A new kind of compatible compact optical picking-up head with two laser waves

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With the advent of HDTV, the high density DVD (HD DVD) and blue-ray disk (BD) series will become the mainstream. Compared with BD, HD DVD has lower producing cost and sailing price, and it can be compatible with DVD. We design a new kind of compact optical picking-up head (PUH) based on HD DVD technology. It is simple in structure and small in size. It has two laser waves, and can be compatible with DVD downward. The PUH is mainly composed of a penta prism, a collimating lens, and an objective lens. The light route is analyzed using ZEMAX, and the results turn out to be successful. The penta prism is used to achieve a much longer optical path, so that the PUH size is reduced.

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In the information era, we need highly advanced information storage technology. With the advent of more and more sophisticated digital consuming products and high-definition TV, the next generation disk storage technology of high density DVD (HD DVD) and blue-ray disk (BD) series that have higher storage volume will become the mainstream[1]. Compared with BD, HD DVD has more advantages. It uses an objective lens of numerical aperture (NA) of 0.65, and the depth of the protective layer of the disk is 0.6 mm. So, it can be compatible with the existing DVD technology easily, and the producing cost and sailing price is much lower. This is very important in the competition of marketing.

Because a single sided single layered HD DVD disk has a content of 15G, it is quite important to enhance the reading speed of the picking-up head (PUH). One method of improving the speed is to reduce the weight and size of the PUH, and then it can reduce the inertia to make the PUH focusing and finding the track faster. It is required that a HD DVD system can be compatible with a DVD system downwardly. So a structure that uses two laser diodes (LDs) is necessary, which can give out blue ray of 405 nm and red ray of 650 nm respectively.

A common structure of a HD DVD system is given in Fig. 1. It uses a blue ray LD, and the laser first passes through a beam splitter (BS), a collimating lens (CL), a reflective mirror(RM), an objective lens (OL), then it reaches the HD DVD disk and is reflected by the disk. And then the laser passes back through the OL, the RM, the CL, the BS. Finally it is received by a photodetector (PD). The whole system has too many optical elements, and each element need some space. So the PUH system has a big size and a loose structure, which will delay the tracking and focusing servo time. Furthermore, the PUH system is fairly strict to the laser beam quality and optical aberration. So each element is needed to be calibrated precisely to make sure that no extra aberration is produced, which increases the technical difficulty.

In this paper we design a new kind of compact optical PUH based on HD DVD technology. It is simple in structure and small in size. It has two laser waves, and can be compatible with DVD downwardly. In the PUH we use a special element in the shape of a penta prism to make the optical path shorter and make the PUH size smaller.

In order to realize the reading and writing of HD DVD and DVD compatibly, we will use LDs with two different wavelengths: 405 and 650 nm. The LDs work separately and do not interrupt each other. Figure 2 gives the illustration of the structure of the picking-up system. It includes a main optical path that is used by two laser beams together. Along the light path, there is a BS, a penta prism, a collimator, an OL sequentially. And then the light is focused on the optical disk. So, the recording layer should be just in the focal plane of the objective lens. After the light reflected by the recording layer, it will travel through the original path reversely.

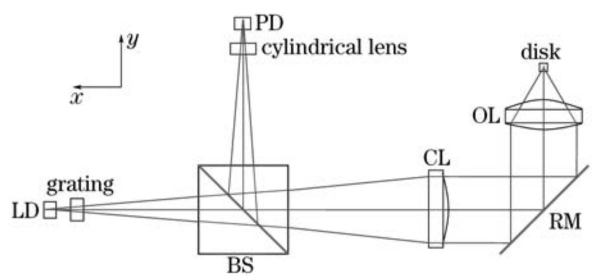

Fig. 1. Common structure of a HD DVD system.

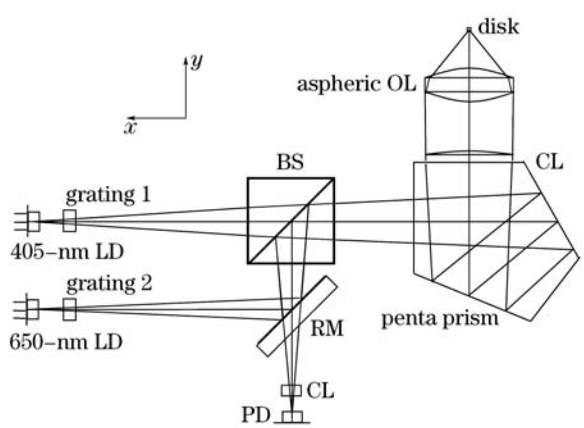

Fig. 2. Optical path and structure of the designed picking-up system.

Finally it is received by the PD and we can get the read out signal. The CL here has a function of beam shaping, which can turn the elliptic beam into the circular beam.

The linear polarization beam from the LD goes through the grating to be divided into 3 parts. According to the need of the spot to read the signals, the relation between the energy of incidence beam (I), the energy of the 0th order sub beam (I_0) and the energy of the ±1st order sub beam (I_1) are $I_0/I_1 = 4.3 \pm 0.3$, $(I_0 + I_1)/I \geq 0.85$. This is designed for the linear polarization beam with both 405 and 650 nm. Then according to the energy requirement and the energy calculation formula[2]

$$I_{0,\pm 1} = I \left[\frac{\sin\left(\frac{N\pi d \sin\theta}{\lambda}\right)}{\sin\left(\frac{\pi d \sin\theta}{\lambda}\right)} \right]^2,$$

where N is the number of the grating bar, d is the grating pitch, and θ is the angle between 0th or ±1st order sub beam and the horizontal line.

The grating pitch is designed with the value of 30 ± 1 μm. As the beam is linearly polarized, we put a phase film on the grating surface and it can have a $90° \pm 5°$ phase difference to change the linearly polarized ray into the circularly polarized one.

The BS here should have a property to penetrate totally with the 405-nm incidence and to reflect totally with the 650-nm incidence, and to reflect totally with the light that returns from the disk. The half mirror should have the property to reflect totally with the 650-nm incidence and to reflect totally with the light that returns from the disk.

To ensure that the LDs can work normally without damage and at the same time to keep enough energy to read signals, we will coats the splitter well for the two wavelength rays. In this condition the LDs will not be destroyed by the reflected energy and simultaneously the PD can receive enough energy to detect the signals.

The parameters of the penta prism are: $A = 4$ mm, $B = 4.5$mm, $\theta = 22.5°$, $\varphi = 45°$. The light is reflected twice in the prism, and travels a length of $(2+\sqrt{2})\,A = 13.656$ mm. So, this has a function of reducing the size of the PUH, which is shown in Fig. 3.

Aiming at reducing the radiation angles of the LD and then according to the OL design theory, we propose a CL with the NA of 1.25. The front surface is flat and the rear surface is hyperboloid, so the CL does not have

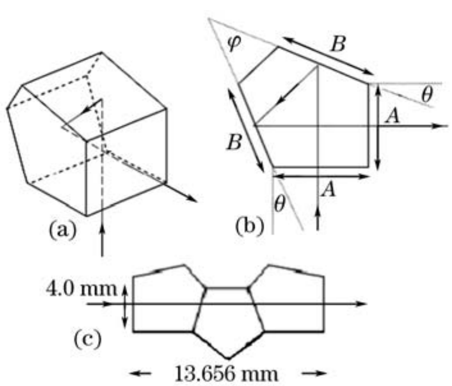

Fig. 3. Structure of the penta prism and the light route. (a) The cubic perspective; (b) the main perspective; (c) the equivalent light route.

high order aspheric coefficients. The focus length is 20.0 mm and the thickness is 0.25 mm. The front surface curvature is infinity and the rear surface curvature is −8.1. The material is BK7 (the refractive index is 1.586, the Abbe number is 64.2). After being collimated, the incidence of the OL is a parallel one, which is useful in adjusting the distance and in correcting the aberration.

The OL is a single aspheric lens. The two sides of the aspheric lens are aspheric. The front surface curvature is 2.88 and the rear surface curvature is −1.62. The center thickness is 1.39 mm. The material is M-BACD5N, and the refractive index is 1.586. The Abbe number is 61.3. The NA is 0.65, which can satisfy the need in the circumstance of the two lasers. The focal length is about 1.9 mm; the work distance is less than 1.2 mm; the outer radius is $\Phi = 1.5$ mm. There are many merits of using the aspheric lens such as the small size, light weight, large NA. Furthermore, it can eliminate the spherical aberration effectively. And it can make the image to reach the diffraction limit to satisfy the demand of reading disk signals.

The working surfaces of the aspheric lens are determined by the function and parameters as follows[3,4]:

$$z = \frac{cr^2}{1 + \sqrt{1-(1+k)c^2r^2}} + \alpha_1 r^2 + \alpha_2 r^4 + \alpha_3 r^6 + \alpha_4 r^8 + \alpha_5 r^{10} + \alpha_6 r^{12} + \alpha_7 r^{14} + \alpha_8 r^{16}, \qquad (1)$$

$c = 1/R$, R is the curvature of the surface; r is the minimum distance from any point on the aspheric surface to the z axis, which is determined by its coordinate x, y, $r^2 = x^2+y^2$; k is the conic constant, which can determine whether the aspheric surface is ellipsoid , paraboloid, or hyperboloid; α_i $(i = 1-8)$ are high order aspheric coefficients, which can determine the shape of the objective lens. In this paper we choose the parameters of the OL and CL as shown in Tables 1 and 2.

According to the data above, the paper assembles all optical elements together with the help of ZEMAX optical design software and optimizes the optical path. Then after simulation and optimization, the purpose is to get a spot size small enough and a root mean square aberration (RMS) that is less than 0.033λ. And the result is that the wave aberration RMS at the focus point of

Table 1. Parameters Chosen for the Objective and Collimating Lenses

Surface	Curvature	Thickness (cm)	Material	Effective Radius (cm)
CL 1	∞	0.25	BK7	1.5
CL 2	−8.1	1.0		1.5
OL 1	2.875967	3.3888	M-BACD5N	1.5
OL 2	−1.624374	1.186		1.5
Disk	∞	0.6	Poly Carbonate	0.3

Table 2. Main Parameters Used in Eq. (1)

Surface	c	k	α_1
OL 1	0.34771	−3.365044	0.007077
OL 2	−0.61563	−4.449736	0.008442

405 nm is less than 0.001λ, that of 650 nm is less than 0.003λ.

Figures 4 − 7 are the simulation results of this PUH system with ZEMAX at 405-nm wavelength. Figure 4 is the transverse aberration analyzing diagram. Figure 5 is the wave aberration analyzing diagram before and behind the focus point. From these two figures, we can see that the aberration has been corrected well and the RMS is in the permitting rank.

Figure 6 is the imaging spot analyzing diagram before and behind the focus point. The size of the focal spot is demanded as small as possible, but it is limited by the sphere aberration and the diffraction limit of the objective aperture. In this example we get a focal spot size of 0.00355 mm. Figure 7 is the point spread function (PSF) diagram. It can show us the central peak intensity of the focusing beam at the girdle plane, that is to say showing the utility ratio of light energy. It can also show us the size of the focal spot relatively.

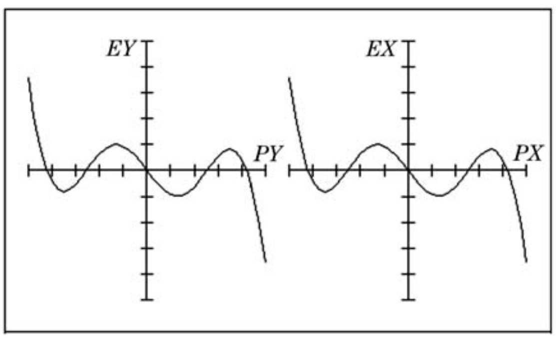

Fig. 4. Transverse aberration analysis.

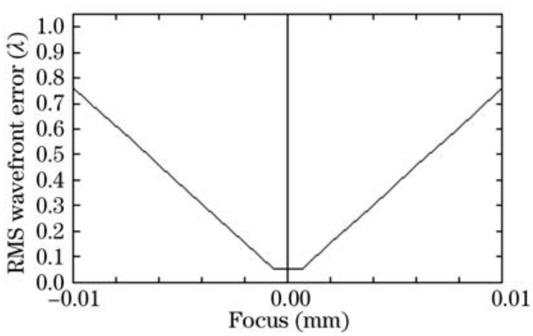

Fig. 5. Wave aberration analysis with focus.

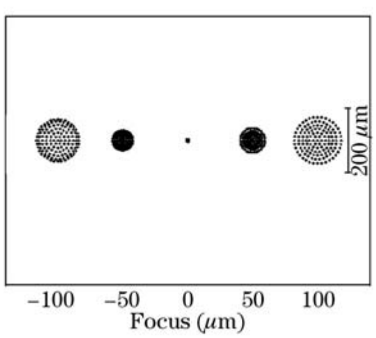

Fig. 6. Imaging spot analysis.

Figures 8 and 9 show the simulation results of the PUH system at the 650-nm wavelength. Figure 8 is the PSF diagram. Its peak value is 0.1 bigger than that of Fig. 7, and its spot size is a little bigger than that of Fig. 7 too. Figure 9 is the wavefront diagram. It shows the wavefront aberration. The aberration analysis, the RMS analysis, and imaging spot analysis diagram at 650 nm are basically the same as those at 405 nm, so we do not give out them in this paper. In this example we get a focal spot size of 0.004358 mm at 650 nm. It is just small enough to read a DVD disk. The RMS is less than 0.003λ.

From above, we can see that the PUH system can realize the compatibility of HD DVD and DVD. For the 405-nm beam path, the distance between the LD and the BS is 4.05 mm, the distance between the OL and the disk (the working distance) is 1.186 mm. For the 650-nm beam path, it enjoys the elements and the light path with 405 nm together in most places. So the HD DVD system only needs to change the distance of several parts to read a DVD disk (use the 650-nm LD, of course). In this example, after the optimization process for the HD DVD system, we changed the working distance (1.19648 mm) and the optical path length of 650-nm LD with BS

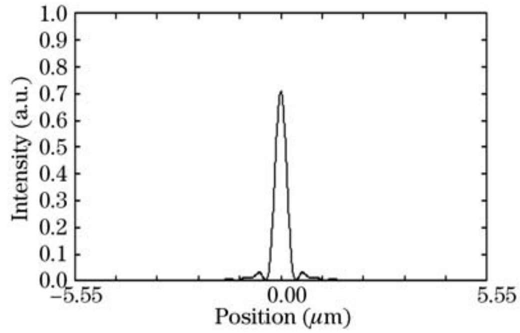

Fig. 7. Point spread function (405 nm).

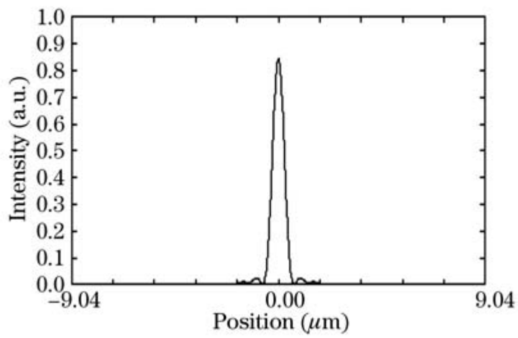

Fig. 8. Point spread function (650 nm).

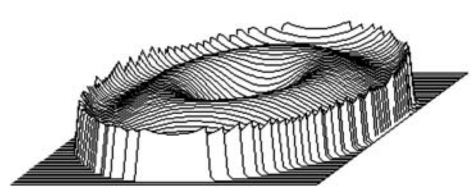

Fig. 9. Wavefront map (650 nm).

(7.653758 mm) and realized the optimization of the DVD system. The results such as the RMS and spherical aberration are ideal. If we let the distance between the 650-nm LD and the half mirror be 4.05 mm, then the distance between the half mirror and the BS will be 3.603758 mm. So, when we make sure the 650-nm LD is right under the 405-nm LD in assembling, and set the half mirror and BS distance fixed, we can get a compatible PUH. When reading a DVD disk, the working distance of the OL can be precisely adjusted by the focusing servo circuit. Then we can realize the compatible reading of HD DVD and DVD easily. The PUH system takes use of the existing tracking and focusing servo circuit of the DVD player — the astigmatic method and the differential phase detection (DPD) method.

In conclution, we designed a model for the compatible HD DVD optical PUH aiming at each optical component function and characteristic. The detailed data can be used in production. The presented PUH is simple in structure and small in size. All of the design work is for the sake of getting a good quality spot, so the entire design process must consider the aberration optimization and the spot size. Since the main part of the light route is used by both 405- and 650-nm waves, it is just needed to change the distance of several components of the HD DVD system for the purpose of reading a DVD disk to achieve compatibility. The system can be compatible to VCD too if we make a little change on it, which is our further step.

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