

ENCAPSULATED ANTI-REFLECTION GRATINGS FOR AUGMENTED REALITY WAVEGUIDE COMBINERS

BACKGROUND

Field

[0001] Embodiments of the present disclosure generally relate to waveguide combiners. More specifically, embodiments described herein provide for waveguide combiners with gratings and a coating portion disposed thereover.

Description of the Related Art

[0002] Virtual reality is generally considered to be a computer generated simulated environment in which a user has an apparent physical presence. A virtual reality experience can be three-dimensionally generated and viewed with a head-mounted display (HMD), such as glasses or other wearable display devices that have near-eye display panels as lenses to display a virtual reality environment that replaces an actual environment.

[0003] Augmented reality, however, enables an experience in which a user can still see through the display lenses of the glasses or other HMD device to view the surrounding environment, yet also see images of virtual objects that are generated for display and appear as part of the environment. Augmented reality can include any type of input, such as audio and haptic inputs, as well as virtual images, graphics, and video that enhance or augment the environment that the user experiences. Image sharpness of the virtual image may be affected by the environment.

[0004] Accordingly, there is a need for improvements to augmented reality technology.

SUMMARY

[0005] Embodiments herein are generally directed to waveguide combiners for augmented reality. More particularly, the present disclosure relates to systems and methods for waveguide combiners with gratings and a coating disposed thereover.

[0006] In an embodiment, a waveguide is provided. The waveguide includes one or more gratings, the one or more gratings including a plurality of structures disposed over a waveguide substrate. The plurality of structures include a waveguide material

and exterior structures at outer edges of the one or more gratings. A film is disposed over the waveguide substrate between the exterior structures, the film including the waveguide material. A coating is disposed over the one or more gratings having an outer boundary at an edge of the film. A refractive index of the coating is less than a refractive index of the one or more gratings.

[0007] In another embodiment, a waveguide is provided. The waveguide includes an output coupling grating having a plurality of output coupling structures disposed over a waveguide substrate. The plurality of output coupling structures include a waveguide material and exterior output coupling structures at outer edges of the output coupling grating. An output coupling coating disposed over the plurality of output coupling structures. The waveguide also includes a pupil expansion grating including a plurality of pupil expansion structures disposed over the waveguide substrate. The plurality of pupil expansion structures include the waveguide material and exterior pupil expansion structures at outer edges of the pupil expansion grating. A film disposed over the waveguide substrate between the exterior output coupling structures and the exterior pupil expansion structures, and the film includes the waveguide material. A refractive index of the output coupling coating is less than a refractive index of the output coupling grating. A pupil expansion coating disposed over the pupil expansion grating having an outer boundary at an edge of the film.

[0008] In yet another embodiment, a waveguide is provided. The waveguide includes an output coupling grating including output coupling structures disposed over a waveguide substrate. The output coupling structures include a waveguide material and exterior output coupling structures at outer edges of the output coupling grating. An output coupling coating disposed over the output coupling structures. The waveguide includes an input coupling grating having a plurality of input coupling structures disposed over a waveguide substrate. The input coupling structures include the waveguide material and exterior input coupling structures at outer edges of the input coupling grating. An input coupling coating is disposed over the input coupling structures. The waveguide includes a pupil expansion grating having a plurality of pupil expansion structures disposed over the waveguide substrate. The pupil expansion structures include the waveguide material and exterior pupil expansion structures at outer edges of the pupil expansion grating. A film is disposed over the waveguide substrate between the exterior output coupling structures, the

exterior input coupling structures, and the exterior pupil expansion structures. The film includes the waveguide material. A pupil expansion coating is disposed over the pupil expansion grating having an outer boundary at an edge of the film. At least one of a refractive index of the output coating, a refractive index of the input coupling coating, or a refractive index of the pupil expansion coating is less than a refractive index of the waveguide material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments of the present disclosure and are therefore not to be considered limiting of its scope, and may admit to other equally effective embodiments of the present disclosure.

[0010] Figure 1 illustrates a schematic top view of a waveguide combiner, according to certain embodiments.

[0011] Figure 2A illustrates a schematic cross-sectional view of a portion of a grating of Figure 1, according to certain embodiments.

[0012] Figure 2B illustrates a schematic cross-sectional view of a portion of a grating of Figure 1, according to certain embodiments.

[0013] Figure 2C illustrates a schematic cross-sectional view of a portion of a grating of Figure 1, according to certain embodiments.

[0014] Figure 2D illustrates a schematic cross-sectional view of a portion of a grating of Figure 1, according to certain embodiments.

[0015] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

[0016] Embodiments herein are generally directed to waveguide combiners for augmented reality. More particularly, the present disclosure relates to systems and methods for waveguide combiners with gratings and a coating disposed thereover.

[0017] Diffractive waveguide combiners use gratings on a transparent substrate to replicate and redirect a virtual image from a light source to the user's eye while allowing the user to see the surrounding environment. The waveguide combiners, however, use high-refractive index substrates or coatings that reflect part of the incoming light, resulting in low transmission and unwanted reflections. The present disclosure provides a waveguide combiner with a coating including boundaries between the grating and waveguide regions that reduces or eliminates the unwanted reflections and increases the transmission through the gratings.

[0018] Figure 1 is a perspective, frontal view of a waveguide 100. It is to be understood that the waveguide 100 described herein is an exemplary waveguide and that other waveguides may be used with or modified to accomplish aspects of the present disclosure. The waveguide 100 includes a plurality of structures 102. The structures 102 may be disposed over, under, or on a surface 103 of a substrate 101, or disposed in the substrate 101. The structures 102 are nanostructures have a sub-micron critical dimension, e.g., a width less than 1 micrometer. Regions of the structures 102 correspond to one or more gratings 104. In one embodiment, which can be combined with other embodiments described herein, the waveguide 100 includes at least a first grating 104a corresponding to an input coupling grating and a third grating 104c corresponding to an output coupling grating. In another embodiment, which can be combined with other embodiments described herein, the waveguide 100 further includes a second grating 104b. The second grating 104b corresponds to a pupil expansion grating or a fold grating.

[0019] Figure 2A illustrates a schematic, cross-sectional view of a portion of the waveguide 100 along section line 2-2. More specifically, Figure 2A shows a cross-section of the first grating 104a, a portion of the surface 103 of the substrate 101, and the third grating 104c taken about the section line 2-2 of Figure 1A. However, it is to be noted that the components described herein may be components of the second grating 104b as well.

[0020] Substrate 101 in waveguide 100 includes a first grating region 220A and a waveguide region 220B. The substrate 101 includes materials with a refractive index of about 2.0, such as a high RI glass or lithium niobate. The first grating region 220A includes the one or more gratings 104 (e.g., the first grating 204a shown in Figure 2A) with a plurality of structures 202 (e.g., the first plurality of structures 202a) disposed thereon. Each of the one or more gratings 104 includes exterior structures 206, e.g., exterior first structures, exterior third structures, and exterior second structures, disposed at the outer edges of the grating 104, e.g., at a first film edge 214a. Each of the plurality of structures 202 of the grating 104 may have a thickness which may be uniform throughout the first grating region 220A. Similarly, each of the structures 202 in each of the first grating 104a, the second grating 104b, and the third grating 104c may have the same thickness in each grating (e.g., the third grating 104c and the second grating 104b having structures 202, e.g., first structures, third structures, and second structures, that have the same thickness), different thickness between each grating, or a combination of both, e.g., the first grating and the third grating have structures 202 with thicknesses equal to each other but different from the second grating. Having a different thicknesses for the second grating 104b, third grating 104c and first grating 104a provides an additional degree of freedom in waveguide design and optimization. To optimize the diffraction efficiency while reducing reflection to the outside environment it may be desirable in certain embodiments to have the structure thickness be different for the first grating 104a, second grating 104b, and third grating 104c.

[0021] The structures of the one or more gratings 104, e.g., the first grating 104a, the second grating 104b, and the third grating 104c may be formed from a waveguide material. The waveguide material may have a refractive index of about 2.0 to about 3.0. In some embodiments, the one or more gratings 104 may have a grating refractive index of about 2.2 to about 2.7. In some embodiments, the waveguide material includes, but is not limited to, titanium oxide, niobium oxide, silicon nitride, silicon oxide, or combinations thereof. Because of the high refractive index of the one or more gratings 104, the one or more gratings 104 produce unwanted reflections that negatively impact the use of the waveguide 100. For example, reflections from the third grating 104c reduces the visibility of the eyes of a user from the world side, making it difficult for social interactions. Ambient light from the user side can reflect

off the second grating 104b into the eyes of the user, reducing effectiveness. Additionally, high reflections and low transmission through the third grating 104c also reduce the visibility of the world for the user. Further, large reflections off the one or more gratings 104 make the gratings more visible against regions without grating, diminishing the aesthetic appearance of the waveguide 100.

[0022] In some embodiments, which may be combined with other embodiments described herein, a coating 208 is disposed over the one or more gratings 104 to prevent unwanted reflections and low transmission. In some embodiments, the coating 208 may be disposed over all of the one or more gratings 104. In other embodiments with more than one grating 104, the coating 208 may be disposed over only some of the gratings 104. The coating 208 has a lower refractive index compared to the grating material, as the coating refractive index is less than the grating refractive index, such as between about 1.2 and about 2.2, and is configured to behave as an anti-reflection coating. The lower coating refractive index allows the coating 208 to increase light transmission through the interface and reduce the reflection produced by the structures 202. In some embodiments, the material for the coating 208 includes, but is not limited to, silicon oxide, silicon nitride, silicon carbide, titanium oxide, niobium oxide, transparent polymers, or combinations thereof.

[0023] The waveguide region 220B includes a film 214 of the waveguide material disposed over the substrate 101. The film 214 extends between the exterior structures 206 of the one or more gratings 104 (e.g., the first grating 204a and third grating 204c as shown in Figure 2A) on the substrate 101. In some embodiments, the film 214 has a film thickness 216 of about 10 nm to about 250 nm. The film 214 includes a first film edge 214a that defines a boundary of the waveguide region 220B and is adjacent to the first grating region 220A.

[0024] The structures 202, e.g., a first plurality of structures 202a, have a structure thickness, e.g., a first structure thickness 210a, that extends from a surface 203 of a grating base layer 201 disposed on the surface 103 of the substrate 101.

[0025] The coating 208, disposed over the one or more gratings 104, includes an overburden thickness, e.g., first overburden thickness 212a of a first coating portion 208A of the coating 208, that extends from the first structure thickness 210a of the first plurality of structures 202a. The overburden thickness is about 0 nanometers

(nm) to about 800 nm, depending on the geometry, such as binary or angled (not shown), and material of the structures 202 that the coating 208 is encapsulating, along with the materials of the coating 208 itself. In embodiments where the coating 208 is disposed over the first grating 104a, the second grating 104b, the third grating 104c, or a combination thereof, the thickness of the coating 208 may vary between each set of gratings and may be based on the grating geometry and material. Further, the coating 208 may include a different refractive index, dependent on which set of gratings the coating 208 is disposed over. In some embodiments, which may be combined with other embodiments described herein, a first coating corresponding to a portion of the coating 208 is disposed over the first grating 104a. The first coating has a first refractive index. In some embodiments, which may be combined with other embodiments described herein, a third coating corresponding to a portion of the coating 208 is disposed over the third grating 104c. The third coating has a third refractive index. In some embodiments, which may be combined with other embodiments described herein, a second coating corresponding to a portion of the coating 208 is disposed over the second grating 104b. The second coating has a second refractive index. At least one of the first refractive index, the third refractive index, and the second refractive index may be different for each other.

[0026] In each of these embodiments, the coating 208 is disposed over the plurality of structures 202 and has a coating edge, e.g., a first coating edge 218a of a first coating portion 208A of the coating 208, at one of the exterior structures 206. The first coating edge 218a defines the outer boundary of the first coating portion 208A, e.g., the first coating portion 208A is disposed inside of the exterior structures 206 of the plurality of structures 202a, and is disposed adjacent to the first film edge 214a of the film 214. Alternatively, the first coating portion 208A may not be disposed over each of the structures 202 (not shown). Further, the first coating portion 208A may be adjacent to a coating disposed over the waveguide region 220B (not shown).

[0027] In the embodiments shown in Figure 2A, the waveguide 100 includes a plurality of gratings, such as a first grating 204a and a third grating 204c. The first coating portion 208A is disposed over and encapsulates the first grating 204a defining a first grating region 220A within the substrate 101. A second coating portion 208C is disposed over and encapsulates the third grating 204c defining a second grating region 220C within the substrate 101. The first grating 204a includes a first plurality

of structures 202a that have a first structure thickness 210a that extends from the surface 203 of the grating base layer 201. The first coating portion 208A includes a first overburden thickness 212a that extends from the first structure thickness 210a, e.g., from a top of the first plurality of structures 202a. Similarly, the third grating 204c includes a second plurality of structures 202c that have a second structure thickness 210c that extends from the surface 203 of the grating base layer 201. The second coating portion 208C includes a second overburden thickness 212c that extends from the second structure thickness 210c, e.g., from a top of the second plurality of structures 202c.

[0028] A film 214 is disposed between the first grating 204a and the third grating 204c and on the surface 103 of the substrate 101, defining a waveguide region 220B within the substrate 101. The film 214 includes a waveguide material and contacts the first grating 204a at a first film edge 214a and the third grating 204c at a second film edge 214c. The film 214 is disposed between the first grating 204a and the third grating 204c such that the first film edge 214a is adjacent to the first coating edge 218a of the first coating portion 208A and a second film edge 214c is adjacent to a second coating edge 218c of the second coating portion 208C. The film 214 has a film thickness 216 extending from the top surface 103 of the substrate 101. As shown in Figure 2A, a top surface of each of the first structure thickness 210a, the second structure thickness 210c, and the film thickness 216 may be substantially coplanar.

[0029] Figure 2B illustrates a schematic, cross-sectional view of a portion of the waveguide 100 and is configured similarly the embodiment shown in Figure 2A, except as described. As shown in Figure 2B, not all gratings need be encapsulated by an anti-reflection coating. For example, the first grating region 220A includes the first grating 204a with the first coating portion 208A disposed over the first plurality of structures 202a, but the second grating region 220C only includes the third grating 204c without the second coating portion 208C disposed over the second plurality of structures 202c. Although the first grating 204a is described as being encapsulated by the first coating portion 208A, any combination of gratings may include an anti-reflective coating while other gratings do not, e.g., a second grating and a third grating may include an anti-reflective coating while a first grating does not. Without being bound by theory, it is desirable to match the reflection and transmission of the first grating 104a, the second grating 104b and the third grating 104c to the waveguide

region, e.g., the waveguide region 220B, so that the waveguide 100 is aesthetically appealing as light is not reflected to the people in the outside environment. I.e., there is not eye glow of the image to people on the opposing side of the device. Thus, if one of the gratings, e.g., the third grating 204c, has low reflection relative to the waveguide region 220B, it would not need the second coating portion 208C. Similarly, if the first grating 204a has a low reflection relative to the waveguide region 220B, the first coating portion 208A may not be needed.

[0030] Figure 2C illustrates a schematic, cross-sectional view of a portion of the waveguide 100 and is configured similarly the embodiment shown in Figure 2A, except as described. As shown in Figure 2C, the coating portions over the first grating region 220A and the second grating region 220C may not be the same thickness. For example, although a top surface of the first structure thickness 210a, the second structure thickness 210c, and the film thickness 216 may be substantially coplanar, the first overburden thickness 212a and the second overburden thickness 212c may not be equal. In some embodiments, if the first plurality of structures 202a include a material with a high refractive index greater than the material of the second plurality of structures 202c, then the first overburden thickness 212a may need to be greater than the second overburden thickness 212c to effectively reduce reflectivity of the first plurality of structures 202a to a desired level, such as to match the reflectivity of the second grating region 220C, e.g., the second plurality of structures 202c and the second coating portion 208C disposed thereover.

[0031] Figure 2D illustrates a schematic, cross-sectional view of a portion of the waveguide 100 and is configured similarly the embodiment shown in Figure 2A, except as described. As shown in Figure 2D, the first structure thickness 210a of the first waveguide region 220A and the second structure thickness 210c of the second waveguide region 220C may be different. In some embodiments, the first overburden thickness 212a and the second overburden thickness 212c may also be different. For example, a thinner first structure thickness 210a may require a thinner first overburden thickness 212a while a thicker second structure thickness 210c may require a thicker second overburden thickness 212c to achieve the desired reflectivity for each grating. Additionally, the grating material and geometry of the plurality of structures 204, such as being binary or angled (not shown), may affect the overall overburden thickness of the anti-reflective coating required for encapsulating the respective gratings.

[0032] The waveguide 100 may also include a plurality of film segments, e.g., a first film segment 214₁ and a second film segment 214₂, disposed on either side of a grating, e.g., third grating 204c shown in Figure 2D. In some embodiments, the first film segment 214₁ is disposed between the first grating 204a and the third grating 204c such that the first film edge 214a is adjacent to a first coating edge 218a of the first coating portion 208A, and a second film edge 214c is adjacent to a second coating edge 218c of the second coating portion 208C. In some embodiments, the second film segment 214₂ is disposed on an opposite end of the third grating 204c such that a third film edge 214b is adjacent to a third coating edge 218b of the second coating portion 208C defining a second waveguide region 220D. The first film segment 214₁ includes a first film thickness 216a and the second film segment 214₂ includes a second film thickness 216b. As shown in Figure 2D, the first film thickness 216a and the second film thickness 216b may be different. In other embodiments, the first film thickness 216a and the second film thickness 216b may be the same.

[0033] The present disclosure provides a coating architecture on a waveguide combiner for head-mounted augmented reality applications. The coating is an anti-reflection coating that prevents light reflection at orthogonal angles within the waveguide substrate while facilitating light propagation for total internal reflection. The coating reduces unwanted reflections on the grating side, greatly enhancing the user experience and reducing distractions.

[0034] While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A waveguide, comprising:
a waveguide substrate;
one or more gratings disposed over the waveguide substrate, wherein each of the one or more gratings comprises a plurality of structures made of a waveguide material, and exterior structures extending along outer edges of each of the one or more gratings;
a film comprising the waveguide material disposed over the waveguide substrate and adjacent the exterior structures of each of the one or more gratings;
and
a coating disposed over at least one of the one or more gratings, wherein a refractive index of the coating is less than a refractive index of the one or more gratings thereunder.
2. The waveguide of claim 1, wherein the coating is disposed over the waveguide substrate inside of the exterior structures of the one or more gratings.
3. The waveguide of claim 1, wherein the one or more gratings comprises a first grating corresponding to an input coupling grating, a second grating corresponding to a pupil expansion grating, and/or a third grating corresponding to an output coupling grating.
4. The waveguide of claim 1, wherein the film and the plurality of structures have the same thickness.
5. The waveguide of claim 1, wherein the coating has a refractive index of less than 2.0.
6. The waveguide of claim 1, wherein the refractive index of the coating is between about 1.2 and about 2.2.
7. A waveguide, comprising:
a third grating corresponding to an output coupling grating, the third grating comprising a plurality of third structures disposed over a waveguide substrate, wherein:
the plurality of third structures comprise a waveguide material, and

the plurality of third structures comprise exterior third structures at outer edges of the third grating;

a third coating disposed over the plurality of third structures;

a second grating corresponding to a pupil expansion grating, the second grating comprising a plurality of second structures disposed over the waveguide substrate, wherein:

the plurality of second structures comprise the waveguide material, and

the plurality of second structures comprise exterior second structures at outer edges of the second grating;

a film disposed over the waveguide substrate between the exterior third structures and the exterior second structures, the film including the waveguide material, wherein a refractive index of the third coating is less than a refractive index of the third grating; and

a second coating disposed over the second grating.

8. The waveguide of claim 7, wherein the third coating is disposed over the waveguide substrate inside of the exterior third structures of the third grating.

9. The waveguide of claim 7, wherein the film, the third structures, and the second structures have the same thickness.

10. The waveguide of claim 7, wherein the third structures have a refractive index of greater than 2.2.

11. The waveguide of claim 7, wherein a refractive index of the third coating is between about 1.2 and about 2.2.

12. The waveguide of claim 7, wherein a refractive index of the third coating is different than a refractive index of the second coating.

13. A waveguide, comprising:

a first grating corresponding to an input coupling grating, the first grating comprising a plurality of first structures made of a waveguide material and disposed over a waveguide substrate, and exterior first structures disposed along outer edges of the first grating;

a first coating disposed over the plurality of first structures;

a third grating corresponding to an output coupling grating, the third grating comprising a plurality of third structures made of the waveguide material disposed over the waveguide substrate, and exterior third structures at outer edges of the third grating;

a third coating disposed over the third structures;

a second grating corresponding to an pupil expansion grating, the second grating comprising a plurality of second structures made of the waveguide material and disposed over the waveguide substrate, and exterior second structures disposed along outer edges of the second grating;

a second coating disposed over the second grating; and

a film made of the waveguide material and disposed over the waveguide substrate between the exterior third structures, the exterior first structures, and the exterior second structures, wherein at least one of a refractive index of the third coating, a refractive index of the first coating, or a refractive index of the second coating is less than a refractive index of the waveguide material.

14. The waveguide of claim 13, wherein the third coating is disposed over the waveguide substrate inside of the exterior third structures of the third grating.

15. The waveguide of claim 13, wherein the film, the third structures, the first structures, and the second structures have the same thickness.

16. The waveguide of claim 13, wherein the second structures have a refractive index of greater than 2.2.

17. The waveguide of claim 13, wherein the refractive index of the third coating is less than a refractive index of the third grating.

18. The waveguide of claim 13, wherein the refractive index of the third coating and the refractive index of the first coating are different.

19. The waveguide of claim 13, wherein the refractive index of the first coating and the refractive index of the second coating are different.

20. The waveguide of claim 13, wherein the refractive index of the third coating and the refractive index of the second coating are different.