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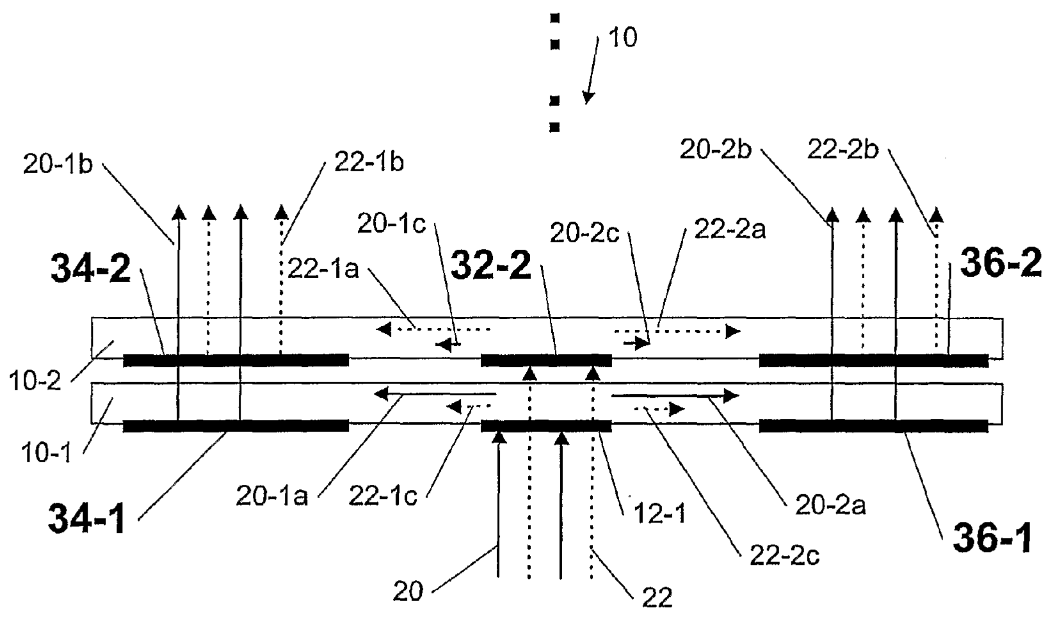
(54) **Title:** COLOR DISTRIBUTION IN EXIT PUPIL EXPANDERS



(57) **Abstract:** The specification and drawings present a new apparatus and method for providing color separation in an exit pupil expander system that uses a plurality of diffractive elements for expanding the exit pupil of a display in an electronic device for viewing by introducing a selectively absorbing area or areas in the exit pupil expanders.

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COLOR DISTRIBUTION IN EXIT PUPIL EXPANDERS

Technical Field

The present invention relates generally to a display device and, more specifically, to providing color separation in exit pupil expanders that use a plurality of diffractive elements for expanding the exit pupil of a display for viewing.

Background Art

While it is a common practice to use a low-resolution liquid-crystal display (LCD) panel to display network information and text messages in a mobile device, it is preferred to use a high-resolution display to browse rich information content of text and images. A microdisplay-based system can provide full color pixels at 50-100 lines per mm. Such high-resolution is generally suitable for a virtual display. A virtual display typically consists of a microdisplay to provide an image and an optical arrangement for manipulating light emerging from the image in such a way that it is perceived as large as a direct view display panel. A virtual display can be monocular or binocular.

The size of the beam of light emerging from imaging optics toward the eye is called exit pupil. In a Near-Eye Display (NED), the exit pupil is typically of the order of 10mm in diameter. Further enlarging the exit pupil makes using the virtual display significantly easier, because the device can be put at a distance from the eye. Thus, such a display no longer qualifies as a NED, for obvious reasons. Head-Up Displays are examples of the virtual display with a sufficiently large exit pupil.

Disclosure of the Invention

According to a first aspect of the invention, an apparatus, comprises: at least one substrate of optical material having a first surface and a second surface; at least one diffractive element disposed on the first or the second surface of the at least one substrate and configured to receive an input optical beam; at least one further diffractive element disposed on the first or the second surface; and at least one optically absorbing area within or disposed on the at least one substrate, wherein at least part of the input optical beam is diffracted in the diffractive element to provide at least one diffracted optical beam substantially within the first and the second surfaces, and at least part of the at least one diffracted optical beam is coupled out of the at least one substrate by diffraction in the at least one further diffractive element, thus providing an output optical beam out of the at least one substrate with an expanded exit pupil in one or two dimensions, wherein the input optical beam comprises K wavelength components and the at least one optically absorbing area is configured to absorb M pre-selected components out of the K wavelength components of the at least one diffracted optical beam and to propagate a selected component out of the K wavelength components of the at least one diffracted optical beam, such that the output optical beam comprises the selected component out of the K wavelength components, wherein K is an integer of at least a value of two and M is an integer between 1 and K-1.

According further to the first aspect of the invention, the optical device may comprise N stacked substrates of optical material separated by a gap, N being an integer of at least a value of one, and the at least one substrate being one of the N substrates, wherein each of the N stacked substrates is configured to expand an exit pupil substantially of only one component out of the K wavelength components of the input optical beam such that all the K wavelength components merge together having substantially the same direction and location in an output of the optical device. Further wherein N=K.

According further to the first aspect of the invention, wherein M may be equal to K-1.

Still further according to the first aspect of the invention, the output optical beam provided by the at least one substrate substantially may comprise only the selected component out of the K wavelength components.

According further to the first aspect of the invention, the at least one optically absorbing area may be configured using at least one of: a) an absorbing tint spread throughout a volume of the at least one substrate, b) an absorbing tint spread throughout a thickness of the at least one substrate only in areas of the at least one substrate between the at least one diffractive element and at least one further diffractive element, c) an absorbing tint spread throughout a resin used to make the at least one diffractive element, d) an absorbing tint spread throughout the resin used to make the at least one further diffractive element, and e) an absorbing coating, having substantially the same index of refraction as the at least one substrate, disposed on the at least one substrate in an area substantially between the at least one diffractive element and the at least one further diffractive element.

According still further to the first aspect of the invention, the apparatus may further comprise: a further substrate of optical material having a further first surface and a further second surface, the further substrate being stacked substantially in parallel with the at least one substrate but maintaining a gap with the at least one substrate; at least one additional diffractive element disposed on the further first or the further second surface of the further substrate and configured to receive a portion of the input optical beam which propagates through the at least one substrate into the further substrate; at least one still further diffractive element disposed on the further first or the further second surface; and at least one further optically absorbing area within or disposed on the further substrate, wherein at least further part of the portion of the input optical beam is diffracted in the additional diffractive element to provide at least one further diffracted optical beam substantially within the further first and the further second surfaces, and at least further part of the at least one further diffracted optical beam is further coupled out of the further substrate by diffraction in the at least one still further diffractive element, thus providing a further output optical beam out of the further substrate with an expanded exit pupil in one or two dimensions, the further output optical beam having substantially the same direction and location as the output optical beam, wherein the at least one further optically absorbing area is configured to absorb P pre-selected components of the K wavelength components and to propagate a further selected component out of the K wavelength components, such that the further output optical beam comprises the further selected component out of the K wavelength components, wherein P is an integer between 1 and K-1. Further, wherein P is equal to K-1. Still further, the at least one further optically absorbing area may be configured using at least one of: a) an absorbing tint spread throughout a volume of the further substrate, b) an absorbing tint spread throughout a thickness of the further substrate only in areas of the further substrate between the at least one additional diffractive element and at least one still further diffractive element, c) an absorbing tint spread throughout a resin used to make the at least one additional diffractive element, d) an absorbing tint spread throughout the resin used to make the at least one still further diffractive element, and e) an absorbing coating, having substantially the same index of refraction as the further substrate, disposed on the further substrate between the at least one additional diffractive element and the at least one still further diffractive element. Yet still further, the gap may be an air gap. Still yet further, the output optical beam provided by the at least one substrate substantially may comprise only the selected component out of the K wavelength components and the further output optical beam provided by the further substrate substantially may comprise only the selected further component out of the K wavelength components and the output optical beam and the further output optical beam merge together having substantially the same direction and location.

Further still, the at least one substrate may be configured to have an additional optically absorbing layer disposed on or adjacent to a surface of the at least one substrate, the surface being a second surface through which the input optical beam propagates, such that the selected component out of the K wavelength components is substantially absorbed in the additional optically absorbing layer.

According further still to the first aspect of the invention, the apparatus may further comprise at least one intermediate diffractive element such that the at least part of the input optical beam diffracted in the at least one diffractive element is first coupled to the at least one intermediate diffractive element, which then couples, using a further diffraction in the at least one intermediate diffractive element, the at least part of the diffracted optical beam to the at least one further diffractive element, which then provides a two-dimensional exit pupil expansion of the input optical beam.

According to a second aspect of the invention, a method, comprises: receiving an input optical beam by at least one diffractive element disposed on a first or a second surface of at least one substrate, the input optical beam comprises K wavelength components, wherein K is an integer of at least a value of two; diffracting at least part of the input optical beam in the at least one diffractive element to provide at least one diffracted optical beam substantially within the first and second surfaces; absorbing M pre-selected components out of the K wavelength components of the at least one diffracted optical beam in at least one optically absorbing area within or disposed on the at least one substrate and propagating a selected component out of the K wavelength components of the at least one diffracted optical beam substantially without an optical intensity attenuation in the at least one optically absorbing area, wherein M is an integer between 1 and K-1; and coupling at least part of the at least one diffracted optical beam out of the at least one substrate by diffraction in the at least one further diffractive element, thus providing an output optical beam out of the at least one substrate with an expanded exit pupil in one or two dimensions, wherein the output optical beam comprises the selected component out of the K wavelength components.

According further to the second aspect of the invention, the output optical beam provided by the at least one substrate substantially may comprise only the selected component out of the K wavelength components.

Further according to the second aspect of the invention, the at least one optically absorbing area may be configured using at least one of: a) an absorbing tint spread throughout a volume of the at least one substrate, b) an absorbing tint spread throughout a thickness of the at least one substrate only in areas of the at least one substrate between the at least one diffractive element and at least one further diffractive element, c) an absorbing tint spread throughout a resin used to make the at least one diffractive element, d) an absorbing tint spread throughout the resin used to make the at least one further diffractive element, and e)an absorbing coating, having substantially the same index of refraction as the at least one substrate, disposed on the at least one substrate in an area substantially between the at least one diffractive element and the at least one further diffractive element.

According to a third aspect of the invention, an electronic device, comprises:

- a data processing unit;
- an optical engine operatively connected to the data processing unit for receiving image data from the data processing unit;
- a display device operatively connected to the optical engine for forming an image based on the image data; and
- an exit pupil expander comprising:

at least one substrate of optical material having a first surface and a second surface;

at least one diffractive element disposed on the first or the second surface of the at least one substrate and configured to receive an input optical beam;

at least one further diffractive element disposed on the first or the second surface; and at least one optically absorbing area within or disposed on the at least one substrate, wherein

at least part of the input optical beam is diffracted in the diffractive element to provide at least one diffracted optical beam substantially within the first and the second surfaces, and

at least part of the at least one diffracted optical beam is coupled out of the at least one substrate by diffraction in the at least one further diffractive element, thus providing an output optical beam out of the at least one substrate with an expanded exit pupil in one or two dimensions, wherein

the input optical beam comprises K wavelength components and the at least one optically absorbing area is configured to absorb M pre-selected components out of the K wavelength components and to propagate a selected component out of the K wavelength components substantially without an optical intensity attenuation, such that the output optical beam comprises the selected component out of the K wavelength components, wherein K is an integer of at least a value of two and M is an integer between 1 and K-1.

Further according to the third aspect of the invention, the exit pupil expander may comprise N stacked substrates of optical material separated by a gap, N being an integer of at least a value of one, and the at least one substrate being one of the N substrates, wherein each of the N stacked substrates is configured to expand an exit pupil substantially of only one component out of the K wavelength components of the input optical beam such that all the K wavelength components merge together having substantially the same direction and location in an output of the optical device. Further, wherein N=K.

Still further according to the third aspect of the invention, M may be equal to K-1.

According further to the third aspect of the invention, the output optical beam provided by the at least one substrate substantially may comprise only the selected component out of the K wavelength components.

According still further to the third aspect of the invention, the at least one optically absorbing area may be configured using at least one of: a) an absorbing tint spread throughout a volume of the at least one substrate, b) an absorbing tint spread throughout a thickness of the at least one substrate only in areas of the at least one substrate between the at least one diffractive element and at least one further diffractive element, c) an absorbing tint spread throughout a resin used to make the at least one diffractive element, d) an absorbing tint spread throughout the resin used to make the at least one further diffractive element, and e) an absorbing coating, having substantially the same index of refraction as the at least one substrate, disposed on the at least one substrate in an area substantially between the at least one diffractive element and the at least one further diffractive element.

According to a fourth aspect of the invention, an apparatus, comprises: at least one means for diffraction,

for receiving an input optical beam by at least one means for diffraction disposed on a first or a second surface of at least one substrate, the input optical beam comprises K wavelength components, wherein K is an integer of at least a value of two, and

for diffracting at least part of the input optical beam in the at least one means for diffraction to provide at least one diffracted optical beam substantially within the first and second surfaces;

at least one absorbing means within or disposed on the at least one substrate, for absorbing M pre-selected components out of the K wavelength components of the at least one diffracted optical beam by the at least one absorbing means and propagating a selected component out of the K wavelength components of the at least one diffracted optical beam substantially without an optical intensity attenuation in the at least one optically absorbing area, wherein M is an integer between 1 and K-1; and

at least one further means for diffraction, for coupling at least part of the at least one diffracted optical beam out of the at least one substrate by diffraction in the at least one further means for diffraction, thus providing an output optical beam out of the at least one substrate with an expanded exit pupil in one or two dimensions, wherein the output optical beam comprises the selected component out of the K wavelength components.

According further to the fourth aspect of the invention, the apparatus may be an exit pupil expander.

Brief Description of the Drawings

For a better understanding of the nature and objects of the present invention, reference is made to the following detailed description taken in conjunction with the following drawings, in which:

Figures 1a and 1b are schematic representations of a virtual reality display (a cross sectional view shown in Figures 1a) having an exit pupil expander system with stacked diffractive exit pupil expanders (a cross sectional view is shown in Figure 1b);

Figures 2a and 2b are schematic representations (cross-sectional views) demonstrating a color separation in an exit pupil expander system using absorbing tint through a volume of the substrates (Figure 1a) and through a thickness of selected areas of the substrates between in-coupling and out-coupling gratings, according to embodiments of the present invention;

Figures 3a and 3b are schematic representations (cross-sectional views) demonstrating a color separation in an exit pupil expander system using absorbing tint spread throughout a resin in in-coupling and out-coupling gratings, according to embodiments of the present invention;

Figures 4a and 4b are schematic representations (cross-sectional views) demonstrating a color separation in an exit pupil expander system using absorbing tint spread throughout a resin in out-coupling gratings and absorbing coating across the in-coupling grating, according to embodiments of the present invention;

Figures 5a and 5b are schematic representations (cross-sectional views) demonstrating a color separation in an exit pupil expander system using absorbing coatings having substantially the same index of refraction as a substrate and disposed on the substrate in areas between in-coupling and out-coupling gratings, according to embodiments of the present invention; and

Figure 6 is a schematic representation of an electronic device, having an exit pupil expander system, according to an embodiment of the present invention.

Modes for Carrying Out the Invention

A new method and apparatus are presented for providing color separation in an exit pupil expander system that uses a plurality of diffractive elements for expanding the exit pupil of a display in an electronic device for viewing by introducing a selectively absorbing area or areas in the exit pupil expanders. The embodiments of the present invention can be applied to a broad optical spectral range of optical beams but most importantly to a visible part of the optical spectrum where the optical beams are called light beams.

According to an embodiment of the present invention, an optical device (e.g., the optical device can be a part of a virtual reality display) can comprise N (N being an integer of at least a value of one) stacked substantially parallel substrates of optical material separated by a gap (the gap can be a material with a substantially smaller index of refraction than in the substrates, e.g., an air gap), each such substrate having a first surface and a second surface and acting as an exit pupil expander. Each substrate can comprise at least one diffractive element (e.g., a diffractive grating) disposed on the first or the second surface of said at least one substrate and which is configured to receive an input optical beam (i.e., at least one diffractive element acts as an in-coupling grating). It is noted that after propagating through the in-coupling grating of the first substrate, some "unselected" wavelength components of the input optical beam (i.e., a portion of the input optical beam) are received by the in-coupling grating of a second substrate in a stack of the N substrates and so on. It is also noted that in a biocular system it can be one or two in-coupling gratings adjacent to each other for the left and for the right eye, which are configured to split the input optical beam into two substantially equal components in two substantially opposite directions. Each substrate can further comprise at least one further diffractive element (e.g., a diffractive grating) disposed on the first or the second surface and acting as an out-coupling grating. Again, in a biocular system it can be two out-coupling gratings symmetrically located in the substrate to provide out-coupling for the left and for the right eye.

Moreover, according to an embodiment of the present invention, each substrate may comprise at least one optically absorbing area or areas within or disposed on the substrate. Thus, at least part of the input optical beam can be diffracted in the diffractive element (the in-coupling grating) to provide at least one (two in the biocular systems) diffracted optical beam substantially within the first and the second surfaces due to a total internal reflection, and then at least part of the at least one diffracted optical beam is further coupled out of each substrate by diffraction in the at least one further diffractive element (the out-coupling grating), thus providing an output optical beam (or two beams for the biocular systems) out of each substrate with an expanded exit pupil in one or two dimensions using wavelength selectivity as explained below.

According to an embodiment of the present invention, the input optical beam can comprise K wavelength components (K being an integer of at least a value of two), such that the at least one optically absorbing area within or disposed on each of the substrates is configured to absorb M (M being an integer between 1 and K-1) pre-selected components of the K wavelength components and to propagate a selected component out of the K wavelength components, e.g., substantially without an optical intensity attenuation due to absorption. Then the output optical beam from each substrate substantially comprises the selected component out of the K wavelength components. It is noted that the diffraction gratings in each substrate are optimized (e.g., by choosing the appropriate period of the periodic lines) for the wavelength component to be selected by that grating.

Thus, each of the N stacked substrates is configured to expand an exit pupil of substantially only one component out of said K wavelength components of the input optical beam such that all said K wavelength components merge together having substantially the same direction and location in an output of said optical device, therefore providing a color separation using the N exit pupil expanders that use a plurality of diffractive elements for expanding the exit pupil, e.g., of a display in the electronic device for viewing.

In one possible embodiment, N can be equal to K, i.e., each substrate only can output one wavelength (color) component. In another embodiment, the optically absorbing area for any substrate out of the N substrates can be configured to absorb all K-1 wavelength components except only one selected wavelength components band to be provided in the output optical beam from that substrate. Also different substrates can be configured to absorb a different number of wavelength components depending on a specific system design.

According to a further embodiment of the present invention, in case of a two-dimensional exit pupil expansion, each substrate can comprise at least one intermediate diffractive element (two intermediate diffractive elements for the biocular case) such that the at least part of the input optical beam diffracted in the at least one diffractive element is first coupled to the at least one intermediate diffractive element, which then couples, using a further diffraction in the at least one intermediate diffractive element, the at least part of said diffracted optical beam to the at least one further diffractive element, which then provides a two-dimensional exit pupil expansion of said input optical beam. The intermediate diffractive element can have an odd number of first order diffractions or an even number of further first order reflections as known in the art and, e.g., described by T. Levola in "Diffractive Optics for Virtual Reality Displays", SID Eurodisplay 05, Edinburg (2005), SID 02 Digest, Paper 22.1.

Furthermore, according to an embodiment of the present invention, the at least one optically absorbing area within or disposed on each substrate can be configured using at least one approach or a combination thereof out of:

a) an absorbing tint spread throughout a volume of each substrate,
b) an absorbing tint spread throughout a thickness of each substrate only in areas of each substrate between the at least one diffractive element and at least one further diffractive element (i.e., between the in-coupling and the out-coupling diffraction gratings),
c) an absorbing tint spread throughout a resin used to make the at least one diffractive element, the at least one further diffractive element, and/or the intermediate grating,
d) an absorbing coating, having substantially the same index of refraction as each substrate, disposed on each substrate in an area substantially between the at least one diffractive element and at least one further diffractive element (i.e., between the in-coupling and the out-coupling diffraction gratings), etc.

In a further embodiment of the present invention, each substrate can be configured to have an additional optically absorbing layer disposed on or adjacent to a surface of that substrate, wherein the surface being a second surface of that substrate through which the input optical beam propagates after being received by the substrate, such that the selected component out of the K wavelength components selected by that substrate is substantially absorbed in the additional optically absorbing layer, thus preventing said selected wavelength component from entering the next substrate.

One practical example for implementing embodiments of the present invention can be a color separation for an RGB (red, green, blue) gamut. In this case, the first substrate in the stack can "select" a short blue wavelength component and "absorb" the green and red, the second substrate can "select" a green component, and "absorb" the blue and red, and finally the third substrate in the stack can "select" a long red wavelength component and "absorb" the green and blue. More implementation examples are provided in Figures 2 through 6, according to various embodiments of the present invention.

Figures 1a and 1b show schematic representations of a virtual reality display (a cross sectional view shown in Figures 1a) having an exit pupil expander system **10a** with stacked diffractive exit pupil expanders **10-1, 10-2,** etc. as shown in a cross sectional view in Figure 1b with in-coupling gratings **12-1** and **12-2**, etc. and out-coupling gratings **14-1, 14-2, 16-1** and **16-2** for the biocular case. For simplicity, the input optical beam has two wavelength components **20** (λ_1) and **22** (λ_2). In an approach shown in Figure 1b, both components **20** and **22** are coupled (see corresponding optical beams **20-1a, 22-1a, 20-2a, 22-2a,** and unwanted optical beams **20-1c, 22-1c, 20-2c, 22-2c**, respectively) to the corresponding out-coupling gratings **14-1, 14-2, 16-1** and **16-2** in each of the substrates **10-1** and **10-2** as shown in Figure 1b, such that both wavelength components **20** and **22** are provided in the output optical beam by each of the substrates **10-1** and **10-2** in spite of the fact that the out-coupling diffraction gratings **14-1** and **16-1** are optimized only for the wavelength component **20** and the out-coupling diffraction gratings **14-2** and **16-2** are optimized only for the wavelength component **22**. This mixing of colors deteriorates the quality of the image provided by the exit pupil expander system **10.** The example of the virtual reality display of Figure 1a with the stacked diffractive exit pupil expanders, shown in Figure 1b, can be used for applying embodiments of the present invention. Figures 2 through 6 provide different implementation examples for eliminating color mixing, according to embodiments of the present invention.

Figures 2a and 2b show examples among others of schematic representations (cross-sectional views) demonstrating a color separation in an exit pupil expander system **10** using absorbing tint through a volume of the substrates **10-1** and **10-2** (Figure 1a) and through a thickness of selected areas **10-1a, 10-2a, 10-1b** and **10-2b** of the substrates **10-1** and **10-2** between the in-coupling gratings **12-1** and **12-2,** and the out-coupling gratings **14-1, 14-2, 16-1** and **16-2**, respectively, as shown in Figure 2b, according to embodiments of the present invention. The absorbing tint in the substrate **10-1** is optimized for absorbing the wavelength component **22** while being transparent to the wavelength component **20**, and the absorbing tint in the substrate **10-2** is optimized for absorbing the wavelength component **20** while being transparent to the wavelength component **22**. Thus, each of the substrates **10-1** and **10-2** provides only one wavelength component: the optical beams **20-1b** and **20-2b** representing the wavelength component **20** are provided by the substrate **10-1**, and the optical beams **22-1b** and **22-2b** representing the wavelength component **22** are provided by the substrate **10-2**, respectively.

Figures 3a and 3b show examples among others of schematic representations (cross-sectional views) of a color separation in an exit pupil expander system **10** using the absorbing tint spread throughout a resin used in the in-coupling gratings **12-1** and **12-2** and/or in the out-coupling gratings **34-1, 34-2, 36-1** and **36-2**, according to embodiments of the present invention. In Figure 3a, the absorbing tint in the diffraction gratings **34-1, 36-1** of the first substrate **10-1** is optimized for absorbing the wavelength component **22** while being transparent to the wavelength component **20**, and the absorbing tint in the diffraction gratings **34-2, 36-2** of the first substrate **10-2** is optimized for absorbing the wavelength component **20** while being transparent to the wavelength component **22**, thus eliminating unwanted optical beams **20-1c, 22-1c, 20-2c, 22-2c** by absorption in the out-coupling gratings **34-1, 34-2, 36-1** and **36-2**. It is noted that the in-coupling grating **12-2** provides an initial attenuation of the unwanted optical beams **20-1c** and **20-2c** as shown in Figure 3a. If the in-coupling grating **12-2** can provide enough attenuation of the unwanted optical beams **20-1c** and **20-2c**, then the out-couplings **14-2** and **16-2** do not need to be tinted at all as shown in Figure 3b. This provides an advantage that the out-coupling beams **20-1b** and **20-2b** from the first substrate **10-1** are not attenuated by the absorbing tint in the diffraction gratings **14-2** and **16-2.**

Figure 4a shows an example among others of schematic representations (cross-sectional views) demonstrating a color separation in an exit pupil expander system **10** using the absorbing tint spread throughout a resin in the out-coupling gratings **34-1, 34-2, 36-1** and **36-2** such that the unwanted optical beams **20-1c, 22-1c, 20-2c, 22-2c** are eliminated by absorption in the out-coupling gratings **34-1, 34-2,**

36-1 and **36-2**, respectively. In addition (optionally), an optically absorbing layer **40** disposed on or adjacent to a surface of the substrate **10-1** across the in-coupling grating **12-1** can absorb the wavelength component **20** for minimizing the presence of the unwanted optical beams **20-1c** and **20-2c**. If the in-coupling grating **12-2** can provide enough attenuation of the unwanted optical beams **20-1c** and **20-2c**, then the out-couplings **14-2** and **16-2** do not need to be tinted at all as shown in Figure 4b. This provides an advantage that the out-coupling beams **20-1b** and **20-2b** from the first substrate **10-1** are not attenuated by the absorbing tint in the diffraction gratings **14-2** and **16-2**, respectively.

Figure 5a shows an example among others of schematic representations (cross-sectional views) demonstrating a color separation in an exit pupil expander system **10** using the absorbing tint spread throughout the resin in the out-coupling gratings **34-1** and **36-1** of the first substrate **10-1** such that the unwanted optical beams **22-1c** and **22-2c** are eliminated by absorption in the out-coupling gratings **34-1** and **36-1**, respectively. In the second substrate **10-2**, absorbing coatings **42-1** and **42-2** having substantially the same index of refraction as the substrate **10-2** and disposed on the substrate **10-2** in areas between the in-coupling grating **12-2** and the out-coupling gratings **14-2** and **16-2**, respectively, according to an embodiment of the present invention. These absorbing coatings **42-1** and **42-2** substantially absorb the unwanted optical beams **20-1c** and **20-2c** in the second substrate **10-2** acting as a boundary for the total internal reflection. In the example of Figure 5b, instead of using the absorbing tint spread throughout the resin in the out-coupling gratings (as shown in figure 5a), further absorbing coatings **44-1** and **44-2** having substantially the same index of refraction as the substrate **10-1** and disposed on the substrate **10-1** in areas between the in-coupling grating **12-1** and the out-coupling gratings **14-1** and **16-1**, respectively, according to a further embodiment of the present invention. These absorbing coatings **44-1** and **44-2** substantially absorb the unwanted optical beams **22-1c** and **22-2c** in the first substrate **10-1** acting as a boundary for the total internal reflection as well.

It is noted that tinting is a known art, e.g., see US patent 6,464,733 "Tinting plastic articles" by C. U. Ryser. For selective tinting of the substrate (see Figure 2b), the parts that needs to be tinted can be tinted separately. Then these parts can be molded together with clear plastics. The tinted and not tinted parts should have the same refractive index, which is usually the case, if the same material is used thoroughly, because the tinting does not usually alter the refractive index. Also radiation methods may be used for creating color centers in the material to alter the spectral absorption. Moreover, the diffraction gratings can be formed using a UV (ultraviolet) curable resin, which is tinted which, as known in the art.

Figure 6 shows an example of a schematic representation of an electronic device, having the exit pupil expander (EPE) system **10**, according to an embodiment of the present invention.

The exit pupil expander (EPE) **10, 10a** or **10b** can be used in an electronic (portable) device **100**, such as a mobile phone, personal digital assistant (PDA), communicator, portable Internet appliance, hand-hand computer, digital video and still camera, wearable computer, computer game device, specialized bring-to-the-eye product for viewing and other portable electronic devices. As shown in Figure 6, the portable device **100** has a housing **210** to house a communication unit **212** for receiving and transmitting information from and to an external device (not shown). The portable device **100** also has a controlling and processing unit **214** for handling the received and transmitted information, and a virtual display system **230** for viewing. The virtual display system **230** includes a micro-display or an image source **192** and an optical engine **190**. The controlling and processing unit **214** is operatively connected to the optical engine **190** to provide image data to the image source **192** to display an image thereon. The EPE **10**, according to the present invention, can be optically linked to an optical engine **190**.

Furthermore, the image source **192**, as depicted in Figure 6, can be a sequential color LCOS (Liquid Crystal On Silicon) device, an OLED (Organic Light Emitting Diode) array, an MEMS (MicroElectro Mechanical System) device or any other suitable micro-display device operating in transmission, reflection or emission.

Moreover, the electronic device **100** can be a portable device, such as a mobile phone, personal digital assistant (PDA), communicator, portable Internet appliance, hand-held computer, digital video and still camera, wearable computer, computer game device, specialized bring-to-the-eye product for viewing and other portable electronic devices. However, the exit pupil expander, according to the present invention, can also be used in a non-portable device, such as a gaming device, vending machine, band-o-matic, and home appliances, such as an oven, microwave oven and other appliances and other non-portable devices.

It is to be understood that the above-described arrangements are only illustrative of the application of the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the scope of the present invention, and the appended claims are intended to cover such modifications and arrangements.

What is claimed is:

1.. An apparatus, comprising:

at least one substrate of optical material having a first surface and a second surface;

at least one diffractive element disposed on the first or the second surface of said at least one substrate and configured to receive an input optical beam;

at least one further diffractive element disposed on the first or the second surface; and

at least one optically absorbing area within or disposed on said at least one substrate, wherein

at least part of the input optical beam is diffracted in the diffractive element to provide at least one diffracted optical beam substantially within the first and the second surfaces, and

at least part of the at least one diffracted optical beam is coupled out of the at least one substrate by diffraction in said at least one further diffractive element, thus providing an output optical beam out of said at least one substrate with an expanded exit pupil in one or two dimensions, wherein

said input optical beam comprises K wavelength components and said at least one optically absorbing area is configured to absorb M pre-selected components out of the K wavelength components of said at least one diffracted optical beam and to propagate a selected component out of the K wavelength components of said at least one diffracted optical beam, such that the output optical beam comprises said selected component out of the K wavelength components, wherein K is an integer of at least a value of two and M is an integer between 1 and K-1.

2. The apparatus of claim 1, wherein said optical device comprises N stacked substrates of optical material separated by a gap, N being an integer of at least a value of one, and said at least one substrate being one of said N substrates, wherein each of said N stacked substrates is configured to expand an exit pupil substantially of only one component out of said K wavelength components of the input optical beam such that all said K wavelength components merge together having substantially the same direction and location in an output of said optical device.

3. The apparatus of claim 2, wherein N=K

4. The apparatus of claim 1, wherein M=K-1.

5. The apparatus of claim 1, wherein the output optical beam provided by the at least one substrate substantially comprises only said selected component out of the K wavelength components.

6. The apparatus of claim 1, wherein said at least one optically absorbing area is configured using at least one of:

a) an absorbing tint spread throughout a volume of the at least one substrate,
b) an absorbing tint spread throughout a thickness of the at least one substrate only in areas of the at least one substrate between the at least one diffractive element and at least one further diffractive element,
c) an absorbing tint spread throughout a resin used to make said at least one diffractive element,
d) an absorbing tint spread throughout the resin used to make said at least one further diffractive element, and
e) an absorbing coating, having substantially the same index of refraction as the at least one substrate, disposed on the at least one substrate in an area substantially between the at least one diffractive element and the at least one further diffractive element.

7. The apparatus of claim 1, further comprises:

a further substrate of optical material having a further first surface and a further second surface, said further substrate being stacked substantially in parallel with said at least one substrate but maintaining a gap with said at least one substrate;

at least one additional diffractive element disposed on the further first or the further second surface of said further substrate and configured to receive a portion of the input optical beam which propagates through the at least one substrate into the further substrate;

at least one still further diffractive element disposed on the further first or the further second surface; and

at least one further optically absorbing area within or disposed on said further substrate, wherein

at least further part of the portion of the input optical beam is diffracted in the additional diffractive element to provide at least one further diffracted optical beam substantially within the further first and the further second surfaces, and

at least further part of the at least one further diffracted optical beam is further coupled out of the further substrate by diffraction in said at least one still further diffractive element, thus providing a further output optical beam out of said further substrate with an expanded exit pupil in one or two dimensions, said further output optical beam having substantially the same direction and location as the output optical beam, wherein

said at least one further optically absorbing area is configured to absorb P pre-selected components of the K wavelength components and to propagate a further selected component out of the K wavelength components, such that the further output optical beam comprises said further selected component out of the K wavelength components, wherein P is an integer between 1 and K-1.

8. The apparatus of claim 7, wherein P=K-1.

9. The apparatus of claim 7, wherein said at least one further optically absorbing area is configured using at least one of:

a) an absorbing tint spread throughout a volume of the further substrate,
b) an absorbing tint spread throughout a thickness of the further substrate only in areas of the further substrate between the at least one additional diffractive element and at least one still further diffractive element,
c) an absorbing tint spread throughout a resin used to make said at least one additional diffractive element,
d) an absorbing tint spread throughout the resin used to make said at least one still further diffractive element, and
e) an absorbing coating, having substantially the same index of refraction as the further substrate, disposed on the further substrate between the at least

one additional diffractive element and the at least one still further diffractive element.

10. The apparatus of claim 7, wherein said gap is an air gap.

11. The apparatus of claim 7, wherein the output optical beam provided by the at least one substrate substantially comprises only said selected component out of the K wavelength components and the further output optical beam provided by the further substrate substantially comprises only said selected further component out of the K wavelength components and the output optical beam and the further output optical beam merge together having substantially the same direction and location.

12. The apparatus of claim 1, wherein said at least one substrate is configured to have an additional optically absorbing layer disposed on or adjacent to a surface of said at least one substrate, said surface being a second surface through which the input optical beam propagates, such that said selected component out of the K wavelength components is substantially absorbed in said additional optically absorbing layer.

13. The apparatus of claim 1, further comprises at least one intermediate diffractive element such that the at least part of the input optical beam diffracted in the at least one diffractive element is first coupled to said at least one intermediate diffractive element, which then couples, using a further diffraction in said at least one intermediate diffractive element, said at least part of said diffracted optical beam to said at least one further diffractive element, which then provides a two-dimensional exit pupil expansion of said input optical beam.

14. A method, comprising:

receiving an input optical beam by at least one diffractive element disposed on a first or a second surface of at least one substrate, said input optical beam comprises K wavelength components, wherein K is an integer of at least a value of two;

diffracting at least part of the input optical beam in the at least one diffractive element to provide at least one diffracted optical beam substantially within the first and second surfaces;

absorbing M pre-selected components out of the K wavelength components of said at least one diffracted optical beam in at least one optically absorbing area within or disposed on said at least one substrate and propagating a selected component out of the K wavelength components of said at least one diffracted optical beam substantially without an optical intensity attenuation in said at least one optically absorbing area, wherein M is an integer between 1 and K-1; and

coupling at least part of the at least one diffracted optical beam out of the at least one substrate by diffraction in said at least one further diffractive element, thus providing an output optical beam out of said at least one substrate with an expanded exit pupil in one or two dimensions, wherein the output optical beam comprises said selected component out of the K wavelength components.

15. The method of claim 14, wherein the output optical beam provided by the at least one substrate substantially comprises only said selected component out of the K wavelength components.

16. The method of claim 14, wherein said at least one optically absorbing area is configured using at least one of:

a) an absorbing tint spread throughout a volume of the at least one substrate,
b) an absorbing tint spread throughout a thickness of the at least one substrate only in areas of the at least one substrate between the at least one diffractive element and at least one further diffractive element,
f) an absorbing tint spread throughout a resin used to make said at least one diffractive element,
g) an absorbing tint spread throughout the resin used to make said at least one further diffractive element, and
h) an absorbing coating, having substantially the same index of refraction as the at least one substrate, disposed on the at least one substrate in an area substantially between the at least one diffractive element and the at least one further diffractive element.

17. An electronic device, comprising:

- a data processing unit;
- an optical engine operatively connected to the data processing unit for receiving image data from the data processing unit;
- a display device operatively connected to the optical engine for forming an image based on the image data; and
- an exit pupil expander comprising:

at least one substrate of optical material having a first surface and a second surface;

at least one diffractive element disposed on the first or the second surface of said at least one substrate and configured to receive an input optical beam;

at least one further diffractive element disposed on the first or the second surface; and

at least one optically absorbing area within or disposed on said at least one substrate, wherein

at least part of the input optical beam is diffracted in the diffractive element to provide at least one diffracted optical beam substantially within the first and the second surfaces, and

at least part of the at least one diffracted optical beam is coupled out of the at least one substrate by diffraction in said at least one further diffractive element, thus providing an output optical beam out of said at least one substrate with an expanded exit pupil in one or two dimensions, wherein

said input optical beam comprises K wavelength components and said at least one optically absorbing area is configured to absorb M pre-selected components out of the K wavelength components and to propagate a selected component out of the K wavelength components substantially without an optical intensity attenuation, such that the output optical beam comprises said selected component out of the K wavelength components, wherein K is an integer of at least a value of two and M is an integer between 1 and K-1.

18. The electronic device of claim 17, wherein said exit pupil expander comprises N stacked substrates of optical material separated by a gap, N being an integer of at

least a value of one, and said at least one substrate being one of said N substrates, wherein each of said N stacked substrates is configured to expand an exit pupil substantially of only one component out of said K wavelength components of the input optical beam such that all said K wavelength components merge together having substantially the same direction and location in an output of said optical device.

19. The electronic device of claim 18, wherein N=K.

20. The electronic device of claim 17, wherein M=K-1.

21. The electronic device of claim 17, wherein the output optical beam provided by the at least one substrate substantially comprises only said selected component out of the K wavelength components.

22. The electronic device of claim 17, wherein said at least one optically absorbing area is configured using at least one of:

a) an absorbing tint spread throughout a volume of the at least one substrate,
b) an absorbing tint spread throughout a thickness of the at least one substrate only in areas of the at least one substrate between the at least one diffractive element and at least one further diffractive element,
c) an absorbing tint spread throughout a resin used to make said at least one diffractive element,
d) an absorbing tint spread throughout the resin used to make said at least one further diffractive element, and
e) an absorbing coating, having substantially the same index of refraction as the at least one substrate, disposed on the at least one substrate in an area substantially between the at least one diffractive element and the at least one further diffractive element.

23. An apparatus, comprising:

at least one means for diffraction,

for receiving an input optical beam by at least one means for diffraction disposed on a first or a second surface of at least one substrate, said input optical beam comprises K wavelength components, wherein K is an integer of at least a value of two, and

for diffracting at least part of the input optical beam in the at least one means for diffraction to provide at least one diffracted optical beam substantially within the first and second surfaces;

at least one absorbing means within or disposed on said at least one substrate, for absorbing M pre-selected components out of the K wavelength components of said at least one diffracted optical beam by said at least one absorbing means and propagating a selected component out of the K wavelength components of said at least one diffracted optical beam substantially without an optical intensity attenuation in said at least one optically absorbing area, wherein M is an integer between 1 and K-1; and

at least one further means for diffraction, for coupling at least part of the at least one diffracted optical beam out of the at least one substrate by diffraction in said at least one further means for diffraction, thus providing an output optical beam out of said at least one substrate with an expanded exit pupil in one or two dimensions, wherein the output optical beam comprises said selected component out of the K wavelength components.

24. The apparatus of claim 23, wherein said apparatus is an exit pupil expander.

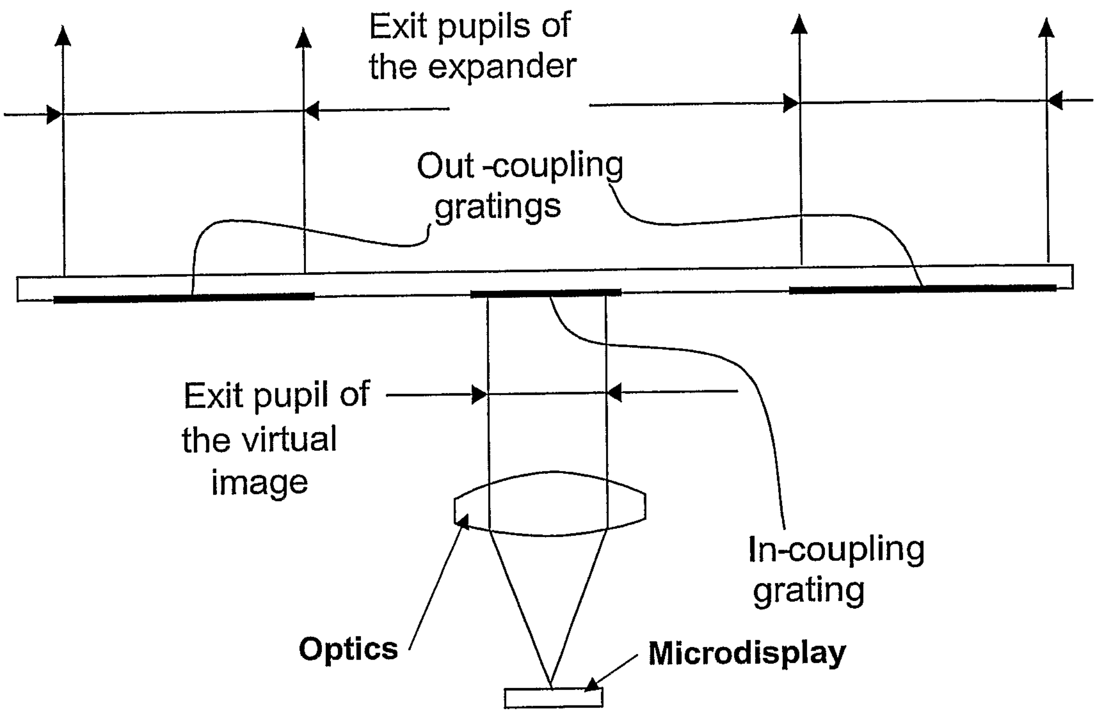

Figure 1a

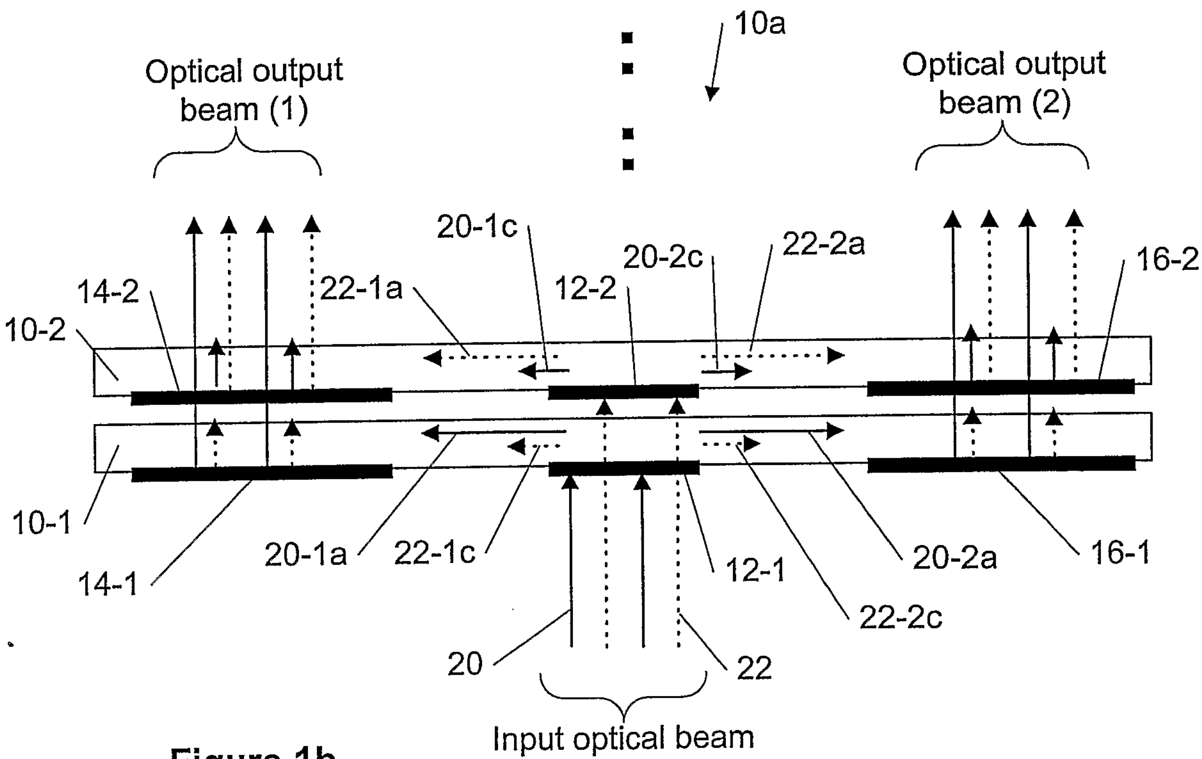

Figure 1b

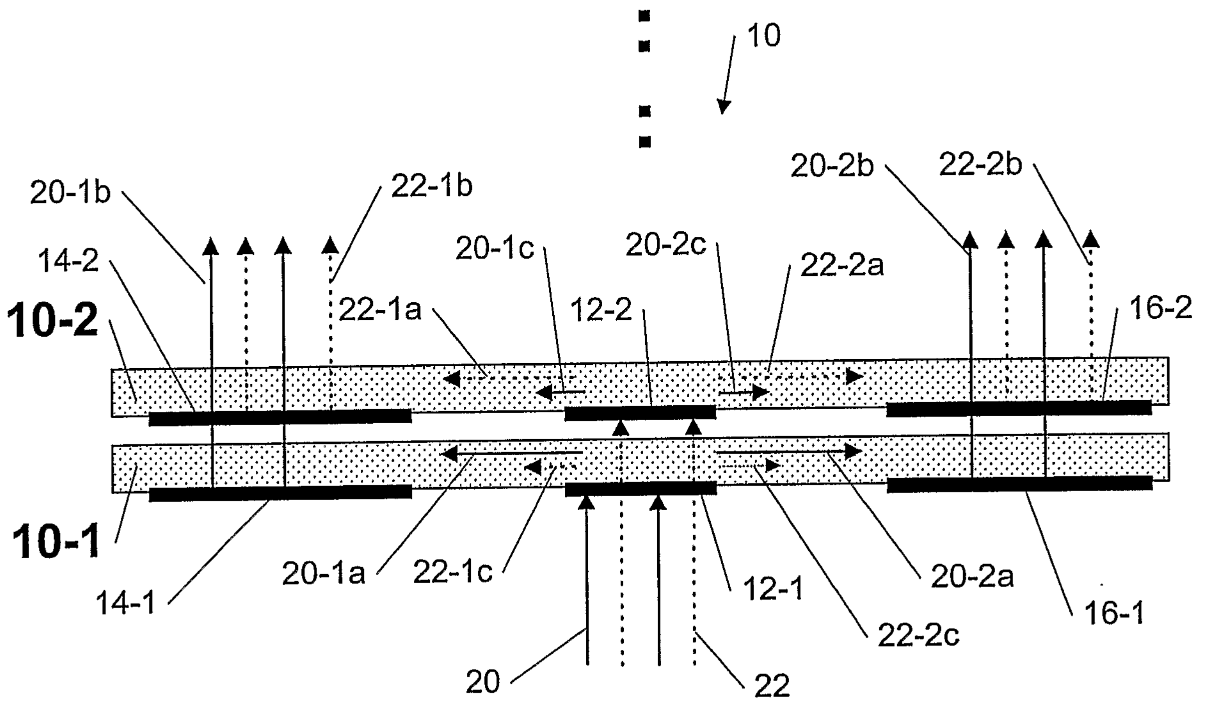

Figure 2a

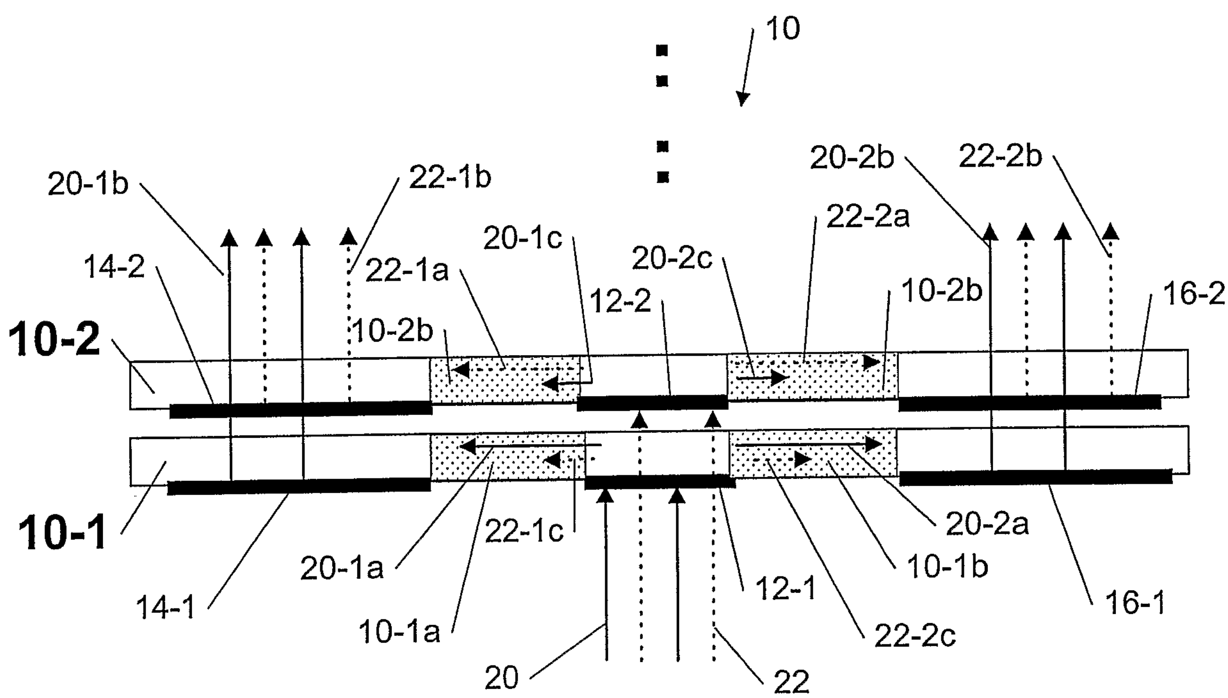

Figure 2b

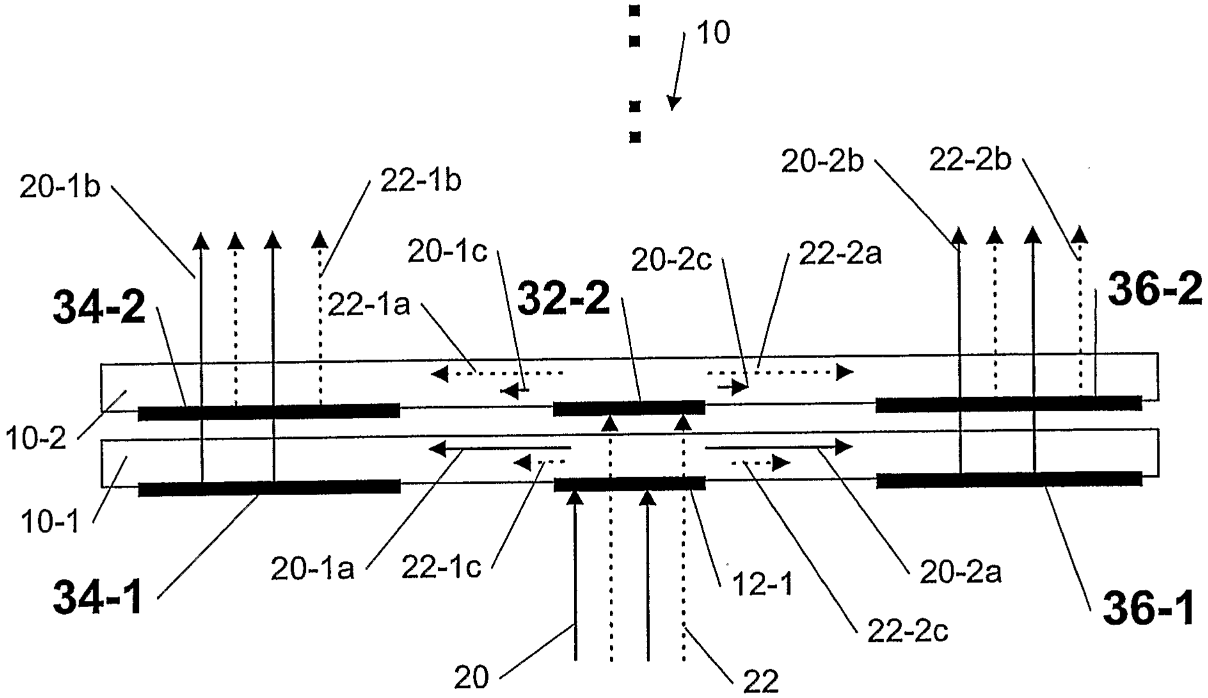

Figure 3a

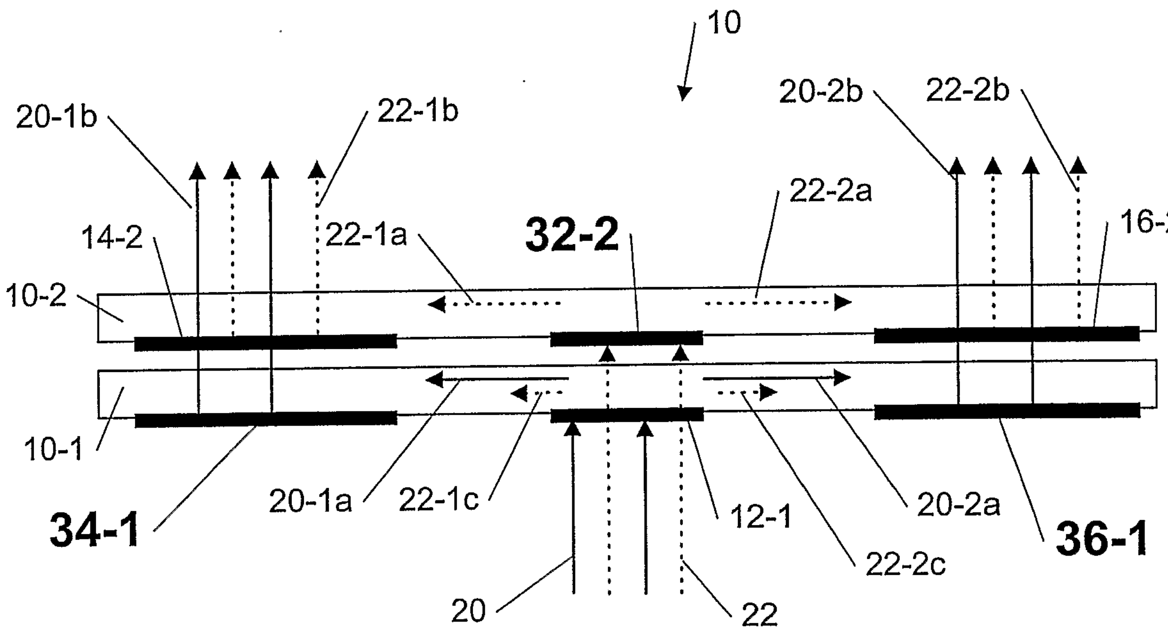

Figure 3b

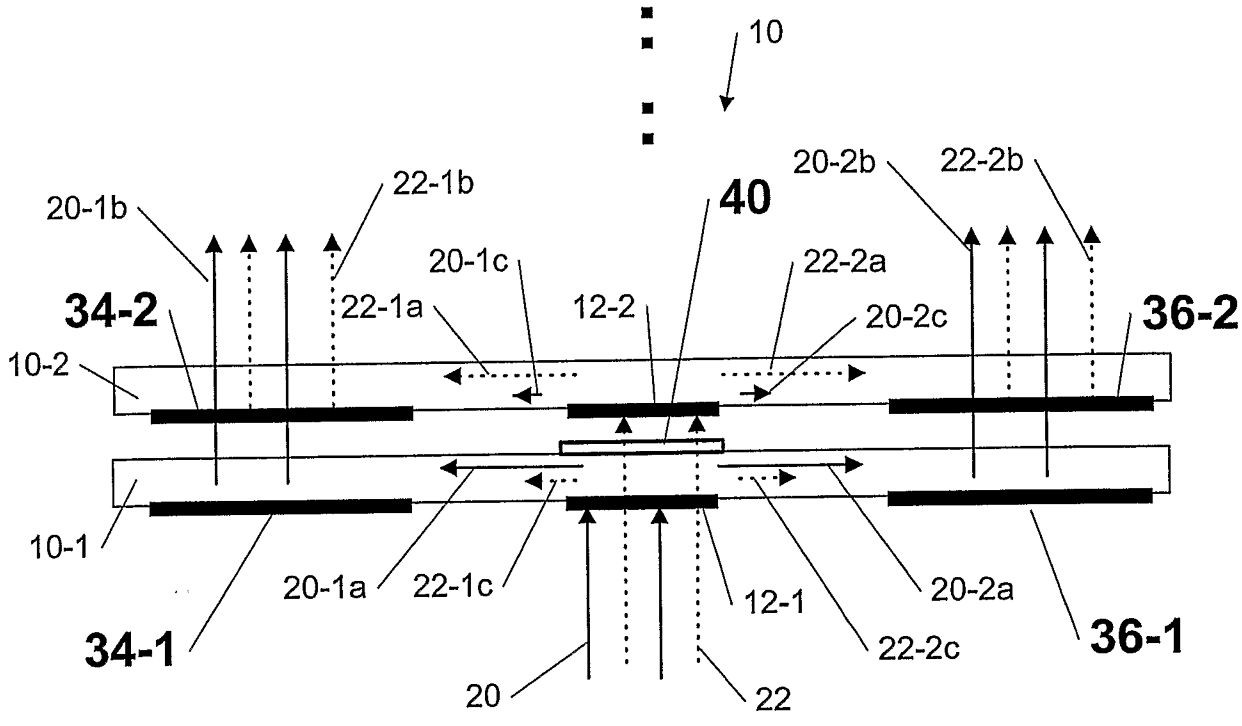

Figure 4a

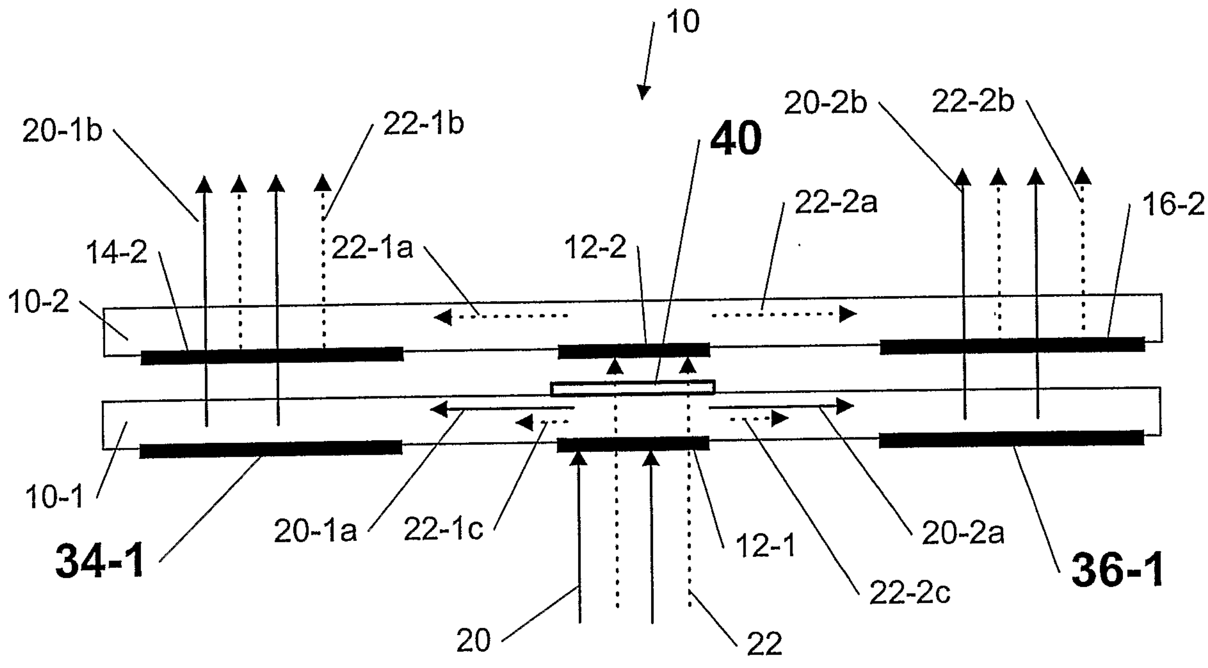

Figure 4b

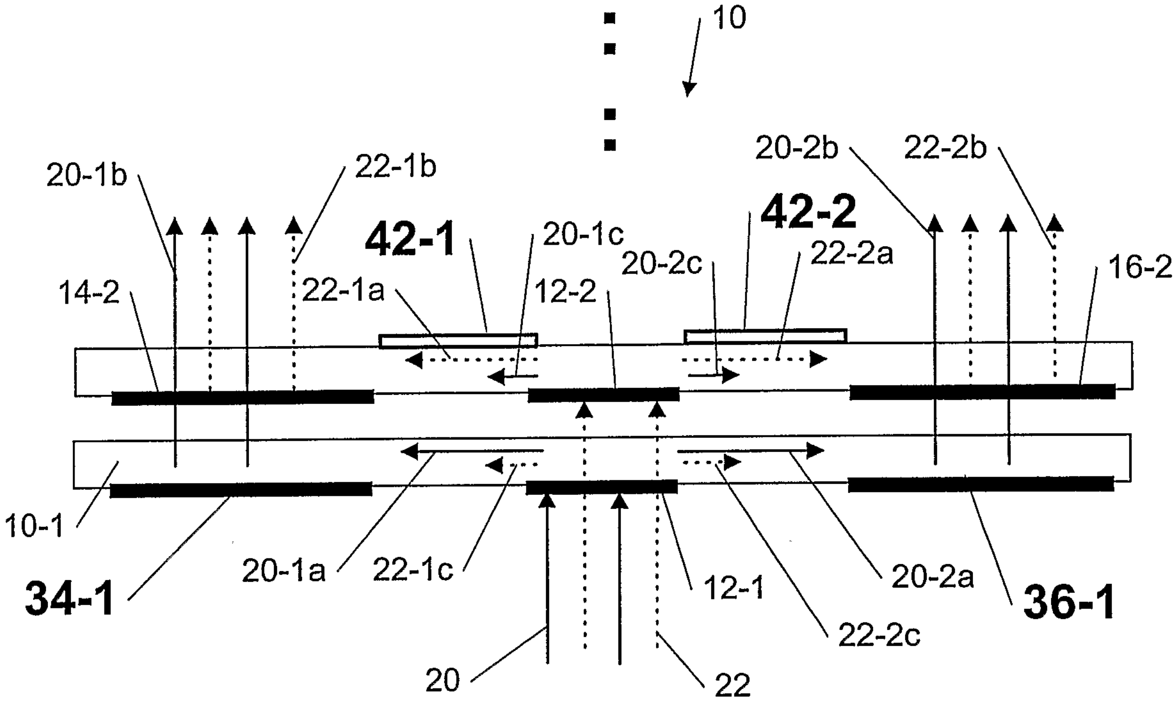

Figure 5a

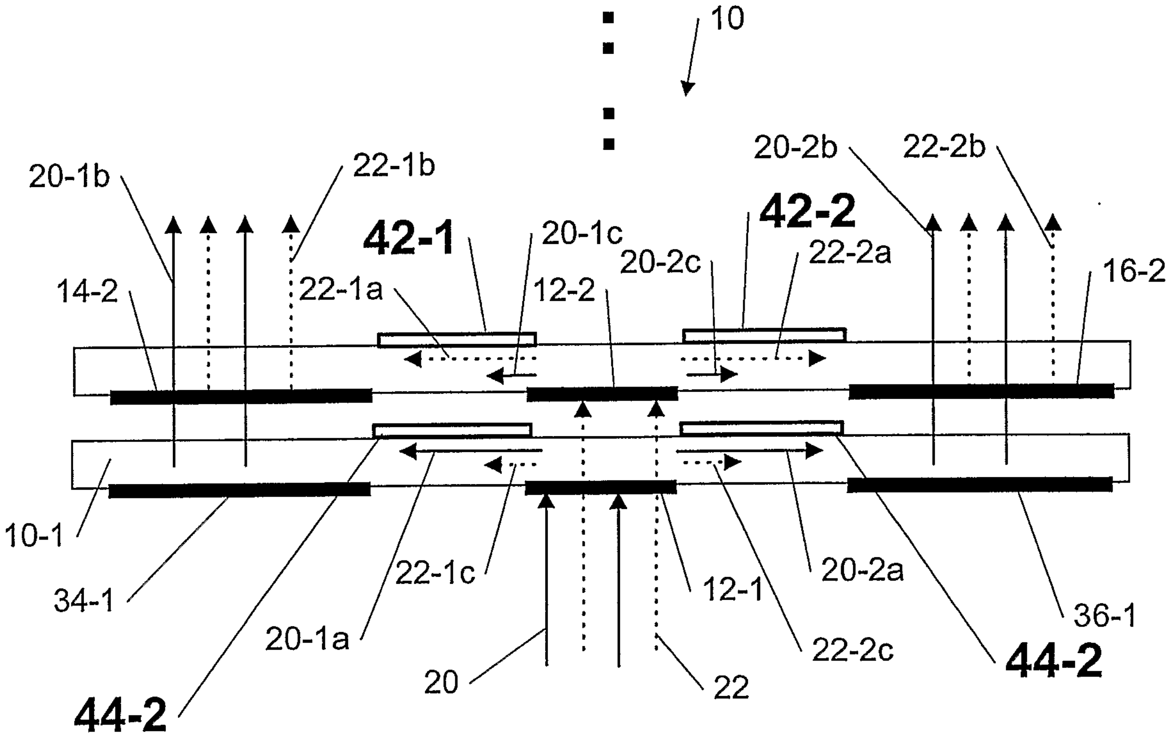

Figure 5b

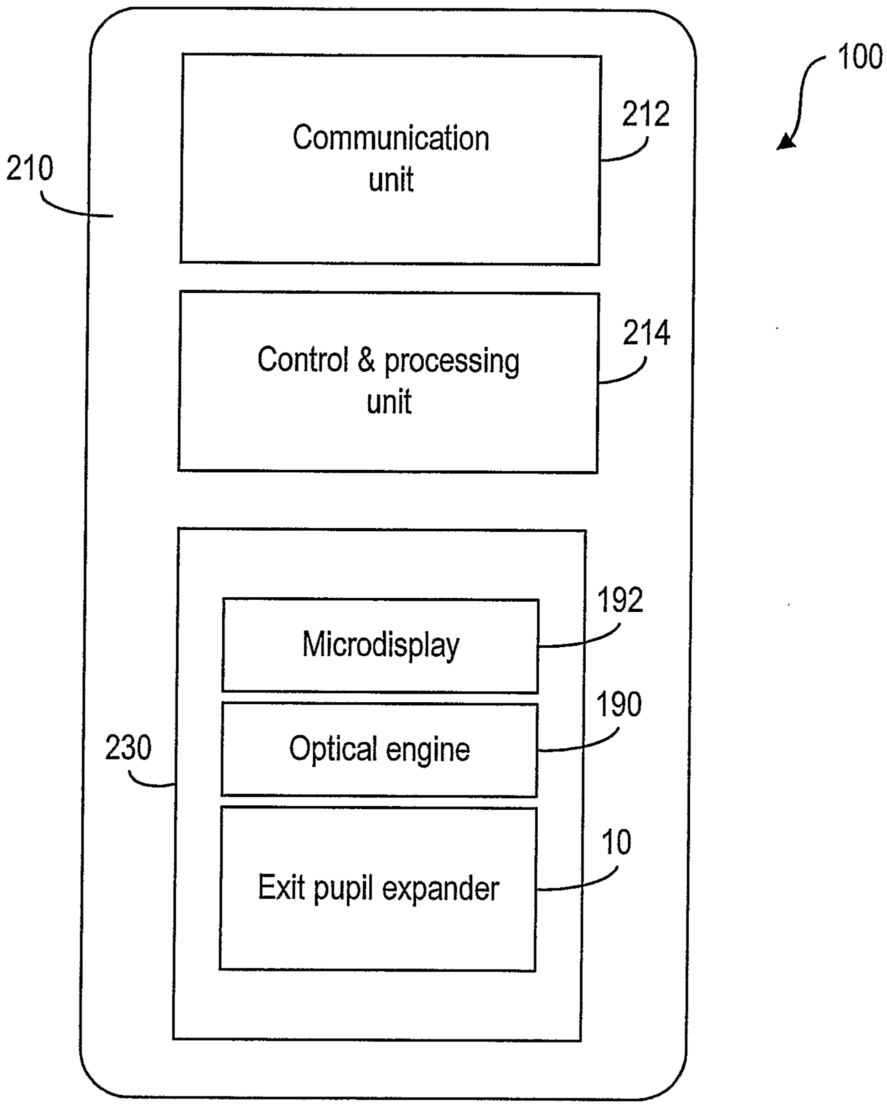
100
212
Communication unit
210
214
Control & processing unit
192
Microdisplay
190
Optical engine
230
10
Exit pupil expander

Figure 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2006/001450

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: G02B

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

SE,DK,FI,NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 20040062502 A1 (TAPANI LEVOLA), 1 April 2004 (01.04.2004), [0056]-[0061],fig.2,3 --	1-24
A	WO 0303217 A2 (PLANOP PLANAR OPTICS LTD.), 17 April 2003 (17.04.2003), page 12, line 3 - page 21, line 16, figures 1-4 -- --------	1-24

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
9 January 2007	17-01-2007
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Fredrik Wallin /itw Telephone No. +46 8 782 25 00

International patent classification (IPC)
G02B 27/00 (2006.01)
G02B 27/44 (2006.01)

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Use the application number as username.
The password is **MRSREZZNWJ**.

Paper copies can be ordered at a cost of 50 SEK per copy from PRV InterPat (telephone number 08-782 28 85).

Cited literature, if any, will be enclosed in paper form.

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			JP	2006501499	T	12/01/2006
			US	6805490	B	19/10/2004
			WO	2004030160	A	08/04/2004
WO 0303217	A2	17/04/2003	NONE			