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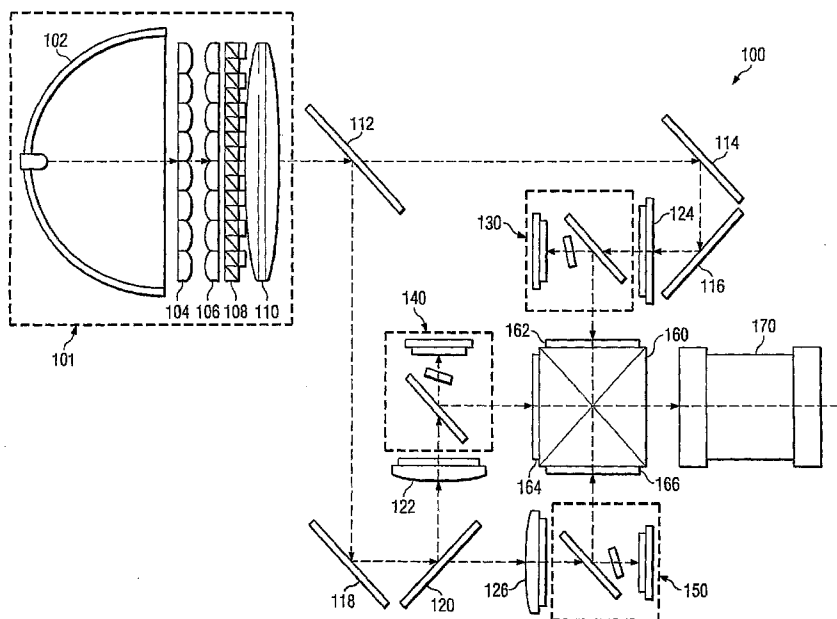
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(57) Abstract: Described are tilted compensators for compensating for in-plate and out-of- plane retardances of LC panels in their dark states, including a single tilted biaxial retarder or compound retarder comprising more than one biaxial film, which are effective to compensate both for nonideal polarization effects of LC panels and other optical components in optical projection systems. Also described are tilted compensators for deflecting away from a projection system optical path unwanted reflected light.

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Contrast Enhancement for Liquid Crystal Based Projection Systems

CROSS-REFERENCE TO RELATED APPLICATIONS

[Para 1] This application is a continuation-in-part of U.S. patent app. no. 10/908,671, filed May 22, 2005, which is hereby incorporated by reference. This application also claims priority to U.S. provisional patent app. no. 60/595,882, filed August 12, 2005, which is hereby incorporated by reference.

TECHNICAL FIELD

[Para 2] Disclosed embodiments herein generally relate to optical devices for use in liquid crystal (LC) display systems, and more in particular to reflective liquid crystal on silicon (LCoS) projection architectures using compensators to enhance contrast. The compensators are configured to compensate for residual in-plane and out-of-plane retardation present in the OFF-state of an LC panel and also to compensate for non-ideal optical effects present in other optical components.

BACKGROUND

[Para 3] Liquid crystal display based front and rear projection systems show great potential for High Definition (HD) and three dimensional video applications due to their superior resolution. Contrast is considered an important performance specification of a projection system, as it ultimately influences the number of true gray levels and the color fidelity. A challenge in such projection systems is to achieve acceptable system contrast despite subtle depolarization effects within the optical modulation system.

[Para 4] In projection displays using LCoS or other LC panels, there is a need to compensate residual, OFF-state panel retardance to ensure sufficient contrast performance, because such residual in-plane retardance applied to incident optical rays can cause polarization mixing and lead to OFF-state leakage. In the case of large screen televisions based on LC panel projection, this leakage manifests itself as a bright dark-state and one that is often colored. When displaying dark video content, such leakage is very obvious and undesirable. Removing residual OFF-state retardance of the LC panels, or at least its adverse affect, can be achieved by introducing birefringent elements in front of the panel, which was described by U.S. Patent Publication No. US 2003/0128320, to Xiang-Dong Mi, and by M. Robinson in commonly-assigned U.S. Pat. App. 10/908,671.

[Para 5] In general, compensators act first to remove residual in-plane OFF-state retardance of the panel, and second to reduce OFF-state light leakage due to the out-of-plane retardance which relates to field-of-view (FOV)

performance of the LC layer. Removing the in-plane retardance is important since it corresponds to the extent to which the LC molecules are not aligned normal to the substrate or not balanced in their orientations when projected onto the panel plane. The substantial out-of-plane retardance alters the polarization state of off-axis rays, and acts to reduce the panel's field-of-view and in non-collimated systems leads again to OFF-state leakage. To get the high contrast demanded of current commercial video projection systems, both in-plane and out-of-plane compensation is desired.

SUMMARY

[Para 6] Disclosed herein are compensation schemes for an LC panel where the projected indices of the LC panel are compensated by the in-plane and out-of-plane retardance components of a compensator with a tilted optical axis. The compensator may also compensate for imperfections of various other optical components in a projection system, including wire-grid, multilayer birefringent cube PBSs, form birefringent PBSs, or MacNeille PBSs.

[Para 7] In an embodiment, an optical projection system is provided for projecting modulated light from an LC panel along a light path. The projection system includes an LC panel and a compensator. The LC panel is positioned in the light path, and the LC panel is substantially planar and operable to receive polarized input light on an illumination portion of the light path. The LC panel is further operable to modulate the input light to form a modulated light that travels along a modulated light portion of the light path, thus imparting a first polarization upon certain portions of the input light, and imparting a second

polarization upon other portions of the input light. A substantially planar compensator is positioned along the light path. The compensator has an optic axis tilted relative to the plane of the LC panel.

BRIEF DESCRIPTION OF THE DRAWINGS

[Para 8] For a more complete understanding of the principles disclosed herein, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings in which:

[Para 9] FIGURE 1 is a schematic diagram of an exemplary optical three-panel LCoS projection system using a wire grid polarization beam splitter in accordance with the present disclosure;

[Para 10] FIGURE 1A is a schematic diagram of an exemplary subsystem that may be used with the three-panel LCoS projection system of FIGURE 1;

[Para 11] FIGURE 2 is a schematic perspective representation of the birefringence of a retardation film as an index ellipsoid.

[Para 12] FIGURE 3 is a schematic perspective diagram illustrating an exemplary compensator component in accordance with the present disclosure;

[Para 13] FIGURE 4 is a graph showing an exemplary relationship of compensator orientation as a function of in-plane retardance for an LC display panel in accordance with the present disclosure;

[Para 14] FIGURE 5 is a schematic diagram illustrating the structure of an exemplary wire grid polarizing beam splitter in accordance with the present disclosure; and

[Para 15] FIGURE 6 is a schematic diagram showing the application and positioning of a wire grid polarizer in an exemplary modulation subsystem in accordance with the present disclosure;

[Para 16] FIGURE 7 is a schematic diagram of an exemplary optical three-panel LCoS projection system using polarization beam splitter cubes in accordance with the present disclosure;

[Para 17] FIGURE 8A is a schematic perspective diagram illustrating another exemplary compensator component in accordance with the present disclosure; and

[Para 18] FIGURE 8B is a schematic diagram illustrating a cross-sectional view of the compensator component shown in FIGURE 8A.

DETAILED DESCRIPTION

[Para 19] Disclosed herein is a system, apparatus, and method that compensates for LC birefringence, birefringence from PBS, and interface reflections, and significantly improves system contrast over conventional techniques.

[Para 20] FIGURE 1 is a schematic diagram of an exemplary optical three-panel LCoS projection system 100. Projection system 100 may include an illumination subsystem 101, which may distribute light to the modulation subsystems 130, 140, 150 via beam splitters 112, 120, and mirrors 114, 116, 118, arranged as shown. Beam splitters 112 and 120 split light into two beams of differing wavelength (color), that selectively reflect or transmit light depending on the light's wavelength. Beam splitters 112 and 120 may be dichroic beam splitters, such as dichroic mirrors or prisms. Projection system 100 may further include projection lens 170 for outputting modulated light, typically to a screen for viewing an image. Modulation subsystems 130, 140, and 150 are adapted to modulate blue, green, and red wavelength portions of the visual light spectrum respectively. A more detailed description of modulation subsystems 130, 140, 150 is provided with reference to FIGURE 1A below.

[Para 21] Illumination subsystem 101 may include a light source 102, lens arrays 104, 106, polarization beam splitter (PBS) array 108, and combining lens 110. Illumination subsystem 101 provides homogenized, telecentric polarized illumination to the modulation subsystems 130, 140, 150. As will be

appreciated by a person of ordinary skill in the art, various illumination subsystems and variations thereof may be used to provide these functions and others, for example, illumination subsystems shown and described in MICHAEL G. ROBINSON ET AL., POLARIZATION ENGINEERING FOR LCD PROJECTION 37-41 (John Wiley & Sons, Ltd 2005), which is hereby incorporated by reference for all purposes [hereinafter referred to as POLARIZATION ENGINEERING].

[Para 22] FIGURE 1A is a schematic diagram of an exemplary modulation subsystem 140 that may be used with the three-panel LCoS projection system 100 of FIGURE 1. Modulation subsystem 140 includes a wire grid PBS (WGP) 142, a modulating panel 144, and a biaxial compensator 146. Although modulation subsystem 140 is illustrated, which modulates green light, this description also applies to modulation subsystems 130 and 150, which are of substantially similar structure and function, except they are adapted to modulate blue and red light respectively. For instance, modulation subsystem 130 (for blue light) includes a WGP 132, a modulating panel 134, and a biaxial compensator 136. Similarly, modulation subsystem 150 (for red light) includes a WGP 152, a modulating panel 154, and a biaxial compensator 156. It should be appreciated that each modulation subsystem may comprise components having variations in optical characteristics to optimize the performance of each respective subsystem for a particular wavelength, or range of wavelengths.

[Para 23] In operation, referring back to FIGURE 1, the light from the projection lamp 102 is transmitted through a fly's eye lens array (104-106) and PBS array 108 to homogenize the light, and a series of dichroic mirrors 112, 120 is used to separate incoming white light from the projection lamp 102 into

red, green, and blue components. Absorption polarizers 122, 124, 126, may be used at each stage (for each color) to polarize the incoming light so at each modulation subsystem 130, 140, 150, the light can be modulated and reflected by the ensuing modulating panel 134, 144, 154, and wire-grid polarizer 132, 142, 152, respectively. As mentioned, both the modulating panel (*e.g.*, 134, 144, 154) and wire-grid polarizers (*e.g.*, 132, 142, 152) for each modulation subsystem 130, 140, 150, respectively, may introduce nonideal polarization effects, such as skew-ray or off-axis polarization effects. Accordingly, a biaxial compensator 136, 146, 156, can be positioned at one or more of the modulation subsystems 130, 140, 150, in order to compensate for these nonideal polarization effects.

[Para 24] Affecting system contrast is the reflection of light off the compensator and panel. For instance, light passing through the compensator 136, 146, 156 and back without encountering the LC will exhibit mixed polarization and contribute to off-state leakage. Although reducing interface reflection (*e.g.*, by using anti-reflective coatings on the compensator component) can reduce this effect, negating it altogether is not practical. The proposed compensation techniques include tilting the compensators 136, 146, 156 to reduce this effect, thereby improving system contrast. Unwanted reflected light off the proposed tilted compensator/air interfaces would be at a bias angle away from the system's optic axis, thereby desirably minimizing its capture and projection onto the display screen. It may also be of benefit to tilt the compensator to accommodate for subtle polarization effects emanating from the wire grid polarizing beam splitter that act to reduce system contrast.

[Para 25] Thus, tilting one or more of compensators 136, 146, 156 relative to the plane of the respective modulating panel 134, 144, 154 provides improvements to system contrast. In general, the biaxial compensators 136, 146, 156 (or compound compensating films having the same polarization effect) within the system, may be oriented about, and may be tilted with respect to, the projection system's 100 optic axis, specifically including tilting them relative to the plane of the respective modulating panels 134, 144, 154 and relative to the usual 45-degree orientation of the PBS surface. Although tilted plates adjacent to LCoS or other LC panels can reduce image quality through astigmatic aberration, an embodiment employs a compensating element of less than 0.5 mm to allow reasonable tilting (e.g., approximately 5 degrees, or less than about 5 degrees, or less than about 10 degrees) of up to ten degrees without significant image defocus (<0.5 pixel). In cases where any astigmatic aberration is unacceptable, a planar compensator with a tilted optic axis may be used such as a biaxial material sandwiched between oppositely wedged glass substrates. Although this does not reduce the surface reflection contribution to the contrast, it does act to further compensate the WGP 132, 142, 152. An exemplary embodiment of such a compensator component 800 is illustrated later with reference to FIGURES 8A and 8B.

[Para 26] Referring back to FIGURE 1, in a similar manner, biaxial materials whose optic axes are tilted with respect to their surfaces could alternatively be used to compensate WGPs. Such materials could include sheared plastic film or obliquely evaporated dichroic-based retardation plates.

[Para 27] Each modulating panel 134, 144, 154 is operable to modulate light by imparting a first polarization state upon certain portions of the light (*e.g.*, in an ON-state), and imparting a second polarization state upon other portions of the light (*e.g.*, in an OFF-state). The modulated light from each modulation subsystem 130, 140, 150 then passes through clean-up polarizers 162, 164, 166, respectively, prior to being recombined by dichroic x-cube 160, and being directed to a screen by projector lens 170.

[Para 28] More detail regarding the compensators 136, 146, 156 is provided below.

[Para 29] FIGURE 2 is a three dimensional schematic representation of the birefringence of a retardation film as an index ellipsoid 200. One or more retardation films may be combined to make a compensator, such as compensator 136, 146, or 156 of FIGURE 1. Any retardation film can be characterized uniquely by three refractive indexes n_x , n_y and n_z , where n_x , n_y and n_z are defined for orthogonal polarization axes. A representation of the three axes is shown by the index ellipsoid 200. It is known that with simple one-dimensional stretching, substantially uniaxial birefringence is formed with associated optical properties. In certain special cases, for instance positive uniaxial stretched films, two of the indexes are substantially equal (*e.g.*, $n_x > n_y = n_z$) and components formed from these materials are termed a-plates if the x-axis is in the plane of the material. Liquid crystal molecules in LCoS panels are positive uniaxial with their x-axis (optic axis) parallel to the molecular alignment direction. Negative c-plates are uniaxial with $n_x = n_y > n_z$, where the z-axis is normal to the plane of the component.

[Para 30] More recently, manufacturers have developed two-dimensional stretching of polycarbonate (PC). Such retarders may be appropriate to address LCD contrast and FOV enhancement requirements. The more complex 2D stretching, which includes shearing, can form layers that exhibit biaxiality. By controlling the extent of biaxiality, improvements in off-axis performance can be achieved. The extent to which off-axis performance is improved can be readily calculated for varying degrees of biaxiality in a viewing plane containing two of the film's three orthogonal optic axes (n_x , n_z). The optical properties of a biaxial film can be characterized by the N_z factor, where $N_z = (n_x - n_z) / (n_x - n_y)$. As described in chapter three of POLARIZATION ENGINEERING, it can be proven that the retardation in this particular incidence plane is independent to first order in angle when $N_z = 0.5$.

[Para 31] FIGURE 3 is a schematic diagram illustrating a possible construction of the elements of an exemplary compensator component 300. Stretched polymer retarders are typically manufactured by coating resin on a metal casting belt. As such, the optical properties (*e.g.*, transmitted wavefront distortion) of a polymer retarder can adversely affect the image quality when incorporated into a projection system. One solution is to mount the polymer film 302 between optically flat substrates 304 (such as glass) using a conforming, index matched optical adhesive 306. An anti-reflective coating 308 may be provided on the optically flat substrates 304. Film casting is followed by stretching. The stretching is accomplished in a continuous fashion via an accurately controlled oven with a pair of rollers turning at different rotation speeds. The precision of this process determines the spatial statistics

of the retarder film, including retardation and optic axis. Stretched polymer retarders are low-cost birefringent elements that can be manufactured with large apertures, good cosmetic quality, high durability, and with varying, prescribed retardances.

[Para 32] It should be appreciated that a single birefringent layer can be approximated by compound structures comprising combinations of retarder films. For example, a combination of an a- and c-plate can, properly designed, yield for certain performance characteristics substantially the same performance as a single biaxial film. Thus, in this application, the terms "compensator" or "biaxial compensator" includes single or compound retarders performing in this way. Furthermore, it should be appreciated that the compensators described herein may, in other embodiments, be made from any equivalent suitable material such as solid crystals, liquid crystal polymers, or another material exhibiting optical properties in which the R_o and R_{th} values of the compensator's retardance (defined below) can be configured consistent with the teachings of the present application. The liquid crystal polymer can have dual homogeneous alignment, splay alignment (homogeneous/homeotropic) or any suitable alignment.

[Para 33] The present application discloses various embodiments of compensators for an LC panel where the projected indices of the LC panel are compensated by the in-plane retardance component (R_o) and out-of-plane retardance component (R_{th}) of the film using a biaxial compensator. Referring back to FIGURE 2, for a single biaxial compensator (retarder), there are two

important parameters, R_0 and R_{th} . They are defined as follows:

$$\begin{aligned} R_0 &= (n_x - n_y)d \\ R_{th} &= ((n_x + n_y)/2 - n_z)d \end{aligned} \quad (1)$$

where d is the thickness of the retarder film. R_0 is used to compensate the head-on residual birefringence of the panel while R_{th} is used to compensate its out-of-plane component affecting FOV. As was the case in the commonly-assigned application, U.S. Pat. App. No. 10/908,671, the solution of the compensator orientation and its R_0 value follows a C-curve, which is shown in this application as FIGURE 4.

[Para 34] In an embodiment, an advantageous approach is to use a biaxial compensator that has an R_{th} value near in magnitude to the total retardance of the modulating panel ($=\Delta n \cdot d$ where Δn is the difference of the LC ordinary and extraordinary indices and d is its thickness) but having opposite sign. A value of R_0 is chosen to be greater than 10 nm more than the residual of the panel such that its x-axis is close ($<10^\circ$) to the input polarization direction. Referring back to FIGURE 1A, in an embodiment, the compensator (*e.g.*, 136, 146, 156) may then be rotated by $\sim 5^\circ$ about an axis parallel to the wire grid metal stripes such that the compensator is at an angle of about 40° relative to the PBS plate 142. As mentioned, however, the five-degree rotation is merely exemplary and other advantageous compensator plate tilting can be employed according to system design needs, including tilted about axes other than that defined by the wire grid stripes.

[Para 35] FIGURE 4 is a graph showing an exemplary relationship of compensator orientation as a function of in-plane retardance for an LC display panel. More specifically, FIGURE 4 illustrates a resulting 'C' curve 400 of optimal compensator orientation (y-axis) as a function of its in-plane retardance (x-axis) when the residual retardance of an LC panel is 3 nm at an input wavelength of 550 nm (*i.e.*, at point 405). The solution equation from which this C-curve is generated is set forth and described in commonly-assigned U.S. Pat. App. No. 10/908,671, which is incorporated by reference, and provides definition and application of that formula in the LC compensating context.

[Para 36] For each value of compensator retardance, there are two orientations (θ_1, θ_2) at which the residual in-plane retardance is compensated, where the orientations are related by $\theta_1 = 90^\circ - \theta_2$. Γ_r is the in-plane retardance of the compensator ($=R_0$ for a biaxial compensator), and Γ_p is the residual in-plane retardance of the panel. Thus, for a given Γ_r (where $\Gamma_r > \Gamma_p$), there are two possible compensator orientations given in FIGURE 4. In the specific illustration of FIGURE 4, the in-plane retardance is shown as an example at $\Gamma_r \cong 7$ nm, which yields $\theta_1 \cong 15^\circ$ and $\theta_2 \cong 75^\circ$, and given the relatively flat slope of the C-curve 400 in this region, the solution would be relatively impervious to variations in the in-plane retardance values of the compensator 146 (Γ_r) and/or LC panel 144 of FIG. 1A (Γ_p). The flatter part of the C-curve exists in some of the described embodiments for $\Gamma_r - \Gamma_p >$ approximately 15 nm.

[Para 37] In some embodiments, applicants have recognized the advantage in choosing a compensator with an in-plane retardance value Γ_r that is mismatched, at least to a certain degree, from that of the LC panel Γ_p in its OFF-state. In particular, because of the steep slope of the C-curve near the 45° solution 205, where $\theta_1 \cong \theta_2 \cong 45^\circ$, small variations in compensator or panel retardance in the 45° implementation can cause relatively dramatic shifts in the orientation solutions according to the illustrated C-curve of FIGURE 4. For example, according to the graph, if in-plane retardance of the compensator shifts from 3 nm to approximately 3.2 nm, a shift in retardance of only approximately 7%, the proper orientation angle shifts approximately a full 10°, from 45° to 55°. Without adjusting the system to compensate for this shift in retardance, there could be a dramatic shift in system performance.

[Para 38] Moving away from the 45° solution 405 to other portions of the illustrated C-curve 400 provides better systemic tolerance of variations of retardance values, Γ_r and Γ_p , thereby improving the manufacturability of the optical systems in which the disclosed compensators are employed. An exemplary solution range would be in those solutions on the C-curve where the orientation angle θ_1 is less than approximately 20° and the orientation angle θ_1 is greater than approximately 70° (e.g., in those areas where the C-curve 200 is flattening out). A wider-angle range would be where the orientation angle θ_1 is less than approximately 30° and the orientation angle θ_1 is greater than approximately 60°. The solutions closer to the 45° solution 405 have the disadvantage of requiring tighter tolerance on the in-plane retardance values in

order to maintain the same the optical system components near their optimal orientations.

[Para 39] The above description provides solutions whereby the in-plane residual retardance of a panel Γ_p can be compensated in a reflective LC projection system by an optical component that has an in-plane retardance equal to, or greater than Γ_r . Although in-plane compensation only may yield sufficient system performance, a more complete solution includes simultaneous out-of-plane panel compensation. Some embodiments of this patent disclosure therefore may include creating a compensating component that has one or more birefringent layers that has an in-plane retardance value greater than that of the panel and properties that can offer some (or indeed complete) out-of-plane compensation. The orientation parameter(s) and tilt component can then be selected in accordance with the above teachings to ensure good in-plane compensation.

[Para 40] In addition to compensating for the LC panel, the compensators described in this application may also be used to compensate for other components in an optical projection system, and in particular may be used to compensate for birefringent effects induced by other optical components, including wire grid, MacNeille, form birefringent (*e.g.*, Vikuiti™ PBS manufactured by 3M, Inc.) or other types of polarizing beam splitters. [An illustration of an exemplary projection system with a cube PBS is shown later with reference to FIGURE 7]. A wire-grid PBS plate, for example, is an important component found in many optical projection systems, and in particular in many LCoS projection systems, and the compensators disclosed by this application

may be used to compensate for nonideal polarization effects introduced by these types of component, as well.

[Para 41] For instance, the overall optimum compensation solution for system contrast in an exemplary optical projection system 100 should also take into account imperfections in polarization handling of this beam splitting component. The plate PBS is a tilted wire-grid polarizer, and in effect can be thought of as a periodic ordering of one-dimensional metal gratings, ideally with a pitch $< 1/10$ of the shortest illuminating wavelength.

[Para 42] The performance of a high aspect ratio ($a'/a \gg 1$) wire grid PBS can be modeled as a form-birefringence element comprising alternate metal/air layers normal to the substrate. In an embodiment, assuming an aluminum wire grid structure of the type shown in FIGURE 5, with a 50% fill factor ($a = b$) and a pitch much smaller than visible light wavelengths ($\ll 0.5\mu\text{m}$), the following uniaxial refractive indexes can be derived:

$$n_o^0 = \sqrt{\frac{n_{air}^2 + n_{Al}^2}{2}} = 0.696 + 4.71i \quad \text{and} \quad n_e^0 = \frac{\sqrt{2}n_{air}n_{Al}}{\sqrt{n_{air}^2 + n_{Al}^2}} = 1.43 + 0.0045i \quad (2)$$

taking the refractive index of the aluminum, n_{Al} to be $0.974 + 6.73i$ at $\lambda = 550$ nm.

[Para 43] The large imaginary index of the ordinary ray (o-mode) (polarized in the plane of the substrate and parallel to the metal stripes), produces severe attenuation in transmission and high reflectivity at boundaries. On the other hand, the e-mode (with electric field perpendicular to metal stripes)

experiences minimal attenuation and reflectivity. Hence theoretically, the structure acts as an e-type polarizer in transmission and an o-type in reflection. In the more practical case, however, $a'/a \sim 1$, making the structure resemble more closely a cylindrical wire grid, which from symmetry would be an o-type polarizer in transmission with its optic axis along the wires.

[Para 44] More detailed measurement of the wire grid PBS shows that its description in terms of a simple o-type polarizer is not entirely adequate. As further described in POLARIZATION ENGINEERING, p.99, direct measurements indicate significant induced ellipticity of skew-ray polarization in transmission consistent with small biaxiality. Thus, to further optimize system contrast, it is desirable to also compensate for the ellipticity of skew-ray polarization of the wire-grid PBS, and the presently disclosed compensation schemes address this.

[Para 45] FIGURE 6 is a perspective schematic diagram showing the application and positioning of a wire grid polarizer in an exemplary modulation subsystem. To achieve high contrast, sheet polarizers 602 and 604 are located on the entrance and exit ports. Exit polarizer 604 may be the absorptive type. Wire grid polarizer 606 may be positioned along the modulated light portion of the light path and operable to direct a first polarization light in a first direction and to direct a second polarization light in a second direction. Of the two input polarization options, geometrical considerations dictate that the wire orientation of wire-grid polarizer 606 should be substantially normal to the system optic axis since the component tends to behave predominantly as an o-type polarizer with its axis along the wires.

[Para 46] The compensator 608 may be tilted about an axis that is substantially parallel to the wires of the wire-grid polarizer. Further, the compensator 608 may be tilted about the axis toward the plane of the wire-grid polarizer 606 such that the angle between the plane of the compensator 608 and the plane of the wire-grid polarizer 606 is substantially reduced. A reflective panel 610 modulates the light, which reflects off the panel 610 toward wire-grid polarizer 606. Since the modulated light is s-polarized, it is reflected by the WGP 606 toward the exit port and sheet polarizer 604.

[Para 47] FIGURE 7 is a schematic diagram of an exemplary optical three-panel LCoS projection system using a polarization beam splitter cube. Projection system 700 shows an exemplary MacNeille 3xPBS/x-cube architecture employing tilted PBS cubes. Collimated light from illumination subsystem 702 is directed toward red, green, and blue modulating subsystems 704, 706, 708, respectively. Each of modulating subsystems 704, 706, 708 respectively includes a MacNeille PBS 710, 712, 714, an LCoS panel 722, 724, 726, and a compensator disposed between the LCoS panel and the PBS, with the elements arranged as shown. As previously described with respect to other embodiments, the compensators 716, 718, 720 may be tilted relative to the plane of the respective LCoS panel 722, 724, 726.

[Para 48] With MacNeille PBSs, it is known that geometrical skew ray polarization mixing can effect the contrast performance of projection system. A way of tackling this issue is to locate pre- and/or post- polarizers at the input and output ports of modulating subsystems 704, 706, 708. The presence of the tilted compensators 716, 718, 720 also improves contrast by

decreasing these geometrical effects. Accordingly, a suitable R_{th} value of the compensator 716, 718, 720 may be chosen to be substantially matched to the retardance of the respective LCoS panel 722, 724, 726. Additionally, the R_{th} value may be chosen to address the geometrical effects from a MacNeille PBS. A further technique includes using a quarter wave plate in addition to a compensator, the QWP is aligned to the PBS's s-polarization axis.

[Para 49] Although a MacNeille type PBS is shown in this exemplary embodiment, it should be appreciated that this is used for illustration only, and other types of PBS may be used. For instance, a multilayer or a form-birefringent PBS may be substituted for the MacNeille type. However, form-birefringent PBSs generally do not suffer from the geometrical skew ray polarization mixing that MacNeille type PBSs incur. Thus, the R_{th} value of the compensator in embodiments using form-birefringent PBSs may be selected to be substantially matched to the total retardance of the respective LCoS panel 722, 724, 726.

[Para 50] FIGURE 8A is a schematic perspective diagram illustrating another exemplary compensator component 800. As mentioned above, in cases where any astigmatic aberration is unacceptable, a planar compensator with a tilted optic axis may be used such as a biaxial material 802 sandwiched between oppositely wedged glass substrates 804. Optionally, an anti-reflective coating 808 may be applied to the glass substrates 804. Biaxial material 802 may be bonded to the glass substrates 804 using a conforming index-matched adhesive 806. An exemplary orientation axis for the biaxial material 802 is shown by arrow 810 at θ° relative to the horizontal. Although this embodiment

does not significantly reduce the surface reflection contribution to the contrast, it does act to further compensate the wire grid PBS.

[Para 51] FIGURE 8B is a schematic diagram illustrating a cross-sectional view of the compensator component 800. This view illustrates that the wedged glass substrates 804 keep the biaxial material 802 at a tilt angle to the surface of compensator component 800. It should thus be appreciated that when compensator component 800 is used with projection systems, such as those illustrated in FIGURES 1 and 7, that the plane of the component 800 is parallel to the LC panel, although the plane biaxial material 802 is tilted relative to the plane of the LC panel, and the optic axis of the compensator is also tilted with respect to the LC panel.

[Para 52] It will be appreciated by those of ordinary skill in the art that the teachings herein can be embodied in other specific forms without departing from the spirit or essential character thereof. The presently disclosed embodiments are therefore considered in all respects to be illustrative and not restrictive. The scope of the invention is indicated by the appended claims rather than the foregoing description, and all changes that come within the meaning and ranges of equivalents thereof are intended to be embraced therein.

[Para 53] Additionally, the section headings herein are provided for consistency with the suggestions under 37 C.F.R. § 1.77 or otherwise to provide organizational cues. These headings shall not limit or characterize the invention(s) set out in any claims that may issue from this disclosure. Specifically and by way of example, although the headings refer to a "Technical

Field,” the claims should not be limited by the language chosen under this heading to describe the so-called technical field. Further, a description of a technology in the “Background” is not to be construed as an admission that technology is prior art to any invention(s) in this disclosure. Neither is the “Summary” to be considered as a characterization of the invention(s) set forth in the claims found herein. Furthermore, any reference in this disclosure to “invention” in the singular should not be used to argue that there is only a single point of novelty claimed in this disclosure. Multiple inventions may be set forth according to the limitations of the multiple claims associated with this disclosure, and the claims accordingly define the invention(s), and their equivalents, that are protected thereby. In all instances, the scope of the claims shall be considered on their own merits in light of the specification, but should not be constrained by the headings set forth herein.

What is claimed is:

[Claim 1] An optical projection system for projecting modulated light from a liquid crystal (LC) panel along a light path, the projection system comprising:

an LC panel positioned in the light path, the LC panel being substantially planar and operable to receive polarized input light on an illumination portion of the light path and to modulate the input light to form a modulated light that travels along a modulated light portion of the light path, the LC panel imparting a first polarization upon certain portions of the input light, and the LC panel imparting a second polarization upon other portions of the input light; and

a compensator positioned along the light path, the compensator being substantially planar, the compensator having an optic axis that is tilted relative to the plane of the LC panel.

[Claim 2] An optical projection system according to claim 1, wherein the optic axis of the compensator lies within its physical plane.

[Claim 3] An optical projection system according to claim 1, wherein the compensator is a single biaxial film.

[Claim 4] An optical projection system according to claim 1, wherein the compensator comprises multiple layers of biaxial films.

[Claim 5] An optical projection system according to claim 1, further comprising a polarizing beam splitter positioned along the modulated light portion of the light path and operable to direct the first polarization light in a first direction and to direct the second polarization light in a second direction.

[Claim 6] An optical projection system according to claim 5, wherein the compensator is operable to compensate for nonideal polarization effects imposed by the LC panel and by the polarizing beam splitter.

[Claim 7] An optical projection system according to claim 5, wherein the compensator is operable to deflect away unwanted reflected light off of the light path.

[Claim 8] An optical projection system according to claim 5, wherein the polarizing beam splitter is a wire-grid polarizer.

[Claim 9] An optical projection system according to claim 8, wherein the compensator is tilted about an axis that is substantially parallel to the wires of the wire-grid polarizer.

[Claim 10] An optical projection system according to claim 9, wherein the compensator is tilted about the axis toward the plane of the wire-grid polarizer such that the angle between the plane of the compensator and the plane of the wire-grid polarizer is substantially reduced.

[Claim 11] An optical projection system according to claim 5, wherein the polarizing beam splitter is a MacNeille polarizer.

[Claim 12] An optical projection system according to claim 5, wherein the polarizing beam splitter is a multilayer birefringent cube polarizer.

[Claim 13] An optical projection system according to claim 1, wherein the LC panel is a reflective panel.

[Claim 14] An optical projection system according to claim 13, wherein the reflective panel is an LCoS panel.

[Claim 15] An optical projection system according to claim 14, and further comprising a wire-grid polarizing beam splitter positioned along the modulated light portion of the light path and operable to direct the first polarization light in a first direction and to direct the second polarization light in a second direction.

[Claim 16] An optical projection system according to claim 1, wherein the LC panel is a transmissive panel.

[Claim 17] An optical projection system according to claim 1, wherein the biaxial retarder compensator is a uniaxial retarder compensator.

[Claim 18] An optical projection system according to claim 1, wherein the compensator compensates for dark-state nonideal polarization effects of the LC panel.

[Claim 19] An optical projection system according to claim 1, wherein the compensator is oriented to compensate for the in-plane residual panel retardance of the LC panel.

[Claim 20] An optical projection system according to claim 19, wherein the orientation of the compensator is in the range of three degrees to forty degrees.

[Claim 21] An optical projection system according to claim 1, wherein an out-of-plane retardance (R_{th}) value of the compensator is substantially matched to the retardance of the LC panel.

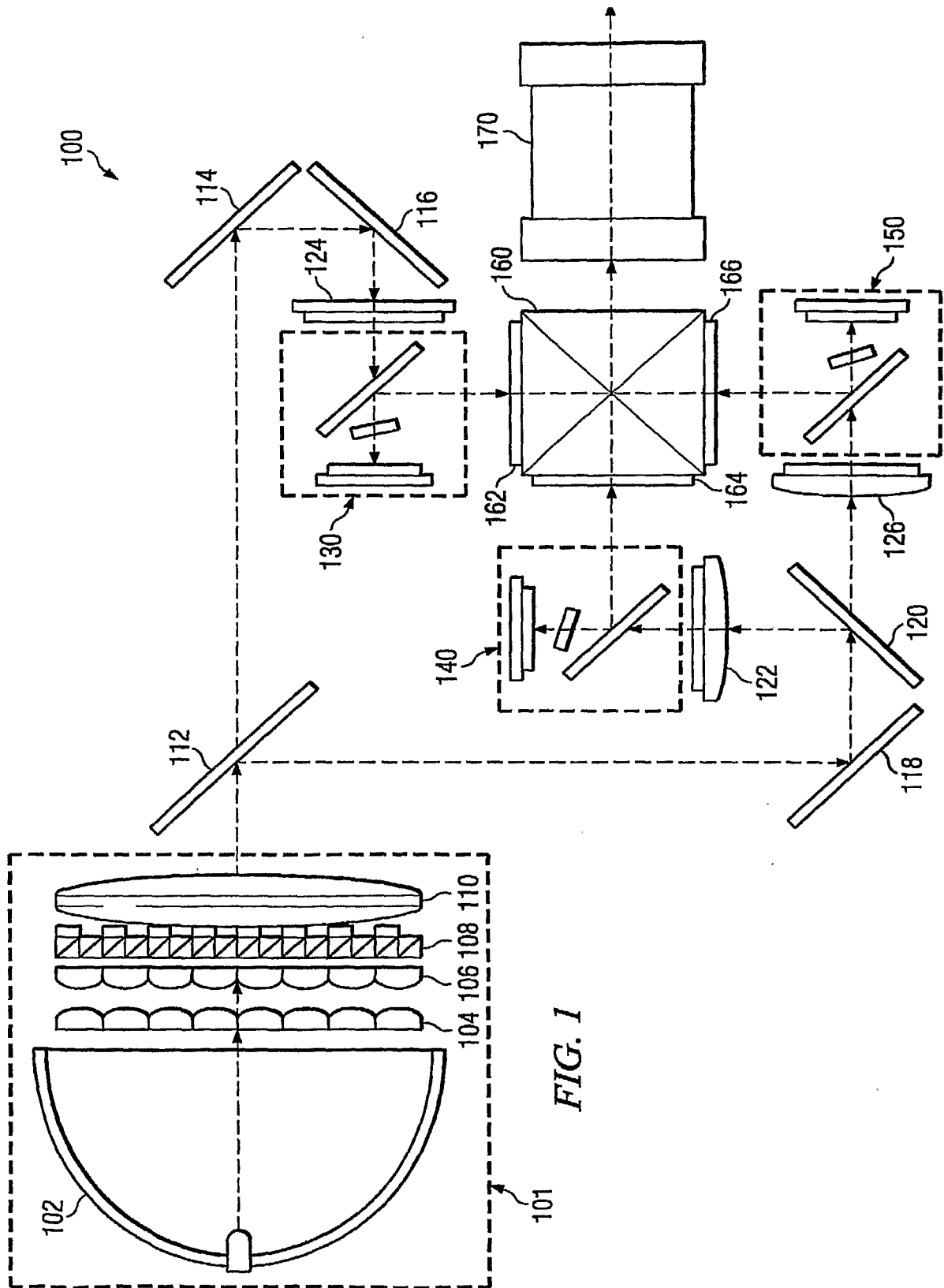
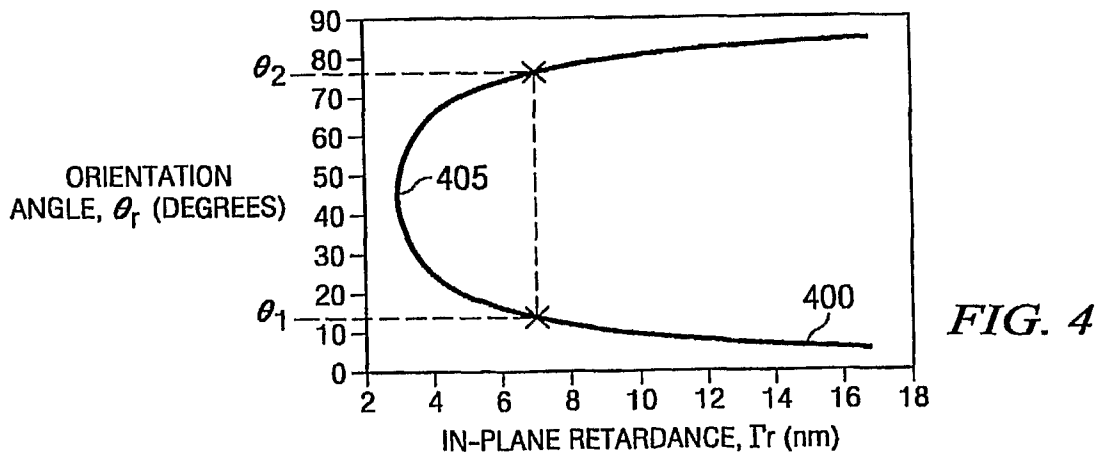
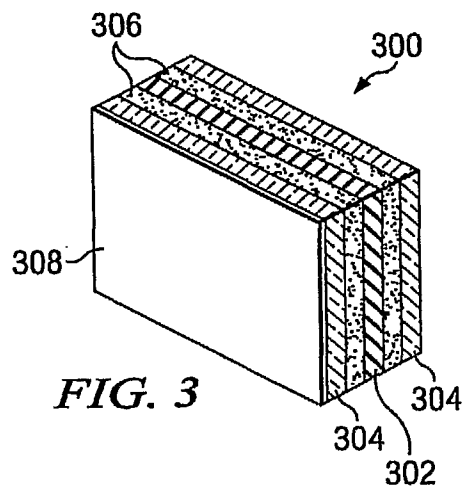
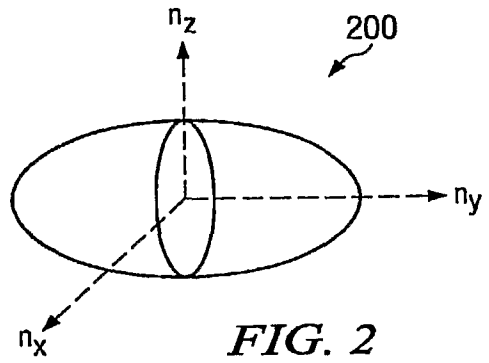
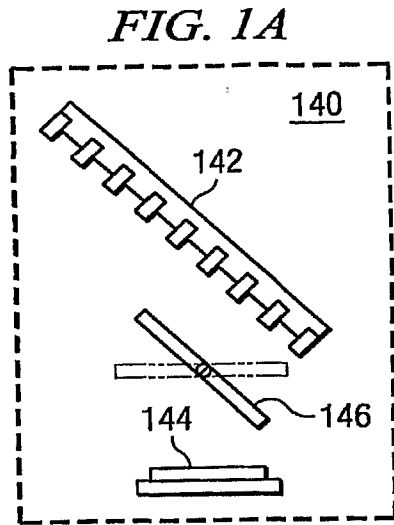


FIG. 1



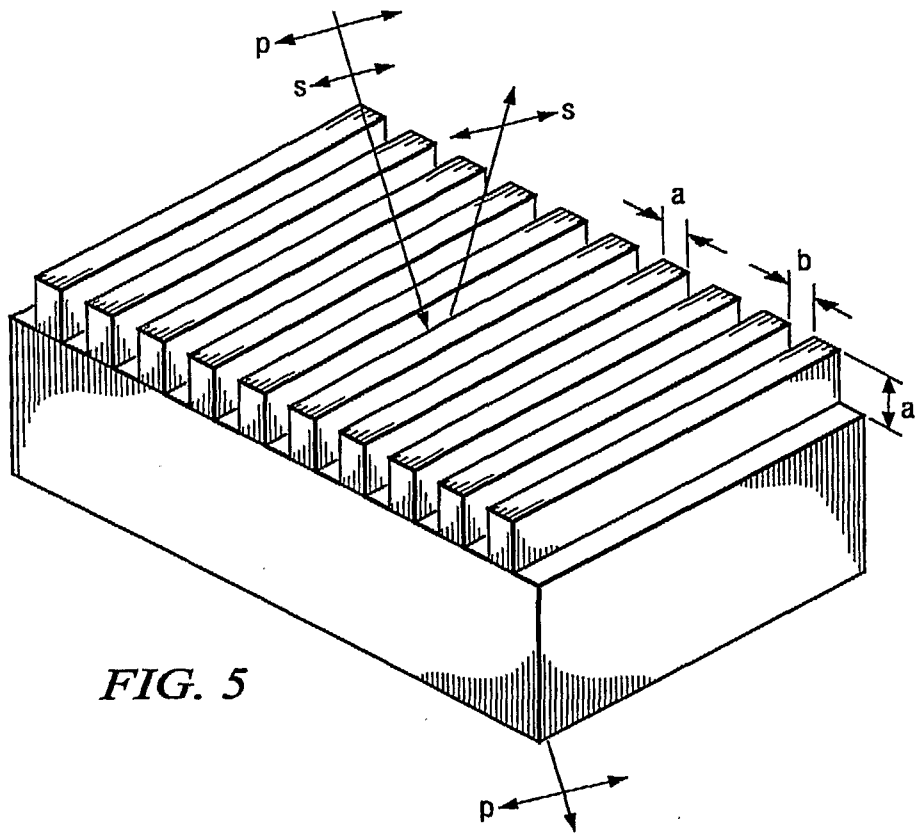


FIG. 5

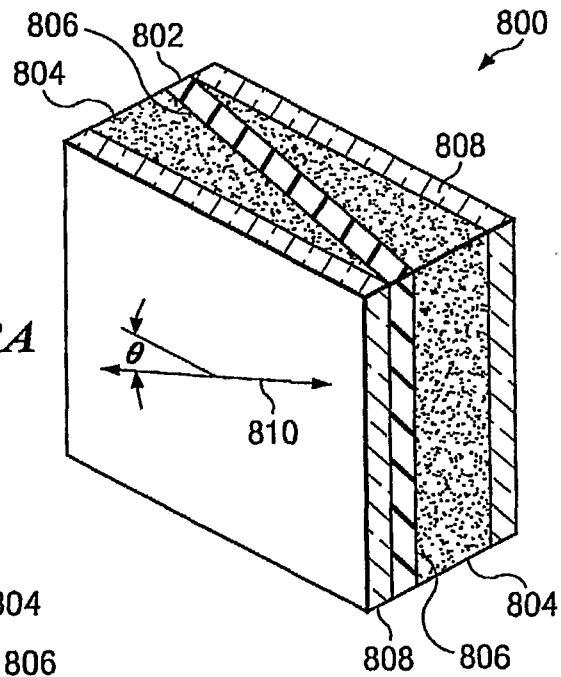


FIG. 8A

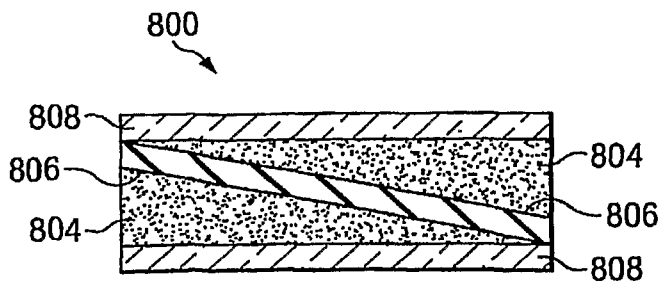


FIG. 8B

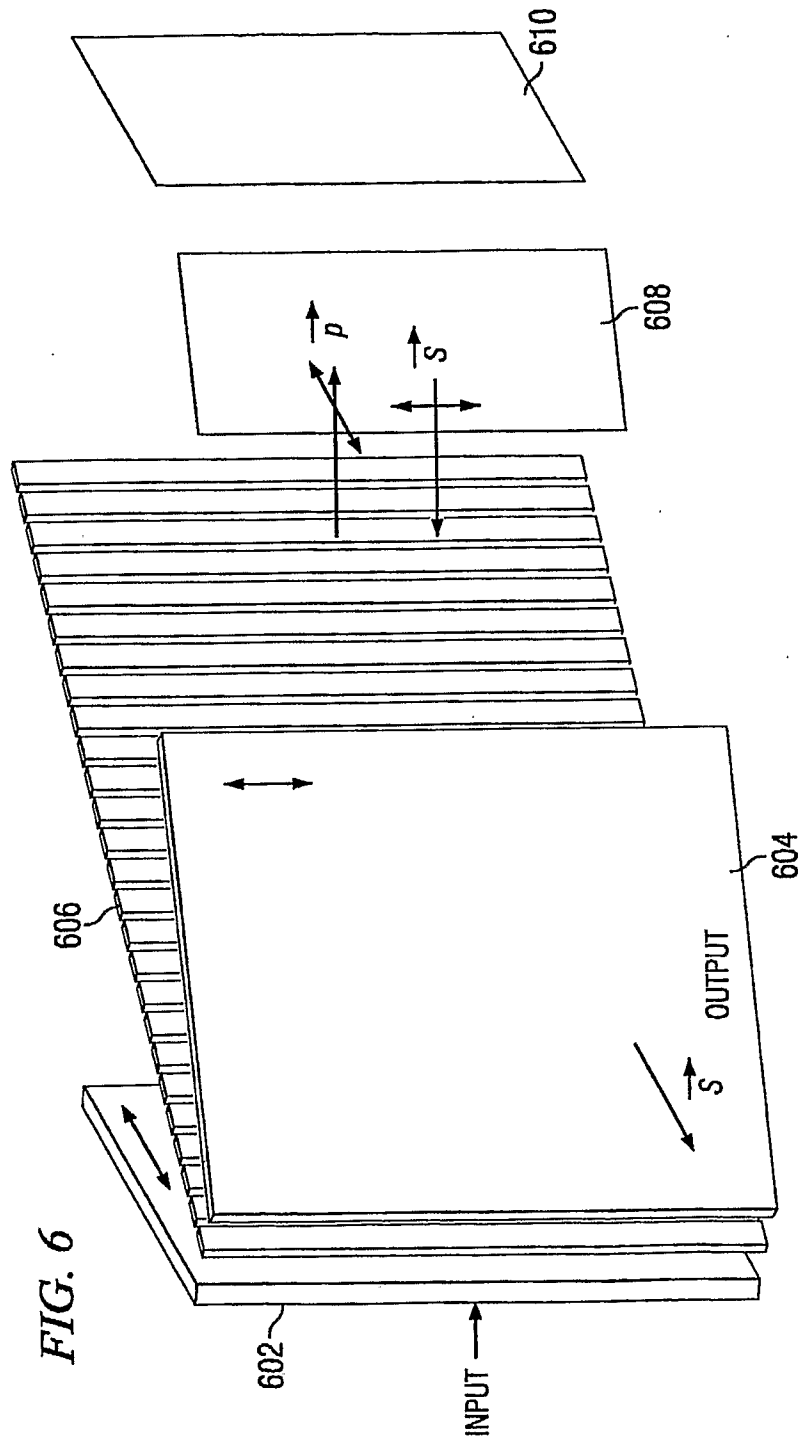


FIG. 6

