Recent advance of aspherical plastic lenses for optical disk system

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Plastic lenses have been widely used in various optical pickup systems. The status of plastic lenses becomes more important for applying new high density optical disk systems, size reduction and improving cost performance. We will introduce some examples of recent advance of plastic lenses, that is, objective lens for small height CD-ROM drives, DVD/CD compatible optical system and improvement of temperature characteristics.

1 Introduction

Twenty years have passed since first optical disk drive, namely LD (Laser Disk) player, appeared in the consumer market. He-Ne laser and conventional glass combination objective lens was used in the optical pick up at that time. After that, CD (Compact Disk) player came into market in 1982.

Diameter of CD is 120mm, which is smaller than that of LD and analog LP disks. Laser diode was used as a light source of CD pick up. Therefore, there existed possibility of downsizing of CD player, which enabled outstanding growth of CD market.

Various kind of optical disk drives such as CD-car CD-ROM, MO, MD, CD-R, PD, CD-V, DVD, CD-RW are appeared until now. Lots of new optical disk systems are being proposed at present.

Annual production volume of total optical disk drives and players were estimated to exceed 200 million sets this year. One of the main reason of this growth is the realization of aspherical plastic singlet objective lens for optical disk use at early stage. [1]

Extensive efforts to apply plastic optical elements in various type of optical pick up have been made continuously until now. In this paper, recent development of plastic optical elements will be introduced.

2 Objective lenses for small height CD-ROM

At early stage, optical system to make diffraction spot in CD pickup was constructed by laser diode, collimator and objective lens. Typical objective lens of early generation was constructed by 3 spherical glass elements. We developed a bi-aspherical singlet objective lens in 1984 and it was replaced the glass combination objective lens. In 1986, we eliminated the collimator by developing aspherical plastic singlet objective lens for finite conjugate optical system layout. Development of objective lens for CD pick-up is summarized in Fig. 1

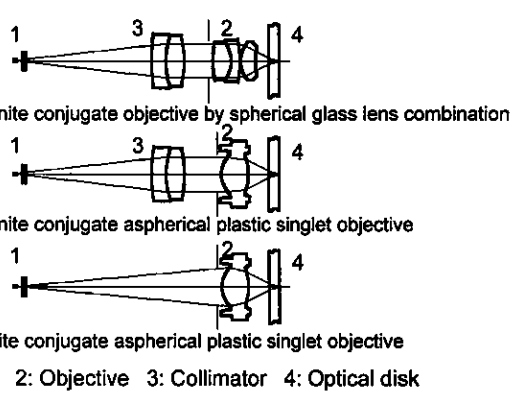

Fig.1 Development of objective lens for CD pick-up

At that time, typical image to object(I-O) distance is 30~36mm. As the development of personal computer (PC), CD-ROM drive spread widely as a key computer peripheral devices. For portable PC, the height of CD-ROM drives must be smaller. Therefore, shorter I-O distance, thinner and smaller objective lenses are necessary. In Fig. 2, outer diameter and I-O distance of finite conjugate aspherical plastic objective lenses are summarized.

In Fig. 2, A lens is a typical aspherical plastic objective lens for CD-Audio use and B lens is a thin and small aspherical plastic objective lens for slim type CD-ROM drive for note PC. As for the plastic objective lenses, molding process and material have to be reconsidered in order to reduce internal strain to realize thickness and outer diameter reduction.

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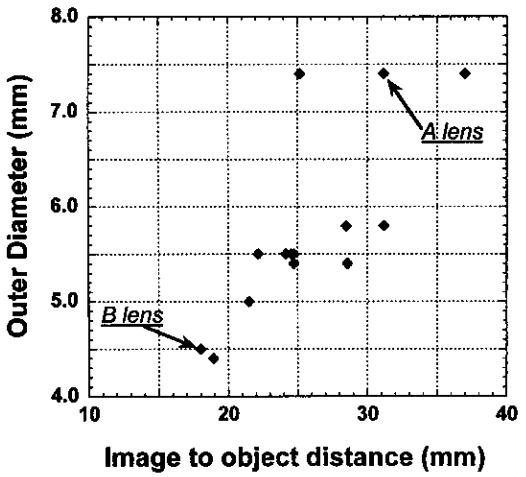


Fig.2 Reduction of size and I-O distance (Konica)

Beside this, wavefront aberration with image height dependence of the objective lens for above purpose becomes worse because of short focal length and thin axial thickness. As a result, RF signal deteriorates more by tracking movement. We developed the plastic objective lens which has residual astigmatic aberration of certain level and certain orientation intentionally in order to reduce astigmatic aberration caused by tracking movement. In Fig. 3, astigmatic aberrations caused by tracking movement of A lens, B lens and modified B lens are compared.

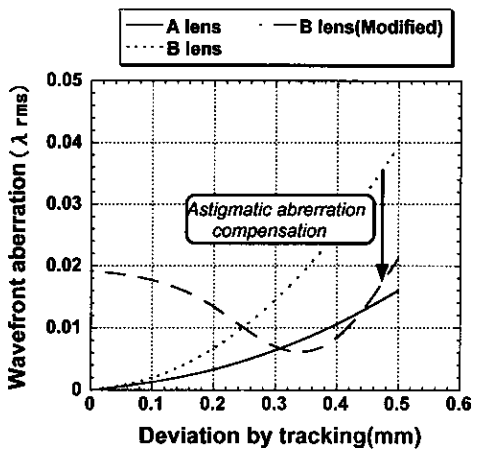


Fig.3 Improvement of tracking performance by objective lens

The amount of astigmatic aberration of modified B lens is same as that of A lens throughout the tracking range. Using the design technique mentioned above, I-O distance which is less than 20mm is realized. Efforts for achieve thinner and smaller aspherical plastic objective lenses are continued.

3 DVD/CD compatible optical system

Aspherical plastic singlet objective lenses with high numerical aperture have been utilized gradually until now. For example, LD(NA:0.50) and WORM(NA0.55) in 1987, MO(NA:0.55) in 1991, MD(NA:0.47) in 1992, and CD-R(NA:0.50) in 1995. Among various optical disks available commercially, DVD has highest density at present (Table 1).

Table 1 Specification comparison of DVD/CD

	Item	Unit	DVD	CD
Disk	Memory Capacity	GB	4.7	0.64
	Disk Structure		Cemented	Single Plate
	Disk Diameter	mm	120	120
	Disk Thickness	mm	0.6	1.2
	Track Pitch Length	μm	0.74	1.6
	Minimum Pit Length	μm	0.4	0.834
Drive	Linear Velocity	m/sec	3.49	1.2~1.4
Optical System	Wave length of Light Source	nm	635~650	780
	Numerical Aperture of Objective Lens		0.60	0.45

The capacity of DVD is 4.7GB which is 7 times as large as that of CD. Therefore, in order to make small spot to reproduce DVD signals, the wavelength of laser diode has to be as short as 635~650nm and the numerical aperture of objective lens should be as large as 0.6. The outer diameter of DVD is same as that of CD. However, the thickness of disk substrate of DVD is 0.6mm, which is different from that of CD(1.2mm). In order to reproduce CD using laser diode whose wavelength is 635nm~650nm, numerical aperture around 0.38 is sufficient.

Because of large stock of CD, people expect to enjoy not only DVD video but also music recorded in CD. Therefore, CD also has to be reproduced by DVD player.

The main reason to complicate DVD-CD compatible pickup is the difference of disk substrate of those med ia. The conventional objective lens for optical disk system is designed and manufactured to attain diffraction limited performance. The relation between disk thickness and wavefront aberration of objective lens designed normally for DVD is shown in Fig. 4. If DVD is replaced by CD, the wavefront aberration amounts to 0.6 λ rms which is far exceed Marechal criterion. Therefore, the focusing spot becomes insufficient to reproduce CD.

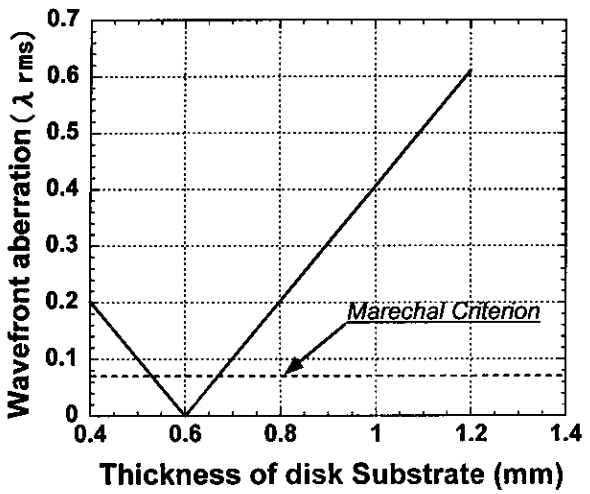


Fig4. Disk thickness vs wavefront aberration (Normal DVD objective lens)

By the way, CD-R media became popular among PC users, especially in the United States, as a large capacity recordable memory. As a consequence, DVD-ROM drive is required to reproduce CD-R also in addition to CD.

Because of low reflection of CD-R memory layer for the wavelength at 635nm~650nm, additional 780nm laser diode is necessary to reproduce CD-R. As a matter of course, numerical aperture of optical system should be 0.45.

To solve these problems, a lot of pick up systems have been proposed and some of them were mass-produced. For example, (1) Two pick-up construction system, (2) One actuator with two objective lenses construction system(One laser type and two laser type), (3) Dual focus optical pickup system using hologram lens[2], (4) Dual focus optical pickup system using additional holographic optical element, (5) Aperture limitation system using liquid crystal shutter[3], (6) Aperture limitation system using annular masked objective lens[4].

Those systems were to realize DVD/CD compatible system of the first generation.

System (1) and (2) are too complicated for cost reduction. Light energy utilization is not good in system (3) and (4). Therefore, they are not suitable for DVD-ROM drive which has compatibility to CD and CD-R. System (5) and (6) is not feasible for attain CD-R compatibility due to large amount of residual spherical aberration.

There are two other solutions for DVD-CD/CD-R compatibility which are more suitable to optical pickup of new generation.

〈Changing magnification method〉

When DVD is replaced by CD in DVD optical system, spherical aberration changes toward over. If this over spherical aberration is compensated by producing under spherical aberration, one can succeed to construct DVD-CD compatibility.

When incident wavefront is parallel, the aberration is perfectly corrected for DVD. However, as mentioned before, large amount of over spherical aberration is existed for CD.

If the magnification of the objective lens is decreased and incident wavefront becomes divergent, the spherical aberration becomes toward under. If suitable magnification is selected, spherical aberration can be greatly improved. The longitudinal spherical aberration curves under conditions mentioned above are shown in Fig. 5.

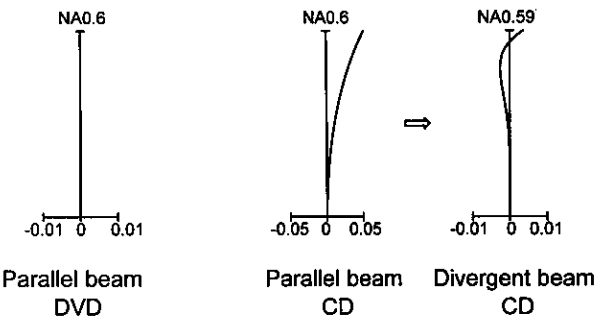


Fig5. Spherical aberration compensation by changing magnification

Relationship between lateral magnification and wavefront aberration for CD using infinite conjugate DVD objective lens is shown in Fig. 6.

In Fig. 6, solid line represents the case where wavelength of the LD is 635nm and numerical aperture is 0.38(i.e. for one laser pickup system). Dotted line represents the case where wavelength of the LD is 780nm and numerical aperture is 0.45(i.e. for two laser pickup system). In both cases, wavefront aberration becomes minimum at magnification around -0.06. The residual aberration is far below the Marechal criterion.

When only one laser diode is utilized, changing lateral magnification is achieved by moving the collimator or laser diode. We call this system zooming pickup and made trial samples of this system[5]. Fig. 7 shows the example of pickup system using zooming optical system.

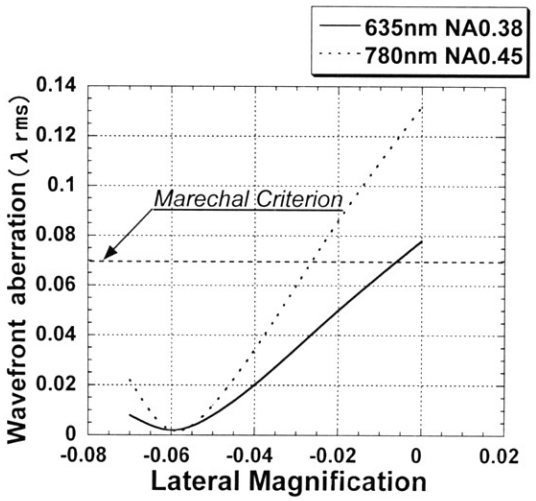


Fig6. Lateral magnification vs wavefront aberration

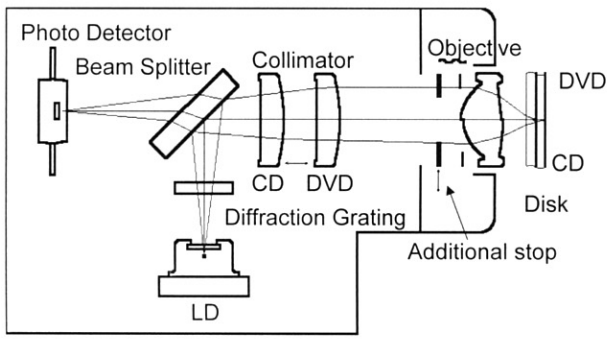


Fig7. Pickup system using zooming optical system

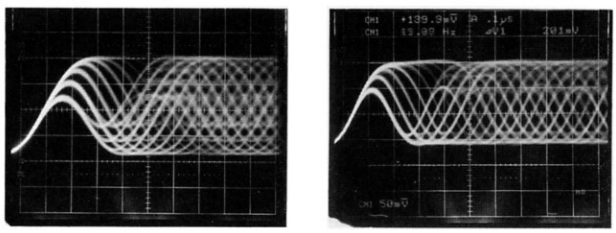
In this case, collimator is moved along optical axis in order to change magnification. When reproducing DVD, the focal point of the collimator is coincident with the light source and light from collimator is parallel. For, reproducing CD, the collimator is moved toward LD. As a result, light from collimator becomes divergent. Additional aperture is inserted mechanically in order to control the spot size suitable for CD reproduction. We developed very simple mechanism for collimator movement and additional stop insertion.

When two lasers are utilized for attaining CD-R compatibility, changing lateral magnification is achieved by changing the optical distance between the collimator and each laser diode.[6] Aperture limitation is also necessary to control the spot size.

〈Using special objective lens〉

We had developed the special objective lens. This lens is designed by optimizing spot profile instead of wavefront aberration. Lateral magnification is same for DVD and CD.

The optical system is optimized without aperture limitation in order to make pick up system simple. We believe that the optical system with this special objective lens will be the most promising one for its simplicity and cost effectiveness. We made not only the objective lens but also pick up to confirm the design principle.[5] RF signal of test PU(one laser type)with special objective lens is shown in Fig. 8



DVD CD

Fig. 8 RF signal of test PU(one laser type)

From this experiment, the effectiveness of DVD/CD compatible pickup using special objective lens was verified.

We had developed the special objective lens for two laser pick up also, where spot profile for DVD at 635nm～650nm wavelength and spot profile for CD/CD-R at 780nm wavelength are taken into consideration.

An example of calculated spot profile of special objective lens for two laser pickup system is shown in Fig. 9

Spot diameter of DVD is 0.89 μm and that of CD is 1.38 μm. Those values are suitable for both optical disks. Beside this, sidelobe of spot profiles is sufficient small.

An example of pickup system using special objective lens is shown in Fig. 10. The pickup construction is very simple, because collimator, objective lens, sensor lens, and photodiode are common to every disks.

Mass-production of those objective lens is very difficult, however, manufacturing process for high precision plastic lenses is effectively used for this purpose.

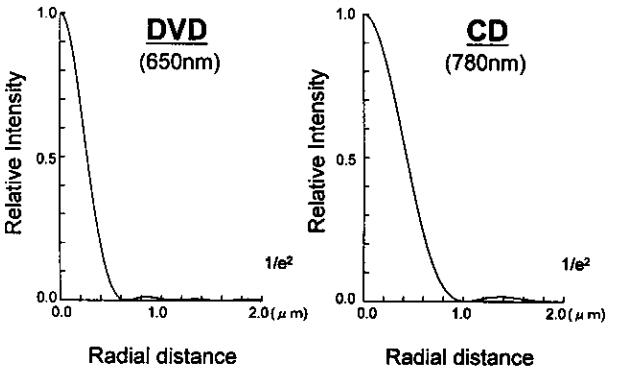


Fig. 9 Spot profile of special objective lens (Two laser pickup system)

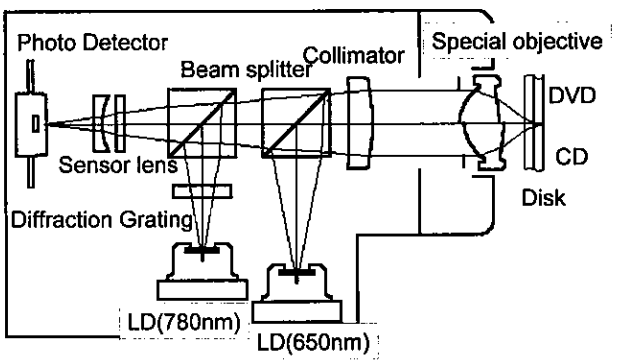


Fig. 10 Two laser pickup system using special objective lens

In Table 2, magnification changing method and special objective lens method are compared. Especia lly, special objective lens method is excellent because of its simplicity. That is, no additional moving part, no aperture limitation, and one common photodiode.

Table 2 Comparison of magnification changing method and special objective lens method

	Method	Moving Part	Aperture limitation	Number of PD	Power Efficiency
1 LD	Magnification Changing	Y	Y	1	◎
	Special Objective	N	N	1	◎
2 LD	Magnification Changing	N	Y	2	◎
	Special Objective	N	N	1	○

Remark Y : Necessary, N: Not Necessary

4 Temperature performance improvement of high NA plastic objective lens

In order to reduce cost for spreading DVD, development of plastic objective lens for DVD- CD compatible system is strongly desired. However, there existed one subject to overcome. That is the improvement of temperature performance. Spherical aberration of plastic objective lens changes according to temperature change.

Main cause of this phenomena is temperature dependence of refractive index. The degree of spherical aberration change is proportional to focal length and 4th power of numerical aperture. Therefore, temperature characteristics must be carefully evaluated in applying high numerical aperture plastic objective lens.

We had proposed the optical system for DVD with plastic objective lens and plastic collimator.[7] This is not merely aiming cost reduction.

The behavior of optical system with plastic objective lens and plastic collimator is illustrated in Fig. 11 Upper diagram is the optical system at normal temperature. The light source is adjusted to the focal point of collimator.

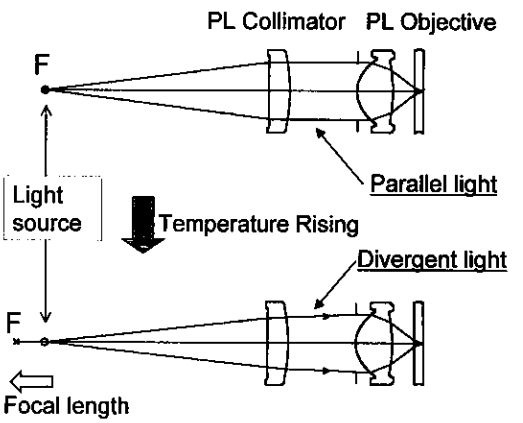


Fig. 11 Optical system with plastic objective lens and plastic collimator

Spherical aberration of the plastic objective lens itself changes toward over when temperature rises. By the way, because the collimator is made of plastic, the focal length of the collimator becomes large. Since light source and collimator are still fixed at its original position, the parallel wavefront from the collimator changes into divergent wavefront. So the lateral

magnification of objective lens changes to negative, and spherical aberration arises a little toward under-correction.

Therefore, temperature performance can be improved automatically by using plastic collimator. This means requires no additional mechanism to increase cost. On the contrary, mass produced plastic collimator saves cost. Temperature characteristic of typical optical systems using plastic objective lens is summarized in Table 3.

The temperature performance of DVD optical system with plastic objective lens and plastic collimator is sufficient compared with that of optical system for other optical disks in market. We suppose that plastic collimator will be widely used in various high density optical disk systems.

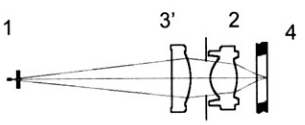
Table 3 Temperature characteristics of typical optical systems using plastic objective lens

	Dimension	CD	LD	MO	DVD
Wavelength	nm	780	780	680	635
Deviation of spherical aberration	λ rms/30 ° C	0.025	0.028	0.023	0.020*

For applying plastic objective lens to higher density optical disk systems in future, we had proposed the quasi-finite conjugate optical system of positive magnification, which has more potential to improve temperature characteristics. [8) 9)]

This optical system is illustrated in Fig. 12

Converging element is used instead of collimator.



1: Laser 2: Objective 3': Convergent element 4: Optical disk

Fig. 12 Quasi finite conjugate optical system of positive magnification

5 Conclusion

21th century is near at hand and the lots of higher density optical disk systems have been proposed recent ly. Especially, optical system with shorter wavelength light source is very promising. Because light sources of this kind will be realized commercially in near future.

In order to apply plastic lens in those systems, it is necessary to level up all technologies which support developing and manufacturing plastic lenses rapidly.

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