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Waveguide combiners having arrangements for image uniformity

Abstract

Embodiments described herein relate to waveguide combiners having arrangements for image uniformity. The waveguide combiners includes an input coupling grating (ICG) defined by a plurality of input structures, a pupil expansion grating (PEG) defined by a plurality of expansion structures, an output coupling grating (OCG) defined by a plurality of output structures The waveguide combiners includes at least one of a pixelated phase modulator is aligned with the PEG of the first side of the waveguide combiners, at least one of a Y expander and an X expander disposed on a second side of the waveguide combiners opposing the first side, or a pupil shifting mechanism operable to shift incident beams of light between a first position and a second position of the ICG.

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Background/Summary

RELATED APPLICATION(S) (1) This application claims benefit of and priority to U.S. Provisional Application No. 63/256,226, filed Oct. 15, 2021, which is herein incorporated in its entirety by reference for all purposes.

BACKGROUND
Field
(1) Embodiments of the present disclosure generally relate to augmented reality waveguide combiners. More specifically, embodiments described herein relate to waveguide combiners having

arrangements for image uniformity.

Description of the Related Art

(2) 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 generated in **3**D 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.

(3) 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 enhances or augments the environment that the user experiences. As an emerging technology, there are many challenges and design constraints with augmented reality.

(4) One such challenge is displaying a virtual image overlaid on an ambient environment. Waveguide combiners are used to assist in overlaying images. Generated light is in-coupled into a waveguide combiner, propagated through the waveguide combiner, out-coupled from the waveguide combiner, and overlaid on the ambient environment. Light is coupled into and out of waveguide combiners using surface relief gratings. The propagation of light in waveguide combiners may result in non-uniformities of the virtual image.

(5) Accordingly, what is needed in the art are waveguide combiners having arrangements for improved image uniformity.

SUMMARY

(6) In one embodiment, a waveguide combiner is provided. The waveguide combiner includes an input coupling grating (ICG) defined by a plurality of input structures, a pupil expansion grating (PEG) defined by a plurality of expansion structures disposed over a first side of the waveguide combiner, an output coupling grating (OCG) defined by a plurality of output structures, a pixelated phase modulator disposed on a second side of the waveguide combiner opposing the first side of the waveguide combiner. The pixelated phase modulator is aligned with the PEG of the first side of the waveguide combiner.

(7) In another embodiment, a waveguide combiner is provided. The waveguide combiner includes an input coupling grating (ICG) defined by a plurality of input structures disposed over a first side of the waveguide combiner, a pupil expansion grating (PEG) defined by a plurality of expansion structures, the PEG having at least one of a Y expander and an X expander disposed on a second side of the waveguide combiner opposing the first side, and an output coupling grating (OCG) defined by a plurality of output structures.

(8) In yet another embodiment, a waveguide combiner is provided. The waveguide combiner an input coupling grating (ICG) defined by a plurality of input structures, a pupil expansion grating (PEG) defined by a plurality of expansion structures, an output coupling grating (OCG) defined by a plurality of output structures, and a pupil shifting mechanism operable to shift incident beams of light between a first position and a second position of the ICG.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) 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 and

are therefore not to be considered limiting of its scope, and may admit to other equally effective embodiments.

(2) FIG. **1** is a perspective, frontal view of a waveguide combiner according to embodiments.

(3) FIG. **2**A is a schematic, cross-sectional view of a portion of a waveguide combiner according to embodiments.

(4) FIG. **2**B is a schematic, top view of a portion of a waveguide combiner according to embodiments.

(5) FIG. **3** is a schematic, top view of an arrangement of a waveguide combiner according to embodiments.

(6) FIG. **4**A is a schematic, top view of an arrangement of a waveguide combiner according to embodiments.

(7) FIGS. **4**B and **4**C are schematic views of a pupil shifting mechanism of an arrangement of a waveguide combiner according to embodiments.

(8) 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

(9) Embodiments described herein relate to waveguide combiners to waveguide combiners having arrangements for image uniformity. The waveguide combiners includes an input coupling grating (ICG) defined by a plurality of input structures, a pupil expansion grating (PEG) defined by a plurality of expansion structures, an output coupling grating (OCG) defined by a plurality of output structures The waveguide combiners includes at least one of a pixelated phase modulator is aligned with the PEG of the first side of the waveguide combiners, at least one of a Y expander and an X expander disposed on a second side of the waveguide combiners opposing the first side, or a pupil shifting mechanism operable to shift incident beams of light between a first position and a second position of the ICG.

(10) FIG. **1** is a perspective, frontal view of a waveguide combiner **100**. It is to be understood that the waveguide combiner **100** described below is an exemplary waveguide combiner. The waveguide combiner **100** includes an input coupling grating (ICG) **102** defined by a plurality of input structures **108**, a pupil expansion grating (PEG) **104** defined by a plurality of expansion structures **110**, and an output coupling grating (OCG) **106** defined by a plurality of output structures **112**. The ICG **102** receives incident beams of light (a virtual image) having an intensity from a microdisplay. Each grating of the plurality of input structures **108** splits the incident beams into a plurality of modes, each beam having a mode. Zero-order mode (T0) beams are either reflected back towards the microdisplay or are transmitted straight through the waveguide combiner **100**, positive first-order mode (T1) beams are coupled though the waveguide combiner **100** to the PEG **104**, and negative first-order mode (T−1) beams propagate in the waveguide combiner **100** a direction opposite to the T1 beams. Ideally, most of the incident beams are split into T1 beams that have all of the intensity of the incident beams in order to direct the virtual image to the PEG **104**. The T1 beams undergo total-internal-reflection (TIR) through the waveguide combiner **100** until the T1 beams come in contact with the plurality of expansion structures **110** in the PEG **104**.

(11) The T1 beams contact an initial expansion structure **110***a* of the plurality of expansion structures **110**. The T1 beams are split into T0 beams of the PEG **104** that continue propagating until the beams contact a successive expansion structure **110***b* of the plurality of expansion structures **110**, or into T1 beams of the PEG **104** that are coupled through the waveguide combiner **100** to the OCG **106**. The T1 beams that undergo TIR in the PEG **104** continue to contact expansion structures of the plurality of expansion structures **110** until the either the intensity of the T1 beams coupled through the waveguide combiner **100** to the PEG **104** is depleted, or remaining

T1 beams propagating through the PEG **104** reach the end of the PEG **104**. The PEG **104** must control the T1 beams undergoing TIR in the PEG **104** in order to control the intensity of the T−1 beams coupled to the OCG **106** over a field of view of the virtual image produced from the microdisplay from a user's perspective, and increase the eyebox over which multiple users can view the virtual image along the length of PEG **104**.

(12) The T−1 beams coupled through the waveguide combiner **100** to the OCG **106** undergo TIR in the waveguide combiner **100** until the T−1 beams contact an initial output structure **112**a of the plurality of output structures **112** where the T−1 beams are split into either the T0 beams that continue propagating along the length of the OCG **106** interacting with a successive output structure **112**b as part of a plurality of output structures **112**, or into T1 beams are out-coupled by the OCG **106** out of the waveguide combiner **100** towards the user. The T0 beams that continue propagating along the length of the OCG **106** continue to contact output structures of the plurality of output structures **112** until the either the intensity of the T−1 beams coupled through the waveguide combiner **100** to the OCG **106** is depleted, or remaining T0 beams propagating through the OCG **106** have reached the end of the OCG **106**.

(13) FIG. **2**A is a schematic, cross-sectional view of a portion **200** of a waveguide combiner **100**. FIG. **2**B is a schematic, top view of the portion **200** of a waveguide combiner **100**. The portion **200** of the waveguide combiner **100** includes the PEG **104** disposed on a first side **201** of the waveguide combiner **100** and a pixelated phase modulator **202** disposed on a second side **203** of the waveguide combiner **100** opposing the first side **201**. The pixelated phase modulator **202** disposed on the second side **203** is aligned with the PEG **104** on the first side **201**. In one example, the pixelated phase modulator includes pixels φ_1-φ_9 in a region where a Mach-Zehnder interference pattern could occur. The pixelated phase modulator **202** may be a spatial light modulator, such as a liquid crystal spatial light modulator (LC-SLM). The waveguide combiner **100** utilizes the pixelated phase modulator **202** such that a first T−1 beam **206**a and a second T−1 beam **206**b coupled to the OCG **106** have the same intensity.

(14) For example, an incident beam contacting an initial expansion structure **204**a can reach a third expansion structure **204**d via two distinct paths. A first path includes T1 and T−1 diffractions by PEG **104** at the initial expansion structure **204**a and a second expansion structure **204**b leading to a beam **205**a to the third expansion structure **204**d. A second path includes T0 and T1 diffractions by PEG **104** at a successive expansion structure **204**c and the third expansion structure **204**d leading to a beam **205**b arriving at the same location at the third expansion structure **204**d. As a result of two distinct paths, the intensity of the second T−1 beam **206**b is a function of the phase differences accumulated by the beams **205**a and **205**b via these two distinct paths. In conventional waveguide combiners, due to subtle changes in grating structures, and substrate profile that cannot be tightly controlled at a nanometer scale, this modulation leads to distinct non-uniform intensity distribution in the final images seen by the users at the OCG **106** since the first T−1 beam **206**a and the second T−1 beam **206**b both propagate towards the OCG **106**. The pixelated phase modulator **202** disposed on the second side **203** is aligned with the PEG **104** on the first side **201** and has a resolution and phase modulation (0-2π) that ensures that the first T−1 beam **206**a and the second T−1 beam **206**b propagate to the OCG **106** with a uniform intensity for all angles within the field-of-view and eyebox of the waveguide combiner **100**.

(15) FIG. **3** is a schematic, top view of an arrangement **300** of the waveguide combiner **100**. The waveguide combiner **100** of the arrangement **300** includes the ICG **102**, the PEG **104**, and the OCG **106**. The PEG **104** has a Y expander **302** and an X expander **304**. The Y expander **304** has a second grating vector **303** that is the same as a first grating vector **301** of the ICG **102**. In one embodiment, a third grating vector **305** of the X expander **304** is orthogonal to the first grating vector **301** of the ICG **102**. In one embodiment, a pitch of the plurality of expansion structures **110** of the X expander **304** is the same as a pitch of the plurality of input structures **108** of the ICG **102**. A fourth grating vector **307** of the OCG **106** is the same as the third grating vector **305** of the X expander **304**. At

least one of the Y expander **302** and the X expander **304** is disposed on the second side **203** of the waveguide combiner **100** opposing the first side **201**. In an embodiment, the Y expander **302** and the X expander **304** are disposed on opposite sides of the waveguide combiner **100**. Disposing at least one of the Y expander **302** and the X expander **304** on the second side **203** opposing the first side **201** avoids a Mach-Zehnder interference pattern. At least one of the Y expander **302** and an X expander **304** on the second side **203** opposing the first side **201** provide for a uniform outcoupled image from the OCG **106** to the user's eye.

(16) FIG. **4**A is a schematic, top view of an arrangement **400** of the waveguide combiner **100**. FIGS. **4**B and **4**C are schematic views of a pupil shifting mechanism **402** of the arrangement **400** of the waveguide combiner **100**. The waveguide combiner **100** of the arrangement **400** includes the ICG **102**, the PEG **104**, and the OCG **106**. The arrangement **400** includes a pupil shifting mechanism, such as a pupil shifting mechanism **402**. The pupil shifting mechanism **402** includes a first liquid crystal (LC) switch **404**, a birefringent slab **406**, and a second LC switch **408**.

(17) In an embodiment, which can be combined with other embodiments herein, an optical axis of the birefringent slab **406** is tilted with respect to a surface of the ICG **102**. As shown in FIG. **4**B, when no voltage is applied to the first LC switch **404**, an incident beam **405** is diffracted at an angle by the birefringent slab **406** via a change in polarization of the incident beam to displace the incident beam **405**. When no voltage is applied to the second LC switch **408**, the second LC switch **48** changes the polarization of the shifted incident beam **405** to be incident of a first position **401**. As shown in FIG. **4**C, when a voltage is applied to the first LC switch **404** and the second LC switch **408**, an incident beam **405** is projected through the birefringent and is incident of a second position **403**. The pupil shifting mechanism therefore shifts incident beams of light (the virtual image) between the first position **401** and the second position **403** on the ICG **102**. The shifting of the incident beams on the ICG **102** has the effect of averaging, and thus improving, the intensity patterns from these corresponding positions **401**, **403** to the user's eye at the OCG **106**.

(18) While the foregoing is directed to examples of the present disclosure, other and further examples of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims

1. A waveguide combiner, comprising: an input coupling grating (ICG) defined by a plurality of input structures; a pupil expansion grating (PEG) defined by a plurality of expansion structures disposed over a first side of the waveguide combiner; an output coupling grating (OCG) defined by a plurality of output structures; and a pixelated phase modulator disposed on a second side of the waveguide combiner opposing the first side of the waveguide combiner, the pixelated phase modulator aligned with the PEG of the first side of the waveguide combiner.

2. The waveguide combiner of claim 1, wherein the pixelated phase modulator is a liquid crystal spatial light modulator (LC-SLM).

3. The waveguide combiner of claim 1, wherein the PEG is operable to diffract and out-couple a beam interacting with the PEG as a first T−1 beam and a T−1 second beam with different local intensities and wherein the pixelated phase modulator is configured to tune the first and second T−1 beams from the PEG and out-couple them to the OCG with a uniform intensity for all angles.

4. The waveguide combiner of claim 3, wherein the pixelated phase modulator is configured to tune a phase difference between the first T−1 beam and the second T−1 beam diffracted and out-coupled by the PEG.

5. The waveguide combiner of claim 1, wherein the pixelated phase modulator comprises a plurality of pixels in a region where a Mach-Zehnder interference pattern by a beam interacting with the PEG could occur.

6. A waveguide combiner, comprising: an input coupling grating (ICG) defined by a plurality of

input structures disposed over a first side of the waveguide combiner; a pupil expansion grating (PEG) defined by a plurality of expansion structures, the PEG having at least one of a Y expander and an X expander disposed on a second side of the waveguide combiner opposing the first side; and an output coupling grating (OCG) defined by a plurality of output structures.

7. The waveguide combiner of claim 6, wherein the Y expander has a second grating vector that is the same as a first grating vector of the ICG.

8. The waveguide combiner of claim 6, wherein the X expander has a third grating vector that is orthogonal to a first grating vector of the ICG.

9. The waveguide combiner of claim 6, wherein the X expander has a third grating vector with a first pitch that is the same as a second pitch of a first grating vector of the ICG.

10. The waveguide combiner of claim 6, wherein the X expander has a third grating vector that is the same as a fourth grating vector of the OCG.

11. The waveguide combiner of claim 6, wherein the Y expander and the X expander are on opposite sides of the waveguide combiner.

12. The waveguide combiner of claim 6, wherein the at least one of the Y expander and the X expander disposed on the second side of the waveguide combiner is operable to provide a uniform out-coupled image from the OCG.

13. The waveguide combiner of claim 6, wherein the at least one of the Y expander and the X expander disposed on the second side of the waveguide combiner is operable to avoid interference caused by splitting of beams interacting with the PEG.

14. A waveguide combiner, comprising: an input coupling grating (ICG) defined by a plurality of input structures; a pupil expansion grating (PEG) defined by a plurality of expansion structures; an output coupling grating (OCG) defined by a plurality of output structures; and a pupil shifting mechanism operable to shift incident beams of light between a first position and a second position of the ICG.

15. The waveguide combiner of claim 14, wherein the pupil shifting mechanism comprises a first liquid crystal (LC) switch, a birefringent slab, and a second LC switch.

16. The waveguide combiner of claim 15, wherein when no voltage is applied to the first and second LC switches, the pupil shifting mechanism is operable to diffract and displace incident beams of light to be incident of the first position.

17. The waveguide combiner of claim 15, wherein when a voltage is applied to the first and second LC switches, the pupil shifting mechanism is operable to project incident beams of light through the birefringent slab to be incident of the second position.

18. The waveguide combiner of claim 15, wherein the birefringent slab comprises an optical axis that is tilted with respect to a surface of the ICG.

19. The waveguide combiner of claim 15, wherein the first and second LC switches comprise half wave plates with an optic axis that is oriented 45 degrees with respect to a linear polarization of incident beams of light.

20. The waveguide combiner of claim 14, wherein the pupil shifting mechanism is operable to average intensity patterns of incident beams of light from each of the corresponding first and second positions to a user's eye at the OCG.