Invited Paper

Low Cost Replicable Plastic HUD combiner element

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ABSTRACT

We present a novel technique to fabricate low cost mass replicable plastic HUDs for the transportation industry. HUD are implemented in numerous sectors today (in avionics, automobile, military, machinery,…). Typical implementations include an optical combiner which produces the desired virtual image while leaving the field mostly unaffected by the optics. Such combiners optics are usually implemented as cumbersome catadioptric devices in automobile, dichroic coated curved plates, or expensive volume holograms in commercial and military aviation.

We propose a novel way to design, model and fabricate combiner masters which can be replicated in mass by UV casting in plastic. We review the various design techniques required for such elements and the novel mastering technology.

Keywords: Head Up Display, Helmet Mounted Displays, Holography, Diffractive Optics, Plastic embossing.

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1. INTRODUCTION

The transportation industry is a heavy user of displays today. Avionics have usually introduced the technology which has been adapted afterwards to the automotive industry. This is the case for flat panel displays (CRTs, LCDs and more recently OLEDs) displays, which are now becoming standard features in cars for GPS and video display, and touch screen displays based on the same technology. This is also true for Head Up Displays (HUDs). HUDs have been introduced to avionics in the 1960s, and have been transferred to automotive in the early 1990s, first in police and other specialized vehicles, and today in higher class cars, such ash the Chevrolet Corvette; the Pontiac Grand Prix, in Mercedes, BMW and the Citroen C6. In most cases; the technology consists of an optical combiner and a display system incorporating imaging optics (see fig.1) [1].

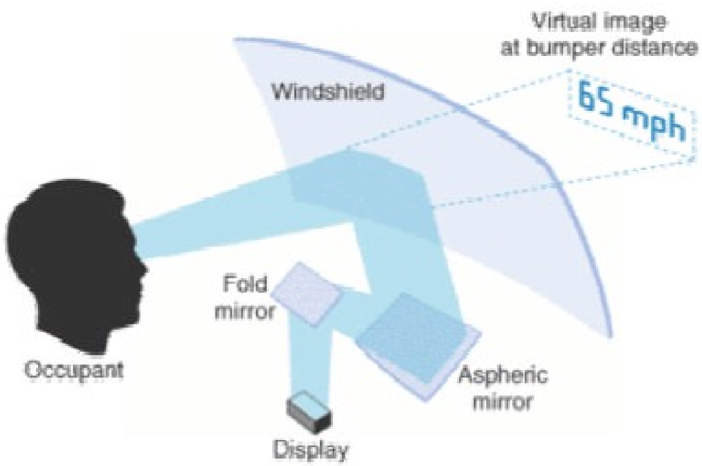


Fig.1: Conventional HUD architecture in automotive today.

The optical combiner is a key element in the HUD system. We review below the various combiners used today in the transportation industry.

2. HUD SYSTEMS AVAILABLE TODAY IN INDUSTRY

- HUD systems using holographic combiners

Holographic combiners are volume Bragg gratings which are acting as transparent plates for the incoming field and reflection or transparent holograms for the display to be superimposed on the field. Such elements can introduce imaging characteristics which are very desirable since the number of imaging optics can be reduced dramatically (footprint, weight, volume). In the case of reflection holograms, the Bragg planes are nearly parallel to the substrate, whereas in transmission holograms, the Bragg planes are more or less normal to the substrate. Holographic combiners have been introduced very early, for military avionics applications. HUDs based on volume hologram combiners are very performant and relatively small, but have a short lifetime due to the deterioration of the organic polymer composing the holographic media (Dichromated Gelatin –DCG-, Silver Halides, Photopolymers, …), under UV, humidity and high temperature exposure. Furthermore, most holograms are not perfectly transparent to the field, and therefore create a darkened field area which can be dangerous for the driver during night operation.

- HUD systems using curved dichroic combiners

Dichroic combiners are made of several thin films which act as a mirror for a specific illumination angle and color (the HUD display), and as a transparent substrate for other angles (i.e. the field). When curving the dichroic substrate, one can introduce a diverging lens functionality which will produce in the driver's field of view a virtual image floating in front of the vehicle. Such combiners can be made of plastic [2] and can thus be replicated with relatively low costs by plastic molding followed by a thin film coating. However, such combiners need to have a non planar surface in order to implement optical imaging; which is in most cases not desirable, especially in automotive applications. Similarly to holographic combiners, dichroic combiners are not completely transparent, tend to have a color hue and thus darken the field.

- HUD systems using catadioptric optics and windshield combiners

Using the windshield as the natural combiner element seems to be the most straightforward way to implement an HUD in the automobile industry. However, this configuration poses several problems. First, the windshield has to be relatively reflective on its first surface to produce enough brightness in the image when viewed in sunlight. Second, parasitic reflections from the outer surface of the windshield (or from intermediate surfaces) should be reduced to avoid ghosts. Third, the curvature of the windshield (different from car to car) has to be compensated in the design of the large catadioptric reflective mirrors used to produce the virtual image (usually buried within the dashboard). Fourth, a large amount of space is used to produce the relay optics in the dashboard to produce the desired image. Nonetheless, this technique is now implemented in many high end cars on the market (Corvette, etc…).

- Other HUD systems.

Other combiner technologies have been proposed in order to alleviate the problems encountered with the previous three technologies. These include projecting an infrared image onto a doped windshield which would in turn produce a fluorescent image [3] to the driver. However, this image will be located in the windshield, not in front of it. Another technique consists of using a laser scanner a projecting a wire framed or pixelated image in full RGB colors in the far field, by using a flat combiner [4], or by using a dynamic holographic projector to project an image in the far field [5].

3. REQUIREMENTS FOR HUD IN AUTOMOBILE

In order to define a better way to design an optical combiner for HUD applications, let us review the various requirements [6] for HUD combiners:

a) - an HUD combiner for automotive has to integrate both the combining and imaging functionalities (no large optics hidden in the dashboard)
b) - an HUD combiner for automotive has to be cheap, and mass replicable.
c) - an HUD combiner for automotive has to be transparent to the field (neither darkening nor coloring the field)
d) - an HUD combiner for automotive has to be safe, therefore should be made of plastic instead of glass.
e) - an HUD combiner for automotive should be as small as possible, and integrate all the functionalities in the substrate (potentially also the display generation).

4. DIGITAL DIFFRACTIVE COMBINER SOLUTION

In order to address the various requirements described in the previous section, we propose to use a plastic diffractive combiner replicable in mass by UV embossing. Our first architecture works in transmission with an LED or laser pico-projector (see fig.2).

- Full color is achieved by time sequencing the three colors generated by three lasers (or LEDs) and a single microdisplay.

- Optical power is achieved by the introduction of an off-axis Diffractive Fresnel lens phase profile [7],[8] which is optimized for the off-axis illumination scheme described in fig.2.

- Diffraction of the three wavelengths is achieved by the use of Harmonic (or multi-order) diffractive structures, a technique that has been developed originally for hybrid optics [9] [11].

- High overall diffraction efficiency through effective analog surface relief elements is achieved by binary sub-wavelength grating carriers [8], which implement an effective refractive medium (EMT: Effective Medium Theory) [10], [12], [13]. Therefore, although the structures constituting the element are sub-wavelength, the resulting diffracted angles remain small (several degrees).

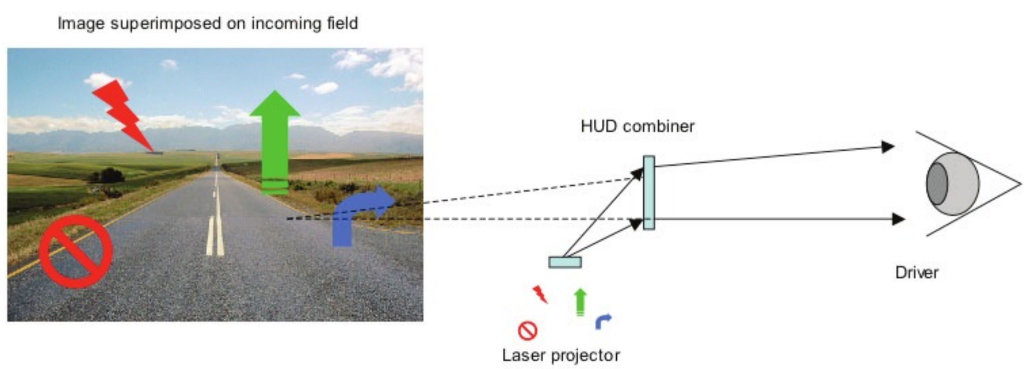


Fig.2: Digital diffractive HUD combiner architecture

5. DESIGN OF THE DIGITAL DIFFRACTIVE COMBINER ELEMENT

The basis of our HUD combiner architecture resides in the way it discriminate between the diffraction efficiency at one (or several) specific wavelengths for a fixed angle (the projected image onto the combiner), and the diffraction efficiency of the wide spectrum incoming field (which is relatively normal to the combiner). In an ideal case, the first should be maximal and the latter minimal. This can be achieved by slanting the sub-wavelength gratings into a direction that produces the highest efficiency for the laser illumination and the lowest efficiency for the incoming field.

We are thus triggering the effects of volume hologram Bragg gratings (spectral and angular bandwidths in the various Bragg regimes) with a thin diffractive element with tilted sub wavelength structures.

The whole gamut of optical design techniques are used for our digital element (see Fig.3), beginning with ray tracing in a conventional optical design program to compute the aspheric phase profile, to fringe generation and broadband diffraction operation through scalar diffraction theory to rigorous electromagnetic methods through the effective medium theory (EMT).

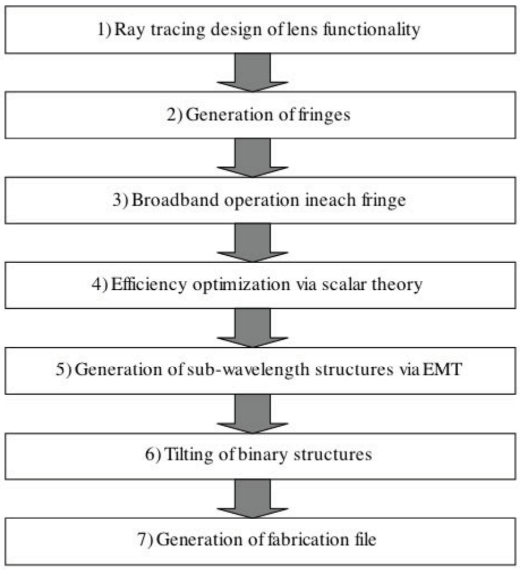


Fig.3: Flow chart of the design process for our digital diffractive combiner.

7. FABRICATION TECHNIQUES USED TO PRODUCE THE COMBINER MASTER

a) Conventional mastering techniques

Conventional fabrication of microstructures that can yield high efficiency such as multilevel surface relief elements [14] [15] can be performed by optical lithography using several successive masking layers (see fig. 4).

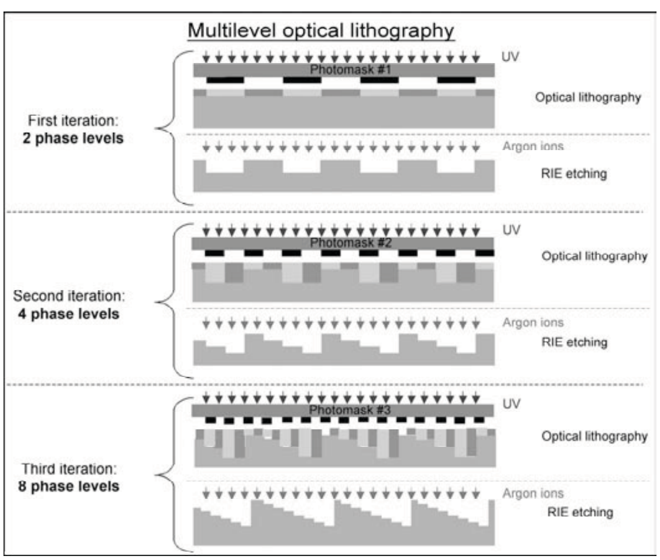


Fig.4: Conventional fabrication technology

b) Optimized techniques for slanted gratings

In order to produce more complex structures required to produce the diffraction efficiency selections from wavelength and angle, we propose to use a fringe writing technology linked to a fringe locking scheme as depicted in Fig. 5.

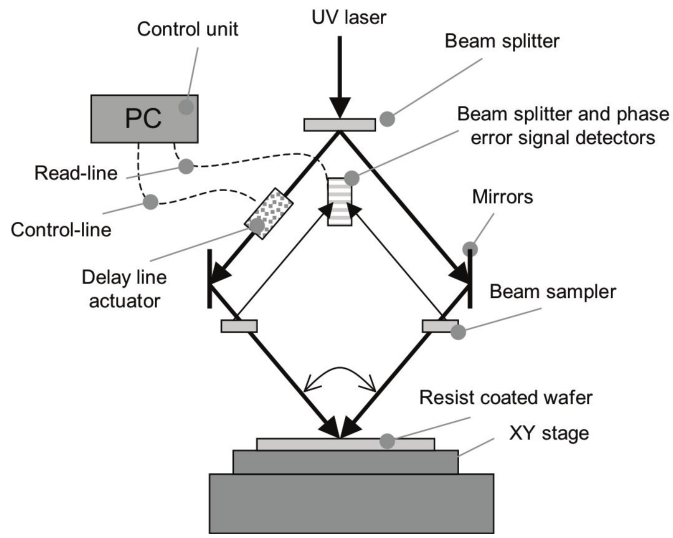


Fig.5: Direct holographic write in thick resist with a fringe locker

Such a fringe write can produce slanted gratings and other type of structures which cannot be produced by traditional lithography methods.

8. REPLICATION TECHNIQUES TO MASS PRODUCE THE COMBINER

The replication of our diffractive combiners will be performed in plastic sheets by UV embossing or roll embossing (see fig.6), or even with nano-imprint techniques [16].

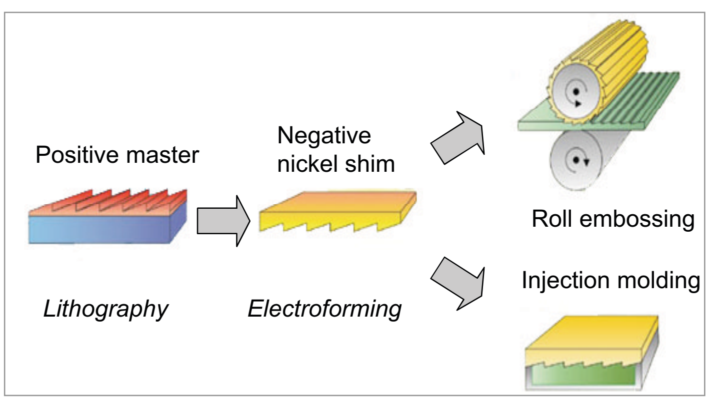


Fig. 6 Mass replication of diffractive structures using embossing or injection molding

9. FIRST EXPERIMENTAL RESULTS

We have fabricated the first generation of digital diffractive combiners in a quartz substrate. The combiner is shown in Fig.7 as well as the surface topology of test structures implementing the EMT effective index.

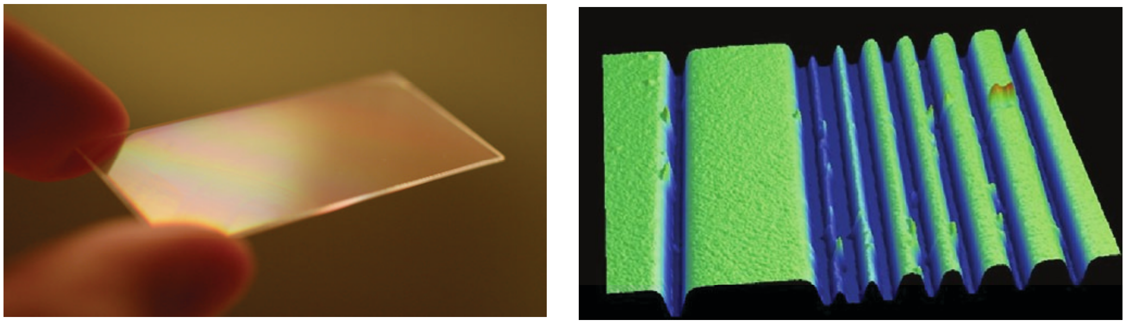
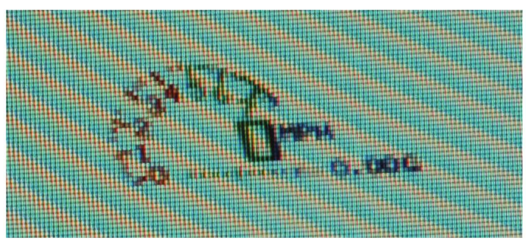
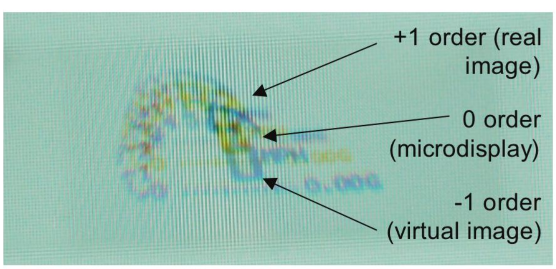


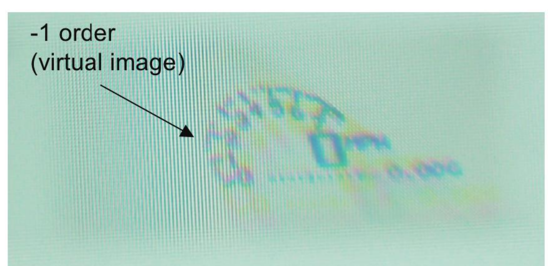
Fig. 7: First generation digital diffractive combiner and surface topology of test structures implementing the EMT effective index.

Fig. 8 shows the first optical experiments with this combiner on an LCD display in transmission. The original object (image on the microdisplay) is shown on the top part. The focus is set on the microdisplay color pixels. We show here the results through two off-axis diffractive combiner lenses, one with standard binary structures, and the other with subwavelength EMT structures. The digital combiner on the lower left side has been lithographically patterned as a conventional binary off-axis diffractive lens, thus yielding two conjugate orders, carrying both the virtual and real images generated by the microdisplay.



Original object on HUD microdisplay (focus is on the color microdisplay pixels)





Binary lens without standard structures

Binary lens with sub-wavelength EMT structures

Fig. 8. First optical tests on digital binary combiners

The digital combiner on the lower right side has been fabricated with binary vertical sub-wavelength EMT structures, this yielding only one diffraction order, carrying the virtual image of the microdisplay. The microdisplay used was here a simple color LCD screen, thus showing that such combiners (both in conventional and EMT modes) can produce decent images with sources that have neither temporal nor spatial coherence. However, for better efficiency and a sharper image, a laser pico-projector will be used.

10. CONCLUSION

We have proposed a novel way to design and fabricate a planar digital HUD combiner that can be replicated in mass by plastic embossing. The digital combiner mimics the traditional angular bandwidth of thick volume Bragg holograms with thin plastic sub-wavelength tilted binary structures. First prototypes have been using EMT theory and conventional lithography. Next prototypes will be fabricated as slanted structures by a fringe writer with phase locking capabilities.

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