



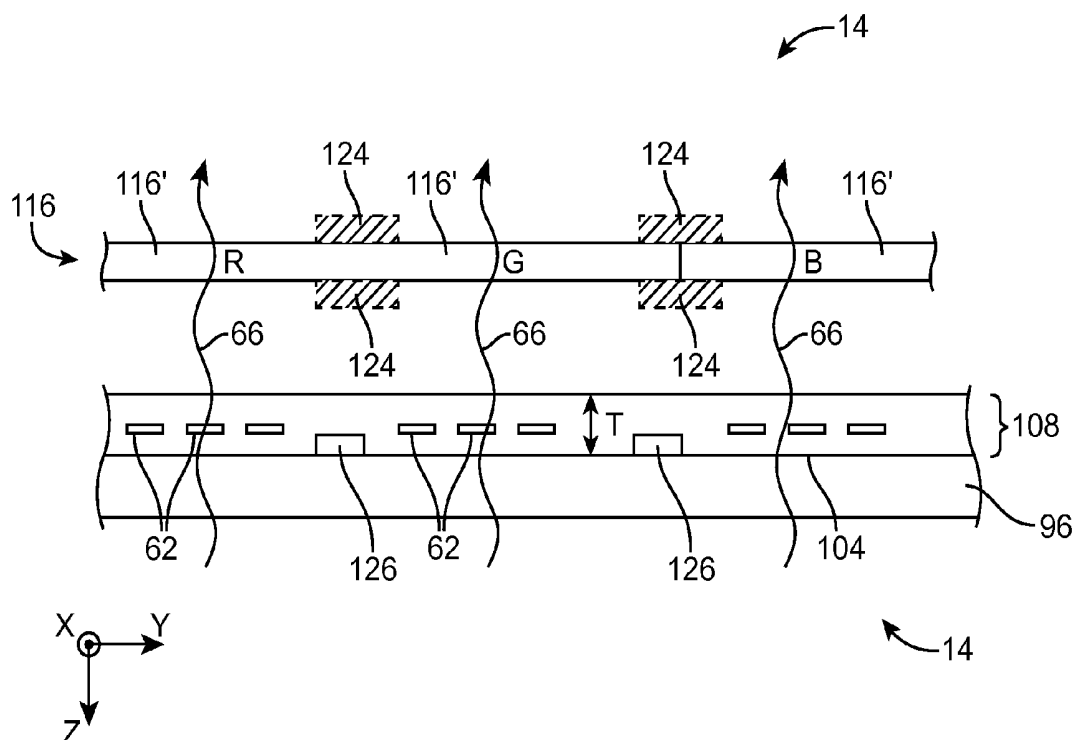
US 20150227000A1

(19) **United States**(12) **Patent Application Publication****Xu et al.**(10) **Pub. No.: US 2015/0227000 A1**(43) **Pub. Date: Aug. 13, 2015**(54) **DISPLAY WITH COLOR MIXING
PREVENTION STRUCTURES**(71) Applicant: **Apple Inc.**, Cupertino, CA (US)(72) Inventors: **Ming Xu**, Sunnyvale, CA (US); **Shawn R. Gettemy**, San Jose, CA (US); **Young Cheol Yang**, Sunnyvale, CA (US); **Zhibing Ge**, San Jose, CA (US); **Cheng Chen**, San Jose, CA (US)(21) Appl. No.: **14/692,659**(22) Filed: **Apr. 21, 2015****Related U.S. Application Data**

(63) Continuation of application No. 13/364,885, filed on Feb. 2, 2012, now Pat. No. 9,025,112.

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G02B 5/20 (2006.01)
G02F 1/1368 (2006.01)(52) **U.S. Cl.**CPC **G02F 1/133514** (2013.01); **G02F 1/1368** (2013.01); **G02F 1/133512** (2013.01); **G02B 5/201** (2013.01); **G02F 2001/133357** (2013.01)(57) **ABSTRACT**

An electronic device may have a liquid crystal display having a backlight and color mixing prevention structures. The color mixing prevention structures may, in part, be formed from one or more arrays of color filter elements. The liquid crystal display may include first and second transparent substrate layers on opposing sides of a liquid crystal layer. The display may include a first array of color filter elements on the first transparent substrate layer and a second array of color filter elements on the second transparent substrate layer. One or more of the arrays of color filter elements may include a black matrix formed over portions of the color filter elements. The color filter elements may fill or partially fill openings in the black matrix. The display may include a collimating layer on the second transparent substrate layer. The color filter elements may include cholesteric color filter elements.



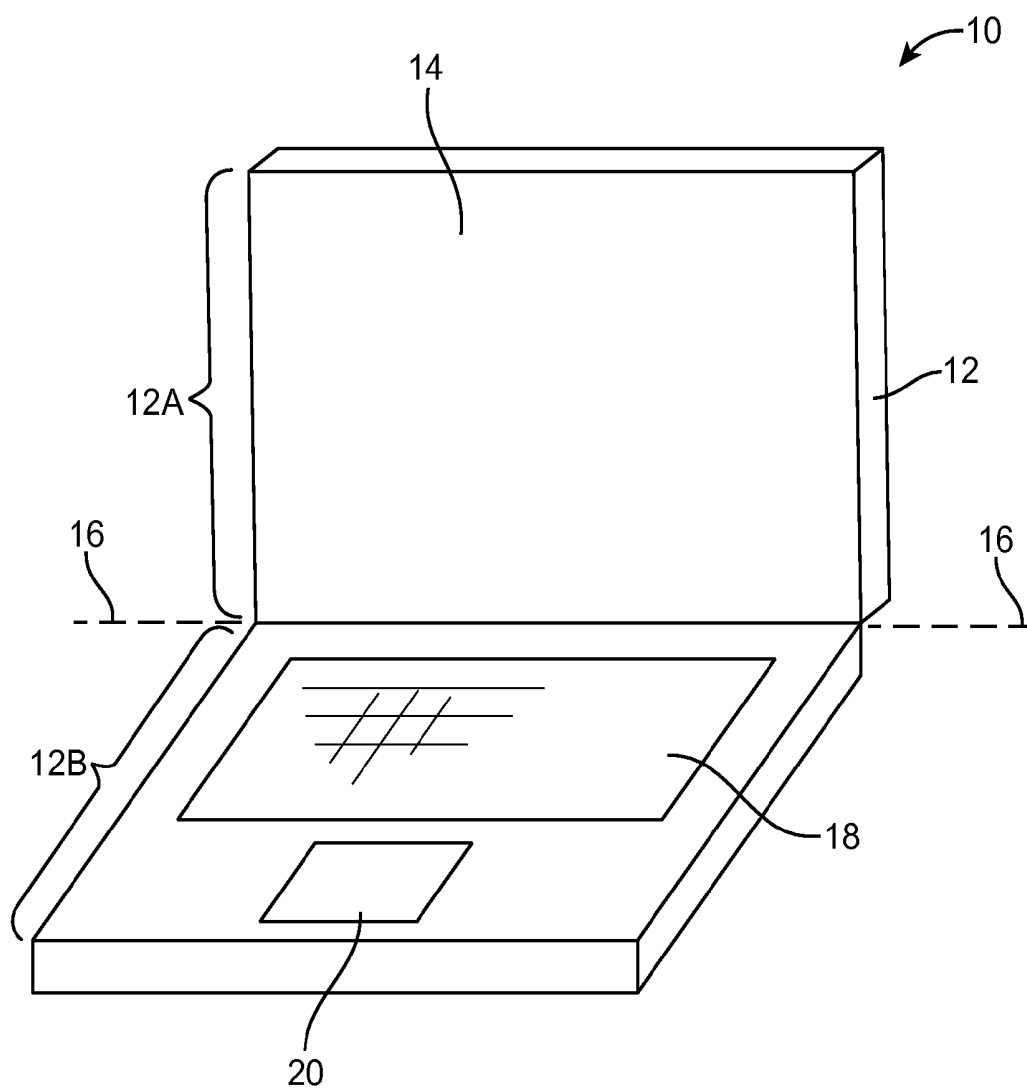


FIG. 1

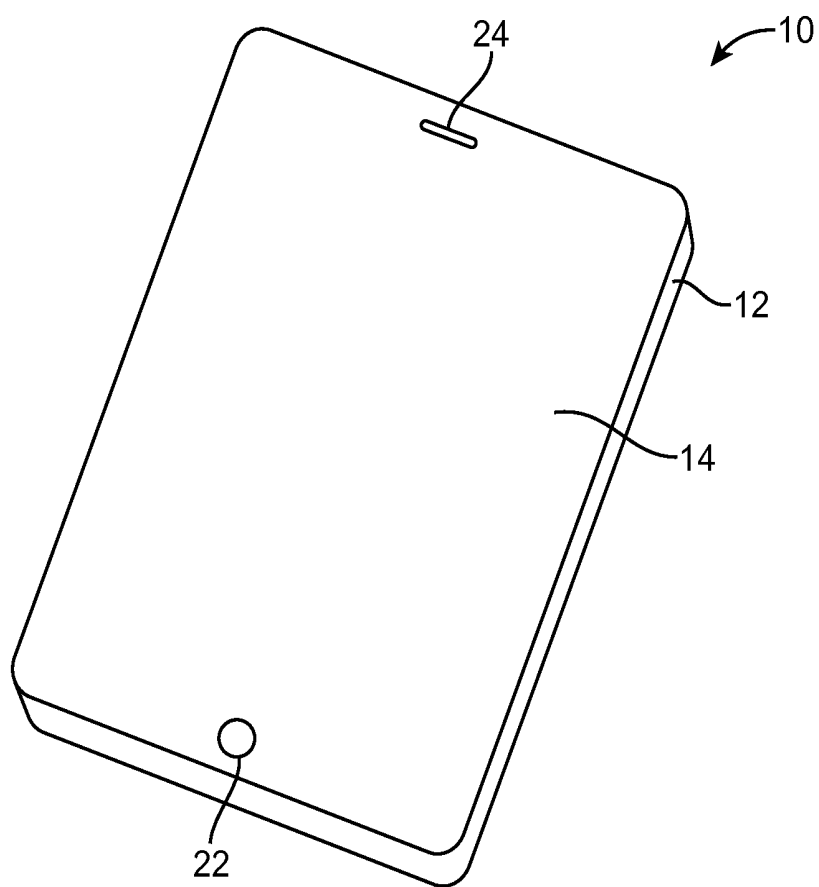


FIG. 2

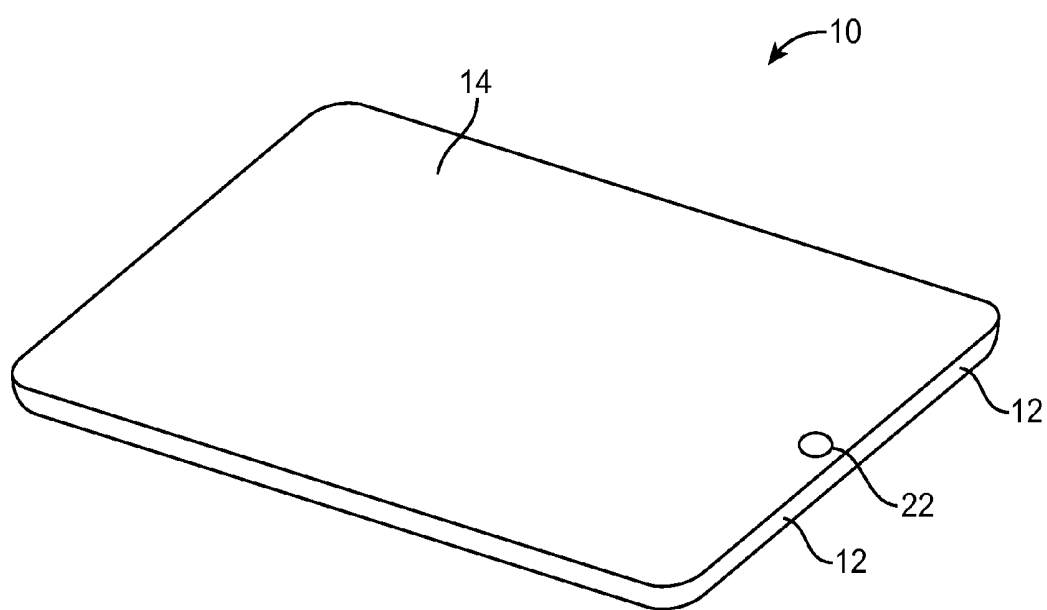


FIG. 3

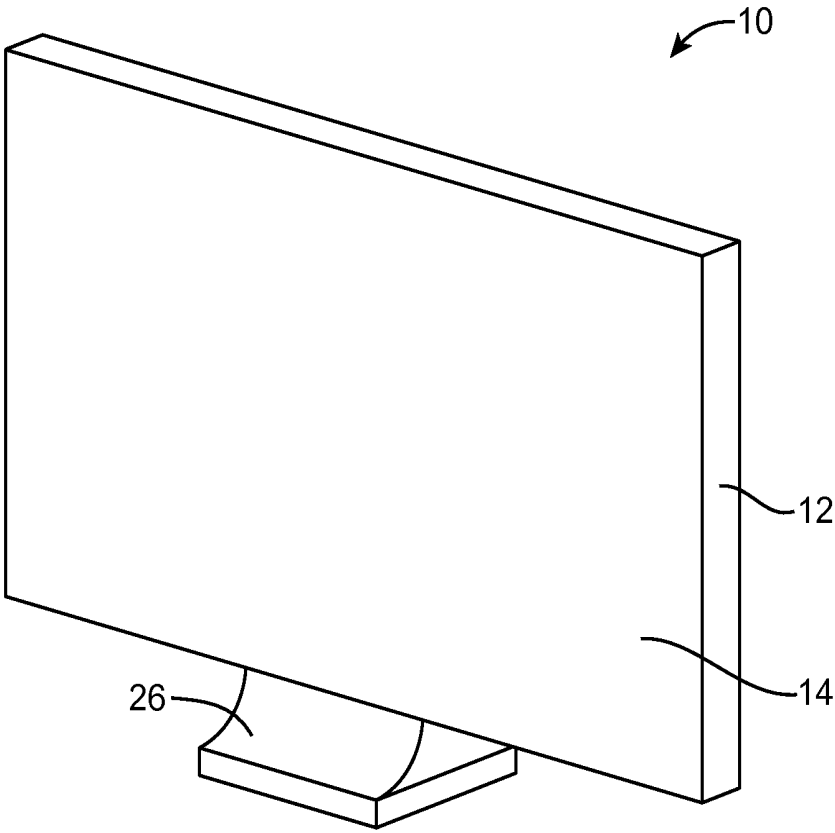


FIG. 4

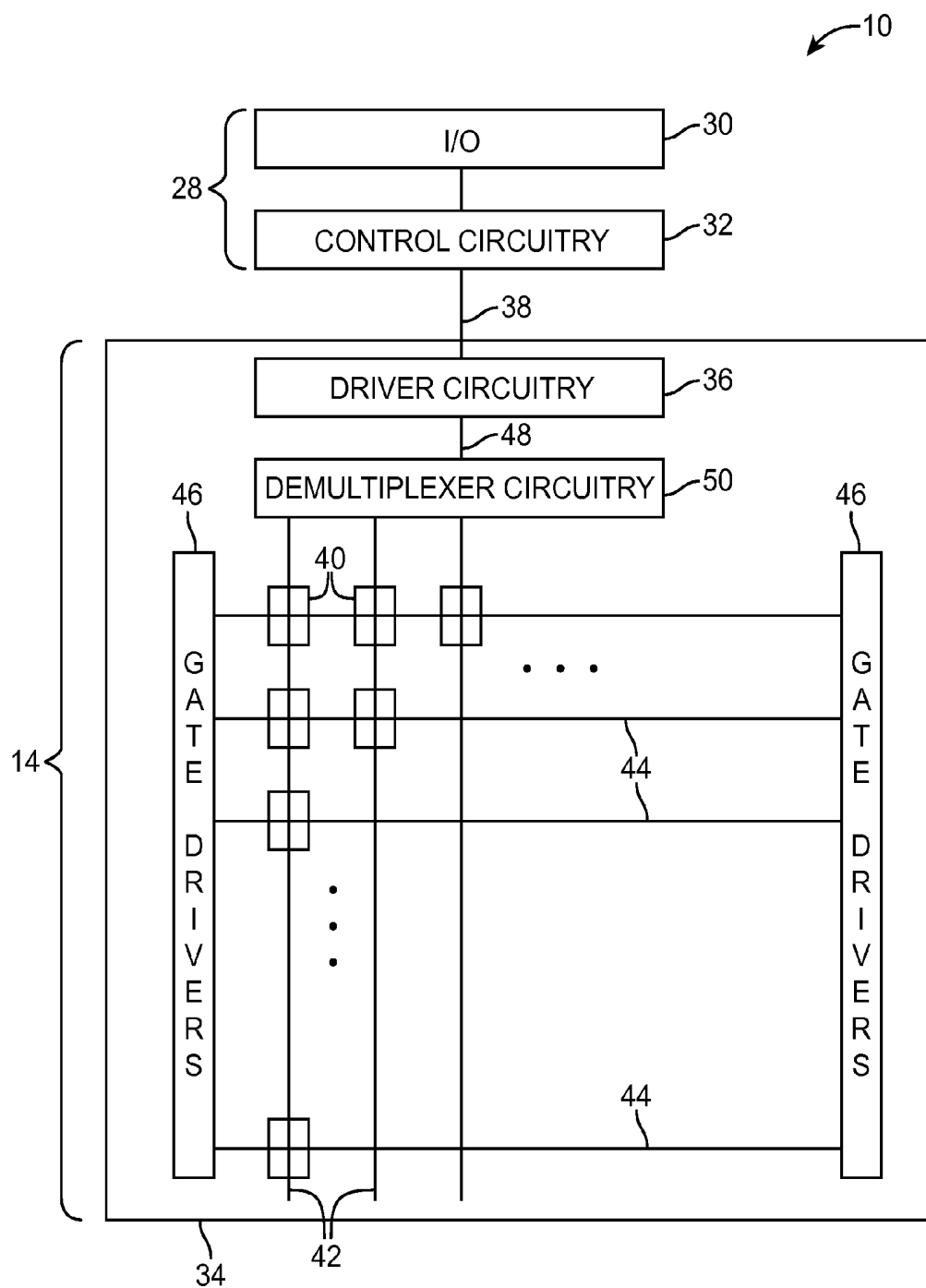


FIG. 5

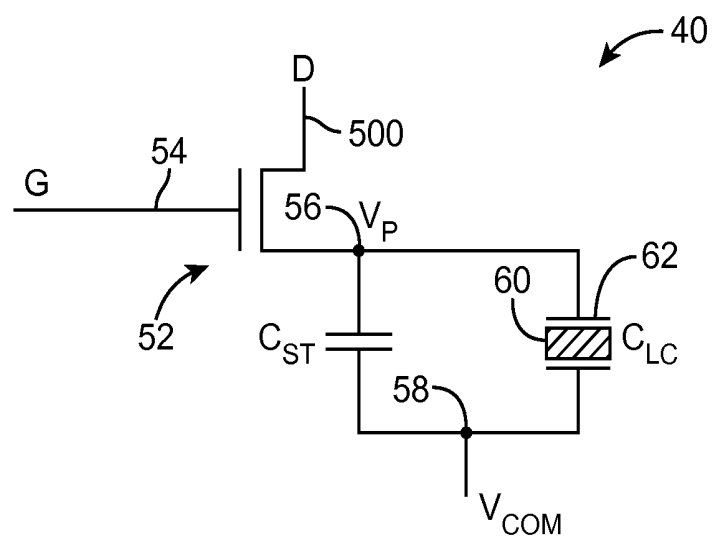


FIG. 6

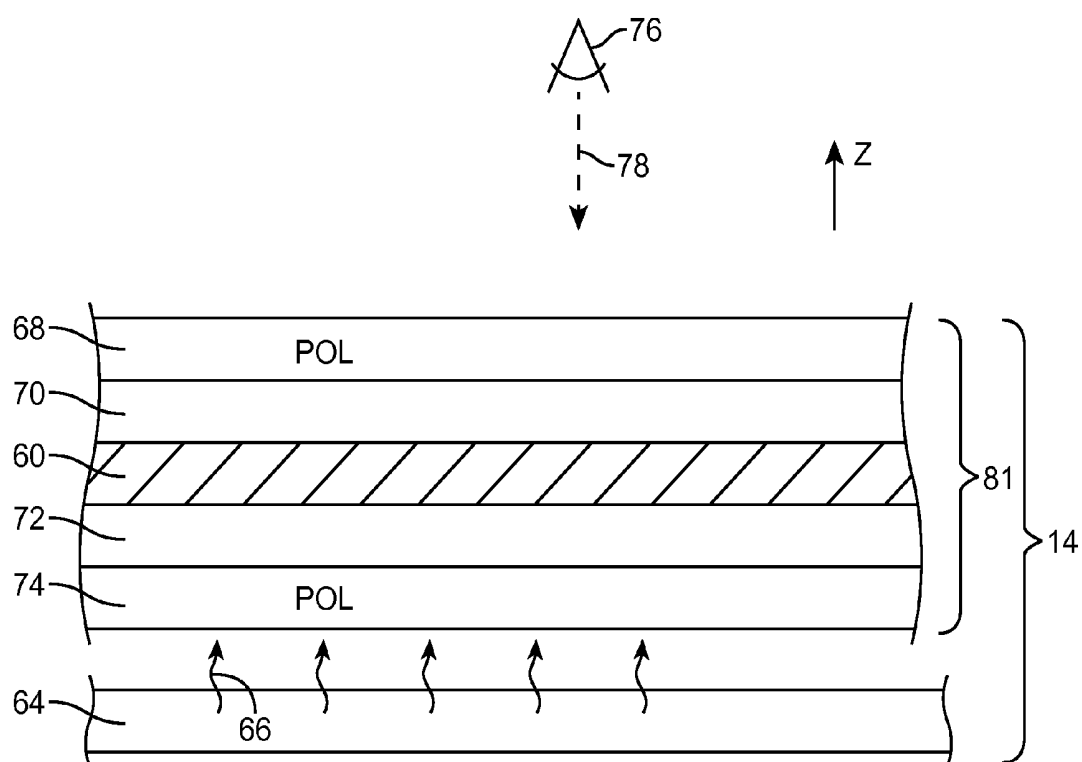


FIG. 7

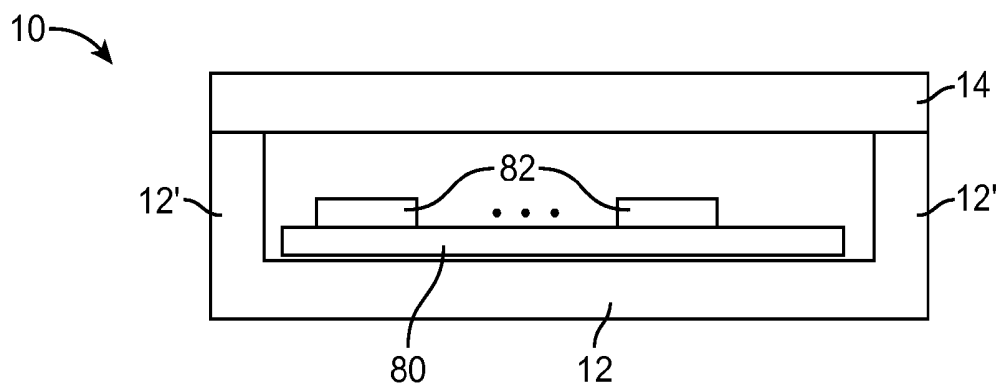


FIG. 8

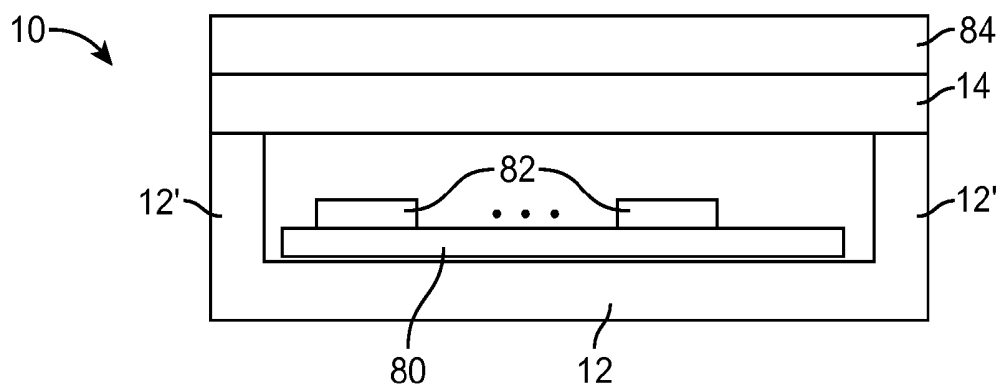


FIG. 9

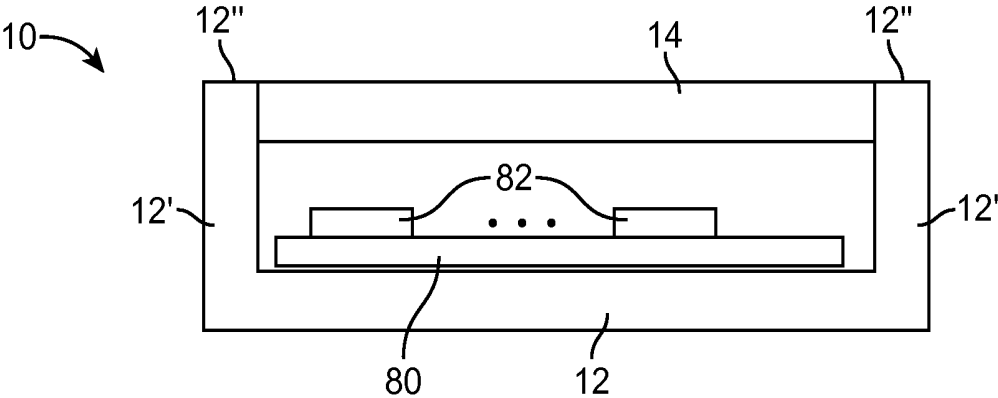


FIG. 10

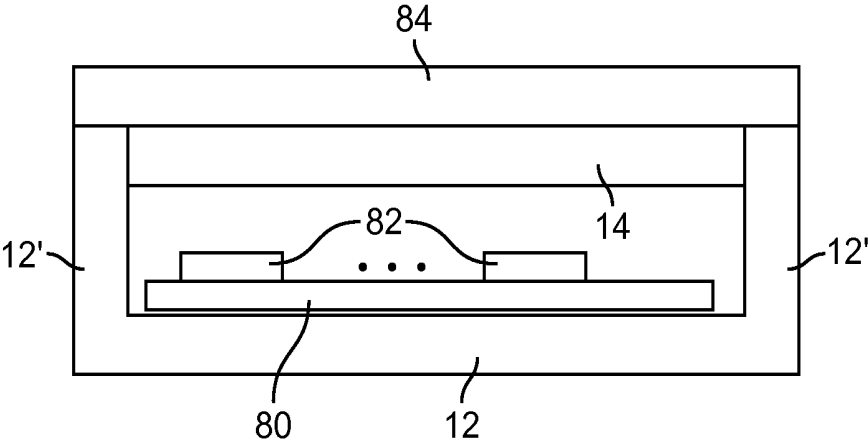


FIG. 11

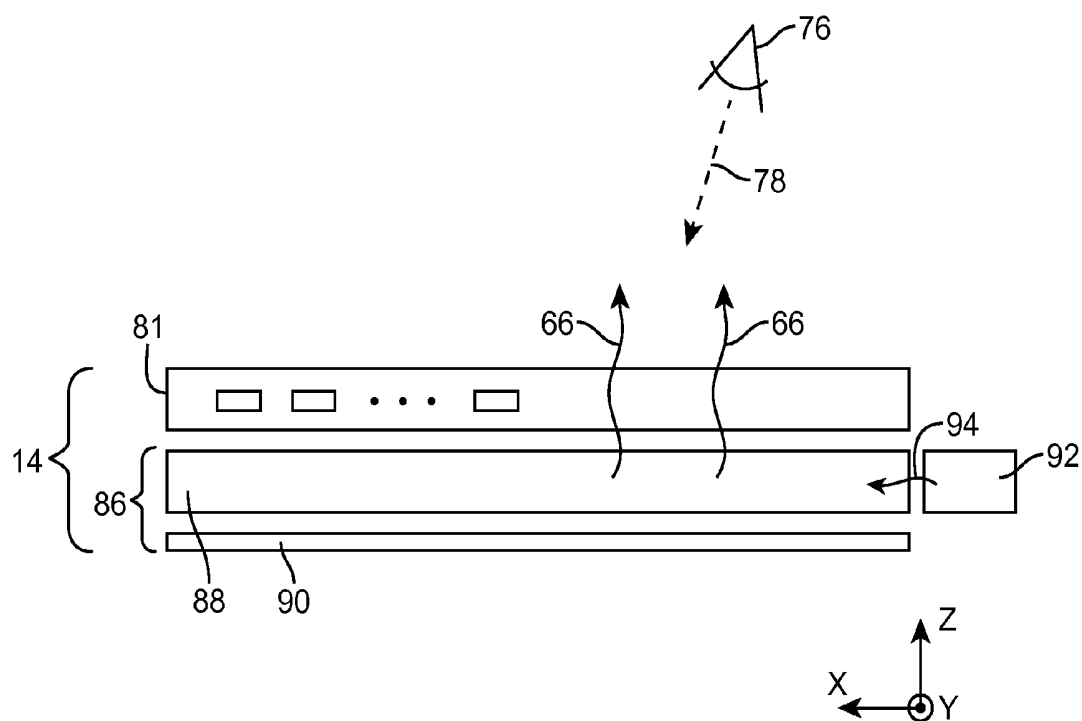


FIG. 12

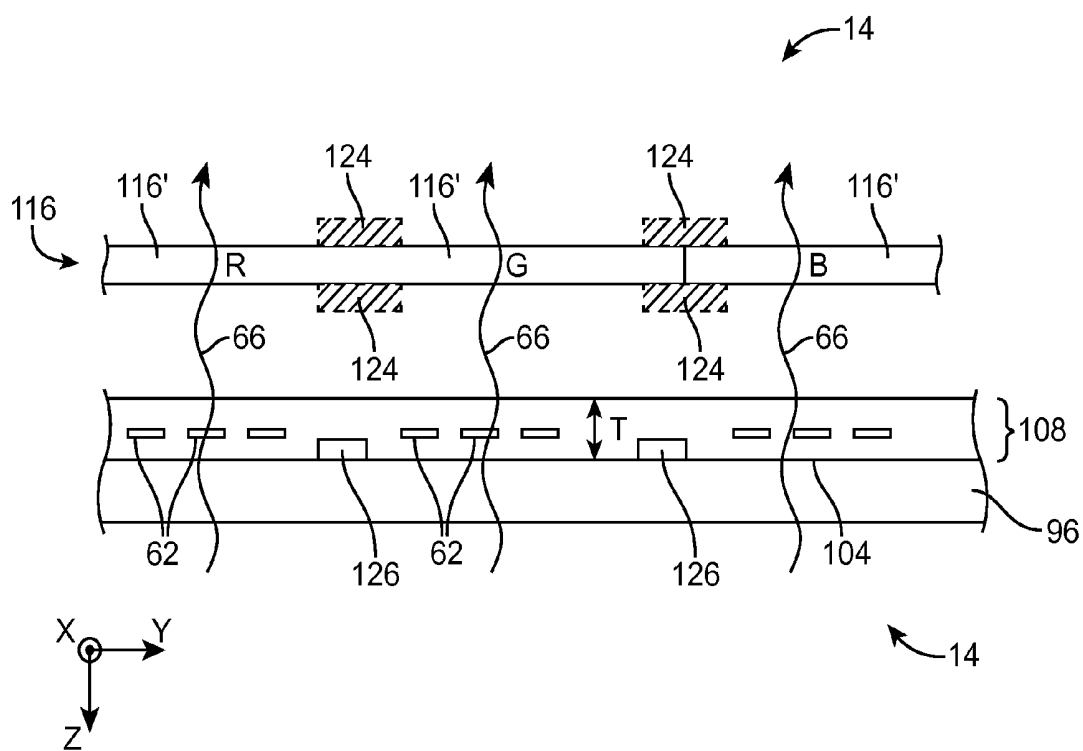


FIG. 13

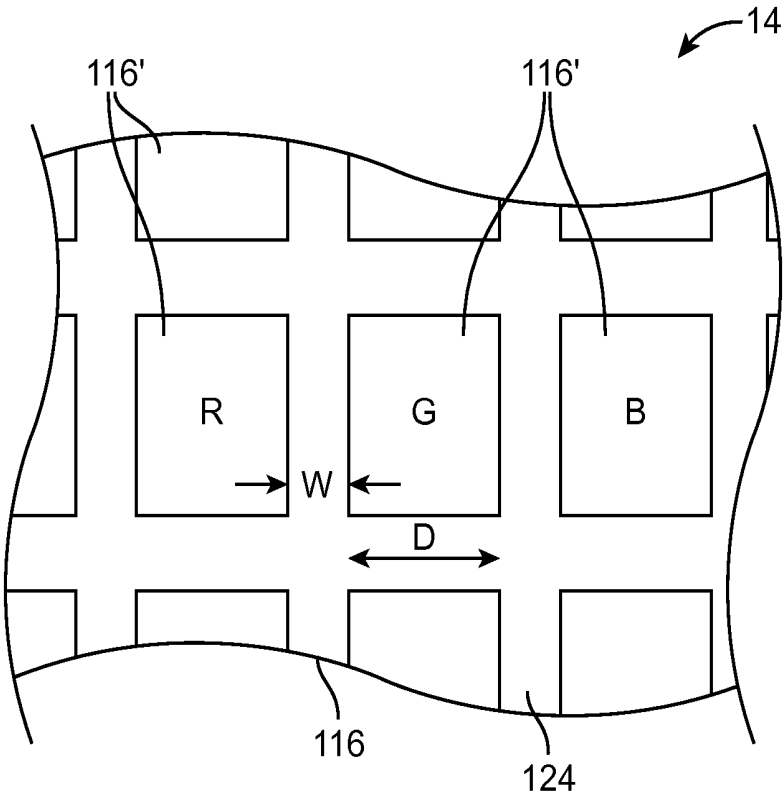
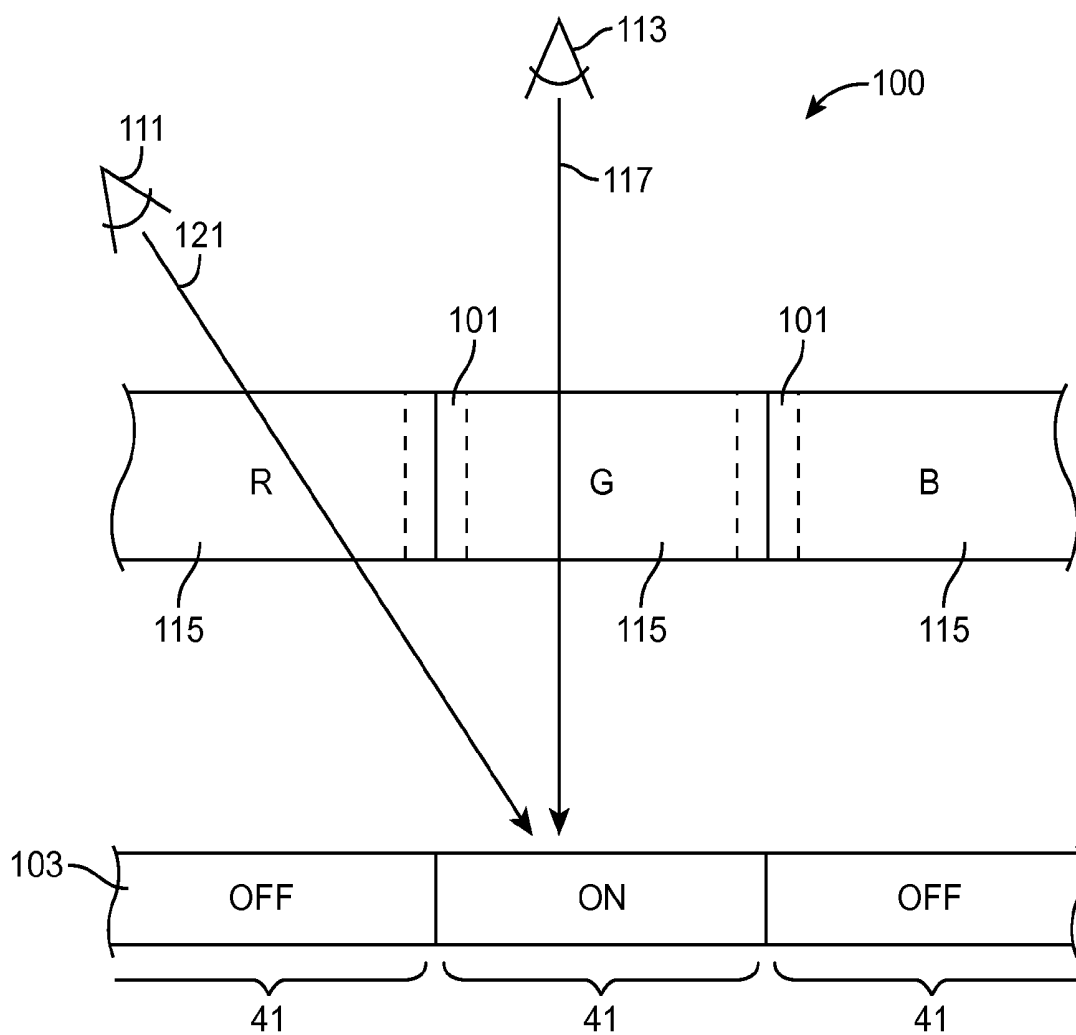


FIG. 14



(PRIOR ART)
FIG. 15

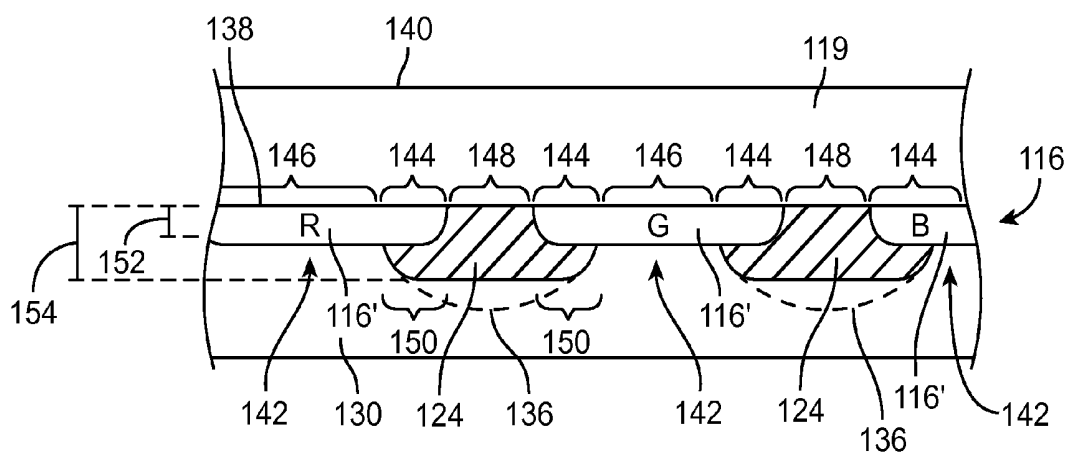


FIG. 17

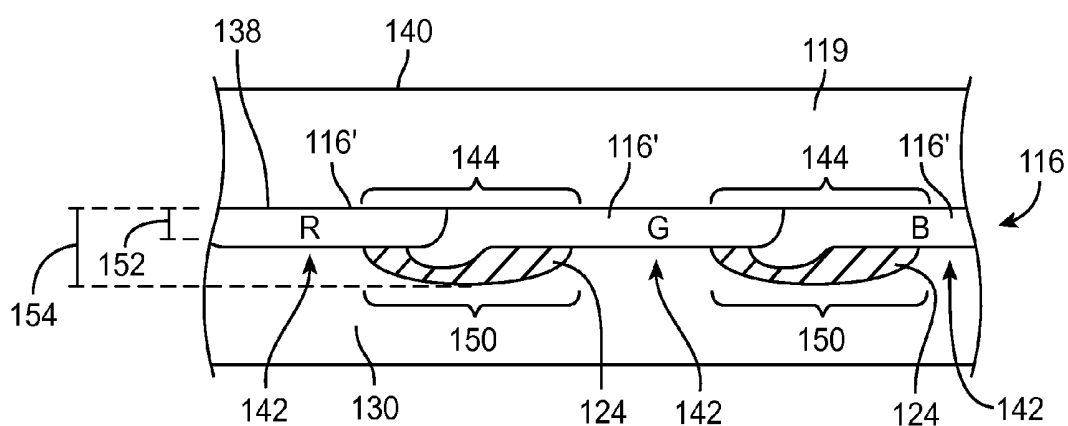


FIG. 18

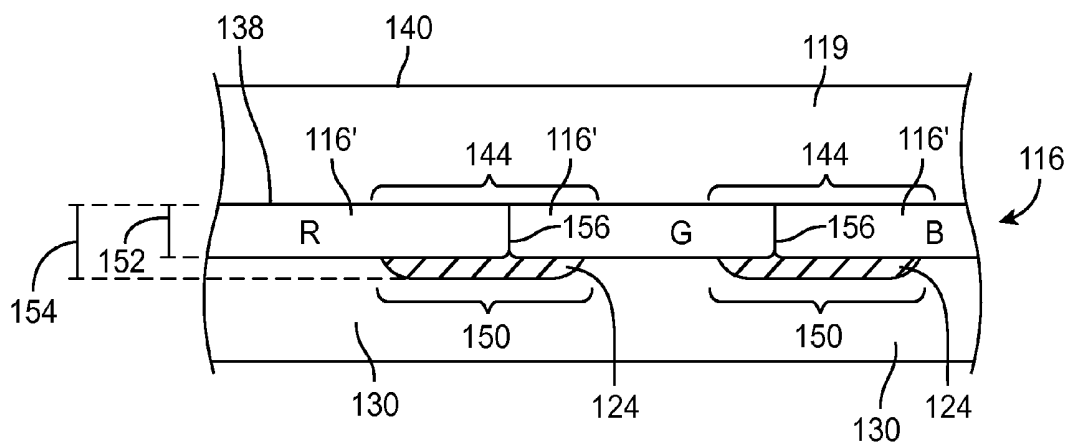


FIG. 19

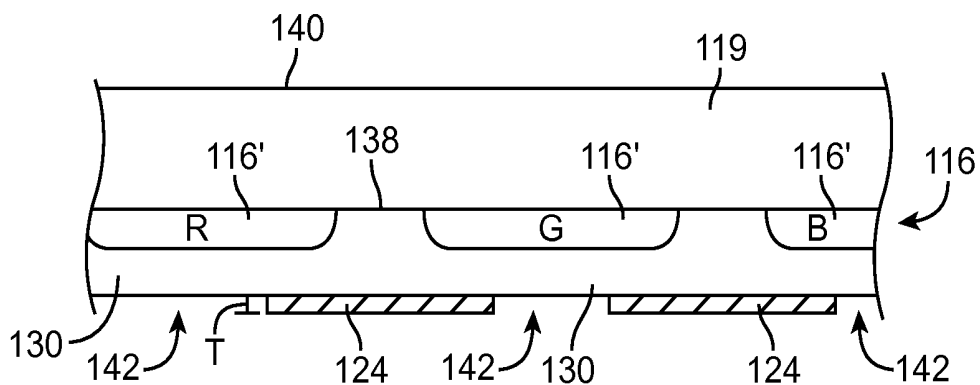


FIG. 20

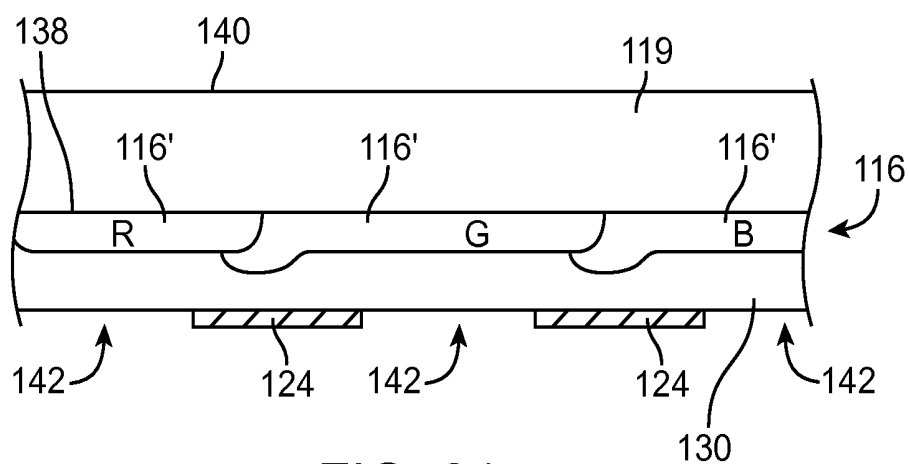


FIG. 21

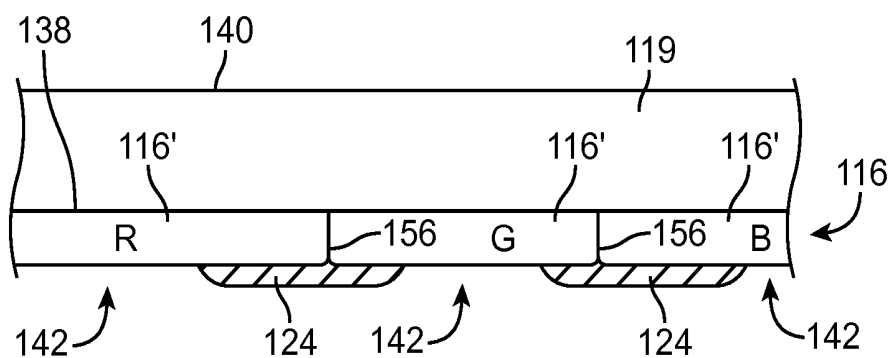


FIG. 22

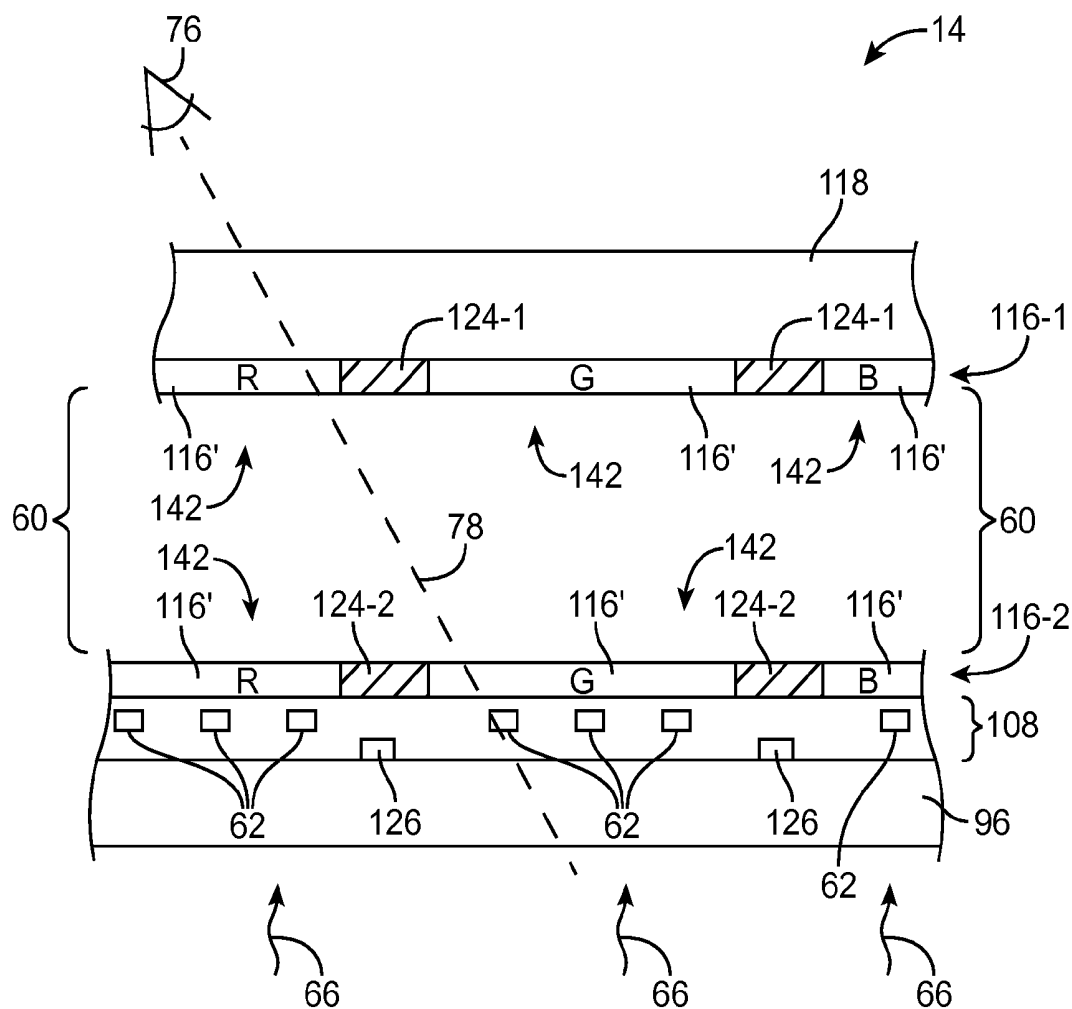


FIG. 23

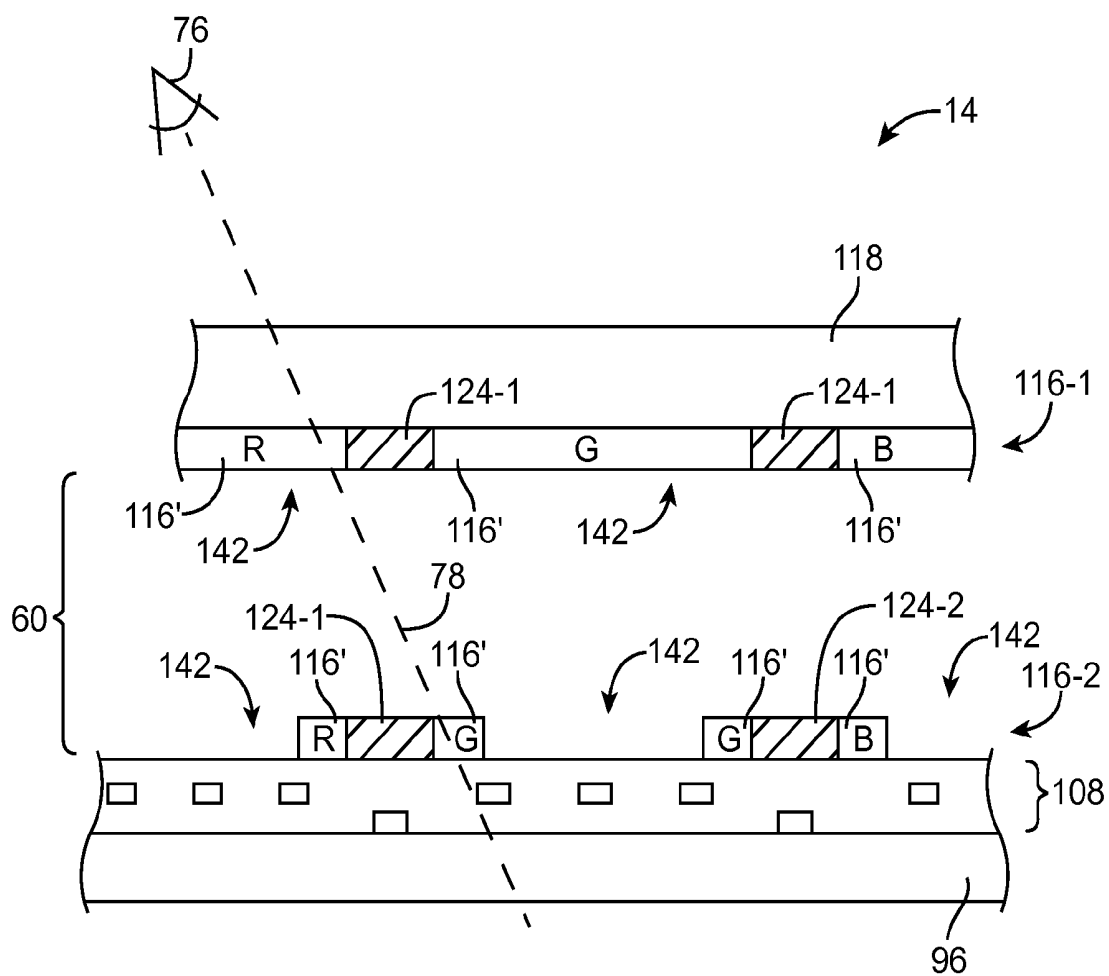


FIG. 24

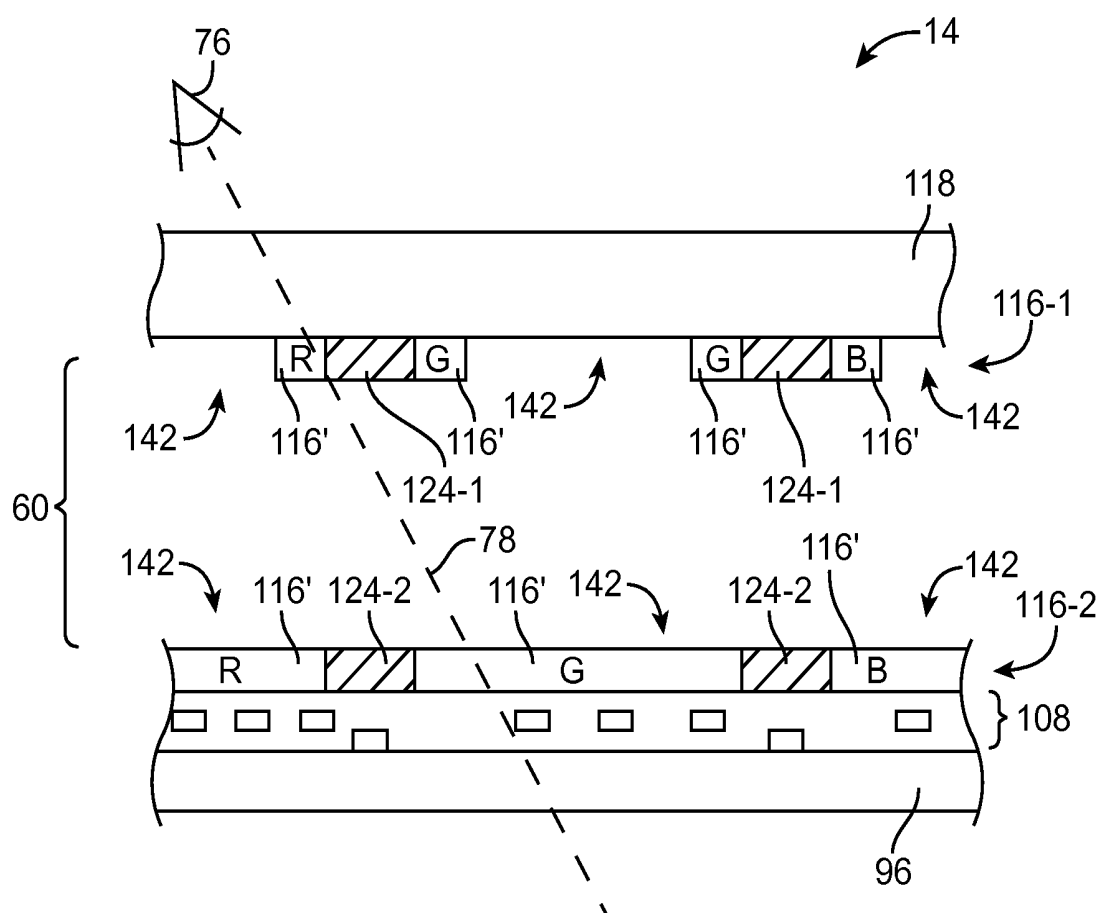


FIG. 25

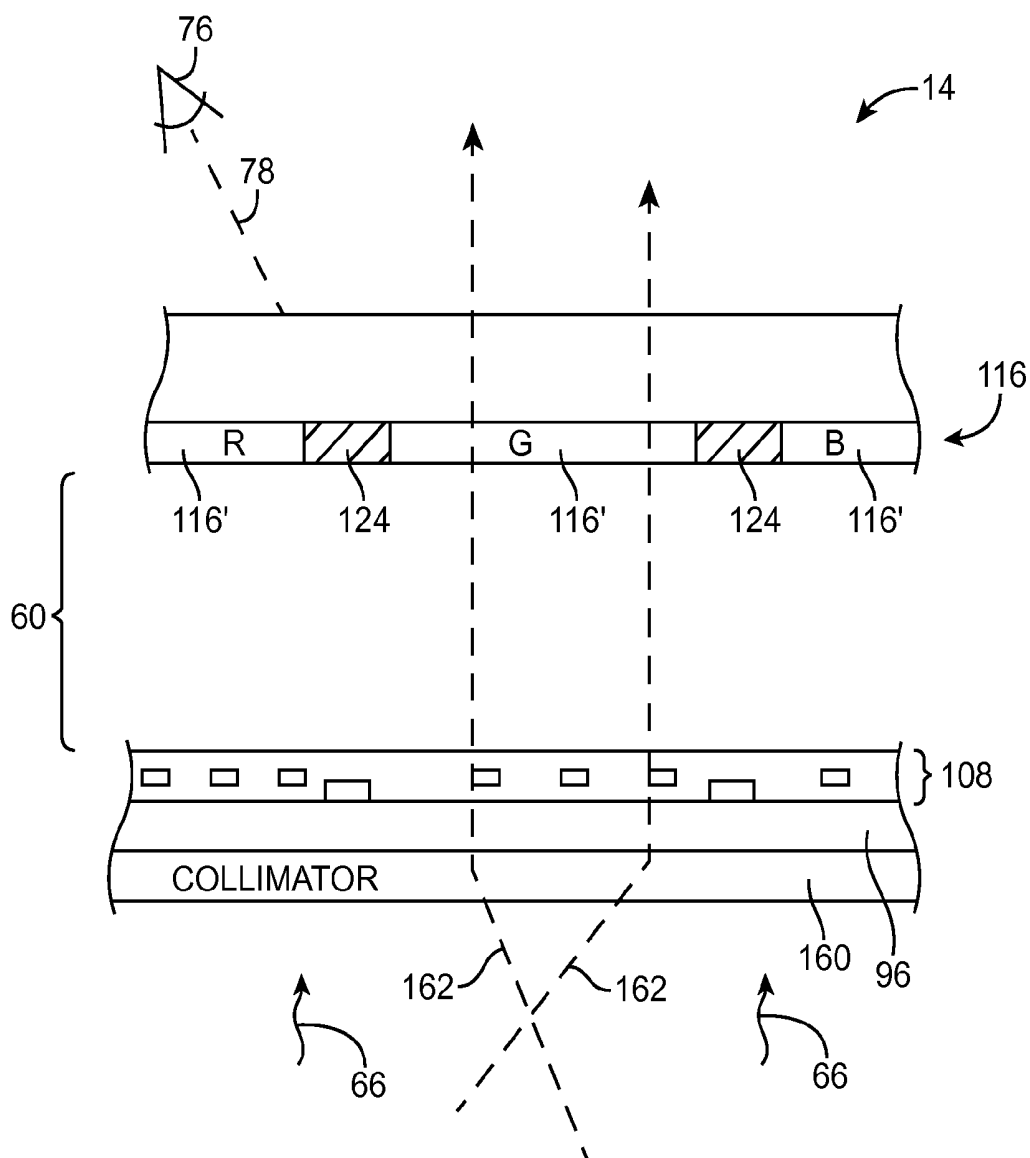


FIG. 26

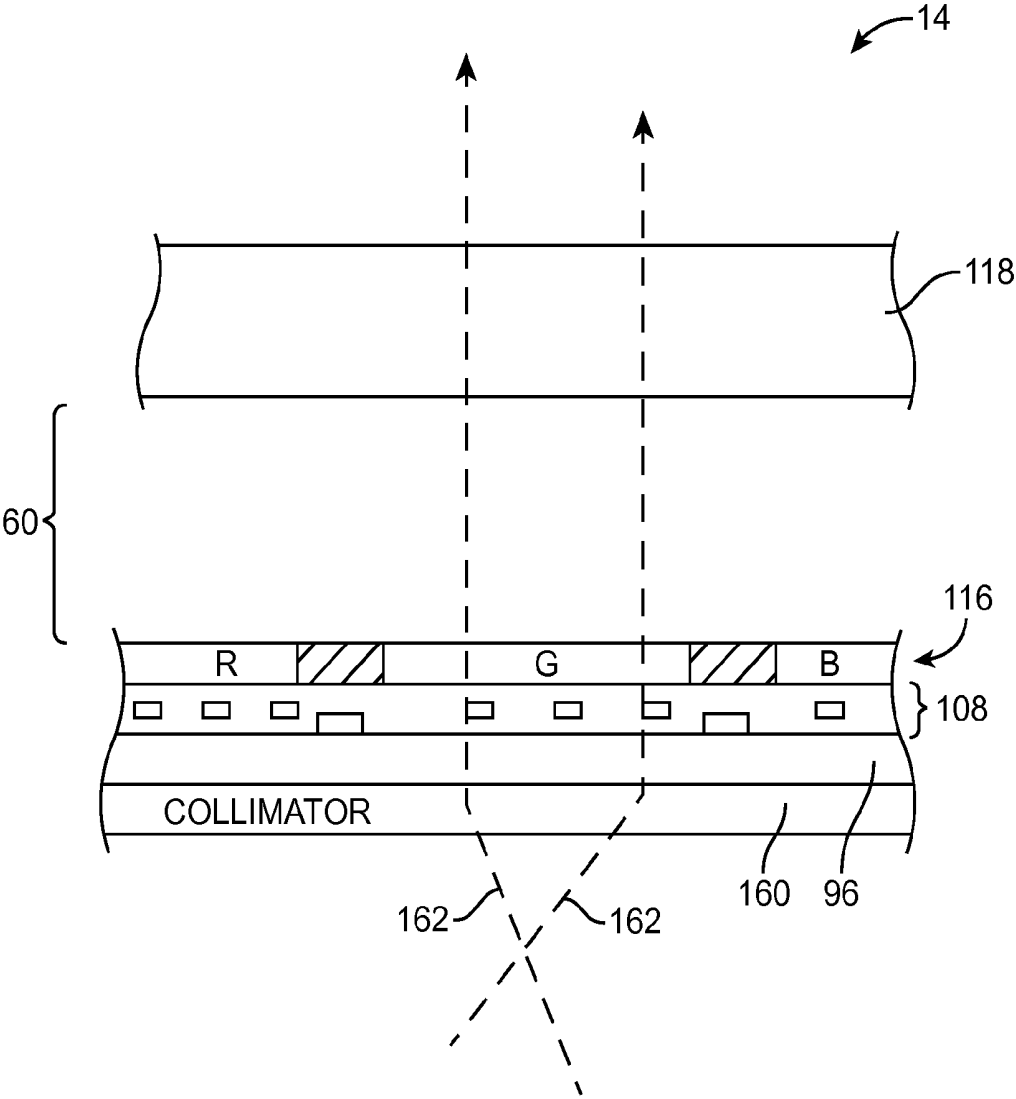


FIG. 27

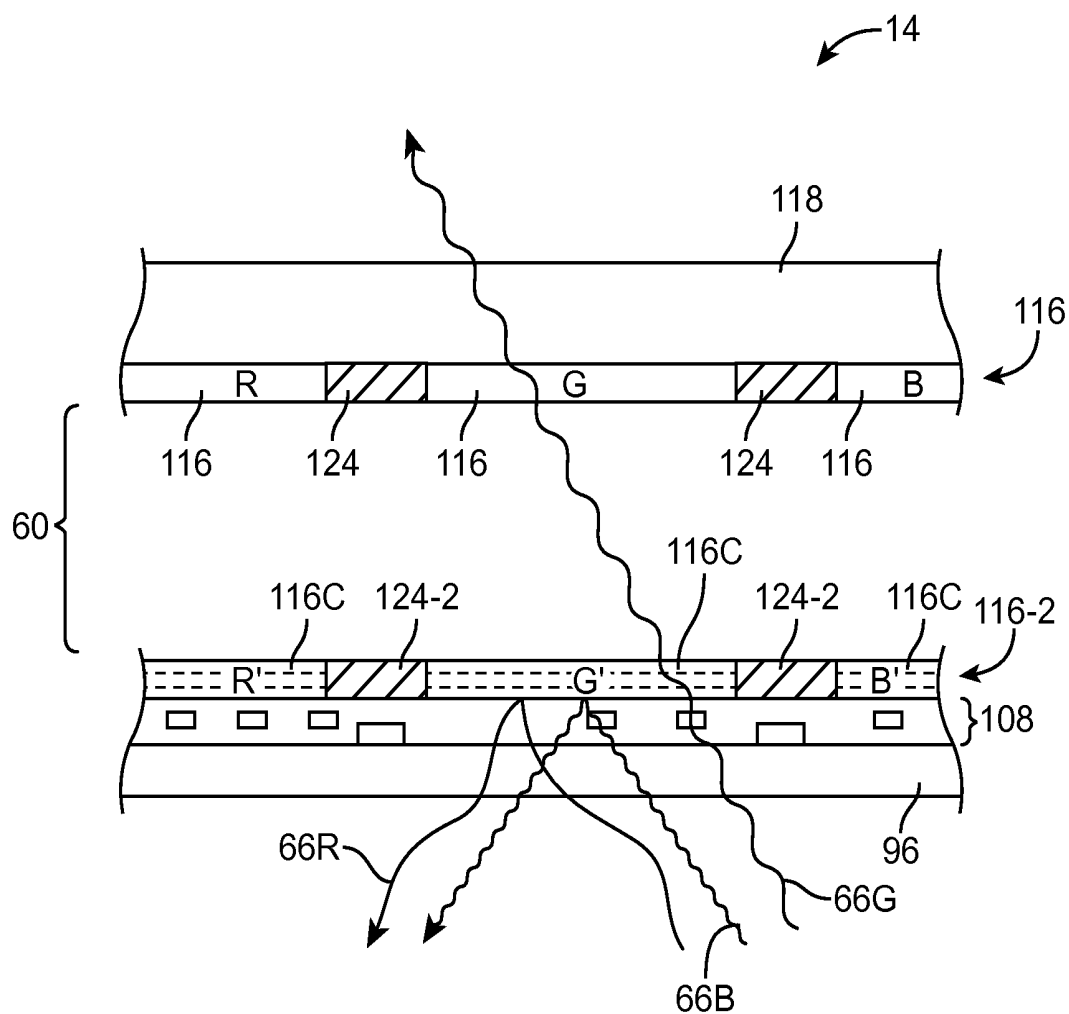


FIG. 28

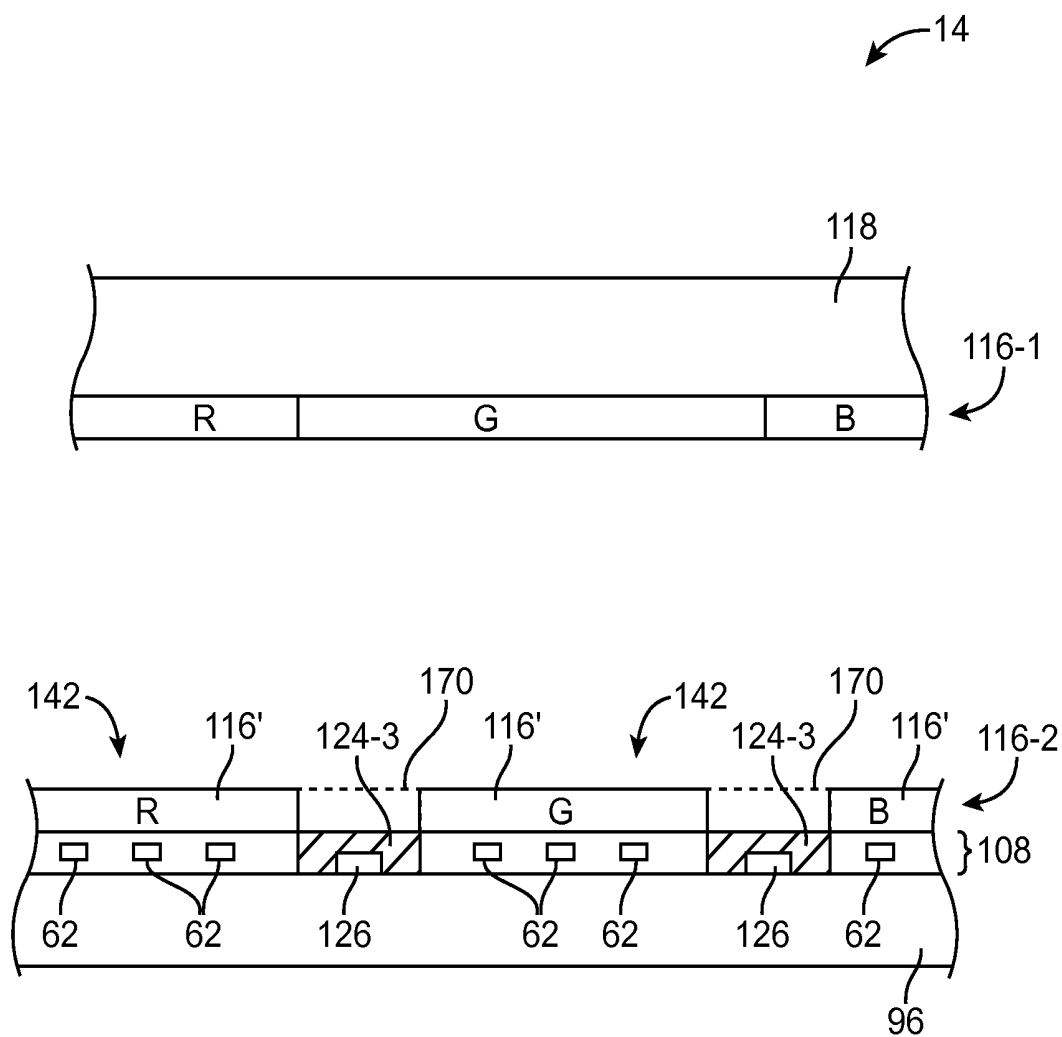


FIG. 29

DISPLAY WITH COLOR MIXING PREVENTION STRUCTURES

[0001] This application is a continuation of U.S. patent application Ser. No. 13/364,885, filed Feb. 2, 2012, which is hereby incorporated by reference herein in its entirety. This application claims the benefit of and claims priority to U.S. patent application Ser. No. 13/364,885, filed Feb. 2, 2012.

BACKGROUND

[0002] This relates generally to electronic devices and, more particularly, to displays for electronic devices.

[0003] Electronic devices such as computers and cellular telephones are generally provided with displays. Displays such as liquid crystal displays contain a thin layer of liquid crystal material. Color liquid crystal displays include color filter layers. The layer of liquid crystal material in this type of display is interposed between the color filter layer and a thin-film transistor. Polarizer layers may be placed above and below the color filter layer, liquid crystal material, and thin-film transistor layer.

[0004] When it is desired to display an image for a user, display driver circuitry applies signals to a grid of data lines and gate lines within the thin-film transistor layer. These signals adjust electric fields associated with an array of pixels on the thin-film transistor layer. The electric field pattern that is produced controls the liquid crystal material and creates a visible image on the display.

[0005] Image quality in conventional displays can be degraded during off-axis viewing, because off-axis viewing angles can allow light from display pixels of one color to bleed into adjacent display pixels of another color. Although off-axis quality can be improved somewhat by incorporating wide black matrix structures into the display, the use of excessively wide black matrix masking lines can adversely affect display brightness and may be impractical for use in a high-resolution display in which increasingly narrow black matrix masking lines are desired.

[0006] It would therefore be desirable to be able to provide improved electronic device displays.

SUMMARY

[0007] Electronic devices may be provided with displays such as liquid crystal displays. A display may have an array of display pixels. A liquid crystal display may be provided with backlight structures. The backlight structures may produce backlight that passes through the array of display pixels. The display pixels may include electrode structures and thin-film transistor structures for controlling electric fields in a layer of liquid crystal material. The liquid crystal material may be formed between an outer display layer formed in part by a first transparent substrate and an inner display layer formed, in part, by a second transparent substrate.

[0008] The inner display layer may be interposed between the backlight structures and the liquid crystal material. Thin-film transistor structures, electrodes, and conductive interconnection lines may be deposited in a layer on the inner surface of the inner display layer. In one suitable configuration, the first transparent substrate may form a layer of cover glass for the display.

[0009] A layer of color filter elements may be used to provide the display with color pixels. Color filter elements may be formed on the thin-film transistor layer. Color filter elements may be formed on the outer display layer. In some

configurations, color filter elements may be formed on both the thin-film transistor layer and the outer display layer.

[0010] A patterned layer of opaque masking material may be formed in a peripheral border region of the outer display layer. A portion of the opaque masking material may form black matrix mask that visually separates adjacent color filter elements. A planarization layer may be used to cover some, or all, of the opaque masking layer. If desired, the planarization layer may be interposed between the black matrix and the color filter elements.

[0011] A first black matrix on the outer display layer may include openings for color filter elements on the outer display layer and a second black matrix on the inner display layer may include openings for the color filter elements on the thin-film transistor layer. The black matrix openings may be completely or partially filled with the color filter elements.

[0012] If desired, some or all of the interconnect lines of the thin-film transistor layer may be embedded within a black matrix that is formed on the thin-film transistor layer.

[0013] If desired, some or all of the color filter elements may be formed using cholesteric filter material such as a multilayer dielectric stack that includes materials with different indices of refraction configured to form an optical filter.

[0014] If desired, a light collimating layer may be provided on the second transparent substrate layer. The light collimating layer may be formed from collimating structures such as Fresnel lens structures, microlens structures, or structures containing an array of micropisms.

[0015] If desired, a portion of the array of color filter elements may be interposed between the black matrix and an inner surface of a transparent substrate layer. The portion of the color filter elements may be interposed between first regions of the black matrix and the inner surface while second regions of the black matrix are formed on the inner surface without any interposed color filter elements.

[0016] If desired, the array of color filter elements may form a contiguous array of color filter elements of different colors having adjoining edges. The black matrix may cover the adjoining edges without touching the inner surface of the transparent substrate layer.

[0017] Further features of the invention, its nature and various advantages will be more apparent from the accompanying drawings and the following detailed description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. 1 is a diagram of an illustrative electronic device with a display such as a portable computer in accordance with an embodiment of the present invention.

[0019] FIG. 2 is a diagram of an illustrative electronic device with a display such as a cellular telephone or other handheld device in accordance with an embodiment of the present invention.

[0020] FIG. 3 is a diagram of an illustrative electronic device with a display such as a tablet computer in accordance with an embodiment of the present invention.

[0021] FIG. 4 is a diagram of an illustrative electronic device with a display such as a computer monitor with a built-in computer in accordance with an embodiment of the present invention.

[0022] FIG. 5 is a circuit diagram showing circuitry that may be used in operating an electronic device with a display in accordance with an embodiment of the present invention.

[0023] FIG. 6 is a circuit diagram of an illustrative display pixel in accordance with an embodiment of the present invention.

[0024] FIG. 7 is a cross-sectional side view of a portion of an illustrative liquid crystal display with backlight structures in accordance with an embodiment of the present invention.

[0025] FIG. 8 is a cross-sectional view of an illustrative electronic device having a display that overlaps housing sidewall structures in accordance with an embodiment of the present invention.

[0026] FIG. 9 is a cross-sectional view of an illustrative electronic device having a display that overlaps housing sidewall structures and having a display cover layer in accordance with an embodiment of the present invention.

[0027] FIG. 10 is a cross-sectional view of an illustrative electronic device having a display with edges that are mounted between opposing housing sidewalls in accordance with an embodiment of the present invention.

[0028] FIG. 11 is a cross-sectional view of an illustrative electronic device having a display with edges that are mounted between opposing housing sidewalls and having a display cover layer in accordance with an embodiment of the present invention.

[0029] FIG. 12 is a cross-sectional side view of a display showing how backlight structures may be used to provide the display with backlight in accordance with an embodiment of the present invention.

[0030] FIG. 13 is a cross-sectional view of an illustrative display having a substrate layer on which thin-film transistor structures have been formed in accordance with an embodiment of the present invention.

[0031] FIG. 14 is a top view of a portion of a display showing how a black matrix may be used to visually separate color filter elements in accordance with an embodiment of the present invention.

[0032] FIG. 15 is a cross-sectional side view of a conventional color filter array showing how color mixing may be present at off-axis viewing angles.

[0033] FIG. 16 is a cross-sectional side view of a portion of an illustrative display showing how formation of a black matrix layer over an array of color filter elements on an outer display layer may help improve off-axis display performance in accordance with an embodiment of the present invention.

[0034] FIG. 17 is a cross-sectional side view of a portion of a color filter array showing how a portion of an array of color filter elements may be interposed between a region of a black matrix and an inner surface of a transparent substrate in accordance with an embodiment of the present invention.

[0035] FIG. 18 is a cross-sectional side view of a portion of a color filter array showing how a portion of an array of color filter elements may be interposed between substantially all of a black matrix and an inner surface of a transparent substrate in accordance with an embodiment of the present invention.

[0036] FIG. 19 is a cross-sectional side view of a portion of a color filter array showing how color filter elements may have adjoining edges and a black matrix may cover the adjoining edges in accordance with an embodiment of the present invention.

[0037] FIG. 20 is a cross-sectional side view of a portion of a color filter array showing how a planarization layer may be interposed between a portion of an array of spatially-separated color filter elements and a black matrix formed from a thin metal matrix in accordance with an embodiment of the present invention.

[0038] FIG. 21 is a cross-sectional side view of a portion of a color filter array showing how a planarization layer may be interposed between a portion of an array of partially overlapping color filter elements and a black matrix formed from a thin metal matrix in accordance with an embodiment of the present invention.

[0039] FIG. 22 is a cross-sectional side view of a portion of a color filter array showing how color filter elements may have adjoining edges and a black matrix formed from a thin metal matrix may cover the adjoining edges in accordance with an embodiment of the present invention.

[0040] FIG. 23 is a cross-sectional side view of a portion of an illustrative display showing how a first color filter array and black matrix may be formed on a first transparent display substrate and a second color filter array and black matrix may be formed on a second transparent display substrate in accordance with an embodiment of the present invention.

[0041] FIG. 24 is a cross-sectional side view of a portion of an illustrative display showing how color filter elements may partially fill openings in a black matrix formed on an inner display layer in accordance with an embodiment of the present invention.

[0042] FIG. 25 is a cross-sectional side view of an illustrative display showing how color filter elements may partially fill openings in a black matrix formed on an outer display layer in accordance with an embodiment of the present invention.

[0043] FIG. 26 is a cross-sectional side view of a portion of an illustrative display showing how a collimating layer may be provided on an inner display layer that redirects light through color filter elements formed on an outer display layer in accordance with an embodiment of the present invention.

[0044] FIG. 27 is a cross-sectional side view of an illustrative display showing how a collimating layer may be provided on an inner display layer that redirects light through color filter elements formed on an opposing surface of the inner display layer in accordance with an embodiment of the present invention.

[0045] FIG. 28 is a cross-sectional side view of an illustrative display showing how some color filter elements may be configured to reflect selected colors of light in accordance with an embodiment of the present invention.

[0046] FIG. 29 is a cross-sectional side view of an illustrative display showing how a first color filter array may be formed on a first transparent display substrate and a second color filter array and black matrix may be formed on a thin-film transistor layer having control lines that are immersed in the black matrix in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0047] An illustrative electronic device of the type that may be provided with a display is shown in FIG. 1. Electronic device 10 may be a computer such as a computer that is integrated into a display such as a computer monitor, a laptop computer, a tablet computer, a somewhat smaller portable device such as a wrist-watch device, pendant device, or other wearable or miniature device, a cellular telephone, a media player, a tablet computer, a gaming device, a navigation device, a computer monitor, a television, or other electronic equipment.

[0048] As shown in FIG. 1, device 10 may include a display such as display 14. Display 14 may be a touch screen that incorporates capacitive touch electrodes or other touch sensor

components or may be a display that is not touch sensitive. Display **14** may include image pixels formed from liquid crystal display (LCD) components or other suitable display pixel structures. Arrangements in which display **14** is formed using liquid crystal display pixels are sometimes described herein as an example. This is, however, merely illustrative. Any suitable type of display technology may be used in forming display **14** if desired.

[0049] Device **10** may have a housing such as housing **12**. Housing **12**, which may sometimes be referred to as a case, may be formed of plastic, glass, ceramics, fiber composites, metal (e.g., stainless steel, aluminum, etc.), other suitable materials, or a combination of any two or more of these materials.

[0050] Housing **12** may be formed using a unibody configuration in which some or all of housing **12** is machined or molded as a single structure or may be formed using multiple structures (e.g., an internal frame structure, one or more structures that form exterior housing surfaces, etc.).

[0051] As shown in FIG. 1, housing **12** may have multiple parts. For example, housing **12** may have upper portion **12A** and lower portion **12B**. Upper portion **12A** may be coupled to lower portion **12B** using a hinge that allows portion **12A** to rotate about rotational axis **16** relative to portion **12B**. A keyboard such as keyboard **18** and a touch pad such as touch pad **20** may be mounted in housing portion **12B**.

[0052] In the example of FIG. 2, device **10** has been implemented using a housing that is sufficiently small to fit within a user's hand (i.e., device **10** of FIG. 2 may be a handheld electronic device such as a cellular telephone). As shown in FIG. 2, device **10** may include a display such as display **14** mounted on the front of housing **12**. Display **14** may be substantially filled with active display pixels or may have an active portion and an inactive portion. Display **14** may have openings (e.g., openings in the inactive or active portions of display **14**) such as an opening to accommodate button **22** and an opening to accommodate speaker port **24**.

[0053] FIG. 3 is a perspective view of electronic device **10** in a configuration in which electronic device **10** has been implemented in the form of a tablet computer. As shown in FIG. 3, display **14** may be mounted on the upper (front) surface of housing **12**. An opening may be formed in display **14** to accommodate button **22**.

[0054] FIG. 4 is a perspective view of electronic device **10** in a configuration in which electronic device **10** has been implemented in the form of a computer integrated into a computer monitor. As shown in FIG. 4, display **14** may be mounted on the front surface of housing **12**. Stand **26** may be used to support housing **12**.

[0055] Other configurations may be used for electronic device **10** if desired. The examples of FIGS. 1, 2, 3, and 4 are merely illustrative.

[0056] A diagram showing circuitry of the type that may be used in device **10** is shown in FIG. 5. As shown in FIG. 5, display **14** may be coupled to device components **28** such as input-output circuitry **30** and control circuitry **32**. Input-output circuitry **30** may include components for receiving device input. For example, input-output circuitry **30** may include a microphone for receiving audio input, a keyboard, keypad, or other buttons or switches for receiving input (e.g., key press input or button press input from a user), sensors for gathering input such as an accelerometer, a compass, a light sensor, a proximity sensor, touch sensor (e.g., touch sensors associated

with display **14** or separate touch sensors), or other input devices. Input-output circuitry **30** may also include components for supplying output.

[0057] Output circuitry may include components such as speakers, light-emitting diodes or other light-emitting devices for producing light output, vibrators, and other components for supplying output. Input-output ports in circuitry **30** may be used for receiving analog and/or digital input signal and may be used for outputting analog and/or digital output signals. Examples of input-output ports that may be used in circuitry **30** include audio ports, digital data ports, ports associated with 30-pin connectors, and ports associated with Universal Serial Bus connectors and other digital data connectors.

[0058] Control circuitry **32** may be used in controlling the operation of device **10**. Control circuitry **32** may include storage circuits such as volatile and non-volatile memory circuits, solid state drives, hard drives, and other memory and storage circuitry. Control circuitry **32** may also include processing circuitry such as processing circuitry in a microprocessor or other processor. One or more integrated circuits may be used in implementing control circuitry **32**. Examples of integrated circuits that may be included in control circuitry **32** include microprocessors, digital signal processors, power management units, baseband processors, microcontrollers, application-specific integrated circuits, circuits for handling audio and/or visual information, and other control circuitry.

[0059] Control circuitry **32** may be used in running software for device **10**. For example, control circuitry **32** may be configured to execute code in connection with the displaying of images on display **14** (e.g., text, pictures, video, etc.).

[0060] Display **14** may include a pixel array such as pixel array **34**. Pixel array **34** may be controlled using control signals produced by display driver circuitry such as display driver circuitry **36**. Display driver circuitry **36** may be implemented using one or more integrated circuits (ICs) and may sometimes be referred to as a driver IC, display driver integrated circuit, or display driver. Display driver integrated circuit **36** may be mounted on an edge of a thin-film transistor substrate layer in display **14** (as an example). The thin-film transistor substrate layer may sometimes be referred to as a thin-film transistor (TFT) layer.

[0061] During operation of device **10**, control circuitry **32** may provide data to display driver **36**. For example, control circuitry **32** may use a path such as path **38** to supply display driver **36** with digital data corresponding to text, graphics, video, or other images to be displayed on display **14**. Display driver **36** may convert the data that is received on path **38** into signals for controlling the pixels of pixel array **34**.

[0062] Pixel array **34** may contain rows and columns of display pixels **40**. The circuitry of pixel array **34** may be controlled using signals such as data line signals on data lines **42** and gate line signals on gate lines **44**.

[0063] Pixels **40** in pixel array **34** may contain thin-film transistor circuitry (e.g., polysilicon transistor circuitry or amorphous silicon transistor circuitry) and associated structures for producing electric fields across liquid crystal material in display **14**. The thin-film transistor structures that are used in forming pixels **40** may be located on a substrate (sometimes referred to as a thin-film transistor layer or thin-film transistor substrate). The thin-film transistor (TFT) layer may be formed from a planar glass substrate, a plastic substrate, or a sheet of other suitable substrate materials.

[0064] Gate driver circuitry 46 may be used to generate gate signals on gate lines 44. Circuits such as gate driver circuitry 46 may be formed from thin-film transistors on the thin-film transistor layer. Gate driver circuitry 46 may be located on both the left and right sides of pixel array 34 (as shown in FIG. 5) or may be located on only one side of pixel array 34.

[0065] The data line signals in pixel array 34 carry analog image data (e.g., voltages with magnitudes representing pixel brightness levels). During the process of displaying images on display 14, display driver integrated circuit 36 may receive digital data from control circuitry 32 via path 38 and may produce corresponding analog data on path 48. The analog data signals on path 48 may be demultiplexed by demultiplexer circuitry 50 in accordance with control signals provided by driver circuitry 36. This demultiplexing process produces corresponding color-coded analog data line signals on data lines 42 (e.g., data signals for a red channel, data signals for a green channel, and data signals for a blue channel).

[0066] The data line signals on data lines 42 may be provided to the columns of display pixels 40 in pixel array 34. Gate line signals may be provided to the rows of pixels 40 in pixel array 34 by gate driver circuitry 46.

[0067] The circuitry of display 14 such as demultiplexer circuitry 50 and gate driver circuitry 46 and the circuitry of pixels 40 may be formed from conductive structures (e.g., metal lines and/or structures formed from transparent conductive materials such as indium tin oxide) and may include transistors that are fabricated on the thin-film transistor substrate layer of display 14. The thin-film transistors may be, for example, polysilicon thin-film transistors or amorphous silicon transistors.

[0068] FIG. 6 is a circuit diagram of an illustrative display pixel in pixel array 34. Pixels such as pixel 40 of FIG. 6 may be located at the intersection of each gate line 44 and data line 42 in array 34.

[0069] A data signal D may be supplied to terminal 500 from one of data lines 42 (FIG. 5). Thin-film transistor 52 (e.g., a thin-film polysilicon transistor or an amorphous silicon transistor) may have a gate terminal such as gate 54 that receives gate line signal G from gate driver circuitry 46 (FIG. 5). When signal G is asserted, transistor 52 will be turned on and signal D will be passed to node 56 as voltage Vp. Data for display 14 may be displayed in frames. Following assertion of signal G in one frame, signal G may be deasserted. Signal G may then be asserted to turn on transistor 52 and capture a new value of Vp in a subsequent display frame.

[0070] Pixel 40 may have a signal storage element such as capacitor Cst or other charge storage element. Storage capacitor Cst may be used to store signal Vp between frames (i.e., in the period of time between the assertion of successive signals G).

[0071] Display 14 may have a common electrode coupled to node 58. The common electrode (which is sometimes referred to as the Vcom electrode) may be used to distribute a common electrode voltage such as common electrode voltage Vcom to nodes such as node 58 in each pixel 40 of array 24. Capacitor Cst may be coupled between nodes 56 and 58. A parallel capacitance Clc arises across nodes 56 and 58 due to electrode structures in pixel 40 that are used in controlling the electric field through the liquid crystal material of the pixel (liquid crystal material 60). As shown in FIG. 6, electrode structures 62 may be coupled to node 56. Capacitance Clc is associated with the capacitance between electrode structures

62 and common electrode Vcom at node 58. During operation, electrode structures 62 may be used to apply a controlled electric field (i.e., a field having a magnitude proportional to Vp-Vcom) across a pixel-sized portion of liquid crystal material 60 in pixel 40. Due to the presence of storage capacitor Cst, the value of Vp (and therefore the associated electric field across liquid crystal material 60) may be maintained across nodes 56 and 58 for the duration of the frame.

[0072] The electric field that is produced across liquid crystal material 60 causes a change in the orientations of the liquid crystals in liquid crystal material 60. This changes the polarization of light passing through liquid crystal material 60. The change in polarization may be used in controlling the amount of light that is transmitted through each pixel 40 in array 34.

[0073] A portion of display 14 illustrating how changes in the light polarization produced by liquid crystal material 60 can be used to affect the amount of light that is transmitted through display 14 is shown in FIG. 7. As shown in FIG. 7, backlight structures 64 may be used to produce backlight 66 that travels upwards (outwards) in dimension Z through display layers 81 of display 14. Display layers 81 may include an upper polarizer layer such as layer 68 and a lower polarizer layer 74. Upper polarizer layer 68 may be attached to one or more substrate layers such as layer 70. Lower polarizer layer 74 may be attached to one or more substrate layers such as layer 72. Layers 70 and/or 72 may be formed from transparent layers such as layers of glass, plastic, or other sheets of material. Layers 70 and/or 72 and other layers of display 81 may include thin-film transistor layers, color filter layers, layers that include thin-film transistor structures and color filter elements, planarization layers, opaque masking patterns, clear layers, or other suitable display layers.

[0074] As light 66 passes through lower polarizer 74, lower polarizer 74 polarizes light 66. As polarized light 66 passes through liquid crystal material 60, liquid crystal material 60 may rotate the polarization of light 66 by an amount that is proportional to the electric field through liquid crystal material 60. If the polarization of light 66 is aligned in parallel with the polarization of polarizer 68, the transmission of light 66 through layer 68 will be maximized. If the polarization of light 66 is aligned so as to run perpendicular to the polarization of polarizer 68, the transmission of light 66 through layer 68 will be minimized (i.e., light 66 will be blocked). The display circuitry of FIG. 5 may be used in adjusting the voltages Vp across the electrodes 62 of display pixels 40 in display pixel array 34, thereby selectively lightening and darkening pixels 40 in pixel array 34 and presenting an image to a user of device 10 such as viewer 76, viewing display 14 in direction 78.

[0075] Displays such as display 14 may be mounted on one or more surfaces of device 10. For example, displays such as display 14 may be mounted on a front face of housing 12, on a rear face of housing 12, or on other portions of device 10.

[0076] As shown in FIG. 8, display 14 may be mounted in housing 12 so that some or all of the edges of display 14 overlap housing sidewalls 12'. Internal electrical components 82 (e.g., input-output components 30, control circuitry 32, etc.) may be mounted on one or more substrates such as substrate 80 within housing 12. Substrate 80 may be formed from one or more printed circuits. For example, substrate 80 may include a rigid printed circuit board (e.g., a printed circuit board formed from a material such as fiberglass-filled epoxy) and/or a flexible printed circuit ("flex circuit") such as

a printed circuit formed from patterned conductive traces on a sheet of polyimide or other flexible polymer.

[0077] If desired, some or all of the outermost surface of display 14 may be covered with a display cover layer such as display cover layer 84 of FIG. 9. Display cover layer 84 may be formed from a layer of glass, a layer of plastic, a layer of ceramic, or other suitable transparent materials. One or more additional display layers may also be included in display 14 if desired (e.g., antireflection films, scratch-resistance coating layers, fingerprint-reducing layers, layers that perform multiple functions such as reducing reflection, reducing scratches, and reducing fingerprints, etc.).

[0078] FIG. 10 is a cross-sectional view of device 10 in a configuration in which display 14 has been mounted between respective housing sidewalls 12' (i.e., without overlapping upper edges 12" of sidewalls 12'). FIG. 11 shows how display cover layer 84 may be used to cover display 14 in a configuration in which display 14 is mounted between housing sidewalls 12'.

[0079] The illustrative mounting arrangements of FIGS. 8, 9, 10, and 11 are merely illustrative examples of ways in which display 14 may be mounted in housing 12 of device 10. Other mounting configurations may be used if desired.

[0080] FIG. 12 is a cross-sectional view of display 14 showing how backlight structures 86 may be used in producing backlight 66 for display 14. As shown in FIG. 12, a light source such as light source 92 may produce light 94. Light source 92 may include, for example, one or more light-emitting diodes. Backlight structures 86 may include a light guide plate and other layers 88 (e.g., a diffuser and other optical films). A reflective layer such as reflector 90 may be placed on the rear surface of the light guide plate. As light 94 travels through the light guide plate, some of light 94 scatters upwards in direction Z towards viewer 76 and serves as backlight 66 for display 14. Light that scatters downwards may be reflected upwards by reflector 90 to serve as additional backlight 66.

[0081] Display layers 81 may include thin-film transistors such as transistor 52 of FIG. 6 and conductive structures (e.g., electrodes such as electrode 62, gate lines, data lines, and other lines and conductive structures formed from metal and/or indium tin oxide or other transparent conductive materials). Display layers 81 may also include color filter structures for imparting colors such as red, blue, and green colors to pixels 40 in pixel array 34. The color filter structures may be formed in an array (e.g., an array of alternating red, green, and blue color filter elements) and are therefore sometimes referred to as a color filter array or color filter array structures.

[0082] Color filter array structures may be formed using colored substances such as dye or pigment (e.g., colored red, blue, and green ink or materials of other suitable colors). Color filter structures may be formed by ink-jet printing, screen printing, pad printing, photolithographic patterning, or other suitable deposition and patterning techniques. Color filter structures may be formed on the same substrate as the thin-film transistors and conductive structures of display pixels 40 or may be formed separately (e.g., on a transparent substrate that is separated from a thin-film transistor substrate layer).

[0083] As shown in FIG. 13, thin-film transistor layer 108 may be formed on substrate 96. Each electrode 62 (i.e., each set of three common electrode finger structures in the example of FIG. 13) may be configured generate electric fields in liquid crystal material associated with a given pixel

40. If desired, color filter elements 116' of color filter layer 116 may be used to impart colors to backlight 66 generated by backlight structures 86 (FIG. 12). Color filter layer 116 may include lines of black matrix material 124.

[0084] Black matrix material 124 may be formed on one or more surfaces of color filter array 116 and may be configured to overlap structures in thin-film transistor layer 108 such as structures 126 (e.g., gate lines 44, data lines 42, etc.) and thereby block structures 126 from view. The thickness T of thin-film transistor layer 108 may be relatively small (e.g., less than 25 microns, less than 5 microns, less than 2 microns, etc.). One or more color filter layers 116 may be provided. If desired, a color filter array such as color filter array 116 may be formed on thin-film transistor layer 108. If desired, a layer of liquid crystal material such as liquid crystal layer 60 may be formed between color filter array 116 and thin-film transistor layer 108.

[0085] As shown in FIG. 14, color filter elements 116' in color filter array 116 may be separated by lines of opaque material (sometimes referred to as black matrix material or opaque masking material). The black matrix may be used to block metal lines and other structures from view by the user of device 10 and may help reduce light leakage between adjacent pixels. The black matrix may be formed from opaque organic or inorganic materials such as chrome and black ink (as examples).

[0086] The top view of color filter array 116 in FIG. 14 shows how black matrix 124 may form a grid of opaque masking lines on color filter layer 116 that visually separate respective color filter elements 116'. The width of the masking lines (shown as width W in FIG. 15) may be less than 50 microns, less than 30 microns, less than 20 microns, less than 15 microns, less than 10 microns, less than 7 microns, less than 3 microns, or any other suitable width. The lateral dimensions of color filter elements 116' may be 500 microns or less, 100 microns or less, 50 microns or less, or 25 microns or less (as examples). For example, rectangular color filter elements 116' in array 116 may be provided with pixel dimensions of 25 microns by 75 microns (as an example).

[0087] It may be desirable to reduce the magnitude of black matrix line width W relative to the lateral dimensions D of color filter elements 116' to improve display brightness (i.e., brightness efficiency). However, as shown in FIG. 15, a conventional display 100 having separators 101 between color filters 115 may provide a line of sight to an operating light source through a color filter associated with a non-operating light source. Conventional display 100 includes an array 103 of light sources associated with pixels 41 that are aligned with color filters 115.

[0088] While the light source associated with the green filter (g) is operating (ON), the light sources associated with the red filter (r) and the blue filter (b) are not operating (OFF). A viewer 113 viewing conventional display 100 along on-axis viewing angle 117 views the operating light source through the desired filter g. However, a viewer 111 viewing conventional display 100 along an off-axis viewing angle 121 will see the operating light source through the incorrect (r) filter, thereby reducing the quality of the content displayed using conventional display 100.

[0089] In order to prevent this type of color mixing display content degradation, device 10 may be provided with color mixing prevention structures. Consider, as an example, display 14 of FIG. 16. As shown in FIG. 16, color filter layer 116 may be provided color mixing prevention structures such as

black matrix material **124** that is formed at least partially on an interior surface of color filter elements **116'** of color filter array **116** on outer display layer **118**.

[0090] Color filter array (color filter layer) **116** may be formed on an inner surface (e.g., a surface that faces liquid crystal layer **60**) of transparent substrate layer **118**. Color filter layer **116** may include an array of color filter elements **116'** and a black matrix **124** having openings **142** for color filter elements **116'**. As shown in FIG. 16, a portion of array **116** of color filter elements **116'** may be interposed between black matrix **124** and the inner surface of layer **118**. If desired, a transparent planarization layer such as planarization layer **130** may be interposed between black matrix material **124** and color filter elements **116'**.

[0091] Viewer **76** may view display **14** through substrate **118** and color filter layer **116** by viewing in a direction such as direction **78**. (Polarizer layers, cover glass, backlight structures and other layers have been omitted from FIG. 16 for clarity). Backlight **66** passes through liquid crystal material **60**. Electrodes **62** are located in thin-film transistor layer **108** on substrate **96**, so the electric field that is produced in liquid crystal material **60** is strongest near layer **108** and is weakest near layer **118**. Color filter array **116** may be deposited on substrate **118**. Layer **118** may be formed from clear glass, clear plastic, or other transparent material.

[0092] In the FIG. 16 example, the red pixel "R" and the blue pixel "B" are not receiving signals on their respective electrodes **62**, so the liquid crystals **60'** in the portions of liquid crystal layer **60** that are associated with the R and B pixels have not been rotated. The electrode **62** that is associated with the green pixel "G" is, however, receiving a signal (in this example) and is therefore producing an electric field in an adjacent portion of layer **60**. As a result, liquid crystals **60'** above electrode **62** in the green pixel "G" are rotated.

[0093] When viewing the pixels of display **14** "on-axis" (i.e., along a direction that is parallel to the surface normal **n** for substrate **118**), backlight **66** will generally not leak appreciably into adjacent pixels and the pixel colors will tend not to bleed into each other. When, however, viewer **76** views display **14** along an off-axis angle such as the angle associated with direction **78** of FIG. 16, there is a risk that the viewer will view part of the liquid crystal material associated with one pixel through the color filter of another pixel. If not well controlled, this effect can reduce display performance by reducing color accuracy.

[0094] With a display of the type shown in FIG. 16, off-axis performance may be enhanced, because off-axis light rays that have the potential to cause interference are blocked by black matrix material **124** that is formed on the inner surface of color filter array **116**. When viewer **76** views display **14** along viewing axis **78**, viewer **76** will observe black matrix structures **124** blocking rotated liquid crystals **60'** associated with green pixel "G". In other words, light **66** that has travelled through rotated (i.e., "on") liquid crystals **60'** toward red ("R") color filter element **116'** is blocked by black matrix material **124**.

[0095] A viewer observing the center of the green pixel "on-axis" will therefore correctly observe that the green pixel is emitting green filtered backlight **66** and has a green color. When viewer **76** views display **14** along viewing axis **78**, however, viewer **76** will only observe black matrix **124**. The red pixel "R" in FIG. 16 will therefore correctly appear "off" (e.g., the red pixel's liquid crystals **60'** have not been rotated,

so the viewer should not be observing any red light through the red color filter element **116'**).

[0096] The enhanced blocking for display **14** of color bleeding between adjacent pixels may be exploited to enhance color accuracy and/or to reduce the width of black matrix **124** and thereby improve display brightness efficiency.

[0097] The example of FIG. 16 is merely illustrative. If desired, color filter array **116** may be formed on thin-film transistor layer **108**. If desired, a color filter array **116** that is formed on thin-film transistor layer **108** may include a black matrix **124** over an interior surface of at least a portion of color filter layer. If desired, a color filter layer **116** and/or a black matrix **124** may be formed on both layer **108** and layer **118**. In configurations in which a color filter layer **116** is formed on both layer **108** and layer **118**, the thickness of each color filter layer may be equal, the thickness of the color filter layer on layer **118** may be larger than the thickness of the color filter layer on layer **108**, or the thickness of the color filter layer on layer **118** may be smaller than the thickness of the color filter layer on layer **108**.

[0098] As shown in FIGS. 17, 18, and 19, black matrix material **124** may be an organic opaque polymer that is formed over at least a portion of color filter elements **116'**. In the examples of FIGS. 17, 18, and 19, color filter elements **116'** are formed on a transparent substrate layer **119**. Transparent substrate layer **119** may be formed from clear glass, plastic, or any other suitable transparent substrate. Transparent substrate layer **119** may be, as examples, an outer display layer such as layer **118** or an inner display layer such as combined layers **96** and **108** of FIG. 16.

[0099] As shown in the example of FIG. 17, individual color filter elements **116'** that have a lateral separation from each other may be formed on layer **119**. Layer **119** may have an inner surface **138** and an outer surface **140**. Inner surface **138** may, for example, be a surface of layer **119** that is closer to a liquid crystal layer such as liquid crystal layer **60** (see, e.g., FIG. 16) than outer surface **140**. Black matrix material **124** may be partially formed on color filter elements **116'** and partially formed on inner surface **138**.

[0100] Regions such as regions **148** of black matrix material **124** may be formed directly on inner surface **138** of layer **119** without any interposed color filter elements. Regions **150** of black matrix material **124** may be formed on portions **144** of array **116** of color filter elements **116'** that are interposed between black matrix **124** and inner surface **138** of layer **119**.

[0101] Black matrix **124** may include openings such as openings **142**. Color filter elements **116'** may be formed in openings **142** so that portions **146** of color filter elements **116'** may pass light of a corresponding color. Color filter elements **116'** may be characterized by a first thickness **152** on inner surface **138**. Black matrix layer **124** may be characterized by a second thickness **154** on inner surface **138** that is greater than thickness **152**. However, this is merely illustrative. If desired, thickness **154** may be substantially the same as thickness **152** or may be smaller than thickness **152**.

[0102] A planarization layer such as layer **130** may be formed over some or all of opaque masking layer **124** and color filter elements **116'**. Planarization layer **130** may be formed from a layer of silicon oxide, silicon nitride, silicon oxynitride, an organic material such as acrylic, other transparent planarizing materials, or a combination of two or more of these materials. Layer **130** may be deposited by screen printing, spin-on coating, spray coating, physical vapor depo-

sition, chemical vapor deposition, or other suitable deposition techniques. If desired, layer 130 may be polished to help planarize layer 130.

[0103] If desired, black matrix 124 may include protruding portions (indicated by dashed lines 136) that extend beyond color filter elements 116' to form extended barriers to light at off-axis viewing angles. Protruding portions 136 may be rounded, may be triangular, may be rectangular, may have faceted edges, or may have any other suitable shape for blocking off-axis light.

[0104] During manufacturing of device 10, a first set of color filter elements 116' (e.g., green color filter elements 116') may be formed on layer 119 by, for example, providing a coating of a first color photoresist (e.g., a photoresist material that is configured to pass green light) on inner surface 138, providing a patterned ultraviolet (UV) light mask on the color photoresist material, etching the color photoresist material using UV light, and removing the UV mask.

[0105] A subsequent set of color filter elements 116' (e.g., red color filter elements 116') may then be formed on layer 119 by, for example, providing a second coating of a color photoresist (e.g., a photoresist material that is configured to pass red light) on inner surface 138 and remaining portions of the first color photoresist material, providing a second patterned UV mask on the second color photoresist material, etching the second color photoresist material using UV light, and removing the UV mask. Additional sets of color filter elements 116' (e.g., blue color filter elements, or other color filter elements) may then be formed on substrate layer 119 by repeating the steps of providing a color photoresist, providing a UV mask, etching the color photoresist, and removing the UV mask.

[0106] Black matrix 124 may then be formed over portions 144 of color filter layer 116 and on portions of inner surface 138 by providing a coating of black matrix material over color filter elements 116' and on exposed portions of inner surface 138 of layer 119, providing a patterned UV mask on the coating of black matrix material 124, etching openings 142 into black matrix material 124 and removing the UV mask.

[0107] Other steps may be involved in forming color filter elements 116' and black matrix 124 such as baking steps (e.g., soft baking and hard baking), deposition steps (e.g., screen printing, spin-on coating, spray coating, physical vapor deposition, and chemical vapor deposition) or other suitable steps. The steps described in connection with FIG. 17 are merely illustrative.

[0108] The example of FIG. 17 in which color filter elements 116' of color filter array 116 are spatially separated and black matrix material 124 is formed in contact with inner surface 138 is merely illustrative. As shown in the example of FIG. 18, individual color filter elements 116' may be formed on layer 119 so that each individual color filter element 116' partially overlaps a portion of an adjacent color filter element 116' of a different color. Black matrix material 124 may be formed over color filter elements 116' so that a portion of black matrix material 124 is formed over overlapping portions of color filter elements 116'.

[0109] In the example of FIG. 18, portion 144 of color filter array 116 that is covered by black matrix 124 may include overlapping portions of color filter elements 116' while portion 150 of black matrix 124 that is formed on color filter elements 116' may include substantially all of black matrix

124 (i.e., black matrix 124 may be formed on color filter elements 116' without touching inner surface 138 of layer 119).

[0110] As with the example of FIG. 17, in the example of FIG. 18, planarization layer 130 is formed over opaque masking layer 124 and color filter elements 116'.

[0111] During manufacturing of device 10, a first set of color filter elements 116' (e.g., red color filter elements 116') may be formed on layer 119 by, for example, providing a coating of a first color photoresist (e.g., a photoresist material that is configured to pass red light) on inner surface 138, providing a patterned ultraviolet (UV) light mask on the color photoresist material, etching the color photoresist material using UV light, and removing the UV mask.

[0112] A subsequent set of color filter elements 116' (e.g., green color filter elements 116') may then be formed on layer 119 by, for example, providing a second coating of a color photoresist (e.g., a photoresist material that is configured to pass green light) on inner surface 138 and remaining portions of the first color photoresist material, providing a second patterned UV mask on the second color photoresist material, etching the second color photoresist material using UV light so that a portion of the second color photoresist material remains on a portion of the first color photoresist material, and removing the UV mask.

[0113] Additional sets of color filter elements 116' (e.g., blue color filter elements, or other color filter elements) may then be formed on substrate layer 119 by repeating the steps of providing a color photoresist, providing a UV mask, etching the color photoresist, and removing the UV mask.

[0114] Black matrix 124 may then be formed over portions 144 of color filter layer 116 by providing a coating of black matrix material 124 over color filter elements 116', providing a patterned UV mask on the coating of black matrix material 124, etching openings 142 into black matrix material 124, and removing the UV mask.

[0115] Other steps may be involved in forming color filter elements 116' and black matrix 124 such as baking steps (e.g., soft baking and hard baking), deposition steps (e.g., screen printing, spin-on coating, spray coating, physical vapor deposition, and chemical vapor deposition) or other suitable deposition steps. The steps described in connection with FIG. 18 are merely illustrative.

[0116] The example of FIG. 18 in which color filter elements 116' of color filter array 116 are partially overlapping is merely illustrative. As shown in FIG. 19, array 116 of color filter elements 116' may form a contiguous array of color filter elements 116' of different colors having adjoining edges 156. Black matrix 124 may be configured to cover adjoining edges 156. Color filter elements 116' having adjoining edges 156 may be interposed between substantially all of black matrix 124 and inner surface 138 of layer 119 (i.e., region 150 of black matrix 124 may include substantially all of black matrix 124 so that black matrix 124 is formed on color filter array 116 and without touching inner surface 138 of layer 119).

[0117] The examples of FIGS. 17, 18, and 19 in which black matrix material 124 is formed from an organic opaque polymer that is formed over at least a portion of color filter elements 116' and covered by planarization layer 130 are merely illustrative. If desired, planarization layer 130 may be interposed between black matrix 124 and color filter elements 116' as shown in FIGS. 20 and 21.

[0118] In configurations in which planarization layer 130 is interposed between black matrix 124 and color filter elements

116', black matrix **124** may be formed from thin patterned inorganic material such as a layer of patterned metal (e.g., chrome) or other inorganic material. A black matrix **124** that is formed from a thin patterned metal layer may have a thickness **T**. Thickness **T** may be (as examples) between 1-25 microns, 1-10 microns, less than 10 microns, less than 5 microns, less than 3 microns, less than 2 microns, or less than 1 micron.

[0119] As shown in FIG. 20, individual color filter elements **116'** that are formed on layer **119** may have a lateral separation from each other. Planarization layer **130** may be formed on color filter elements **116'** and on portions of inner surface **138** in gaps between color filter elements **116'** (i.e., some of planarization layer **130** may be interposed between color filter elements **116'** in array **116** of color filter elements). Black matrix material **124** may be formed on planarization layer **130** over gaps between color filter elements **116'**. Openings **142** in black matrix **124** may be aligned with color filter elements **116'** so that color filter elements **116'** that are formed in openings **142** may pass light of a corresponding color.

[0120] If desired, some of color filter elements **116'** formed on layer **119** may have a portion that partially overlaps a portion of an adjacent color filter element **116'** of a different color. Planarization layer **130** may be formed over color filter elements **116'** so that raised overlapping portions of color filter array **116** may be covered by a planar layer. Black matrix material **124** may be formed on planarization layer over color filter elements **116'** so that a portion of black matrix material **124** is formed on planarization layer **130** over overlapping portions of color filter elements **116'**.

[0121] During manufacturing of display **14**, color filter elements **116'** of FIGS. 20 and 21 may be formed using some or all of the illustrative steps described above in connection with FIGS. 17 and 18, respectively. Planarization layer **130** may then be deposited over color filter elements **116'**. Black matrix **124** may then be formed on planarization layer **130** by providing a coating of black matrix material **124** on planarization layer **130**, providing a patterned UV mask on the coating of black matrix material **124**, etching openings **142** into black matrix material **124** and removing the UV mask.

[0122] The examples of FIGS. 20 and 21 in which planarization layer **130** is interposed between color filter array **116** and a patterned metal black matrix **124** is merely illustrative. As shown in FIG. 21, a patterned metal black matrix **124** may be formed directly on color filter elements **116'** so that patterned metal black matrix **124** covers adjoining edges **156** of adjacent color filter elements **116'** and color filter elements **116'** are interposed between substantially all of black matrix **124** and inner surface **138** of layer **119**.

[0123] During manufacturing of display **14**, color filter elements **116'** of FIG. 22 may be formed using some or all of the illustrative steps described above in connection with FIGS. 17 and/or 18. Black matrix **124** may then be formed on color filter elements **116'** by providing a coating of black matrix material **124** over color filter elements **116'**, providing a patterned UV mask on the coating of black matrix material **124**, etching openings **142** into black matrix material **124** and removing the UV mask.

[0124] Black matrix **124** and color filter layer **116** may be formed on outer display layer **118** (see, e.g., FIG. 16) in any of the configurations described above in connection with FIG. 17, 18, 19, 20, 21, or 22, or in any combination of those configurations.

[0125] As shown in FIG. 23, display **14** may be provided with multiple color filter layers. Color filter layers such as color filter layers **116-1** and **116-2** may be formed on opposing sides of liquid crystal layer **60**. Color filter layers **116-1** and **116-2** may, if desired, each be provided with black matrix material **124**.

[0126] Black matrices **124-1** and **124-2** may be formed on color filter layers **116-1** and **116-2** respectively in any of the configurations described above in connection with FIGS. 17, 18, 19, 20, 21, or 22, or in any combination of those configurations.

[0127] In the example of FIG. 23, color filter layer **116-1** is formed on transparent substrate layer **118** and color filter layer **116-2** is formed over layer **108** on transparent substrate layer **96**. In this way, backlight **66** may pass through both layers **116-1** and **116-2** as backlight **66** passes through display **14**.

[0128] Viewer **76** may view display **14** through substrate **118** and color filter layers **116-1** and **116-2** by viewing in a direction such as direction **78**. (Polarizer layers, cover glass, backlight structures and other layers have been omitted from FIG. 23 for clarity). In configurations in which color filter elements **116'** are formed on both the inner display layer (e.g., thin-film transistor layer **108** and transparent substrate layer **96**) and the outer display layer (e.g., transparent substrate layer **118**), black matrix **124-1** may include openings **142** for color filter elements **116'** of array **116-1** and black matrix **124-2** may have openings **142** for color filter elements **116'** of array **116-2**.

[0129] In the example of FIG. 23, openings **142** in both black matrix **124-1** and black matrix **124-2** are completely filled with color filter elements **116'** of array **116-1** and **116-2** respectively. However, this is merely illustrative. As shown in FIG. 24, if desired, openings **142** of black matrix **124-1** on array **116-1** may be completely filled with color filter elements **116'** of array **116-1** and black matrix openings **142** of black matrix **124-2** may be partially filled with color filter elements **116'** of array **116-2**. Each color filter element **116'** of array **116-2** may have a central opening within one of openings **142**. As shown in FIG. 25, if desired, openings **142** of black matrix **124-1** on array **116-1** may be partially filled with color filter elements **116'** of array **116-1** and black matrix openings **142** of black matrix **124-2** may be completely filled with color filter elements **116'** of array **116-2**. Each color filter element **116'** of array **116-1** may have a central opening within one of openings **142**.

[0130] As shown in FIG. 26, display **14** may be provided with a single color filter array **116** on substrate **118** and a light collimating layer such as collimator **160** on transparent substrate **96**. Substrate **96** may have opposing first and second surfaces **97** and **95**. Thin-film transistor layer **108** may be formed on first surface **97** of substrate **96**. Light collimating layer **160** may be formed on opposing second surface **95** of substrate **96**. In this way, display **14** may be configured to redirect backlight **66** that is emitted in an off-axis direction such as one of directions **162** onto an on-axis path so that light that passes through liquid crystal layer **60** forms a collimated beam of light with minimal off-axis components.

[0131] Collimating layer **160** may be formed from, as examples, collimating structures such as Fresnel lens structures, microlens structures, or structures containing an array of micropisms that generates multiple internal reflections of light that is received from off-axis directions and re-transmits that light after an internal reflection into an on-axis direction.

[0132] The arrangement of FIG. 26 is merely illustrative. In configurations in which display 14 is provided with a collimating layer such as collimating layer 160 on substrate 96, color filter array 116 may, if desired, be formed on thin-film transistor layer 108 as shown in FIG. 27.

[0133] If desired, color filter elements 116' of color filter arrays 116 (including arrays 116-1 and 116-2 of FIGS. 23, 24, and 25) may each be formed from a common color filter material or, if desired, some of color filter elements 116' may be formed from one or more different color filter materials. As an example, color filter array 116-2 on thin-film transistor layer 108 may include one or more color filter elements 116C that are formed from a different material than the material used to form color filter elements 116' as shown in FIG. 28.

[0134] In the example of FIG. 28, color filter elements 116C may be formed from a multilayer dielectric stack that includes materials with different indices of refraction configured to form an optical filter that selectively reflects some colors of light while reflecting other colors of light. Color filter elements 116C may, for example, be cholesteric color filter elements formed from chiral nematic materials or other wavelength-dependent reflective materials that are configured to reflect selected colors of light. As shown in FIG. 28 as an illustrative example, green "G" color filter element 116C may reflect red light 66R and blue light 66G and to pass green light 66G. Similarly, red "R" color filter element 116C may be configured to reflect green light and blue light while passing red light and blue "B" color filter element 116C may be configured to reflect green light and red light while passing blue light.

[0135] As shown in FIG. 29, a color filter layer such as color filter array 116-1 on substrate 118 may be formed free of black matrix material. In configurations in which color filter array 116-1 on substrate 118 is formed free from black matrix material, at least some of interconnect lines 126 may be embedded within black matrix 124-3 that is part of a color filter layer such as color filter array 116-2 on thin-film transistor layer 108. Black matrix 124-3 may include openings 142 for the color filter elements 116' of array 116-2. If desired, black matrix 124-3 may have an inner surface that is coplanar with color filter elements 116' of array 116-2 (as indicated by dashed lines 170) or black matrix 124-2 may have an inner surface that is formed in a different plane from color filter elements 116' of array 116-2.

[0136] Black matrices 124 and color filter layers 116 of FIGS. 24, 25, 26, 27, 28 and 29 may be formed having any of the configurations described above in connection with FIG. 17, 18, 19, 20, 21, or 22, or in any combination of those configurations.

[0137] The foregoing is merely illustrative of the principles of this invention and various modifications can be made by those skilled in the art without departing from the scope and spirit of the invention.

What is claimed is:

1. A display, comprising:

a transparent substrate layer; and

a color filter layer comprising a first color filter element formed on the transparent substrate layer and a second color filter element formed on the transparent substrate layer, wherein a portion of the first color filter element is interposed between a portion of the second color filter element and the transparent substrate layer.

2. The display defined in claim 1, wherein the first color filter element and the second color filter element each contact the transparent substrate layer.

3. The display defined in claim 1, further comprising:

an opaque masking material formed over the portion of the second color filter element such that the portion of the second color filter element is interposed between the portion of the first color filter element and the opaque masking material.

4. The display defined in claim 3, wherein the opaque masking material is formed directly on the first color filter element and the second color filter element.

5. The display defined in claim 4, wherein the first color filter element and the second color filter separate the black masking material from the transparent substrate layer.

6. The display defined in claim 1, wherein the first color filter element transmits light of a first color and wherein the second color filter element transmits light of a second color that is different than the first color.

7. The display defined in claim 6, wherein the color filter layer further comprises:

a third color filter element formed on the transparent substrate layer, wherein an additional portion of the second color filter element is interposed between a portion of the third color filter element and the transparent substrate layer, and wherein the third color filter element transmits light of a third color that is different than the first color and the second color.

8. A display, comprising:

a transparent display substrate;

a color filter layer having adjacent first and second color filter elements formed on the transparent display substrate, wherein a portion of the first color filter element overlaps the second color filter element; and

opaque masking material formed over the portion of the first color filter element that overlaps the second color filter element.

9. The display defined in claim 8, wherein the opaque masking material is formed directly on the first and second color filter elements.

10. The display defined in claim 9, wherein the first and second color filter elements separate the opaque masking material from the transparent display substrate.

11. The display defined in claim 8, further comprising a planarization layer formed over the first and second color filter elements and the opaque masking material.

12. The display defined in claim 11, wherein the opaque masking material comprises protrusions that extend into the planarization layer.

13. The display defined in claim 12, wherein the protrusions are selected from the group consisting of:

rounded protrusions, triangular protrusions, and protrusions with faceted edges.

14. A display, comprising:

a first transparent substrate having an inner surface and an outer surface;

a second transparent substrate;

a layer of liquid crystal material formed between the first transparent substrate and the second transparent substrate;

a color filter layer formed on the inner surface of the first transparent substrate, the color filter layer including a plurality of partially overlapping color filter elements; and

a black matrix formed over the plurality of partially overlapping color filter elements.

15. The display defined in claim **14**, wherein the inner surface is interposed between the outer surface and the layer of liquid crystal material.

16. The display defined in claim **14** further comprising:
an array of thin-film transistors formed on the second transparent substrate.

17. The display defined in claim **14**, wherein the plurality of partially overlapping color filter elements includes at least one color filter element having an edge that is interposed between an adjacent second color filter element and the inner surface of the first transparent substrate.

18. The display defined in claim **17**, wherein the second color filter element is interposed between the edge of the first color filter element and the black matrix.

19. The display defined in claim **14**, further comprising:
a planarization layer formed over the black matrix and the color filter layer.

20. The display defined in claim **19**, wherein the black matrix includes openings, and wherein the planarization layer is formed directly on the color filter layer in the openings.

* * * * *

专利名称(译)	显示颜色混合预防结构		
公开(公告)号	US20150227000A1	公开(公告)日	2015-08-13
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摘要(译)

电子设备可以具有液晶显示器，该液晶显示器具有背光和混色防止结构。防混色结构可以部分地由一个或多个滤色器元件阵列形成。液晶显示器可包括在液晶层的相对侧上的第一和第二透明基板层。显示器可包括第一透明基板层上的第一滤色器元件阵列和第二透明基板层上的第二滤色器元件阵列。一个或多个滤色器元件阵列可包括在滤色器元件的部分上形成的黑色矩阵。滤色器元件可以填充或部分填充黑色矩阵中的开口。显示器可以包括在第二透明基板层上的准直层。滤色器元件可包括胆甾型滤色器元件。

