Near-Eye Displays with Reflective Liquid Crystal Gratings for Metaverse

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Abstract: We present a near-eye display featuring a triple-channel waveguide with reflective liquid crystal gratings. Our triple-channel waveguide is capable of dividing one field of view into three through both the polarization orthogonality and angular separation.

1. Introduction

One of the most crucial building blocks of metaverse is arguably the near-eye displays (NEDs), *e.g.* augmented/virtual reality (AR/VR) eyewear. The mainstream NEDs often come in three types of architectures, *i.e.* combiners, magnifiers, and waveguides [1]. Which type of architecture is ideal for NEDs? In the short run, combiners and magnifiers are prevailing in the sectors of AR and VR, respectively. However, in the long run, waveguides are tipped to overtake the former two for both AR and VR. This prediction is not groundless for several reasons. Number one, waveguides could support big field of views (FOVs). Number two, waveguides are compatible with minimal designs, more resembling normal eyeglasses. Number three, waveguides, by leveraging the total internal reflection, lend themselves to the exit pupil or eyebox expansion. Yet, waveguides have many issues too. One major concern, among others, is about the poor uniformity across the eyebox region. This is because that different fields propagate at different angles within the waveguide. And it will only get worse as the FOV becomes bigger. To address this issue, we hereby introduce a triple-channel-waveguide-based NED, which aims to push the FOV further without sacrificing the uniformity.

2. Proposed Structure

Fig. 1 shows a cross-section of our triple-channel waveguide, with its top, middle and bottom layers being referred to as channel 1, channel 2 and channel 3, respectively. The input FOV is divided equally into left (FOV$_1$), center (FOV$_2$) and right (FOV$_3$) sub-FOVs, which in turn carry the left-handed (L), right-handed (R) and left-handed circular polarizations. Accordingly, gratings—including the in-coupling and out-coupling—of channel 1/2/3 are responsive merely to FOV$_{1/2/3}$. This can be fulfilled by adjusting both the polarization selectivity and tilt angles $\theta_{1/2/3}$ of gratings [2]. For the sake of big FOV, a lanthanum dense flint glass LASF35 (Schott) is chosen as the material of waveguide, whose refractive index n_{wg} at 633/546/486 nm is 2.0149/2.0304/2.0471, yielding to a critical angle θ_c of 29.76°/29.51°/29.25°. To accommodate longer wavelengths, it would be safer to use a slightly larger angle, say 30°, as the common critical angle θ_c.

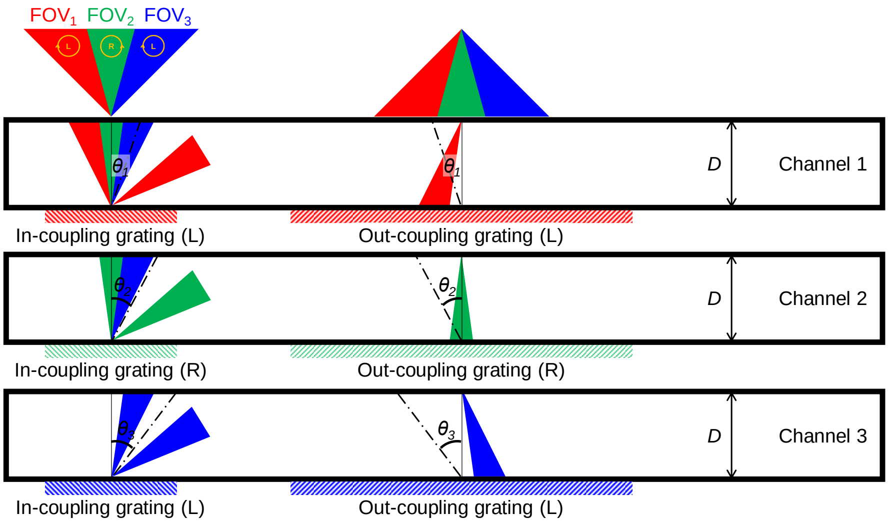

Fig. 1. Schematic drawing of the proposed NED.

3. Results and Discussion

Since the FOV is equally divided and all angles propagating within channel 1/2/3 are identical, channel 2, where the center of FOV or FOV_2 is located, is selected. The optical setup for our simulation is shown in Fig. 2, where the sub-gratings of out-coupling grating are labeled as O1 to O10. The thickness D of waveguide is 1.17 mm. The width W_i of in-coupling grating shall match with the size of input pupil—a circle with a diameter D_p of 2 mm. The width W_o of out-coupling grating is 20 mm, with each sub-grating being 2 mm across. Hence, if the eye relief is 10 mm, exit pupil will be 4.9 × 4.9 mm^2. The input intensity I_0 of the source is normalized to be 1 V^2/m^2. From the ray tracing, the footprints of duplicated pupils of central field can be obtained, as shown in Fig. 3(a). On top of the footprints, Fourier modal method is employed to calculate the electromagnetic fields captured by the detector. For the fields of overlapped regions, the coherent summations are applied. After the optimization, the normalized grating efficiencies of reflected zeroth (R0) and first (R1) orders are tweaked for the sake of uniformity. As $I_{min}= 0.0433\ V^2/m^2$ and $I_{max}= 0.0541\ V^2/m^2$, the transmittance—the ratio of $(I_{min}+I_{max})/2$ to I_0—and uniformity are 4.9% and 89%, respectively, which agrees with our experimental results, as shown in Fig. 3(b).

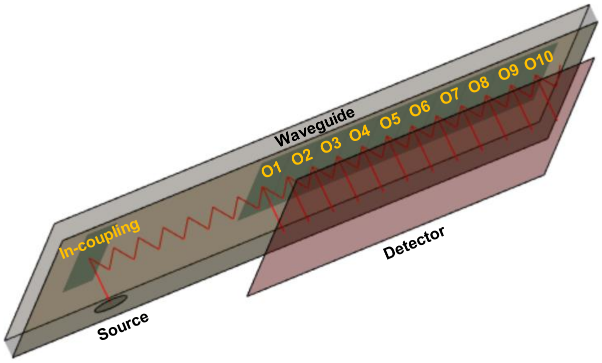

Fig. 2. Optical setup for the simulation on VirtualLab Fusion.

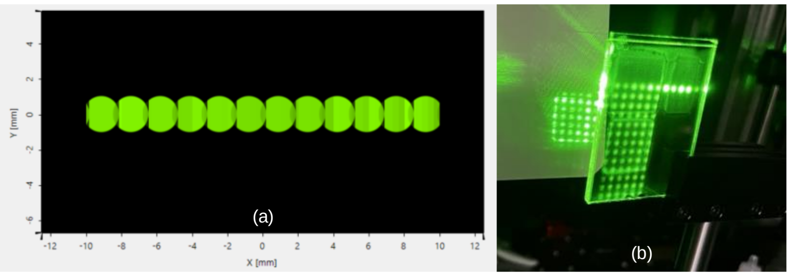

Fig. 3. (a) Simulated and (b) experimental footprints and intensities of duplicated pupils of central field.

4. Summary

In a nutshell, a NED with a triple-channel waveguide has been proposed. Three major contributions are identified as follows. Contribution 1. FOV wise, the triple-channel waveguide beats out its closet variants, *e.g.* the dual-channel waveguides or the alike [3]. Contribution 2. Compared to the other works [4], our derivation of upper limit of FOV is more accurate by factoring into the aspect ratio of FOV. Contribution 3. How the grating efficiency modulates the uniformity is formulated. This would enable the designers to roughly estimate the uniformity from scratch.

5. Acknowledgments

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References

[1] Y. Wu, C. P. Chen, L. Zhou, Y. Li, B. Yu, and H. Jin, “Design of see-through near-eye display for presbyopia,” Opt. Express **25**(8), 8937–8949 (2017).

[2] C. P. Chen, Y. Cui, Y. Chen, S. Meng, Y. Sun, C. Mao, and Q. Chu, “Near-eye display with a triple-channel waveguide for metaverse,” Opt. Express **30**(17), 31256–31266 (2022).

[3] C. P. Chen, L. Mi, W. Zhang, J. Ye, and G. Li, “Wide-field-of-view near-eye display with dual-channel waveguide,” Photonics **8**(12), 557 (2021).

[4] C. P. Chen, L. Mi, W. Zhang, J. Ye, and G. Li, “Waveguide-based near-eye display with dual-channel exit pupil expander,” Displays **67**, 101998 (2021).