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Integrated Optical Pickup with Highly Sensitive Servo Signal Detection

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We proposed a novel structure for an integrated optical pickup based on monolithic integration of waveguide mirrors and photodetectors in a waveguide on a Si substrate. The detection characteristics of focusing and tracking error signals have been demonstrated to be sufficient for practical applications.

KEYWORDS: integrated optical pickup, waveguide, waveguide mirror, prism coupler, photodetector, Si substrate, focusing error signal, tracking error signal

§1. Introduction

A monolithic integrated-optic disc pickup (IODPU) using a focusing grating coupler (FGC) has been proposed and demonstrated.[1-3] These studies suggest a futuristic type of optical disk pickup which has the advantages of producibility and reducibility of both size and weight. Integrated optical disk pickup devices using a bulk object lens instead of the FGC were proposed.[4-7] For an optical disk drive of the next generation, it stands to reason that an integrated optical pickup should be able to read and write optical disks used in present optical disk memory systems to preserve the compatibility of new optical disk drives with current optical disks. For this purpose, it is necessary to increase the amplitude of servo signals, transmit laser power efficiently to the optical disk, and adopt a structure whose performance is not affected by the wavelength change of the laser diode.

In this paper, we present an integrated optical pickup using a waveguide, which is compatible with the present optical disk. We will also demonstrate the capability of this integrated optical disk pickup to detect servo signals.

§2. Device Configuration

2.1 *Device description*

The schematic illustration of the proposed integrated optical pickup (IOP) is shown in Fig. 1. The IOP consists of a laser diode, a collimating lens, an object lens and an integrated optical detection device (IODD). This IODD is constructed by integrating twin telephoto waveguide mirrors (TTWM), two pairs of photodetectors (PD's) on a Si substrate and a coupler prism. A collimated laser beam is incident on the bottom of the coupler prism and is reflected. This laser beam is focused on an optical disk with the object lens. The beam reflected from the optical disk is coupled into the waveguide with the coupler prism. The TTWM divides the guided wave into halves, then totally reflects and focuses them into the centers of both pairs of PD's.

In this configuration, the focusing and tracking signals are obtained by simple processing of the photocurrents of the four photodetectors. The focusing error detection is based on the Foucault method and the tracking error detection is based on the push-pull method.[2)]

2.2 *Prism coupler*

The top view of the IODD is shown in Fig. 2(a) and its cross-sectional view along the line A-A′ is shown in Fig. 2(b). This device is composed of a prism coupler region and a signal detection region. The prism coupler region

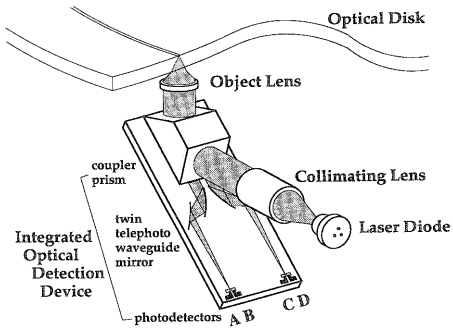

Fig. 1. Schematic construction of the proposed integrated optical pickup.

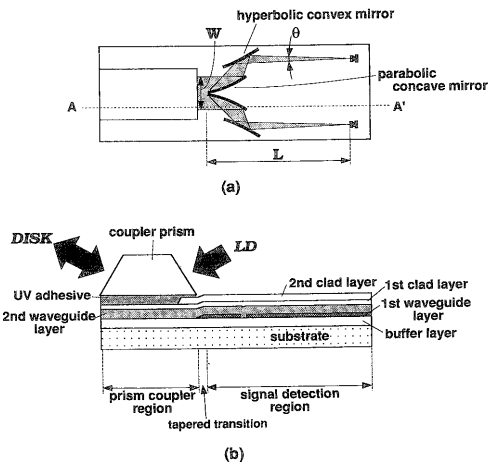

Fig. 2. Schematic view of the integrated optical detection device. (a) Top view. (b) Cross-sectional view along the line A-A′.

consists of the first clad layer, the second clad layer, the second waveguide layer and a buffer layer on a substrate. The coupler prism is attached to the first and second clad layers with a UV cured adhesive. The thickness of the first clad layer is adjusted to obtain high coupling efficiency and the second clad layer prevents the guided wave from decoupling to the coupler prism. A collimated laser beam is incident on the bottom of the coupler prism at an angle of phase matching the waveguide, coupled into the waveguide and decoupled from the waveguide to the coupler prism. As a result, the incident laser beam is totally reflected at the bottom of the coupler prism and focused on the optical disk by the object lens. Therefore, its energy is transferred to the optical disk with minimal loss. The beam reflected from the optical disk is again incident on the bottom of the coupler prism. The incident beam is partly coupled into the waveguide as a TE_0 mode, while the remaining energy of this beam is reflected and returns to the laser diode. The coupled wave propagates in the waveguide without decoupling to the coupler prism because the second clad layer is positioned on a propagation region.

2.3 *Twin telephoto waveguide mirrors (TTWM)*

The signal detection region consists of two clad layers, the first waveguide layer, the second waveguide layer and a buffer layer. The prism coupler region and the signal detection region are connected by a tapered transition region. The coupled wave propagates in the second waveguide layer and transfers gradually into the first waveguide layer at this tapered transition region. The TTWM consists of a pair of parabolic concave mirrors and a pair of hyperbolic convex mirrors. Its reflection facets are formed by removing the first waveguide layer. The TTWM has no spherical aberration for a parallel incident beam and it increases the effective focal length of the optics because of the telephoto configuration. The focal points of the TTWM show substantial stability against wavelength changes of the laser diode, as well as against deviation of the refractive index and thickness of the fabricated waveguide layer from the designed values. In the design process of the TTWM, a focus spot size and the total longitudinal magnification of the optics of the integrated optical pickup including the object lens are considered. The numerical aperture (NA) of the TTWM is determined from the total longitudinal magnification, the Lagrange theorem and the relations in longitudinal, lateral and angular magnifications, and is defined as $N_{eff}\sin\theta$, where N_{eff} is the effective refractive index of the signal detection region and θ is the angle of the converging beam in Fig. 2(a). The size and configuration of the TTWM are determined by ray tracing calculation to obtain the desired NA.

§3. Fabrication

The IODD was fabricated by planar processes. The specifications of the fabricated IODD are summarized in Table I. At first, the SiO_2 buffer layer was thermally grown on a Si substrate, and then, PD's were fabricated in the substrate. The PD's, which were pin-type Si photodiodes, had a tapered transition region (taper angle$=6°$) in order to decrease the scattering of guided waves at the edge of the detection portion. Then, the first waveguide layer, which was an SiN film, was deposited by plasma-enhanced chemical vapor deposition (P-CVD). The TTWM pattern was defined on a photoresist and was transferred to the SiN waveguide layer by the reactive ion etching technique. The second waveguide layer, the first clad layer and the second clad layer were made of SiON films, which were deposited by P-CVD. Refractive indices and thicknesses of these films were measured by the PRETTI method[8] using a laser diode at $\lambda=0.788$ μm.

Table I. Specifications of the fabricated IODD.

Waveguide	Buffer layer	n=1.455 d=0.986 μm
	First waveguide layer	n=1.860 d=0.341 μm
	Second waveguide layer	n=1.521 d=1.459 μm
	First clad layer	n=1.456 d=0.737 μm
Second clad layer	n=1.456 d=0.813 μm	
Prism coupler	Prism (flint glass)	n=1.6575
	Synchronous angle	65.5 deg.
	UV cured adhesive	n=1.63
TTWM	Aperture size (W)	4 mm
	Optics length (L)	19 mm
	NA	0.16
PD	Element size	500×300 μm^2

§4. Experimental Results

4.1 *TTWM characteristics*

A linear polarized He-Ne laser ($\lambda=0.633$ μm) was used for examining the focusing characteristics of the TTWM to ensure visibility of a streak of a guided wave, since the streak of the guided wave was weak when a laser diode ($\lambda=0.790$ μm) was used. Figure 3 is a photograph of the streak of the guided wave, which is focused into the PD's by the TTWM. The focus spot and intensity distribution of the guided wave at the front end of the PD, that is, at the focal point, are shown in Figs. 4(a) and 4(b). The full

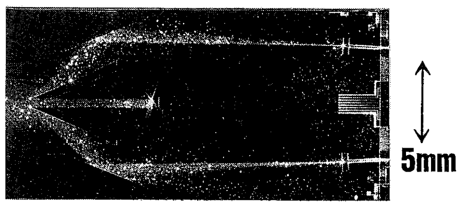

Fig. 3. Photograph of the guided wave in the integrated optical detection device ($\lambda=0.633$ μm).

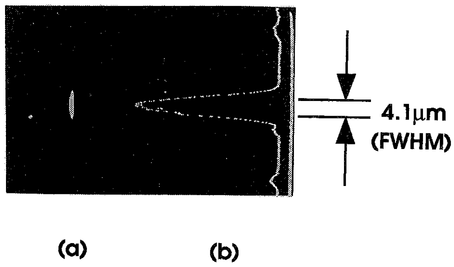

Fig. 4. Photographs of the guided wave at the front end of the PD. (a) Focus spot. (b) Intensity distribution.

width at half maximum of the focus spot was 4.1 μm, which nearly reached the diffraction limit of 3.9 μm. The reflection efficiency of each reflection surface in the TTWM was higher than 90%. The focal point observed for the He–Ne laser agreed well with the designed focal point for the laser diode. This result confirmed that the focal point was not affected by the wavelength change.

4.2 *Pickup operation*

The IOP was constructed using the IODD, a laser diode with wavelength of 0.790 μm, a collimating lens with NA of 0.22, and an object lens with NA of 0.50. We examined servo signals using a grooved mirror with a reflectivity of 25% and a groove period of 1.4 μm to simulate an optical disk. In this measurement, the laser diode power was 0.4 mW after the collimating lens, and a laser beam of 0.3 mW was irradiated onto the grooved mirror. The measured focusing error signal is shown in Fig. 5. A change of 12% in the amplitude of the focusing error signal was obtained for a deviation of 1 μm off-focus. The amplitude of the tracking error signal was 40%p-p of the total photocurrent. The performance results obtained are considered to be sufficient for practical application.

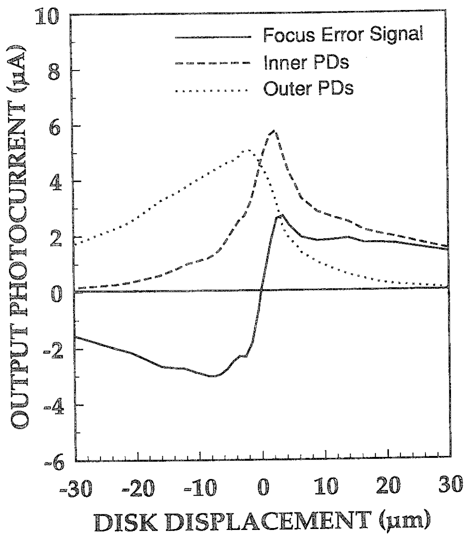

Fig. 5. Measured focusing error signal.

§5. Conclusions

The structure of an integrated optical pickup, which was based on monolithic integration of waveguide mirrors and photodetectors in a waveguide on a Si substrate, was presented. The integrated optical pickup was successfully fabricated and the detection characteristics of servo signals have been demonstrated. We confirmed that the performance of this device was compatible with present optical disks.

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