Hybrid Optical Elements for Dual-Focus Pickup

Der-Chin Su, Jen-Tsorng Chang and Yang-Tung Huang,

a Institute of Electro-Optical Engineering,
b Department of Electronics Engineering and Institute of Electronics,
National Chiao Tung University, 1001 Ta-Hsueh Rd., Hsinchu 30050, Taiwan, R.O.C

ABSTRACT

Two hybrid optical elements are presented for dual-focus pickup in the digital versatile disk (DVD) system. One is a hybrid dual-focus lens and the other is a holographic regional mirror. The optical head consisting of these two hybrid optical elements can read the information recorded on two layers of DVD simultaneously. Its specifications are described. The fabrication parameters of these two hybrid optical elements are derived.

Keywords: Dual focus, optical pickup, digital versatile disk, holographic optical element, volume hologram.

1. INTRODUCTION

Because the digital versatile disk (DVD) has a large storage capacity and can be used as a multipurpose storage, it becomes a high potential product. In general, there are two layers on DVD. In order to pick up the information recorded on two layers, its optical pickup head should have the performance of dual focus. Although some types of dual focus optical pickup heads were proposed, they need an additional controlled micro-machine or an aspheric lens with holographic optical elements. It is not easy to introduce a micro-machine in a limited space or to fabricate an aspheric lens and align it with other holographic optical elements. In this presentation, two hybrid optical elements for dual-focus pickup are presented. One is a hybrid dual-focus lens and the other is a holographic regional mirror. The pickup consisting of these two hybrid optical elements can read the information on two layers of DVD simultaneously. The hybrid optical elements can be easily fabricated by the technique of shorter-wavelength construction for longer-wavelength reconstruction, and are suitable for mass-production to reduce the cost. In addition, it is easy to assemble them. The specifications of this new type of dual-focus optical pickup head are described, and the fabrication parameters for these two hybrid optical elements are derived and summarized in tables for clearness.

2. THE ARCHITECTURE OF THE DUAL-FOCUS OPTICAL PICKUP HEAD

Fig. 1 The architecture of this new type of the dual-focus pickup head.
The architecture of this new type of dual-focus optical pickup head consisting of these two hybrid optical elements is shown in Fig. 1. A linearly, vertically polarized light (i.e., s-polarization) coming from a laser diode LD is collimated by a collimating lens CL, and is reflected with nearly 100% reflectance by a polarization beam-splitter PBS. Next, the light is circularly polarized after the quarter-wave plate Q, and is divided into two parts by a hybrid dual-focus lens HDL: the inner part and the outer part. They are focused on the upper and lower layers of DVD, respectively. Consequently, the reflected lights with the information propagate along their original paths and pass through the corresponding regions of HDL as they passed before. And they are re-collimated and become linearly horizontal by polarized lights (i.e., p-polarization) after their second passage through HDL and Q. Then they pass through PBS directly with nearly 100% transmittance and arrive the holographic regional mirror HRM. HRM consists of two different holographic mirrors: the inner holographic mirror HM_{i} and the outer holographic mirror HM_{o}. They have the same optical axis and Bragg angle, but have different diffraction angles. HM_{i} and HM_{o} will diffract the lights coming from the upper and lower layers to detectors D_{1} and D_{2}, respectively, and the information recorded on two layers is read simultaneously.

3. HYBRID OPTICAL ELEMENTS

(a) HYBRID DUAL-FOCUS LENS

![Fig. 2 The configuration and performance of the hybrid dual-focus lens.](image)

The configuration of this hybrid dual-focus lens HDL is depicted in Fig. 2. It consists of two plano-convex lenses and a small holographic lens HL, which is cemented between the plane surfaces of these two plano-convex lenses with the same optical axis as shown in Fig. 2(b). Its two focal lengths of HDL for the upper and the lower layers are \( f_{i} \) and \( f_{o} \), and the focal lengths of these two plano-convex lenses are \( f_{1} \) and \( f_{2} \), respectively. To meet with the requirements for reading the information recorded on two layers simultaneously, the thickness \( d \) of a layer should be equal to the difference between \( f_{i} \) and \( f_{o} \). Then the focal length \( f_{h} \) of HL should be satisfied the following equations:

\[
\frac{1}{f_{d}} = \frac{1}{f_{1}} + \frac{1}{f_{2}} + \frac{1}{f_{h}}.
\]
and

\[
\frac{1}{f_u} = \frac{1}{f_1} + \frac{1}{f_2}.
\]  

(2)

From Eqs. (1) and (2), and the relation \(d = f_u - f_d\), we have

\[
f_h = \frac{f_u f_d}{d}.
\]

(3)

The diffraction properties of HL depend on the geometries of recording and reconstruction. The relevant coordinates \(R_{q_i}, \beta_{q_i}\) are the positions of the point sources; where \(R_{q_i} (q = o, r, c, i)\) are the distances from the point sources of (object, reference, reconstruction, image) to the center of hologram. The necessary conditions for an efficient, aberration-free holographic lens are given as

\[
\frac{1}{R_o} = a \frac{1}{R_i} + b \frac{1}{R_c}, \\
\frac{1}{R_r} = a \frac{1}{R_c} + b \frac{1}{R_i},
\]

(4)

and

\[
\sin \beta_o = a \sin \beta_i + b \sin \beta_c, \\
\sin \beta_r = a \sin \beta_c + b \sin \beta_i,
\]

(5)

where \(a = [(\mu + 1)/2 \mu] + \Delta, b = [(\mu - 1)/2 \mu] + \Delta, \Delta = [(\mu^3 - 1)\sin^3 \beta_i/(16n^2 \mu^3)] + [(\sin^4 \beta_i)/(32n^4)]\), \(\mu\) is the ratio between the reconstruction and recording wavelengths, and \(n\) is the refractive index of the recording material. Among these parameters, \(\lambda_o, R_i, R_c, \beta_i, \beta_c, f_h\) and \(f_1\) can be obtained from the specifications of the optical pickup head, the fabrication parameters of HL can be derived with Eqs. (4) and (5).

Next, the radius \(r_h\) and the diffraction efficiency \(\eta\) of HL should be considered. Because the incident light has a Gaussian distribution as shown in Fig. 2, its normalized intensity profile can be expressed in polar coordinates as follows:

\[
U(r) = \exp\{-2 h^2 r^2\},
\]

(6)

where \(h\) is a Gaussian truncation coefficient. The light intensities being incident on the upper and lower layers are

\[
I_u = \eta U(r_h),
\]

(7)

and

\[
I_d = U(r_p) - U(r_h),
\]

(8)

respectively; where \(r_p\) is the radius of the plano-convex lens. If the reflectances of the upper and lower layers are \(R_u\) and \(R_d\), then the light intensities of \(I_u\) and \(I_d\) will become \(I_u'\) and \(I_d'\), respectively, after the second passage through HDL. And \(I_u'\) and \(I_d'\) can be written as

\[
I_u' = \eta^2 U(r_h) R_u.
\]

(9)
and

\[ I_d' = [U(r) - U(r_h)] R_d. \]  \hfill (10)

For good signal qualities, the relation \( I_u' = I_d' \) should be satisfied, that is,

\[ \eta^2 U(r_h) R_u = [U(r) - U(r_h)] R_d. \]  \hfill (11)

(b) **HOLOGRAPHIC REGIONAL MIRROR**

![Diagram of holographic regional mirror](image)

**Fig. 3** The configuration and performance of the holographic regional mirror.

The configuration and performance of the holographic regional mirror HRM are shown in Fig 3. It consists of the inner holographic mirror HM\(_i\) and the outer holographic mirror HM\(_o\), which diffract the reflected light coming from the upper and the lower layers to detectors D\(_1\) and D\(_2\), respectively. HM\(_i\) and HM\(_o\) have the collimated reconstruction lights at the same optical axis and Bragg angle \( \theta_B = 45^\circ \), but have different diffraction angles. And their fabrication parameters can be obtained similarly with Eqs. (4) and (5).

4. **SPECIFICATIONS AND FABRICATION**

To get compatible with common DVD systems, the specifications of this new type of dual-focus optical pickup head are carefully chosen and summarized in Table. 1. The holographic lens and the holographic regional mirror can be fabricated with the shorter recording technique of shorter-wavelength construction for longer-wavelength reconstruction. In our experiments, they are fabricated with self-made dichromated gelatin (DCG) and a He-Cd laser of wavelength 441.6 nm.
Under these conditions and above specifications, their fabrication parameters can be calculated based on above Eqs. (1)-(11), and are summarized in Table 2.

5. DISCUSSION

The diffraction efficiencies of the holographic lens and the holographic regional mirror depend on the exposure energy. Before we fabricated them, their corresponding diffraction efficiency versus exposure energy were measured. According to the results, the optional exposure energy can be chosen for the desired diffraction efficiencies. If these elements are fabricated with photoresist, then the hologram copying technique can be used for mass-production and reduce the cost.

6. CONCLUSION

Two hybrid optical elements for dual-focus optical pickup head in the digital versatile disk system are presented. This pickup head can read the information on two layers of DVD simultaneously. The specifications of this new type pickup are so chosen carefully that it can be compatible with the common DVD systems. The fabrication parameters of the holographic lens and the holographic regional mirror are derived, and they are fabricated.

ACKNOWLEDGMENT

This study was supported in part by the National Science Council, R.O.C., under contract number NSC86-2215-E-009-007.

REFERENCES

<table>
<thead>
<tr>
<th></th>
<th>H D L</th>
<th>NA=0.6</th>
<th>λr=635nm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>f_u = 5.6mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>f_d = 5mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>f_h = 46.7mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>A = 7.5mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>h = 1mm^-1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>r_p = 3.5mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>r_h = 0.7976mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R_u = 0.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R_d = 0.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ΔD = 3.6mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L_y = 20mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>d_1 = 20mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>d_2 = 20.7mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>r_i = 0.78mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>r_0 = 3.5mm</td>
<td></td>
</tr>
</tbody>
</table>

Table. 1 Specifications of this new type of hybrid dual-focus optical pickup head.

<table>
<thead>
<tr>
<th>(mm)</th>
<th>R_i (635nm)</th>
<th>R_r (635nm)</th>
<th>R_c (441.6nm)</th>
<th>R_o (441.6nm)</th>
<th>β_i (635nm)</th>
<th>β_r (635nm)</th>
<th>β_c (441.6nm)</th>
<th>β_o (441.6nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHL</td>
<td>46.7</td>
<td>∞</td>
<td>55</td>
<td>306</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HM_o</td>
<td>20</td>
<td>∞</td>
<td>125</td>
<td>23.81</td>
<td>30°</td>
<td>45°</td>
<td>42.3°</td>
<td>32°</td>
</tr>
<tr>
<td>HM_i</td>
<td>20.6</td>
<td>∞</td>
<td>129.4</td>
<td>24.64</td>
<td>40°</td>
<td>45°</td>
<td>44°</td>
<td>40.8°</td>
</tr>
</tbody>
</table>

Tab. 2 Fabrication parameters of the holographic lens and the holographic regional mirrors.