TITLE OF THE INVENTION

Objective Lens, Optical Head Device and Optical Disc Reproducing Apparatus

BACKGROUND OF THE INVENTION

This invention relates to an objective lens for focusing a light beam outgoing from a light source on a signal recording surface of each of two optical discs having different thicknesses of the light transmitting layers from the light incident surfaces to the signal recording surfaces. The invention also relates to an optical head device employing the objective lens and an optical disc reproducing apparatus employing such optical head device.

An optical disc, shown in Fig.1, among customary optical recording media, has a light transmitting layer 51 comprised of a disc substrate having a thickness of 1.2 mm. On one side of the light transmitting layer 51 is formed a signal recording portion in the form of information pits or guide grooves, while a reflecting film 52 and a protective film 53 for protecting the reflective film 52 are formed in this order on the signal recording portion. The laser light condensed by an objective lens 54 of an optical head device is transmitted through the light transmitting layer 51 so as to be illuminated on the information pits or the guide grooves.

Thus, looking from the side of the objective lens 54 of the optical head device, the reproducing laser light beam is

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radiated through the light transmitting layer 51, with a thickness of, for example, 1.2 mm, to information pits, from which the laser light beam is reflected back through the light transmitting layer 51 for reading out the information.

Up to now, attempts have been made for increasing the recording density and hence the recording capacity. This high density recording may be achieved by, for example, reducing the wavelength of the laser light beam used for information writing during recording or by increasing the numerical aperture of the objective lens. For reproducing a disc-shaped optical recording medium on which information signals have been recorded with high recording density, attempts have also been made for achieving high-density reproduction by reducing the wavelength of the laser light beam or by increasing the numerical aperture of the objective lens.

If the numerical aperture NA is increased as described above, the apparatus is lowered in stability in connection with, for example, tilt of the optical disc, even although the high density reproduction is thereby achieved. The reason is that, if the numerical aperture NA is increased, the depth of focus is decreased thus reducing the tolerance of disc tilt.

If the optical disc is tilted with respect to the optical axis of the objective lens, the wavefront surface W(x, y), which is produced in proportion to an approximately third power of the numerical aperture NA and to an approximately first power of the

skew θ, is given by

$$W(x, y) = W_{31} * x(x^2 + y^2)$$

....(1)

so that coma aberration of the order three becomes predominant. The Seidel's coma aberration coefficient of order three W_{31} is given by

$$W_{31} = \frac{n^2 - 1}{2n^2} t * \theta * NA^3 / \lambda$$

....(2)

wherein the unit is normalized with the wavelength λ and t, n, θ and NA denote a thickness of the light transmitting layer, refractive index of the light transmitting layer, the amount of disc skew and the numerical aperture of the objective lens, respectively.

If an objective lens with a numerical aperture of 0.6 equal to 1.33 times as large as the numerical aperture NA of 0.45 used for a customary compact disc player is used for a conventional optical pickup device, and the disc skew produced in the compact disc player is the same, the coma aberration produced is 3.5 times as large as that with the use of the objective lens with the numerical aperture NA of 0.45, because the coma aberration coefficient is normalized with the wavelength λ.

Above all, if a mass-produced optical disc whose substrate

is formed of polycarbonate and hence has a disc skew of ±0.5 to 1° is reproduced using an objective lens whose numerical aperture NA is 0.6, the wavefront W(x,y), having the wavefront W(x,y) shown by the equation (1), with the predominant coma aberration coefficient W_{31} shown in the equation (2), is generated. The result is that a spot of an image formed on the optical disc becomes non-symmetrical and inter-symbol interference is significantly increased, while the waveform distortion is increased, thus rendering it difficult to read out signals satisfactorily.

In this consideration, attempts have been made for e.g., halving the thickness $\underline{t}$ of the light transmitting layer from a conventional value of 1.2 mm to 0.6 mm for halving the coma aberration coefficient w_{31} of the order three shown by the equation (2).

For focusing a light beam via an objective lens used for an optical head device on signal recording layers formed on the two light transmitting layers, it has been known to use an optical element designed for generating two light beams having different focal lengths, such as a hologram. However, the double-focus hologram, exploiting the diffraction, is expensive and low in efficiency.

It has also been known to restrict the width of the light beam from the light source prior to incidence on the objective lens by a light-shielding actuator for varying the focal length.

In an apparatus employing such actuator, the number of component parts is increased, while the apparatus becomes expensive and cannot be easily reduced in size.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an objective lens whereby at least two light beams of different focal lengths may be produced without employing special devices, above all, peripheral devices.

In one aspect, the present invention provides an objective lens having at least two regions of different numerical apertures and configured for focusing a light beam outgoing from a light source as light beams transmitted through the regions of the different numerical apertures on signal recording surfaces of at least two optical discs having light transmitting layers of different thicknesses.

In another aspect, the present invention provides an optical head device including a light source radiating a light beam, light beam separating means for separating an outgoing light from the light source and a return light from the optical disc, an objective lens arranged between the light beam separating means and the optical disc and photo-electric conversion means for receiving the reflected light beams from signal surfaces of at least two optical discs separated by the separating means for converting the reflected light beams into electrical signals. The objective lens has at least two regions of different numerical

apertures configured for focusing a light beam outgoing from a light source as light beams transmitted through the regions of the different numerical apertures on signal recording surfaces of at least two optical discs having light transmitting layers of different thicknesses.

In yet another aspect, the present invention provides an optical disc reproducing apparatus including an optical head portion for radiating a light beam on a signal recording surface of an optical disc and for receiving the light beam reflected by the signal recording surface for converting the received light beam into electrical signals, and reproducing means for reproducing information signals recorded on the signal recording surface based upon an output of the optical head portion. The head portion has an objective lens having at least two regions of different numerical apertures configured for focusing a light beam outgoing from a light source as light beams transmitted through the regions of the different numerical apertures on signal recording surfaces of at least two optical discs having light transmitting layers of different thicknesses.

Since the objective lens is integrally formed by at least two lens portions, a light beam outgoing from a common light source is focused on signal recording surfaces of at least two optical discs having light transmitting layers of different thicknesses.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 is a cross-sectional view showing the structure of an optical disc whose light transmitting layer has a thickness of, for example, 1.2 mm.

Fig.2 is a schematic block diagram showing the structure of an optical disc reproducing apparatus embodying the present invention.

Fig.3 is a schematic side view showing an optical head portion employed in the optical disc reproducing apparatus shown in Fig.1.

Fig.4 is a schematic side view showing another optical head portion employed in the optical disc reproducing apparatus shown in Fig.1.

Fig.5 is a schematic side view showing the state in which the optical head portion shown in Fig.2 is radiating a light beam on an optical disc having a light transmitting layer of increased thickness.

Fig.6 is a schematic side view showing the state of stray light produced when the optical head portion shown in Fig.2 is radiating a light beam on an optical disc having a light transmitting layer of increased thickness.

Fig.7 shows the state of the stray light at the photosensor portion.

Fig.8 is a schematic side view showing the state in which the optical head portion shown in Fig.2 is radiating a light beam on an optical disc having a light transmitting layer of decreased

thickness.

Fig.9 is a schematic side view showing the state of stray light produced when the optical head portion shown in Fig.2 is radiating a light beam on an optical disc having a light transmitting layer of decreased thickness.

Fig.10 shows the state of the stray light at the photosensor portion.

EMBODIMENTS

Referring to the drawings, preferred embodiments of an objective lens, an optical head device and an optical disc reproducing apparatus according to the present invention will be explained in detail. Fig.2 shows an optical disc reproducing apparatus configured for reproducing information signals from a signal recording surface 1a of an optical disc 1 and from a signal recording surface 2a of an optical disc 2. The two optical discs 1 and 2 have light transmitting layers of different thicknesses.

The light transmitting layer of the optical disc 1 from the light incident surface 1b to the signal recording surface 1a has a thickness t1 which is larger than the thickness t2 of the light transmitting layer of the optical disc 2 from the light incident surface 2b to the signal recording surface 2a. The light transmitting layer of the optical disc 1 having the thickness t1 and the light transmitting layer of the optical disc 2 having the thickness t2 are denoted as 1c and 2c, respectively. The

thicknesses t1 and t2 may, for example, be 1.2 mm and 0.6 mm, respectively.

The optical disc reproducing apparatus includes an optical head portion 3 for radiating a light beam with a wavelength of, for example, 635 nm, on the two signal recording surfaces 1a or 2a via the light transmitting layers 1c or 2c of the different thicknesses t1 or t2, and for converting the reflected light from the optical discs 1 or 2 into electrical signals, and a reproducing unit 4 responsive to electrical signals produced by the optical head portion 3 for reproducing information signals recorded on the signal recording surfaces 1a or 2a.

The reproducing unit 4 processes electrical signals detected by the optical head portion 3 for generating playback signals, such as RF signals, tracking error signals or focusing error signals. The RF signals are processed with, for example, EFM demodulation and CIRC decoding, for producing playback digital data. In the case of an optical disc having a diameter of 64 mm, speech decoding for data expansion is further carried out for producing playback digital data. The playback digital data, outputted by the reproducing unit 4, is converted by a digital/analog (D/A) converter 5 into analog audio data of L and R channels, which are outputted at an output terminal 6.

The tracking error signals and the focusing error signals are supplied to a servo circuit 7. The servo circuit 7 is responsive to these signals to effect tracking error control,

focusing control and thread control. That is, a focusing drive signal is applied to a bi-axial mechanism 9 holding an objective lens 8 in the optical head portion 3 for driving the objective lens 8 for movement towards and away from the optical disc 1 or 2 for performing focusing control. Also, a tracking driving signal is applied to the bi-axial mechanism 9 for driving the objective lens 8 radially of the optical disc 1 or 2 for performing tracking control. In addition, low-range components of the tracking error signals are extracted for generating thread drive signals for driving a thread mechanism for radially moving the optical head portion 3 in its entirety along the radius of the optical disc 1 or 2.

The reproducing unit 4 also generates a spindle error signal from clocks produced on supplying the playback data into a PLL circuit. The spindle error signal thus generated is supplied to the servo circuit 7 which then controls the spindle motor 10 so that the motor 10 will be rotated at a constant linear velocity (CVV).

Referring to Fig.3, the optical head 3 includes a light source 11, such as a laser diode, for radiating a common light beam to the signal recording surfaces 1a or 2a of the optical disc 1 or 2, and a beam splitter 13 for reflecting at least a portion of the light beam from a light source 11 incident on the beam splitter via a diffraction lattice 12 and for transmitting at least a portion of the return light from the optical disc.

The optical head portion 3 also includes a double-focus objective lens 8 and a bi-axial mechanism 9 for driving the double-focus objective lens 8 in the focusing direction and in the tracking direction. The double-focus objective lens 8 is formed integrally from two lens portions 8a, 8b configured for focusing the light beam reflected by the beam splitter 13 on the signal recording surfaces 1a and 2a of the two optical discs 1 and 2, respectively. In addition, the optical head portion 3 includes a photodetector 16, such as a photodiode, for converting the reflected light beams from the signal recording surfaces 1a and 2a of the two optical discs 1 and 2 via beam splitter 13 for converting the received light into electrical signals.

The optical head portion 3 is of a finite system since no collimator lens is used. Alternatively, a collimator lens 17 may be arranged between the beam splitter 13 and the double-focus objective lens 8, the optical head portion 3 then being of an infinite system, as shown in Fig.4. In the following description, the optical head portion 3 is assumed to be of a finite system.

The optical head portion 3 guides the light beam radiated by the light source 11 to the double-focus objective lens 8 via the diffraction lattice 12 and the beam splitter 13. The double-focus objective lens system 8 focuses the incident light beam with a wavelength of, for example, 635 nm, on the signal recording surfaces 1a or 2a in a manner tabulated in Table 1.

TABLE 1

design specifications		mid part 8a	rim part 8b
light beam wavelength		635 nm	635 nm
focal length		2.85 mm	2.62 mm
numerical aperture		0.35	0.60
multiplication factor		-1/7.1	-1/8.0
operating distance		1.20 mm	1.20 mm
ref. object image distance		28.845 mm	28.245 mm
cover glass	light source side	1.0 mm (BK7)	1.0 mm (BK7)
	disc side	1.2 mm(PC)	0.6 mm (PC)

In the above Table 2, the two lens portions of the double-focus objective lens 8 are divided into a mid part 8a and a rim part 8b. The mid part 8a focuses the light beam with a wavelength of 635 nm on the signal recording surface 1a of the optical disc 1 with a focal length of 2.85 nm. On the other hand, the rim part 8b focuses the light beam with a wavelength of 635 nm on the signal recording surface 2a of the optical disc 2 with a focal length of 2.62 nm.

Meanwhile, if the light beam from the mid part 8a of the double-focus objective lens 8 is focused on the signal recording surface 1a for detecting the reflected light, as shown in Fig.5, the light beam from the rim part 8b of the double-focus objective lens 8 is radiated so as to be focused on the signal recording surface 2a of the optical disc 2, as shown in Fig.6. This light beam is reflected by the signal recording surface 1a of the optical disc 1 so as to be returned as stray light rays via the

double-focus objective lens 8 and the beam splitter 13 towards the photodetector 16.

These stray light rays are focused at a conjugate focal point P_f associated with the signal recording surface 1a of the optical disc 1 before being incident on the photodetector 16, as shown in Fig.6. Thus, these stray light rays cancel one another, so that the photodetector 16 detects only the reflected light of the light beam focused on the signal recording surface 1a shown in Fig.5, as indicated by broken lines in Fig.5.

On the other hand, if the light beam from the rim part 8b of the double-focus objective lens 8 is focused on the signal recording surface 2a for detecting the reflected light, as shown in Fig.8, the light beam from the mid part 8a of the double-focus objective lens 8 is radiated so as to be focused on the signal recording surface 1a of the optical disc 1, as shown in Fig.9. This light beam is reflected by the signal recording surface 2a of the optical disc 2 so as to be returned as stray light rays via the double-focus objective lens 8 and the beam splitter 13 towards the photodetector 16.

These stray light rays are focused at a conjugate point associated with a focal point of the light beam reflected by the signal recording surface 1a of the optical disc 1. Thus, although the stray light rays are incident on the photodetector 16, as shown in Fig.10, these light rays cancel one another, so that the photodetector 16 detects only the reflected light of the

light beam focused on the signal recording surface 2a shown in Fig.8, as indicated by broken lines in Fig.9.

The optical disc reproducing apparatus of the instant embodiment has the double-focus objective lens 8 in the optical head portion 3 thereof for focusing the light beam on two signal recording surfaces having different distances from the light incident surface, thereby enabling the size and the production costs to be reduced. On the other hand, the stray light produced as shown in Fig.6 when one of the optical disc, such as the optical disc 1, is reproduced, as shown in Fig.5, is not detected by the photodetector 16, so that it becomes possible with the present optical disc reproducing apparatus to reproduce two optical discs with high accuracy.

WHAT IS CLAIMED IS:

1. An objective lens having at least two regions of different numerical apertures and configured for focusing a light beam outgoing from a light source as light beams transmitted through said regions of the different numerical apertures on signal recording surfaces of at least two optical discs having light transmitting layers of different thicknesses.

2. The objective lens as claimed in claim 1 wherein said regions thereof have numerical apertures of focusing the light beam outgoing from the light source for optical discs having the light transmitting layers with the thicknesses of 1.2 mm or 0.6 mm.

3. The objective lens as claimed in claim 1 having the regions with different numerical apertures in the radial direction, with a radially inner portion of the objective lens being higher in numerical aperture than a radially outer portion thereof.

4. An optical head device comprising:

a light source radiating a light beam; light beam separating means for separating an outgoing light from said light source and a return light from the optical disc;

an objective lens arranged between said light beam separating means and said optical disc, said objective lens having at least two regions of different numerical apertures and configured for focusing a light beam outgoing from a light source as light beams transmitted through said regions of the different

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numerical apertures on signal recording surfaces of at least two optical discs having light transmitting layers of different thicknesses; and

photo-electric conversion means for receiving the reflected light beams from signal surfaces of at least two optical discs separated by said separating means for converting the reflected light beams into electrical signals.

5. The optical head device as claimed in claim 4 wherein the regions of said objective lens are of the numerical apertures of focusing the light beam outgoing from the light source on said optical discs having the light transmitting layers with the thicknesses of 1.2 mm or 0.6 mm.

6. The optical head device as claimed in claim 4 wherein said objective lens has the regions with different numerical apertures in the radial direction, with a radially inner portion of the objective lens being higher in numerical aperture than a radially outer portion thereof.

7. An optical disc reproducing apparatus comprising:

an optical head portion for radiating a light beam on a signal recording surface of an optical disc and for receiving the light beam reflected by the signal recording surface for converting the received light beam into electrical signals; and

reproducing means for reproducing information signals recorded on said signal recording surface based upon an output of said optical head portion;

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said head portion having an objective lens having at least two regions of different numerical apertures and configured for focusing a light beam outgoing from a light source as light beams transmitted through said regions of the different numerical apertures on signal recording surfaces of at least two optical discs having light transmitting layers of different thicknesses.

8. The optical disc reproducing apparatus as claimed in claim 7 wherein said reproducing means reproduces said electrical signals corresponding to the reflected light beams from the signal recording surfaces of at least two optical discs detected by said optical head.

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