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A Plastic Holographic Waveguide Combiner for Light-weight and Highly-transparent Augmented Reality Glasses

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Abstract

We have developed a unique production process of a full-color plastic holographic waveguide combiner with a light-weight and see-through capability. The novel plastic waveguide technology enables us to increase design flexibility in the eyewear and to expand the market for augmented reality (AR). This paper presents the approach to production.

Keywords

Augmented Reality Glasses; Plastic waveguide; Near-eye display; Volume hologram; See-through

1. Introduction

Recently, the application and device developments for augmented reality (AR) are very active with the infrastructure seen in communication speed improvement and the communication cost reduction. Among several proposed Near-eye displays [1][2], those with see-through capability [3] are especially important for mobile uses and AR applications.

We developed a full color Near-Eye display with two in- and out-coupling reflection volume holograms on an optical glass waveguide in 2008 [4]. This technology had many advantages such as high see-through capability and a small thickness with minimum size. It enabled us to get information by a hands-free approach without looking away from the object and to display information such as images and letters overlapped with the landscape. We also achieved a high-luminance (1000cd/cm²) using the design of two in-coupling and one out-coupling HOEs in 2015 [5].

On the other hand, the consumers expect a Near-Eye display, in addition to display performance, to be light-weight and unbreakable like plastic lenses of glasses and to deal with the several design shapes according to user preferences and use cases. However, to expose the hologram, an optical grade glass substrate was required and conventionally a plastic substrate was not able to be used. We have studied a plastic waveguide technology and developed a plastic full-color holographic waveguide combiner using our novel roll-to-roll (R2R) hologram exposure and laminating process and demonstrated the same optical characteristics as a glass substrate. In this paper, we describe the production process and the optical characteristics.

2. Production technology

2.1. Structure overview

Figure 1 illustrates a structure of a full color hologram waveguide combiner with an in-coupling and an out-coupling reflection volume hologram. The in-coupling and out-coupling holographic optical elements (HOE) had exactly the same fringe pattern and were mirror symmetrically positioned. We used two plastic holographic waveguides, one for Green, the other for Red and Blue. The red and blue HOEs were laminated at the opposing surface of the substrate. We used a cyclo-olefin polymer as a plastic waveguide and the thickness was 1mm. The hologram materials used a photopolymer that did not require a heat processing. We employed Bayfol® HX films [6].

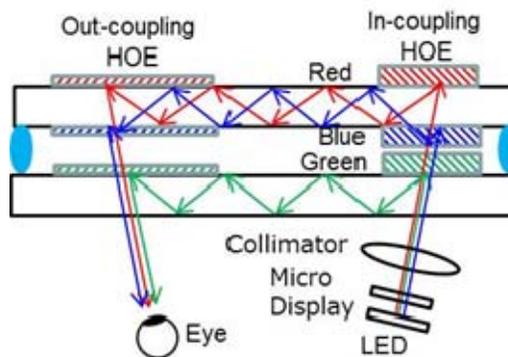


Figure 1.An optical structure of the holographic waveguide combiner

2.2. R2R process for the plastic holographic waveguide

The R2R process of the plastic holographic waveguide is shown in Fig. 2.

Firstly, the HOE was formed on a photopolymer film using two-beam interference exposure method. Secondly, the plastic waveguide was formed by an injection molding, which had a severe specification such as a warpage and a thickness variation. As a result of the light ray tracing calculation, the warpage of the plastic waveguide needed to be less than 5 μ m and thickness variation needed to be within 1 μ m in the optical effective area. The result of the thickness variation is shown in Fig. 3. Uniformity of the thickness was achieved less than 1 μ m in the

optical effective area. After that, HOE laminating process was to stick the HOE film on the plastic waveguide with alignment. Next, in the punching process, we cut the plastic holographic waveguide in a necessary design. Finally, in the color registration process, the inclination of the Red and Blue plastic waveguide was adjusted to the Green plastic waveguide and fixed by UV resin. The challenges of both the punching and the color registration processes were that the plastic substrate could be kept flat before and after each process. Figure 4 shows photographs of the color HOE roll-films, with green, red, and blue HOE, and photographs of the full-color plastic holographic waveguide. The weight of the full-color plastic holographic waveguide was only about 3.6 g, less than half that of the glass. Figure 5 shows photographs of the shape variations of the plastic holographic waveguide through the punching process. This R2R production technology enabled a light-weight and fashionable design near-eye display.

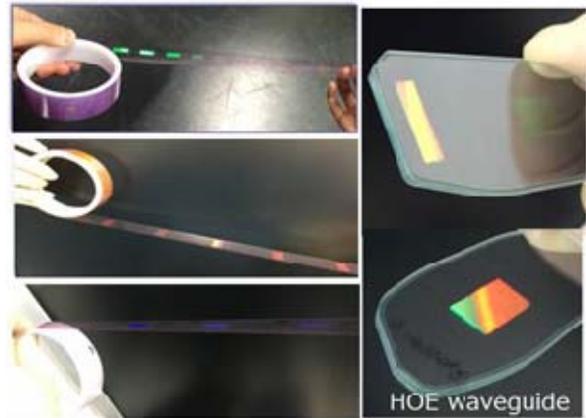


Figure 4. Green, Red & Blue HOE in the roll-film, and Full-color plastic holographic waveguide

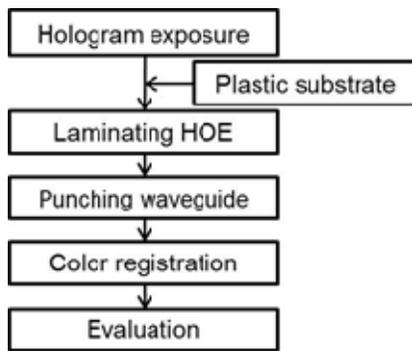


Figure 2. Process flow diagram of the plastic holographic waveguide

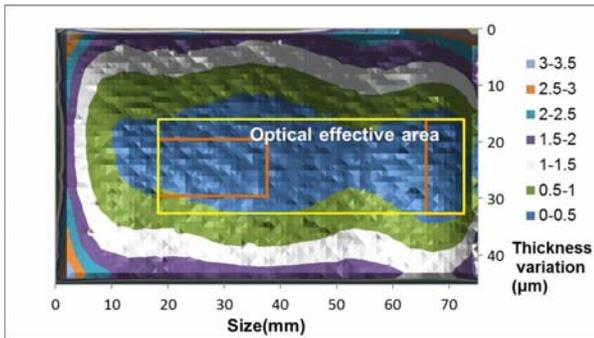


Figure 3. Thickness variation result of the plastic substrate (The color coding denotes 0.5µm contours)

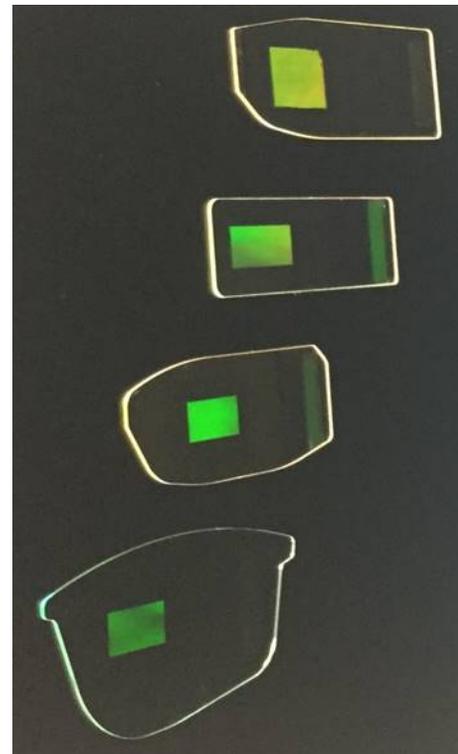


Figure 5. Shape variations of the plastic holographic waveguide in a punching process

3. Image-quality improvement

3.1. Simulation of the HOE laminating accuracy

We introduced the laminating process into forming the hologram on the plastic waveguide at this process. We calculated the degree of accuracy in alignment in the laminating process and showed the results in the trial production.

The laminating process should maintain two conditions; one was the mirror symmetry of the in-coupling and out-coupling HOE, the other was the positional relation in the two-layer lamination.

As shown in Fig. 6, "laminating deviation" includes two types of elements, which were shifted in parallel and shifted in rotation. In the former case, the mirror symmetry of the in-coupling and out-coupling HOE did not break. On the other hand, in the latter case, the deviation due to rotational misalignment of the in-coupling HOE was mainly recognized as the view angle shift.

For these two points, the allowable HOE laminating tolerance was calculated from a viewpoint of the view angle shift and the resolution (Modulation Transfer Function, MTF). Calculations were made assuming that the view angle shift was 1.3 arc minutes or less and the allowable deterioration amount of the MTF is 5% at 5 line- pair per degree (lp / deg).

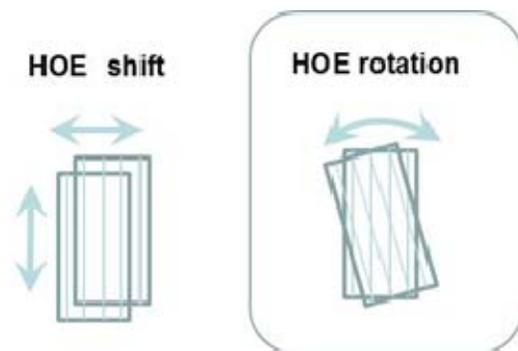


Figure 6. Variations of the HOE shift in a laminating process

At first, the simulation of the light ray tracing by vector analysis was performed to examine the influence on an image quality. The light rays were entered into the in-coupling HOE, and when the rotational misalignment of the in-coupling HOE occurred, the deviation of the light ray emitted from the out-coupling HOE was calculated. The view angle shift due to the rotation misalignment of the in-coupling HOE was recognized as a vertical image shift in subjective evaluation, and a horizontal image shift and a distortion occurred as the rotation deviation increased.

The allowable value of the view angle shift depended on the resolution of the display device and the field of view of the optical system.

Secondly, the simplified calculation of the laminating tolerance of the in-coupling HOE from a viewpoint of the MTF was carried out. As calculation conditions, the MTF function used a sine function, the image pattern was 5 lp / deg (which corresponded to a 12 arc minutes in the light ray angle), and the MTF degradation tolerance was 5%.

Consequently the tolerance was calculated to be about 50 arc seconds in both aspects. The tolerance was evenly distributed in the hologram exposure process of the in-coupling and out-

coupling HOE and laminating process of the in-coupling HOE. The process design was carried out with the alignment tolerance of ± 17 arc seconds.

3.2. Experimental results and Discussions

In the laminating process, the in-coupling and out-coupling HOE were accurately laminated to the plastic waveguide with alignment. The result of the view angle shift in laminating process is shown in Fig. 7. Red dots show the measurement value and a black line shows the calculated value. The view angle shift increased in proportion to the amount of rotational misalignment of the in-coupling HOE. Most of the measurement values fell within the tolerance of the calculated value. In a full color system, the red and blue color alignment was needed in addition to the in-coupling and out-coupling HOE.

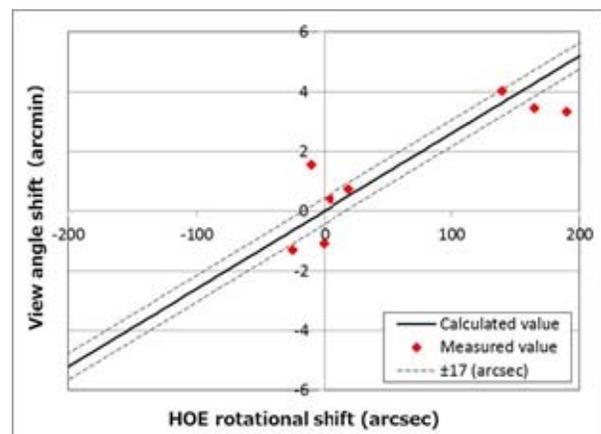


Figure 7. View angle shift in a laminating process

3.3. Image-quality evaluation

Figure 8 shows the MTF result of the green plastic holographic waveguide compared with that of a glass waveguide. The MTF value of the glass waveguide at each field of view is set to 100%. The horizontal MTF value of the green plastic waveguide was almost the same as that of the glass waveguide at a center field of view. The MTF values of the plastic waveguide at peripheral field of view showed a decrease of 5% or less as a relative value.

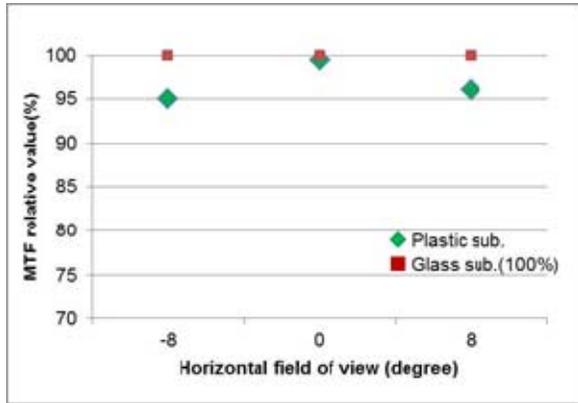


Figure 8. MTF result comparison of the plastic substrate to the glass substrate

4. Conclusions

We have developed a full color light-weight and highly-transparent see-through near-eye display using the plastic holographic waveguides combiner with novel R2R production process. We achieved optical characteristics including high MTF specification on our target. The strength of our development is the R2R process technology starting with precision molding technology of a plastic substrate, holographic exposure to the roll film, and accurate laminating the HOE to plastic waveguide without deforming the HOE. By using a plastic waveguide, the degree of freedom in design of eyewear has become very high. Furthermore, by improving mass productivity, we believe that device cost will decrease and contribute to the market expansion.

5. Acknowledgement

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