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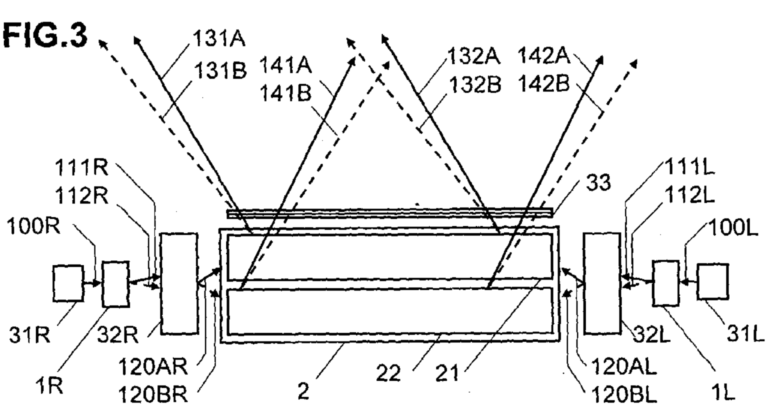
FIG.3



(57) Abstract: There is provided a switchable holographic beam deflection device for autostereoscopic displays comprising: at laser illumination source; a micro scanner; a beam deflection means comprising: a left eye beam deflector for directing light to a left eye viewing direction; a right eye beam deflector for directing light to a right eye viewing direction; a first means for coupling light from the micro scanner into the left eye beam deflector to provide a first input illumination path; and a second means for coupling light from the micro scanner into the right eye beam deflector to provide a second input illumination path.

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HOLOGRAPHIC BEAM DEFLECTOR FOR AUTOSTEREOSCOPIC DISPLAYS

REFERENCE TO PRIORITY APPLICATION

This application claims the priority of US Provisional Patent Application No. 61/457,835 entitled "HOLOGRAPHIC BEAM STEERING DEVICE FOR AUTOSTEREOSCOPIC DISPLAYS" filed on 16 June 2011, US Provisional Patent Application No. 61/457,834 entitled "HOLOGRAPHIC BEAM STEERING DEVICES FOR AUTOSTEREOSCOPIC DISPLAYS" filed on 16 June 2011, and US Provisional Patent Application No. 61/573,018 entitled "FURTHER IMPROVEMENTS TO HOLOGRAPHIC BEAM STEERING DEVICES FOR AUTOSTEREOSCOPIC DISPLAYS" filed on 5 August 2011.

CROSS REFERENCE TO RELATED APPLICATIONS

This application incorporates by reference in their entireties PCT Application No.: PCT/GB2010/001982 entitled COMPACT EDGE ILLUMINATED EYEGLASS DISPLAY, PCT/GB2010/002023 filed on 2 November 2010 entitled APPARATUS FOR REDUCING LASER SPECKLE, PCT Application No.: US2006/043938 filed on 13 November 2006 entitled METHOD AND APPARATUS FOR PROVIDING A TRANSPARENT DISPLAY, US Provisional Patent Application No. 61/457,835 entitled "HOLOGRAPHIC BEAM STEERING DEVICE FOR AUTOSTEREOSCOPIC DISPLAYS" filed on 16 June 2011, US Provisional Patent Application No. 61/457,834 entitled "HOLOGRAPHIC BEAM STEERING DEVICES FOR AUTOSTEREOSCOPIC DISPLAYS" filed on 16 June 2011, and US Provisional Patent Application No. 61/573,018 entitled "FURTHER IMPROVEMENTS TO HOLOGRAPHIC BEAM STEERING DEVICES FOR AUTOSTEREOSCOPIC DISPLAYS" filed on 5 August 2011.

BACKGROUND OF THE INVENTION

The present invention relates to an electro optical beam deflection device, and more particularly to a beam deflection device based on electrically switchable Bragg gratings.

Beam deflectors are required in a range of applications. Devices designed for more demanding applications such as laser radar tend to rely on mechanical scanning using lenslet arrays, micro-electrical-mechanical (MEM) devices and other techniques. Recently a role has been identified for beam deflectors in autostereoscopic displays as a means for providing head position-slaved left and right eye illumination. The size, complexity and reliability issues of mechanical scanners make them unsuitable for consumer autostereoscopic displays where extremely compact and robust designs are required. Non–mechanical solutions using liquid crystal (LC) offer the benefits of variable blaze, variable period, large birefringence and low driving voltages but suffer from limited efficiency at angles greater than a few degrees. To achieve efficient continuous scanning over large angles it is therefore necessary to combine low angle LC continuous sweep scanners with alternate large angle discrete sweep scanning technologies.

There is a requirement for a compact wide angle electro optical beam deflection device. There is a further requirement for a compact transparent electro optical beam deflection device for providing alternate left and right eye perspective illumination light in autostereoscopic displays.

SUMMARY OF THE INVENTION

It is a first object of the invention to provide a compact wide angle electro optical beam deflection device. It is a further objective of the invention to provide a compact transparent electro optical beam deflection device for providing alternate left and right eye perspective illumination light in autostereoscopic displays.

The objects of the invention are achieved in a first embodiment in which there is provided a light beam deflection device for use in autostereoscopic displays comprising: at least one source of laser illumination; at least one micro scanner; a beam deflection means comprising: a left eye beam deflector for directing light to a left eye viewing direction; a right eye beam deflector for directing light to a right eye viewing direction; a first means for coupling light from the micro scanner into the left eye beam deflector to provide a first input illumination path; and a second means for coupling light from the micro scanner into the left eye beam deflector to provide a second input illumination path. The first and second input illumination paths are in opposing directions. The left eye beam deflector comprises a first array of selectively switchable grating elements. The left eye beam deflector comprises a second array of selectively switchable grating elements. Each grating element has a diffracting state and a non diffracting state. The grating elements are shaped as columns with long edges aligned orthogonally to the illumination path directions. The micro scanner applies a time varying angular displacement to the laser illumination. The elements of the first and second arrays are switched on and off cyclically with one element in each array being in its diffracting state at any time. The left eye beam deflector when in its diffracting state diffracts first input illumination light into the left eye direction. The right eye beam deflector when in its diffracting state diffracts second input illumination light into the right eye direction.

In one embodiment of the invention the source provides sequential, first, second and third wavelength light. The array elements of the left and right eye deflectors are SBGs into which are recorded a first Bragg grating for diffracting first and second wavelengths into a predetermined direction superimposed on a second SBG grating for directing third wavelength light into said predetermined direction. The SBG elements are sandwiched by a pair of transparent substrates with transparent electrodes applied to their opposing faces. The left and right eye deflectors are stacked to form a lightguide. The first and second illumination paths are confined by total internal reflection within the lightguide.

In one embodiment of the invention the apparatus further comprises an angle expander means disposed at the output of the micro scanner for magnifying the angular displacement of the laser illumination.

In one embodiment of the invention the array elements are grouped into supercolumns. The refractive index modulation of each element in a supercolumn is dynamically controlled such that a predetermined amount of light with a predetermined spatial distribution is diffracted out of the supercolumn into the left or right eye viewing directions.

In one embodiment of the invention each grating element comprises a SBG and a non switchable grating overlaid over the SBG.

In one embodiment of the invention each grating element comprises a surface relief grating backfilled with a variable refractive index material switchable grating overlaid over a SBG.

In one embodiment of the invention the non switchable grating is a surface relief grating.

In one embodiment of the invention the non switchable grating is a blazed surface relief grating.

In one embodiment of the invention a micro scanner comprises: a first transparent optical substrate with an input surface and an output surface; a second transparent optical substrate with an input surface and an output surface; transparent electrodes applied to the output surface of the first substrate and the input surface of the second substrate; variable index layer having a planar surface and a second surface shaped to provide an array of prisms; and a fixed refractive index layer having a planar surface and a second surface shaped to provide an array of prismatic cavities. The prisms and prismatic cavities have identical geometries, each prism abutting a prismatic cavity. The planar surface of the variable index layer abuts the output surface of first substrate while the planar surface of the polymer layer abuts the input surface of the second substrate. The transparent electrodes are electrically coupled to a variable voltage generating means.

In one embodiment of the invention at least one of the transparent electrodes is patterned into independently switchable electrode elements having substantially the same cross sectional area as the prisms such that the variable index prisms may be selectively switched in discrete steps from a fully diffracting to a non diffracting state by an electric field applied across the transparent electrodes.

In one embodiment of the invention the variable index layer is a subwavelength grating recorded in HPDLC.

In one embodiment of the invention the refractive index differential between the variable refractive index layer and the fixed refractive index layer is positive when a first voltage is applied and negative when a second voltage is applied and zero when a third voltage is applied. The application of the first, second or third voltages causes light entering the beam deflection device normal to the input surface of the first transparent substrate to emerge from the output surface of the second substrate in first, second or third directions respectively. The first and second directions are in opposing angles to the normal to the output surface and the third direction is parallel to the normal to the output surface.

In one embodiment of the invention one face of each prism is at ninety degrees to said planar surface of the variable refractive index layer.

In one embodiment of the invention the prisms are provided by a linear array of elements of triangular cross section.

In one embodiment of the invention the micro scanner further comprises a means for expanding the angular deflection provided by the variable refractive index layer and fixed refractive index layers.

In one embodiment of the invention randomly varying voltages are applied across each variable refractive index prism.

In one embodiment of the invention there is provided a means for generating left and right eye perspective illumination light in which a stack of four SBGs provides the beam deflection means. The apparatus comprises a backlight means a light source , means for coupling light from the source into the backlight and first, second, third and fourth SBG beam deflectors. Desirably the backlight incorporates a brightness enhancement film (BEF) which limits the angular extent of the beam emitted by the backlight. Advantageously, the backlight also includes means for recycling light that falls outside the required emission angular range. In a first state of the apparatus the first and third SBGs are in a diffracting state and the second and fourth SBGs are in a non diffracting state. Light from the backlight undergoes a first deflection at the first SBG and a second deflection at the third SBG into a left eye perspective. In a second state of the apparatus the second d and fourth SBGs are switched into their diffracting states and the first and third SBGs are switched into their non diffracting states. Light from the backlight undergoes a first deflection at the second SBG 142 and second deflection at the fourth SBG into a right eye perspective.

In one embodiment of the invention the left and right perspective light is produced time-sequentially.

In one embodiment of the invention the left and right eye perspective light is produced by means of a scrolling illumination scheme in which portions of the left and right eye perspective light beams are presented simultaneously. In this embodiment the third and fourth SBGs are each patterned into selectively switchable SBG elongate elements. The elements of the third SBG diffract light into a right eye perspective while the elements of the fourth SBG diffract light into a left eye perspective. The active elements in each SBG are switched in scrolling fashion to provide at least one band of diffracting elements that propagate across the SBG the first element in a band being switched into its diffracting stated at the same time as the last element in the group is switched into a non diffracting states, all other elements remaining in a non diffracting state. The elements of the two SBGs have complementary states such that at any instant in time each point in the emission area of the illuminator provides either left or right eye perspective light.

In one embodiment of the invention the SBGs are designed to compensate for chromatic dispersion.

In one embodiment of the invention there is provided a backlight comprising a slab of transparent optical material, a structured diffusion layer applied to a first face of the slab, a brightness enhancement film (BEF) applied to the opposing face of the slab, a mirror coating applied to one edge of the slab and an optical portion the opposing edge of the slab for inputting light from a light source. Light from the source is coupled into the slab via a lens system along an optical path. The BEF has a prism structured surface.

In one embodiment of the invention there is provided a means for providing opposing angle beam deflections in which the deflection means is a variable refractive index layer sandwiched between first and second Diffractive Optical Elements (DOEs). The first and second DOEs are fabricated from materials of first and second refractive indices respectively. Each DOE has a planar surface and a diffracting surface comprising a surface relief structure designed to provide a specified diffusion ray angular distribution for a predefined input ray angular distribution. The diffracting surfaces of the DOEs abut the variable refractive index layer.

In one embodiment of the invention the left and right eye deflectors are blazed gratings backfilled with a variable refractive index material. The preferred variable refractive index medium being one based on HPDLC and specifically a HPDLC configured as a sub wavelength grating. Each blaze grating steers red, green or blue incident beams in to a multiplicity of different directions corresponding to diffraction orders of the blazed grating for each primary color by tuning the voltage across the variable index layer to predefined values.

In one embodiment of the invention the blazed grating provides four distinct output beam directions for each primary colour.

In one embodiment of the invention two blazed gratings each providing four distinct output beam directions for each primary colour are operated in tandem to produce sixteen output beam directions for each primary colour

In one embodiment of the invention the difference between fixed and variable refractive indices equals an integer number times the ratio of wavelength to the thickness of the blazed grating.

In one embodiment of the invention the voltages applied across the grating elements in the left and right eye beam deflector arrays are modulated in time.

In one embodiment of the invention the beam deflector array columns may comprise columns of pixels.

In one embodiment of the invention the beam deflector arrays columns may comprise columns of pixels and the voltages applied across each pixel is modulated in so that the beam deflectors array may be used to display a two dimensional gray level image.

The desired diffracting states of the left or right eye beam deflector elements are achieved by applying a voltage across each element via the transparent electrodes which are applied to the opposing faces of substrates sandwiching the diffractive element. In one embodiment of the invention the voltage comprises either a predefined maximum voltage or no voltage.

In one embodiment of the invention the voltage applied across each element of a left or right eye beam deflector element is varied to provide intermediate voltage levels between 0 volts and a predefined maximum voltage. In one embodiment of the invention the voltage is varied continuously. In one embodiment of the invention the voltage is varied in discrete steps. In one embodiment of the invention the voltage is varied to provide image grey levels.

In one embodiment of the invention the deflector arrays columns may comprise columns of pixels provide a two dimensional array

In one embodiment of the invention at least one of left or right eye beam deflector may be used to provide a grey level two dimensional image on the surface of the beam deflector.

In one embodiment of the invention there is provided an autostereoscopic display using a light beam deflection device according to the principles of the invention, said display being switchable between a three dimensional mode in which the display panel is is updated field sequentially with left/right eye information and a two dimensional mode the display panel displays a common left/right eye image.

A more complete understanding of the invention can be obtained by considering the following detailed description in conjunction with the accompanying drawings wherein like index numerals indicate like parts. For purposes of clarity details relating to technical material that is known in the technical fields related to the invention have not been described in detail.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG.1 is a schematic front elevation view of one embodiment of the invention.

FIG.2 is a schematic front elevation view of one embodiment of the invention.

FIG.3 is a schematic front elevation view of one embodiment of the invention.

FIG.4 is a schematic side elevation view of a micro scanner in one embodiment of the invention.

FIG.5 is a schematic side elevation view of first aspect of one embodiment of the invention.

FIG.6 is a schematic side elevation view of second aspect of one embodiment of the invention.

FIG.7 is a schematic side elevation view of third aspect of one embodiment of the invention.

FIG.8A is a schematic plan view of the viewing geometry of an autostereoscopic display provided in one embodiment of the invention.

FIG.8B is a schematic plan view of the viewing geometry of 2D display provided in one embodiment of the invention.

FIG.9 is a schematic side elevation view of a beam angle expansion means used in one embodiment of the invention.

FIG.10 is a schematic side elevation view of a beam angle expansion means used in one embodiment of the invention.

FIG.11A is a chart illustrating the sequential display of left and right eye images on a SLM

FIG.11B is a chart illustrating a voltage waveform use in an autostereoscopic display according to the principles of the invention.

FIG.12 is a chart illustrating a random voltage waveform used in one embodiment of the invention.

FIG.13 is a schematic front elevation view of one embodiment of the invention showing ray deflection by left and right eye beam deflectors

FIG.14 is a schematic front elevation view the left and right eye beam deflectors used in one embodiment of the invention.

FIG.15 is a schematic front elevation view of one embodiment of the invention showing ray deflection by left and right eye beam deflectors based on multiplexed SBGs.

FIG.16 is a schematic front elevation view of a multiplexed SBG element.

FIG.17 is a schematic front elevation view the left and right eye beam deflectors based on multiplexed SBGs used in one embodiment of the invention.

FIG.18 is a set of ray diagrams illustrating the production of left and right eye illumination by the left and right eye beam deflectors in one embodiment of the invention.

FIG.19 is a schematic front elevation view of an illumination apparatus for an autostereoscopic display in one embodiment of the invention.

FIG.20 is a schematic plan view of an SBG array used in left or right eye beam deflector one embodiment of the invention.

FIG.21 is a schematic plan view of an SBG array used in left or right eye beam deflector one embodiment of the invention showing the division of the array into supercolumns

FIG.22 is a cross sectional view of a supercolumn indicating ray paths and light extraction parameters.

FIG.23 is a cross sectional view of a supercolumn with geometric parameters indicated.

FIG.24 is table show typical bounce ray bounce lengths and numbers of bounces across a super column.

FIG.25 is a chart illustrating the refractive index modulation of a SBG.

FIG.26 is a table providing data on SBG diffraction efficiency as a function refractive index modulation.

FIG.27A is a chart illustrating SBG diffraction efficiency as a function of incidence angle for blue and green illumination.

FIG.27B is a chart illustrating SBG diffraction efficiency as a function of incidence angle for red illumination.

FIG.28 is a k-vector diagram used to characterize the diffraction characteristics of a beam deflector using Bragg gratings.

FIG.29 is a plan view of an autostereoscopic illuminator showing the key geometrical parameters used in the design of a beam deflector according to the principles of the invention.

FIG.30 is a table showing typical values of the parameter FIG.29.

FIG.31 is a table showing examples oftypical data for a beam deflector based on the design data given in FIG.29.

FIG.32 is a front elevation view of a beam deflector element comprising a SBG and a surface relief grating.

FIG.33 is a detail of a blazed surface relief grating used in a beam deflector element comprising a SBG and a surface relief grating.

FIG.34A is a schematic front elevation view of a first aspect of upper and lower elements of a beam deflector based on blazed surface relief gratings backfield with a variable refractive index material.

FIG.34B is a schematic front elevation view of a second aspect of upper and lower elements of a beam deflector based on blazed surface relief gratings backfield with a variable refractive index material.

FIG.35 is a schematic front elevation view of a first aspect of an alternative beam deflector based on blazed surface relief gratings backfilled with a variable refractive index material.

FIG.36A is a schematic front elevation view of a first aspect of another beam deflector based on blazed surface relief gratings backfilled with a variable refractive index material.

FIG.36B is a schematic front elevation view of a second aspect of another beam deflector based on blazed surface relief gratings backfilled with a variable refractive index material.

FIG.36C is a schematic front elevation view of a third aspect of another beam deflector based on blazed surface relief gratings backfilled with a variable refractive index material.

FIG.37 is a schematic front elevation view of one embodiment of the invention.

FIG.38A is a schematic front elevation view of one embodiment of the invention related to the embodiment of FIG.37.

FIG.38B is a schematic plan view of one embodiment of the invention related to the embodiment of FIG.37.

FIG.39 is a schematic side elevation of a backlight for use in certain embodiments of the invention.

FIG.40A is a schematic side elevation view of a first operational state of one embodiment of the invention.

FIG.40B is a schematic side elevation view of a second operational state of one embodiment of the invention.

FIG.40C is a schematic side elevation view of a third operational state of one embodiment of the invention.

FIG.41 is a schematic side elevation view of a blazed grating used in a beam deflectors used in one embodiment of the invention.

FIG.42A is a chart shows a first diffraction efficiency versus wavelength characteristic of a blazed grating used in a beam deflector in one embodiment of the invention

FIG.42B is a diagram showing the diffraction orders of a blazed grating used in a beam deflector in one embodiment of the invention

FIG.43A is a chart shows a second diffraction efficiency versus wavelength characteristic of a blazed grating used in a beam deflector in one embodiment of the invention

FIG.43B is a diagram showing the diffraction orders of a blazed grating used in a beam deflector in one embodiment of the invention

FIG.44A is a chart shows a third diffraction efficiency versus wavelength characteristic of a blazed grating used in a beam deflector in one embodiment of the invention

FIG.44B is a diagram showing the diffraction orders of a blazed grating used in a beam deflector in one embodiment of the invention

FIG.45A is a schematic illustration of the beam deflection directions produced by a blazed grating used in a beam deflectors used in one embodiment of the invention.

FIG.45B is a schematic illustration of the beam deflection directions produced by two blazed gratings configured in tandem in a beam deflectors used in one embodiment of the invention.

FIG.46 is a schematic illustration of a voltage supply scheme in one embodiment of the invention.

FIG.47 is a schematic plan view of a beam deflector array comprising pixelated columns in one embodiment of the invention.

FIG.48 is a schematic plan view of one embodiment of the invention in which the left or right eye beam deflector provides a two dimensional image.

FIG.49 is a schematic plan view of one embodiment of the invention in which the left or right eye beam deflector provides a two dimensional image.

FIG.50 is a chart illustrating a random voltage waveform in one embodiment of the invention.

FIG.51 is a schematic plan view of one embodiment of the invention in which the left or right eye beam deflector provides a two dimensional image.

FIG.52A is a schematic plan view of a first aspect of an illuminator for used in a switchable autostereoscopic/two dimensional display one embodiment of the invention.

FIG.52B is a schematic plan view of a second aspect of an illuminator for used in a switchable autostereoscopic/two dimensional display one embodiment of the invention.

FIG.52C is a schematic plan view of a third aspect of an illuminator for used in a switchable autostereoscopic/two dimensional display one embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

It is a first object of the invention to provide a compact electro optical beam deflection device. It is a further object of the invention to provide a compact elector optical beam deflection device for providing alternate left and right eye perspective image light from a spatial light modulator to provide an autostereoscopic displays. It is a further object of the invention to a compact elector optical beam deflection device that can switch between a first state in which it provides alternate left and right eye perspective image light from a SLM and a second state in which it provides diffused image light for viewing a two dimensional image on said SLM. It is a yet further object of the invention to a compact elector optical beam deflection device that can provide an angular diversity laser beam despeckler.

It will be apparent to those skilled in the art that the present invention may be practiced with only some or all aspects of the present invention as disclosed in the following description. For the purposes of explaining the invention well-known features of laser technology and laser displays have been omitted or simplified in order not to obscure the basic principles of the invention.

Parts of the following description will be presented using terminology commonly employed by those skilled in the art of optics and laser displays in particular.

In the following description the terms light, ray, beam and direction will used interchangeably and in association with each other to indicate the propagation of light energy along rectilinear trajectories.

Unless otherwise stated the term optical axis in relation to a ray or beam direction refers to propagation parallel to an axis normal to the surfaces of the optical components described in relation to the embodiments of the invention.

It should also be noted that in the following description of the invention repeated usage of the phrase "in one embodiment" does not necessarily refer to the same embodiment.

A Switchable Bragg Grating (SBG) is formed by recording a volume phase grating, or hologram, in a polymer dispersed liquid crystal (PDLC) mixture. Typically, SBG devices are fabricated by first placing a thin film of a mixture of photopolymerizable monomers and liquid crystal material between parallel glass plates. Techniques for making and filling glass cells are well known in the liquid crystal display industry. One or both glass plates support electrodes, typically transparent indium tin oxide films, for applying an electric field across the PDLC layer. A volume phase grating is then recorded by illuminating the liquid material with two mutually coherent laser beams, which interfere to form the desired grating structure. During the recording process, the monomers polymerize and the HPDLC mixture undergoes a phase separation, creating regions densely populated by liquid crystal micro-droplets, interspersed with regions of clear polymer. The alternating liquid crystal-rich and liquid crystal-depleted regions form the fringe planes of the grating. The resulting volume phase grating can exhibit very high diffraction efficiency, which may be controlled by the magnitude of the electric field applied across the PDLC layer. When an electric field is applied to the hologram via transparent electrodes, the natural orientation of the LC droplets is changed causing the refractive index modulation of the fringes to reduce and the hologram diffraction efficiency to drop to very low levels. Note that the diffraction efficiency of the device can be adjusted, by means of the applied voltage, over a continuous range from near 100% efficiency with no voltage applied to essentially zero efficiency with a sufficiently high voltage applied. U.S. Patent 5,942,157 and U.S. Patent 5,751,452 describe monomer and liquid crystal material combinations suitable for fabricating SBG devices. Typically, the SBG element is configured with its cell walls perpendicular to an optical axis. An SBG element diffracts incident off-axis light in a direction substantially parallel to the optical axis when in said active state. However, each SBG element is substantially transparent to said light when in said inactive state. An SBG element can be designed to diffract at least one wavelength of red, green or blue light.

An illuminator for providing left and right eye illumination light according to the principles of the invention is illustrated in the schematic side elevation view of FIG.1. The illuminator comprises a micro scanner 1 for providing a small angle sweep to collimated input light 100 from the laser module 31; a beam deflector means 2 further comprising left and right eye beam deflectors 21, 22, a laser module 31 providing red green and blue collimated light, a beam angle expander 32 for magnifying the angular sweep indicated by the rays111,112 from the micro scanner 1 to provide the magnified sweep 120A,120B which is optically coupled into the left and right eye beam deflectors 21 22 . The left 131,132 and right eye 141 142 illumination light from the beam deflectors 21,22 (where the symbols A and B indicate the extreme rays of the angular sweep produced by the micro scanner 1) illuminates a transmissive display panel 33. The illumination light is transmitted through the display panel to provided image light to left and right eye viewing points which are not illustrated. The display panel would typically be a LC device. However, the invention does not assume any particular display technology.

An important feature of the illuminator is its transparency resulting from the use of SBGs which diffract light which satisfies the Bragg conditions but allow off-Bragg light to be transmitted without substantial deviation or attenuation. The significance of this property will be made clearer in the following description. In the embodiment of the invention illustrated in FIG.2 the transparency of the beam deflector means 2 enables an illuminator for a reflective display 34. The illuminator components are identical to those shown in FIG.1. The left 133,134 and right eye 143 144 illumination light (where, once again, the symbols A and B indicate the extreme rays of the angular sweep produced by the micro scanner 1) from the beam deflectors 21,22 illuminates a reflective display panel 34. The illumination light is then reflected at the surface of the display to provide the left 135,136 and right eye 145, 146 image light which passes through the beam deflector means 2 without substantial deviation or attenuation.

Advantageously the scanned illuminated is introduced into the beam deflector means 2 from the left and right as indicated in FIG.3 in which the left and right illumination laser , micro scanner and beam angle expander modules are identical to the module of FIGS.1-2 with the left and right modules being referenced by the symbols L,R.

The most compact and efficient method of providing beam deflectors using SBG technology is to create a multilayer light-guiding SBG architecture. Such an architecture has been disclosed in PCT Application No.: PCT/GB2010/001982 entitled Compact edge illuminated eyeglass display by the present inventors which is incorporated herein by reference in its entirety. In such architectures the SBG cell substrates provided a light guiding structure in which the input light undergoes TIR before being diffracted into the illumination direction by active portions of the SBGs which are advantageously configured as arrays of selectively switchable SBG elements. Since SBG devices are very thin and transparent the designer may be tempted to be generous with the number of layers. For example in the present autostereoscopic display application providing separate SBG layers for red, green and blue and right/left perspective results in a total of at least six layers. Furthermore, the angular bandwidth of SBGs (ie the range of operating angles over which 50%of peak diffraction efficiency is obtained) may not be high enough to provide the require range of illumination angles (which in the present application typically can cover 30-40 degrees in total. This may require that the number of gratings is doubled-up resulting in problems of cost, and manufacturing complexity. Accordingly, the inventors design goal was to limit the number of SBG layers to two layers ie one per beam deflector. The embodiments of the invitation are discussed in more detail in the following paragraphs starting with a description of the micro scanner.

Description of the Micro scanner

In one embodiment of the invention illustrated in the schematic side elevation view of FIG.4 a micro scanner beam deflection device 1 comprises: a first transparent optical substrate 11 with an input surface and an output surface; a second transparent optical substrate 12 with an input surface and an output surface; transparent electrodes applied to the output surface of the first substrate and the input surface of the second substrate; a variable index layer 13 having a planar surface and a second surface shaped to provide an array of prisms; and a polymer layer 14 having a planar surface and a second surface shaped to provide an array of prismatic cavities. The prisms and prismatic cavities have identical geometries, each prism abutting a prismatic cavity. The planar surface of the variable index layer abuts the output surface of first substrate while the planar surface of the polymer layer abuts the input surface of the second substrate. The transparent electrodes are electrically coupled to a variable voltage generating means 17 via an electrical switching network generally indicated by 18. The refractive indices of the variable index layer, polymer layer and the glass comprising the first and second substrates are indicated by symbols n_h , n_p and n_g .

In one embodiment of the invention the above described variable index material is a subwavelength grating recorded in HPDLC. A subwavelength grating is fabricated in a similar way to a SBG. However, unlike a SBG a subwavelength grating functions as a variable refractive index medium. The principles of subwavelength gratings recorded in HPDC material system are disclosed in US Patent No.: 5,942,157 by Sutherland et al, entitled SWITCHABLE VOLUME HOLOGRAM MATERIALS AND DEVICES, issued 24 August 1999.

Although the present description of the micro scanner refers to the fixed refractive index prisms being fabricated from polymer it should be apartment to those skilled in the art of optics that other optical plastics and glasses may be used.

In one embodiment of the invention at least one of said transparent electrodes is patterned into independently switchable electrode elements such as the one indicated by 15. The second electrode 16 may be continuous over the substrate area or may also be patterned in an identical fashion to the first electrode. The electrode elements have substantially the same cross sectional area as the prisms such that the variable index prisms may be selectively switched in discrete steps from a from a minimum average refractive index to a maximum index. In other embodiments of the invention the voltage across the SBGs may be varied continuously. In one embodiment of the invention both of the transparent electrodes are continuous such that electric fields may be applied across each variable index prism simultaneously. In one embodiment of the invention the electrode elements have substantially the same +cross sectional area as an SBG prism.

In one embodiment of the invention one face of each SBG prism is at ninety degrees to said planar surface of the variable index layer.

In one embodiment of the invention the variable index prisms are provided by a linear array of identical elements of triangular cross section.

The ray geometry is illustrated in more detail in the schematic side elevation view of FIG.5which illustrates ray propagation through one prism of the embodiment of FIG.4. The refractive indices of the variable index layer, polymer layer and the glass comprising the first and second substrates are again indicated by symbols n_h, n_p and n_g. The incident ray 520 which is normal to the first substrate passes through the first substrate emerging as ray 521 and strikes the interface between the variable index prism and the polymer prism at an angle α_1 to the normal to the interface. From Snell's law the ray is refracted into the polymer prism as the ray 522 at the angle α_2 which is given by $\alpha_2 = \arcsin((n_h/n_g)\sin(\alpha_1))$, which is approximately equal to $(n_h/n_g)\alpha_1$. The angle α_1 is given by $\alpha_1 = \arctan(h/D)$, where D is the length of the prism (or period) and h is its height. The ray 521 is next refracted into the glass substrate as the ray 523. The incidence angle α_3 at the polymer glass interface is given by $\alpha_2 - \alpha_1$. Applying Snell's law at the interface the refracted angle α_4 is given by the equation $\alpha_2=\arcsin(n_p\sin(\alpha_2)/n_g)$. Finally, we apply Snell's law once again at the glass to air interface to obtain the output angle α_5 for the emerging ray 524 which is given by $\alpha_5=\arcsin(n_g\sin(\alpha_4))$. In FIG.5 the average refractive index of the variable index layer is greater than that of the polymer layer.

Turning now to FIG.6 we consider the case where the variable index material has a refractive index less than the polymer index. In this case the refracted ray bends closer to the normal to the variable index -polymer interface. Hence the angle α_2 is now smaller than the angle α_1 with the result that the angle α_3 is now negative. It will be clear from consideration of FIGS.5-6 that if in each case the modulus of the difference between the variable index and polymer index is maintained the refracted angles α_4 and α_5 have the same magnitudes as in FIG.5 however they are now in opposing directions. The angular symmetry is achieved by choosing a polymer index which is exactly at the center of the H-PDLC average refractive index swing, which typically extends from1.55 to 1.65. In this case the polymer index should be 1.60. There is no need for a redirection prism to equalise the angles. It should be clear from consideration of FIGS.5-6 that that the resultant angular sweep is twice the prism deflection angle ie it is equal to $2\alpha_5$. FIG.7 illustrates the case where the variable index material refractive index is identical to the polymer index, incident light 520 propagating through the prisms without deviation emerging from the second substrate as the light 527.

Typically the prism deflection angles provided by the apparatus of FIG.4 will be small. In most cases the total angle swing is below 1-2 degrees. To achieve a viable autostereoscopic display it is therefore necessary to magnify the small angular deflection of the prisms into a much larger angular sweep. For example, if we consider an implementation in which a 100 mm wide SLM is viewed normally at a range of 500mm. and assume a viewer inter-pupillary distance (IPD) of 65 mm. it can be shown that the left/right beam separation (ie the full angle sweep to be provided by the beam deflector) is up to 7.4 degrees depending on field position, the largest angle occurring at the centre of the field. Advantageously, the SLM is updated at a frequency of 120Hz so that each eye views the displayed image at the maximum resolution.

In one embodiment of the invention there is provided an autostereoscopic display device that can be switched between two operational modes. The two modes are illustrated in the schematic plan views of FIG.8. The autostereoscopic mode is shown in FIG.8A where the SLM 33 has a width indicated by the symbol d and the range is indicated by the symbol R. Then eyes are positioned at the points 34L,34R separated by the IPD. In this case the beam divergences only need to be wide enough to provide illumination at the left/right eye points at the specified viewing range. The sweep angle required to provide image rays at each eye point is indicated by the symbol β. The second mode in which the display provides 2D imagery is illustrated in FIG.8B. In this case a much greater diffusion angle is needed. In one embodiment of the invention this additional diffusion may be provided by a further variable index layer configured as a switchable diffuser. The maximum distance between the left and right eye during the maximum allowed head movement for the above display example corresponds to an effective IPD of 95mm which is equivalent to total full angle sweep of 10.75 degrees. The full max angle deflection from normal is approximately 11 degrees. The maximum 2D display angular that must be provided by the beam deflection is ± 9.5 degrees (19 degrees full angle).

To provide full 2D and 3D scanning capability it is estimated from first order optics that a x20 to x25 expansion is required. In one embodiment of the invention illustrated in FIG.9 there is provided a beam deflection device based on the embodiment of FIG.4 which further comprises an angle expansion means 120. The angular swing from the beam deflection device of FIG.4 1is indicated by the rays 530 with beam divergence angle 531. The angle expansion means converts the beam 530 into the divergent output beam 533 which is symmetrical around the optical axis 532 defined by the normal to the substrates. The beam divergence angle is indicated by 534. In one embodiment of the invention illustrated in FIG.10 the angle expansion is provided by means of two microlens arrays 121,122 configured as an afocal magnifier. For example if we assume a micro-prism angle sweep range of 0.7 degrees based on the variable index and polymer index values quoted above we find that the output angle has to be 18 degrees Therefore, if the focal lengths of the microlenses are f1 and f2 the angle enlargement factor is f2/f1= 25x. The F-numbers are given by f1# = f1/D and f2# =f2/D. Typically, the fastest relative aperture that can be achieved in a practical array is f2# =1.25. If we assume a lens diameter D in each array of 50 microns, we find that the minimum value of the focal length f2 is 1.25*50 = 62.5 microns. Hence f2=1562.5 microns. The separation d of the arrays is given by d=f1-lf2l. The spacing between both lenslet arrays is thus: d=1562.5-62.5 microns = 1500 microns. The invention does not assume any particular means for providing the angle expansion means 120. The afocal magnifier of FIG.10 may be based on any optical configurations known to those skilled in the art of optical design. Desirably, the prisms and lenslets should be as small as possible. Note that the sizes of the prisms and lenslet do not need to be identical. The lenslet size should not exceed 50micron. In order that the prisms operate within the refractive regime their aperture should ideally be greater than 40 microns. The invention does not assume any particular type of microlens array. In many applications of the invention refractive solutions are preferred to diffractive optical elements.

FIG.12A is a chart representing the alternating left/right image states 551 of the spatial light modulator as s function of time 550. FIG.12B.is a chart illustrating the voltage waveform 554 applied to the variable index prism element of FIGS.2-3 as a function of time 550. The voltage levels corresponding to the image states 551,552 are indicate by 555,556. Since the variable index material has an approximately linear refractive index vs. applied voltage characteristic the charts may also represent the index change. The state in which no beam deflection takes place (ie for variable index material refractive index 1.60) is indicated by the dashed line 557.

In one embodiment of the invention random voltage the voltages applied to the beam deflector illustrated in FIGS 5-6 may have random waveforms such as the one illustrated in the chart provided in FIG.12. The chart is a plot of voltage applied across the variable index layer 554 plotted against time. One voltage step is indicated by 557. From consideration of FIGS.5-6 it should be apparent that applying a random voltage across a given variable index prism results in beam deflections randomly distributed around some mean direction in space. Such an embodiment has many applications. In the case of displays it provides an alternative to using a separate diffuser to increase the cone angle of light the light from a display pixel. The advantage of this approach in relation to the autostereoscopic display described above is a single variable index prism layer can be used to provide left and right beam steering for stereo viewing together with direct 2D viewing with an acceptable range of viewing positions. In one embodiment the display may be combined with an eye or head tracker to allow the viewing angles for the 2D mode to be matched to the instantaneous viewing position thereby providing a privacy functions

In one embodiment of the invention the prisms are configured as a linear array of elements of triangular cross section.

In one embodiment of the invention the prisms are configured as a two dimensional array of elements of triangular cross section.

In one embodiment of the invention the surface angles of the variable index prisms have a random distribution.

In one embodiment of the invention the variable index prisms are each characterised by one of at least two different surface geometries.

In one embodiment of the invention the variable index prisms are each characterised by one of at least two different surface geometries with the prismatic elements of each surface geometry being distributed uniformly across the prism array.

In alternative embodiments of the invention the variable index layer may be replaced by a PDLC material. However, such a material would suffer from the problem of slow response to applied electric fields.

In certain embodiments of the invention the variable index prisms illustrated in FIGS.5-7 may incorporate optical power. The effect of incorporating optical power into the variable index prisms is equivalent to disposing a microlens array in series with the variable index prism array. Advantageously, an variable index element incorporating optical power is fabricated by first designing and fabricating a CGH with the required optical properties and then recording said CGH into the variable index element. Recording the CGH into the variable index element essentially means forming a hologram of the CGH using conventional holographic recording techniques well known to those skilled in the art of holography.

Description of a Preferred Embodiment of the Invention

In one embodiment of the invention illustrated in the schematic front elevation view of FIG.13 the left and right beam deflectors 21,22 comprise two SBG layers. Each SBG layer are divided into independently switchable elements such as the SBGs labelled *1,i,N* Elements *1* and *N* are at the left and right extremities of the arrays. Element *i* is near the centre of the array. The elements comprise in the upper layer SBG grating devices 94A and in the lower layer SBG grating devices 95A-95C. The upper and lower SBG layers are identical, one layer being a reversed (in the plane of the drawing) replica of the other. Each SBG element in each layer has a unique prescription.

The input light, which is introduced from the left and right, comprises red, green and blue beams scanned through small angular sweeps by micro scanner and beam expander devices based on the principles describe above. The left and right beam geometries are symmetrical. Each SBG element is illuminated sequentially by the red, green and blues beams. Each beam has a central ray, about which the scanned rays are substantially uniformly distributed, that is diffracted to provide the central ray of the output beam from the element. Note that FIG.13 shows rays of one colour only. The ray geometry will differ for the other two colours owing to the dependence of the diffraction angle on wavelength. The output beam has an output divergence determined by the diffraction angle of the grating and the sweep angle of the incident rays. For a ray incident at an SBG element at an ankle $\emptyset_1$ to the normal to the SBG and diffracted at an angle $\emptyset_2$ the input and output beam divergences α_1, α_2 are related approximately by the formula $\cos \emptyset_1 \sin \alpha_1 = \cos \emptyset_2 \sin \alpha_2$. Each SBG element only diffracts light incident from either the left or right direction. Diffraction of light from both directions is excluded by angular bandwidth considerations. The output ray angles may be determined using standard grating theory.

Each SBG element is designed to provide a small output illumination sweep contributing a portion of the illumination to either the left or right eye position. At the leftmost extremity of the upper layer the illumination sweep extends from 0° to +U while at the furthest right extremity the sweep extends from –U to -2U. Near the centre of the upper layer the sweep at element "i" extends from 0° to +U. Considering next the lower layer we see that the furthest left sweep is +U to +2U and the furthest right sweep is *0° to +U with the central sweep at element* "i" extending from 0° to +U. It should be apparent from FIG.13 that by combining the sweeps of the two layers the aggregates sweep is from 0° -2U on the furthest left extremity and 0° to -20 on the further right extremity.

The rays 1150A-152A at element 1in the upper layer and the rays 170A-172A at element 1 and 170B- 172B at element "i" in the lower SBG layer correspond to beams from the left hand side of the deflectors. The rays 150B-152B at element i rand the arrays 150C-152C at element N in the upper layer and the rays 170C-172C at element N the lower SBG layer correspond to beams from the right hand side of the deflectors. It will be appreciated from consideration of the output angular variations across the array that each SBG element will require a unique prescription. However the symmetry of the upper and lower layers means that only array needs to be specified.

In the preferred embodiment of the invention The SBGs are stacked with their substrates forming a light guide as indicated in the schematic side elevation view of FIG.4. In the preferred embodiment of the invention the SBG array elements switched sequentially in scrolling fashion, backwards and forwards. Only one SBG element in each layer is in a diffracting state at any time. A further aspect of the preferred embodiment of the invention is that input light from the micro scanner is provided in opposing directions ie from left to right and from right to left in each SBG layer.

Description of Embodiment using Multiplexed Grating SBGs

So far we have not described the SBG elements in detail. A SBG element as described above contains at least one grating. It is well known that for any Bragg grating different wavelength and angle combinations will satisfy the Bragg equation which suggests that a single SBG layer may be used to diffract red, green and blue with high efficiecny. However, the difficulty here is that the red, green and blue illumination must overlap exactly. The inventors have found that at best only two wavelengths (blue and green) can be diffracted by a typical SBG element with adequate efficiency. The same SBG will not diffract red owing to the required incidence angle being too large, even where the incident light is delivered via a light guide. To address this problem in one embodiment of the invention the first and second deflectors each comprise SBG arrays in which each element contains two superimposed (multiplexed) Bragg gratings. In each case the first grating diffracts red and the second grating diffracts blue and green. The principles of recording two or more holograms into a single hologram are well known to those skilled in the art of holography. The total available diffraction efficiency is shared by the two gratings. The diffraction efficiency and angular bandwidth of multiplexed gratings recorded in HPDLC are potentially very high.

In one embodiment of the invention illustrated in the schematic illustration of FIG.15 there is provided a beam deflector comprising two layers. Each SBG layers comprises elements such as the SBGs labelled *1,i,N*. Elements *1* and *N* are at the left and right extremities of the arrays. Element “i” is near the centre of the array. Each SBG array element comprises multiplexed blue-green diffracting and red-diffracting gratings. The SBGs are operated in scrolling fashion as discussed above. The elements comprise in the upper layer SBG elements 94A-94B sandwiched between transparent substrates 90A-90C and 91A-91C and in the lower layer SBG elements 95A-95B sandwiched between transparent substrates 92A-92C and 93A-93C The upper and lower SBG layers are identical, one layer being a reversed replica of the other. Each grating element in a layer has a unique prescription. The SBGs are stacked to form a single lightguide.

TIR light is provided in opposing directions ie from left to right and from right to left in each layer. The input light is provided by separate laser, micro scanner and angle expander modules as illustrated in FIG.3. The array elements are scrolled. The rays in the Figures are for one wavelength only. Rays 700A-702A at element 1in the upper layer and the rays 720A-722A at element 1 and 720B- 722B at element i in the lower SBG layer correspond to TIR beams from the left hand side of the deflectors. Rays 700B-702B at element “i” and the rays 700C-702C at element N in the upper layer and the rays 720C-722C at element N the lower SBG layer correspond to TIR beams from the right hand side of the deflectors.

FIG.16 shows a cross section of a multiplexed SBG 94A combining first and second grating 96,97. The substrates and transparent electrodes are not illustrated.

FIG.17 is a schematic side elevation view of an SBG deflector based on the principles of FIG.19 showing the upper and lower arrays in contact to provide a lightguide.

FIG.18 illustrates the process of building up the output illumination sweep in more detail. The upper or left deflector illuminates only the left half 98L of the illumination surface while the lower or right deflector illuminates on the right half of 98R of the illumination surface. Left hand deflection columns are indicated by the points P1-P5 and right hand deflection column are indicated by the points Q1-Q5. Successive sweep ranges are indicated by the sequence 751L-755L in the left field and 751R-755R in the right field. Each sweep element correspond sot a Bragg deflection and micro scanned sweep within the bandwidth of the SBG as discussed above. Other equivalent schemes for building up the output illumination may be used. For example in one embodiment of the invention the angular sweep from each point P,Q fills both the left and right fields.

FIG.19 is a schematic side elevation view of an illuminator based on the multiplexed grating SBG deflector of FIGS.15-18. The illuminator comprises symmetrical SBG left and right beam deflectors each comprising an SBG array 104L,104R and grating coupling device 107L,107R. The arrays elements are column-shaped with small gaps between adjacent elements. The gratings are sandwiched between transparent substrates 102L,103L and 102R,103R. The black shaded areas 101L,101R represent non-grating regions. Where the SBG arrays and grating couples are recorded in HPDLC material said regions would correspond to unexposed HPDLC. Input red, green blue laser light from the left/right input illumination modules 110L,110R is coupled into the deflector by means of the couplings gratings.

The input illumination modules comprise the laser sources red 111RL,111RR, green 111GL,1116R and blue 111BL,111BR beam combiners 112L,112R for combining the RGB beams 760RL,760GL,760BL and 760RR,760GR,760BR to provide combined output beams 113L,113R. The most compact beam combiner is advantageously an X-cube (or cross dichroic prism) which uses four triangular prisms with suitable dichroic coatings to combine red, green and blue beams into a singe beam. X-cubes suitable for use with the present invention are supplied by the Nitto Optical Company (Japan). Other components for combining RGB beams will be known to those skilled in the art of optical design. Each module further comprises a micro scanner 1L,1R according to the principles described above. Advantageously, the micro scanner comprises two identical micro scanner layers to double the angular sweep obtained from a single layer. The scanned output beams 763L,763R from the micro scanners are expanded in angles by an angle expander 114L,114R according to the principles discussed above to give the scanned beams 760L,760R. The scanned beams 763L,763R are coupled into the lightguide 101L,101R by the coupling gratings 106L,106R which launch the beams into the opposing TIR paths generally indicated by 764L,764R. It should be noted that RGB light will be deflected into different angles the smallest angle occurring for blue light ie limiting TIR angles is set by blue. Note that the rays illustrated in the deflector have been limited to one wavelength for the purposes of explanation.

The SBG gratings 104L,104R are based on the multiplexed grating discussed above with a red diffracting grating and a blue-diffracting grating being superimposed in one SBG. The SBG arrays have identical prescriptions but the second grating is reversed with respect to the first so that the output angles are in opposing (ie left-right) directions. For example the elements 105L,106L diffract TIR light into the directions 765LA,765LB as determined by the Bragg condition. The beam sweep produced by the micro scanner leads to swept output beams defined by the limiting rays 766LA,767LA from element 105L and 766LB,767LB from element 106L. For design purposes the limiting rays are defined by the limits of the diffraction efficiency angular bandwidth (usually to the 50% of peak diffraction efficiency points). However, other measures may be used The rays 75LA,765LB are defined by the exact Bragg condition and would in theory be diffracted with 100% efficiency in the absence of transmission losses and higher order diffraction effects. In practice the inventors have found the peak diffraction efficiency allowing for losses in the substrates, HPDLC medium and electrodes is in the region 85-95%.

Fig.20 is a schematic plan view of the SBG array 104R showing one column elements 105R. The same process applies to the SBG array 104R which produces the swept beam rays 766RA-767RA,766RB-767RB around the Bragg ray directions 765RA,765RB. The same process applies to all three primary colours.

Typically a SBG array has 70 elements. The micro scanner provides a sweep of ±0.8° for each of the input red, green, blue beams. It is configured as a stack of two identical arrays based on the principles discussed above. Typically the angle expander has a 10:1 expansion ratio to expand the sweep from the micro scanner to typically ±5°. The SBGs operate in nominally 10° (±5°) bandwidths (in air). Based on the SBG bandwidths and the micro scanner sweep angles a reasonable design goal is to provide total output illumination angular swing to the left or right eye position of approximately ±20°. Hence referring again to FIG.15 the sweep angle U would be of magnitude 10°. Typically the TIR angles for blue to red are in the range 41.6- 63.2°. Using currently available HPDLC material systems and allowing for transmission losses in the substrates and electrodes the peak diffraction efficiencies at the above ray angles are typically 80% (Blue), 90% (Green) and 95%(Red).

Embodiments of the invention using Supercolumns

In one set of embodiments of the invention each SBG array is subdivided into groups of columns to be referred to as supercolumns. The purpose of a supercolumn is to extract as much of the incident illumination from the lightguide into the output illumination field as possible. The supercolumn allows non-diffracted or zero-order light which would otherwise be confined to the lightguide by TIR to be incrementally diffracted out of the supercolumn each time the beam interacts with a column. In other applications zero-order light must be treated as a loss. However, in the present application the zero order light is recycled to allow uniform out-coupling of TIR light across a supercolumn. The diffraction efficiency of individual column elements can be controlled by adjusting the index modulation in synchronisation with the micro scanning.

FIG.21 is a schematic plan view of the SBG array 104R showing how the array is divided up into supercolumns such as101 each comprising a multiplicity of column elements such as 101A. Note that invention does not place any restrictions on the width of and number of column elements in a supercolumn.

The extraction uniformity over the supercolumn is controlled by the modulation of the SBG refractive index. By increasing the refractive index modulation in steps along the supercolumn the reduction in the amount of 0-order light being transmitted by TIR is approximately balanced by the increased out-coupling by the SBG columns.

The refractive index modulation variation across a supercolumn can be set by the SBG recording conditions or can be varied dynamically by modulating each element in synchronization with the scanning of the input light. Alternatively, a combination of fixed and dynamic index modulation may be used.

FIG.22 is a cross-sectional detail of the SBG array 104R showing a series of columns elements inside a supercolumn such as 101 in the light guide formed by the substrates 102,103. Input scanned light from the laser – micro scanner module is indicated by 780. The TIR path light inside the light guide is indicated by the rays 781,782. The diffraction efficiency of the SBG column elements 101A,101B,101C for rays meeting the exact Bragg diffraction angle (referred to as on-Bragg rays) are k,k',k'' respectively. If the light 780 is injected into the lightguide with power P_0 the power diffracted at element 101A is kP_0 in to the ray direction 784. The power diffracted at the element 101B is $k'(1-k)P_0$ and so on until most of the beam power has been extracted and the output light is distributed over the ray directions generally indicated by 783. The k factors are specified to give a fixed light output at each bounce.

Incident rays with incidence angles that do not meet the exact Bragg condition (off-Bragg rays) will be diffracted with progressively smaller efficiency as the angle increases up to the angular bandwidth limit and therefore more bounces are needed before the beam or an acceptable portion of the beam is ejected from the lightguide. Hence the width w of a supercolumn will vary with the TIR incidence angle.

Typically a supercolumn is wide enough to accommodate several TIR bounces and is typically 10 mm wide although the invention does not assume any particular width.FIG.23 shows the geometrical parameters used to calculate the bounce length L1 and the number of bounces N in a supercolumn width L2 are tabulated in FIG.24. The bounce length L1 and hence number of bounces depends on the TIR angle. The calculations summarised in Table 29 assume that L2= 10 mm. For two stacked SBG arrays of substrate thickness 300 micron, the overall thickness (ignoring the 3 micron HPDLC thickness is 1200 micron. The bounce length is: $L1 = 2 \tan \theta_{TIR}$. For a supercolumn width w the number of bounces is: $N = w / (2\tan \theta_{TIR})$.

FIG.26 is a table showing the variation of peak (on-Bragg) diffraction efficiency with refractive index modulation for red green and blue light. The refractive index modulation is defined in the chart of FIG.25 where 786 is the refractive index modulation and 786 is distance along the normal to the Bragg fringes. The index is give by the formula $n = n_0 + \delta n \cos(k.x)$ where n_0 is the mean refractive index dn is the modulation ie half peak to trough index variation, k is the grating vector which is orientated perpendicular to the Bragg fringe planes and is of length $k=2\pi/\Lambda$ and x is the spatial coordinate along the grating which in this case are in the same direction. The off- Bragg efficiencies typically exhibit a similar fall-off. The graph defines the refractive index modulation of a SBG. The maximum modulation corresponds to 0.04.

A multiplexed SBG gives much better control of the angular content of the illumination output allowing more practically achievable TIR angles for the red input beam. FIG.27A is a chart showing a typical set of green and blue diffraction efficiency curves for a multiplexed SBG plotted against TIR angle (in the medium). FIG.27B is a chart showing a typical red diffraction efficiency curve for a multiplexed SBG plotted against TIR angle (in the medium). The diffraction efficiency and TIR angle axes are indicated by 791,792. The multiplexed grating superimposes first and second Bragg gratings. The first grating diffracts blue and green giving the blue and green diffraction efficiecny curves indicated by 793,794. The second grating diffracts red giving the diffraction efficiency curve indicated by 795. The blue and green TIR angle ranges for the first grating are indicated by the regions labelled B,G in the upper chart. The red TIR angle range for the second grating is indicated by the region labelled R in the lower chart. Note the red, green and blue illumination is presented sequentially

Each SBG element will have a slightly different prescription to its neighbours. In other words the peak diffraction efficiency, incident TIR angle and angular bandwidth for RGB will vary across each SBG array. In the example shown in FIG.27 the blue-green grating has a pitch of 0.43 micron and a grating slant angle of 115°. The red grating in FIG.27 has a pitch of 0.47 micron and a grating slant angle of 109°.

As discussed above optimal extraction of light using the supercolumn method will require dynamic control of the refractive index modulation and hence the diffraction efficiency of individual SBG columns. Since a lossy grating is desirable for the purposes of controlling illumination uniformity across a supercolumn very high diffraction efficiency is not required.

Although the red and blue-green diffraction efficiency curves overlap the degree of cross talk between the red green and blue light at a given SBG element can be controlled by suitable choice of TIR angles in relation the angular bandwidth of the SBG element.

The diffraction properties of the multiplexed SBG deflector may be represented using the Born Approximation with the aid of a k-vector diagram which is shown in FIG.28. The diagram indicates that Blue(AB) and Red (FG) are on-Bragg while Green (CE) is in a de-tuning state but sufficiently close to being on-Bragg for Green (CD) for high DE. The incident and diffracted beams are labelled by the numerals 781,782 with R,G,B indicating red, green and blue light. The grating vectors are indicated by the numbers 784 with R,G,B again indicating red, green and blue light. The de-tuned green resultant vector is indicated by 783. The k-vectors are plotted for a 0° diffraction angle. This formalism is generally used for weak gratings.

The basic geometry of an autostereoscopic display illuminator in one embodiment of the invention is shown in FIG.29. It is a requirement that the angular sweep range must accommodate any possible left eye position from any point on the display; and any possible right eye position from any point on the display. Based on the dimensions in the drawing the illuminator must therefore have at least 30.9deg (+/-15.45deg) steering capability on axis, and slightly less at display edges, 28.1deg (+/-14.05deg). The full sweep range required is given by 2*atan((166/2)/300)=30.9degrees. Typical values for the parameters in FIG.29 are provided in the table in FIG.30. FIG.31 tabulates SBG diffraction angles and angular sweeps obtained using the design data of FIG.30.

Embodiments based on Combinations of Non Switchable Grating and SBGs

In one embodiment of the invention the left and right eye beam deflectors are arrays configure in a similar fashion to the ones illustrated in FIG.13 in which each element comprises an SBG and a non-switchable grating. The non-switchable grating overlays the SBG element. The left and right deflectors are stacked to form a lightguide. Each SBG element contains a single grating which diffracts blue and green light into a specified output illuminination direction which the non-switchable grating is designed to steer red light diffracted by the SBG element into said output illumination direction.

In one embodiment of the invention which will be discussed later in the description the SBG element is a multiplexed grating superimposing separated blue and green Bragg gratings.

In one embodiment of the invention the non-switchable gratings is a surface relief grating. Typically the grating is etched or moulded into the surface of a transparent substrate. FIG.32 is a schematic side elevation view of a beam deflector which combines a SBG 67 and surface relief grating 68. The SBG diffracts incident RG TIR light incident in TIR beam directions 650R,650G,650B into the directions 651R,651G,651B. By suitable choice of blue and green TIR angles and SBG prescription it is possible to steer the blue and green beams into directions that are substantially parallel. The red beam diverges substantially from the blue and green beam directions. The prescription of the surface grating is designed diffract the red light into an output direction 652R that is substantially parallel to the blue green directions 651B,651G while transmitting blue and green light 651G,651B without significant deviation. In practice some of the blue and green light will be diffracted into at least one order as indicated by the rays 653G,653B. This light will tend to be at high angles and will not interfere with the left right eye illumination. However higher order diffracted light will result in throughput loss that will need to be balanced by a higher input power.

In principle any type of surface relief grating may be used in the embodiment of FIG.32 and the further embodiments to be described in the following description, including sinusoidal, rectangular and blazed forms. Blazed gratings provide the highest diffraction efficiencies. The efficiencies of sinusoidal and rectangular forms are too low and will result in most of the red going into the zero order.

In one embodiment of the invention the grating 66 is a blazed surface relief grating as illustrated in FIG.33 in which the rays are labelled using the same numerals as in in FIG.32. The blaze angle θ_{Blaze} and grating pitch d are indicated. The mathematical problem is to firstly, optimise the blaze angles, blaze wavelength and red, green, blue TIR angle to obtain: red, green, blue registration with high diffraction efficiency; secondly, to achieve minimal re-diffraction during the downward portions of the TIR path; and thirdly to minimise the effect of higher order diffraction by directing higher orders out of the output illumination field.

The bending of the red light by the blazed grating is determined by the blaze angle. The blaze wavelength λ_{Blaze} depends on the blaze angle, grating pitch and order. For an input beam angle U1, output beam angle U2, grating pitch d, diffraction order m and wavelength λ, the grating equation is: $\sin(U1)+\sin(U2) = (1/d)\, m\lambda$. The blaze angle for transferring most of the input energy into the mth order is: $V = (U1+U2)/2$. The blaze wavelength is then given by: $\lambda_{Blaze} = (2d/m)\sin(V)\cos(U1-V)$

Any surface relief grating will suffer from the problem that an air gap must be provided between the grating and the upper clad layer of the SBG to overcome the problem that the blazed grating will inhibit TIR along the lightguide. Adding a low index cladding layer between the Blazed grating and SBG upper substrate is not an alternative to an air gap as it would increase the critical angle preventing green and blue TIR.

Embodiments based on Backfilled Blazed Grating

In one embodiment of the invention the left and right eye beam deflectors are arrays configure in a similar fashion to the ones illustrated in FIG.13 in which each element comprises a surface relief blazed gratings backfilled with a HPDLC sub wavelength grating. The two arrays are stacked to form a TIR light guide.

Referring to the schematic front elevation view of FIG.34, which illustrates one element left eye deflector and the underlying element of the right eye deflector, there are provided first and second blazed gratings 87,88 formed in a transparent optical material and each have a flat surface and a blazed surface. In each grating the blazed faces are backfilled with HPDLC material. The HPDLC material functions as a variable refractive index layer. The blazed grating 87 and adjacent HPLC layer 85 are sandwiched by the transparent substrate 81,82. The blazed grating 88 and adjacent HPLC layer 86 are sandwiched by the transparent substrate 82,83. The

HPDLC layer has a first state in which it matches the index of the adjacent blazed grating layer and a second state in with an index differential exists between the HPDLC layer and the adjacent blazed grating layer. In FIG.34A the HPDLC layer 85 is in the first state and the HPLC layer 86 is in the second state. TIR light incident from the left hand side of the deflector 680R, 680G, 680B is reflected in the directions 681R, 681G, 681B onto a the blazed grating 88 and diffracted into the output directions 6802R, 682G, 682B. In FIG.34B the HPDLC layer 86 is in the first state and the HPLC layer 85 is in the second state. TIR light incident from the right hand side of the deflector 690R, 690G, 690B is reflected in the directions 691R, 691G, 681B onto a the blazed grating 87 and diffracted into the output directions 692R, 692G, 692B. Red, green and blue illumination is provided colour sequentially. The elements in each layer are switched in scrolling fashion.

In the embodiment of FIG.35 an air gap separates the left and right eye beam deflectors. The embodiment of FIG.35 is identical to the one of FIG.34 except in that the substrate 88 is replaced by the air separated transparent substrates 82A,82B.

<u>Embodiment based on Blazed Gratings Configured in Three Monochromatic Layers</u>

In one embodiment of the invention the left and right eye beam deflectors are provided by a threes layer stack in which each layer provides a surface relief blazed grating backfilled with a HPDLC material. Each layer diffracts a one primary colour and transmits the other two primaries without substantial deviation or attenuation. In contrast to the above described embodiments, each layer provides both left and right eye illuminination. The layers are pixelated into column shaped elements. The illustration schematically represents the beam deflector in its entirety but omits the pixel structure. Note that the facet structures have been simplified for illustration purposes. Each facet in the drawing represents a multiplicity of facets with incrementally increasing (or decreasing) blaze angles. The blaze angles will change in much fines stapes than the ones illustrated. Each facet in a layer is blazed for the layer wavelength.

Referring to FIG.36 there are provided first, second and third blazed gratings 76R,76G,76B formed in a transparent optical material and each have a flat surface and a blazed surface. In each grating the blazed faces are backfilled with HPDLC material. The blazed grating 75R and adjacent HPLC layer 76R are sandwiched by the transparent substrate 70,71. The blazed grating 75G and adjacent HPLC layer 76G are sandwiched by the transparent substrate 71,72. The blazed grating 75B and adjacent HPLC layer 76B are sandwiched by the transparent substrate 72,73.

The HPDLC layer has a first state in which it matches the index of the adjacent blazed grating layer and a second state in with an index differential exists between the HPDLC layer and the adjacent blazed grating layer. The stacked layers provide a lightguide into which micro scanned light is injected from the left and right as indicated by the numerals 670,671 with red, green and blue light being indicated by the symbols R,G,B.

In FIG.36A the HPDLC layer 75R is in the first state 76RB and the HPLC layers 76G,76B are each in the second state 76GA,76BA. TIR light 670R,671R incident from the left and right hand sides of is diffracted by the blazed grating 75R in the output directions generally indicated by 673R. For example the TIR light indicated by 672R is diffracted into the direction 674R with the scanning of the input beam by the micro scanner giving rise to the angular sweep indicated by 675R

In FIG.36B the HPDLC layer 75G is in the first state 76GB and the HPLC layers 76R,76B are each in the second state 76RA,76BA. TIR light 670G,671G incident from the left and right hand sides of is diffracted by the blazed grating 75G in the output direction. For example the TIR light indicated by 672G is diffracted into the direction 674G with the scanning of the input beam by the micro scanner giving rise to the angular sweep indicated by 675G

In FIG.36C the HPDLC layer 75B is in the first state 76BB and the HPLC layers 76R,76G are each in the second state 76RA,76GA. TIR light 670B,671B incident from the left and right hand sides of is diffracted by the blazed grating 75B in the output direction. For example the TIR light indicated by 672B is diffracted into the direction 674B with the scanning of the input beam by the micro scanner giving rise to the angular sweep indicated by 675B

Note that in the embodiment of FIG.36 each grating column must provide angular sweeps that are approximately twice the size of those provided in the above described embodiments. This is due to each layer being required to provide the full output illumination angular sweep as defined by the left and right eye positions. The layers are operated colour sequentially such that two gratings are cleared at any time. The elements in each layer are switched in scrolling fashion.

<u>Further embodiments of the invention</u>

In one embodiment of the invention there is provided a means for generating left and right eye perspective illumination light in which a stack of four SBGs provides the beam deflection means. In contrast to the SBGs used in the above described embodiments, which function as variable refractive index media, the SBGs in the embodiment illustrated in the schematic side elevation view of FIG.37 functions as beam deflecting Bragg gratings. The apparatus of FIG.37 comprises a backlight means 34, a light source 31, means for coupling light from the source into the backlight generally indicated by the arrow 600 and first, second, third and fourth SBG beam deflectors 41, 42, 43, 44. The invention does not assume any particular type of backlight. Desirably the backlight incorporates a brightness enhancement film (BEF) such as the ones manufactured by 3M Inc. (MN) which limits the angular extent of the beam emitted by the backlight. Advantageously, the backlight also includes means for recycling light that falls outside the required emission angular range. The source may employ LEDs or lasers. Alternatively, the source may be a quantum dot device. One particular backlight scheme for use with the embodiment of FIGS.37-38 is described later.

We next consider the generation of left and right eye perspective light by the apparatus of FIG.37 in which left and right eye perspective light is represented by solid and dashed rays. In a first state of the apparatus the SBGs 41 and 43 are in a diffracting state and the SBGs 42, 44 are in a non diffracting state. Light 610R from the backlight undergoes a first deflection at the SBG 43 into the direction 611R and a second deflection at the SBG 41 into the direction 612R. The light is transmitted through the SBGs 42, 44 without substantial deviation or attenuation towards a spatial light modulator such as an LCD (not illustrated). In a second state of the apparatus the SBGs 42 and 44 are switched into their diffracting states and the SBGs are switched into their non diffracting states. Light 600L from the backlight undergoes a first deflection at the SBG 44 into the direction 611L and second deflection at the SBG 42 into the direction 612L. The light is transmitted through the SBGs 41, 43 without substantial deviation or attenuation towards said spatial light modulator (LCD).

In one embodiment of the invention the left and right perspective light 612L,612R is produced time-sequentially.

In one embodiment of the invention the first, second, third and fourth SBG beam deflectors 41, 42, 43, 44 are stacked in the order 41, 43, 42, 44.

In one embodiment of the invention illustrated in FIG.38 which is based on the embodiment of FIG.37 the left and right eye perspective light is produced by means of a scrolling illumination scheme in which portions of the left and right eye perspective light beams are presented simultaneously. In this embodiment the SBGs and 41 and 42 are each patterned into selectively switchable SBG elongate elements (ie columns). FIG.38A shows a schematic front elevation view of the SBG layer 42 and FIG.38B is a schematic plan view of the SBGs 41, 42. The elements of the SBG 41 diffract light into a right eye perspective while the elements of the SBG 42 diffract light into a left eye perspective. The active elements in each SBG are switched in scrolling fashion to provide at least one band of diffracting elements that propagate across the SBG the first element in a band being switched into its diffracting stated at the same time as the last element in the group is switched into a non diffracting states, all other elements remaining in a non diffracting state. The scrolling direction is indicated by the arrow 616. The diffracting elements of the SBGs are indicated by shaded areas. As indicated in FIG.38B the elements of the two SBGs have complementary states such that at any instant in time each point in the emission area of the illuminator provides either left or right eye perspective light. The diffracting elements of the SBG 41 provide the output right eye perspective light band 613R and 614R at the same time as the diffracting elements of the SBG 42 provides the light eye perspective light band 613L.

The element 46 of the array 44 provides the output light indicated by the ray 615R. The element 45 of the array provides the output light indicate by the array 615L.

Advantageously the SBGs are designed to compensate for chromatic dispersion. Since at any time two SBGs will be in their diffracting states dispersion can be minimized by suitable choice of the diffraction angles (subject to the constraints imposed by the illumination input and output angles). The principles of chromatic dispersion compensation in optical systems comprising at least two gratings are well known to those skilled in the art of holographic optical elements and are summarized in US Patent No. 4,981,332 by Smith issued January 1991.

In one embodiment of the invention there is provided a backlight for use with the apparatus of FIGS.37-38. The backlight which is illustrated in the schematic side elevation view of FIG.39 and generally indicated by 5 comprises a slab of transparent optical material 51, a structured diffusion layer 55 applied to a first face of the slab, a brightness enhancement film (BEF) 53 applied to the opposing face of the slab, a mirror coating 54 applied to one edge of the slab and an optical port 52 on the opposing edge of the slab for inputting light from a light source 50. Light from the source 50 is coupled into the slab via a lens system(which is not illustrated) along an optical path generally indicated by 620. Other methods for coupling light into the slab such as prisms, and gratings will be well-known to those skilled in the art of optical design. The present invention does not assume any particular method for coupling light into the slab. The BEF has a prism structured surface generally indicated by 58 and comprising prismatic elements such as the ones indicated by 56A,56B,56C. Light from the source is expanded and directed into the slab by the lens system. The structured diffuser comprises a multiplicity of dispersed microdots formed from a diffusing material which scatter light 620,621,625 through the slab towards the BEF. The BEF transmits the scattered light while limiting its angular extent. Rays such as 620,621 emanating from a diffusing microdot and separated by a first angle are transmitted through the prisms 56A,56B emerging from the backlight as rays 622,623 which are separated by a second angle which is much smaller than said first angle. Typically the first angle would be ±50 degrees while the second angle may be as small as ±2-5 degrees. The precise amount of angular compression depends on the application. Light falling outside a predefined angular extent such the ray indicated by 625 for example is reflected and refracted along optical paths such as the one indicated by the ray path 625,626. This recycled light is directed towards the structured diffuser where the above described diffusion process is repeated. Typically such recycled light will undergo one reflection at the mirror 54. In the light of FIG.39 and the above description it will be appreciated that a significant portion of the input light from the source 50 will end up being emitted from the backlight in the prescribed angular range. The light source may be a LED or laser. Alternatively the source may be based on quantum dot technology. The lens may be a single refracting or diffracting element or a system comprising more than one such elements.

In one embodiment of the invention illustrated in the schematic side elevation views of FIGS.40A-40C there is provided a means for providing opposing angle beam deflections in which the deflection means is an SBG layer sandwiched between DOEs. In this embodiment the SBG again functions as a variable refractive index medium. Each DOE has a planar surface and a diffracting surface comprising a surface relief structure designed to provide a specified diffusion ray angular distribution for a predefined input ray angular distribution. The DOE may be based on the principles of the Light Shaping Diffusers (LSDs) manufactured by Precision Optical Corp. (CA). The diffracting surfaces of the DOEs which are indicated by the dashed lines 64,65 abut the SBG layer. The first DOE 63 has a refractive index n_A. The second DOE 61 has a refractive index n_B. The refractive index of the SBG n_{SBG} can be varied between the refractive index values of the first and second DOEs. For example in one embodiment of the invention $n_A = 1.55$, $n_B = 1.65$ and n_{SBG} can be switched between the values 1.55 to 1.65. Three states of the apparatus are illustrated in the schematic side elevation views of FIGS.40A-40C. In a first operational state illustrated in FIG.40A in which $n_{SBG} = nB$ an incident ray 640 is diffracted by the DOE 63 into the output ray direction 641. The diffractive effect of the DOE 61 is cancelled since in this operational state it is surrounding by media of equal refractive index. In a second operational state illustrated in FIG.40B in which $n_{SBG} = n_A$ the incident ray 640 is diffracted by the DOE 61 into the output ray direction 642. The diffractive effect of the DOE 63 is cancelled since it is surrounding by media of equal refractive index. In a third operational state illustrated in FIG.40C the refractive index of the SBG is equal to a value n_0 in the range n_A - n_B . In this case both DOEs 61 and 63 will diffract incident light. The DOE 63 diffracts incident light 640 into the direction 643. The DOE 61 diffracts a portion of the light 643 into the direction 644 and allows a portion of the light 643 to propagate as zero-order light 645 ie without substantial deviation. The emerging rays 644 and 645 are disposed symmetrically about the normal to the output surface of the DOE 61.

<u>Further embodiments based on blazed gratings</u>

As discussed in the preceding paragraphs the beam deflections obtained from beam deflectors based on Bragg gratings are limited by the tight constraints on input and output angles imposed by the Bragg equation. The problem is exacerbated by the fact that said angular constraints must be satisfied separately for each primary colour. Violating the Bragg equation results in poor light throughput and illumination non-uniformities.

A beam deflector based on blazed gratings rather than Bragg gratings can be used to overcome the above problem. The beam deflection characteristics of blazed gratings have already been discussed above.

FIG.41 is a schematic side elevation view of a simple blazed grating backfilled with an electrically variable refractive index medium that may be used in a switchable element of a left or right eye beam deflector according to the principles of the invention. The beam deflector shown in FIG.41 is based on the embodiment of FIG.35. The following discussion applies to any practical embodiment of a backfilled blazed gratings regardless of the shape of the blaze profile or the variable index and fixed index medium. The preferred refractive index medium is one based on HPDLC and specifically a HPDLC configured as a sub wavelength grating.

Simulated diffraction efficiency versus wavelength of a blazed grating backfilled with HPDLC is plotted in FIGS.42-44. The diffraction efficiency and wavelength axes are labelled by the numerals 801,802. The curves may be identified using the legend 803. In each case the 0-order is indicated by the numeral 804. The curves were calculated using the scalar theory of diffraction under the Fraunhoffer approximation. In each of the plots in FIGS.42-44 the fixed index material is quartz; the grating has a blazed depth of 6 microns; and the maximum index modulation is 0.15.

FIG.42A shows diffraction efficiency curves 806-809 calculated for four successive diffraction orders 1-4 with refractive index modulations being carefully selected over the range 0-0.15 to give maximum diffraction efficiency in diffraction orders 1-4 at the wavelength 500nm. FIG.42B relates the diffraction orders indicated by 805 to the corresponding refractive index modulations that result in maximum diffraction efficiency at each order.

FIGS.43A shows the diffraction efficiency dependence on wavelength 816-819 in diffraction orders 1-4 with the refractive index modulation fixed at 0.05. The output deflected beam in this case would be the 4th order diffracted beam as indicated by FIG.44B.

FIGS.44 shows the diffraction efficiency dependence on wavelength 826-829 at the same diffraction orders with the refractive index modulation again fixed at 0.05. The output deflected beam in this case would be the 2nd order diffracted beam as indicated by FIG.44B.

It should be apparent from the diffraction efficiency curves of FIGS.42-44 that high efficiencies and good extinction between the diffracted beams may be obtained. The extinction ratio between consecutive orders will be near to 100% at the selected wavelength which in this case is 500nm.

It should further be appreciated the beam angle switching is fundamentally a digital process. If an analog voltage ramp is applied to the grating elements, the beam switching is still digital in angle, but the intensity variation in the spots is analog. It should also be noted that since quartz is used for the fixed refractive index material the embodiments of FIGS.42-44 do not provide a zero order beam (ie one with no deflection) owing to the index mismatch between quartz and the variable index material. To obtain the zero order we need to replace quartz with a material of index equal to that of the HPDLC (at the maximum or minimum voltage settings).

FIG.45A-45B compares the beam deflections from a single blazed grating (45A) and two blazed gratings configured in tandem (45B). The incident light beam direction and the optical axis are indicated by 27A,27B The single grating can steer red, green or blue incident beams in to four different directions for each color simply by tuning the voltage across the variable index layer to four specific values as indicated by the numerals 1-4 to provide the angular sweep 28. By combining two such cells in tandem we can produce a 4^2=16 output beam directions for each colour as indicated by the numerals 1-16 to provide the angular sweep indicated by 29. If we count the states in which no diffraction take place (zero order), we can increase this number to 5^2=25 directions. The wavelength response of the scanner can be tuned by controlling the prism heights and the applied voltages. It will be apparent that a blazed grating provides a very significant increase in beam angle diversity over a Bragg grating where we are limited to one diffraction direction per cell (two if we count the zero order), and thus only four directions with two cells in tandem. It should be noted that in the above described examples the incident red green and blue wavelengths may be incident at the same angles.

Eliminating beam spread due to diffraction

The blazed gratings used in the above described embodiments of the invention are typically sufficiently small to give rise to beam divergences owing to the small aperture the prismatic faces of the grating present to incident light. This is an issue in the design of the left and right eye beam deflectors and also in the micro scanner which as discussed above relies on prism arrays to perform small angle scanning.

If the difference between the fixed and variable refractive indices equals an integer number times the ratio of wavelength to the thickness (prism height) of the blazed grating. the blazed grating will deflect light into the refraction direction. In other wards the backfilled blazed grating behaves like a single prism element operating entirely in the refractive regime.

Design of blazed gratings

Blazed gratings suitable for use with the present invention may be designed using standard grating theory principles well known to those skilled in the art. Relevant background information on blazed gratings may be found in the technical publication entitled "Diffraction Grating Handbook", by Christopher Palmer (Editor), second edition (page 4), published by the Milton Roy Company (Rochester New York) in 1984. Another useful reference is the book entitled "Optics" by Eugene Hecht and Alfred Zajac published by the Addison-Wesley Publishing Company in 1980 (5th Edition) page 358. Other useful background reference material is providing by grating manufacturers such as Horiba Jobin Yvon (New Jersey, USA) in their websites and technical publications.

According to the standard theory of blazed the best diffraction efficiency is obtained when the grating groove profiles satisfy the Littrow condition. In this case the diffracted ray directions and refracted (in the case of a transmission grating) or reflected (in the case of a reflection grating) ray directions coincide. In the case of the transmission blazed gratings used with the present invention this condition is, to first order, equivalent to treating the blazed as a single prism element operating entirely in the refractive regime. Many of the properties of blazed gratings can be predicted to first order using the grating equation and Snell's law. However precise estimates of diffraction efficiency, particularly at wavelengths other than the blaze wavelength, require a much more rigorous analysis. Since the period of a typical grating is often of the same order of magnitude as the wavelength, it is necessary to solve Maxwell's equations using numerical methods. One well known method is the rigorous coupled-wave analysis (RCWA). The above information is provided for background purposes only. The invention is not limited by any particular procedure for designing blazed gratings.

Embodiments in which dynamic voltages are applied to the beam deflector elements

In all of the above described embodiments the desired diffracting states of the left or right eye beam deflector elements are achieved by applying a voltage across each element via the transparent electrodes which are applied to the opposing faces of substrates sandwiching the diffractive element. The voltage may have binary states ie providing either a predefined maximum voltage or no voltage. In certain embodiments of the invention it is advantageous to provided intermediate voltage levels to control the rates of extraction of light from the deflectors. The need for dynamic control of refractive index modulation and hence time-varying applied voltage has already been discussed in relation to the supercolumn technique (see FIGS.21-24). FIG.46 illustrates the application of a time (t) varying voltage $V_i(t)$ from a voltage source 26 to the ith element of the beam deflector 21B in the embodiment of FIG.13. The electrical circuit linking the voltage source and the beam deflector element electrodes (which are not illustrated) is indicated by 25A,25B.

Embodiment in which the left or right eye beam deflector provides a two dimensional image

In one embodiment of the invention the voltage means illustrated in FIG.46 may be used to provide grey levels.

In one embodiment of the invention the deflector arrays columns may comprise columns of pixels. For example referring to FIG.47 which is based on the right eye beam deflector 104R of FIG.20 the column 105R comprises pixels such as 108R.

In one embodiment of the invention the voltage means illustrated in FIG.46 combined with the beam deflector of FIG.47 may be used to provide a grey level two dimensional image located at a surface in the beam deflector.

As discussed above in FIGS.13-26 optimal extraction of light using the supercolumn method will require dynamic control of the refractive index modulation and hence the diffraction efficiency of individual SBG columns. FIGS.48- 49 show the embodiments of FIGS1-2 with a voltage controller 36 for providing a time varying voltage and switching circuitry generally indicated by 37 for applying voltages across each SBG element in the left and right deflectors 21,22. A typical voltage characteristic applied to a single SBG element is shown in FIG.50 which is a chart shown the variation of voltage 203 with time where the ordinate 201 is the voltage and the abscissa 202 is time. Although a digital voltage characteristic is illustrated the voltage characteristic may be analogue depending on the application. The invention does not assume any particular method for providing a voltage generator and associated switching circuitry. Many alternative schemes suitable for use with the invention will be known to those skilled in the design of drive electronics and logic circuitry for displays.

Although the invention is directed at an illuminator for autostereoscopic displays it should be apparent from the description and drawings that the ability to modulate the light output from individual SBG elements in the manner described above allows the beam deflectors to function as a spatial light modulator or display panel. To this end the column element SBG arrays used in the embodiments of FIGS.13-26 may be replaced by two dimensional arrays. For example the right eye deflector array104R shown in FIG.20 may be replaced by the two dimensional array 108R shown in the schematic plan view of FIG.43 comprising pixels such as 109R. Where the invention is used to provide a display panel the illumination apparatus of may be simplified by removing one of the deflector layers as illustrated in FIG.51 which is identical to the embodiment FIG.48 except in that the deflector 22 has been eliminated. In the embodiment of FIG.51 the output beams would desirable be symmetrically disposed about the optical axis of the deflector. In many cases retaining the two deflector layers would be an advantage as the viewing angles would be twice as large as for the single deflector layer embodiment. In the case of FIG.51 the displayed image occurs at the viewable image occurs at the surface of the beam deflector. In embodiments where the two deflector layers 21,22 are retained the images at each deflector would be relatively displaced by the thickness of the SBG array substrates which will typically be of the order of a few hundred microns.

Switchable autostereoscopic/two-dimensional display embodiment

In one embodiment of the invention there is provided an illuminator for a switchable autostereoscopic/two-dimensional display. The basic concept is illustrated in FIG.52 which shows three operational states of illuminator corresponding to left eye (FIG.52A) and right eye (FIG.52B) illumination and left and right eye illumination delivered simultaneously (FIG.52C).

In each case the diffracting state of the left and right eye deflectors is indicated by the labels DIFFRACTING or NON-DIFFRACTING. In the autostereoscopic mode the display panel is updated field sequentially with left/right eye information. In its two dimensional mode the display panel displays a common left/right eye image. The ray geometry of FIG.52 is identical to that of FIG.1 and FIG.48. In the case of FIG.52C the rays from the left and right eye deflectors are displayed simultaneously.

It should be clear from consideration of the description and drawings that the exemplary architecture illustrated in FIGS.19-20 may be implements with some modifications to use any of the grating schemes discussed in th present disclosure. In other words the basic prinicplie of combineinn a micro scannere and left and right eye beam deflectiors may be applied using multiplexed SBGs or grating elements comprising combineations of SBGs and surface relief gratings.

The present invention does not assume any particular process for fabricating SBG devices. The fabrication steps may be carried out used standard etching and masking processes. The number of steps may be further increased depending on the requirements of the fabrication plant used. For example, further steps may be required for surface preparation, cleaning, monitoring, mask alignment and other process operations that are well known to those skilled in the art but which do not form part of the present invention

The method of fabricating the SBG pixel elements and the ITO electrodes used in any of the above-described embodiments of the invention may be based on the process disclosed in the PCT Application No.: US2006/043938, claiming priority to US provisional patent application

60/789,595 filed on 6 April 2006, entitled METHOD AND APPARATUS FOR PROVIDING A TRANSPARENT DISPLAY, filed on 13 November 2006 which is incorporated by reference herein in its entirety.

The invention is not limited to any particular type of HPDLC or recipe for fabricating HPDLC.

It should be emphasized that the Figures are exemplary and that the dimensions have been exaggerated. For example thicknesses of the SBG layers have been greatly exaggerated.

The SBGs may be based on HPDLC material systems in which a Bragg grating appears when an electric field is applied across the SBG and switches clear when the field is removed. Such HPDLC systems are referred to as "reverse mode" to distinguish them from more conventional HPDLC in which the grating exist when no electric field is applied and clears on application of the field.

The SBGs may be based on HPDLC material systems using any liquid crystal material including nematic and chiral types.

In particular embodiments of the invention any of the SBG arrays discussed above may be implemented using super twisted nematic (STN) liquid crystal materials. STN offers the benefits of pattern diversity and adoption of simpler process technology by eliminating the need for the dual ITO patterning process described earlier.

The invention may also be used in other applications such as optical telecommunications.

In the above description of the embodiments of the invention red, green and blue light may be interchanged.

In the above description of the embodiments of the invention light of other wavelengths including ultraviolet or infrared may replace any of red, green and blue light.

Although the invention is directed at autostereoscopic displays it may also be applied in other fields such as communications, radar, industrial metrology, optical sensors and any other application requiring beam deflection.

It should be understood by those skilled in the art that while the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. Various modifications, combinations, sub-combinations and alterations may occur depending on design requirements and other factors insofar as they are within the scope of the appended claims or the equivalents thereof.

CLAIMS

What is claimed is:

1. A light beam deflection device comprising:

at least one source of laser illumination (31,31R,31L);

at least one micro scanner (1,1R,1L);

a beam deflection means (2) comprising :

a left eye beam deflector for directing light to a left eye viewing direction (131A,131B,132A,132B);

a right eye beam deflector for directing light to a right eye viewing direction (141A,141B,142A,142B),

a first means (107L) for coupling light from said micro scanner into said left eye beam deflector to provide a first input illumination path; and

a second means (107R) for coupling light from said micro scanner into said right eye beam deflector to provide a second input illumination path,

wherein said micro scanner applies a time varying angular displacement to said laser illumination,

wherein said first and second input illumination paths are in opposing directions.

said left eye beam deflector comprising a first array of selectively switchable grating elements,

said left eye beam deflector comprising a second array of selectively switchable grating elements,

said elements having a diffracting state and a non diffracting state.

said elements being shaped as columns with long edges aligned orthogonally to said illumination paths directions,

said elements of said first and second arrays being switched on and off cyclically, one element in each said array being in said diffracting state at any time

said left eye beam deflector when in its diffracting state diffracting said first input illumination light into said left eye direction,

said right eye beam deflector when in its diffracting state diffracting said second input illumination light into said right eye direction.

2. The apparatus of claim 1 wherein said source provides sequential, first, second and third wavelength light, wherein said array elements are SBGs, wherein each said grating elements are SBG elements into which are recorded a first Bragg grating for diffracting first and second wavelengths in to a predetermined direction superimposed on a second SBG grating for directing third wavelength light into said predetermined direction, wherein said SBG elements sandwiched by a pair of transparent substrates with transparent electrodes applied to their opposing faces, wherein said deflectors are stacked to form a lightguide, wherein said first and second illumination paths are confined by total internal reflection within said lightguide.

3. The apparatus of claim 1 further comprising an angle expander means disposed at the output of said micro scanner for magnifying said angular displacement.

4. The apparatus of claim 2 wherein said array element are grouped into supercolumns, wherein each element in said supercolumn is which the refractive index modulation of

each element in said supercolumn is dynamically controlled such that a predetermined amount of light with a predetermined spatial distribution is diffracted out of said supercolumn into said left or right eye viewing directions.

5. The apparatus of claim 1 wherein each said grating element comprises a SBG and a non switchable grating overlaid over said SBG.

6. The apparatus of claim 1 wherein each said grating element comprises a surface relief grating backfilled with a variable refractive index material switchable grating overlaid over said SBG.

7. The apparatus of claim 5 wherein each said non switchable grating is a surface relief grating.

8. The apparatus of claim 5 wherein each said non switchable grating is a blazed surface relief grating.

9. The apparatus of claim 1 wherein said micro scanner comprises:
a first transparent optical substrate with an input surface and an output surface;
a second transparent optical substrate with an input surface and an output surface;
transparent electrodes applied to said output surface of said first substrate and said input surface of said second substrate;
an variable refractive index layer having a planar surface and a second surface shaped to provide an array of prisms; and

a fixed refractive index layer having a planar surface and a second surface shaped to provide an array of prismatic cavities, said prisms and said prismatic cavities having identical and opposing geometries, each said prism abutting one of said prismatic cavities,

wherein said planar surface of said variable refractive index layer abuts said output surface of said first substrate and said planar surface of said fixed refractive index layer abuts said input surface of said second substrate, wherein said transparent electrodes are electrically couple to a variable voltage generating means.

10. The device of claim 9 wherein at least one of said transparent electrodes is patterned into independently switchable electrode elements having substantially the same cross sectional area as said prisms such that said variable refractive index prisms may be selectively switched in discrete steps from a fully diffracting to a non diffracting state by an electric field applied across said transparent electrodes.

11. The device of claim 9 wherein said variable refractive index layer is a subwavelength grating.

12. The device of claim 9 wherein the refractive index differential between the variable refractive index layer and the fixed refractive index layer is positive when a first voltage is applied and negative when a second voltage is applied and zero when a third voltage is applied wherein said the application of said first, second or third voltages cause light entering said device normal to said input surface of said first transparent substrate to emerge from output surface of said second transparent substrate in a first, second or third directions respectively, wherein said first and second directions are in opposing angles to the normal to said output surface and said third direction is parallel to said normal to said output surface.

13. A light beam deflection device comprising:

at least one source of laser illumination (31,31R,31L);

at least one micro scanner (1,1R,1L);

a beam deflection means (2) comprising :

a left eye beam deflector for directing light to a left eye viewing direction (131A,131B,132A,132B);

a right eye beam deflector for directing light to a right eye viewing direction (141A,141B,142A,142B),

a first means (107L) for coupling light from said micro scanner into said left eye beam deflector; and

a second means (107R) for coupling light from said micro scanner into said right eye beam deflector,

wherein said micro scanner applies a time varying angular displacement to said laser illumination.

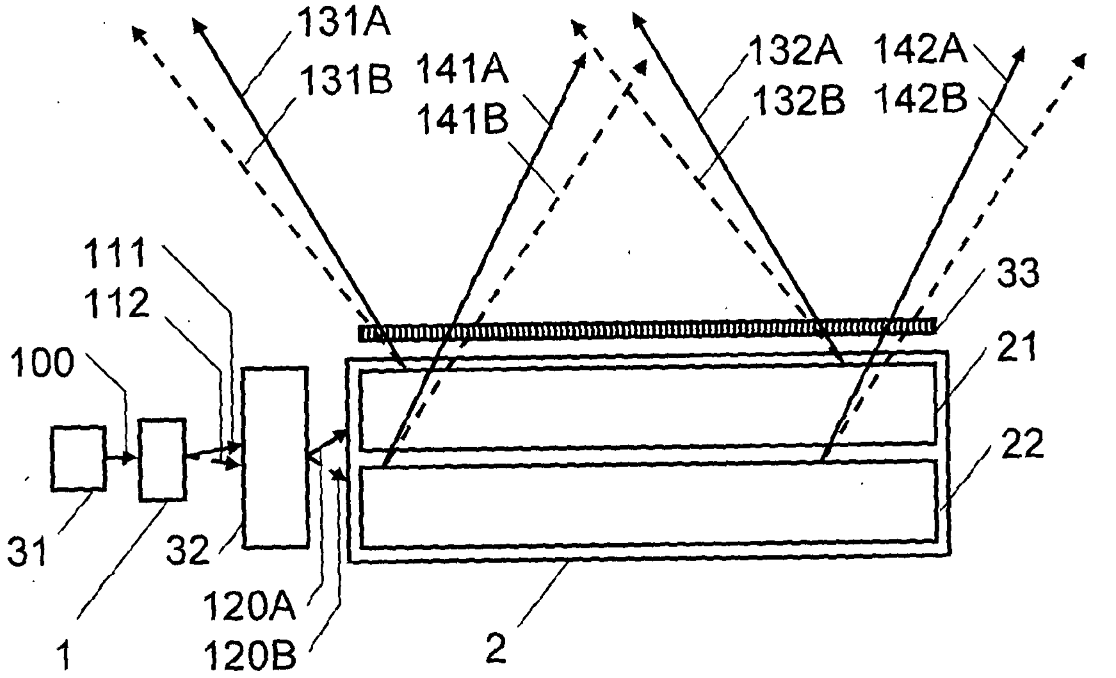

131A
131B
141A
141B
132A
132B
142A
142B
111
112
100
33
21
22
31
32
1
120A
120B
2

FIG.1

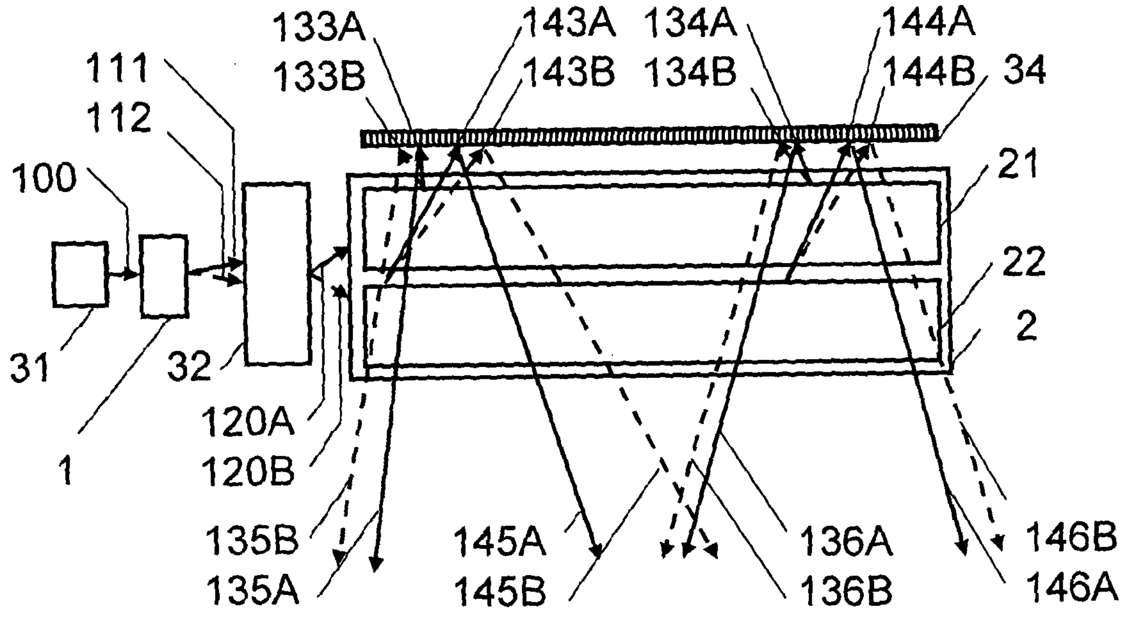

133A
133B
143A
143B
134A
134B
144A
144B
34
111
112
100
21
22
2
31
32
1
120A
120B
135B
135A
145A
145B
136A
136B
146B
146A

FIG.2

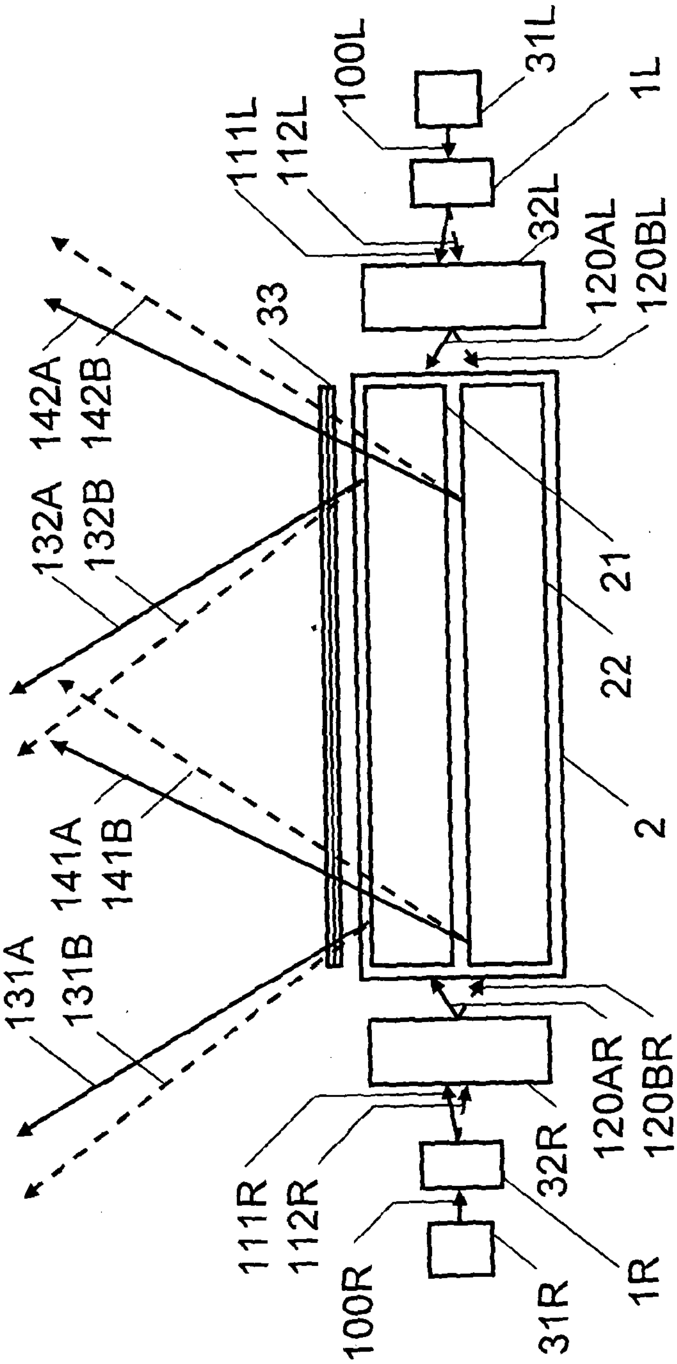

100L
31L
111L
112L
1L
32L
120AL
120BL
33
142A
142B
132A
132B
21
22
2
141A
141B
131A
131B
120AR
120BR
111R
112R
32R
100R
31R
1R

FIG.3

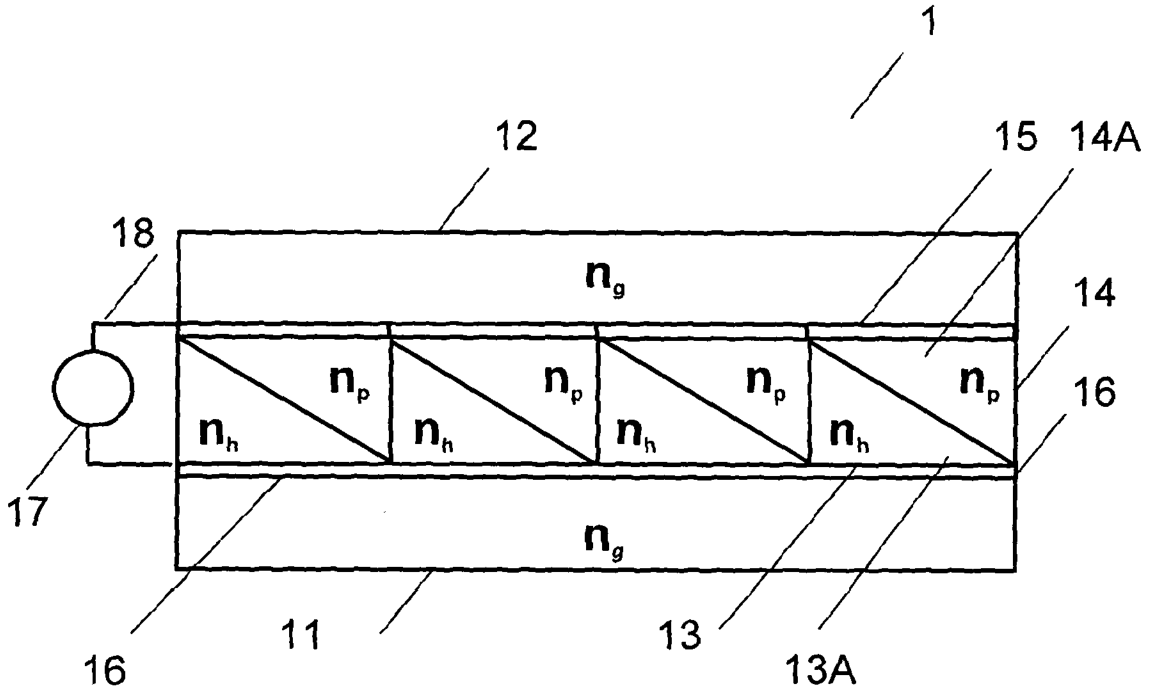


FIG.4

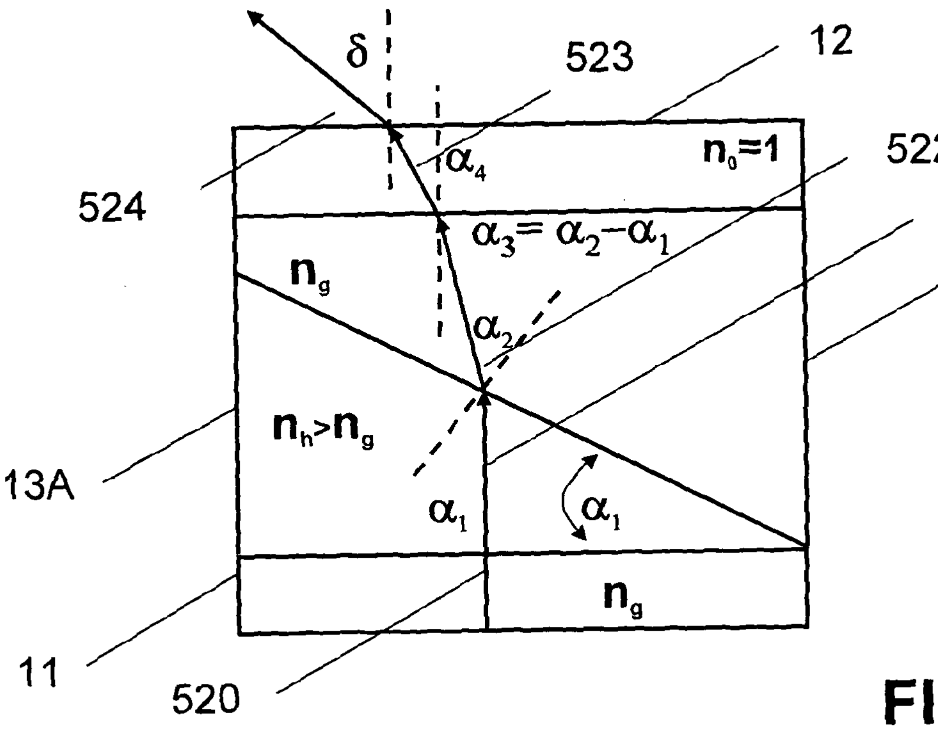

δ
523
12
524
α4
n0=1
522
α3= α2−α1
521
ng
14A
α2
nh>ng
13A
α1
α1
ng
11
520

FIG.5

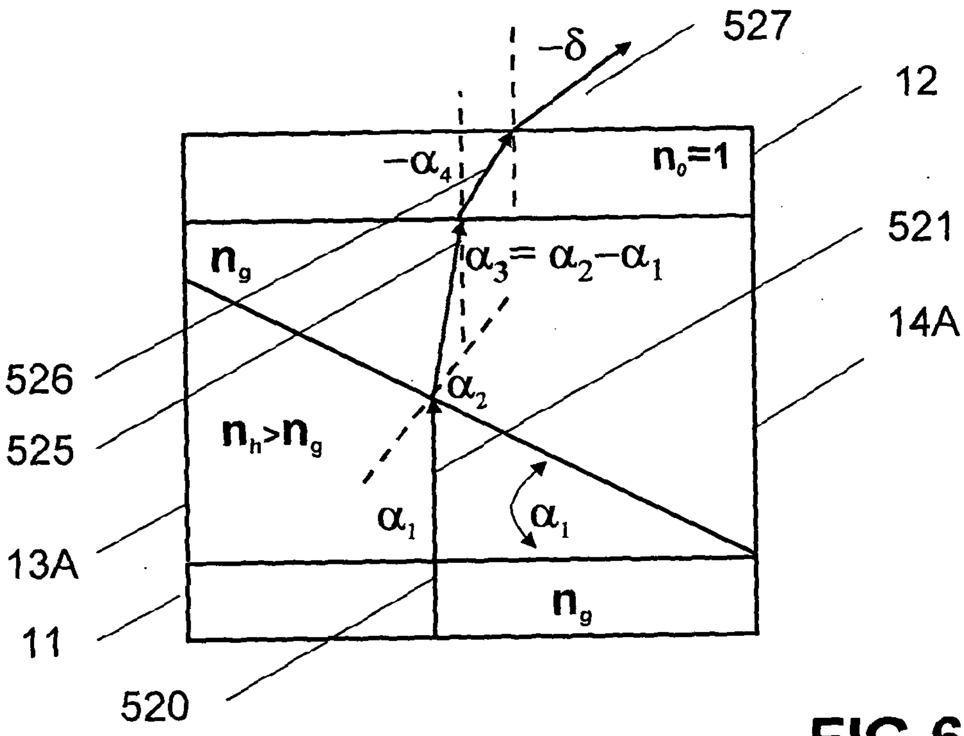

−δ
527
12
−α4
n0=1
521
ng
α3= α2−α1
14A
526
α2
525
nh>ng
13A
α1
α1
ng
11
520

FIG.6

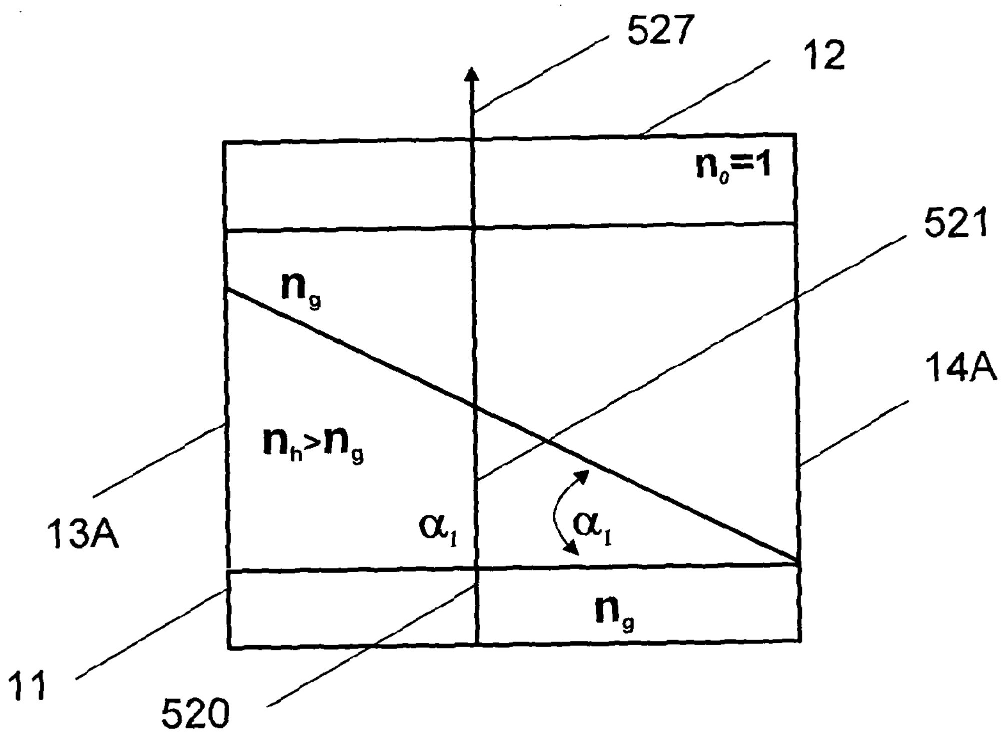
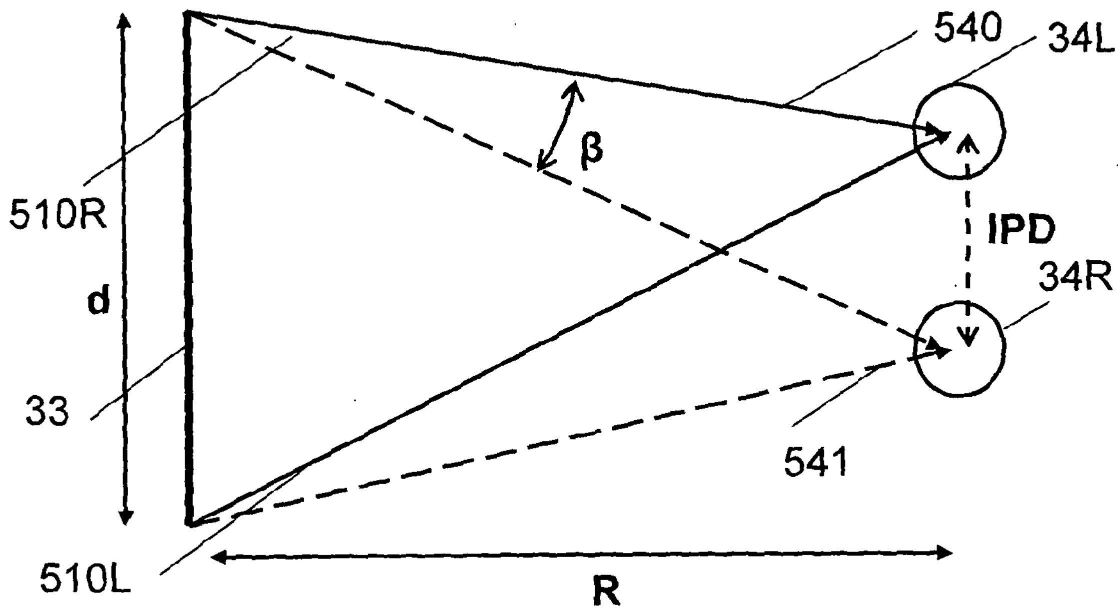
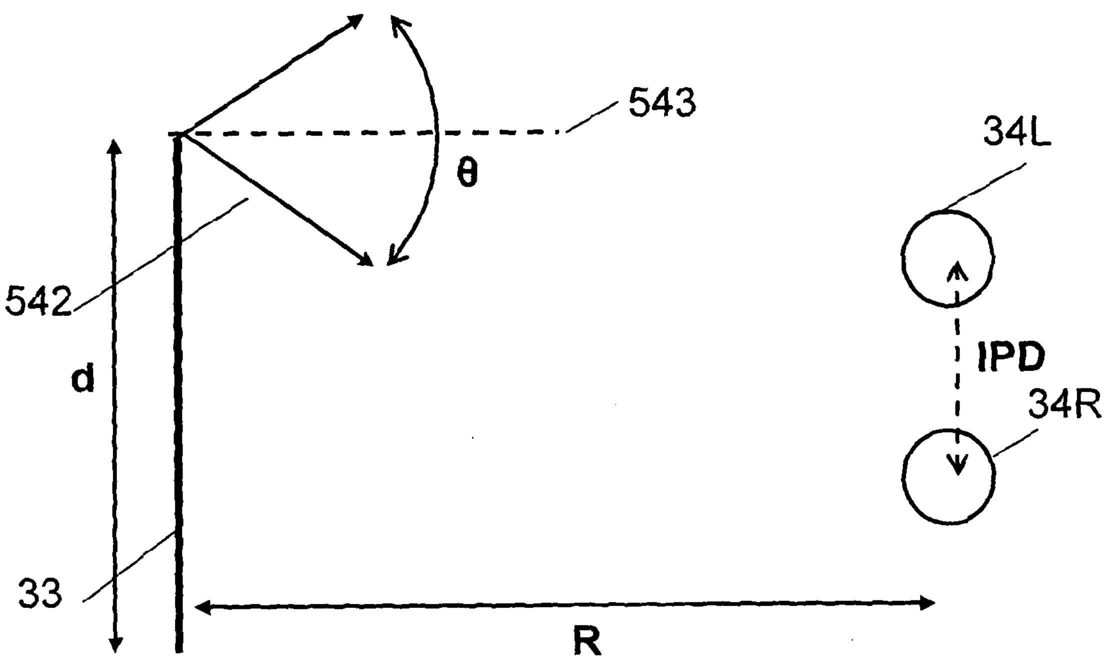


FIG.7



(A)



(B)

FIG.8

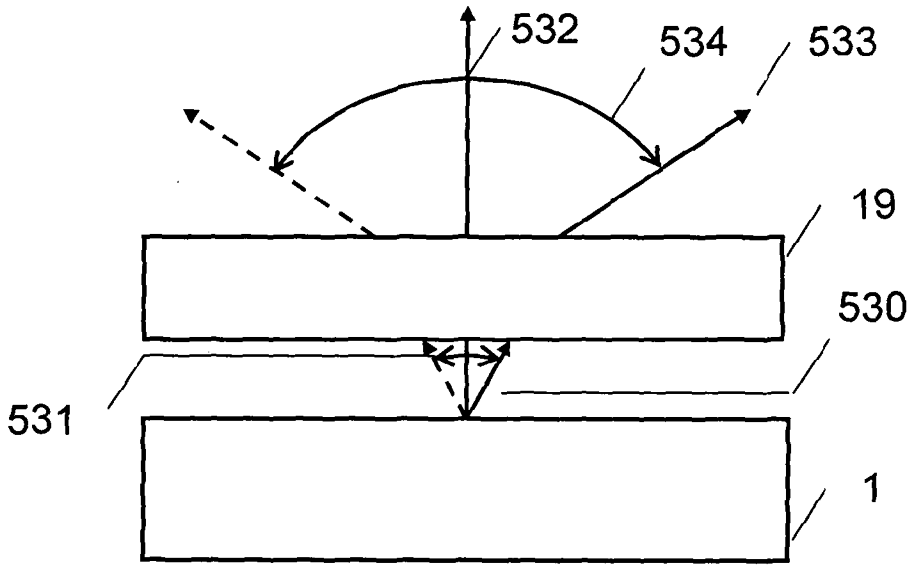


FIG.9

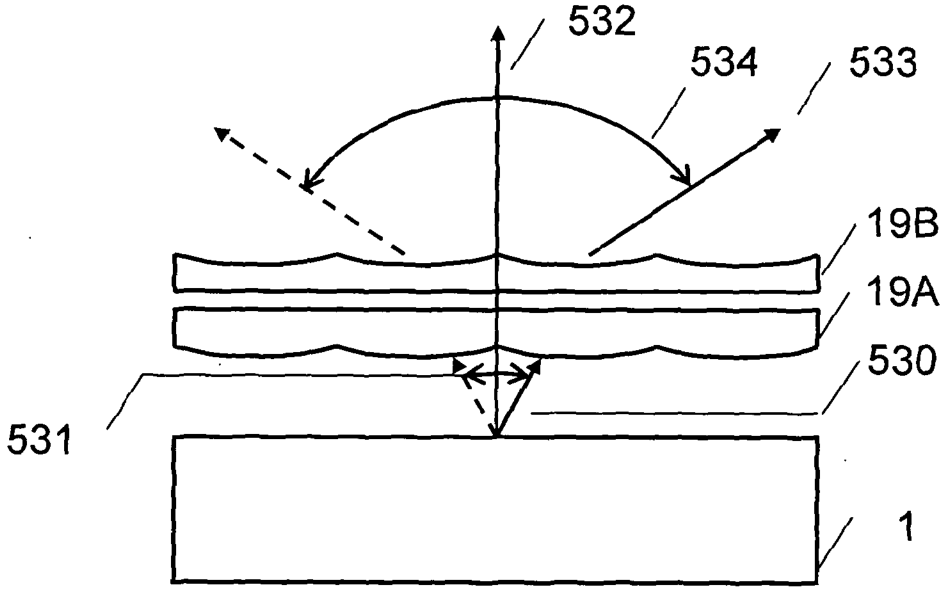


FIG.10

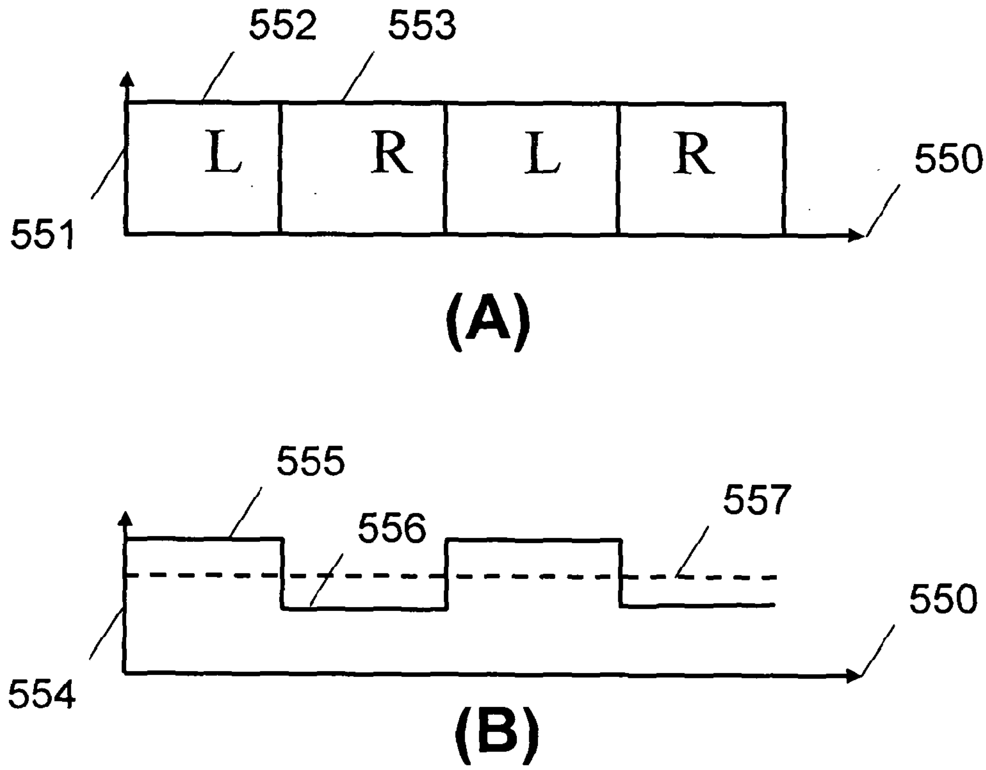


FIG.11

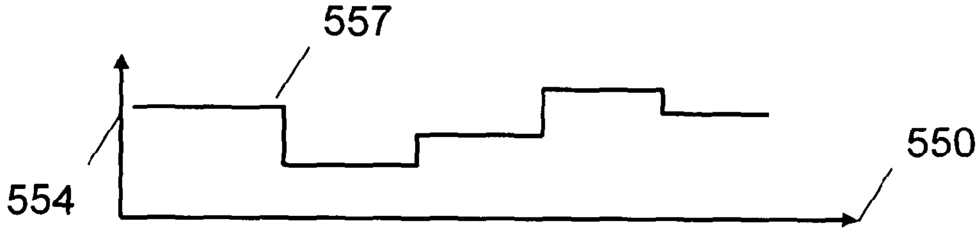


FIG.12

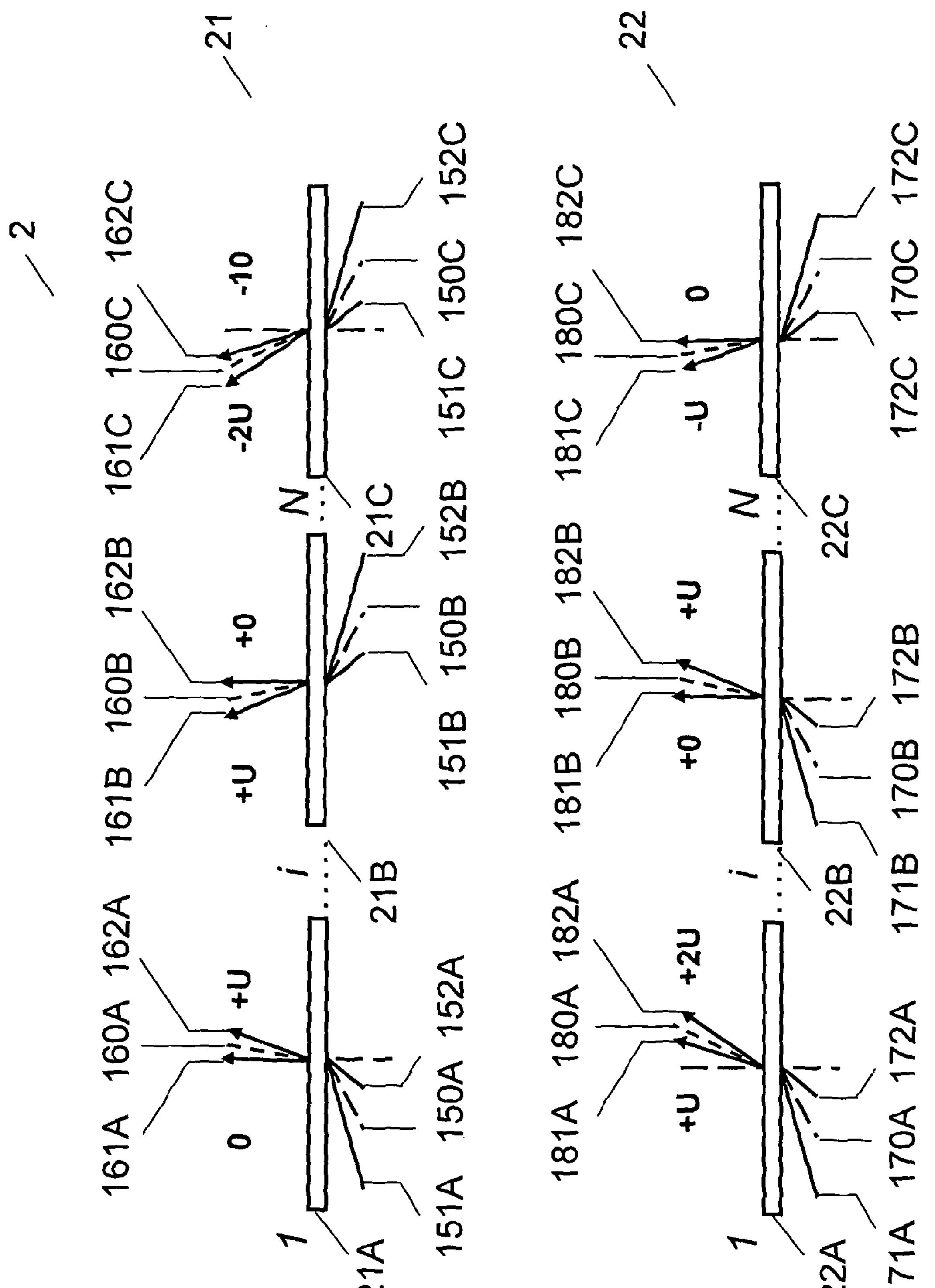

2
21
22
1
i
N
21A
21B
21C
22A
22B
22C
0
+U
+0
-2U
-10
+2U
-U
150A
151A
152A
160A
161A
162A
150B
151B
152B
160B
161B
162B
150C
151C
152C
160C
161C
162C
170A
171A
172A
180A
181A
182A
170B
171B
172B
180B
181B
182B
170C
172C
180C
181C
182C

FIG.13

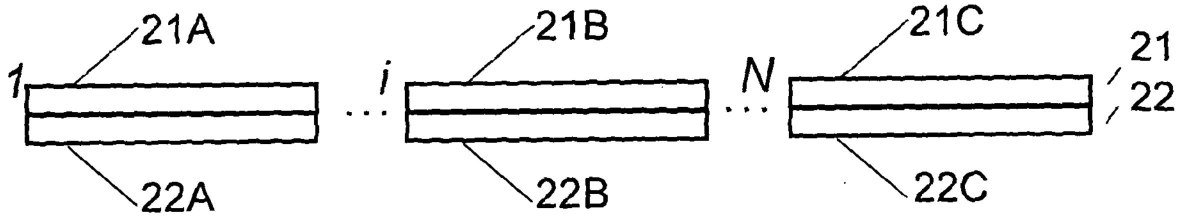


FIG.14

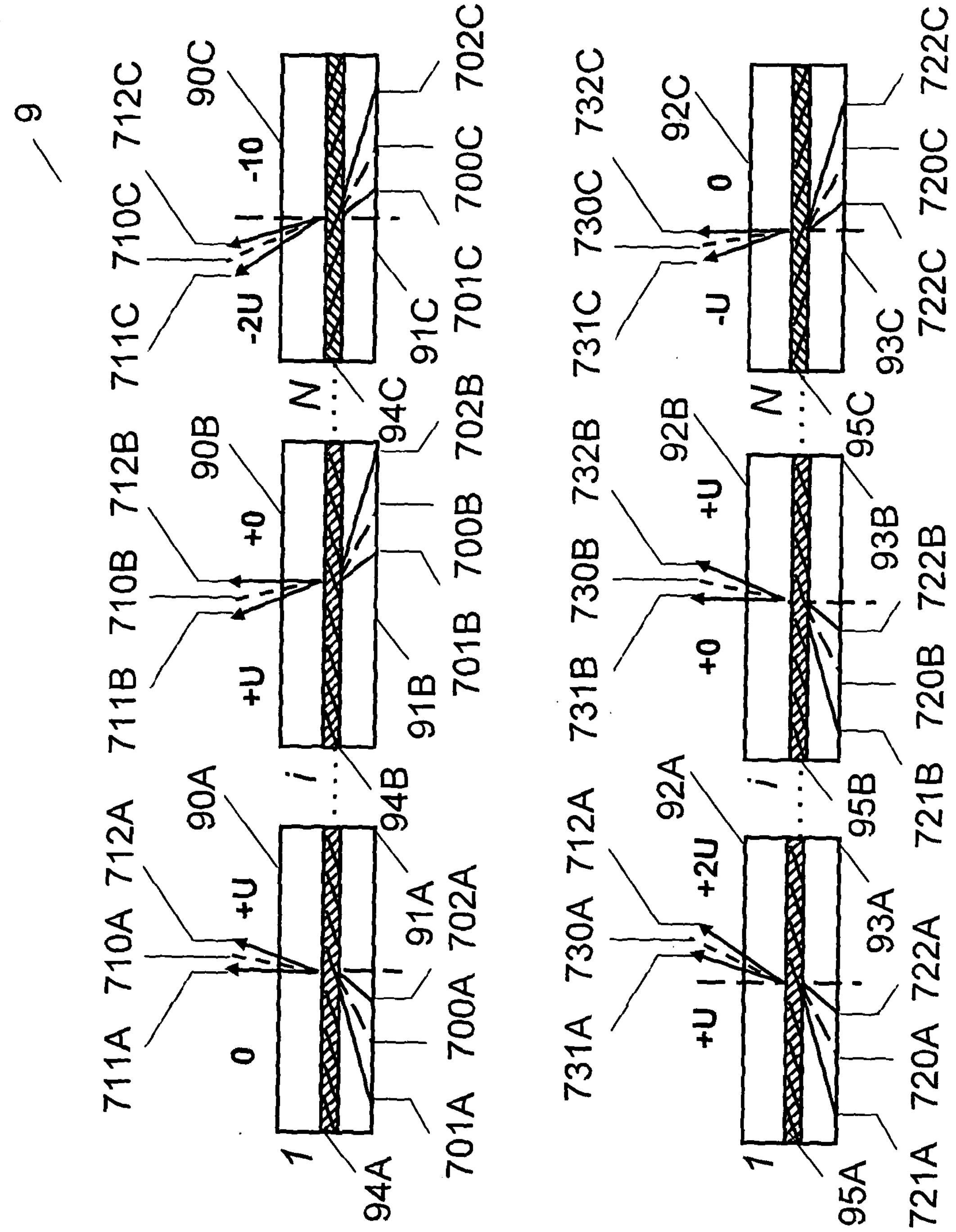

9
711A 710A 712A
90A
0 +U
1
94A
701A 700A 702A
91A
i
711B 710B 712B
90B
+U +0
94B
91B
701B 700B 702B
N
711C 710C 712C
90C
-2U -10
94C
91C
701C 700C 702C
731A 730A 712A
92A
+U +2U
1
95A
721A 720A 722A
93A
731B 730B 732B
92B
+0 +U
95B
93B
721B 720B 722B
731C 730C 732C
92C
-U 0
95C
93C
722C 720C 722C

FIG.15


94A
96
97

FIG.16

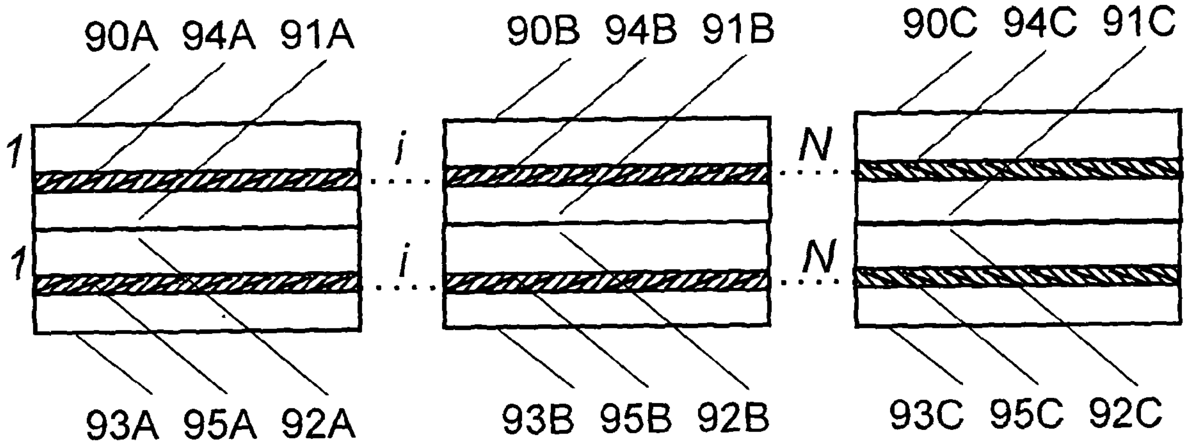

90A 94A 91A
90B 94B 91B
90C 94C 91C
1
1
i
i
N
N
93A 95A 92A
93B 95B 92B
93C 95C 92C

FIG.17

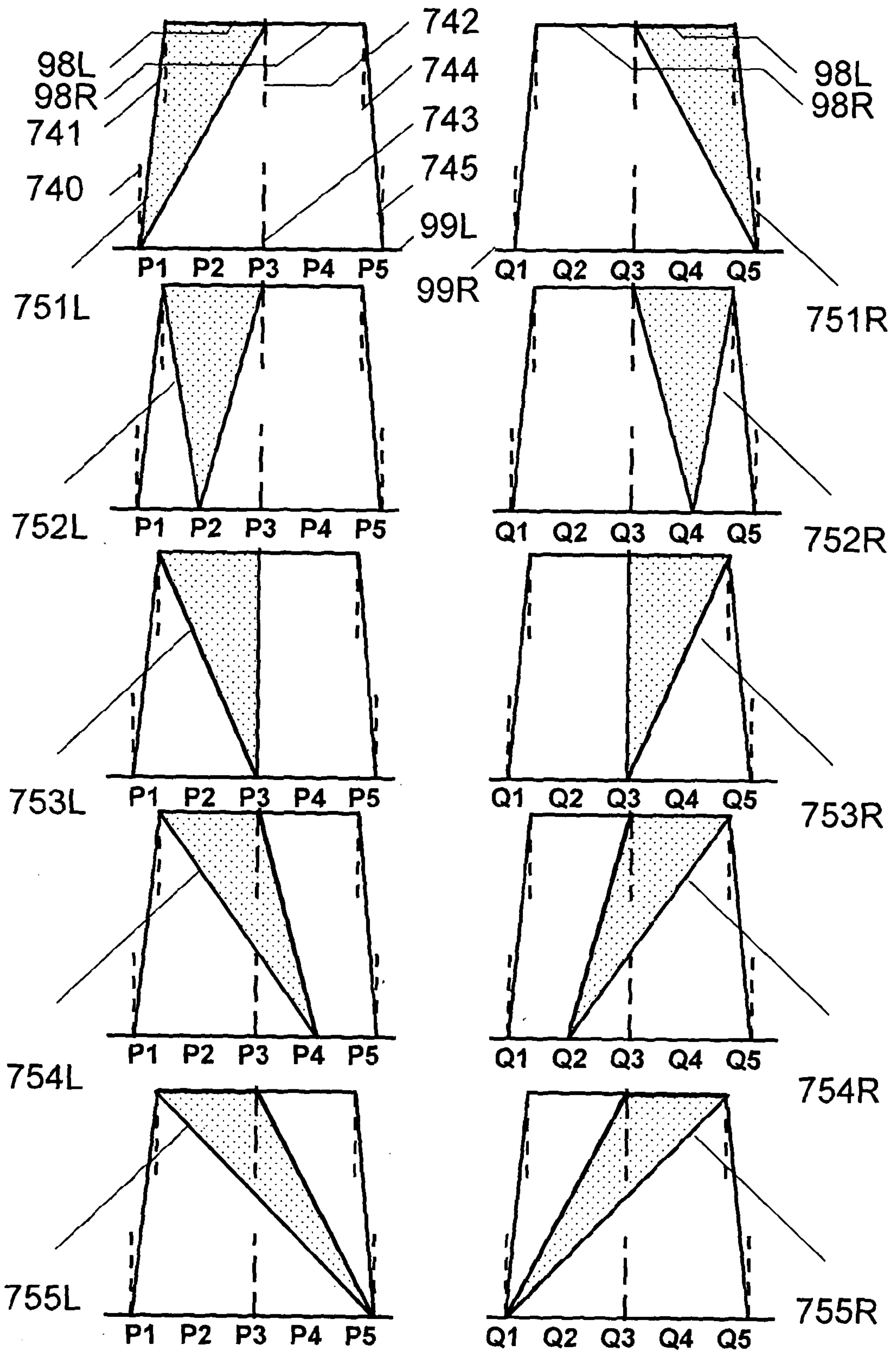

98L
98R
741
740
742
744
743
745
99L
99R
98L
98R
P1 P2 P3 P4 P5
Q1 Q2 Q3 Q4 Q5
751L
751R
752L
752R
753L
753R
754L
754R
755L
755R

FIG.18

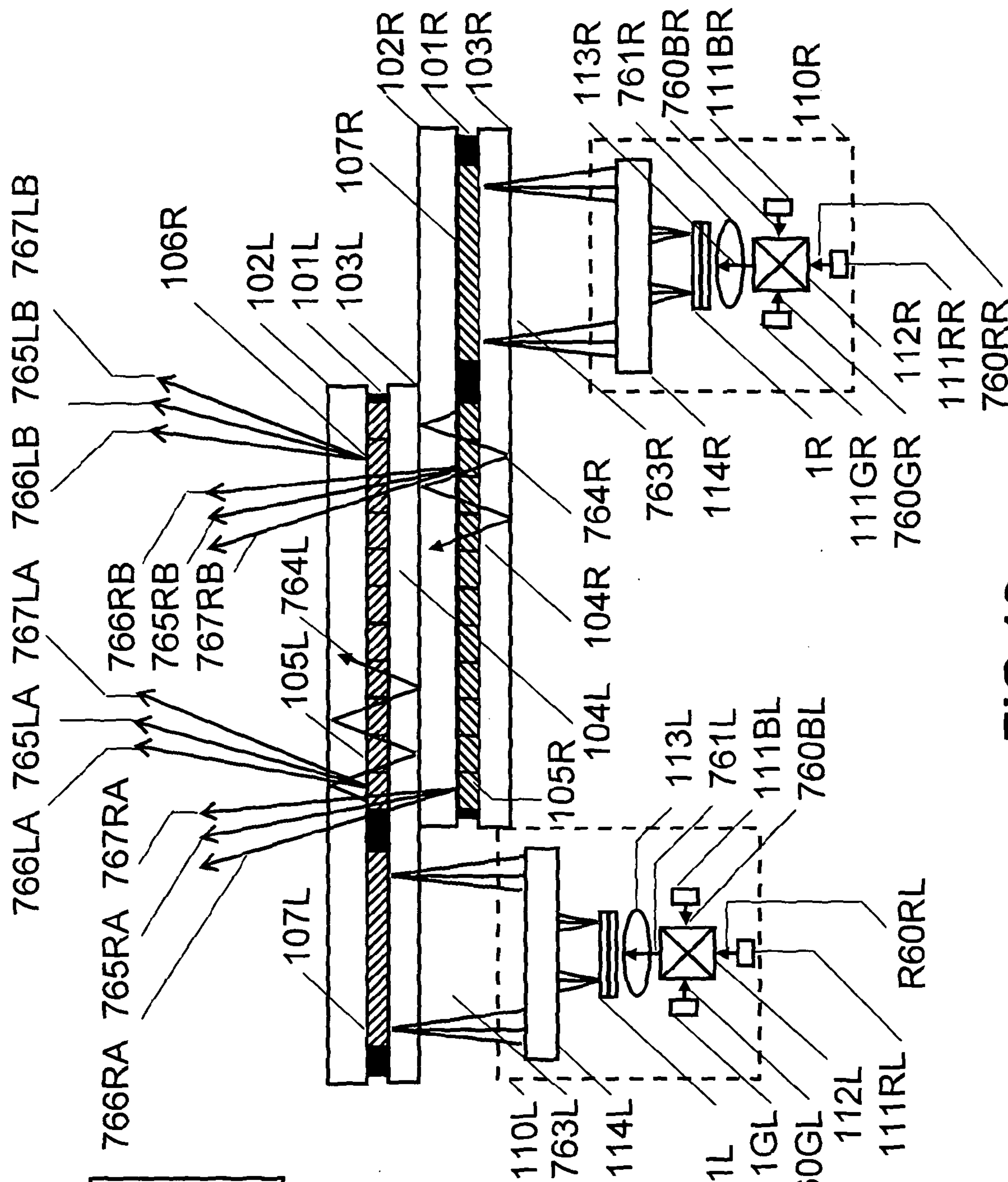

102R
101R
103R
107R
106R
102L
101L
103L
766LB
765LB
767LB
766RB
765RB
767RB
766LA
765LA
767LA
766RA
765RA
767RA
105L
764L
104L
105R
104R
764R
107L
113R
761R
760BR
111BR
110R
112R
111RR
760RR
763R
114R
1R
111GR
760GR
113L
761L
111BL
760BL
R60RL
110L
763L
114L
1L
111GL
760GL
112L
111RL

FIG.19

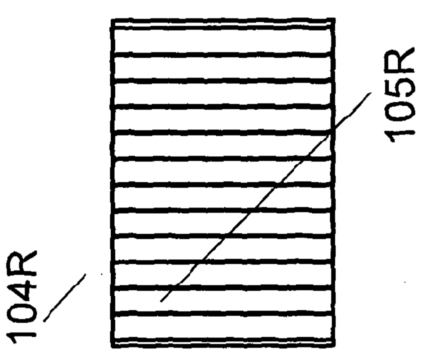

104R
105R

FIG.20

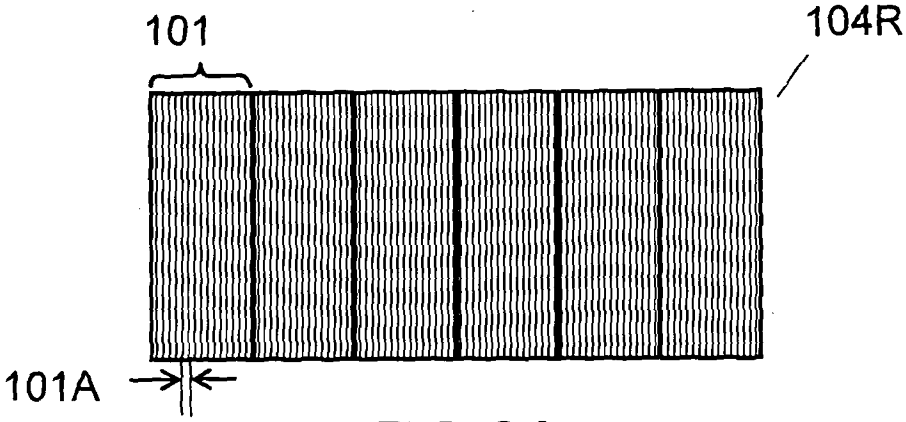


FIG.21

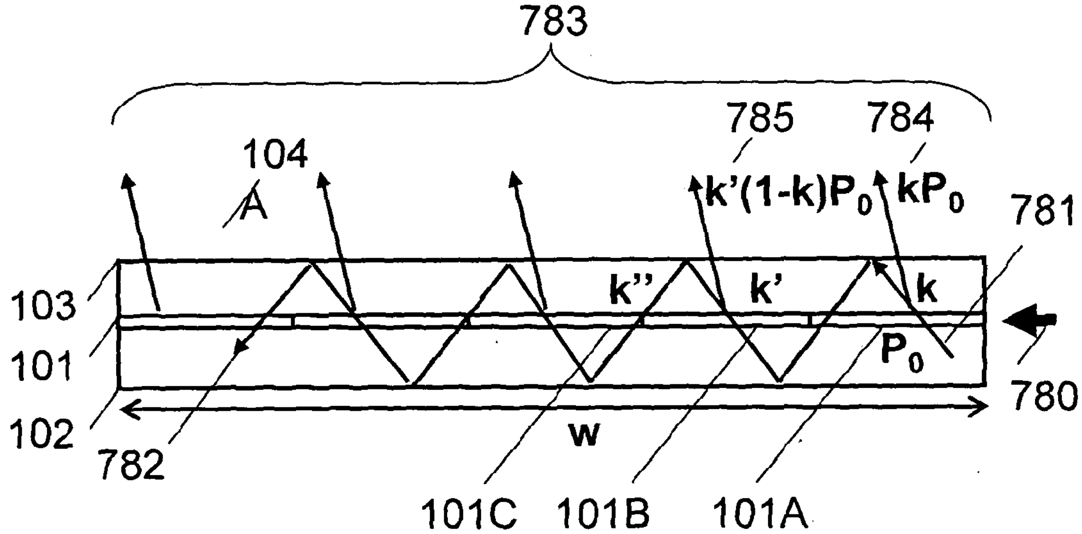


FIG.22

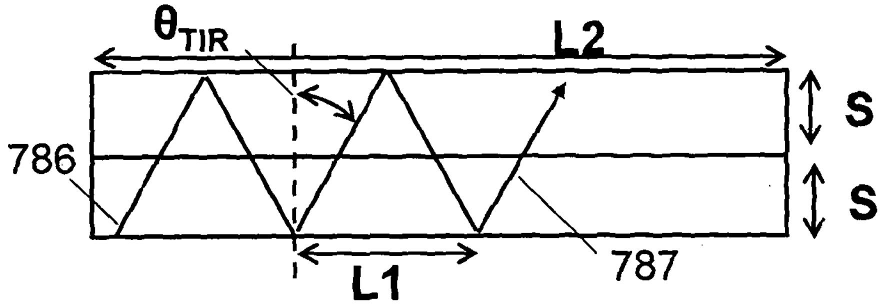


FIG.23

TIR ANGLE (DEG.)	BOUNCE LENGTH (MM.)	NUMBER OF BOUNCES
65	5.2	2
55	3.4	3
42	2.2	5

FIG.24

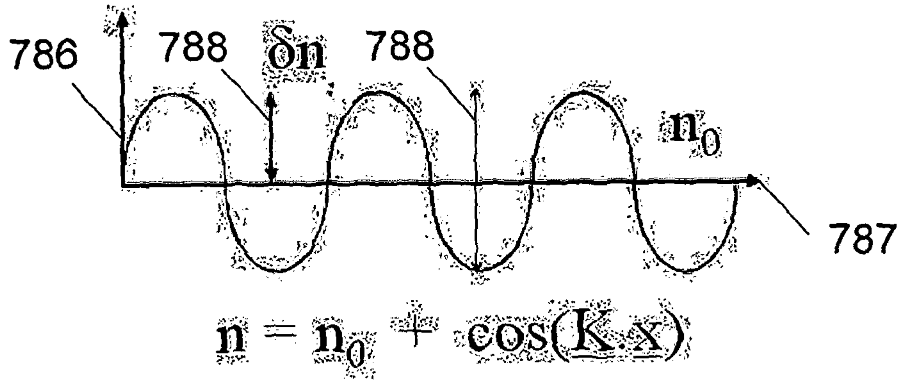


FIG.25

Index Modulation	PEAK DIFFRACTION EFFICIENCY (%)		
	BLUE	GREEN	RED
0.01	6	5	4
0.02	20	18	13
0.03	45	37	25
0.04	70	60	42

FIG.26

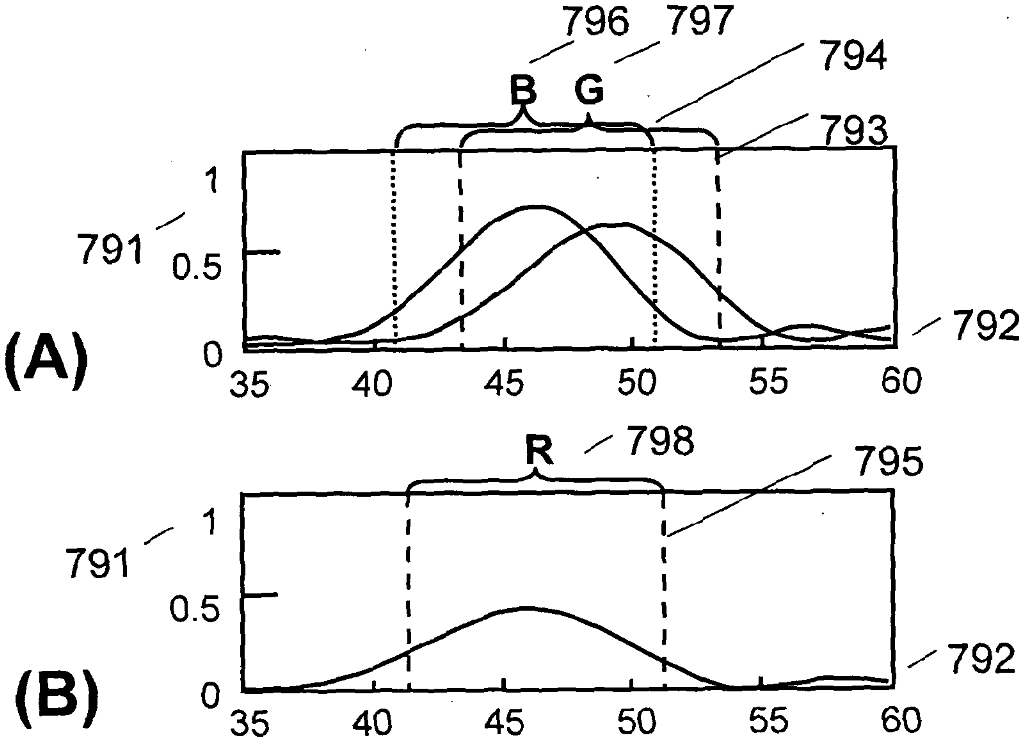

796
797
794
793
B
G
791
1
0.5
0
(A)
35
40
45
50
55
60
792
R
798
795
791
1
0.5
0
(B)
35
40
45
50
55
60
792

FIG.27

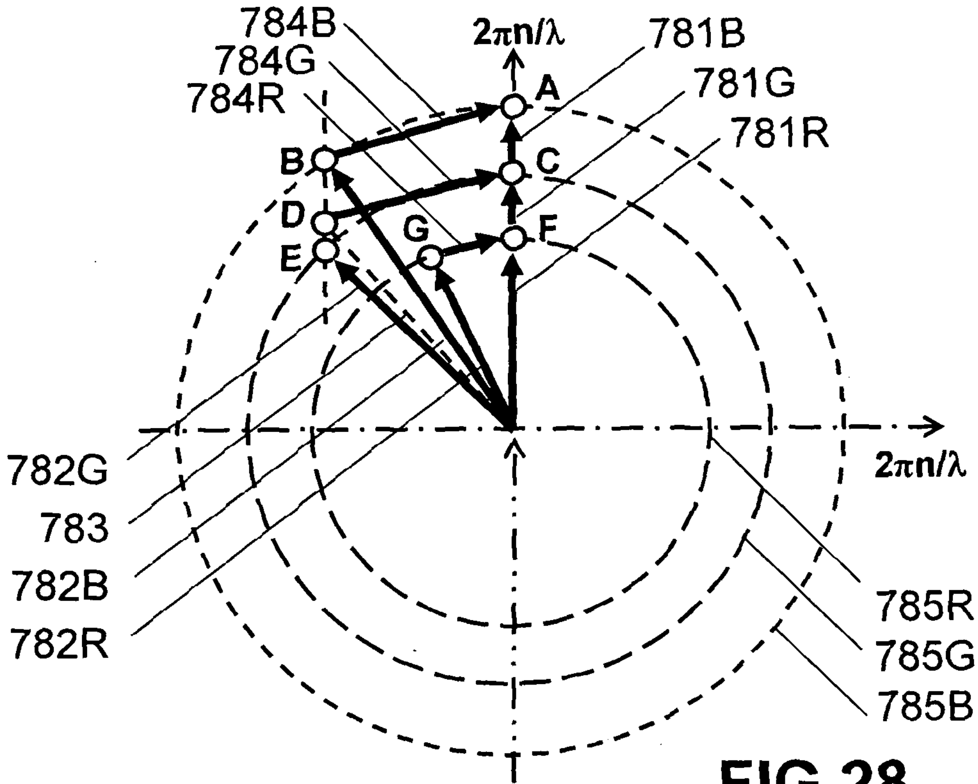

784B
784G
784R
2πn/λ
781B
781G
781R
A
B
C
D
G
F
E
782G
783
782B
782R
2πn/λ
785R
785G
785B

FIG.28

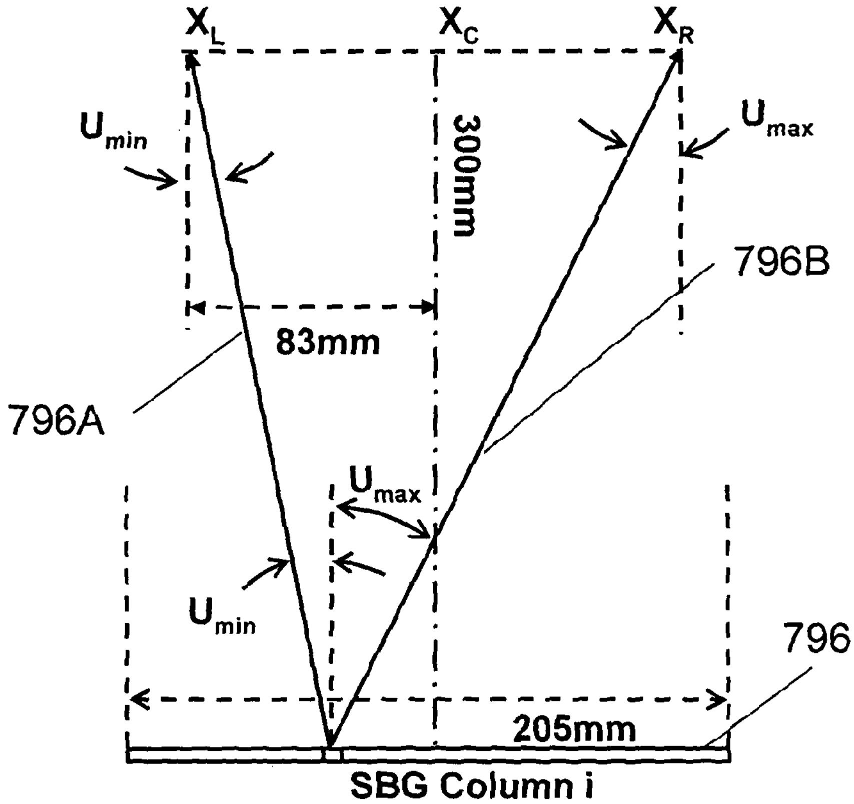


FIG.29

Green wavelength (micron)	0.532
Blue wavelength (micron)	0.465
Red wavelength (microns)	0.645
Holographic medium index	1.55
Eye Range	166
Range	300
Display width	205
XL	83
XC	41.5
XR	0
TIR Angle Red	50
TIR Angle Blue-Green	52

FIG.30

SBG Column	-100	-80	-60	-40	-20	0	20	40	60	80	100
Umax	-31.38	-28.51	-25.48	-22.29	-18.95	-15.46	-11.86	-8.16	-4.38	-0.57	3.24
Umin	-18.43	-14.93	-11.31	-7.59	-3.81	0.00	3.81	7.59	11.31	14.93	18.43
U mean	-24.91	-21.72	-18.40	-14.94	-11.38	-7.73	-4.02	-0.28	3.46	7.18	10.84
Angular Sweep (Umax - U min)	-12.95	-13.58	-14.17	-14.70	-15.13	-15.46	-15.67	-15.75	-15.69	-15.50	-15.19
SBG1 diffraction angle (air)	-28.14	-25.12	-21.94	-18.62	-15.16	-11.60	-7.94	-4.22	-0.46	3.30	7.04
SBG2 diffraction angle (air)	-21.67	-18.33	-14.85	-11.27	-7.60	-3.87	-0.10	3.66	7.39	11.05	14.64
SBG1 diffraction angle (SBG)	-17.72	-15.89	-13.95	-11.89	-9.72	-7.45	-5.11	-2.72	-0.30	2.13	4.54
SBG2 diffraction angle (SBG)	-13.78	-11.70	-9.52	-7.24	-4.89	-2.49	-0.07	2.36	4.76	7.11	9.38
Pitch SBG1 Red Grating	0.90	0.85	0.79	0.74	0.70	0.65	0.61	0.58	0.55	0.52	0.49
Pitch SBG1 Blue Green Grating	0.55	0.51	0.48	0.45	0.43	0.40	0.38	0.36	0.34	0.33	0.32

FIG.31

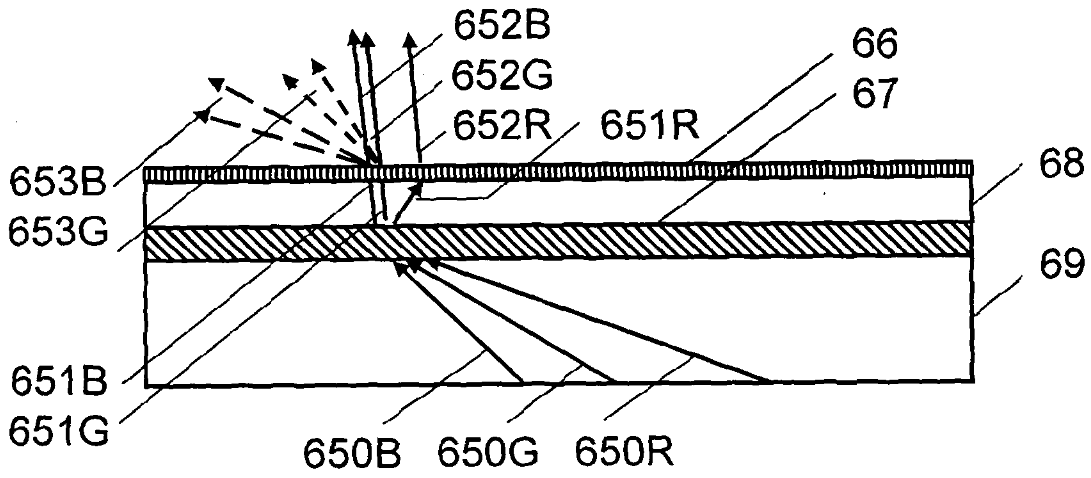

652B
652G
652R
651R
66
67
68
69
653B
653G
651B
651G
650B
650G
650R

FIG. 32

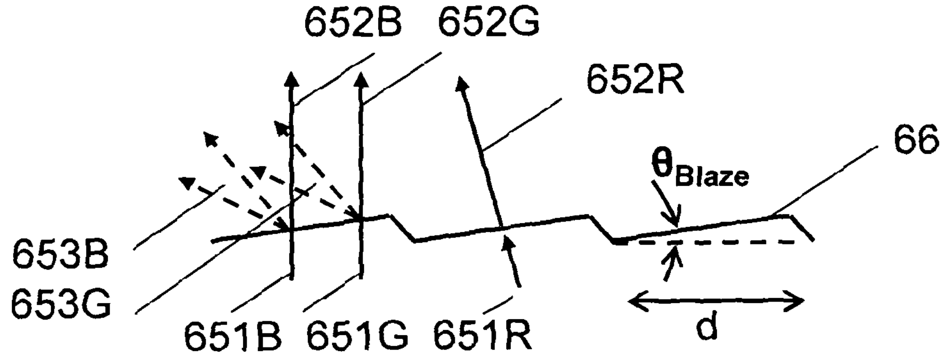

652B
652G
652R
66
θBlaze
653B
653G
651B
651G
651R
d

FIG.33

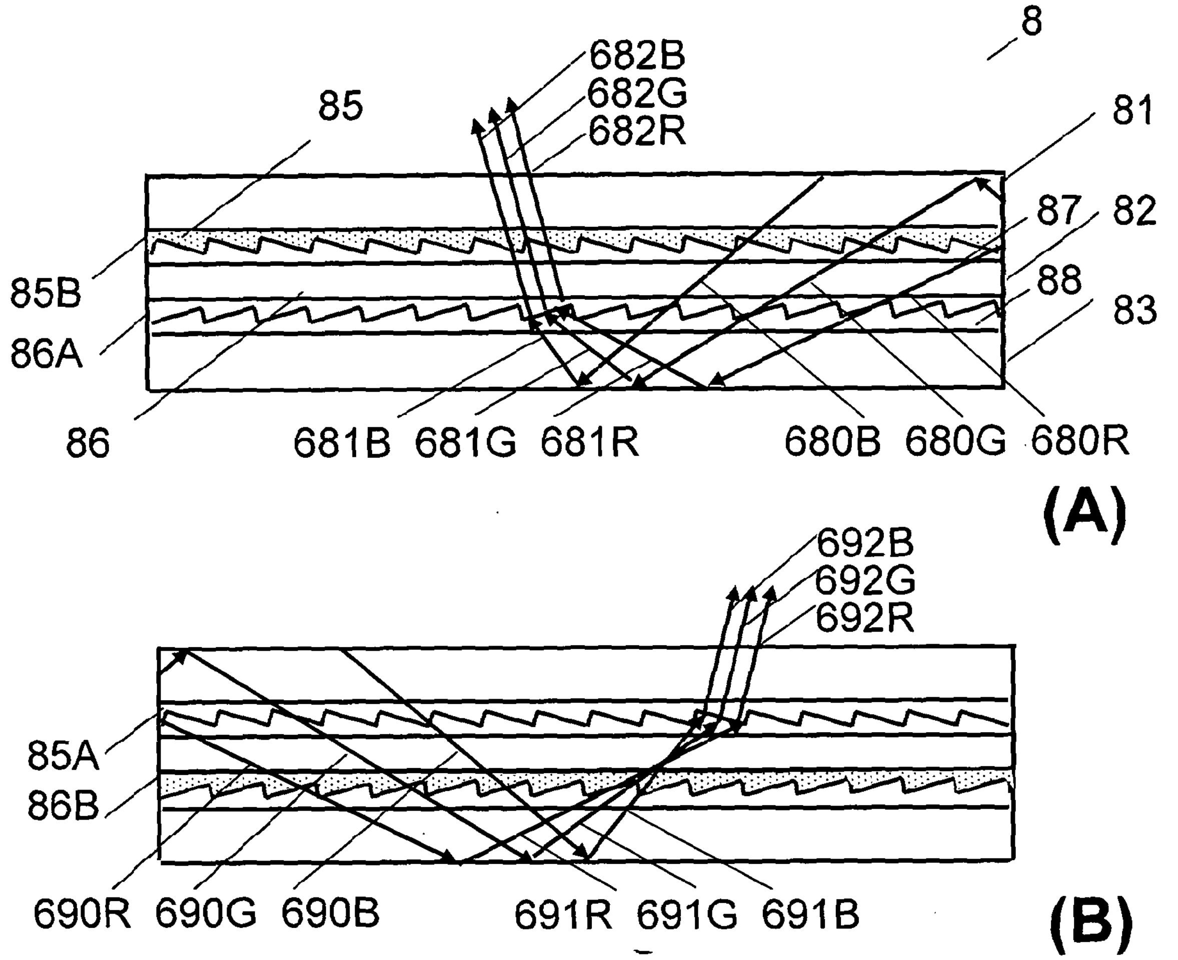

8
682B
682G
682R
85
81
87
82
85B
88
86A
83
86
681B 681G 681R
680B 680G 680R
(A)
692B
692G
692R
85A
86B
690R 690G 690B
691R 691G 691B
(B)

FIG.34

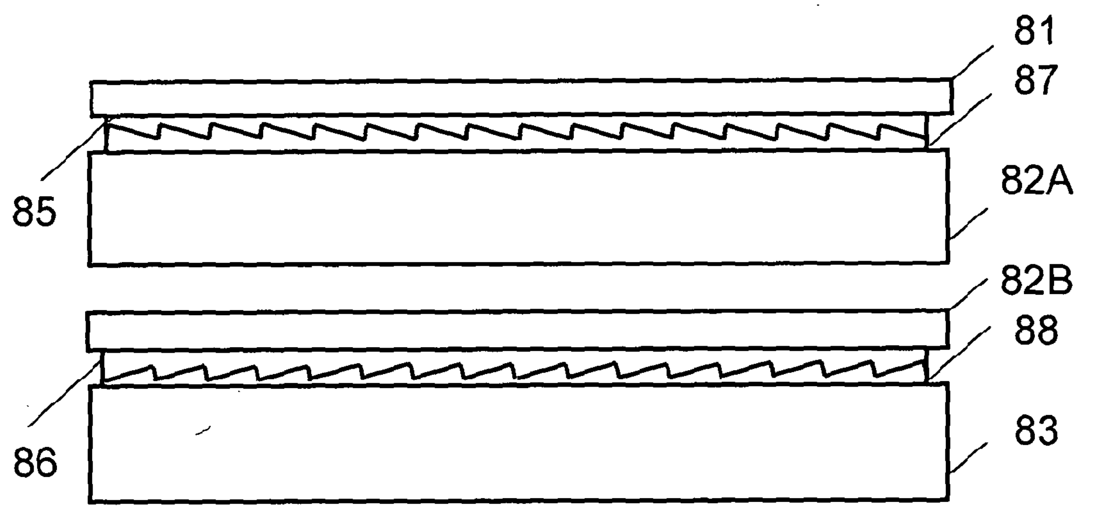
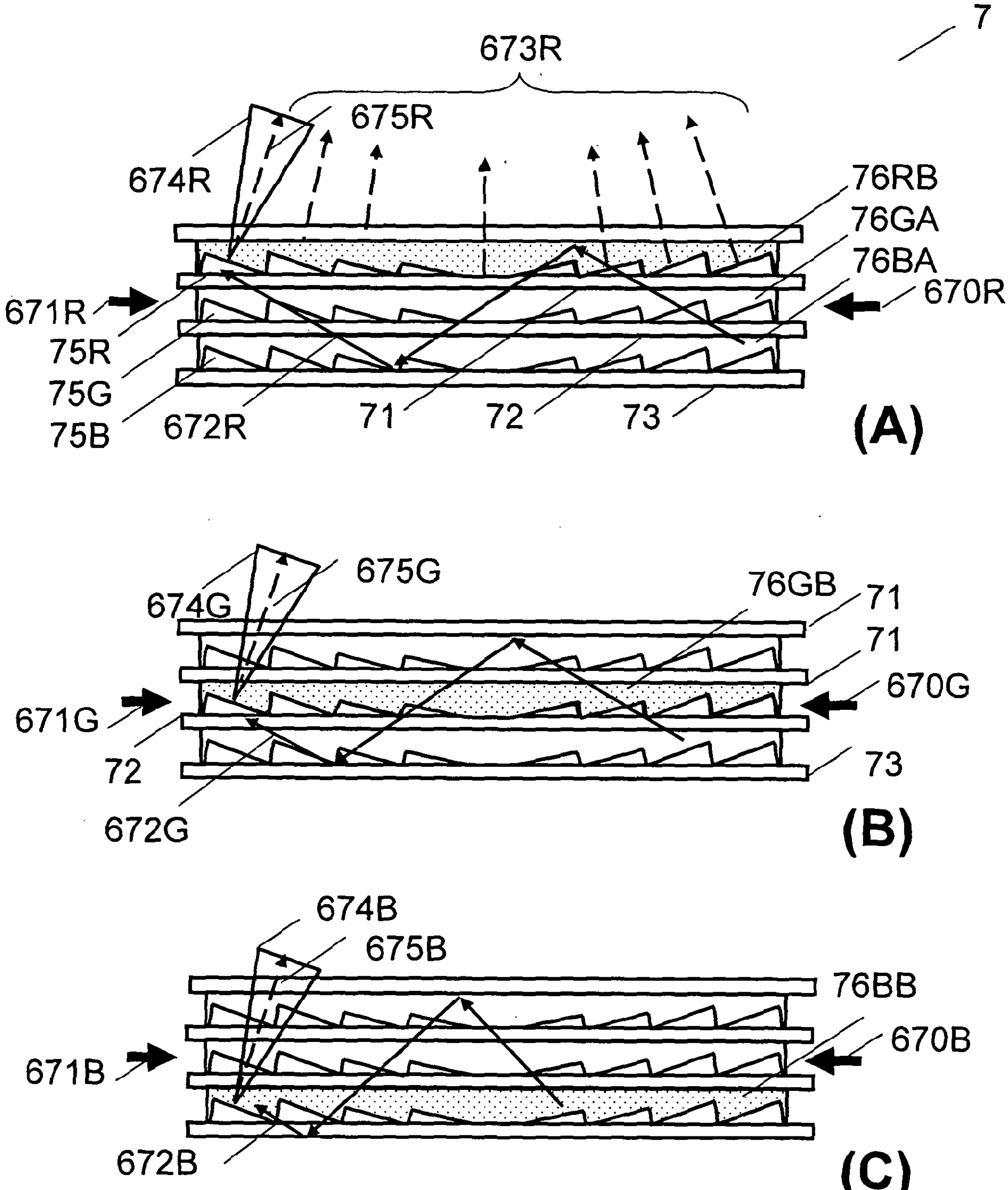

81
87
85
82A
82B
88
86
83

FIG.35



7
673R
675R
674R
76RB
76GA
76BA
670R
671R
75R
75G
75B
672R
71
72
73
(A)
675G
674G
76GB
71
71
670G
671G
72
73
672G
(B)
674B
675B
76BB
670B
671B
672B
(C)

FIG.36

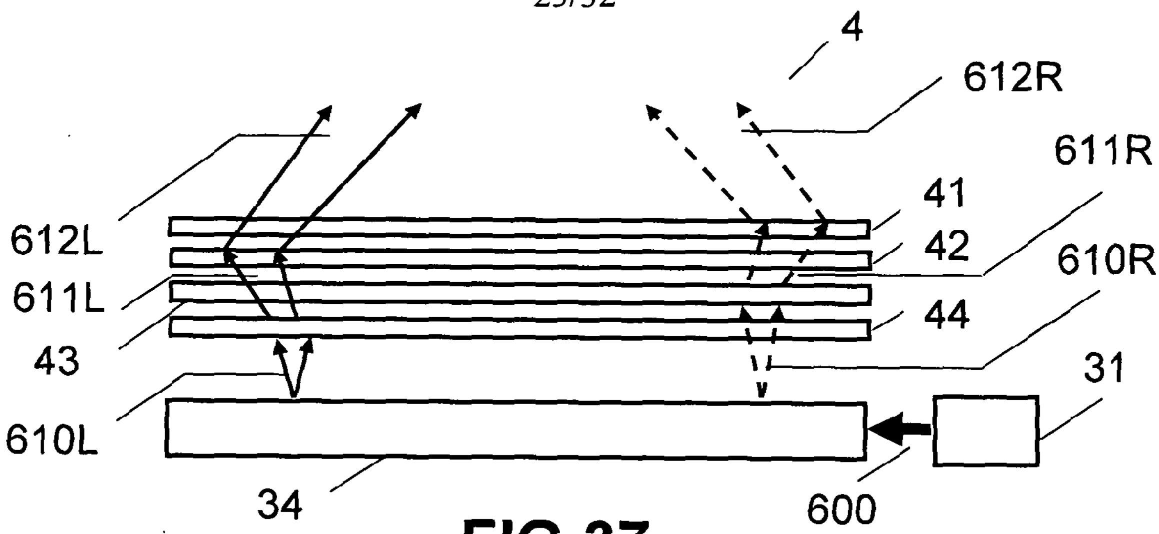

4
612R
611R
41
42
610R
44
31
612L
611L
43
610L
34
600

FIG.37

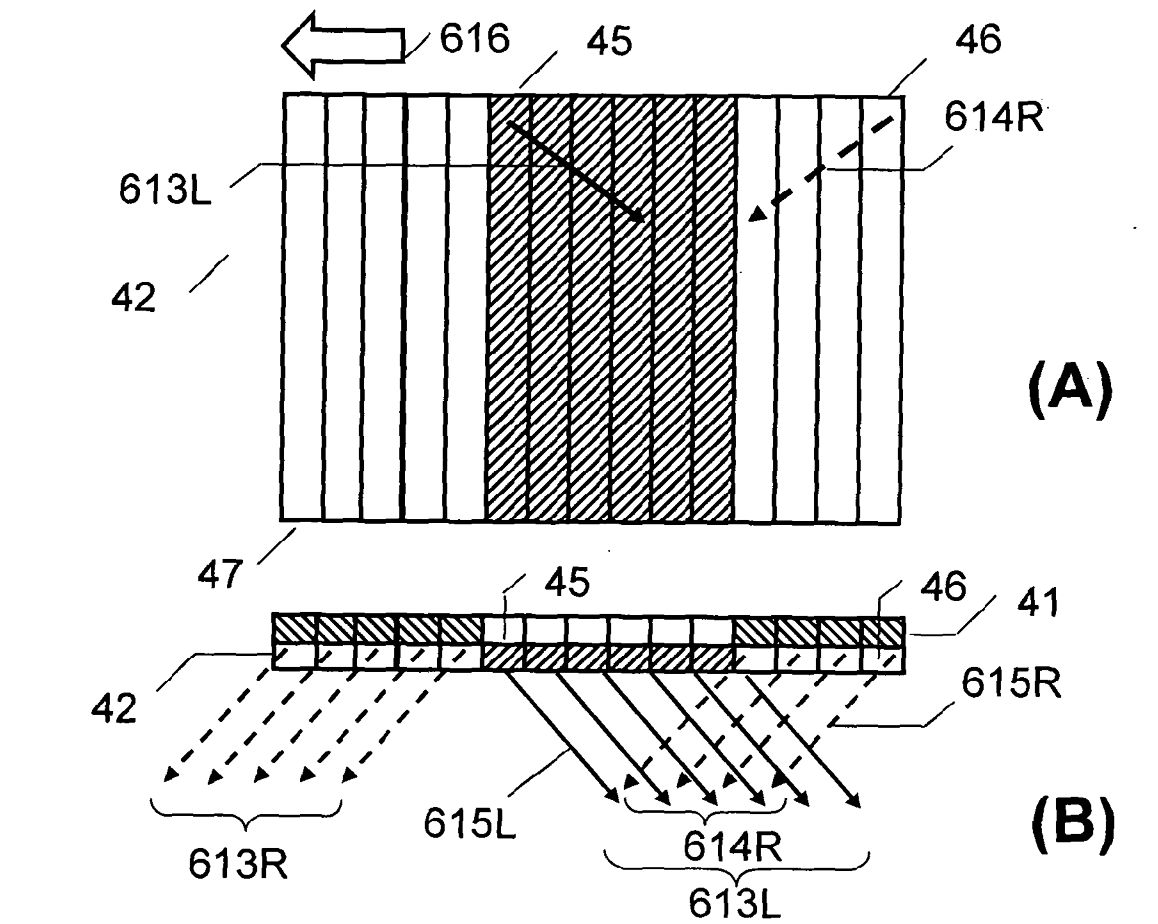

616
45
46
614R
613L
42
(A)
47
45
46
41
42
615R
613R
615L
614R
613L
(B)

FIG.38

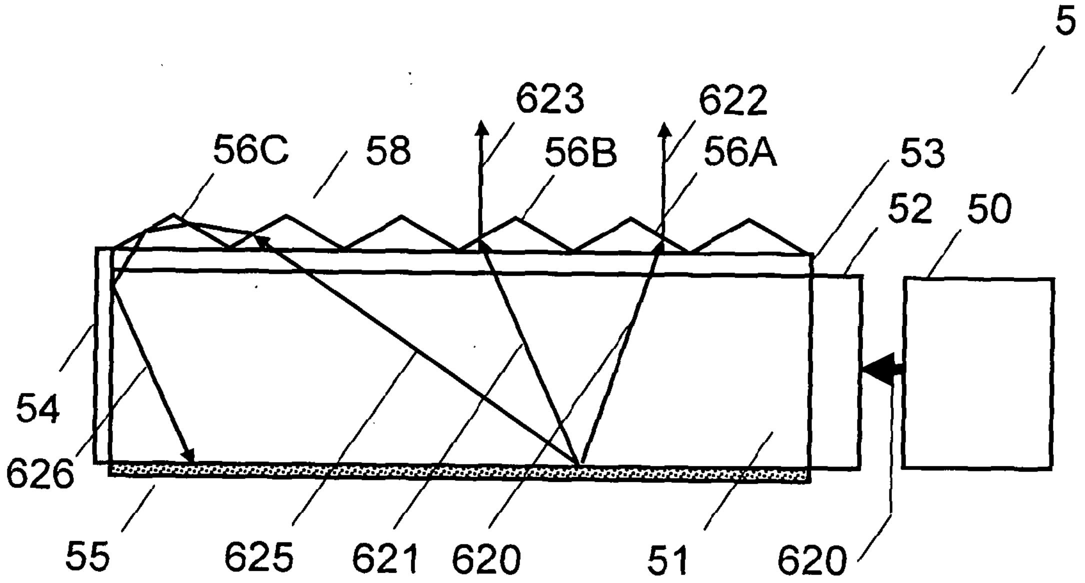

5
623
622
56C
58
56B
56A
53
52
50
54
626
55
625
621
620
51
620

FIG.39

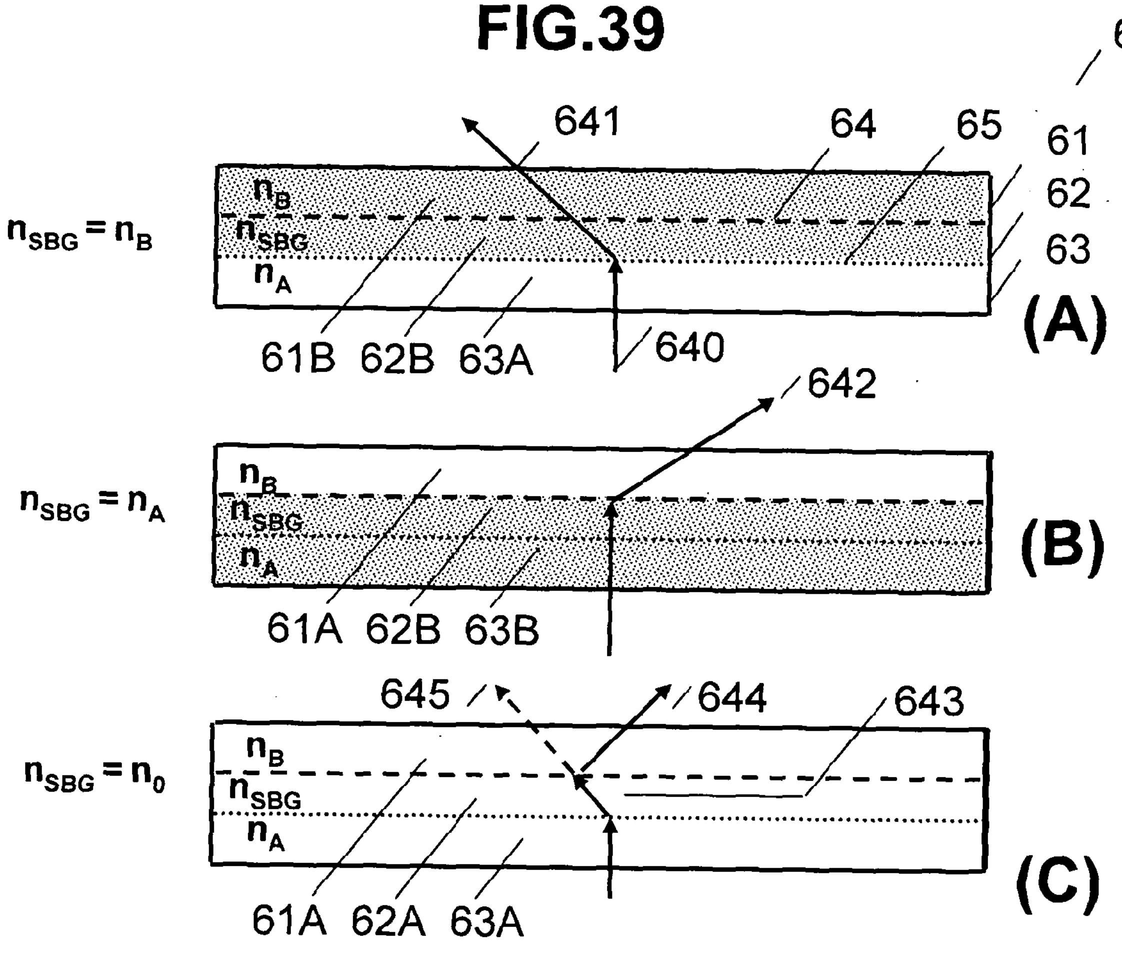

6
641
64
65
61
62
63
$n_{SBG} = n_B$
n_B
n_{SBG}
n_A
61B 62B 63A
640
(A)
642
$n_{SBG} = n_A$
n_B
n_{SBG}
n_A
(B)
61A 62B 63B
645
644
643
$n_{SBG} = n_0$
n_B
n_{SBG}
n_A
(C)
61A 62A 63A

FIG.40

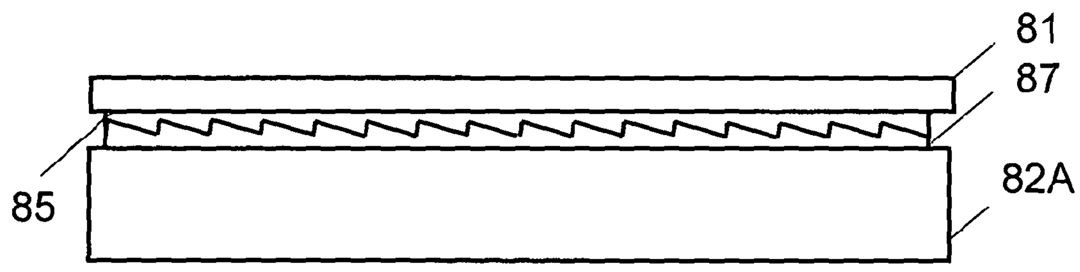

81
87
85
82A

FIG.41

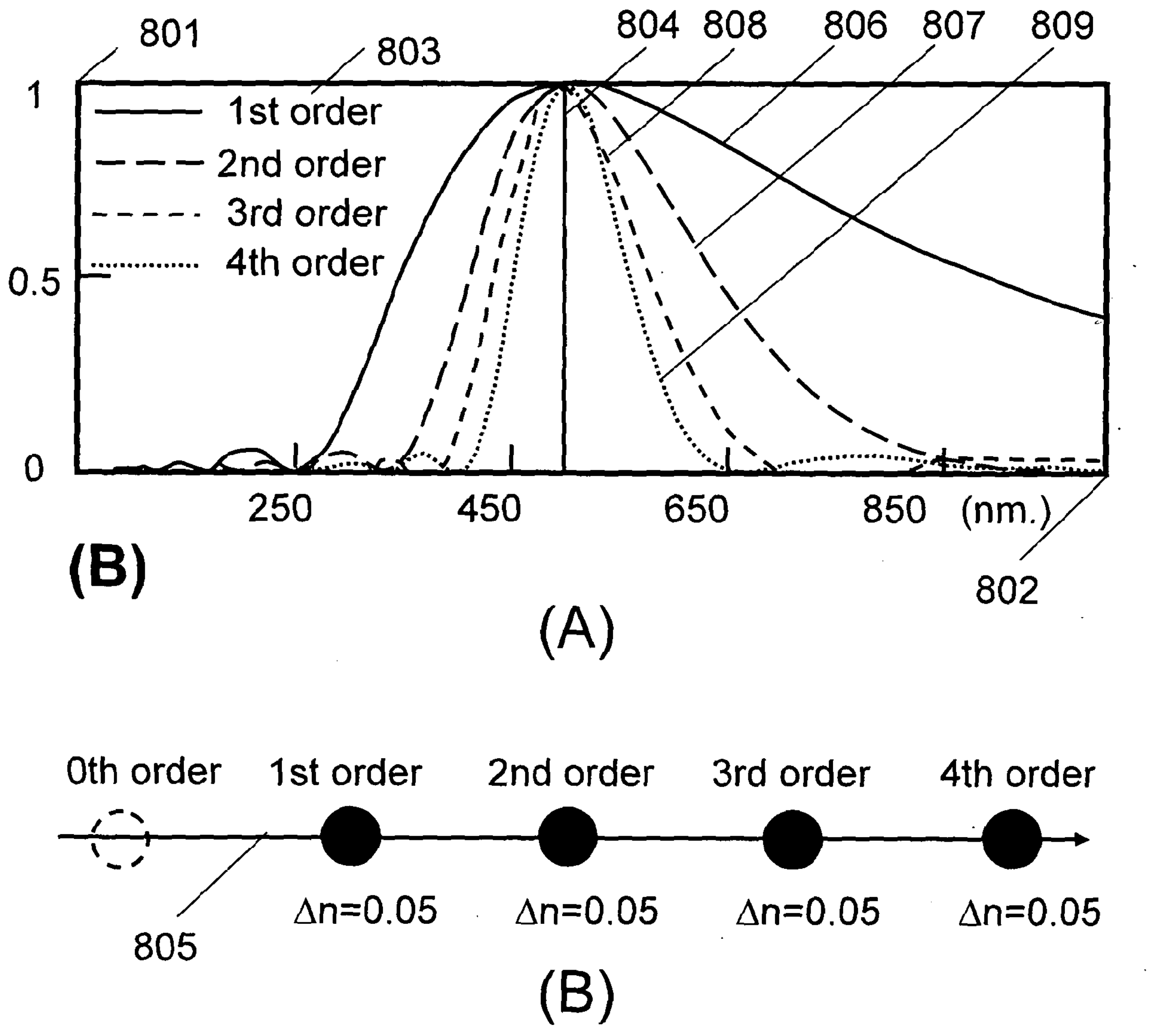

801
803
804 808
806
807
809
1
0.5
0
1st order
2nd order
3rd order
4th order
250
450
650
850
(nm.)
(B)
802
(A)
0th order
1st order
2nd order
3rd order
4th order
805
Δn=0.05
Δn=0.05
Δn=0.05
Δn=0.05
(B)

FIG.42

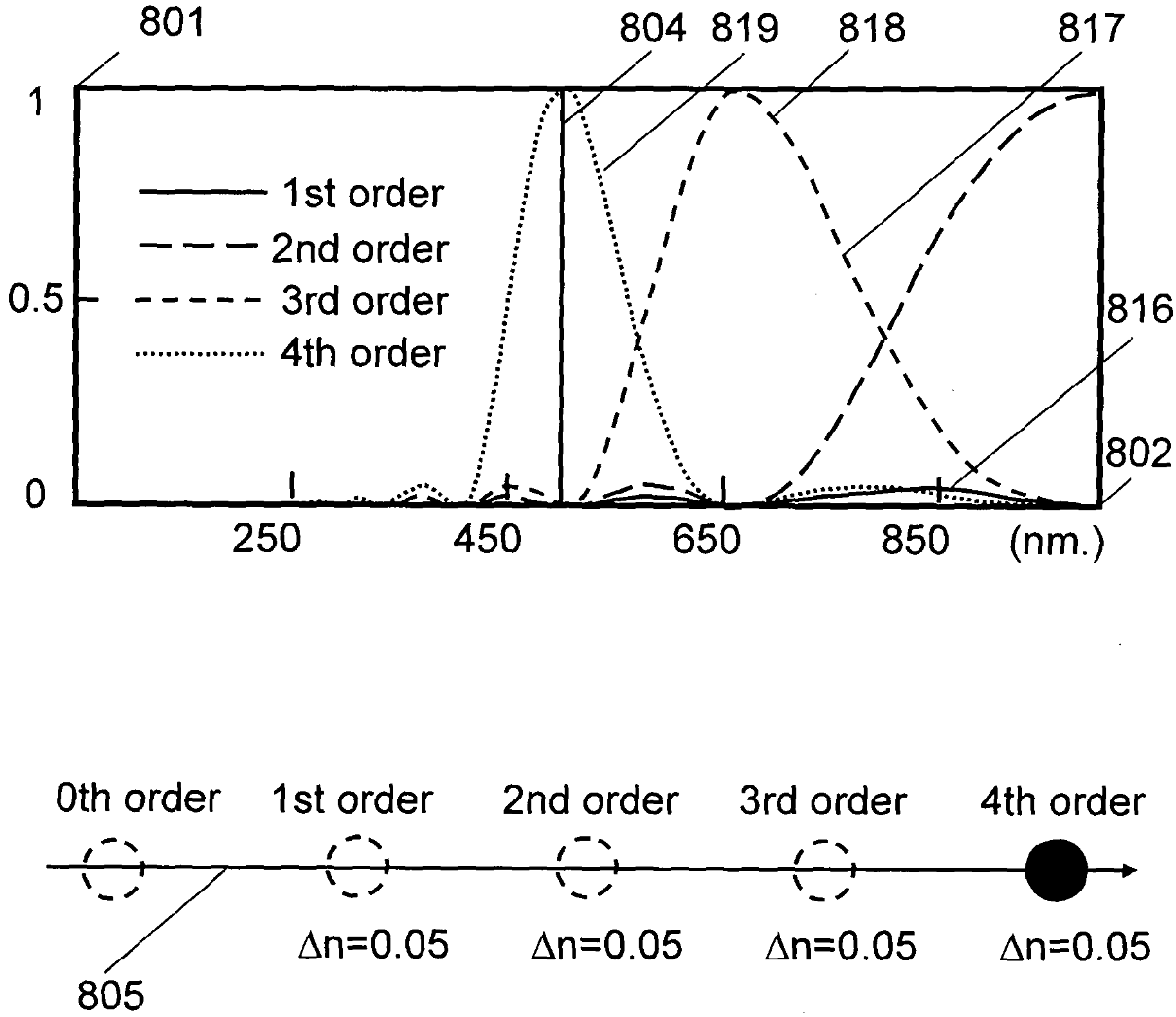

801
804
819
818
817
1
0.5
0
1st order
2nd order
3rd order
4th order
816
802
250
450
650
850
(nm.)
0th order
1st order
2nd order
3rd order
4th order
Δn=0.05
Δn=0.05
Δn=0.05
Δn=0.05
805

FIG.43

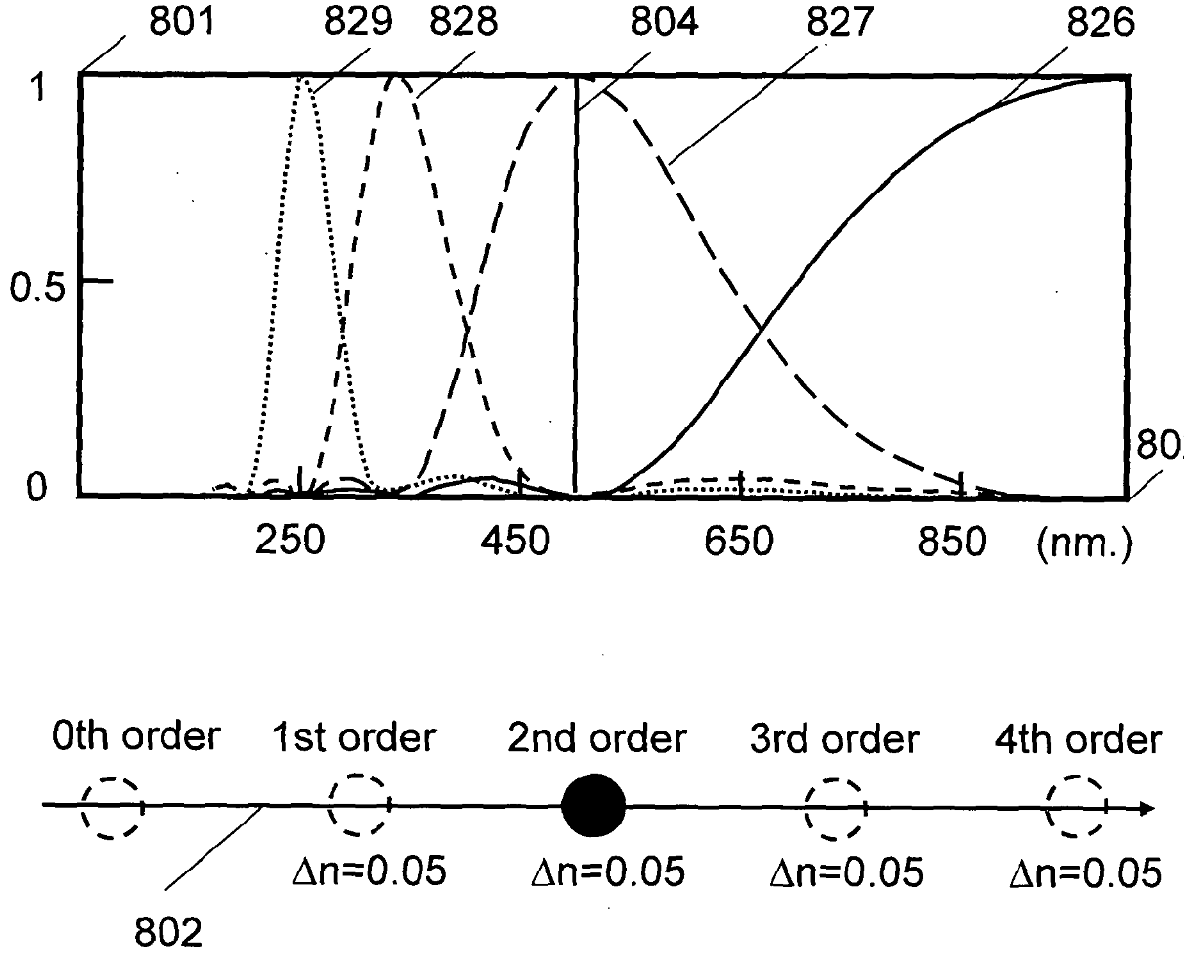

801
829
828
804
827
826
1
0.5
0
802
250
450
650
850
(nm.)
0th order
1st order
2nd order
3rd order
4th order
Δn=0.05
Δn=0.05
Δn=0.05
Δn=0.05
802

FIG.44

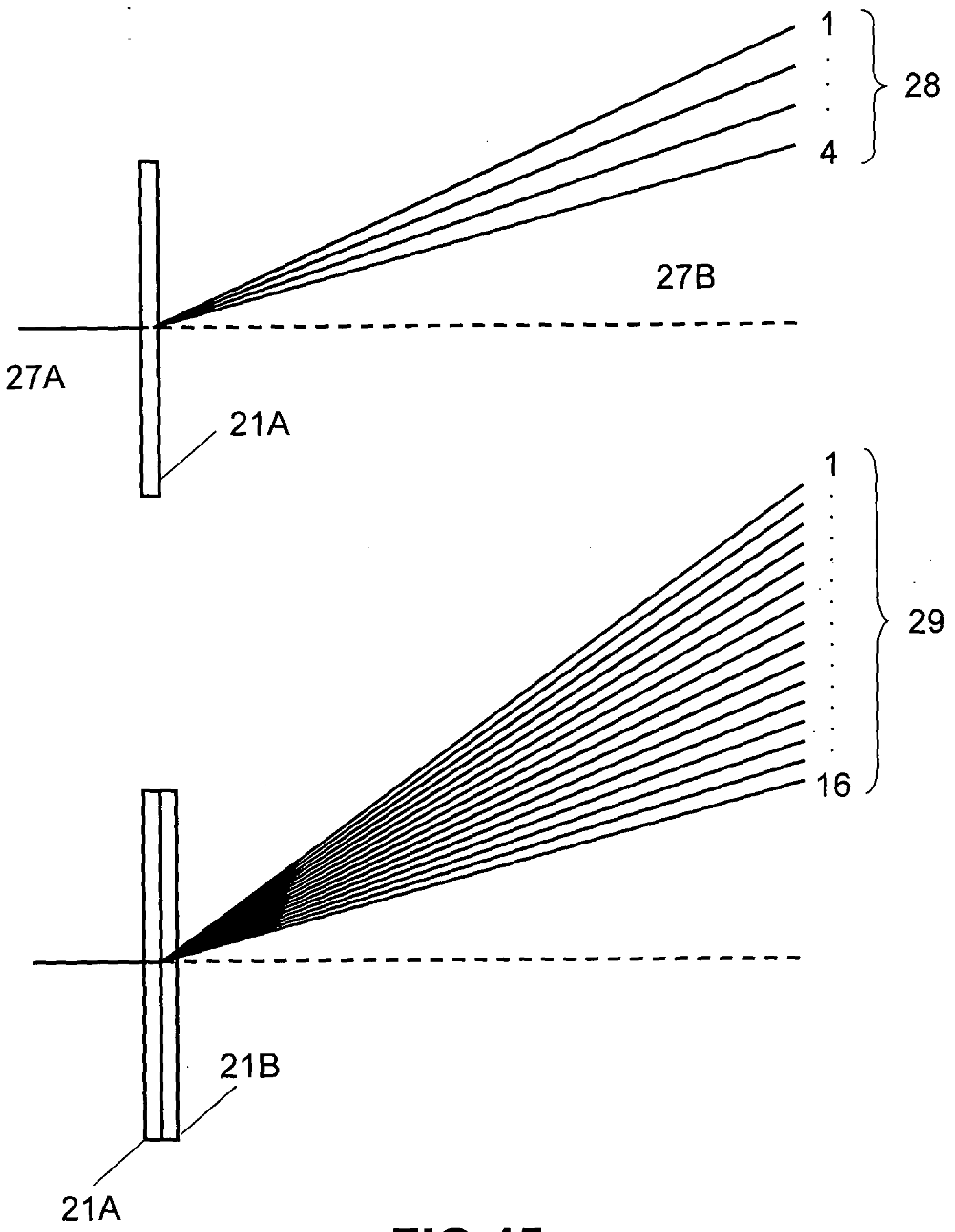


FIG.45

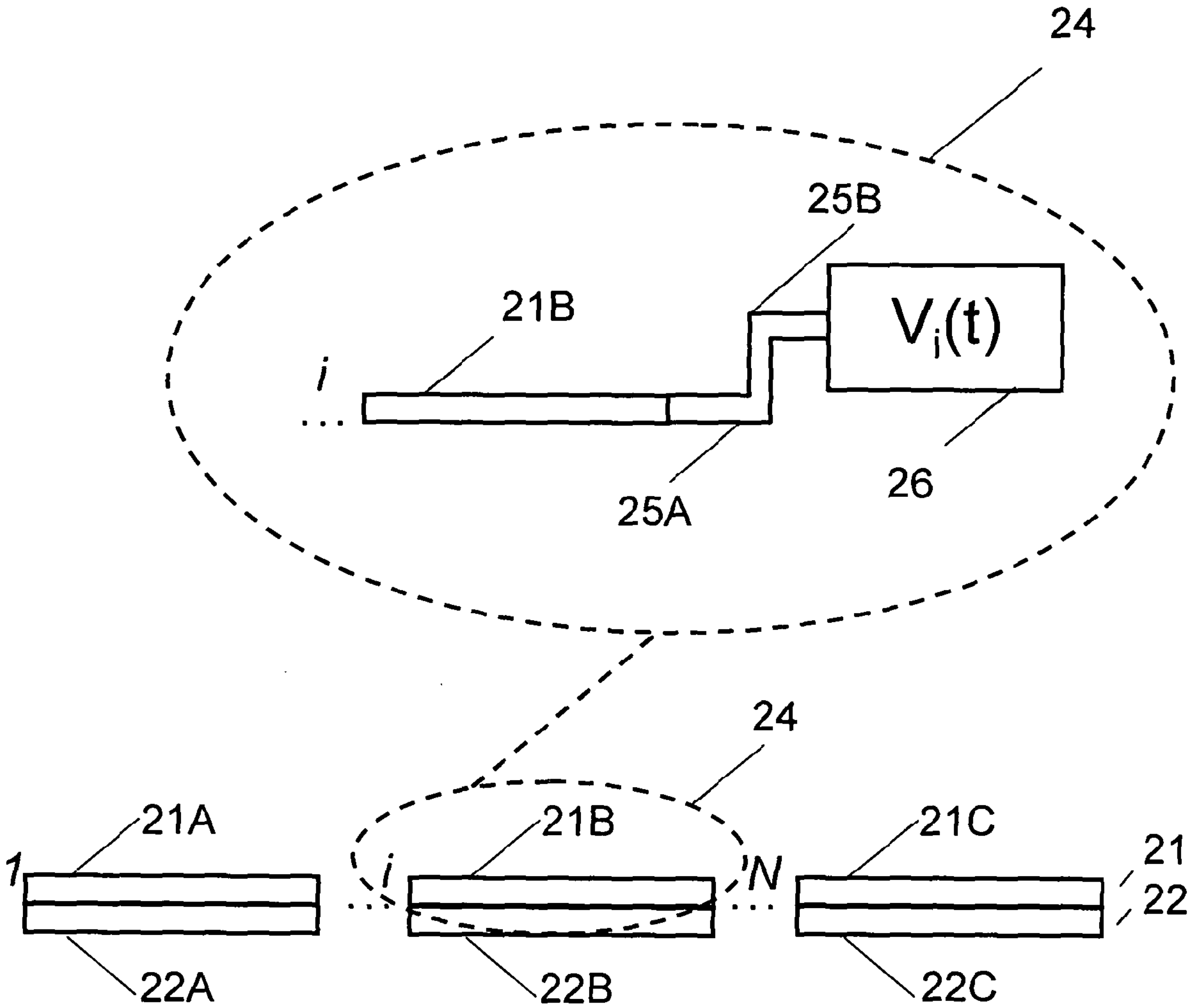

24
25B
21B
i
$V_i(t)$
26
25A
24
21A
21B
21C
1
i
N
21
22
22A
22B
22C

FIG.46

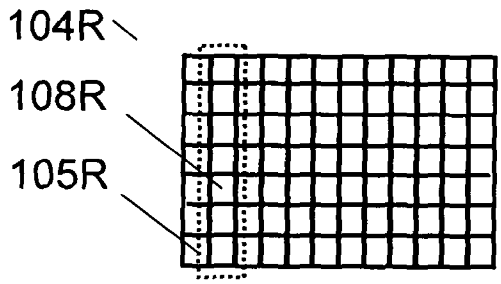

104R
108R
105R

FIG.47

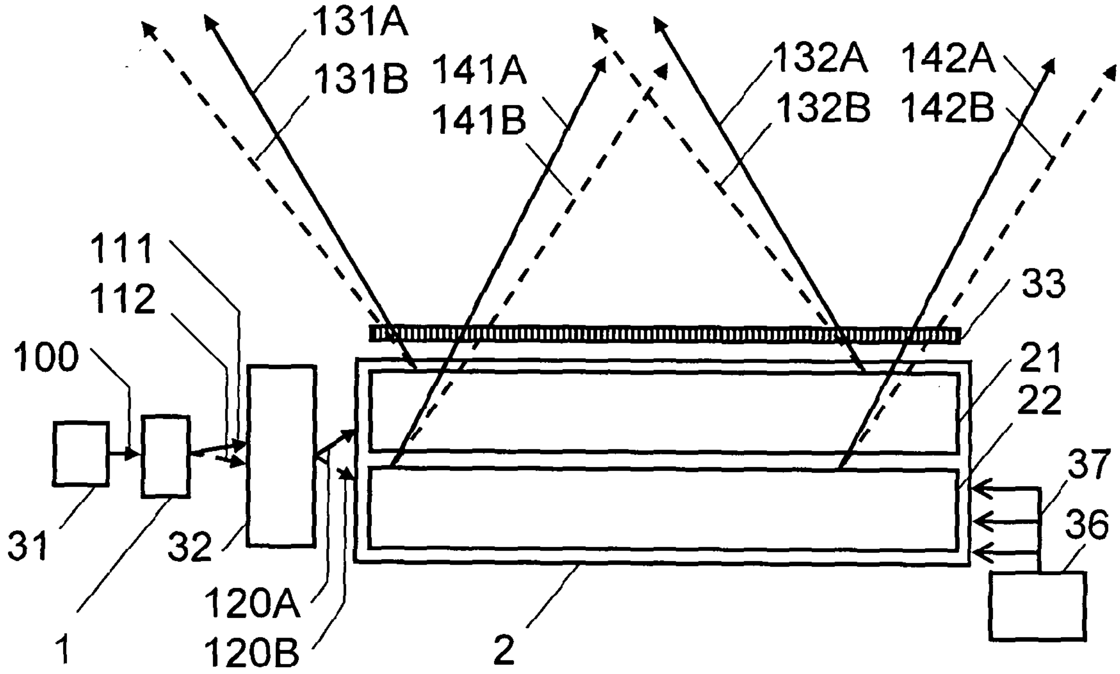

131A
131B
141A
141B
132A
132B
142A
142B
111
112
100
33
21
22
37
36
31
32
120A
120B
1
2

FIG.48

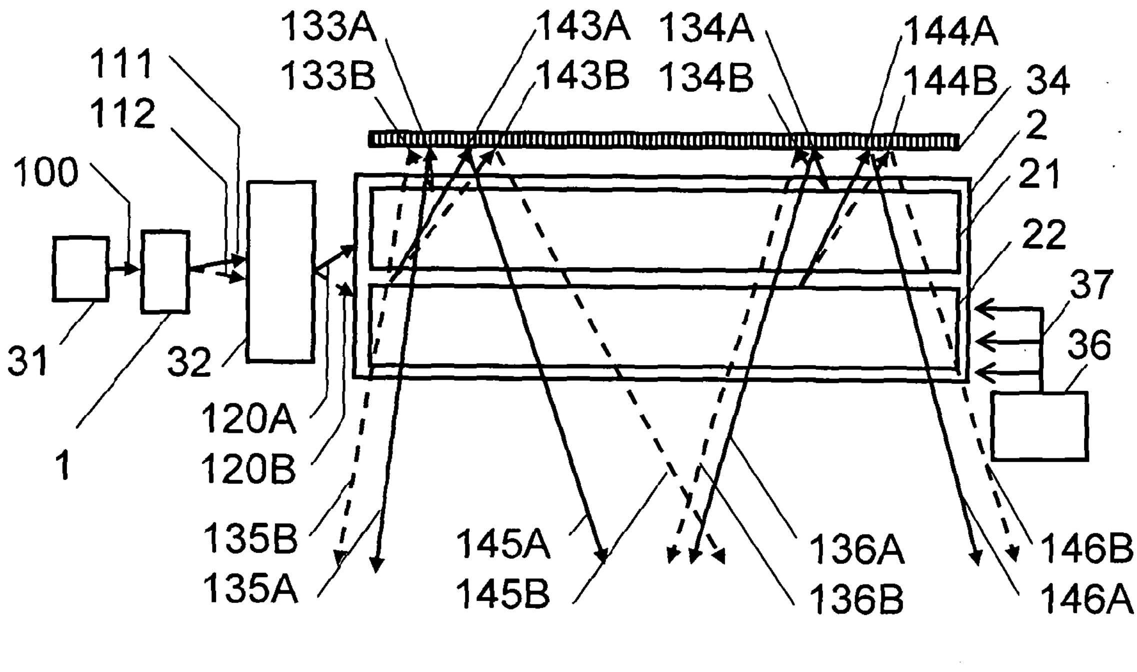

133A
133B
143A
143B
134A
134B
144A
144B
34
111
112
100
2
21
22
37
36
31
32
120A
120B
1
135B
135A
145A
145B
136A
136B
146B
146A

FIG.49

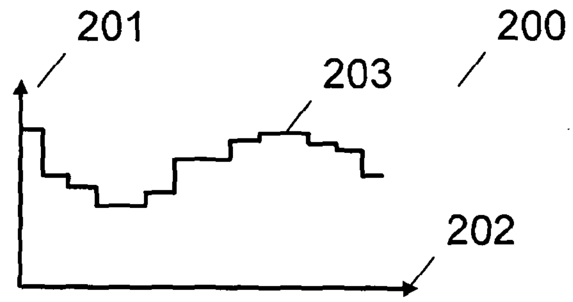

201
200
203
202

FIG.50

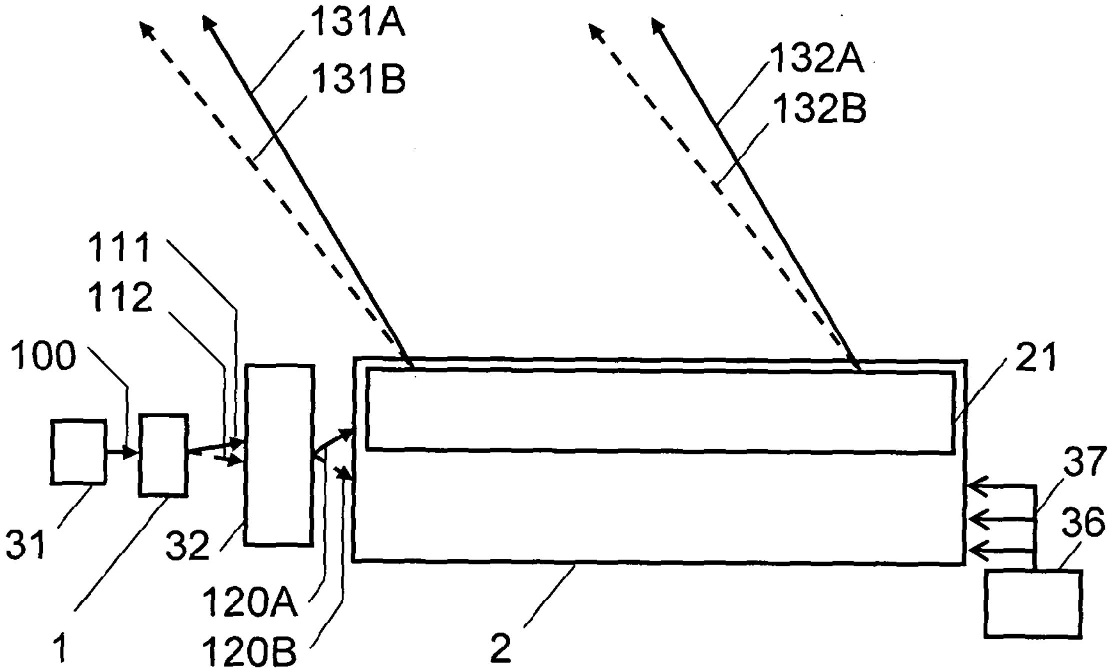
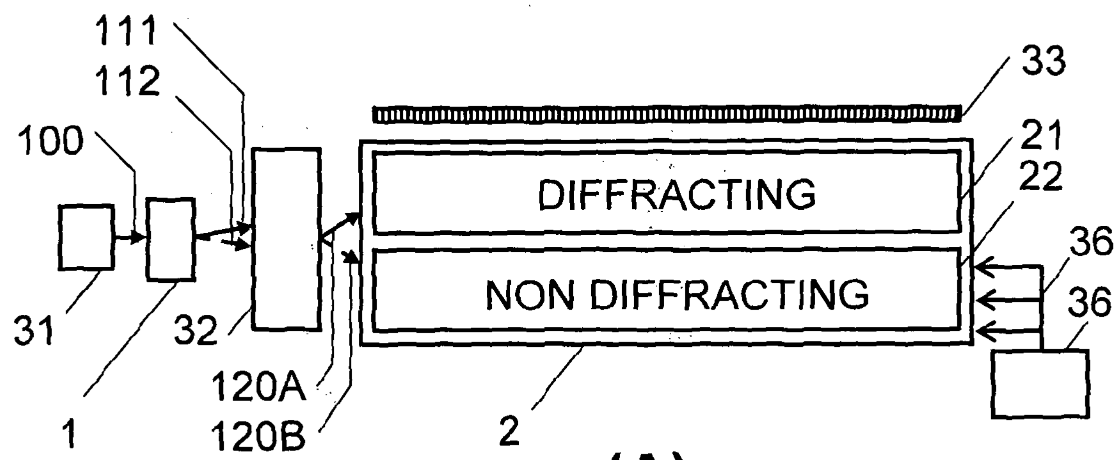
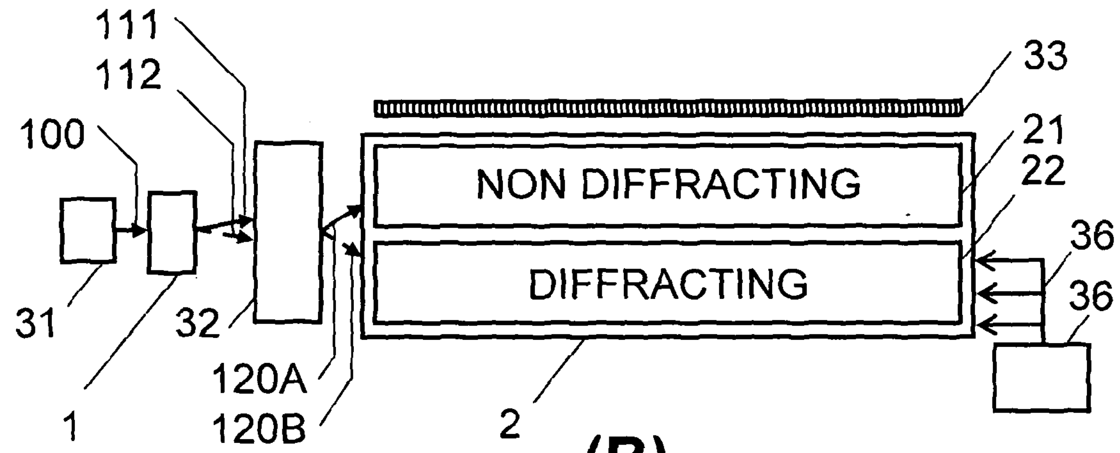

131A
131B
132A
132B
111
112
100
21
37
36
31
32
120A
120B
1
2

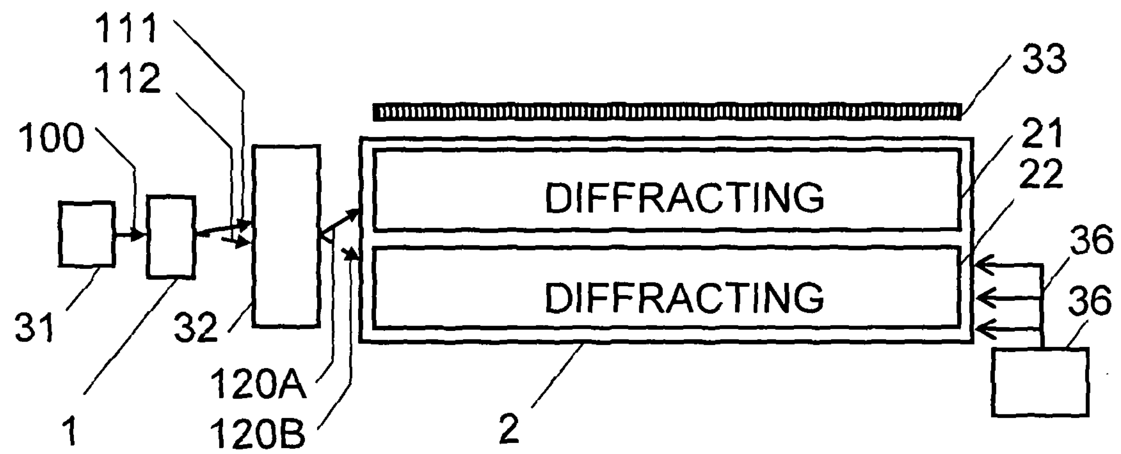
FIG.51


111
112
100
33
21
22
DIFFRACTING
NON DIFFRACTING
36
36
31
32
1
120A
120B
2

(A)


111
112
100
33
21
22
NON DIFFRACTING
DIFFRACTING
36
36
31
32
1
120A
120B
2

(B)


111
112
100
33
21
22
DIFFRACTING
DIFFRACTING
36
36
31
32
1
120A
120B
2

(C)

FIG. 52

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2012/000525

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B27/22 G02F1/1334 H04N13/04
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G02B G02F H04N

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2010/149587 A2 (SEEREAL TECHNOLOGIES SA [LU]; KROLL BO [GB]; LEISTER NORBERT [DE]; FUE) 29 December 2010 (2010-12-29)	1-8,13
Y	page 33, line 1 - page 34, line 37; figures 2,11,12	9-12
Y	US 6 169 594 B1 (AYE TIN M [US] ET AL) 2 January 2001 (2001-01-02) column 7, line 1 - column 8, line 5; figure 2	9-12
X	WO 2010/125337 A2 (POPOVICH MILAN MOMCILO [GB]) 4 November 2010 (2010-11-04)	1-8,13
A	page 29 - page 37; figures 16-23	9-12

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

☒ See patent family annex.

* Special categories of cited documents :

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 September 2012	08/10/2012

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2012/000525

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			US	6169594 B1	02-01-2001
			WO	0011515 A1	02-03-2000
WO 2010125337	A2	04-11-2010	NONE		