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Near-Field Phase Change Optical Recording Using a GaP Hemispherical Lens

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A GaP solid immersion lens and a modified liquid immersion lens (MLIL) are studied. The phase change marks exhibit a diameter of approximately 200 nm when recorded by the MLIL.

KEYWORDS: optical data storage, near-field optics, near-field recording, super resolution, GaP lenses, vector diffraction

1. Introduction

Data density of an optical recording medium depends on the focused beam spot size, which is limited by diffraction. The beam spot size can be reduced by using a shorter wavelength light source or a larger numerical aperture (*NA*) objective lens. Recently, near-field optical techniques using evanescent light have been developed to overcome the diffraction limit of far-field optics. In particular, Betzig *et al.*[1)] have applied a scanning near-field optical microscope (SNOM) for magneto-optical (MO) recording. In other research, Terris *et al.*[2)] have developed a near-field optical recording optics using the solid immersion lens (SIL). They demonstrate recording 350 nm diameter marks on an MO media using a SIL. Phase change recording using a SIL is also demonstrated in our previous report.[3)]

The SIL optical head is composed of a hemisphere or truncated sphere, which is made from high refractive index glass ($n = 1.8$ to 3.5) and a high *NA* focusing objective lens. The SIL can reduce the spot size of the focused beam at the bottom of the lens by reducing the wavelength in the high refractive index glass of that lens. The *effective numerical aperture* NA_{EFF} takes into account focusing in the glass material and is given by $NA_{\mathrm{EFF}} = n \sin\theta_m$, where θ_m is the marginal ray angle. The refractive index of the glass material limits the maximum NA_{EFF} of the SIL to n.

The focused light beam at the bottom surface of the SIL propagates to the recording layers through a very thin air gap ($<\lambda/2$). In the air gap, both propagating light and evanescent light are present. The high frequency components of the focused-beam angular spectrum ($n \sin\theta > 1$, where 1 is the refractive index of the air gap and θ is the angle of the incident plane wave) couple to the recording layers through evanescent light in the air gap. The amplitude of the evanescent field significantly decays in the air gap. On the contrary, the low spatial frequency components ($n \sin\theta < 1$) couple to the recording layers without significant decay.

NA_{EFF} can be large if a high refractive index material such as GaP ($n = 3.3$) is used. Also, the beam spot size characteristics of the SIL system can be improved by using a very thin liquid lubricant layer (immersion oil) in the gap, whose refractive index is 1.5. The liquid lubricant layer enlarges the total internal reflection angle at the bottom surface of the SIL. Therefore, the transmission efficiency of both propagating and evanescent light in a high NA_{EFF} device (such as $NA_{\mathrm{EFF}} = 1.5 \rightarrow 2.2$) can be improved. We call this configuration a *modified liquid immersion lens* (MLIL) head. In this context, the MLIL differs from the conventional liquid immersion lens system and can produce $NA_{\mathrm{EFF}} > 1.4$. The configurations of SIL and MLIL are illustrated schematically in Fig. 1.

In this paper, we describe a SIL and a MLIL using a GaP hemispherical lens and discuss the optical characteristics of these lens systems as well as a phase change recording using the MLIL.

2. Simulation

Figure 2 shows a comparison of the spot sizes[4)] from a GaP SIL with air gap, which is referred to as a standard SIL, and the GaP MLIL. Spot size refers to the $1/e^2$ diameter of the irradiance distribution at the top of the recording layer in a phase-change recording medium. The size of the irradiance distribution is different for crystalline and amorphous recording layers, which are indicated with c and a, respectively. The recording layers used in the simulation are gap/ZnS-SiO2, $n = 2.15$, 40 nm/GeSbTe, c: $n = 4.2 + 4.2i$, a: $4.4 + 2.1i$, 19 nm/ZnS-SiO2/Al-alloy, $n = 1.2 + 5.8i$, 150 nm/glass. The optical parameters are $\lambda = 650$ nm, x-polarized beam incident on the entrance pupil of the objective lens, and $NA_{\mathrm{EFF}} = 1.98$. As shown in Fig. 2(a), the x-direction spot profile of the standard SIL is quite sensitive to air gap variations. The spot size of the MLIL in Fig. 2(b) is much less sensitive to the gap variations, provided that the lubricant can fill the gap. Figure 3 shows the signal and contrast[4)] versus gap for the standard SIL and the MLIL. The signal is normalized by the reflection without recording layers or substrate. A significant contrast improvement is achieved with the MLIL geometry.

3. Experimental Setup

We use two types of hemispherical lenses: (a) GaP ($n = 3.3$, $r = 0.5$ mm) and (b) LaSFN9 ($n = 1.843$, $r = 1.5$ mm) in this study. The spherical surface of the GaP lens is coated with a quarter-wavelength anti-reflection layer, which consists of HfO_2, in order to reduce a large reflection at the surface. The GaP SIL and MLIL exhibits $NA_{\mathrm{EFF}} = 1.98$, and the LaSFN9 SIL exhibits $NA_{\mathrm{EFF}} = 1.1$.

A schematic view of the experimental setup is illustrated in Fig. 4. Standard optical recording optics for phase change recording are used, except for the setup of the SIL installed between the focusing objective lens and the recording medium. The focusing objective lens is a $NA = 0.6$ long-working-distance type microscope objective lens ($f = 5$ mm, $WD = 3$ mm). A semiconductor laser (wavelength: $\lambda = 650$ nm) is used for the light source. Light from the laser diode is circularly polarized on the recording medium. The