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Optical Design for the Optimum Solid Immersion Lens with High Numerical Aperture and Large Tolerance

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Super hemispherical solid immersion lens system becomes a matter of interest due to its high numerical aperture (NA) gain. However, because of the instability of the aplanatic condition, even small amount of alignment error can easily lower the optical performance. To overcome the instability while maintaining high NA gain, we suggest an optimum solid immersion lens (opti-SIL) system which combines the advantages of both super hemispherical SIL (hyper-SIL) and hemispherical SIL (hemi-SIL). Exemplary designs and simulation results of the tolerance analysis show that opti-SIL system has much higher tolerances to various performance-lowering factors than hyper-SIL, even with relatively small NA resignation.
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KEYWORDS: opti-SIL, hyper-SIL, hemi-SIL, tolerance, NA gain, near field recording

1. Introduction

Among the methods used to increase data density of an optical recording system, one of the most effective technologies is near-field optical recording using solid immersion lens (SIL).[1–3] To increase the numerical aperture (NA) value of an optical system, and thus to reduce the focused beam spot, two systems that are named hemispherical SIL (hemi-SIL) and super-hemispherical SIL (hyper-SIL) with their NA being $nNA_{\rm obj}$ and $n^2NA_{\rm obj}$ respectively has been commonly considered. The primary factors that should be considered in the objective lens of data storage systems are the numerical aperture value and the tolerances of the system. Due to the advantage of a high NA gain, hyper-SIL system is more frequently investigated in near field recording. However, the misalignment and figure error tolerance of the SIL surface are too low to ensure its optical quality. In order to achieve the favorable optical performances, the new idea to improve the system tolerances is needed.[4–6]

In a recent paper, Zhang introduced an idea based on the not aberration free but stable point of the spherical aberration curve according to the SIL thrust,[7] showing that the tolerance performances in the new system are better than the traditional aplantic SIL systems (same as hemi- and hyper-SIL) when applied to the multilayer two photon data read out system.

In this paper we suggest a new system namely optimum SIL (opti-SIL) which has large tolerance with relatively small NA resignation. Design of it is based on the stable point of the spherical aberration curve according to the SIL thrust. Unlike Zhang, we would like to show that even when using a single objective lens without compensators to the single data layer, the opti-SIL system can overcome the low NA demerit of hemi-SIL system and small tolerance demerit of hyper-SIL system.

2. Lens Design

The amount of spherical aberration according to the distance of SIL thrusting on the optical axis is shown in Fig. 1.[8] Four specific points are considered. Point A is stable and aberration free, point B is also aberration free but not stable, whereas points C and D are not aberration free but stable. Hemi-SIL and hyper-SIL systems are represented by points A and B. However, point C, which has not been previously a matter of importance, is the point we considered by the fact that it is stable with a relatively high NA. If the objective lens which is conjugated to SIL position C has some proper aberration that can compensate for the non aplanatic SIL induced aberration, it would have both a large tolerance and a relatively high NA (opti-SIL).

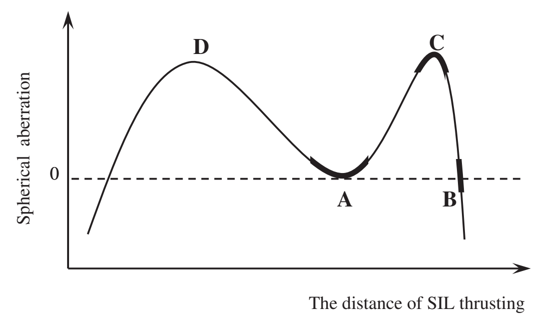

Fig. 1. The spherical aberration of a focused beam inside a SIL. Points A and B correspond to hemi- and hyper-SIL respectively. Point C is interesting one. It is stable on the curve with relatively high NA.

The optical design data for the near field systems corresponding to point C are shown in Table I. We designed hemi- and hyper-SIL systems with their maximum NA in order to compare tolerances with opti-SIL system. Because the tolerance of an optical system largely depends on its NA, we also designed hyper- and opti-SIL system with NA = 1.64 and 1.84 respectively (Table II). After considering production, we used poly(methyl methacrylate) (PMMA) for the single molded even aspheric objective lens and LaSF35 for the SIL.

3. Simulation Results and Discussion

For the tolerance analysis of SIL system, following principal factors that induce degradation of the optical performances are selected; axial distance error between objective lens and SIL (Δz), SIL decenter (Δd), SIL thickness error (Δt), and field (Fig. 2). In this paper 0.05λ rms optical path difference (OPD) error is determined as a tolerable margin of the system performance deterioration.

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