# A Forgettable Near Eye Display

Ichiro Kasai, Yasushi Tanijiri, Takeshi Endo and Hiroaki Ueda
*Optics Technology Division, Minolta Co., Ltd.*
*ueda@optec.minolta.co.jp*

## Abstract

*This paper describes a very light wearable display so light that you can forget that you are actually wearing it. It is a virtual image display device consists of a prism with two total internal reflection surfaces and a holographic optical element. The sophisticated display is only 3.4mm thick, weighs 25grams, and has high transparency, providing comfort to wear all day long. Also, its size and weight is small enough to be put on cellular phones. Optical design and experimental results are described.*

Keywords: holographic optical element, see-through, wearable display, total internal reflection

## 1. Introduction

Many see-through type head mounted displays (HMDs) have been reported. One type of see-through HMDs uses a half mirror to combine displayed virtual images and real image from the scene in front of a viewer [1]. This type with a half mirror not only reduces brightness of both virtual and real image by half but also requires large optical path to combine two images. Another see-through type display uses a prism that has asymmetrical or a free-form surface(s). Optics used in this type has negligible brightness loss because the prism makes use of internal total reflection [2]. However, 17mm of thickness still remains. An eyeglass display proposed by MicroOptical Co. [3] has aesthetic figure and remarkably thin compared to the two types of displays described above, but it has still 6mm thick. The half-mirror-combiner placed just in front of the pupil is also bothersome for observers' fovea. Displays with Maxwellian optics are also reported [4]. Displays with Maxwellian optics must be illuminated by a point source such as lasers to reduce image blur. Also the light source and the exit pupil must be conjugates. Thus, the exit pupil will essentially have no area. In other words, because the resolution defined by the aperture of the display device is inversely proportional to the size of the display, this optics cannot provide a good enough resolution.

Display types discussed above provide different solutions for wearable display, but our goal goes further to negligible display that is wearable all day long. We say "are you going dotty?" when we look for our glasses when we are actually wearing it. Our goal is to realize this laughing matter; we aim for not just a glass-type or glass-like display but rather the display embedded in glasses and its existence is negligible.

## 2. Optical design

The optical design is very simple as shown in Fig.1. A liquid crystal display panel (LCD) is illuminated by a light emitting diode (LED) through a condenser lens. The beam from the LCD refracts into prism from surface A. Next, the beam undergoes total internal reflection by surface B followed by total internal reflection by surface C followed by total internal reflection again by surface B. Finally the beam reaches holographic optical element (HOE) to be diffracted and guided to the exit pupil through the prism surface B. The angle of the surfaces are designed so that the beam makes total internal reflection from surface A to HOE and exits the prism after being diffracted by HOE. This reflection hologram selects particular wavelength, reflects the beam at desired angle, and also work as an eyepiece to magnify the virtual image. Also notice that the HOE has a slant angle to the optical axis as shown in Fig.1. In this configuration, axially symmetric power will not cancel aberration such as distortion. Thus, the HOE must possess asymmetrical power to cancel distortion caused by this de-centered optics.

HOE has wavelength selectivity [5] depending on its thickness, difference of the refractive index between the gratings, and incident angle. HOE generally has sharp wavelength selectivity for large incident angle. When the wavelength of the LED matches the selected wavelength of HOE, the display will consequently have high efficiency. Horizontal and vertical field of view (FOV) is 27 degrees and 10 degrees respectively, and horizontal resolution is more than 320 dots when the thickness of the optics is only 3.4mm. Exit pupil is 3mm diagonal. Thickness can be reduced to 2mm if we reduce the vertical FOV to 7 degrees. Internal reflecting mirror instead of total internal reflection surfaces will not be an alternative because we want to keep the thickness minimum. Half mirror with coating will not be an alternative for see-through display as discussed before.

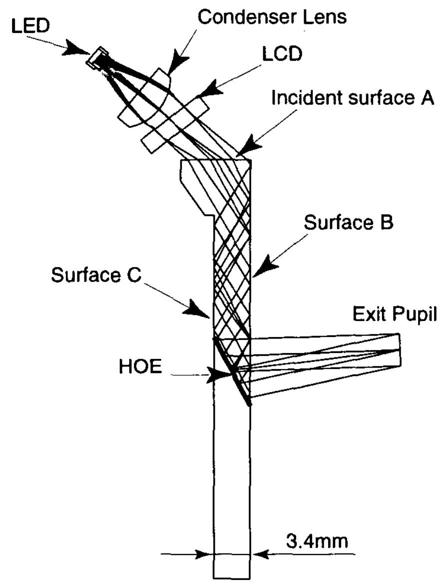


**Fig.1 Optical layout of forgettable display (cross section)**

## 3. Holographic Optical Element

Reflection hologram is fabricated by exposing two wave fronts opposite to each other as shown in Fig.2. The HOE in Fig.2 has too large of an incident angle to reconstruct with sufficient resolution even with the vertical FOV less than 10 degrees. We designed a prism with total internal reflection and a null-lens to reduce the incident angle and to compensate aberrations. The null lens is composed of several lenses that are arranged in off axis layout. The HOE is exposed by wave fronts that comes through a spatial filter and the null lens; object beam; and the other from another spatial filter that is located at the conjugate of the exit pupil; reference beam. The exposed HOE therefore has equivalent optical power to an asymmetrical surface.

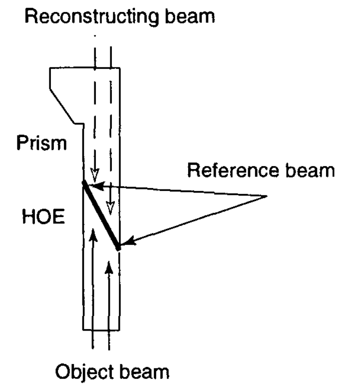


**Fig.2 Schematic layout for HOE recording**

Computer-generated hologram (CGH) can replace the null lens to generate a wave front. Transmission CGH can simply replace the null lens, however the CGH must be designed so that the zeroth order beam does not reach the hologram material. The hologram can be made by only one light source when reflection CGH adhered or placed very close to the hologram material diffracts the reference beam that come through the material to be the object beam. We have simulated the CGH but not exposed a hologram.

As we mentioned above, volume holograms have wavelength selectivity that depends on the incident angle, refractive index, and thickness of medium. The intensity of the reconstructed beam from the hologram decreases in proportional to the difference between the incident angle of the illuminating beam and Bragg condition. Thus, if a volume hologram is illuminated at a given angle, only one wavelength satisfies the Bragg condition and appears as a brightly reflected beam. Equation 1 shows the half bandwidth at which the reflected wave is completely extinguished. [5]

$$\Delta\lambda = \frac{\lambda_o^2}{(1+\cos\theta_r)nT} \quad (1)$$

The bandwidth was roughly found to be 11nm when the original wavelength is 532nm, the refractive index n and the thickness T of the hologram are 1.4 and 20 microns respectively, and the incident angle is 40 degrees. This wavelength selectivity means the beam is not diffracted except for the selected wavelength. Thus, most light comes from real objects in front of the observer sees the hologram transparent, therefore, the hologram is "negligible" when there is nothing on LCD.

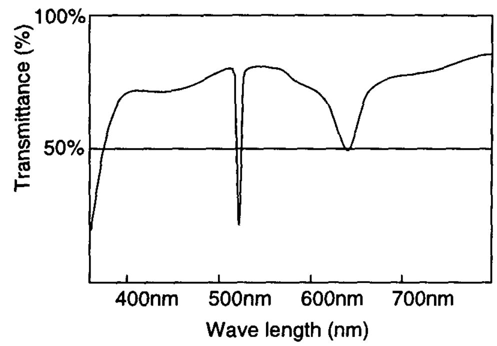


**Fig.4 Transmission spectrum of the HOE**

## 4. Experiments

Hologram material is adhered on the slant surface of the prism. The HOE is exposed by YVO4-SHG laser (532nm) as shown in Fig.3 (for monochromatic display). Fig.4 shows the transmission spectrum when the incident angle is perpendicular to the prism. The half band width at green spectrum well matches to the estimation by the equation 1. Needless absorption still remains because material has not been optimized, however sharp efficiency is observed at green.

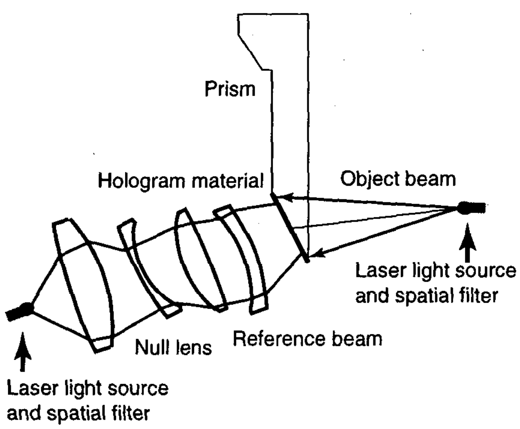


**Fig.3 Optical layout for HOE recording**

Fig.5 shows the display unit consists of an LCD, an LED, a prism and an HOE. The display unit is assembled with an acrylic plate having a hollow corresponds to the prism and the assembly becomes an oval plate as shown in Fig.6. The LCD panel is 0.25 inches in diagonal and the illumination source is a green LED. Total weight is only 25g excluding cables. The essential block shown in Fig 5. with an LCD and an LED attached on the glasses weigh only 5.5 grams. Materials of the prism and glasses are acrylic. Glasses are around 15 square centimeters each and that means the glasses are around 3 grams per 1mm thick.

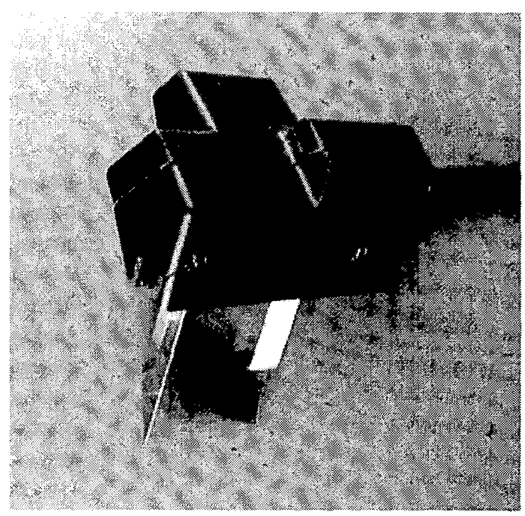

**Fig.5 Display unit**

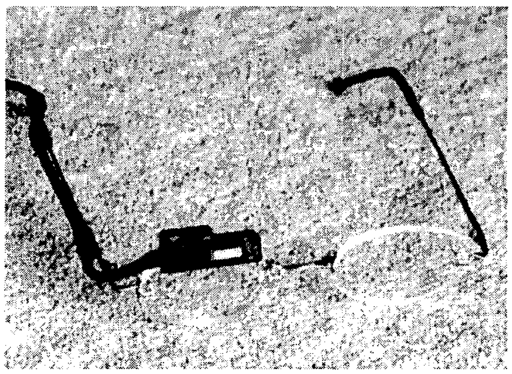

**Fig.6 Forgettable near eye display**

**Fig.7 See-through image**

Fig. 7 shows how we can see-through the forggetable display. Notice that only slight edge can be seen at the center of the glass. Transparency is almost constant. No noise, no diffracted or reflected image from LCD is observed from outside. The observer can not see the HOE nor the edge of the prism.

Fig. 8 shows another application for cellular phones. Only the prism is shown on the flipper of the phone. The LED and the LCD should be integrated in the body. The display unit shown in Fig.5 weighs only 5.5 grams and its projected size is five square cm. This is an affordable increase in size and weight for cellular phones.

Although this experiments was done with green monochromatic display, however full color display is possible if we expose the HOE by three primary color lasers and by illuminating it with three LEDs at corresponding wavelengths.

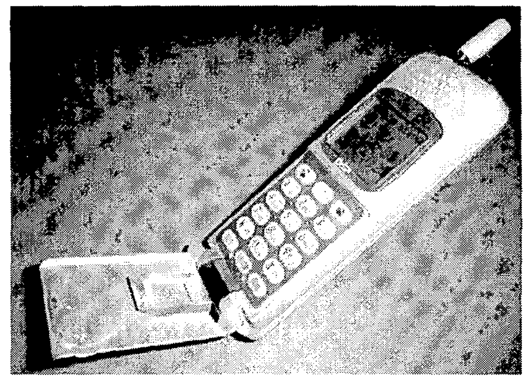

**Fig.8 Cellar phone application**

## 5. Conclusion

We were successful of making a "forgettable-near-eye-display" using a total internal reflection prism and an HOE with clever optical layout. This display is much lighter and much thinner than ever and has perfect transparency for observers.

## 6. References


[1] Y. Ohta and H. Tamura, Mixed Reality, pp. 31-40, Ohmsya, Tokyo, Japan, 1999

[2] S.Yamazaki, K. Inoghchi, Y. Saito, H. Morishima and N. Taniguchi, "Thin wide-field-of-view HMD with free-form-surface prism and applications", SPIE Proc., Vol. 3639, pp. 453-462, 1999

[3]. M. B. Spitzer, P.D. Aquilino, R.W. McClelland and N.M. Rensing, "Toward eyeglasses-based electronic displays", SPIE Proc., Vol. 3058, pp. 178-182, 1997

[4] T. Ando, K. Yamasaki, M. Okamoto, T. Matsumoto and E. Shimizu, "Evaluation of HOE for head-mounted display", SPIE Proc., Vol. 3637, pp.110-118, 1999

[5] H. Ueda, E. Shimizu and T. Kubota, "Image blur of edge-illuminated holograms", Optical Engineering, Vol. 37 No. 1, pp. 241-246, 1998