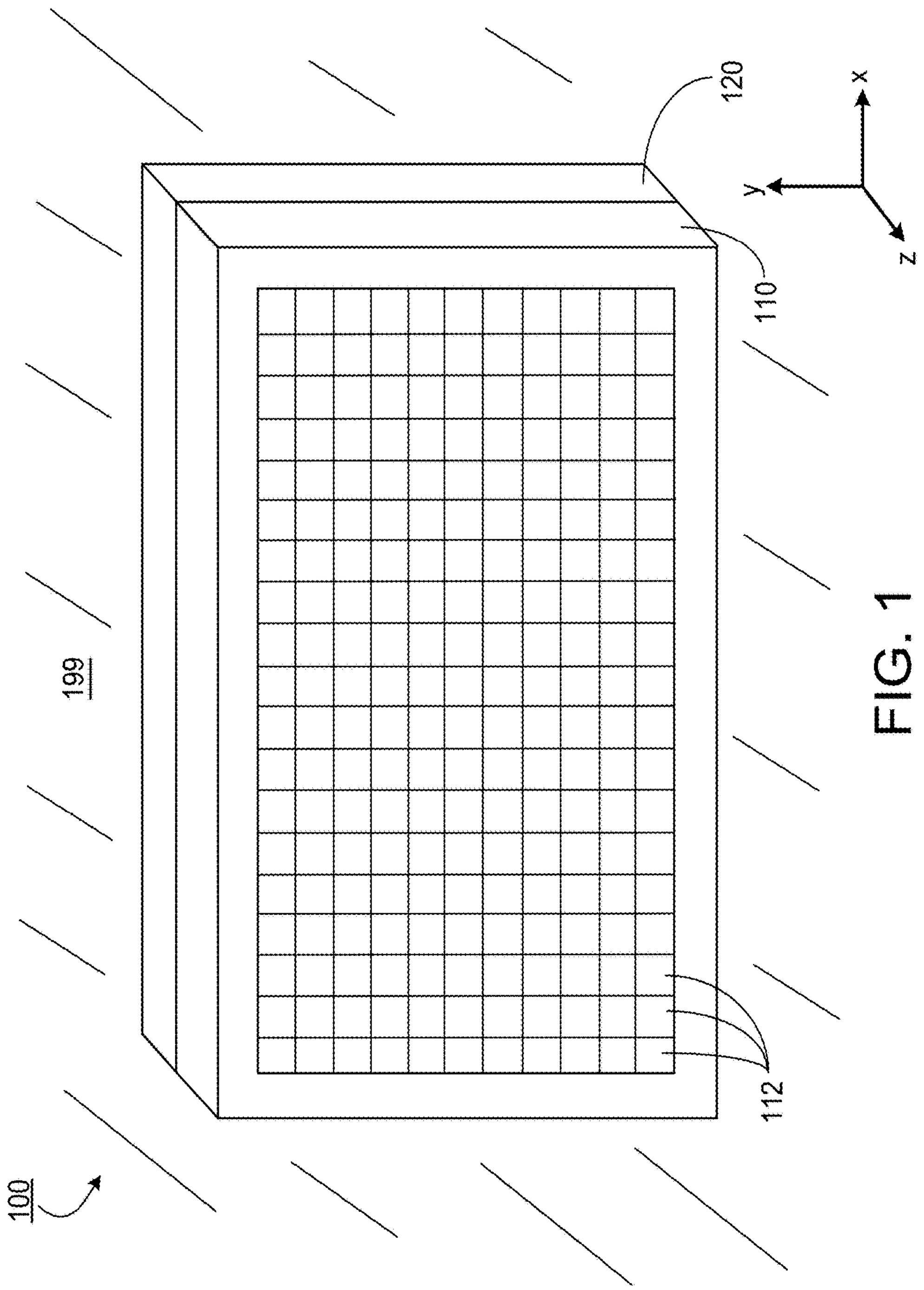
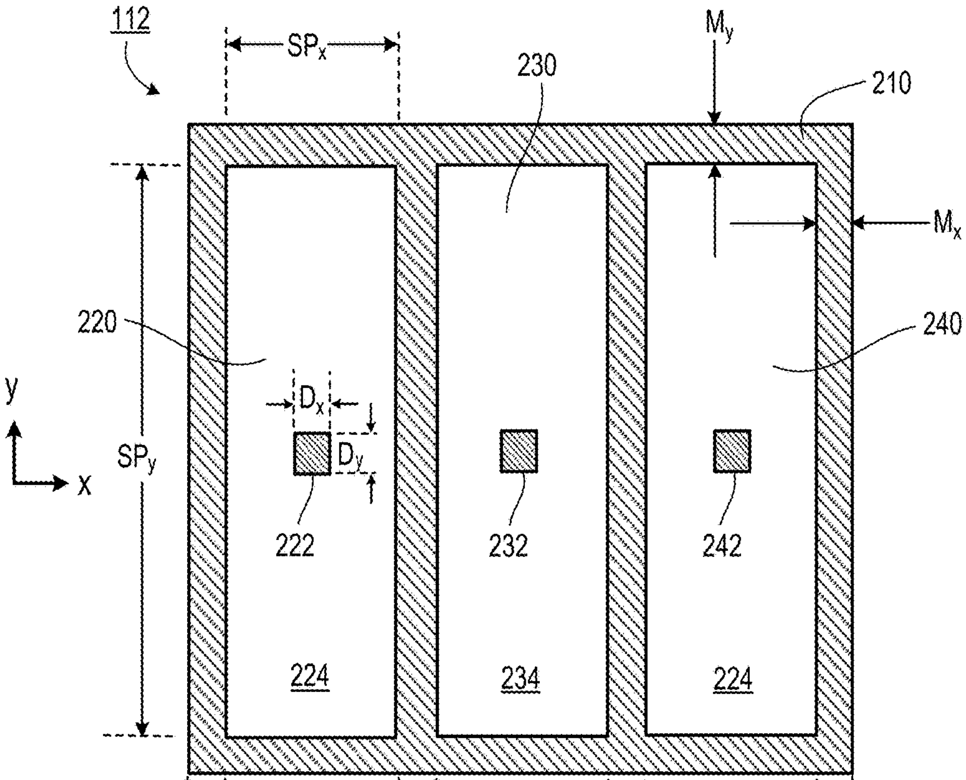
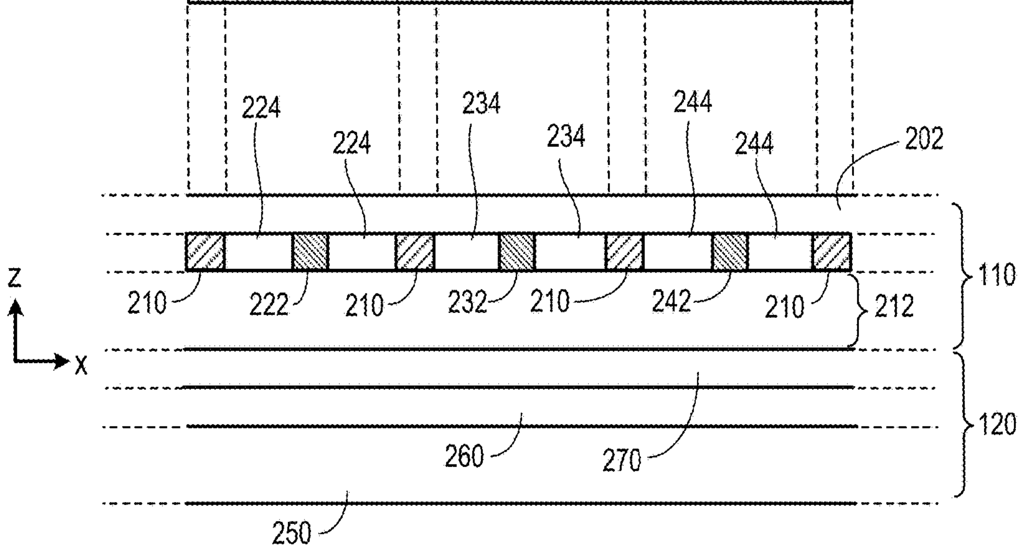


FIG. 1

FIG. 2A



112
SP_x
M_y
230
210
M_x
220
240
SP_y
D_x
D_y
y
x
222
232
242
224
234
224



224
224
234
234
244
244
202
z
x
210
222
210
232
210
242
210
212
110
120
260
270
250

FIG. 2B

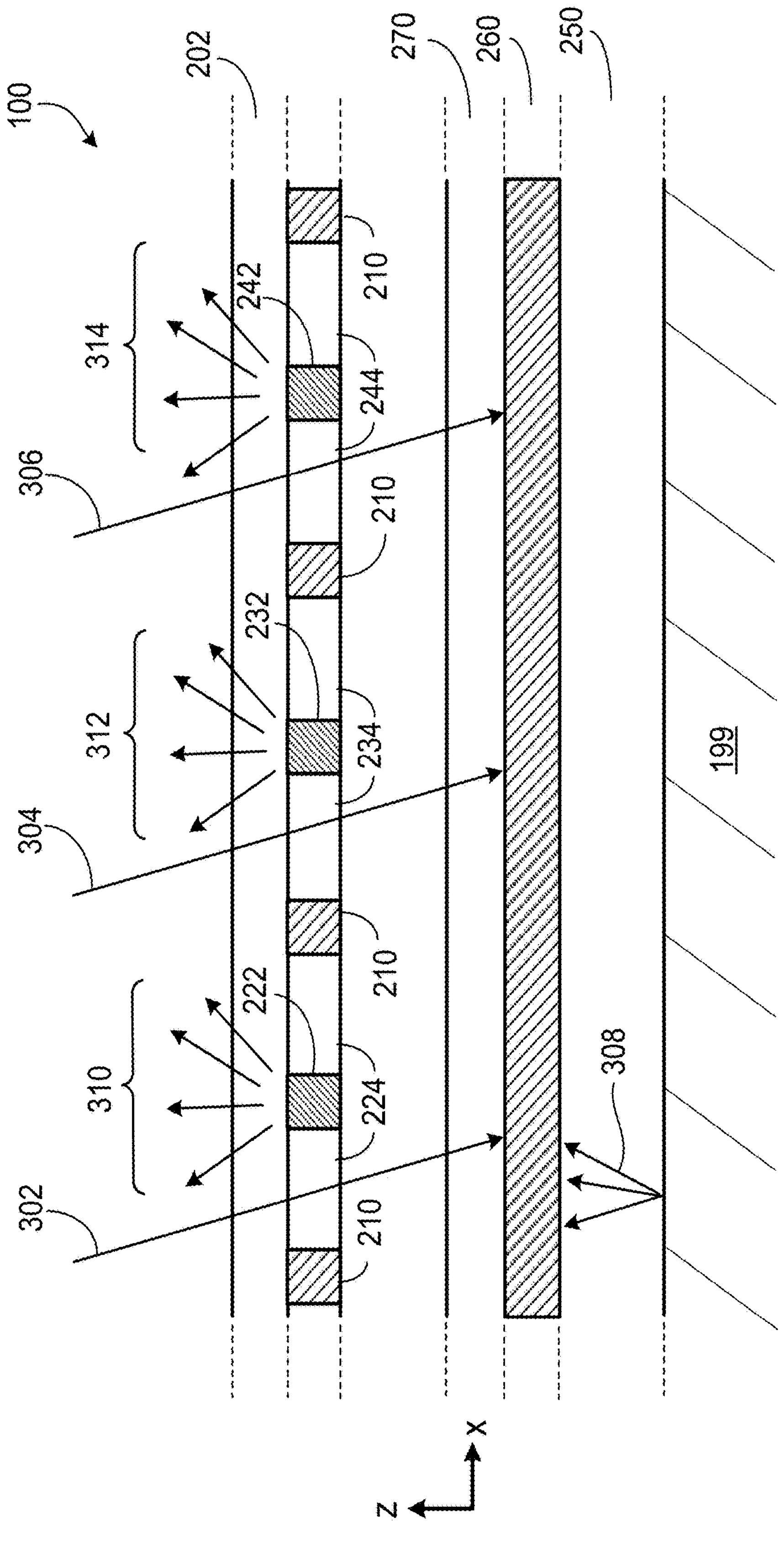
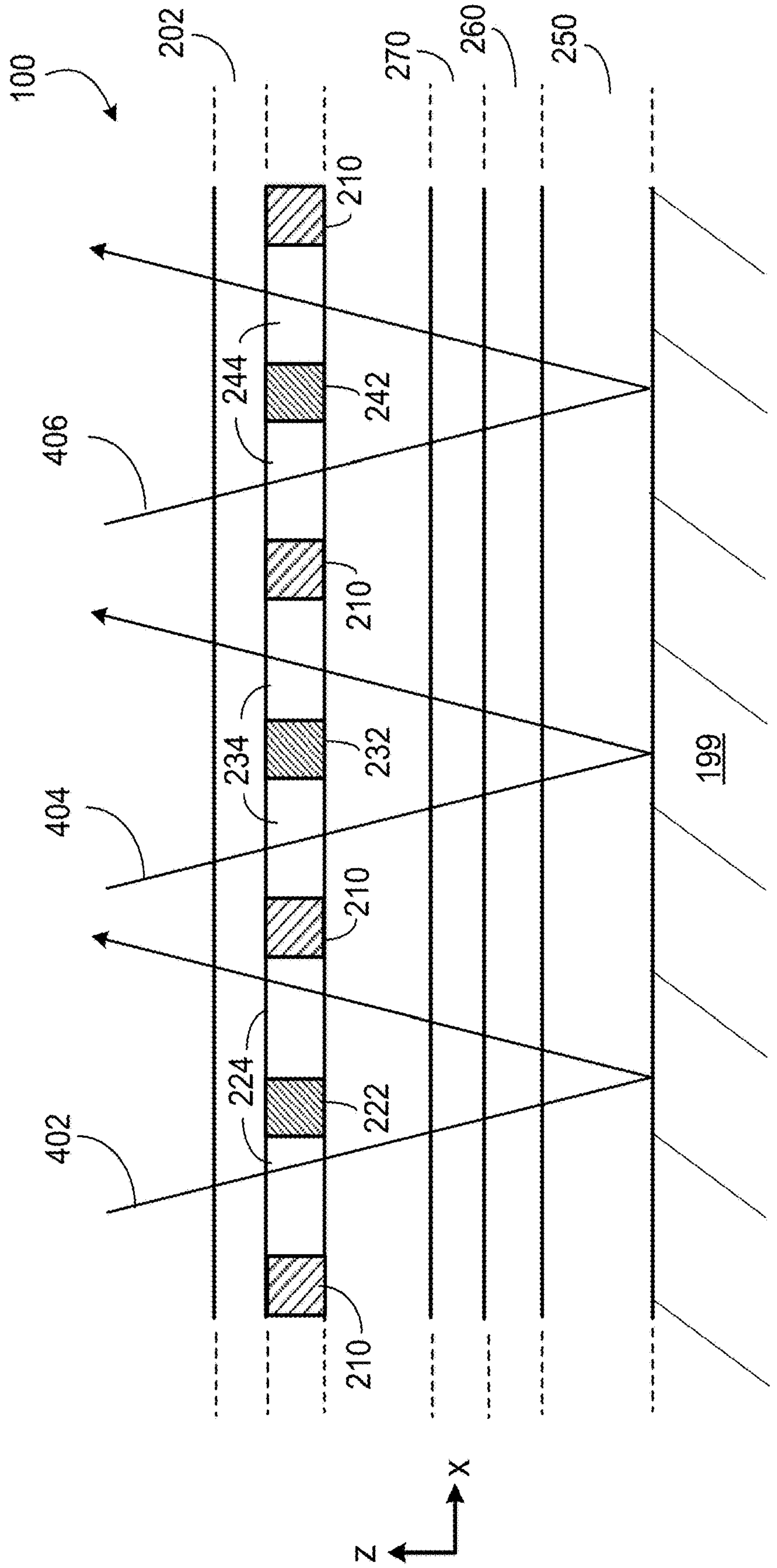

100
202
270
260
250
210
242
244
314
306
232
234
312
304
222
224
310
302
308
199
x
z

FIG. 3



100
202
270
260
250
210
244
242
406
210
234
232
404
199
210
224
222
402
210
X
Z

FIG. 4

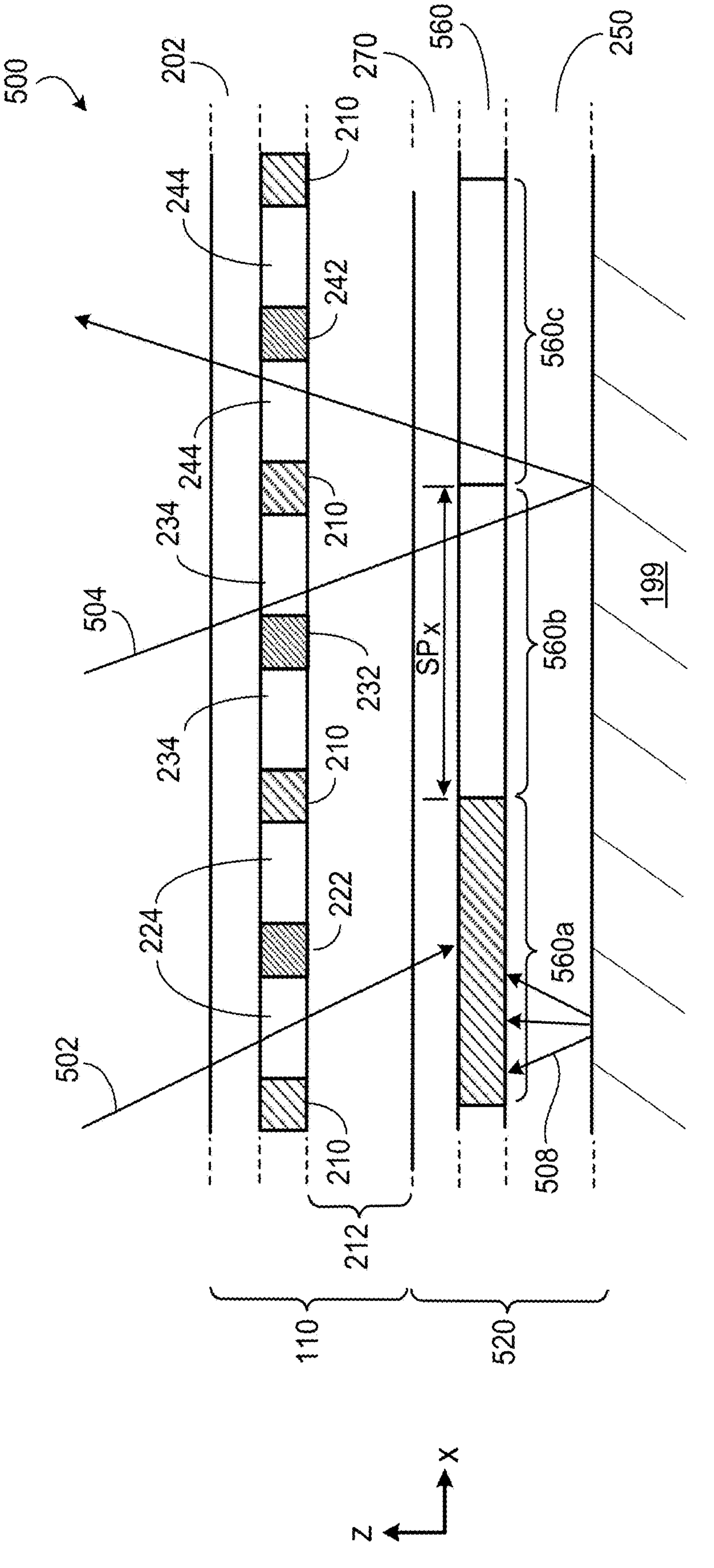

500
202
270
560
250
210
244
242
560c
244
234
210
504
199
232
560b
SPx
234
210
224
222
560a
502
210
508
212
110
520
x
z

FIG. 5

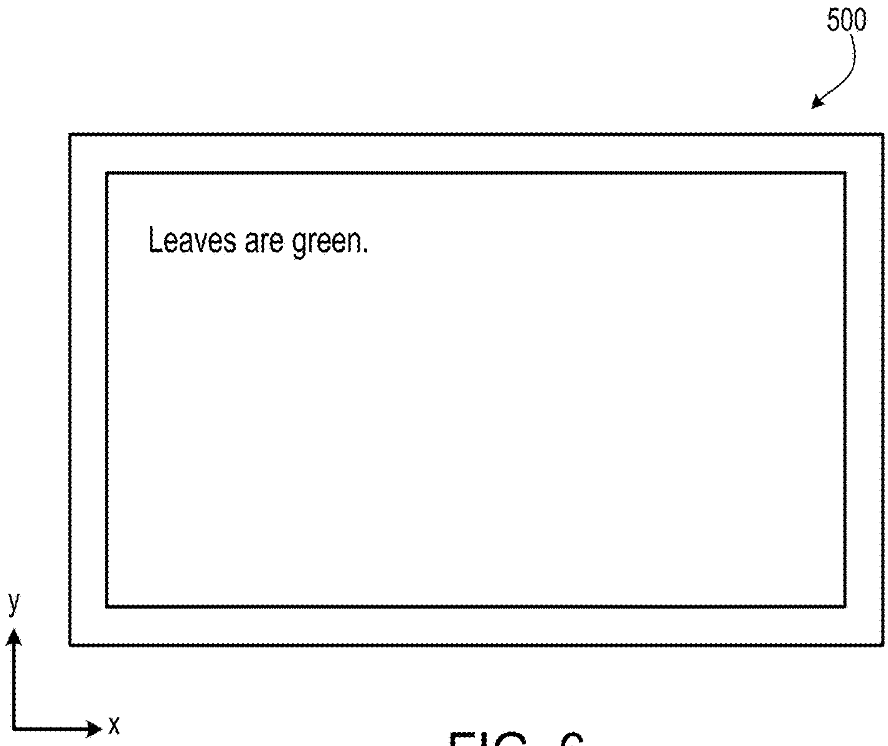


FIG. 6

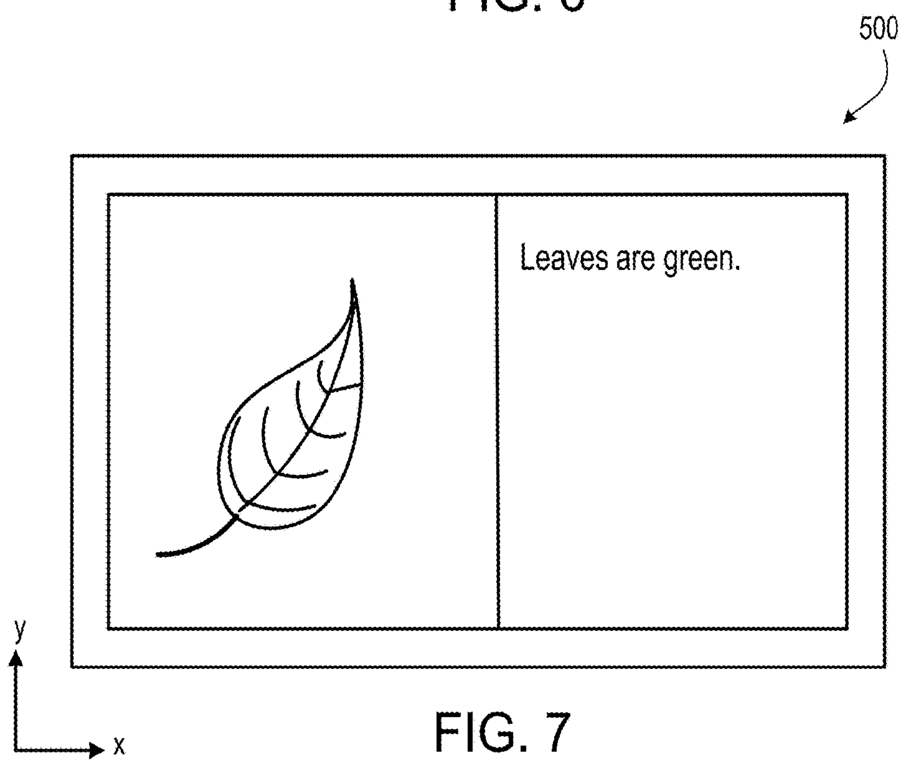


FIG. 7

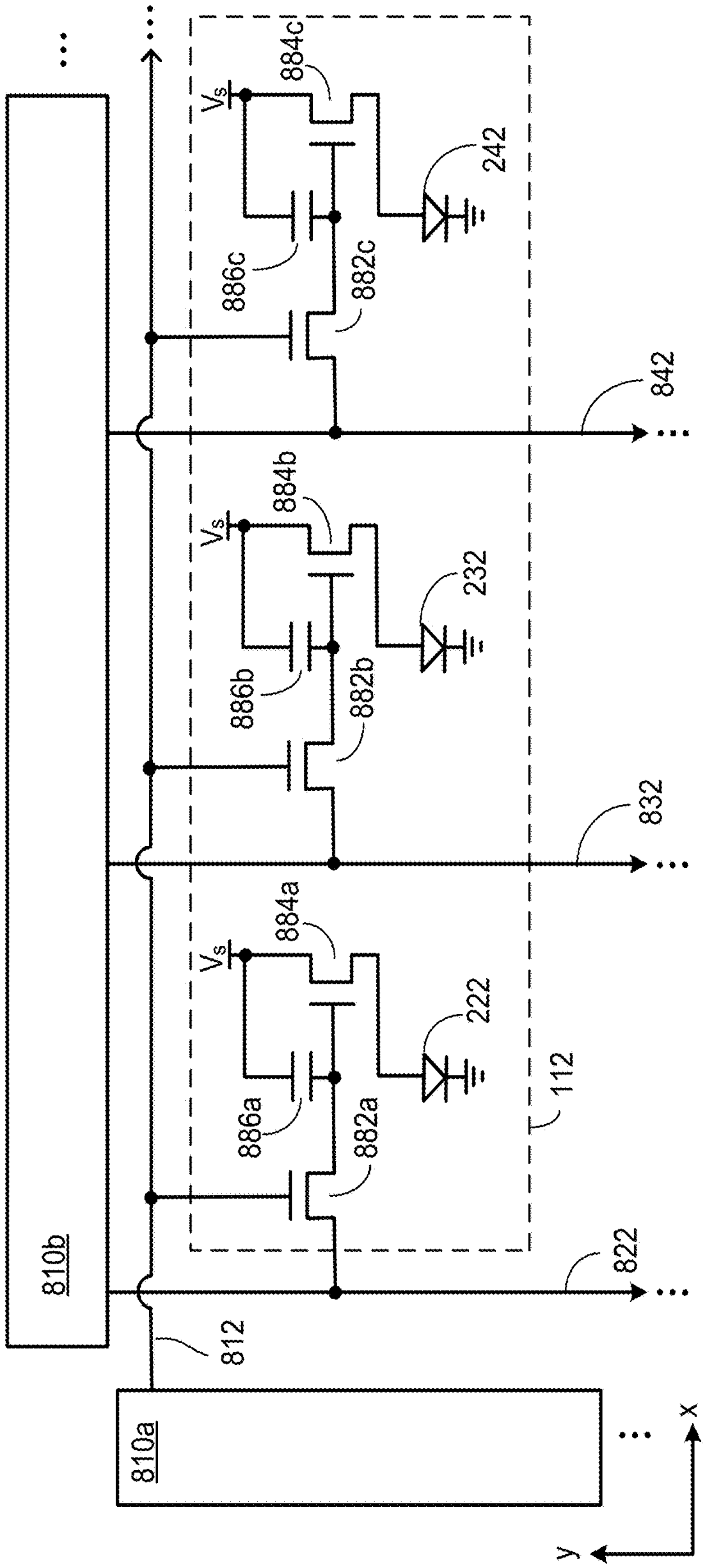

810b
810a
812
822
832
842
112
V_s
884a
886a
882a
222
V_s
884b
886b
882b
232
V_s
884c
886c
882c
242
x
y

FIG. 8

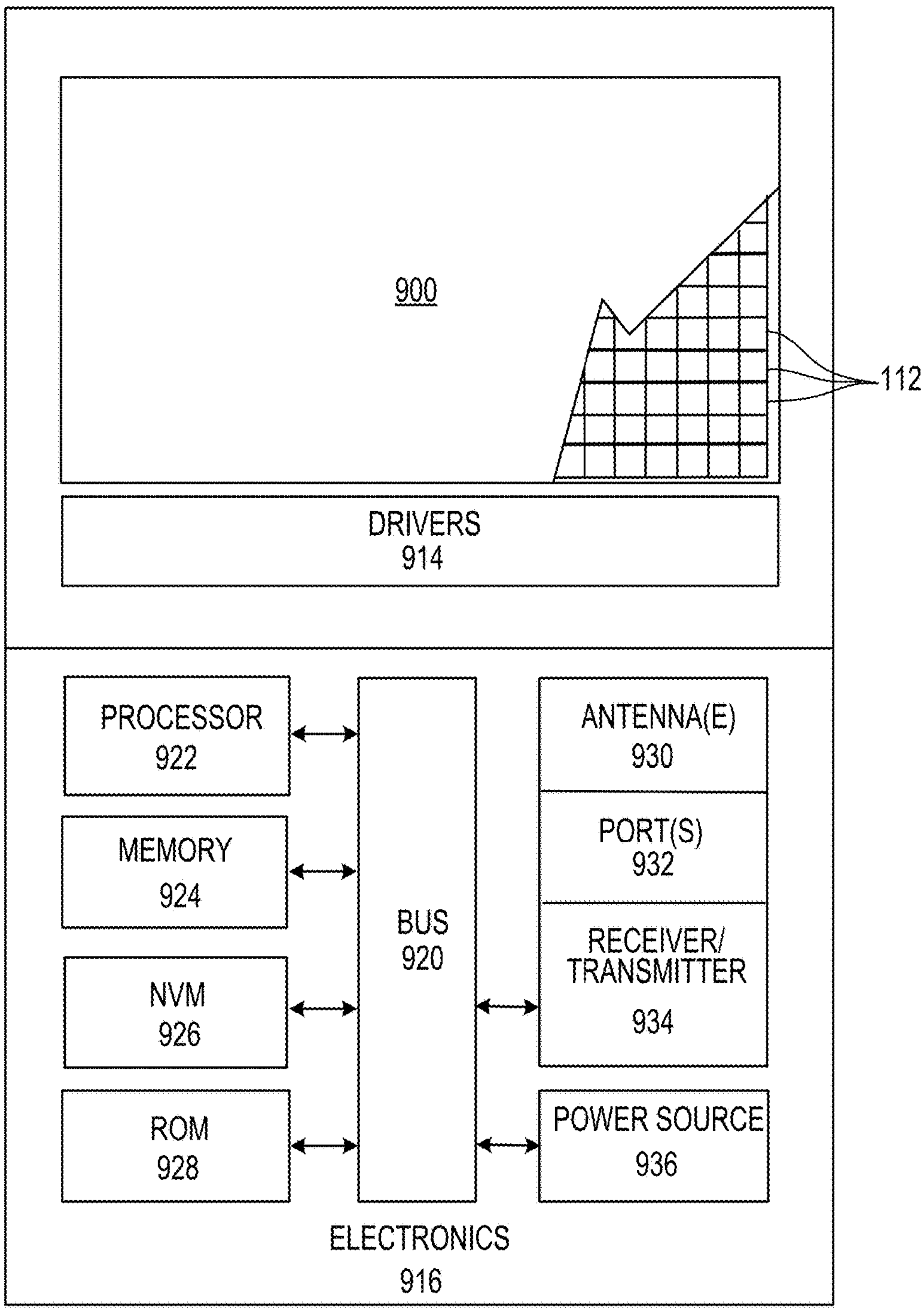

900
112
DRIVERS
914
PROCESSOR
922
MEMORY
924
NVM
926
ROM
928
BUS
920
ANTENNA(E)
930
PORT(S)
932
RECEIVER/
TRANSMITTER
934
POWER SOURCE
936
ELECTRONICS
916

FIG. 9

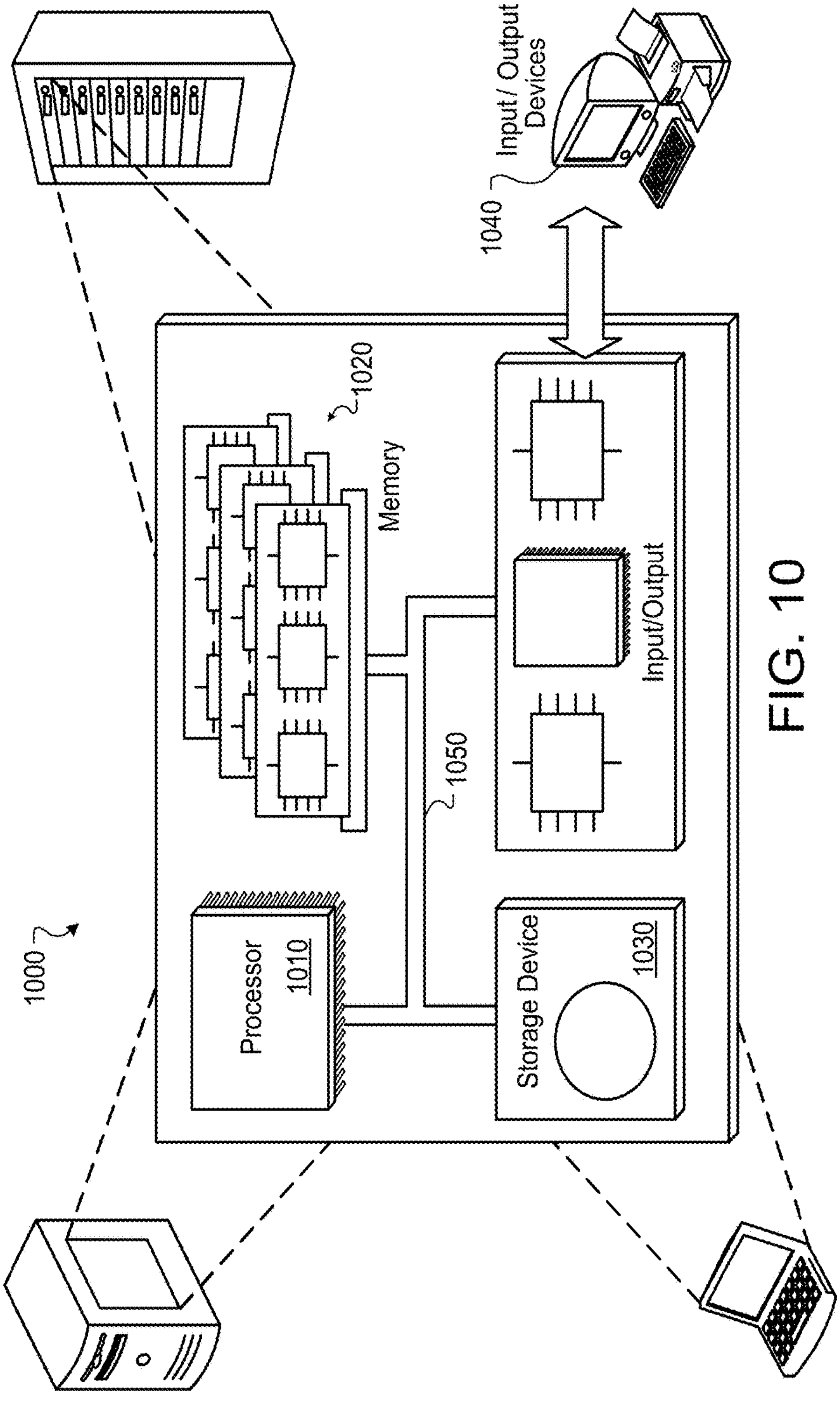

1000
Processor
1010
Memory
1020
1050
Storage Device
1030
Input/Output
1040
Input / Output Devices

FIG. 10

DUAL-MODE MICRO-LED DISPLAY

FIELD

[0001] The disclosure relates to electronic displays.

BACKGROUND

[0002] Flat panel displays are ubiquitous in today's world, providing critical user interfaces in wearable devices, smart phones, computers, televisions, automobile dashboards, advertising billboards, etc. Typically, such displays are composed of an array of picture elements (pixels), which either emit or transmit variable amounts of light. In full color flat panel displays, color is often spatially synthesized using, e.g., red, green, and blue or cyan, yellow, and magenta subpixels. Most flat panel displays, when not displaying imagery, appear black. As such, when not in use, televisions and computer monitors are often conspicuous black rectangles hanging on walls or standing on desks.

SUMMARY

[0003] Electronic displays are disclosed that provide full-color image rendering with a switchable background appearance. Such displays are attainable using micro-light emitters, such as micro-LEDs. Due to their very small size and high efficiency, micro-LEDs can be arrayed with a low fill-factor when compared to other display technologies, making them imperceptible to the naked eye when turned off. Accordingly, sparsely-arrayed micro-LED displays can be stacked on top of another switchable panel that is visible to a viewer when the micro-LEDs are switched off. The switchable panel can have one appearance during operation of the micro-LED display, and a different appearance while the micro-LED display is switched off. For example, when powered on, the micro-LEDs can provide a full-color appearance with a brightness comparable to a conventional display. Generally, the switchable substrate is black when the micro-LED pixels are activated, providing dynamic, full-color images with high contrast. However, the switchable substrate allows the appearance of the display to vary when the micro-LEDs are in the off state. For example, the substrate can be transparent when the micro-LEDs are off, allowing a viewer to see through the display to whatever is behind the display. In some embodiments, the substrate can adopt a different color, e.g., one that matches the color of the wall on which the display is mounted.

[0004] In some embodiments, the switchable substrate is itself a display, capable of providing various images when the micro-LED display is off. For example, bi-stable, reflective displays (e.g., dielectrophoretic displays or cholesteric LCDs) can be used to provide static or varying imagery while consuming very little power. Taking advantage of the fact that the appearance of the micro-LED display is independent of that of the switchable substrate, the device can operate as two separate displays at the same time by powering only a portion of each display in the stack.

[0005] In general, in one aspect, the invention features an electronic display, that includes a first array of pixels each including a light-emitting element, each light-emitting element having a maximum lateral dimension, P_d, in a plane of the display and each light-emitting element being separated from the light-emitting element in each adjacent pixel by a distance, D, wherein $D \geq 5P_d$, the light-emitting elements being configured to emit light of a first color to a viewing side of the display. The electronic display also includes a panel supporting the light-emitting elements, wherein portions of the panel between the light-emitting elements are visible from the viewing side of the display, the panel including a second array of pixels each switchable between different optical states. The electronic display further includes a controller in communication with the array of pixels and the panel, the controller being programmed to selectively activate the first array of pixels to display a first image and to selectively activate the second array of pixels to display a second image.

[0006] Embodiments of the electronic display can include one or more of the following features and/or one or more features of other aspects. For example, each pixel can include a second light-emitting element configured to emit light of a second color, and a third light-emitting element configured to emit light of a third color, the first, second, and third colors being different. The first, second, and third light-emitting elements can be configured to emit, red, green, and blue light, respectively, or cyan, magenta, and yellow light, respectively.

[0007] In some embodiments, the light-emitting element is arranged in a corresponding aperture, the aperture being transparent to incident light. The aperture can also have at least one dimension that is at least five times or more larger than a corresponding dimension of the corresponding light-emitting element. Furthermore, the aperture can have two perpendicular dimensions that are at least five times or more larger than corresponding dimensions of the corresponding light-emitting element. The electronic display can further include an aperture that has an area that is 10 times or more larger than a corresponding area of the corresponding light emitting element, or an aperture that has an area that is 50 times or more larger than a corresponding area of the corresponding light emitting element.

[0008] In some embodiments, the light-emitting elements of the electronic display are light-emitting diodes, while in other embodiments the light-emitting diodes are μLEDs. The light-emitting elements can have a maximum lateral dimension of 50 μm or less or a maximum lateral dimension of 10 μm or less.

[0009] The panel of the electronic display that includes the second array of pixels can also constitute a reflective display.

[0010] In some embodiments, the panel that includes the second array of pixels can also constitute a transmissive display.

[0011] In addition, the panel that includes the second array of pixels can constitute an emissive display.

[0012] The electronic display can include a controller that is programmed to control the first and second arrays of pixels so that pixels in the second array can be in a black state when adjacent light-emitting elements are emitting light.

[0013] The controller can also be programmed to control the first and second arrays of pixels so that pixels in the first array display a first image in a first area of the display and pixels in the second array simultaneously display a second image in a second area of the display. In some embodiments, the first and second areas are non-overlapping areas.

[0014] In some embodiments, the first and second arrays can have the same resolution.

[0015] In other embodiments, the first array can have a higher resolution than the second array.

[0016] Other features and advantages will be apparent from the description below and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. **1** shows a perspective view of a display, according to an embodiment.

[0018] FIG. **2**A shows a front view of a single pixel of the display shown in FIG. **1**.

[0019] FIG. **2**B shows a cross sectional view of the single pixel of the display shown in FIG. **1**.

[0020] FIG. **3** is a cross sectional view of the display shown in FIG. **1** in which an optically switchable layer of the display is opaque.

[0021] FIG. **4** is a cross sectional view of the display shown in FIG. **1** in which an optically switchable layer of the display is transparent.

[0022] FIG. **5** is a cross-sectional view of a display in which an optically switchable layer of the display includes a plurality of individually addressable pixels.

[0023] FIG. **6** is a front view of the display shown in FIG. **5** in which the front panel of the display is in the off state and a rear panel of the display is showing an image.

[0024] FIG. **7** is a front view of the display shown in FIG. **5** in which a portion of the device is showing an image with the front panel of the display while another portion of the device is showing an image with the rear panel of the display.

[0025] FIG. **8** is a schematic of the front panel of the display shown in FIG. **1**.

[0026] FIG. **9** is a schematic diagram of an embodiment of a display.

[0027] FIG. **10** is a schematic diagram of an embodiment of a computer system.

DETAILED DESCRIPTION

[0028] FIG. **1** shows a perspective view of a display **100** mounted on a wall **199**. A three-dimensional Cartesian coordinate system is provided for ease of reference. Display **100** is a flat panel display extending in the X-Y plane, where Y is the vertical and X the horizontal viewing directions, respectively. In general, display **100** is often best viewed along the Z-axis or along a direction relatively close to the Z-axis, although displayed images may be viewed from most any location in the hemisphere centered on the Z-axis.

[0029] In general, the size and resolution of display **100** can vary. Typically, display **100** has a diagonal dimension in a range from about 25 inches to about 150 inches, although the disclosed technology can be applied to smaller and larger displays. Resolution can be UXGA, QXGA, 480p, 1080p, 4K UHD or higher, for example.

[0030] Moreover, while display **100** is depicted as being mounted on wall **199**, more generally the technology disclosed can be implemented in other environments, such as, for example, desktop monitors, billboard displays, mobile devices (e.g., handheld devices, such as smartphones and tablet computers), wearable computers (e.g., smartwatches), etc.

[0031] Display **100** includes a front panel **110** and a rear panel **120**, which both include optically switchable layers and are capable of independently changing their appearance to a viewer. Front panel **110** includes an array of pixels **112** surrounded by a bezel. During operation, front panel **110** operates as a high-resolution (e.g., 1080p, 4K or higher), full-color display capable of delivering video images (e.g., at frame rates of 30 Hz or more, 60 Hz or more, 120 Hz or more). When idle, front panel **110** is substantially transparent allowing a viewer to see through to rear panel **120**.

[0032] Separately, the appearance of rear panel **120** can switch between different optical states. For example, in one state, rear panel **120** appears black and in another state, transparent. In this way, when front panel **110** is idle, rear panel **120** can appear transparent too. Accordingly, viewers see through the display to wall **199** behind, allowing the display to blend into wall **199**. On the other hand, rear panel **120** can be switched to a black state during operation of front panel **110**, allowing display **100** to deliver full-color video images with high contrast.

[0033] Referring to FIG. **2**A, each pixel **112** includes three subpixels, namely, a red subpixel **220**, a green subpixel **230**, and a blue subpixel **240**. Each subpixel is made up of a corresponding light-emitting element and a subpixel aperture, shown here as light-emitting elements **222**, **232**, and **242**, and subpixel apertures **224**, **234**, and **244**, respectively. A black matrix **210** surrounds each subpixel. Black matrix **210** is a dark-colored material that surrounds each subpixel aperture **224**, **234**, and **244** and absorbs incident light. Black matrix **210** can be made of one or more materials including a metal and oxide layer, such as chromium and chromium oxide, a dark-colored plastic, or a dark-colored resin. Subpixel apertures **224**, **234**, and **244** are transparent areas of each subpixel that allow the passage of light incident on front panel **110** from either the front (viewer side) or back (wall side).

[0034] The width of each subpixel aperture is denoted by the distance SP_x, measured in the x-direction. The height of each subpixel aperture is denoted by vertical distance SP_y, measured in the y-direction. Generally, these dimensions depend on the size of the display and its resolution. For example, a 110 inch (diagonal) display with 1080p resolution has a pixel density of approximately 20 dpi, which corresponds to a pixel width of about 1,200 μm. On the other hand, a 20 inch display with a 4K resolution has a pixel density of about 220 dpi, which corresponds to a pixel width of about 115 μm. Accordingly, SP_y can be in a range from about 30 μm to about 400 μm and SP_x can be in a range from about 10 μm to about 130 μm. As shown for red light-emitting element **222**, the width of each light-emitting element is denoted by D_x, measured in the x-direction, while the height of each light-emitting element is denoted by D_y, measured in the y-direction. In general, the subpixel aperture is much larger than the size of the light-emitting elements in at least one dimension. For instance, SP_x can be much larger than D_x, and/or SP_y can be much larger than D_y. For example, SP_x and SP_y can be more than 5 times larger than D_x and D_y, respectively (e.g., 8 times or more larger, 10 times or more larger, 15 times or more larger). By area, the relative size of a subpixel aperture to a light-emitting element (in the X-Y plane) is large. For example, the subpixel aperture area can be about 25 times or more larger than the light-emitting element area (e.g., 50 times or more, 100 times or more).

[0035] The small size of the light-emitting elements relative to the subpixel apertures also means that each light-emitting element has a maximum lateral dimension (e.g., a diagonal dimension in the case of a square element, such as that shown in FIG. **2**A) that is small compared to the separation between like-colored light-emitting elements in adjacent pixels. For example, the lateral separation (i.e., in the X-Y plane as shown), D, of like-colored light-emitting elements in adjacent pixels can be five or more (e.g., 8 or more, 10 or more, 12 or more, 15 or more) times larger than a maximum lateral dimension, P_d, of the light-emitting elements.

[0036] As previously mentioned, incident light can pass through subpixel apertures **224**, **234**, and **244**, after which this light can be reflected off the elements of rear panel **120**. The reflected light can then pass through subpixel apertures **224**, **234**, and **244**. Light-emitting elements **222**, **232**, and **242** are small enough in comparison to subpixel apertures **224**, **234**, and **244** so as not to visibly obscure the reflected light, when the display **100** is viewed by the naked eye.

[0037] The dimensions of black matrix **210** are generally relatively small compared to the subpixel dimensions so that the majority of the area of pixel **112** is made up of the subpixel apertures. As shown, the width, measured in the x-direction, of the vertical segments of black matrix **210** is denoted as M_x, while the width, measured in the y-direction, of the horizontal segments is denoted as M_y. Both M_x and M_y are small enough that black matrix **210** is not visible to the naked eye of a viewer of display **100**. For example, the distances M_x and M_y can be on the order of 20 μm or less.

[0038] FIG. **2**B shows a cross-sectional view of pixel **112**. In particular, FIG. **2**B shows elements of front panel **110**, introduced with regard to FIG. **2**A, including black matrix **210**, subpixels **222**, **232**, and **242**, and subpixel apertures **224**, **234**, and **244**.

[0039] Red light-emitting element **222**, green light-emitting element **232**, and blue light-emitting element **242** are each components that produce correspondingly colored light, with variable intensity. In some embodiments, light-emitting elements **222**, **232**, and **242** are micro-light-emitting diodes (μLEDs), which refer to microscopic LEDs. Typically, μLEDs are composed of epitaxially-grown inorganic semiconductor layers (e.g., GaN) arranged to form a P-N junction with a bandgap corresponding to a desired spectral band. Charge carriers are injected via electrical contacts on opposing sides of the junction. The charge carriers recombine at the junction to emit a photon within the desired spectral band. In addition to having microscopic lateral dimensions, μLEDs can be extremely thin, e.g., having a thickness of 10 μm or less (in the Z-direction). Other types of light-emitting elements can also be used, such as, e.g., organic light-emitting diodes (OLEDs), lasers, and elements that produce light from phosphor.

[0040] Front panel **110** also includes a front panel top layer **202** and a front panel substrate **212**. Front panel top layer **202** is a transparent protective layer, which encapsulates the underlying components, structurally supporting them and protecting them from environmental contaminants. Generally, front panel top layer **202** and front panel substrate **212** are made from materials at visible wavelengths, such as a plastic or glass.

[0041] Regarding rear panel **120**, display **100** also includes a rear panel substrate **250** which supports an optically switchable layer **260** and a rear panel top layer **270**. Rear panel top layer **270** and rear panel substrate **250** are analogous in form and function to front panel top layer **202** and front panel substrate **212**, respectively. Optically switchable layer **260** is an electro-optic layer that is switchable between a transparent state and an opaque state.

[0042] In some embodiments, optically switchable layer **260** can alter its appearance from transparent to translucent or from one solid color to another solid color. In addition, optically switchable layer **260** could both alter its appearance from one solid color to another solid color, and appear as a shade in a gradient between the two solid colors. Optically switchable layer **260** can be made of one or more electro-optic technologies. In some embodiments, the optically-switchable layer can include a layer of a liquid crystal (LC) material (e.g., a nematic LC arranged in a twisted nematic mode, or a vertically aligned LC layer) between two absorptive linearly-polarizing layers (e.g., with crossed transmission axes). Optically switchable layer **260** can also include smart glass or switchable glass materials, such as suspended particle devices, electrochromic devices, and electrophoretic devices. Optically switchable layer **260** can also include one or more mechanically-powered technologies such as two polarizers that can be moved mechanically to vary the amount of polarization of light passing through them.

[0043] Display **100** has two principal modes of operation, which are illustrated in FIGS. **3** and **4**. Referring specifically to FIG. **3**, in one mode of operation, light-emitting elements **222**, **232**, and **242** are activated and emit varying intensities of red, green, and blue light, respectively, through top layer **202**. The emitted red, green, and blue light is illustrated by rays **310**, **312**, and **314**, respectively. Meanwhile, optically switchable layer **260** is optically opaque, having a black appearance. In this mode of operation, display **100** operates as a full-color display capable of rendering high-contrast images, including video images at a refresh rate corresponding to the switching speed of the light-emitting elements.

[0044] In this mode, ambient light (illustrated by rays **302**, **304**, and **306**) passes through front panel top layer **202**, subpixel apertures **224**, **234**, and **244**, front panel substrate **212**, and rear panel top layer **270**, to reach optically switchable layer **260**, where it is absorbed. Similarly, optically switchable layer **260** absorbs any light reflected by wall **199** (illustrated by rays **308**). Because optically switchable layer **260** absorbs ambient light, display **100** appears dark when the light-emitting elements in any pixel are in a black state, providing high contrast imagery.

[0045] Referring to FIG. **4**, in display **100**'s other principal mode, light-emitting elements **222**, **232**, and **242** are inactive. Ambient light (illustrated by rays **402**, **404**, and **406**) passes through front panel top layer **202** and subpixel apertures **224**, **234**, and **244**. This light then passes through the remaining layers of front panel **110** and rear panel **120** to wall **199**, where it is reflected. The reflected light again traverses rear panel **120** and front panel **110**, exiting display **100** through subpixel apertures **224**, **234**, and **244**, and front panel top layer **202**. Because of the sizes of the dimensions of black matrix **210** and light-emitting elements **222**, **232**, and **242**, the majority of the ambient light that enters display **100** is able to exit the device without being significantly impeded by these components, as is illustrated by the rays **402**, **404**, and **406** entering display **100**, being reflected of wall **199**, and subsequently exiting the device. Therefore, when optically switchable layer **260** is transparent, wall **199** is visible to a viewer through display **100**.

[0046] While subpixels **220**, **230**, and **240** are rectangular in FIG. **2**A, other shapes are also possible. For example, the subpixels can be square, trapezoidal, hexagonal, etc. Moreover, the light-emitting elements need not be positioned in the middle of each subpixel aperture. In some embodiments, the light-emitting elements are positioned on an edge or in a corner of its subpixel aperture.

[0047] Also, while pixel **112** is composed of red, green, and blue subpixels, other colors are also possible. For example, cyan, yellow, and magenta subpixels can be used. In some embodiments, each pixel is composed of more than three different colored subpixels. Monochrome pixels, e.g., having only a single light-emitting element in a single pixel aperture, are also possible.

[0048] In display **100**, rear panel **120** includes a uniformly switchable layer. In some embodiments, the rear panel itself can be pixelated, allowing the rear panel to display imagery independent of the images displayed on front panel **110**.

[0049] FIG. **5** is a cross-sectional view of a display **500** showing an embodiment in which the device includes the previously described front panel **110** along with a rear panel **520**. Rear panel **520** features an optically switchable layer **560** which includes optically switchable pixels **560***a*, **560***b*, and **560***c*. Rear panel **520** also includes rear panel substrate **250** and rear panel top layer **270**.

[0050] In this embodiment, the resolution of rear panel **520** is the same as that of front panel **110**. Each pixel of optically switchable layer **560** lines up with one of the spaces defined by subpixel aperture **224**, **234**, or **244** so that the pixel can be viewed through the space formed by the aperture. This alignment can also reduce any Moiré effects that may arise from patterning the pixels of optically switchable layer **560** under black matrix **210**. In accordance with this configuration, the x and y dimensions of each pixel of optically switchable layer **560** is approximately equal to SP_x and SP_y, respectively. In some embodiments, the pixels of optically switchable layer **560** are separated by a black matrix similar to black matrix **210** that surrounds subpixel apertures **224**, **234**, and **244**. In these embodiments, the black matrix that surrounds the pixels of optically switchable layer **560** aligns with black matrix **210**, so as to reduce any Moiré effects that arise from layering the two black matrices.

[0051] Each pixel of optically switchable layer **560** can change its optical properties independently of the other pixels that comprise this layer. For example, a plurality of pixels of optically switchable layer **560** can be opaque, in accordance with optically switchable layer **260** of display **100**, described in FIG. **3**, while another plurality of pixels can be transparent, in accordance with optically switchable layer **260** of display **100**, described in FIG. **4**. As an example of this, FIG. **5** shows an optically switchable pixel **560***a* which is in an opaque state. A ray of ambient light (illustrated by ray **502**) enters display **500** where it is incident upon pixel **560***a*. Because pixel **560***a* is opaque, it absorbs ray **502**. Ambient light that is reflected of wall **199** and incident on pixel **560***a* (illustrated by rays **508**) is also absorbed. FIG. **5** also shows optically switchable pixels **560***b* and **560***c* which are in a transparent state. Optically switchable pixels **560***b* and **560***c* allow ambient light (illustrated by ray **504**) to pass through them to be reflected off of wall **199**.

[0052] FIG. **6** shows a front view of a display **500** that includes front panel **110** and rear panel **520**. Front panel **110** is in the off state while rear panel **520** is displaying an image using the pixels of optically switchable layer **560**. Rear panel **520** produces this image by addressing each pixel of optically switchable layer **560**. The pixels of optically switchable layer **560** can be configured to allow rear panel **520** to display a monochrome image. Rear panel **520** can also be configured to display full-colored images. In some embodiments, optically switchable layer **560** is made of an electrophoretic material, for example, electronic paper, which is able to maintain an image indefinitely without electricity. In these embodiments, display **500** can show an image on rear panel **520** while the light-emitting elements of front panel **110** are in the off state, therefore consuming little to no power. Examples of images that display **500** can show while consuming little to no power include text, a work of art, or a welcome sign.

[0053] FIG. **7** shows a front view of a display **500** that includes front panel **110** and rear panel **520**. In this embodiment, a portion of display **500** shows an image with front panel **110** while another portion of the device displays an image with rear panel **520**. In this figure, a plurality of light-emitting elements **222**, **232**, and **242** are in the on state, while a second plurality of these components are in the off state. Also in this embodiment, a plurality of the pixels of optically switchable layer **560** are opaque, while a second plurality display an image. The portion of display **500** that shows an image using front panel **110** corresponds to a portion in which the plurality of light-emitting elements **222**, **232**, and **242** that are in the on state align with the plurality of pixels of optically switchable layer **560** that are opaque. In other words, this portion of display **500** operates in accordance with the embodiment discussed with regard to FIG. **3**. The portion of display **500** that shows an image using rear panel **520** corresponds to that in which the plurality of light-emitting elements **222**, **232**, and **242** that are in the off state align with the plurality of pixels of optically switchable layer **560** that display an image. In other words, this portion of display **500** operates in accordance with the embodiment discussed with regard to FIG. **6**.

[0054] As an example of the operation of display **500**, a portion of the device can be used to show an image or a video using front panel **110**, while another portion of display **500** can be used to show text from an electronic book using rear panel **520**. As another example, optically switchable layer **560** can appear transparent, so that rear panel **520** is transparent. In this example, display **500** can use front panel **110** to show the current time, date, and weather superimposed on the otherwise transparent display **500**.

[0055] In general, the displays described above also include electrode layers connecting each optically-active element with a display driver module. Electrode layers are formed from a transparent electrically-conducting material, such as indium tin oxide (ITO).

[0056] Furthermore, one or more of the panels forming display **100** and/or display **500** can include active addressing, where the signal sent to each light-emitting element is controlled using a corresponding thin-film transistor. For example, FIG. **8** is a schematic of front panel **110**. Electrical components shown in FIG. **8** include a front panel select driver **810***a*, a front panel data driver **810***b*, light-emitting elements **222**, **232**, and **242**, thin-film transistors (TFTs) **882***a*, **882***b*, **882***c*, **884***a*, **884***b*, and **884***c*, and capacitors **886***a*, **886***b*, and **886***c*. The electrical components can be small enough so as not to be visible to a viewer of the device. They can also be placed underneath or on top of black matrix **210**, as well as underneath or on top of light-emitting elements **222**, **232**, and **242**. Signal lines shown in FIG. **8** include front panel select signal line **812**, as well as front panel data signal lines **822**, **832**, and **842**. One of front panel select signal lines **822**, **832**, or **842** is said to be "activated" when front panel select driver **810***a* is outputting a signal on that line. Similarly, one of front panel data signal lines **822**, **832**, and **842** is said to be activated when front panel data driver **810***b* is outputting a signal on that line. The widths of the signal lines can be small enough so as not to be visible to a viewer of the device.

[0057] Drivers **810***a* and **810***b* are integrated circuits that control the light output of pixel **112** by managing the power supplied to the pixel. Together, front panel select driver **810***a* and front panel data driver **810***b* selectively turn on light-emitting elements **222**, **232**, and **242** and control the brightness of light output by these elements. Front panel data driver **810***b* is responsible for outputting a data signal to the source terminals of TFTs **882***a*, **882***b*, and **882***c*. The data signal can be a voltage that controls the magnitude of current allowed to flow through each light-emitting element **222**, **232**, and **242**. Increasing the magnitude of the current flowing through light-emitting elements **222**, **232**, and **242** results in an increase in element brightness. Front panel select driver **810***a* determines whether the gate terminals of TFTs **884***a*, **884***b*, and **884***c* receive the data signal output by front panel data driver **810***b*.

[0058] To turn on red light-emitting element **222**, front panel data driver **810***b* outputs a data signal to the source terminal of TFT **882***a* using front panel data signal line **822**. Meanwhile, front panel select driver **810***a* outputs a select signal to the gate terminal of TFT **882***a* using front panel select signal line **812**. The select signal turns on TFT **882***a* allowing the data signal to pass from front panel data driver **810***b* through TFT **882***a* to the gate terminal of TFT **884***a*. The data signal turns on TFT **884***a* allowing current to flow from a voltage source, denoted as Vs, through TFT **884***a* and through red light-emitting element **222**. When TFT **882***a* is turned on, the data signal output by front panel data driver **810***b* also charges capacitor **886***a*. When TFT **882***a* is turned off, the data signal voltage stored by capacitor **886***a* can ensure TFT **884***a* remains on, therefore allowing light-emitting element **222** to remain on when TFT **882***a* is off i.e., when the data signal itself cannot turn on TFT **884***a*. In other words, light-emitting element **222** can remain in the on state while data signal line **822** is deactivated. Front panel data driver **810***b* can cycle through front panel data driver lines **822**, **832**, and **842**, activating each one of these lines for a certain time interval. So long as capacitors **886***a*, **886***b*, and **886***c* can maintain a sufficient voltage to keep TFTs **884***a*, **884***b*, and **884***c* in the on state for longer than it takes data driver **810***b* to complete a full cycle through front panel data driver lines **822**, **832**, and **842**, all three light-emitting elements **222**, **232**, and **242** can remain in the on state during the cycle.

[0059] Just as front panel **110** can be actively addressed using the schematic described with regard to FIG. **8**, rear panel **520** can be actively addressed in a similar way. It is also possible for either or both front panel **110** and rear panel **520** to be passively addressed.

[0060] As noted previously, the disclosed displays are controlled by drivers that deliver signals to each subpixel coordinating their operation so that the device displays the desired images. In general, the drivers and electronic components that interface with the drivers can be housed in the same housing as the display and/or can be contained in a separate housing.

[0061] FIG. **9** is a schematic diagram of a display that includes drivers **914** and electronics **916**. In general, drivers **914** can include any number of drivers used to control the pixels of a front panel or a rear panel, as previously described. The quantity of drivers included in drivers **914** depends on the driving scheme, e.g., active addressing or passive addressing, as well as the number of panels included in the display. For example, with regard to a display that includes an actively addressed front panel and an actively addressed rear panel, drivers **914** can include both a front panel and rear panel select driver, and both a front panel and rear panel data driver.

[0062] Electronics **916** includes a processor **922** coupled to bus **920**, to provide control instructions for the display. Generally, processor **922** can include one or more processors or controllers, including one or more physical processors and one or more logical processors. General-purpose processors and/or special-processor processors can be used.

[0063] Electronics **916** further includes a random access memory (RAM) or other dynamic storage device or element as a main memory **924** for storing information and instructions to be executed by processor **922**. Electronics **916** also includes a non-volatile memory (NVM) **926** and a read-only memory (ROM) **928** or other static storage device for storing static information and instructions for the processor.

[0064] Electronics **916** also includes one or more transmitters or receivers **934** coupled to bus **920**, as well as one or more antenna(e) **930** and one or more port(s) **932**. Antennae **930** can include dipole or monopole antennae, for the transmission and reception of data via wireless communication using a wireless transmitter, receiver, or both. Ports **932** are used for the transmission and reception of data via wired communications. Wireless communication includes, but is not limited to, Wi-Fi, Bluetooth™, near field communication, and other wireless communication standards. Wired communication includes, but is not limited to, USB® (Universal Serial Bus) and FireWire® ports.

[0065] Electronics **916** can also include a battery or other power source **936**, which may include a solar cell, a fuel cell, a charged capacitor, near field inductive coupling, or other system or device for providing or generating power for electronics **916**. The power provided by power source **936** may be distributed as required to elements of electronics **916**.

[0066] In some embodiments, the foregoing displays are interfaced with or form part of a computer system. FIG. **10** is a schematic diagram of an example computer system **1000**. The system **1000** can be used to carry out the operations described in association with the implementations described previously. In some implementations, computing systems and devices and the functional operations described above can be implemented in digital electronic circuitry, in tangibly-embodied computer software or firmware, in computer hardware, including the structures disclosed in this specification (e.g., system **1000**) and their structural equivalents, or in combinations of one or more of them. The system **1000** is intended to include various forms of digital computers, such as laptops, desktops, workstations, personal digital assistants, servers, blade servers, mainframes, and other appropriate computers, including vehicles installed on base units or pod units of modular vehicles. The system **1000** can also include mobile devices, such as personal digital assistants, cellular telephones, smartphones, and other similar computing devices. Additionally, the system can include portable storage media, such as, Universal Serial Bus (USB) flash drives. For example, the USB flash drives may store operating systems and other applications. The USB flash drives can include input/output components, such as a wireless transmitter or USB connector that may be inserted into a USB port of another computing device.

[0067] The system **1000** includes a processor **1010**, a memory **1020**, a storage device **1030**, and an input/output device **1040**. Each of the components **1010**, **1020**, **1030**, and **1040** are interconnected using a system bus **1050**. The processor **1010** is capable of processing instructions for execution within the system **1000**. The processor may be designed using any of a number of architectures. For example, the processor **1010** may be a CISC (Complex Instruction Set Computers) processor, a RISC (Reduced Instruction Set Computer) processor, or a MISC (Minimal Instruction Set Computer) processor.

[0068] In some implementations, the processor **1010** is a single-threaded processor. In other implementations, the processor **1010** is a multi-threaded processor. The processor **1010** is capable of processing instructions stored in the memory **1020** or on the storage device **1030** to display graphical information for a user interface on the input/output device **1040**.

[0069] The memory **1020** stores information within the system **1000**. In one implementation, the memory **1020** is a computer-readable medium. In one implementation, the memory **1020** is a volatile memory unit. In another implementation, the memory **1020** is a non-volatile memory unit.

[0070] The storage device **1030** is capable of providing mass storage for the system **1000**. In one implementation, the storage device **1030** is a computer-readable medium. In various different implementations, the storage device **1030** may be a floppy disk device, a hard disk device, an optical disk device, or a tape device.

[0071] The input/output device **1040** provides input/output operations for the system **1000**. In one implementation, the input/output device **1040** includes a keyboard and/or pointing device. In another implementation, the input/output device **1040** includes a display unit for displaying graphical user interfaces.

[0072] The features described can be implemented in digital electronic circuitry, or in computer hardware, firmware, software, or in combinations of them. The apparatus can be implemented in a computer program product tangibly embodied in an information carrier, e.g., in a machine-readable storage device for execution by a programmable processor; and method steps can be performed by a programmable processor executing a program of instructions to perform functions of the described implementations by operating on input data and generating output. The described features can be implemented advantageously in one or more computer programs that are executable on a programmable system including at least one programmable processor coupled to receive data and instructions from, and to transmit data and instructions to, a data storage system, at least one input device, and at least one output device. A computer program is a set of instructions that can be used, directly or indirectly, in a computer to perform a certain activity or bring about a certain result. A computer program can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment.

[0073] Suitable processors for the execution of a program of instructions include, by way of example, both general and special purpose microprocessors, and the sole processor or one of multiple processors of any kind of computer. Generally, a processor will receive instructions and data from a read-only memory or a random access memory or both. The essential elements of a computer are a processor for executing instructions and one or more memories for storing instructions and data. Generally, a computer will also include, or be operatively coupled to communicate with, one or more mass storage devices for storing data files; such devices include magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; and optical disks. Storage devices suitable for tangibly embodying computer program instructions and data include all forms of non-volatile memory, including by way of example semiconductor memory devices, such as EPROM, EEPROM, and flash memory devices; magnetic disks such as internal hard disks and removable disks; magneto-optical disks; and CD-ROM and DVD-ROM disks. The processor and the memory can be supplemented by, or incorporated in, ASICs (application-specific integrated circuits).

[0074] To provide for interaction with a user, the features can be implemented on a computer having a display such as a CRT (cathode ray tube) or LCD (liquid crystal display) monitor for displaying information to the user and a keyboard and a pointing device such as a mouse or a trackball by which the user can provide input to the computer. Additionally, such activities can be implemented via touchscreen flat-panel displays and other appropriate mechanisms.

[0075] The features can be implemented in a computer system that includes a back-end component, such as a data server, or that includes a middleware component, such as an application server or an Internet server, or that includes a front-end component, such as a client computer having a graphical user interface or an Internet browser, or any combination of them. The components of the system can be connected by any form or medium of digital data communication such as a communication network. Examples of communication networks include a local area network ("LAN"), a wide area network ("WAN"), peer-to-peer networks (having ad-hoc or static members), grid computing infrastructures, and the Internet.

[0076] The computer system can include clients and servers. A client and server are generally remote from each other and typically interact through a network, such as the described one. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other.

[0077] While this specification contains many specific implementation details, these should not be construed as limitations on the scope of any inventions or of what may be claimed, but rather as descriptions of features specific to particular implementations of particular inventions. Certain features that are described in this specification in the context of separate implementations can also be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations separately or in any suitable subcombination.

Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0078] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products.

[0079] Thus, particular implementations of the subject matter have been described. Other implementations are within the scope of the following claims. For example, while the foregoing displays are depicted as direct view displays (e.g., televisions or computer monitors), other implementations are possible. For instance, the disclosed technologies can be implemented in displays for handheld devices, automotive displays, wearable displays (e.g., head mounted displays), and/or avionic displays (e.g., either in cockpit displays or in-flight entertainment systems). In some embodiments, either or both of the panels are formed with minimal or no black matrix. For example, in certain embodiments, electrical components can be positioned beneath the light emitting elements in each subpixel, eliminating the need to obscure them using black matrix material.

What is claimed is:

1. An electronic display, comprising:

a first array of pixels each comprising a light-emitting element, each light-emitting element having a maximum lateral dimension, P_d, in a plane of the display and each light-emitting element being separated from the light-emitting element in each adjacent pixel by a distance, D, wherein $D \geq 5P_d$, the light-emitting elements being configured to emit light of a first color to a viewing side of the display;

a panel supporting the light-emitting elements, wherein portions of the panel between the light-emitting elements are visible from the viewing side of the display, the panel comprising a second array of pixels each switchable between different optical states; and

a controller in communication with the first and second array of pixels and the panel, the controller being programmed to selectively activate the first array of pixels to display a first image and to selectively activate the second array of pixels to display a second image.

2. The electronic display of claim **1**, wherein each pixel further comprises a second light-emitting element configured to emit light of a second color, and a third light-emitting element configured to emit light of a third color, the first, second, and third colors being different.

3. The electronic display claim **2**, wherein the first, second, and third light-emitting elements are configured to emit, red, green, and blue light, respectively, or cyan, magenta, and yellow light, respectively.

4. The electronic display of claim **1**, wherein each light-emitting element is arranged in a corresponding aperture, the aperture being transparent to incident light.

5. The electronic display of claim **4**, wherein the aperture has at least one dimension that is at least five times or more larger than a corresponding dimension of the corresponding light-emitting element.

6. The electronic display of claim **4**, wherein the aperture has two perpendicular dimensions that are at least five times or more larger than corresponding dimensions of the corresponding light-emitting element.

7. The electronic display of claim **4**, wherein the aperture has an area that is 10 times or more larger than a corresponding area of the corresponding light emitting element.

8. The electronic display of claim **4**, wherein the aperture has an area that is 50 times or more larger than a corresponding area of the corresponding light emitting element.

9. The electronic display of claim **1**, wherein the light-emitting elements are light-emitting diodes.

10. The electronic display of claim **9**, wherein the light emitting diodes are μLEDs.

11. The electronic display of claim **9**, wherein the light-emitting elements have a maximum lateral dimension of 50 μm or less.

12. The electronic display of claim **9**, wherein the light-emitting elements have a maximum lateral dimension of 10 μm or less.

13. The electronic display of claim **1**, wherein the panel comprising the second array of pixels constitutes a reflective display.

14. The electronic display of claim **1**, wherein panel comprising the second array of pixels constitutes a transmissive display.

15. The electronic display of claim **1**, wherein the panel comprising the second array of pixels constitutes an emissive display.

16. The electronic display of claim **1**, wherein the controller is programmed to control the first and second arrays of pixels so that pixels in the second array are in a black state when adjacent light-emitting elements emit light.

17. The electronic display of claim **1**, wherein the controller is programmed to control the first and second arrays of pixels so that pixels in the first array display a first image in a first area of the display and pixels in the second array simultaneously display a second image in a second area of the display.

18. The electronic display of claim **17**, wherein the first and second areas are non-overlapping areas.

19. The electronic display of claim **1**, wherein the first and second arrays have the same resolution.

20. The electronic display of claim **1**, wherein the first array has a higher resolution than the second array.

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专利名称(译)	双模微型led显示屏		
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[标]申请(专利权)人(译)	X开发有限责任公司		
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当前申请(专利权)人(译)	X开发有限公司		
[标]发明人	SCHUBERT MARTIN FRIEDRICH GRUNDMANN MICHAEL JASON		
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摘要(译)

一种电子显示器，包括第一像素阵列，每个像素阵列包括发光元件，每个发光元件在显示器的平面中具有最大横向尺寸P d ，并且每个发光元件与发光元件分离。每个相邻像素距离D，其中D≥5P d ，发光元件发出第一颜色的光。电子显示器还包括支撑发光元件的面板。从显示器的观察侧可以看到发光元件之间的面板部分。该面板包括第二像素阵列，每个像素可在不同的光学状态之间切换。电子显示器还包括控制器，该控制器被编程为选择性地激活第一像素阵列以显示第一图像，并且第二像素阵列显示第二图像。