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Fiber-Lens-based Module for Optical Recording Applications

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An optical fiber-lens-type pickup with numerical aperture $(NA) \cong 0.27$ was demonstrated for thermal recording of continuous 1.6-μm-wide lines on MO disks with 50% throughput efficiency. Moreover, a Si-micromachined near-field module integrated with a fiber lens, solid immersion lens (SIL), and submicron aperture was fabricated to improve the mechanical fragility and increase the *NA* of the optical-fiber-based pickup. The preliminary configuration design and measurement suggest the feasibility of the module as a submicron heat source for high-density optical data storage. [DOI: 10.1143/JJAP.42.4345]

KEYWORDS: fiber lens, SIL, near field, optical data storage, submicron aperture

1. Introduction

A microlens formed on the end of a single-mode fiber (SMF) is widely used as optoelectronic passive devices to facilitate laser-to-fiber coupling in optical communication systems.[1–3] We have demonstrated a novel design and fabrication of fiber lenses for optical recording applications.[4] In this paper, we first review and optimize the optical properties of a hemispherical-shaped fiber lens. The performance of the lens is evaluated by means of the Ronchi ruling test. Next we demonstrate an optical fiber lens-based configuration as a pickup for thermal writing of micron-width lines with high throughput efficiency.

Although the fiber-lens-type pickup is feasible as a thermal source, several drawbacks limit its application: (1) control of the lens-sample distance is difficult in a dynamic environment, (2) poor mechanical strength of the bare fiber lens cause it to be easily damaged due to contact between the microlens and the spinning disk, and (3) low numerical aperture (*NA*) of the fiber lens also limits the recording density. Thus we explore the possibility of a well-controlled mechanical structure with an ultra small aperture as the heater source for recording.

We then developed a Si-micromachined module integrated with a fiber lens, solid immersion lens (SIL) and submicron aperture to improve the mechanical fragility and increase the *NA* of the optical-fiber-based pickup. This highly integrated module can be driven by a radial actuator, which can potentially be applied for near-field recording.

2. Focusing Properties

The most critical issue of the optical-fiber-based system is the focusing characteristics of the fiber lens, which is directly related to the size of the recorded marks. The structure of the fiber lens is illustrated in Fig. 1. A hemispherical microlens on the end of a pure silica rod is used as the focusing element. The length of the silica rod g is designed to control the focused beam size $2W_i$ and focal length d. The objective of our scheme is to achieve the smallest possible focused spot at a reasonable working distance.

In our design, the beam emitted from the SMF continuously expands as it approaches the microlens, as shown in Fig. 1. In this case, the intensity of the incoming beam is expanded over the whole entrance pupil formed by the microlens rim and results in spherical aberration (*SA*) and the apodization effect. Both *SA* and focal length are functions of the silica rod length g according to Fresnel diffraction integrals.[2] The effect of the silica rod length g on the optical performance is tabulated in Table I. The wavefront deformation W [or optical path difference (OPD)] in the normalized exit pupil (x, y) of the fiberlens with respect to the vicinity of focal position is $W(x, y) = C_{040}(x^2 + y^2)^2 + C_{020}(x^2 + y^2)$, where C_{040} and C_{020} are the primary third-order spherical aberration (*SA*) and defocusing terms, respectively. The paraxial focal distance L_1 is defined by $C_{020} = 0$; the best focal distance L_2 is defined as the position that minimizes the root mean square (rms) of the wavefront error over the exit pupil. As shown in Table I, the

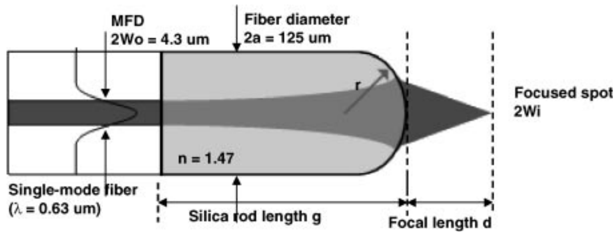

Fig. 1. Schematics of a microlens on the end face of a SMF (refractive index of pure silica rod $n_0 = 1.47$, cladding diameter $2a = 125$ μm, mode field diameter $2W_0 = 4.3$ μm in the single-mode fiber at wavelength $\lambda = 0.63$ μm).

Table I. Optical properties of fiber lenses with various lengths of the silica rod g ($\lambda = 0.63$ μm, $n = 1.47$, and radius of curvature $r = 62.5$ μm).

g (mm)	L_1 (mm)	L_2 (mm)	NA	C_{040} (λ) at L_2	P
0.3	0.381	0.373	0.13	0.013	0.99
0.4	0.260	0.248	0.18	0.056	0.99
0.5	0.218	0.202	0.21	0.160	0.99
0.6	0.197	0.176	0.24	0.363	0.96
0.7	0.184	0.157	0.26	0.717	0.87
0.736	0.181	0.150	0.27	0.94	0.8
0.8	0.176	0.142	0.27	1.281	0.59
0.9	0.169	0.131	0.28	2.125	0.32

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