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Design and Fabrication of Bragg Gratings for Transparent Smart Surfaces

Design and fabrication of Bragg gratings for transparent smart surfaces

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Abstract: A concave mirror is designed and recorded as reflective Bragg gratings on transparent photopolymer layers, which can be laminated on glass surfaces to generate color images without ghost effect for compact augmented reality laser displays.

Keywords: Bragg grating, volume hologram, laser projector, augmented reality, transparent display, ghost image

1. Introduction

Transparent surfaces have been used as the combiner in numerous display applications for Augmented Reality (AR), e.g. smart glasses and Head-Up Display (HUD) [1]. One issue is the reflections from multiple surfaces of the glasses, leading to the ghost effect, as illustrated in Fig. 1, while another issue is the package size of the optical system required to magnify the image to provide a necessary Field of View (FoV). There is also a need to generate farther, multiple or variable virtual image planes for AR, leading to an even higher optical system package size.

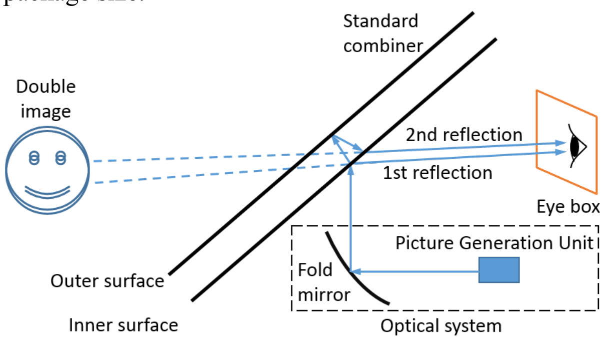

Fig. 1. Ghost effect in a virtual image display system.

Different approaches have been proposed to remove the ghost image, as well as to reduce the optical system package size. A wedge combiner can be fabricated to bring the reflections from the two surfaces closer together, at the constraints of manufacturing cost and precision, especially on a wide display area as in a windshield HUD [2]. A holographic waveguide system on a flat glass with multiple total internal reflections can be used to reduce the optical path inside the optical system, but there is still a need to magnify the image to provide the required FOV. In this paper, we report the use of a reflective Bragg grating which is designed and recorded as a concave mirror to remove the ghost effect and to reduce the package size.

2. Hologram design

Bragg grating or volume hologram is an optical element produced by holographic recording process, where a reference laser beam and an object beam interfere in a photo-sensitive material. The light intensity variation in the interference pattern results in a spatial modulation of the refractive index of the recording material. When re-illuminated using the reference laser beam, the recorded element functions as a phase modulation, and the object beam is reconstructed. We chose reflection holograms due to their incident angle and wavelength selectivity compared to transmission holograms [3]. In particular, reflection hologram has a wider and flatter angular selectivity, which helps provide a wider and more uniform eye box. On the other hand, reflection hologram has a narrower bandwidth which allows the remaining of the visible spectrum from the ambient to be transmitted to the viewer. Thanks to these benefits, a reflection hologram can be designed as a concave mirror and integrated on a combiner for AR, therefore reducing the size of the optical display device.

Fig. 2 illustrates our system design for a transparent display using a reflective volume hologram. As Bragg grating can diffract the illumination beam in a certain angle which does not follow the law of reflection, the reconstruction beam is separated from the glass surface reflections, results in a single image within the eye-box. The double image is not only out of sight, but also has lower intensity than the single image, as the Fresnel reflection at almost perpendicular incidence is about 4%, while the Bragg diffraction can be up to 100%. The single image is also bigger and farther than the double image, thanks to the concave mirror function recorded in the grating.

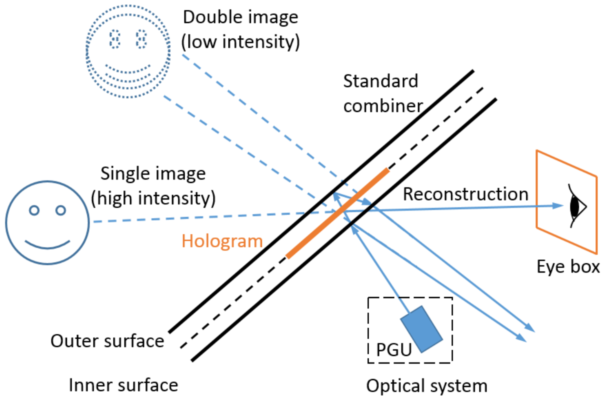

Fig. 2. Image separation using a reflection hologram.

3. Simulation verification

To display a two color image, two reflection Bragg gratings can be recorded at two laser wavelengths and

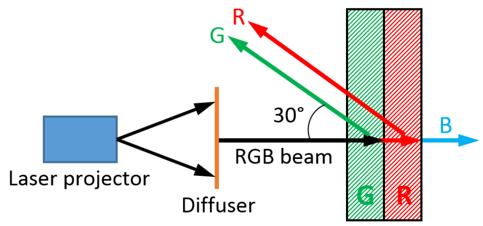

Fig. 3. Two layer structure for two color displays.

stacked on top of each other. Both holograms were recorded using a perpendicular reference beam and an object beam at 30° incident angle from the opposite direction. In the reconstruction, each hologram is highly reflective for its recording wavelength, while highly transparent for all other wavelengths. Therefore, an illumination beam consists of the two wavelengths will be reflected consecutively at the respective holograms, and a two color reconstruction beam can be observed at 30° angle, as illustrated in Fig. 3.

Computational results were obtained using the Rigorous Coupled Wave Analysis implemented by the commercial software VirtualLab [4]. The wavelengths used for the holographic recording were 532 nm and 633 nm, respectively. The photopolymers were 50 µm thick, with a refractive index of 1.46, while the index modulation was 0.03. The intensity of the laser beams, energy density and exposure time were set to 1 W/m², 0.5 J/m² and 1 sec, accordingly. Fig. 4 shows the performance of the combined reflective gratings with regard to variations in incident angle and wavelength.

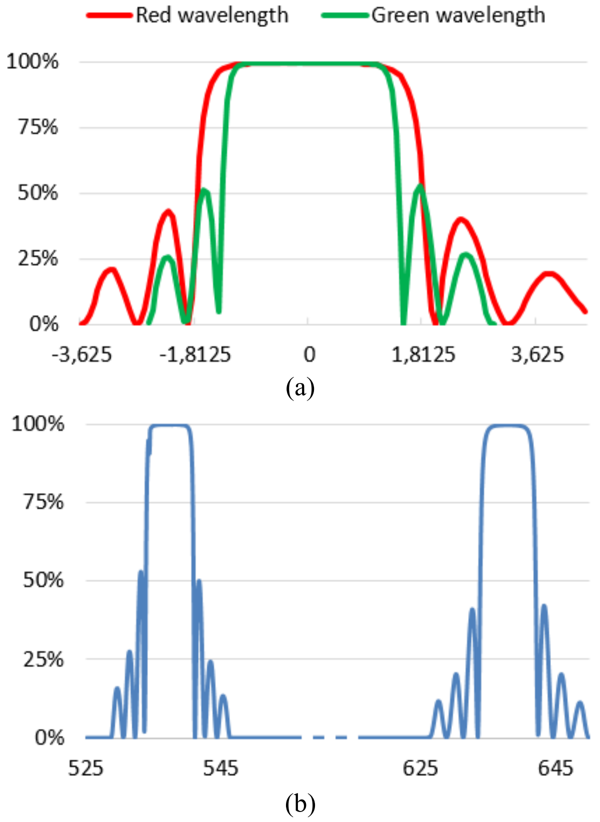

Fig. 4. (a) Angular and (b) Wavelength selectivity of the combined reflection holograms.

4. Experimental results

To evaluate the display system experimentally, we recorded the optical function of a spherical mirror into two holograms using Bayfol® HX200 photopolymers at red and green laser wavelengths. The recorded films were then laminated on flat glass surfaces using Liquid Optically Clear Adhesive and spatially aligned to match the reflections from the two colors. A laser scanning projector from MicroVision [5] was used to generate a real, full color image on a light shaping diffuser, which illuminates the combined reflection hologram structure at perpendicular direction.

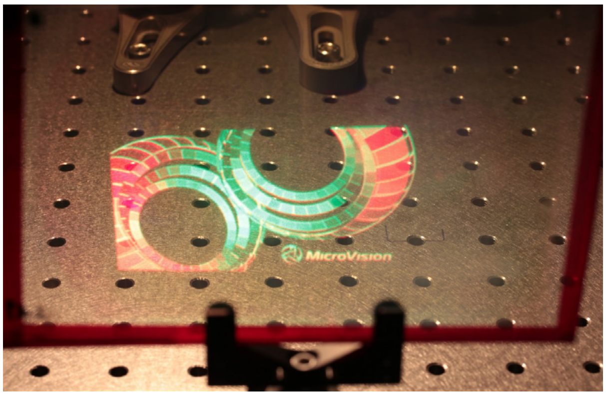

Fig. 5. A two color virtual image from the combined reflection hologram structure.

Fig. 5 shows the image observed at about 30° from the combined reflection holograms, consisting of two color red and green. The image reflection from the glass surfaces, i.e. the ghost image, can be observed only at perpendicular direction of the structure, hence separated from the two color virtual image. Moreover, this image is bigger and farther away from the structure surface than the ghost image, without the need of magnification optics, thanks to the optical power recorded in the holograms. The background information is also clearly visible through the combined reflection hologram surfaces, allowing AR content to be shown.

5. Conclusions

In summary, we have designed and recorded reflective holograms with spherical wavefront on transparent photopolymer layers, to generate two color images without ghost effect for compact augmented reality laser displays. Future work will focus on the recording of more complex optical function, for full color image and on a single photopolymer layer for easier alignment of the color channels.

6. References

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