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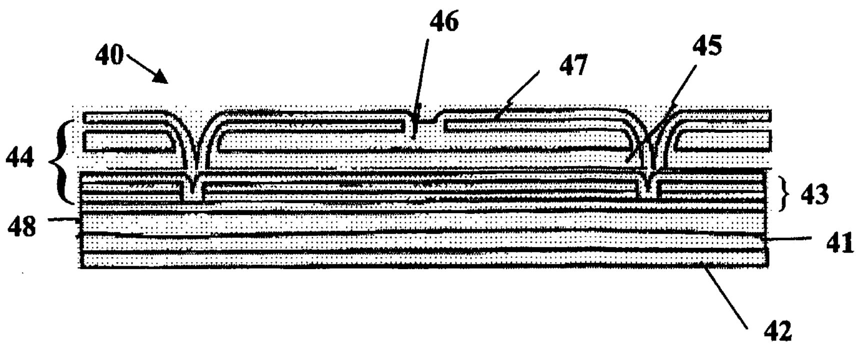
(54) **Title:** SPATIAL LIGHT MODULATOR WITH INTEGRATED OPTICAL STRUCTURE




(57) **Abstract:** A spatial light modulator comprises an integrated optical compensation structure, e.g., an optical compensation structure arranged between a substrate and a plurality of individually addressable light-modulating elements, or an optical compensation structure located on the opposite side of the light-modulating elements from the substrate. The individually addressable light-modulating elements are configured to modulate light transmitted through or reflected from the transparent substrate. Methods for making such spatial light modulators involve fabricating an optical compensation structure over a substrate and fabricating a plurality of individually addressable light-modulating elements over the optical compensation structure. The optical compensation structure may be a passive optical compensation structure. The optical compensation structure may include one or more of a supplemental front-lighting source, a diffuser, a black mask, a diffractive optical element, a color filter, an anti-reflective layer, a structure that scatters light, a microlens array, and a holographic film.

WO 2005/076051 A1

# SPATIAL LIGHT MODULATOR WITH INTEGRATED OPTICAL COMPENSATION STRUCTURE

## Cross-Reference to Related Applications

**[0001]** This application is a continuation of U.S. Patent Application No. 11/036,965, filed January 14, 2005, which claims priority to U.S. Provisional Patent Application Serial No. 60/541,607, filed February 3, 2004; U.S. Provisional Patent Application Serial No. 60/613,482, filed September 27, 2004; U.S. Provisional Patent Application Serial No. 60/613,536, filed September 27, 2004; and U.S. Provisional Patent Application Serial No. 60/613,542, filed September 27, 2004.

## Background

### Field of the Invention

**[0002]** This invention relates to improvements in the manufacturing and performance of spatial light modulators such as interferometric modulators.

### Description of the Related Art

**[0003]** Spatial light modulators are display devices that contain arrays of individually addressable light modulating elements. Examples of spatial light modulators include liquid crystal displays and interferometric modulator arrays. The light modulating elements in such devices typically function by altering the characteristics of light reflected or transmitted through the individual elements, thus altering the appearance of the display.

## Summary

**[0004]** As spatial light modulators become increasingly sophisticated, the inventor anticipates that difficulties associated with fabricating them by current manufacturing process flows will also increase. Accordingly, the inventor has developed spatial light modulators having integrated optical compensation structures and methods for making them.

**[0005]** An embodiment provides a spatial light modulator that includes a substrate; a plurality of individually addressable light-modulating elements arranged over the substrate and configured to modulate light; and an optical compensation structure; wherein the optical compensation structure is arranged between the substrate and the plurality of individually addressable light-modulating elements. In certain embodiments, the optical compensation structure is a passive optical compensation structure.

**[0006]** An embodiment provides a spatial light modulator that includes a substrate; a plurality of individually addressable light-modulating elements arranged over the substrate and configured to modulate light; and an optical compensation structure; wherein the plurality of individually addressable light-modulating elements is arranged between the substrate and the optical compensation structure. The optical compensation structure comprises at least one of a color filter, black mask, and anti-reflective layer.

[0007] Another embodiment provides a method of making a spatial light modulator that includes fabricating an optical compensation structure over a transparent substrate; and fabricating a plurality of individually addressable light-modulating elements over the optical compensation structure, the individually addressable light-modulating elements being configured to modulate light transmitted through the transparent substrate. In certain embodiments, fabricating the optical compensation structure includes fabricating a passive optical compensation structure.

[0008] Another embodiment provides a method of making a spatial light modulator that includes fabricating a plurality of individually addressable light-modulating elements over a substrate; and fabricating an optical compensation structure over the plurality of individually addressable light-modulating elements, the individually addressable light-modulating elements being configured to modulate light transmitted through the optical compensation structure. The optical compensation structure comprises at least one of a color filter, mask, and anti-reflective layer.

[0009] Another embodiment provides a spatial light modulator that includes a transparent substrate; a plurality of individually addressable interferometric light-modulating elements arranged over the transparent substrate and configured to modulate light transmitted through the transparent substrate, the interferometric light-modulating elements comprising a cavity and a movable wall; and at least one optical compensation structure arranged between the transparent substrate and the plurality of individually addressable interferometric light-modulating elements, the optical compensation structure comprising a color filter or diffuser.

[0010] Another embodiment provides a spatial light modulator that includes a substrate; a means for modulating light transmitted through or reflected from the substrate; and a means for compensating the light transmitted through or reflected from the substrate; wherein the means for compensating the light is operatively arranged between the substrate and the means for modulating light transmitted through or reflected from the substrate. In certain embodiments, the means for compensating the light transmitted through or reflected from the substrate is a means for passively compensating the light transmitted through or reflected from the substrate.

[0011] Another embodiment provides a spatial light modulator that includes a substrate; a means for modulating light transmitted through or reflected from the substrate; and a means for compensating the light transmitted through or reflected from the substrate; wherein the means for modulating light transmitted through or reflected from the substrate is operatively arranged between the substrate and the means for compensating the light. The means for compensating the light transmitted through or reflected from the substrate comprises at least one of a color filter, black mask, and anti-reflective layer.

[0012] Another embodiment provides a spatial light modulator made by a method that includes fabricating an optical compensation structure over a transparent substrate; and fabricating a plurality of individually addressable light-modulating elements over the optical compensation structure, the individually addressable light-modulating elements being configured to modulate light transmitted through the transparent substrate.

[0013] Another embodiment provides a spatial light modulator made by a method that includes fabricating a plurality of individually addressable light-modulating elements over a substrate; and fabricating an optical compensation structure over the plurality of individually addressable light-modulating elements, the individually addressable light-modulating elements being configured to modulate light transmitted through the optical compensation structure. The optical compensation structure comprises at least one of a color filter, black mask, and anti-reflective layer.

[0014] Other embodiments described herein may also provide for simplified fabrication in some cases.

[0015] In another embodiment, a display region comprises a black and white light-modulating element and a color filter. The black and white light-modulating element includes first and second reflective surfaces and a cavity therebetween. The second surface is movable with respect to the first surface. The color filter is configured to transmit colored light when illuminated with white light. The color filter is positioned with respect to the light-modulating element such that light output from the light-modulating element is filtered by the color filter.

[0016] The black and white light-modulating element may comprise a black and white interferometric modulator. The black and white light-modulating element may be included in an array of other light-modulating elements such as other black and white modulating elements. Additional color filters, possibly in an array, may also be included. Color filters with different responses may be used for different light-modulating elements to yield different colors (e.g., red, green, and blue).

[0017] In another embodiment, a display region comprises a plurality of light-modulating elements that includes first and second reflective surfaces and a cavity therebetween. The second surface is movable with respect to the first surface. The display region further comprises a plurality of color filter elements configured to transmit a narrower range of wavelengths when illuminated with a broader range of wavelengths. The color filter elements are positioned with respect to the light-modulating elements such that light output from the light-modulating elements is filtered by the color filter elements. The first reflective surface is separated from the second reflective surface by a substantially equal distance for each of the plurality of light-modulating elements when the light-modulating elements output light (e.g., white light).

[0018] The light-modulating elements may comprise black and white light-modulating elements. The light-modulating elements may comprise interferometric modulators or other types of modulators. The light-modulating elements may output light when in, for example, a reflective state.

[0019] The plurality of color filter elements may include two or three or more color filter elements configured to produce different color output (e.g., red, green, blue). The color filter elements may comprise material (e.g., dyed material like dyed photoresist) that transmits a narrower range of wavelengths when illuminated with a broader range of wavelengths. In various embodiments, this material may transmit color light when illuminated with white light.

[0020] In another embodiment, a display region comprises a plurality of light-modulating elements and a color filter array. Each of the light-modulating elements includes first and second reflective surfaces and a cavity therebetween. The second surface is movable with respect to the first surface. The color filter array includes a plurality of color filter elements configured to transmit a narrower range of wavelengths when illuminated with a broader range of wavelengths. The color filter array is positioned with respect to the light-modulating elements such that light output from the light-modulating elements is filtered by the color filter elements. The first reflective surface is separated from the second reflective surface by a substantially equal distance for each of the plurality of light-modulating elements when the light-modulating elements output light (e.g., white light). At least two of the color filter elements are configured to produce different color output.

[0021] Another embodiment includes a method of manufacturing a display device. In this method, a black and white light-modulating element is provided. The black and white light-modulating element that is provided includes first and second optical surfaces, wherein the second optical surface is movable with respect to the first optical surface. A color filter is positioned with respect to the light-modulating element so that white light output from the light-modulating element is filtered by the color filter. The color filter is configured to transmit colored light when illuminated with white light.

[0022] The black and white light-modulating element may comprise a black and white interferometric modulator. The black and white light-modulating element may be included in an array of other light-modulating elements such as other black and white modulating elements. Additional color filters, possibly in an array, may also be included. Color filters with different responses may be used for different light-modulating elements to yield different colors (e.g., red, green, and blue).

[0023] Another embodiment includes a method of manufacturing a display region. In this method, a plurality of light-modulating elements each including first and second optical surfaces and a cavity therebetween are provided. The first reflective surface is separated from the second reflective surface by a substantially equal distance for each of the plurality of light-modulating elements when the light-modulating elements output light. Color filter elements are positioned with respect to the light-modulating elements so that light output from the light-modulating elements is filtered by respective color filter elements. In various embodiments, the color filter elements may include material configured to transmit a narrow range of wavelengths when illuminated with a broad range of wavelengths. In certain embodiments, the color filter elements are included in an array. The array may include at least two color filter elements configured to produce different color output.

**[0024]** The light-modulating elements may comprise black and white light-modulating elements. The light-modulating elements may comprise interferometric modulators or other types of modulators. The light-modulating elements may output light when in, for example, a reflective state.

**[0025]** The plurality of color filter elements may include two or three or more color filter elements configured to produce different color output (e.g., red, green, blue). The color filter elements may comprise material such as a dyed material like dyed photoresist. The material may transmit color when illuminated with white light.

**[0026]** Another embodiment includes a display device comprising means for producing a modulated white light signal including first and second optical surfaces, wherein the second optical surface is movable with respect to the first optical surface. The display device further comprises means for filtering the modulated white light signal so as to transform the white light signal into a colored light signal.

**[0027]** These and other embodiments are described in greater detail below.

<u>Brief Description of the Drawings</u>

**[0028]** These and other aspects of the invention will be readily apparent from the following description and from the appended drawings, which are meant to illustrate and not to limit the invention, and wherein:

**[0029]** Figures 1A and 1B illustrate some characteristics of a typical interferometric modulator (see Figures 1A and 1B of U.S. Patent Publication No. 2002/0126364 A1).

**[0030]** Figure 2 illustrates some characteristics of a typical interferometric modulator (see Figure 2 of U.S. Patent Publication No. 2002/0126364 A1).

**[0031]** Figures 3A – 3F illustrate optical compensation films fabricated on the opposite surface of the substrate from which an array of light modulating elements resides (see Figure 6A – 6F of U.S. Patent Publication No. 2002/0126364 A1).

**[0032]** Figure 4 illustrates an optical compensation film (diffuser) fabricated on the opposite surface of the substrate from which a light modulating element resides.

[0033] Figures 5A to 5C illustrate various embodiments of spatial light modulators comprising integrated optical compensation structures.

[0034] Figure 6 illustrates an embodiment of a spatial light modulator comprising an integrated optical compensation structure that scatters light.

[0035] Figures 7A and 7B illustrate various embodiments of spatial light modulators comprising integrated optical compensation structures.

[0036] Figure 8 illustrates an embodiment of a manufacturing process flow diagram for making spatial light modulators comprising integrated optical compensation structures.

[0037] Figure 9 illustrates an embodiment of a spatial light modulator comprising an integrated optical compensation structure.

## Detailed Description of Preferred Embodiments

[0038] A preferred embodiment is an interferometric modulator that includes at least one integrated optical compensation structure. In some configurations, the optical compensation structure is arranged between the substrate and the light-modulating elements of the interferometric modulator. In other configurations, the light-modulating elements are arranged between the substrate and the optical compensation structure.

[0039] Various examples of interferometric modulators are described in U.S. Patent Publication No. 2002/0126364 A1. Figures 1 and 2 illustrate some characteristics of a typical interferometric modulator (see Figures 1 and 2 of U.S. Patent Publication No. 2002/0126364 A1 and the corresponding text). Referring to Figures 1A and 1B, two interferometric modulator structures **114** and **116** each include a secondary mirror **102** with a corrugated pattern **104** etched into its upper (outer) surface **103**, using any of a variety of known techniques. The corrugation does not extend through the membrane **106** on which the mirror is formed so that the inner surface **108** of the mirror remains smooth. Figure 1B reveals the pattern of etched corrugation **104** on the secondary mirror and the smooth inner surface **112** which remains after etch. The corrugated pattern, which can be formed in a variety of geometries (e.g., rectangular, pyramidal, conical), provides structural stiffening of the mirror, making it more immune to variations in material stresses, reducing total mass, and preventing deformation when the mirror is actuated.

[0040] In general, an interferometric modulator which has either no voltage applied or some relatively steady state voltage, or bias voltage, applied is considered to be in a quiescent state and will reflect a particular color, a quiescent color. As referenced in U.S. Patent Publication No. 2002/0126364 A1, the quiescent color is determined by the thickness of the sacrificial spacer upon which the secondary mirror is fabricated.

[0041] Each interferometric modulator **114**, **116** is rectangular and connected at its four corners to four posts **118** via support arms such as **120** and **122**. In some cases (see discussion in U.S. Patent Publication No. 2002/0126364 A1), the interferometric modulator array will be operated at a selected constant bias voltage. In those cases, the secondary mirror **102** will generally maintain a quiescent position which is closer to corresponding primary mirror **128** than without any bias voltage applied. The fabrication of interferometric modulators with differently sized support arms allows for the mechanical restoration force of each interferometric modulator to be determined by its geometry. Thus, with the same bias voltage applied to multiple interferometric modulators, each interferometric modulator may maintain a different biased position (distance from the primary mirror) via control of the dimensions of the support arm and its resulting spring constant. The thicker the support arm is, the greater its spring constant. Thus different colors (e.g., red, green, and blue) can be displayed by different interferometric modulators without requiring deposition of different thickness spacers. Instead, a single spacer, deposited and subsequently removed during fabrication, may be used while color is determined by modifying the support arm dimensions during the single photolithographic step used to define the arms. For example, in Figure 2, interferometric modulators **114, 116** are both shown in quiescent states with the same bias voltage applied. However, the gap spacing **126** for interferometric modulator **114** is larger than gap spacing **128** for interferometric modulator **116** by virtue of the larger dimensions of its respective support arms. Various other examples of interferometric modulators are also known.

**[0042]** U.S. Patent Publication No. 2002/0126364 A1 also describes various passive optical compensation structures for minimizing color shift as the angle of incidence changes (a characteristic typical of interferometric structures) and active optical compensation structures for supplying supplemental illumination. For example, as illustrated in Figures 3A – 3F (see Figures 6A – 6F of U.S. Patent Publication No. 2002/0126364 A1), an optical compensation film may be fabricated on the opposite surface of the substrate from which the array of light modulating elements resides. Such films can be designed and fabricated in a number of ways, and may be used in conjunction with each other.

**[0043]** In Figure 3A, a passive optical compensation film **600** is a volume or surface relief holographic film. A volume holographic film may be produced by exposing a photosensitive polymer to the interference pattern produced by the intersection of two or more coherent light sources (e.g., lasers). Using the appropriate frequencies and beam orientations arbitrary periodic patterns of refractive indices within the film may be produced. A surface relief holographic film may be produced by creating a metal master using any number of microfabrication techniques known by those skilled in the art. The master is subsequently used to pattern the film. Such films can be used to enhance the transmission and reflection of light within a definable cone of angles, thus minimizing off-axis light. The colors and brightness of a display viewed with on axis light are enhanced and color shift is diminished because brightness goes down significantly outside of the cone.

**[0044]** In Figure 3B, another approach is illustrated for a device **604** in which an array of passive optical compensation structures **606** is fabricated on the substrate. These structures, which can be fabricated using the techniques referenced in U.S. Patent Publication No. 2002/0126364 A1, can be considered photonic crystals, as described in the book "Photonic Crystals", by John D. Joannopoulos, et al. They are essentially three-dimensional interferometric arrays which demonstrate interference from all angles. This provides the ability to design waveguides which can perform a number of functions including channeling incident light of certain frequencies to the appropriately colored pixels, or by changing light of a certain incidence angle to a new incidence angle, or some combination of both.

**[0045]** In another example of a passive optical compensation structure, seen in Figure 3C, a three-layer polymeric film **610** contains suspended particles. The particles are actually single or multi-layer dielectric mirrors which have been fabricated in the form of microscopic plates. These plates, for example, may be fabricated by deposition of multilayer dielectric films onto a polymer sheet which, when dissolved, leaves a film which can "ground up" in a way which produces the plates. The plates are subsequently mixed into a liquid plastic precursor. By the application of electric fields during the curing process, the orientation of these plates may be fixed during manufacture. The mirrors can be designed so that they only reflect at a range of grazing angles. Consequently, light is either reflected or transmitted depending on the incidence angle with respect to the mirror. In Figure 3C, layer **612** is oriented to reflect light **609** of high incidence that enters the film **610** closer to the perpendicular. Layer **614** reflects light **613** of lower incidence into a more perpendicular path. Layer **616** modifies the even lower angle incident light **615**. Because the layers minimally affect light which approaches perpendicularly, they each act as a separate "angle selective incidence filter" with the result that randomly oriented incident light couples into the substrate with a higher degree of perpendicularly. This minimizes the color shift of a display viewed through this film.

**[0046]** In another example of a passive optical compensation structure, illustrated in Figure 3D, micro lenses **622** are used in an array in device **620**. Each lens **622** may be used to enhance the fill factor of the display by effectively magnifying the active area of each pixel. This approach may be used by itself or in conjunction with the other color shift compensation films.

**[0047]** In an example of an active optical compensation structure, illustrated in Figure 3E, device **624** uses supplemental lighting in the form of a frontlighting array. In this case an organic light emitting material **626**, for example, Alq/diamine structures and poly(phenylene vinylene), can be deposited and patterned on the substrate. The top view, Figure 3F, reveals a pattern **627** which corresponds with the interferometric modulator array underneath. That is, the light emitting areas **626** are designed to obscure the inactive areas between the interferometric modulator, and allow a clear aperture in the remaining regions. Light is actively emitted into the substrate onto the interferometric modulator and is subsequently reflected back to the viewer. Conversely, a patterned emitting film may be applied to the backplate of the display and light transmitted forward through the gaps between the sub-pixels. By patterning a mirror on the front of the display, this light can be reflected back upon the interferometric modulator array. Peripherally mounted light sources in conjunction with films relying on total internal reflection are yet another approach. U.S. Patent No. 6,055,090 also discloses an interferometric modulator having an active optical compensation structure that includes a supplemental frontlighting source.

**[0048]** Figure 4 illustrates an interferometric modulator **10** comprising a passive optical compensation film (a diffuser **22**) fabricated on the opposite surface of the substrate from which a light modulating element resides. The diffuser **22** generally compensates for the specular appearance of an uncompensated spatial light modulator array, e.g., by making the reflective array appear less like a mirror and more like paper. In Figure 4, a light modulating element **8** comprises a movable wall or element **16**, a cavity **20**, and a support post **18**. As illustrated in Figure 4, the movable wall **16** is supported over the cavity **20** by the support post **18**. An optical stack **14** forms a wall of the cavity **20** opposite to the movable wall **16**. The optical stack **14** may be considered part of the light modulating element **8**. The optical stack **14** is fabricated on a transparent substrate **12**, and the diffuser **22** is fabricated on the opposite side of the substrate **12** from the light modulating element **8**. In operation, the movable wall **16** moves through planes parallel to the front wall of the cavity **20**. The movable wall **16** is highly reflective and typically comprises a metal. As the movable wall **16** moves toward the optical stack **14** on the opposite side of the cavity **12**, self-interference of light (typically entering through the transparent substrate **12** and the optical stack **14**) within the cavity **20** occurs. The color of the reflected light that exits the cavity through the transparent substrate **12** and the optical stack **14** may be controlled by varying the distance between the optical stack **14** and the movable wall **16**. The surface of the transparent substrate **12** in contact with the optical stack **14** is the surface upon which the light modulating element **8** is fabricated. The diffuser **22** is typically fabricated or attached to the opposite surface of the transparent substrate **12** after fabrication of the light modulating element **8**.

**[0049]** As illustrated in Figure 4 and by the disclosure of U.S. Patent Publication No. 2002/0126364 A1, passive optical compensation structures for spatial light modulators are typically fabricated on the opposite surface of the substrate from which the array of light modulating elements resides to facilitate existing manufacturing process flows. Manufacturing of the overall display system typically involves producing the various components separately, such as the passive optical compensation structures, the interferometric modulator structures, the driver electronics, the graphics control functions, etc., and then integrating them at a later stage in the manufacturing process flow. Producing the various components separately and then integrating them at a later stage simplifies the delicate task of manufacturing the light modulating elements by reducing the need for complex deposition and micro-fabrication schemes.

[0050] As spatial light modulators become increasingly sophisticated, it is anticipated that difficulties associated with fabricating them by current manufacturing process flows will also increase. Accordingly, spatial light modulators having integrated optical compensation structures and methods for making them have been developed. An embodiment provides spatial light modulators having an integrated optical compensation structure, e.g., an optical compensation structure located between the substrate and the light-modulating elements, or an optical compensation structure located on the opposite side of the light-modulating elements from the substrate. The optical compensation structure may be active or passive, as desired. In this context, a "passive" optical compensation structure is one that does not supply a supplemental frontlighting source.

[0051] As discussed above, Figure 4 illustrates a passive optical compensation film (a diffuser **22**) fabricated on the opposite surface of the substrate from which a light modulating element resides. In Figure 4, the light modulating element **8** is an interferometric modulator comprising the movable wall or element **16**, the cavity **12**, the support post **18**. The optical stack **14** is fabricated on the transparent substrate **12**, and the diffuser **22** is fabricated on the opposite side of the substrate **12** from the light modulating element **8**. The optical stack **14** may be considered part of the light modulating element **8**. Those skilled in the art appreciate that, in some embodiments, an interferometric modulator may modulate between a black, or absorbing state, and a reflecting state. The reflecting state is a non-interference based state that appears to be white. While the white state in these embodiments does not particularly depend on the interference characteristics of the modulator, the modulating elements preferably have a structure that is similar to those embodiments of interferometric modulators that rely upon the interference characteristics and will be referred to as such herein. Interferometric modulators may modulate between an absorbing state and an interference state, between an absorbing state and a reflective state, between a reflective state and an interference state, or between two different interference states.

[0052] Figure 5A illustrates an embodiment of a spatial light modulator **40** in which a passive optical compensation structure (diffuser **41**) is arranged between a substrate **42** and a light-modulating element **44**, rather than being on the opposite side of the substrate from the light modulating element as shown in Figure 4. In the embodiment illustrated in Figure 5A, the light-modulating element **44** is an interferometric modulator comprising a cavity **45**, a movable wall **46**, an optical stack **43**, and a support **47**. The optical stack **43** is on the wall of the cavity **45** that is opposite to the movable wall **46**. In the illustrated embodiment, the spatial light modulator **40** further comprises a planarization layer **48** between the substrate **42** and the optical stack **43**. Both the movable wall **46** and the optical stack **43** are reflective, so that operation of spatial light modulator **40** is generally similar to that described for the spatial light modulator **10** illustrated in Figure 4. Typically, the substrate **42** is at least partially transparent. Those skilled in the art will appreciate that the light-modulating element **44** may be configured in an array comprising a plurality of individually addressable light-modulating elements arranged over a transparent substrate and configured to modulate light transmitted through the transparent substrate.

**[0053]** Those skilled in the art will also appreciate that the diffuser **41** illustrated in Figure 5A is representative of various optical compensation structures (both active and passive) that may be arranged between the substrate and the plurality of individually addressable light-modulating elements. For example, an active optical compensation structure may supply a supplemental frontlighting source. Non-limiting examples of passive optical compensation structures include an anti-reflective layer, a diffractive optical element, a structure that scatters light, a black mask, a color filter, a microlens array, a holographic film (e.g., that mitigates a shift in reflected color with respect to an angle of incidence of the light transmitted through the transparent substrate), or a combination thereof. In Figure 5, the light-modulating element **44** comprises an interferometric modulator, but other spatial light modulators may also be used.

**[0054]** Figure 5B illustrates an embodiment of a spatial light modulator **33** in which a passive optical compensation structure (black mask **32)** is arranged between a transparent substrate **12** and a reflecting element **31**. The reflecting element may be an optical stack. Black masks such as the black mask **32** may be used to mask parts of the spatial light modulator structure that are not desirable for the viewer to see. A light modulating element or elements (e.g., a plurality of individually addressable light-modulating elements) are omitted from Figure 5B for clarity, but are understood to be arranged over the transparent substrate **12** and configured to modulate light transmitted through the transparent substrate **12**. For example, the light modulating element of Figure 5B may comprise a plurality of individually addressable light-modulating elements arranged over the reflecting element **31** as discussed above with respect to Figure 5A. The spatial light modulator **33** may include a planarization layer **30**, e.g., between the black mask **32** and the reflecting element **31** as shown in Figure 5B.

**[0055]** Figure 5C illustrates an embodiment of a spatial light modulator **37** in which a passive optical compensation structure (comprising color filter elements **34**, **36**, **38)** is arranged between a transparent substrate **12** and a reflecting element **39**. As in Figure 5B, the reflecting element **39** may be an optical stack. In the illustrated embodiment, the color filter elements **34**, **36**, **38** are red, green and blue, respectively, but other colors may be selected by those skilled in the art so that the resulting spatial light modulator produces the desired colors. As in Figure 5B, a light modulating element or elements (e.g., a plurality of individually addressable light-modulating elements) are omitted from Figure 5C for clarity, but are understood to be arranged over the transparent substrate **12** and configured to modulate light transmitted through the transparent substrate **12**. For example, the light modulating element of Figure 5C may comprise a plurality of individually addressable light-modulating elements arranged over the optical stack as discussed above with respect to Figure 5A. The spatial light modulator **37** may include a planarization layer **30**, e.g., between the color filter elements **34**, **36**, **38** and the optical stack **39** as shown in Figure 5C.

**[0056]** Interferometric modulators that produce only black and white may be used in combination with color filters to produce colored light. Interferometric modulators may be fabricated to produce various colors by varying the size of the cavity. However, varying the size of the cavity may involve varying the manufacturing process, e.g., by manufacturing a different size cavity for an interferometric modulator that produces green light than for an interferometric modulator that produces red light. The use of black and white interferometric modulators in combination with color filters may substantially simplify the manufacturing process. Other improvements in the manufacturing process are realized by integrating the color filter into the interferometric modulator as illustrated in Figure 5C.

**[0057]** Figure 6 illustrates an embodiment of a spatial light modulator **100** in which a passive optical compensation structure **105** (a planarization layer comprising a scattering element **110**) is arranged between a transparent substrate **115** and a light-modulating element **120**. In the embodiment illustrated in Figure 6, the light-modulating element **120** is an interferometric modulator comprising a cavity **130**, a movable wall **125**, and an optical stack **135**. The optical stack **135** is on the wall of the cavity **130** that is opposite to the movable wall **125**. Both the movable wall **125** and the optical stack **135** are reflective (the optical stack **135** is partially reflective), so that operation of spatial light modulator **100** is generally similar to that described for the spatial light modulator **10** illustrated in Figure 4. Light **140** passes through a slot **150** in the movable wall **125** and reflects from the scattering element **110** such that it scatters the light **140** back to the movable wall **125** (and in some cases back again to the scattering element **110**), ultimately passing through the transparent substrate **115** and exiting **160, 165** as shown in Figure 6. Preferably, the scattering element **110** is shaped such that the light **140** is scattered randomly. For clarity, a single scattering element **110** and a single slot **150** are illustrated in Figure 6, but it will be understood that the spatial light modulator **100** may comprise a plurality of scattering elements and slots, arranged to provide the desired amount of scattered light.

**[0058]** Figures 7A and 7B illustrate embodiments of spatial light modulators comprising different combinations of integrated optical compensation structures. Figure 7A illustrates an embodiment of a spatial light modulator **60** in which a passive optical compensation structure (comprising a color filter element **34** and a black mask **32**) is arranged between a transparent substrate **12** and an optical stack **61**. Figure 7B illustrates an embodiment of a spatial light modulator **62** in which a first passive optical compensation structure (comprising a color filter element **40** and a black mask **32**) and a second passive optical compensation structure (comprising diffuser **26**) are arranged between a transparent substrate **12** and an optical stack **63**. As in Figures 5B and 5C, a light modulating element or elements (e.g., a plurality of individually addressable light-modulating elements) are omitted from Figures 7A and 7B for clarity, but are understood to be arranged over the transparent substrate **12** and configured to modulate light transmitted through the transparent substrate. The spatial light modulators **60, 62** may include a planarization layer **30** e.g., between the passive optical compensation structure (comprising the color filter element **34** and the black mask **32**) and the optical stack **61** as shown in Figure 7A, or between the first and second passive optical compensation structures as shown in Figure 7B. The spatial light modulator may include an additional planarization layer, e.g., a planarization layer **35** as shown in Figure 7B between the first passive optical compensation structure (comprising a color filter element **40** and a black mask **32**) and the optical stack **63**.

**[0059]** Spatial light modulators may comprise an optical compensation structure that performs one or more functions (e.g., a color filter and a black mask as illustrated in Figure 7A), and/or the optical compensation structure may comprise multiple layers, optionally separated from each other by planarization layers (e.g., as illustrated in Figure 7B). Those skilled in the art will understand that the term "optical compensation structure" may be used to refer to a structure having a particular function (e.g., the diffuser **26**), a layer having multiple functions (e.g., comprising the color filter element **34** and the black mask **32**), or multiple layers each having one or more functions as illustrated in Figure 7B, optionally including planarization layer(s). Thus, spatial light modulators may comprise any combination of active and/or passive optical compensation structures, e.g., a black mask and a color filter; a black mask and a diffuser; a color filter and a diffuser; a black mask, color filter and a diffuser, etc. Means for compensating the light transmitted through the transparent substrate include optical compensation structures as described herein.

**[0060]** Spatial light modulators comprising an optical compensation structure may be fabricated by integrating the fabrication of the optical compensation structure into the process for fabricating the spatial light modulator. An example of such a process is illustrated in Figure 8. The process begins with the substrate being provided at step **50**. Typically, the substrate is glass, plastic or other transparent substrate. Those skilled in the art will appreciate that the term "transparent" as used herein encompasses materials that are substantially transparent to the operational wavelength(s) of the spatial light modulator, and thus transparent substrates need not transmit all wavelengths of light and may absorb a portion of the light at the operational wavelength(s) of the spatial light modulator. For example, the transparent substrate may be tinted and/or polarized if desired for a particular application. Thus, the transparency and reflectivity of the substrate may be varied, depending on the configuration and the function desired. In some embodiments, the substrate is at least partially transparent and may be substantially transparent. In other embodiments, the substrate is at least partially reflective and may be substantially reflective. It is understood that a substrate may be both partially transparent and partially reflective.

**[0061]** The process illustrated in Figure 8 continues at step **52** with the fabrication of the optical compensation structure. Depending on the structure, the materials and methods used for its fabrication may vary. For example, it is often convenient to fabricate the optical compensation structures using techniques and methods compatible with the manufacturing of the individually addressable light-modulating elements, e.g., by spin coating and/or chemical vapor deposition techniques. For example, a diffuser film may be fabricated by spin-coating the substrate using a polymer or polymer solution that contains scattering elements dispersed therein. For example, the polymer may be a polyimide and the scattering elements may be microscopic glass beads. Color filters and black masks may be appropriately dyed photoresist polymers fabricated on the substrate using known photoresist deposition and masking techniques. Black masks may also be inorganic materials such as chrome oxide, also known as black chrome, fabricated on the substrate using known deposition and masking techniques.

**[0062]** The process illustrated in Figure 8 continues at step **54** with the deposition of a planarization layer. The planarization layer or layers are typically polymers, e.g., polyimide, and may be deposited using known deposition and masking techniques. The deposition of a planarization layer is an optional, but is often preferred because it results in a suitable substrate for subsequent processing steps. The process illustrated in Figure 8 continues at step **56** with the fabrication of individually addressable light-modulating elements (e.g., interferometric modulator elements) over the optical compensation structure and, if present, the planarization layer. Interferometric modulators are generally fabricated using thin film deposition processes, e.g., as described in U.S. Patent Nos. 5,835,255 and 6,055,090, and in U.S. Patent Publication No. 2002/0126364 A1. A variation of this process, also illustrated in Figure 8, involves the fabrication of an additional planarization layer at step **58**, followed by the fabrication of an additional optical compensation structure at step **59**. After fabrication at step **59**, the fabrication process may return to steps **58**, **59** for the fabrication of additional planarization layer(s) and optical compensation structure(s), or may proceed to steps **54**, **56** for the fabrication of the planarization layer and individually addressable light-modulating elements. Those skilled in the art will understand that the process illustrated in Figure 8 or variations thereof may be used to fabricate the spatial light modulators described herein, including without limitation the spatial light modulators illustrated in Figures 5-7. Means for modulating light transmitted through the transparent substrate include interferometric modulators and liquid crystal displays.

[0063] Figure 9 illustrates an embodiment of a spatial light modulator **200** in which a light modulating element **205** is arranged between a substrate **210** and an optical compensation structure **215**. In the embodiment illustrated in Figure 9, the light-modulating element **205** is an interferometric modulator comprising a cavity **220**, a movable wall **225**, an optical stack **230**, and supports **235**. The optical stack **230** is on the wall of the cavity **220** that is opposite to the movable wall **225**. The optical compensation structure **215** may be any of the optical compensation structures described herein, e.g., an active optical compensation structure that supplies a supplemental frontlighting source, and/or a passive optical compensation structure, e.g., an anti-reflective layer, a diffractive optical element, a structure that scatters light, a black mask, a color filter, a diffuser, a microlens array, a holographic film that mitigates a shift in reflected color with respect to an angle of incidence of the light transmitted through the substrate, or a combination thereof. In Figure 9, the light-modulating element **205** comprises an interferometric modulator, but other spatial light modulators may also be used.

[0064] A spatial light modulator in which a light modulating element is arranged between a substrate and an optical compensation structure (such as that illustrated in Figure 9) may be fabricated by a process similar to that illustrated in Figure 8, except that the individually addressable light-modulating elements are fabricated over the substrate, followed by fabrication of the optical compensation structure(s) over the individually addressable light-modulating elements (e.g., step **56** in Figure 8 is conducted after step **50** and prior to step **52**). Optionally, a planarization layer may be fabricated over the over the individually addressable light-modulating elements, followed by fabrication of the optical compensation structure(s) over the planarization layer.

[0065] While the above detailed description has shown, described, and pointed out novel features of the invention as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the device or process illustrated may be made by those skilled in the art without departing from the spirit of the invention. As will be recognized, the present invention may be embodied within a form that does not provide all of the features and benefits set forth herein, as some features may be used or practiced separately from others.

# CLAIMS

WHAT IS CLAIMED IS:

1. A spatial light modulator comprising:

a substrate;

a plurality of individually addressable light-modulating elements arranged over the substrate and configured to modulate light transmitted through the substrate; and

an optical compensation structure;

wherein the optical compensation structure is arranged between the substrate and the plurality of individually addressable light-modulating elements.

2. The spatial light modulator of Claim 1 in which the individually addressable light-modulating elements comprise an interferometric modulator.

3. The spatial light modulator of Claim 2 in which the interferometric modulator comprises a movable element and a cavity.

4. The spatial light modulator of Claim 1 in which the optical compensation structure comprises a black mask.

5. The spatial light modulator of Claims 1 or 4 in which the optical compensation structure comprises a color filter.

6. The spatial light modulator of Claims 1 or 4 in which the optical compensation structure comprises a diffuser.

7. The spatial light modulator of Claim 1 in which the optical compensation structure comprises an anti-reflective layer.

8. The spatial light modulator of Claim 1 in which the optical compensation structure comprises a plurality of scattering elements.

9. The spatial light modulator of Claim 1 in which the optical compensation structure comprises a microlens array.

10. The spatial light modulator of Claim 1 in which the optical compensation structure comprises a holographic film that mitigates a shift in reflected color with respect to an angle of incidence of the light transmitted through the substrate.

11. The spatial light modulator of Claim 1 in which the optical compensation structure comprises a diffractive optical element.

12. The spatial light modulator of Claim 1, wherein said optical compensation structure is disposed in front of said light-modulating element such that light transmitted through the substrate passes through the optical compensation structure to be modulated by the light-modulating element.

13. The spatial light modulator of Claim 1 in which the optical compensation structure comprises a planarization layer that comprises a scattering element.

14. The spatial light modulator of Claim 1 in which the optical compensation structure is a passive optical compensation structure.

15. The spatial light modulator of Claim 1 further comprising a planarization layer.

16. The spatial light modulator of Claim 1 in which the substrate is partially reflective.

17. A spatial light modulator comprising:

a substrate;

a plurality of individually addressable light-modulating elements arranged over the substrate and configured to modulate light; and

an optical compensation structure comprising at least one of a color filter, black mask, and anti-reflective layer,

wherein the plurality of individually addressable light-modulating elements is arranged between the substrate and the optical compensation structure.

18. The spatial light modulator of Claim 17 in which the individually addressable light-modulating elements comprise an interferometric modulator.

19. The spatial light modulator of Claim 18 in which the interferometric modulator comprises a movable element and a cavity.

20. The spatial light modulator of Claim 17 in which the optical compensation structure comprises a black mask.

21. The spatial light modulator of Claims 17 or 20 in which the optical compensation structure comprises a color filter.

22. The spatial light modulator of Claim 17 in which the optical compensation structure further comprises an anti-reflective layer.

23. The spatial light modulator of Claim 17 in which the optical compensation structure further comprises a planarization layer that comprises a scattering element.

24. The spatial light modulator of Claim 17 in which the optical compensation structure comprises a black mask and a diffuser.

25. The spatial light modulator of Claim 17 in which the optical compensation structure comprises a color filter and a diffuser.

26. The spatial light modulator of Claim 17 further comprising a planarization layer.

27. The spatial light modulator of Claim 17 in which the substrate is at least partially transparent such that the light-modulating elements modulate light transmitted through the substrate.

28. The spatial light modulator of Claim 17 in which the substrate is at least partially reflective.

29. A method of making a spatial light modulator, comprising:

fabricating an optical compensation structure over a transparent substrate; and fabricating a plurality of individually addressable light-modulating elements over the optical compensation structure, the individually addressable light-modulating elements being configured to modulate light transmitted through the transparent substrate.

30. The method of Claim 29 in which fabricating the individually addressable light-modulating elements comprises fabricating a cavity and a movable element.

31. The method of Claim 29 further comprising fabricating a second optical compensation structure over the transparent substrate.

32. The method of Claim 29 further comprising fabricating a planarization layer over the optical compensation structure.

33. The method of Claim 29 in which fabricating the optical compensation structure comprises fabricating at least one of a color filter and diffuser.

34. The method of Claim 33 in which fabricating the individually addressable light-modulating elements comprises fabricating an interferometric modulator.

35. The method of Claim 29, wherein said fabricating the optical compensation structure comprises depositing material over the transparent substrate such that light transmitted through the transparent substrate passes through the material to be modulated by the light-modulating element.

36. The method of Claim 35, wherein said material comprises dyed photoresist or spin-coated polyimide.

37. The method of Claim 29 in which fabricating the optical compensation structure comprises fabricating a passive optical compensation structure.

38. A spatial light modulator made by the method of Claim 29, wherein the transparent substrate comprises at least one of plastic and glass.

39. A method of making a spatial light modulator, comprising:

fabricating a plurality of individually addressable light-modulating elements over a substrate; and

fabricating an optical compensation structure over the plurality of individually addressable light-modulating elements, the optical compensation structure comprising at least one of a color filter, mask, and anti-reflective layer, the individually addressable light-modulating elements being configured to modulate light transmitted through the optical compensation structure.

40. The method of Claim 39 in which fabricating the individually addressable light-modulating elements comprises fabricating a cavity and a movable element.

41. The method of Claim 39 further comprising fabricating a second optical compensation structure over the plurality of individually addressable light-modulating elements.

42. The method of Claim 39 further comprising fabricating a planarization layer over the plurality of individually addressable light-modulating elements.

43. The method of Claim 39 in which fabricating the individually addressable light-modulating elements comprises fabricating an interferometric modulator.

44. A spatial light modulator made by the method of Claim 39, wherein the substrate comprises plastic or glass.

45. A spatial light modulator comprising:

a transparent substrate;

a plurality of individually addressable interferometric light-modulating elements arranged over the transparent substrate and configured to modulate light transmitted through the transparent substrate, the interferometric light-modulating elements comprising a cavity and a movable wall; and

at least one optical compensation structure arranged between the transparent substrate and the plurality of individually addressable interferometric light-modulating elements, the optical compensation structure comprising a color filter or diffuser.

46. A spatial light modulator comprising:

a substrate;

a means for modulating light transmitted through or reflected from the substrate; and

a means for compensating the light transmitted through or reflected from the substrate;

wherein the means for compensating the light is operatively arranged between the substrate and the means for modulating light transmitted through or reflected from the substrate.

47. The spatial light modulator of Claim 46 in which the means for modulating light transmitted through or reflected from the substrate comprises a plurality of individually addressable light-modulating elements arranged over the substrate.

48. The spatial light modulator of Claim 46 in which the means for modulating light transmitted through or reflected from the substrate comprises a plurality of interferometric modulators.

49. The spatial light modulator of Claim 46 in which the means for compensating the light transmitted through or reflected from the substrate comprises a diffractive optical element, a color filter, a diffuser, an anti-reflective layer, a plurality of scattering elements, a microlens array, or a holographic film.

50. The spatial light modulator of Claim 46 in which the means for compensating the light transmitted through or reflected from the substrate comprises a a color filter or a diffuser.

51. A spatial light modulator comprising:

a substrate;

a means for modulating light transmitted through or reflected from the substrate; and

a means for compensating the light transmitted through or reflected from the substrate, said means for compensating comprising at least one of a color filter, a black mask, and an anti-reflective layer;

wherein the means for modulating light transmitted through or reflected from the substrate is operatively arranged between the substrate and the means for compensating the light.

52. The spatial light modulator of Claim 51 in which the means for modulating light transmitted through or reflected from the substrate comprises a plurality of individually addressable light-modulating elements arranged over the substrate.

53. The spatial light modulator of Claim 52 in which the means for modulating light transmitted through or reflected from the substrate comprises a plurality of interferometric modulators.

54. A spatial light modulator made by a method comprising:

fabricating an optical compensation structure over a transparent substrate; and

fabricating a plurality of individually addressable light-modulating elements over the optical compensation structure, the individually addressable light-modulating elements being configured to modulate light transmitted through the transparent substrate.

55. The spatial light modulator of Claim 54 in which fabricating the individually addressable light-modulating elements comprises fabricating a cavity and a movable element.

56. The spatial light modulator of Claim 54 in which the method further comprises fabricating a second optical compensation structure over the transparent substrate.

57. The spatial light modulator of Claim 56 in which the method further comprises fabricating a planarization layer over the optical compensation structure.

58. The spatial light modulator of Claim 54 in which fabricating the optical compensation structure comprises fabricating at least one of a color filter and diffuser.

59. The spatial light modulator of Claim 58 in which fabricating the individually addressable light-modulating elements comprises fabricating an interferometric modulator.

60. The spatial light modulator of Claim 54 in which fabricating the optical compensation structure comprises fabricating a passive optical compensation structure.

61. A spatial light modulator made by a method comprising:

fabricating a plurality of individually addressable light-modulating elements over a substrate; and fabricating an optical compensation structure over the plurality of individually addressable light-modulating elements, said optical compensation structure comprising one of a color filter, an anti-reflective filter and a black mask, the individually addressable light-modulating elements being configured to modulate light transmitted through the optical compensation structure.

62. The spatial light modulator of Claim 61 in which fabricating the individually addressable light-modulating elements comprises fabricating a cavity and a movable element.

63. The spatial light modulator of Claim 61 in which the method further comprises fabricating a second optical compensation structure over the plurality of individually addressable light-modulating elements.

64. The spatial light modulator of Claim 61 in which the method further fabricating a planarization layer over the plurality of individually addressable light-modulating elements.

65. The spatial light modulator of Claim 61 in which fabricating the individually addressable light-modulating elements comprises fabricating an interferometric modulator.

66. A display region comprising:

a black and white light-modulating element including first and second reflective surfaces and a cavity therebetween, the second surface being movable with respect to the first surface; and

a color filter configured to transmit colored light when illuminated with white light,

wherein the color filter is positioned with respect to said light-modulating elements such that light output from the light-modulating element is filtered by said color filter.

67. The display region of Claim 66, wherein said light-modulating element comprises an interferometric modulator.

68. The display region of Claim 66, further comprising an optical stack that forms said first surface.

69. The display region of Claim 66, wherein at least one of the first and second reflective surfaces is partially reflective.

70. A display region comprising:

a plurality of light-modulating elements, each of the light-modulating elements including first and second reflective surfaces and a cavity therebetween, the second surface being movable with respect to the first surface; and

a color filter array comprising a plurality of color filter elements configured to transmit a narrower range of wavelengths when illuminated with a broader range of wavelengths, the color filter array being positioned with respect to said light-modulating elements such that light output from the light-modulating elements is filtered by said color filter elements,

wherein the first reflective surface is separated from the second reflective surface by a substantially equal distance for each of the plurality of light-modulating elements when the light-modulating elements output light and wherein at least two of said color filter elements are configured to produce different color output.

71. The display region of Claim 70, wherein said light-modulating elements comprise interferometric modulators.

72. The display region of Claim 70, further comprising an optical stack that forms said first surface.

73. The display region of Claim 70, wherein at least three of the color filter elements are configured to produce different color output.

74. The display region of Claim 73, wherein the plurality of color filter elements include red, green, and blue color filter elements.

75. The display region of Claim 70, wherein the plurality of color filter elements comprise material that transmits a narrower range of wavelengths when illuminated with a broader range of wavelengths.

76. The display region of Claim 75, wherein the material comprises dyed material.

77. A method of manufacturing a display device comprising:

providing a black and white light-modulating element including first and second optical surfaces, said second optical surface movable with respect to said first optical surface; and

positioning a color filter with respect to the light-modulating elements so that white light output from the light-modulating element is filtered by said color filter, said color filter configured to transmit colored light when illuminated with white light.

78. A display device fabricated by the method of Claim 77.

79. A method of manufacturing a display region comprising:

providing a plurality of light-modulating elements each including first and second optical surfaces and a cavity therebetween, the first reflective surface separated from the second reflective surface by a substantially equal distance for each of the plurality of light-modulating elements when the light-modulating elements output light; and

positioning color filter elements with respect to the light-modulating elements so that light output from the light-modulating elements is filtered by respective color filter elements, said color filter elements comprising material configured to transmit a narrow range of wavelengths when illuminated with a broad range of wavelengths.

80. The method of Claim 79, wherein said providing an array of light-modulating elements comprises providing an array of interferometric modulators.

81. A display region fabricated by the method of Claim 79.

82. A display device comprising:

means for producing a modulated white light signal including first and second optical surfaces, said second optical surface movable with respect to said first optical surface; and

means for filtering said modulated white light signal to so as to transform said white light signal into a colored light signal.

83. The display device of Claim 82 wherein said means for providing a modulated white light signal comprises an array of light-modulating devices wherein the first reflective surface is separated from the second reflective surface by a substantially equal distance for each of the plurality of light-modulating elements when the light-modulating elements output white light.

84. The display device of Claim 82, wherein said means for filtering said white light signal comprises a color filter array comprising at least two color elements configured to produce different color output from white light.

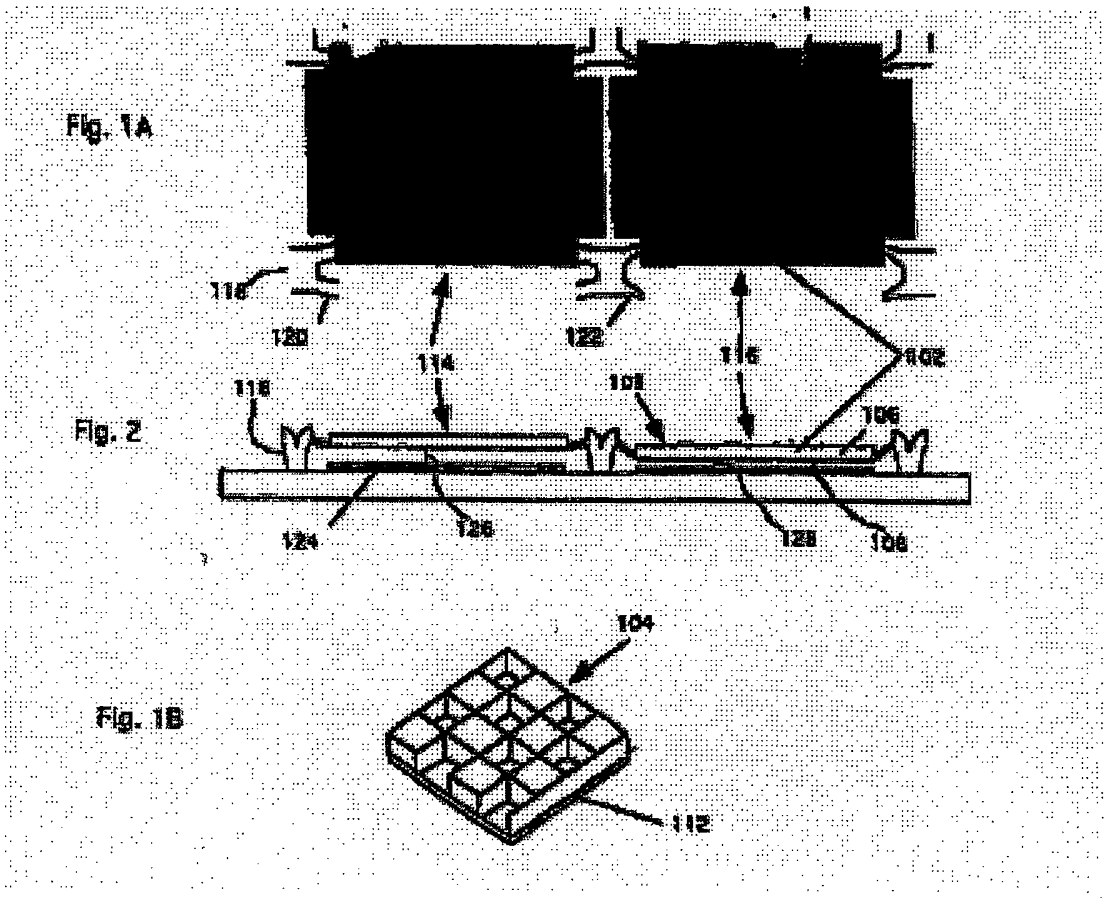


Fig. 1A
118
120
122
114
116
102
118
101
106
Fig. 2
124
126
128
108
104
Fig. 1B
112

Fig. 3A

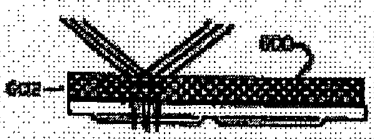



Fig. 3B

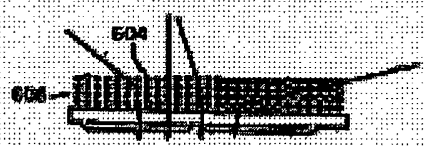



Fig. 3C

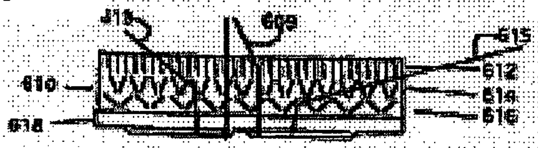



Fig. 3D

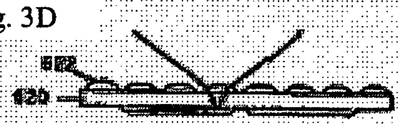



Fig. 3E


Fig. 3F

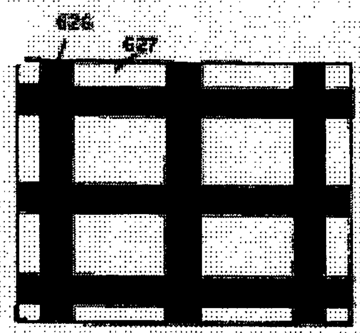
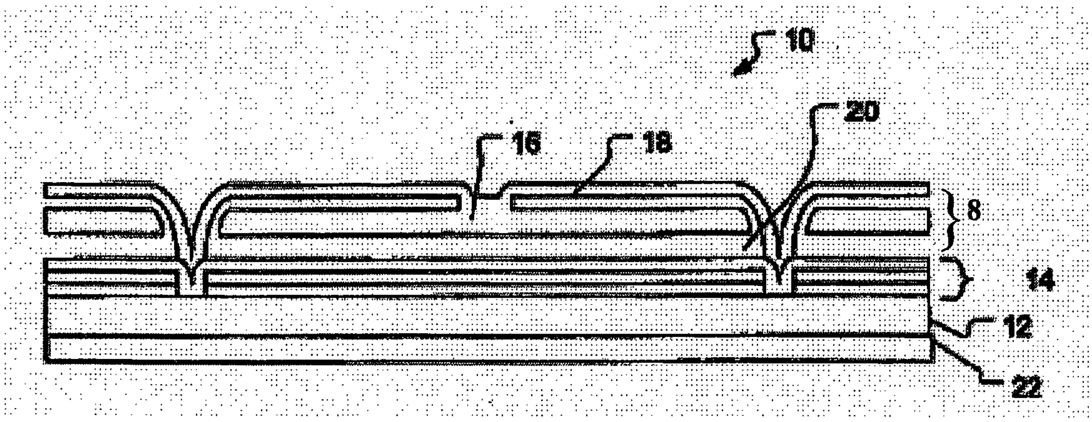


**FIGURE 4**



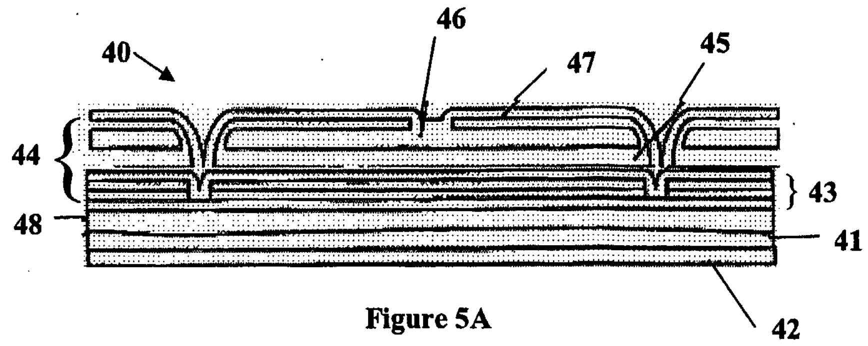



Figure 5A

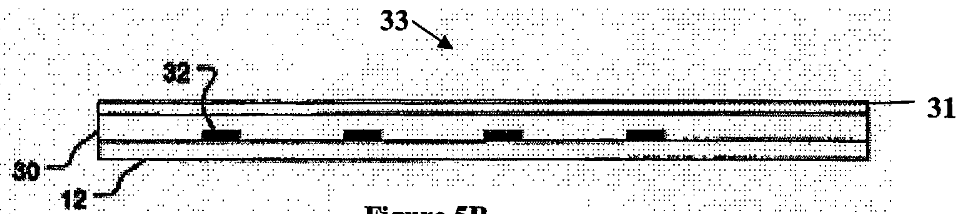



Figure 5B

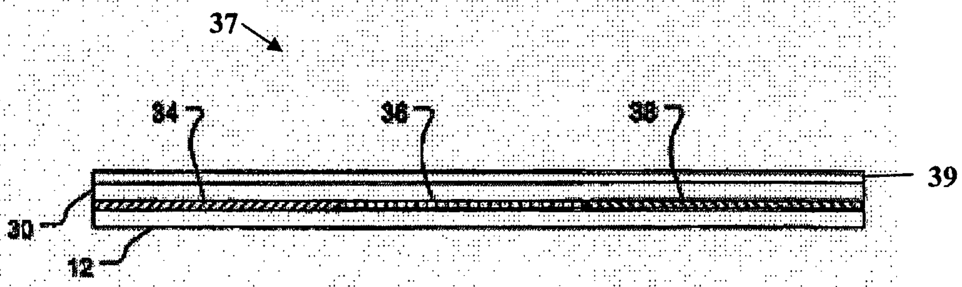
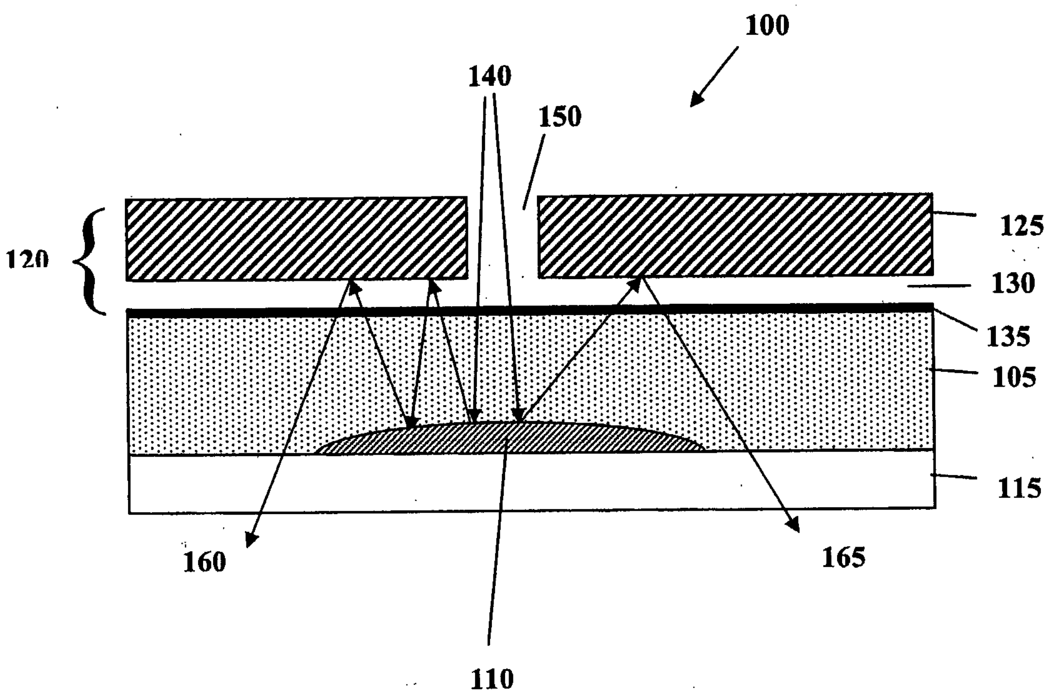



Figure 5C

**Figure 6**



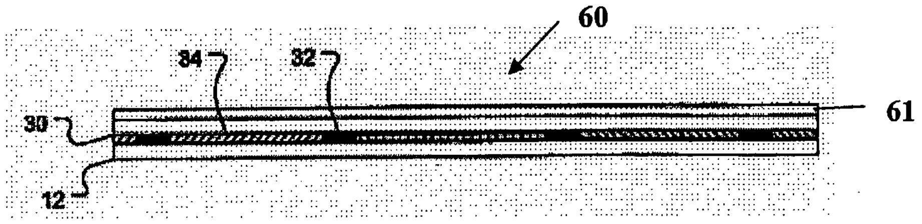



Figure 7A

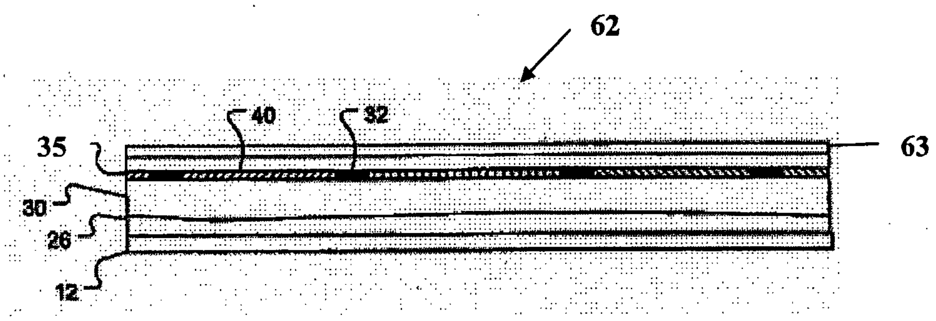



Figure 7B

**FIGURE 8**

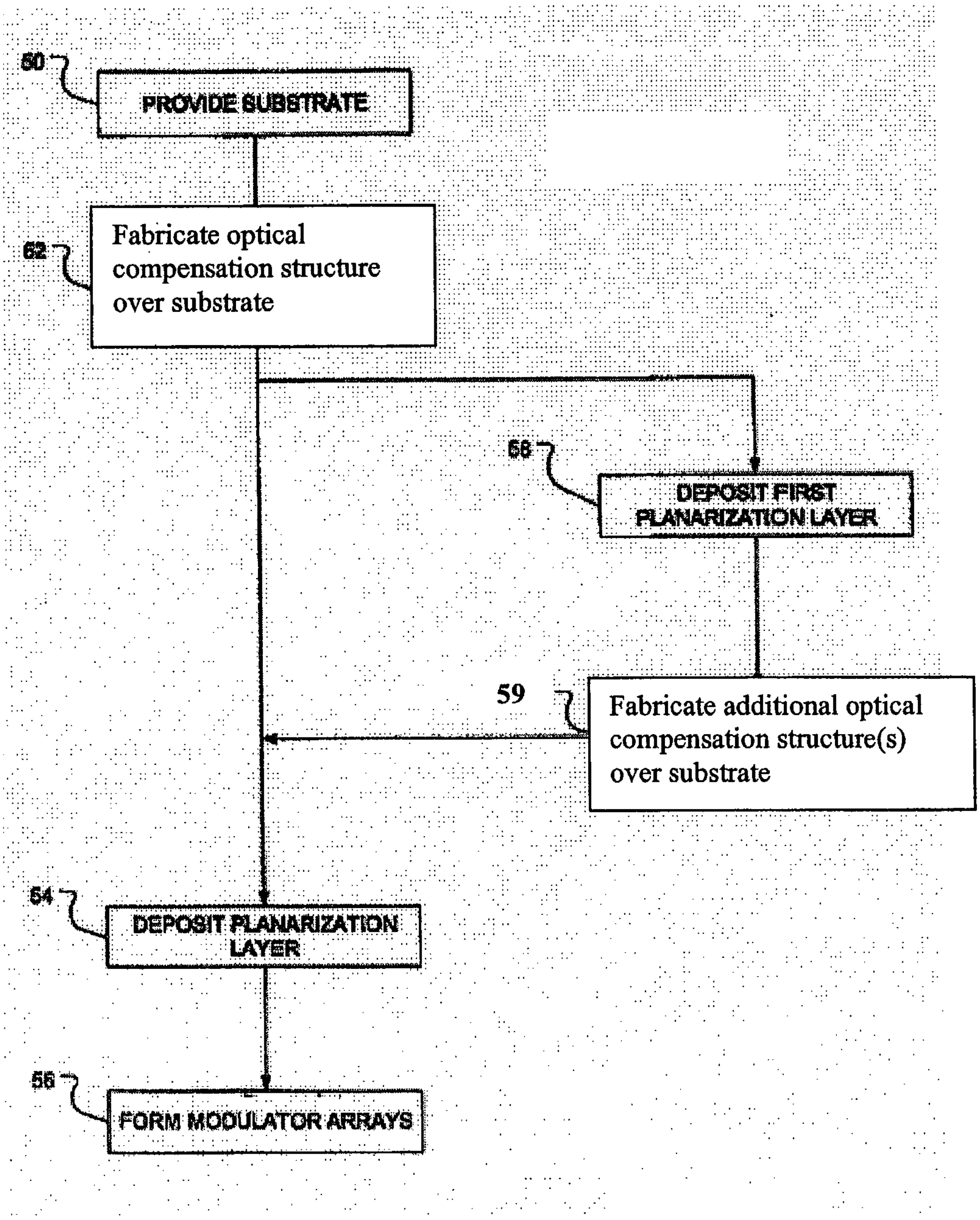
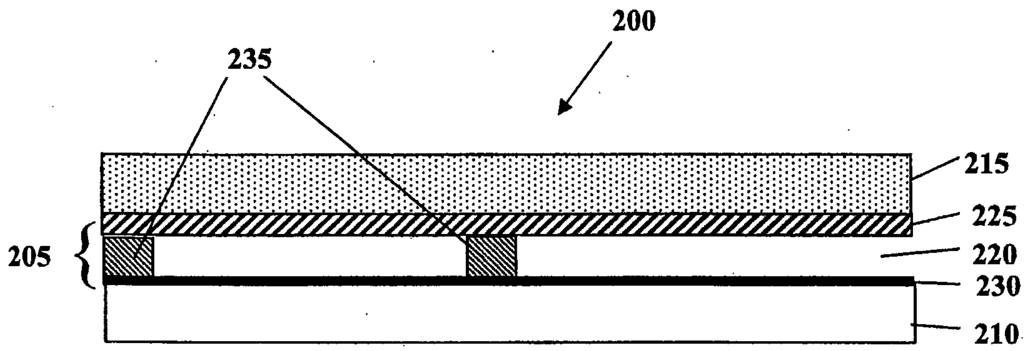

50
PROVIDE SUBSTRATE
62
Fabricate optical compensation structure over substrate
58
DEPOSIT FIRST PLANARIZATION LAYER
59
Fabricate additional optical compensation structure(s) over substrate
54
DEPOSIT PLANARIZATION LAYER
56
FORM MODULATOR ARRAYS

**Figure 9**



# INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/002986

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 7 G02B26/00 G02F1/136

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B G02F

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

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

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | DE 196 22 748 A1 (FORSCHUNGSZENTRUM JUELICH GMBH, 52428 JUELICH, DE) 11 December 1997 (1997-12-11)<br><br>the whole document<br>----- | 1,7,17, 29,39, 46,51, 52,54, 61,66, 77,82 |

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 1 June 2005 | 08/06/2005 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL – 2280 HV Rijswijk<br>Tel. (+31–70) 340–2040, Tx. 31 651 epo nl,<br>Fax: (+31–70) 340–3016 | Daffner, M |

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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