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미디어 내부 2층 근접장 광기록을 위한 타원형상 고체침지렌즈의 설계

Design of Elliptic Solid Immersion Lens for Dual Layer Near Field Recording

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ABSTRACT

Near field recording (NFR) technology has been considered as a strong candidate to surpass the far-field diffraction limit imposed by the nature of light in present optical disk drives such as CD, DVD, and BD (Blu-ray Disk). In this paper, we suggest novel inside near-field dual layer recording concept using elliptic shape solid immersion lens (ESIL).

Keywords: Elliptic Solid Immersion Lens(ESIL), Near Field Recording, High Numerical Aperture(NA), Dual Layer Recording, Zoom Optics

1. Introduction

Among various researches for NFR, NFR using SIL optics is highlighted for the reason of similarities with present ODD and less complexity of optical system than other NFR technologies. Recently, there have been practical results using hemispherical and super-hemispherical SIL to have 75Gbytes per 1 layer on 12cm disk with extremely high numerical aperture (NA) of 1.5.[1] However, these optical recording systems are based on media surface recording, it can provoke contamination and thermal instability of SIL and disk surface due to dust and high recording temperature as well as mechanical disturbance such as scratches and collision of optical head and media.

These natural defects of disk surface recording can be improved by the recording inside the disk likewise present CD and DVD. Surely, inside recording concept has the demerit of relatively smaller storage capacity than surface recording concept because of the limit for selection of the media having high refractive index, but this problem can be improved by dual or multi-layer inside recording concept. Phillips showed the concept of media inside recording using hemisphere SIL to overcome problems of media surface recording, and they proved that media inside recording has better optical tolerances than surface recording.[2] We have already reported for the truncated elliptical SIL to realize media inside recording in ISOM 2003.[3] Using elliptical SIL (ESIL), it is possible to improve problems, which conventional SILs have, such as assembly of objective lens and SIL, and heavy optical head, because ESIL optics can be used in the condition of infinite optics directly without objective lens.

In this research, we propose the concept of dual layer media inside recording using the ESIL and a focus adjustment method. Therefore, we designed feasible dual layer recording system, and analyze optical performances and tolerances. Also, we'll refer to possible problems in near filed recording using ESIL and suggest methods of solutions.

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2. Design of Elliptical SIL using point to point conjugation method

Figure 1 shows concept of media inside near field recording. In general, for the case of media surface near field recording, we use evanescent wave propagation of diffracted spot, because spot position is located on bottom surface of the SIL. This evanescent wave propagation effect happens also in geometrical optics region. Therefore, it can appear in air gap which exist between two different medium. Therefore, using evanescent wave propagation in geometrical optics region, it is possible to perform media inside near field recording.[4] Figure 2 shows shape of the ESIL designed by point to point conjugation method.

Geometrical shape of ESIL is shown in Eq(1), and for the specific case of $n_1 = n_2$, the configuration of the ESIL become ellipse which has only conic constant. For instance, when $n_1 = n_2 = 1.56$, ESIL has NA 1.2, and when $n_1 = 2.0$, $n_2 = 1.56$, ESIL has NA 1.56.[5]

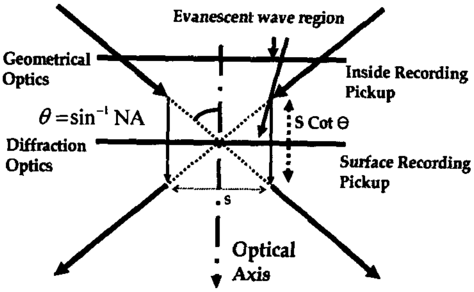

Fig. 1 Concept of inside near field recording

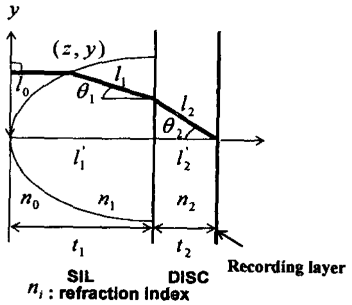

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Fig. 2 Design of elliptical SIL

$$z = \frac{n_1 t_1 + n_2 t_2 - n_1 t_1 / \cos\theta_1 - n_2 t_2 / \cos\theta_2}{n_0 - n_1 / \cos\theta_1}, \quad (1)$$

$$x = (t_1 - z)\tan\theta_1 + t_2 \tan\theta_2$$

It is impossible to express ESIL in general aspherical mathematical formula, because the shape of ESIL is defined by point to point conjugation method. So in this study, firstly, we define initial shape of ESIL expressed with only conic constant, and then we optimize initial design model of ESIL using commercial lens design software. In this optimization process of ESIL, we choose LaSF35 with n=2.086 at 405nm as the material of ESIL and polycarbonate with n=1.6224 as the material of cover layer. Theoretically, it is possible to obtain NA=1.6 with designed shape of ESIL, but considering feasibility of fabrication, we only use the region of NA= 1.4. Also, to select cover and spacer layer thickness, we refer to Philips's consideration for crosstalk between recording layers. To prevent crosstalk, cover and spacer layer thickness are inverse proportional to NA. In case of NA of 1.5, cover and spacer layer thickness are 3μm. Therefore, we select cover and spacer layer thickness with 5μm, considering NA of 1.4. [2] It is possible to jump focus point by moving position of collimator lens to the direction of optical axis. But it is hard to obtain sufficient optical performances in the range of spacer layer thickness, 5μm. Therefore, we use zoom optics between CL and ESIL for focus adjustment. Near field optical system configuration is shown in Fig. 3 and optical performance is summarized in Table 1.

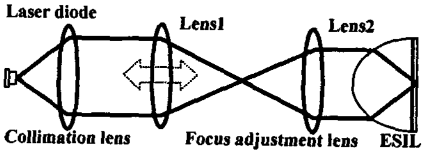

Fig. 3 Schematic diagram of dual layer NFR using ESIL

Table 1 NA and Wavefront error of each layer.

1st Recording layer (10μm)	NA	1.4
	Wavefront error	0.017λ_{rms}
2nd Recording layer (5μm)	NA	1.4
	Wavefront error	0.013λ_{rms}

3. Tolerance analysis

For designed near field optical recording system, tolerance analysis was performed for thickness of ESIL, decenter and tilt margins of each lens. Through tolerance analysis, it is known that ESIL tolerance of thickness for 0.05λ RMS wavefornt aberration, and focus adjusting zoom lens has very large tolerance of movement. In Tables 2 and 3, we summarize tolerance characteristics of each lens and zoom lens movement.

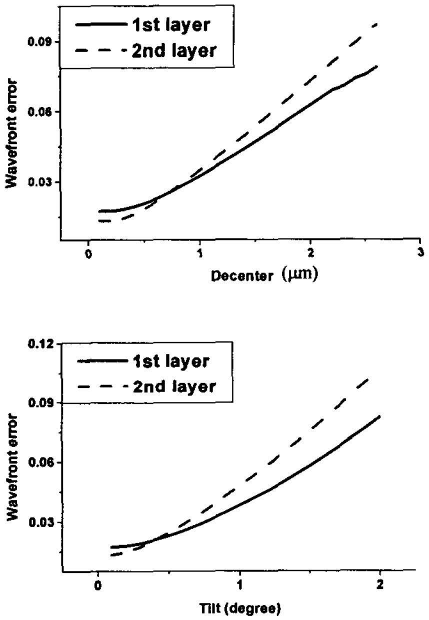

Fig. 4 Decenter and Tilt Tolerance of Lens 2

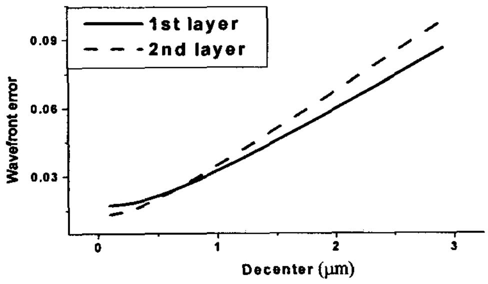

Fig. 5 Decenter Tolerance of ESIL

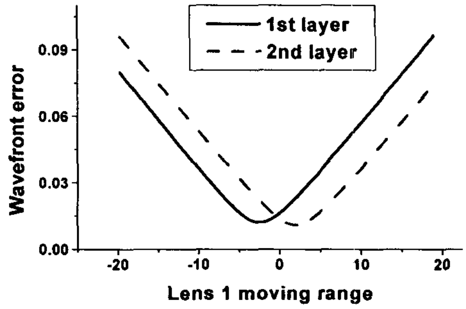

Fig. 6 Movement Range of Lens 1

Table 2 Decenter and tilt tolerance

	Recording layer	Decenter (μm)	Tilt
Lens 1	1^{st}	20.5	2.5°
	2^{nd}	12.5	2.2°
Lens 2	1^{st}	2.3	1.7°
	2^{nd}	2.0	1.4°
ESIL	1^{st}	2.3	
	2^{nd}	2.0	

Table 3 Lens 1 moving range

Recording layer	Position from Lens2 (μm)	Moving range (μm)		Max.-Min. (μm)
1^{st}	984	Max	12.7	30
		Min.	-17..3	
2^{nd}	1044	Max	17.8	31.5
		Min.	-13.7	

4. Fabrication Concept and Complementary Design of ESIL

To obtain high NA with ESIL, refractive lens is designed to have high refractive index, 2.086. However, it is not easy to fabricate elliptic surface with direct glass molding process because it is hard to find high refractive index lens material available of glass mold.

Therefore, there is need of novel fabrication method to generate ESIL having high refractive power. In this paper, we propose the fabrication method of replicating photo polymer which has low refractive index on the hemisphere lens which has higher refractive index. As ESIL material, LaSF35, is commercialized as a ball lens, it is possible to generate hemi-sphere lens by chemical mechanical polishing and focused ion beam milling. Also, initial design of ESIL has to be complemented to use ball lens and replicated layer.

Using ball lens, initial design of ESIL is complemented. Figure 7 shows the complementary designed shape of replicated ESIL on the basis of initial lens design. In this design, we selected ball lens having diameter of 1mm and refractive index of 2.086. And the designed thickness of recording layer is 10μm and its material is polycarbonate which has refractive index of 1.6224 at the wavelength 405nm.

In addition, as we use near ultra violet ray, there is severe change of refractive index by the change of wavelength. Therefore, to cope with this chromatic aberration, diffractive optical element is applied in this design. Fig. 8 shows phase profile of diffractive optical element. It has 62 pitches and minimum pitch size is 4 μm. In this design, PMMA is used for material of DOE, and fused silica is used for base glass plate.

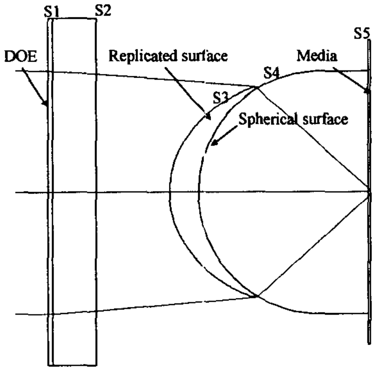

Fig. 7 Complementary Design of Replicated E-SIL

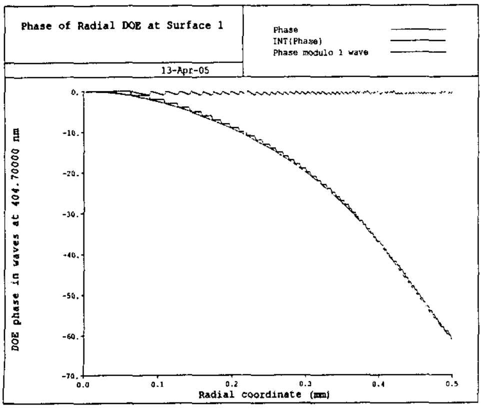

Fig. 8 Phase Profile of Diffractive Optical Element

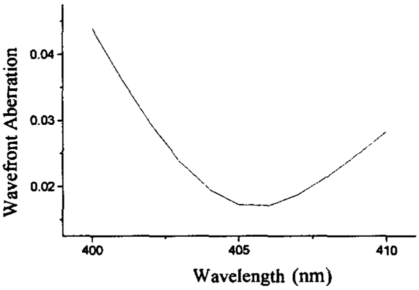

Fig 9. RMS Wavefront Error of ESIL

Table 4 Performance of ESIL

Spherical surface radius	500μm
Wavefront aberration (at 405nm)	$0.017\lambda_{rms}$
NA	1.39
DOE minimum pitch	4μm

Table 5 Tolerance Analysis of ESIL

	Decenter (μm)	Tilt (°)	Thickness (μm)	Radius (μm)
S1	2.6	0.18	10	
S2		0.7	10	
S3	2	0.09	0.15	-0.16/+0.04
S4	6	0.6	0.07	-0.27/+0.04
S5		0.95	0.05	

In Fig. 9, compensated amount of chromatic aberration is shown. From wavelength of 400nm to wavelength of 410nm, RMS wavefront error do not exceeds $0.05\lambda_{rms}$. And tolerance analysis is shown in table 5. The Designed ESIL has relatively enough tilt tolerance for SIL Surface and media.

5. Conclusion and Discussion

Using the ESIL having elliptic surface, we investigated possibility of media inside recording. Through tolerance and optical performance analysis for the optimized optics for dual layer near field recording, we obtained fairy good optical performance with high NA for dual focusing layer and sufficient tolerance of ESIL thickness and tilt tolerance. In our optical setup, using zoom optics consist of two lenses having relatively low NA, it is possible to increase tolerance of ESIL thickness. In addition, considering possibility of fabrication of ESIL, we suggest novel fabrication method of elliptic surface. And, on the basis of initial design, we complement design of ESIL by use of diffractive optical element to minimize chromatic aberration. As the result of complementary design, we obtained stable optical performance over broad wavelength band. Also the designed optics shows relatively good tilt tolerance and high NA similar with initial design.

Acknowledgements

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