

High-performance readout and recording by a combination aperture

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A solid immersion lens combined with a conical dielectric tip exhibits good resolution and efficiency in reading and recording data marks on optical storage media. We demonstrate a combination aperture that produces ~ 200 -nm full-width $1/e^2$ spot size and achieves 50% optical efficiency in an edge-scan experiment. A comparison of recording with the combination aperture, with an unmodified solid immersion lens, and with a far-field system is made. © 2001 Optical Society of America

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Both solid immersion lenses (SILs) and aperture probes are being developed as near-field techniques to be used in optical data storage systems.^{1,2} SIL systems, although they offer substantially improved spot size, do not have the resolution that can be observed with aperture probes. However, aperture probes suffer from low throughput, limiting optical efficiency. We present a new technique that combines a SIL and a dielectric aperture probe. The combination aperture can achieve higher performance (in terms of spot size and efficiency) for optical data storage and microscopy than those observed when the SIL or the aperture probe is used alone.

The geometry of the combination aperture is basically that of a conical dielectric aperture probe attached to the bottom of a SIL with refractive index n_{SIL} .³ As can be seen from Fig. 1, light of wavelength λ from an objective lens is focused on the base of a SIL at the aperture probe. The light then propagates to the recording layers. The bottom diameter of the probe is d , which is $\sim 0.5\lambda/n_{\text{SIL}}$. Because of the use of a SIL, the focused spot that illuminates the aperture is smaller than that of a far-field system, thus causing improved transmission through the aperture. Owing to the small d of the probe, a small spot size is produced. The spot has approximately the same dimensions as the aperture, which are much smaller than those produced by the SIL system alone.⁴

It is also possible to fabricate a metallic aperture in combination with a SIL. Experimental results indicate that large background reflection from the metallic layer that surrounds the aperture limits the detectable signal. The background reflection from dielectric apertures is negligible, so these apertures are the focus of this research. Details of the design and the fabrication of both metallic and dielectric apertures can be found in Refs. 3 and 4.

To evaluate the combination aperture in optical reading, we use a phase grating of $1.6\text{-}\mu\text{m}$ pitch as a test object in an edge-scan experiment with a $\lambda = 488\text{ nm}$ argon laser. Parameters for the combination aperture include $n_{\text{SIL}} = 1.843$, $d = 200\text{ nm}$, and $\text{NA}_{\text{EFF}} = 2.4$, where NA_{EFF} is the effective nu-

merical aperture. The experimental setup is shown schematically in Fig. 2. Laser light is focused into the combination aperture by a 0.5-NA objective lens. Spacing between the combination aperture and the grating is controlled to $\sim 40\text{ nm}$ by a small movement of a picomotor along the z direction as well as by a strain gauge attached to the SIL mount. The microscope stage, which holds the grating, oscillates along the x direction, thus making the focused light spot scan across the lands and grooves of the grating. The reflected light is then collected by the objective lens and directed by a relay lens to a CCD and a detector located at the pupil plane conjugate to the stop. The detector has two segments (A and B), which can provide electrical voltage as a result of the sum and difference of the light levels detected at A and B.

Two aspects of the readout experimental results are studied. One is the pupil modulation pattern captured by the CCD. The other is the readout signal generated by the detector. When the grating translates along the x direction, the pupil modulation patterns for the far-field system, the SIL system, and the combination aperture system are as shown in Figs. 3, 4, and 5, respectively. In Figs. 3 and 4, the pupils show a typical overlap pattern that is due to diffraction from the 0th and ± 1 st orders of the grating. The 0th diffracted order fills the pupil entirely, whereas the ± 1 st diffracted orders appear as sections of circles displaced on opposite sides of the 0th order. Modulation in the pupil occurs where the ± 1 st orders overlap the 0th order. Comparing Figs. 4 and 3, we find that the SIL

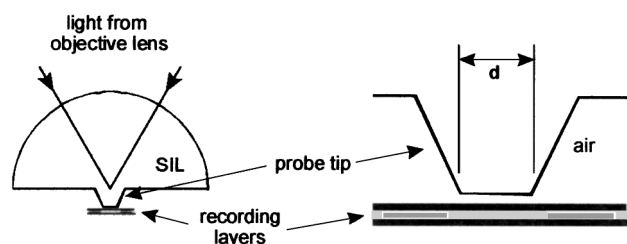


Fig. 1. Geometry of a combination aperture.