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Flying head read/write characteristics using a monolithically integrated laser diode/photodiode at a wavelength of 1.3 μm

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ABSTRACT

A feasibility study is shown for an optical disk drive using an optically switched laser (OSL) flying head. This head consists of an AlN slider and a 1.3-μm wavelength InGaAsP laser diode monolithically integrated with a photodiode. The laser diode has a taper-ridged waveguide on the top of the facet facing the recording medium. The disk consists of an SiN dielectric protective layer, an SbTeGe recording medium, and 1.5-μm-track-pitch sampled servo format pits on the glass substrate. The lensless near-field flying head gives excellent read/write performance and head/medium reliability: a high-quality readout SNR of 35 dB, stable write operation with 16 mW of laser power, and a lifetime of 4.4×10^8 passes under experimental room conditions.

I. INTRODUCTION

We recently proposed a super-small flying optical head and reported on its high quality readout characteristics when used as an optically switched laser (OSL) head.[1] The basic concept involved the use of light emitted or collected through a 1-μm apperture of a laser diode (LD) placed less than 2 μm from a recording medium. For autofocuse, the head operates like a magnetic head: air-bearing technology stabilizes the slider flying height about 1 μm. Controlled by a sampled servo track error signal, the arm used to seek from track to track is also used for track following.

A monolithically integrated laser diode/photodiode with a taper-ridged waveguide has the same functions like conventional head optics composed of many optical parts (Fig. 1). Since the conventional head illuminates the recording medium through the disk substrate thickness (1.2 mm) and has a working distance (1.3 mm), the objective lens diameter becomes large (more than 4mm) due to the NA (larger than 0.55) required to make the light spot small. All the optical parts must be larger than the objective lens diameter, making the head large. Various proposals, such as a multifunctional holographic element and a thin-film waveguide, have been made for miniaturizing the optical head. But because of substrate thickness, they all share the problems due to the size of the objective lens. Furthermore, the performance of the waveguide type has been reported to be insufficient for practical applications.[2]

To make a smaller head, substrate thickness or head-medium spacing must be reduced. The smallest possible spacing is attained by a head working in the near field of the LD. The flying head works not through the substrate but through a very thin (0.24 μm) protective film. The head-medium spacing need not be less than 1 μm, as with magnetic disks, because the light beam has a "proximity" range (less than or nearly equal to the aperture) over which its energy is almost constant.[3]

The very short working distance of the flying optical head requires that optical disk drive some

0-8194-0608-2/91/$4.00

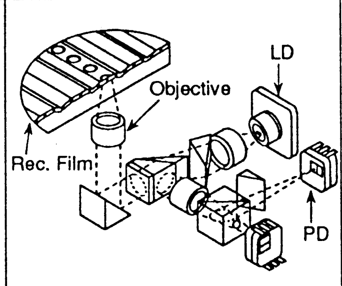
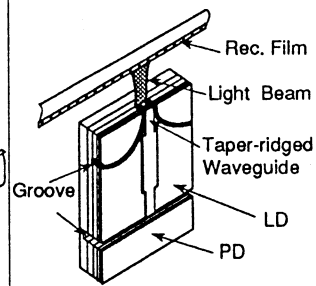
Type	Conventional Optical Head	Flying Optical Head
Configuration		
Features	· Expensive · Large & Heavy · Slow Access	· Inexpensive · Small & Light · Fast Access

Fig. 1. Comparison of conventional and proposed flying optical head.

kind of data insurance mechanism such as disk cartridge or disk enclosure. This insurance, however, can be provided by using techniques already developed for magnetic disks.

The present work examines the feasibility of an optical disk drive using a flying head made of only an LD-PD on a slider. We report its high signal-to-noise ratio and its high track density readout mechanism, thermal recording characteristics, and head/disk reliability. We also discuss the expected applications of the proposed flying head.

1. FEASIBILITY STUDY OF OPTICAL DISK DRIVE

1.1. Drive structure

A prototype drive consisting of the flying head and a phase-change medium disk is constructed for experimental purposes (Fig. 2). Figure 3 shows how the head is placed close to an SbTeGe recording medium. The laser diode (LD) monolithically integrated with a photodiode (PD) is mounted junction-up on a slider. Light reflects from the medium back into the active region of the LD. Head-medium spacing h (between the LD facet and the SbTeGe recording film) is about 2 µm: the sum of the slider flying height h_0, LD-PD attachment error h_1, and the protective layer thickness h_2.

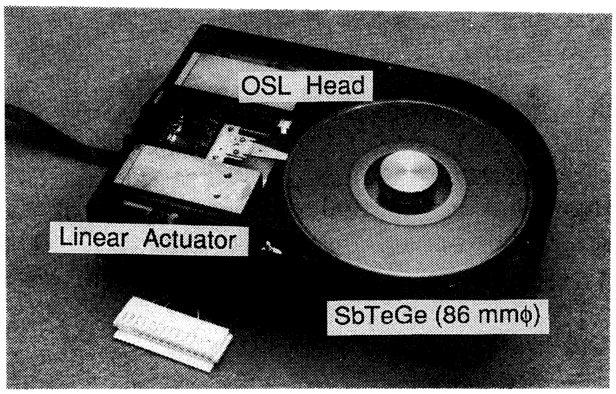


Fig. 2. Experimental drive using an OSL flying head and a phase-change recording medium.

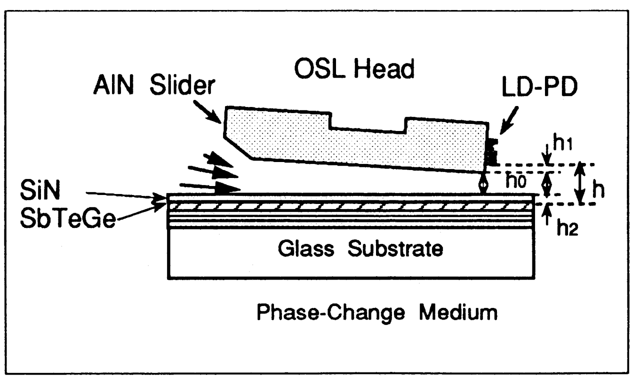


Fig. 3. Schematic diagram of the head/medium interface.

Autofocuse is accomplished by air-bearing technology, which determines the spacing and eliminates the conventional head focus servo system. Track following is driven by a single linear actuator movement, which presently limits the servo speed to less than 900 rpm.

1.2. Head structure

Figure 4 is an SEM photograph of the monolithically integrated LD-PD chip[4] with a wavelength of 1.3 μm. The LD is isolated from the PD by reactive ion beam etching (RIBE). The space between LD and PD is about 5 μm and the monitor current sensitivity is 0.1 mA/mW. The right side of this figure shows the 1.2-μm-wide taper-ridged waveguide on the laser facet. This waveguide on the top of the LD cavity was also fabricated by RIBE. Full widths at the half-maxima of its near field pattern are approximately 1 μm. This sharpened LD is useful for the flying optical head because it doesn't require an additional lens to converge the light beam, and hence doesn't lose power before reaching the recording medium.

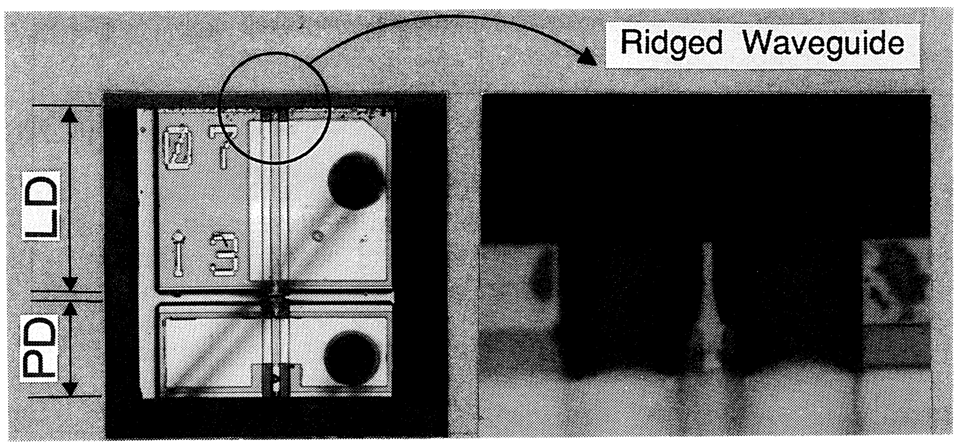


Fig. 4. Photograph of a monolithically integrated 1.3 μm-wavelength laser diode/photodiode (LD-PD) chip[4] with a taper-ridged waveguide[5].

A long-wavelength (1.3 μm) InGaAsP LD (reliable in the air) can be used in our flying head because its spot diameter is mainly constrained by the shape of the ridged waveguide.[5] A short-wavelength (0.83 μm) GaAlAs LD could be used if its facets were covered with dielectric protective films to prevent oxidation in air.

1.3. Medium structure

As shown in Fig. 3, the disk is made up of multiplelayers: SiN, SbTeGe, SiN, Au, SiN, and a glass substrate . The first SiN layer operates as a protective film[6] for a head-medium reliability. The SbTeGe layer serves as the phase-change recording medium. The second SiN layer and the Au layer enhance the reflectivity change and the thermal diffusion speed of the recording medium. The last SiN layer increases adhesion to the glass substrate. The reflectivity, transmissivity, and absorptivity of the as-deposited SbTeGe recording medium were 0.24, 0.22, and 0.54.

1.4. Basic read/write operation

The laser diode (LD) used in an optically switched laser (OSL) flying head forms a complex cavity with the recording medium acting as an external mirror. In Fig. 5 (a), R_1 and R_2 are the power reflectivities of the LD facets, and R_3^h and R_3^l are those of the two states for the external recording medium. R_2^{eff} is the effective reflectivity coupled with the external recording medium. Figure 5 (b) shows the light output versus bias current in the two medium reflectivity states. There are two threshold currents: I_{th}^h for high reflectivity (R_3^h) and I_{th}^l for low reflectivity (R_3^l). Information bits are read as the laser switches from P_R' to P_R, biased between I_{th}^h and I_{th}^l by the PD on the opposite side of the medium.[7] The reflectivity change due to an information bit on the recording medium changes the light output of the LD at a height of h.

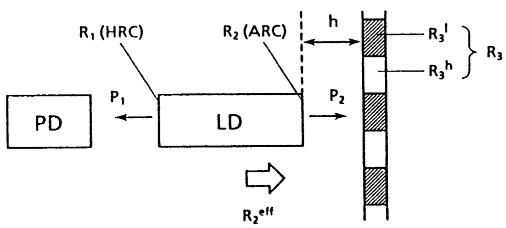
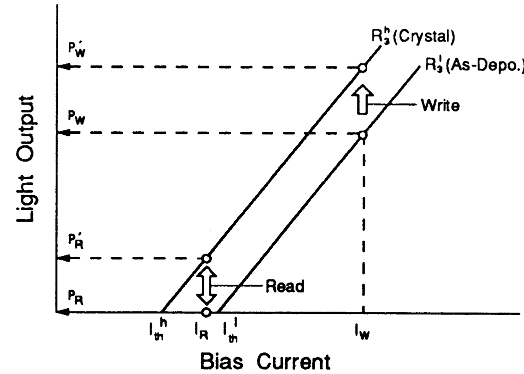


Fig. 5. (a) Detailed schematic representation of the OSL head. R_1 and R_2 are the reflectivities of the LD, and R_3^l and R_3^h are the reflectivities in two states for the external recording medium. R_2^{eff} is the effective reflectivity coupled with the external recording medium.



(b) Read/write operation for a phase-change medium with the OSL flying head. I_R is the read current and I_W is the write current. The medium has two reflectivity states, as-deposited and crystalized.

Information bits are written, in this experiment, as the laser-induced phase change shifts the medium reflectivity from R_3^l ("0": as depo. state) to R_3^h ("1": crystal state). During the write operation, the light output changes from P_w to P_w' at a fixed write current of I_w according to the reflectivity change. The light output difference P_R'-P_R (nearly eaqual to P_W'- P_W) is less than 1 mW, which doesn't destroy the information even if the medium stops. If the light output were 20 mW, the variation ratio in the write process would be only 5%. We, thereby achieve stable write operation.

To increase the signal-to-noise ratio (SNR)[8] and light output from the medium side laser facet, the medium side LD facet is coated with an antireflection film of $(SiO)_x(Si_3N_4)_{1-x}$[9].

2. READ MECHANISM

2.1. Data signal

Data signals are obtained by the light output difference due to the medium reflectivity. Varying the medium reflectivity R_3 as a parameter, Figure 6 plots the light output characteristics of the OSL flying head. These values are calculated for the steady state single-mode operation by using the rate equations.[7] The external cavity can be described[7] by replacing medium side laser facet reflectivity R_2 by effective reflectivity R_2^{eff}. The reflectivities R_2, R_3, and the transmission coefficient η are included in R_2^{eff}. We define the transmission coefficient as

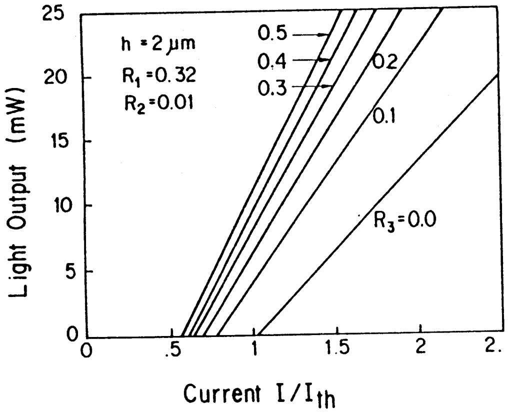


Fig. 6. OSL head light output characteristics with the medium reflectivity R_3 as a parameter.

$$\eta = \int_{-w_{p0}}^{w_{p0}} \int_{-w_{s0}}^{w_{s0}} I(2h)\, dxdy \,/ \int_{-w_p}^{w_p} \int_{-w_s}^{w_s} I(0)\, dxdy \qquad (1)$$

where $I(z)$ is Gauss beam power distribution, w_{p0} and w_{s0} are light beam radii ($1/e^2$) at the LD facet ($z = 0$), and w_p and w_s are the radii at $z = 2h$. The transmission coefficient η is a feedback light power ratio, which is the amount of feedback light power in the original output beam aperture. As for a Gaussian half-power beam. width 25^0 ($2w_{s0}$ = 1.3 μm) and 10^0 ($2w_{p0}$ = 2.54 μm), transmission coefficient η is 0.5 for h = 2 μm and 0.75 for h = 1 μm.

Since the LD facet reflectivity R_2 facing the medium is greatly reduced by an antireflection coating to improve the signal-to-noise ratio, the light output P_1 (photodiode side) differs from P_2 (medium side). The light output ratio for a complex cavity laser is calculated using effective reflectivity R_2^{eff} instead of laser facet reflectivity R_2.[10] Therefore,

$$P_2 / P_1 = (R_1 / R_2^{eff})^{1/2} (1 - R_2^{eff}) / (1 - R_1) \qquad (2)$$

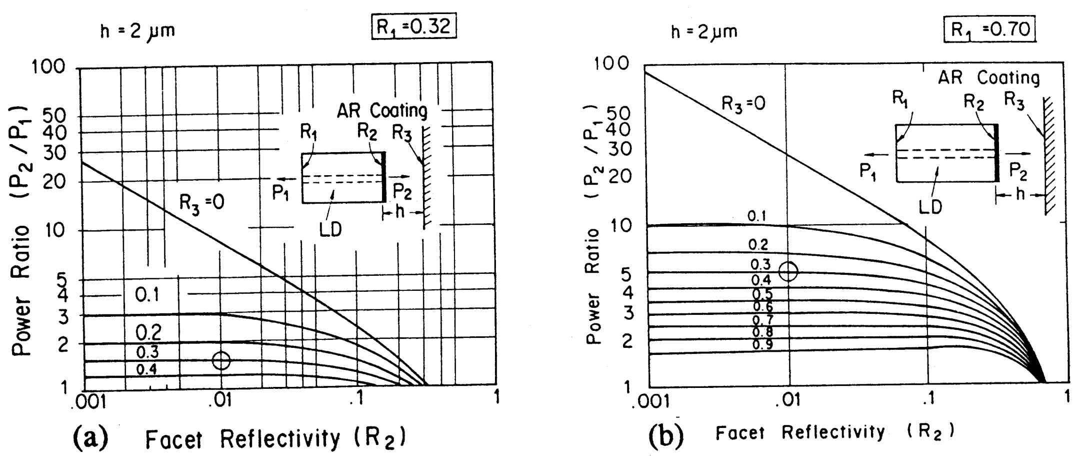


Fig. 7. Relationships between the power ratio and the medium side LD facet reflectivity for various medium reflectivities: (a) uncoated, (b) coated R_1 facet.

where,

$$R_2^{eff} = R_2 \left(1 + (1 - R_2)^2 R_3 \eta / R_2\right) . \tag{3}$$

With medium reflectivity R_3 as a parameter, Figure 7 shows the light output power - calculated by Eqs. (1),(2), and (3) - versus medium side laser facet reflectivity R_2. Figure 7 (a) shows that $P_2 / P_1 = 1.5$ for an uncoated facet R_1 with $h = 2\ \mu m$, $R_1 = 0.32$, $R_2 = 0.01$, and $R_3 = 0.3$. And Figure 7 (b) shows that $P_2 / P_1 = 5$ for a high-reflection coated facet R_1 with $h = 2\ \mu m$, $R_1 = 0.70$, $R_2 = 0.01$, and $R_3 = 0.3$. We used these ratios to estimate read/write power P_2 from the measured light output P_1.

2.2. Track error signal

Because our head has only one photodiode (PD), track error signals are obtained by the sampled servo method instead of the push-pull method for the continuous servo. Sampled servo method is expected to give good stability and compatibility.

Discrete block format (DBF)[11] marks with a 1.5-μm-track-pitch are reproduced by the OSL flying head as shown in Fig. 8. They are preformatted on the glass substrate in phase pits. The upper and the middle portions of this figure show three patterns, different in phase, that correspond to the wobble A, clock, and wobble B DBF marks. Each pulse composed of five

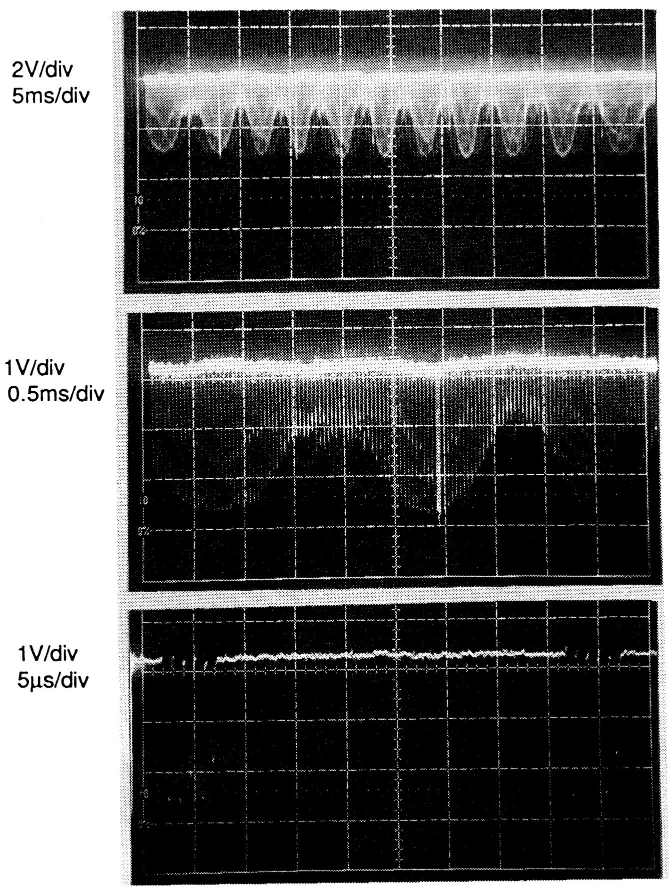


Fig. 8. Sampled servo format signals at 900 rpm. Laser diode bias current is 40 mA.

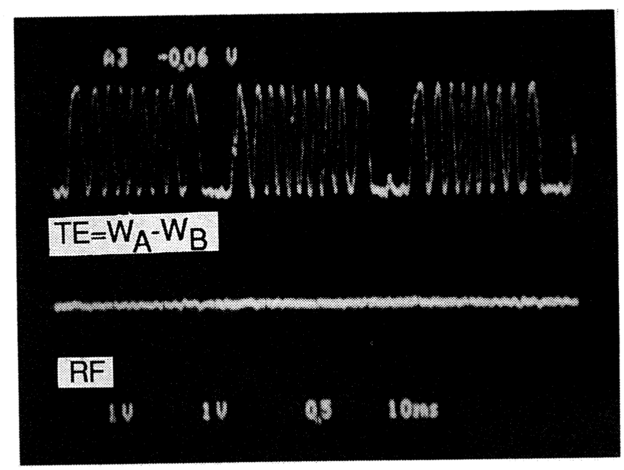


Fig. 9. Example of track error signal obtained by the signal amplitude difference between the two wobbling signals of the discrete block format.

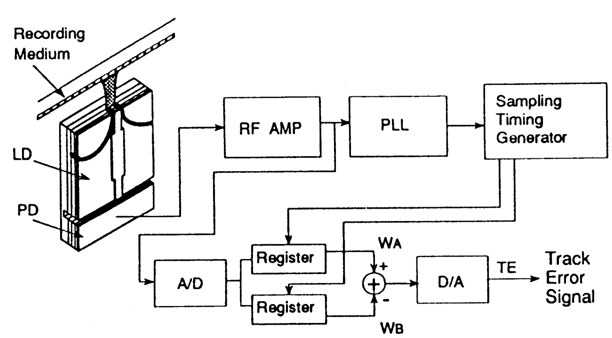


Fig. 10. Block diagram of track error signal detection.

peaks (as shown in the lower portion of the figure), represents the servo signals at the beginning of each 1672 block per revolution. The third and the fifth peaks are wobbling signals, whose marks are displaced +1/4 and -1/4 pitches from the track center. Track error signals were derived from the difference in signal amplitudes between the two wobbling signals (Fig. 9). Figure 10 is a block diagram of the track error signal ($TE = W_A - W_B$) detection system.

The reproduced track error signal confirms that the spot diameter of the lensless but taper-ridged waveguide[5] LD is small enough to reproduce the 1.5-μm track pitch DBF servo marks.

3. SNR IMPROVEMENT

3.1. Causes of SNR degradation

The signal-to-noise ratio (SNR) of the OSL flying head is high because of the large signal amplitude due to laser switching and the lack of feedback laser noise due to the external cavity being so much shorter (2 μm) than the LD cavity (250 μm). The SNR is degraded, however, by fluctuation of both high- and low-frequency light output. The former is caused by intensity laser noise due to mode competition, while the latter is caused by variation of head-medium spacing (external cavity length) and of temperature.

3.2. Reducing laser noise by optimizing bias current

The SNR degradation due to high-frequency laser noise can be reduced by increasing the difference between I_{th}^{l} and I_{th}^{h}, e.g., by reducing reflectivity of the medium side LD facet, and also by biasing the current between noise peaks located around threshold currents. This laser facet was therefore coated with an $(SiO)_x(Si_3N_4)_{1-x}$ antireflection film by ion beam sputtering using a high purity silicon target and mixed O_2-N_2 discharges. Figure 11 shows the reflectivity of different films obtained by controlling gas flow rates to minimize reflectivity. Reflectivities less than 1×10^{-4} were reproducibly obtained.[9]

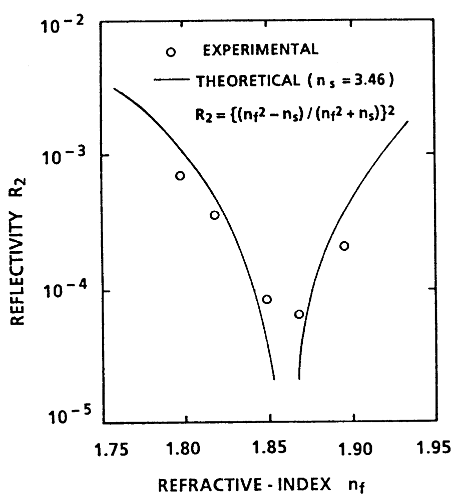


Fig. 11. Relationship between antireflection-coated (ARC) facet reflectivity and ARC-film refractive index. Circles show experimental results. Solid lines are fitting curves calculated using a plane wave approximation.

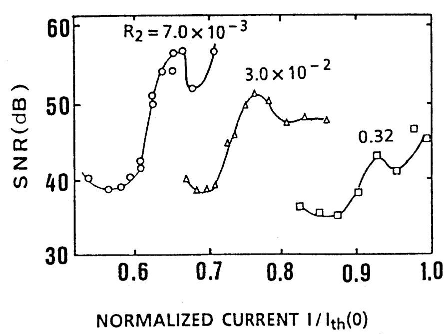


Fig. 12. Current dependence and effects of reflectivity on an OSL head SNR. The current is normalized by the original (uncoated) threshold current $I_{th}(0)$.

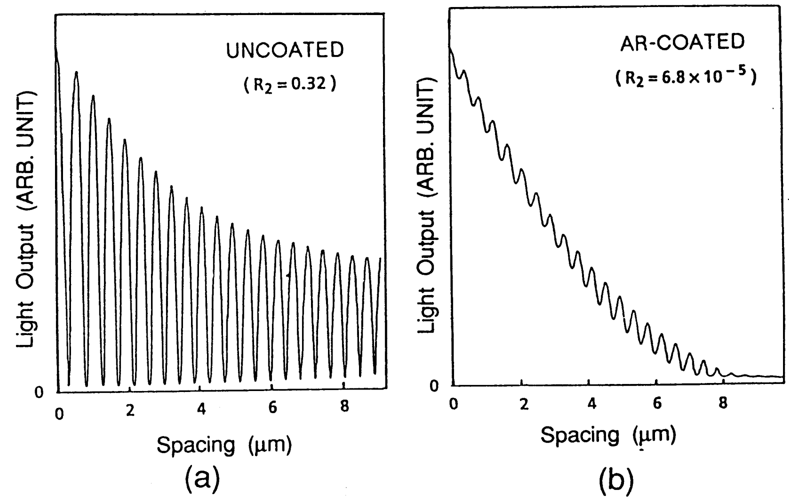


Fig. 13. Light output of a composite cavity laser as a function of spacing (external cavity length). (a) Light output varies by a half-wavelength period as the spacing varies. (b) Variation can be suppressed by an antireflection coating on the LD facet facing the recording medium.

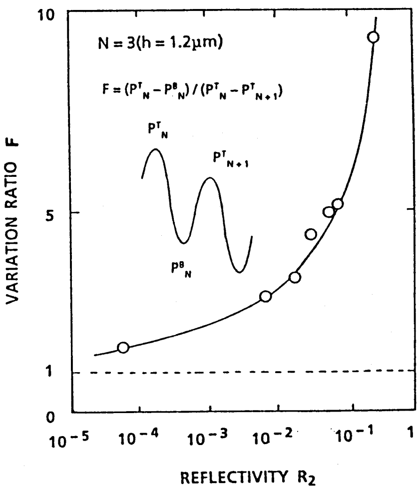


Fig. 14. Variation ratio versus facet reflectivity at the optimum bias current for OSL readout operation.

To ascertain the optimum drive condition, the data signal amplitude and the SNR were measured with effective noise defined as the rms of the noise spectrum from 40 kHz to 20 MHz. Figure 12 shows the effects of reducing facet reflectivity on SNR, plotted here as a function of current normalized to the uncoated laser threshold current $I_{th}(0)$: an SNR peak, corresponding to the noise valley, appears as facet reflectivity is reduced. This SNR peak, giving the optimum bias current, increases as reflectivity decreases. In a medium static condition, the SNR reaches 56 dB at a facet reflectivity of $R_2 = 7.0 \times 10^{-3}$. In a dynamic condition, it is 35 dB, which has been previously reported[12] to be adequate for an optical disk drive. Reflectivity of the coated facet was estimated from the amplified spontaneous emission spectrum by the Fabry-Perot modulation depth method.[13]

3.3. Reducing the variability of light output variation

3.3.1. Spacing

Degradation of the SNR due to variation of head-medium spacing can be compensated by reducing interference between the internal and the feedback lights. This can be done by reducing the reflectivity of the laser facet facing the recording medium.

Figure 13 shows a typical suppression of light output variation induced by reducing facet reflectivity (medium reflectivity R_3=0.30). The variation using an uncoated LD (left side) with a facet reflectivity of R_2=0.32 is extremely high due to strong interference between internal and feedback light, both of which have almost the same intensity. Using an antireflection-coated laser diode (right figure), on the other hand, with extremely low reflectivity of $R_2 = 6.8 \times 10^{-5}$ weakens interference and greatly reduces variation of light output.

Figure 14 shows the relationship between facet reflectivity R_2 and the variation ratio F, defined as the ratio of the amplitude change. The variation ratio decreases as facet reflectivity decreases. At a facet reflectivity $R_2 = 6.8 \times 10^{-5}$, the variation ratio was reduced to the extremely small value of 1.6 compared to 9.2 for an uncoated LD.

3.3.2. Temperature

The dotted line in Fig. 15 shows SNR degradation due to temperature. For the optimum current at room temperature, the SNR decreases by 10 dB as temperature increases from 15 to 45 ^{0}C. This is because bias current is constant, but the LD threshold current changes according to $I_{th}=I_0 \exp(T/T_0)$. Here, T_0 is a characteristic temperature. From 15 to 45 ^{0}C, the optimum current has been found to increase linearly with increasing temperature.[8] This means that SNR degradation can be prevented by linear control of the bias current (solid line).

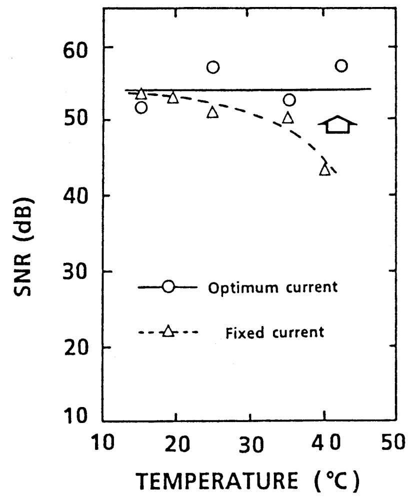


Fig. 15. Improvement in SNR, degraded by temperature, by controlling optimum current.

4. WRITE CHARACTERISTICS

4.1. Increasing thermal write power

Laser power density on the medium is increased not only by the taper-ridged waveguide laser, but also by the highly thermally conductive slider and the reduction of LD-PD attachment error. Figure 16 shows the dependence of LD-PD light output on the head-medium spacing h for AlN and sapphire sliders. Light output is higher for the slider with the higher thermal conductivity (AlN) than the lower thermal conductivity (sapphire). Not only the thermal property but also

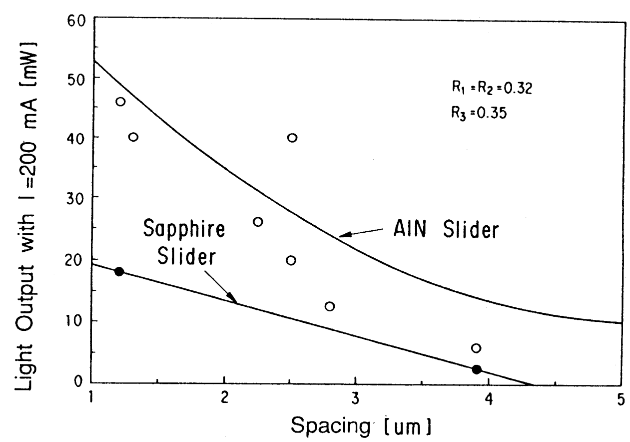


Fig. 16. Dependence of light output on LD-medium spacing $h(=h_0+h_1+h_2)$ for sapphire and AlN sliders.

the electrical properties, precise fabrication, and head/medium reliability must be considered when choosing a slider material. We used an AlN slider for the following experiments.

This figure also shows that as the head-medium spacing decreases the light output increases due to increased light feedback. The spacing h - set at 2 µm to keep the beam diameter bellow 1 µm - is the sum of the slider flying height h_0, LD-PD attachment error h_1 (facet-to-slider surface error due to mismounting), and the protective-layer thickness h_2. Since $h_0 = 0.9$ µm and $h_2 = 0.24$ µm in this experiment, h_1 must be <0.9 µm. We have developed a high-precision bonding machine to satisfy this requirement.[14] Length measurement accuracy is 0.1 µm with an autofocus mechanism, and moving resolution accuracy is 0.1 µm with electrically controlled motion.

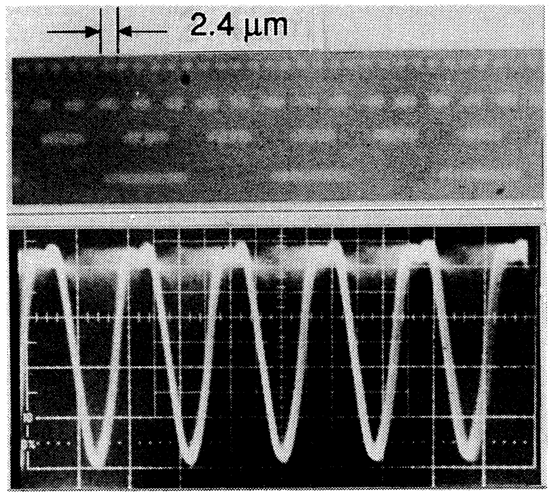


Fig. 17. Written bit patterns for 50% -duty-cycle 16-mW write power and reproduced signal at 1MHz.

4.2. Write performance

Figure 17 shows the dependence of write frequency on written bit patterns for 16-mW light pulses with a 50 % duty cycle. These bits were written as spots crystallized from the as-deposited state in this experiment. The phase change was caused by the thermal energy of the light output with a fixed write current. The upper portion of this figure suggests that both the bit shapes and the levels of crystalization are uniform. Bit pitch was 2.4 µm at a write frequency of 1 MHz. These bits are readout with a high SNR as the medium reflectivity changed between the two states (shown in the lower traces). The medium velocity here is 6.9 m/s. A detailed description of the flying head write characteristics will be reported elsewhere.[15]

5. HEAD/MEDIUM RELIABILITY

5.1. Protective layer material

In an actual disk drive, contact between the slider and the disk is inevitable. We therefore identify a combination of slider and protective layer materials that reduces wear (scratching) during contact start/stop (CSS).

We have investigated experimentally the protective films such as silicon-dioxyside (SiO_2), zinc-sulfid (ZnS), and silicon-nitride (SiN). We also evaluated their thermal conductivity for writing sensitivity and thermal expansion difference between the multi layers describved in 1.3. The SiN protective layer had smallest amount of scratch caused by repeated CSS with the AlN slider. Fabrication of the film was also studied with regard to internal stress and adhesion strength. The films, containing hydrogen atoms a-SiN:H (hydrogenated amorphous silicon nitride), showed good write sensitivity.[6] Its mechanical property is also good because it has a high tensile force and resists scratching.

5.2. Adhesion material on the LD facet

Figure 18 is an SEM photograph of the LD facet after 10,000 CSS cycles (900 rpm) in an office environment (class 350,000). The disk has an SiN / SbTeGe /SiN / Plastic substrate structure. Protuberance dust (particles) adheres to the LD facet.

The chemical composition of 12 randomly selected samples of protuberance dusts, analyzed by Auger electron spectroscopy, is primarily C, O, Al, Si, and S, that is, the dust element included in the air. The elements from slider and protective layer are included only two of the twelve dusts (samples). These results indicate a very small amount of slider/disk wear were

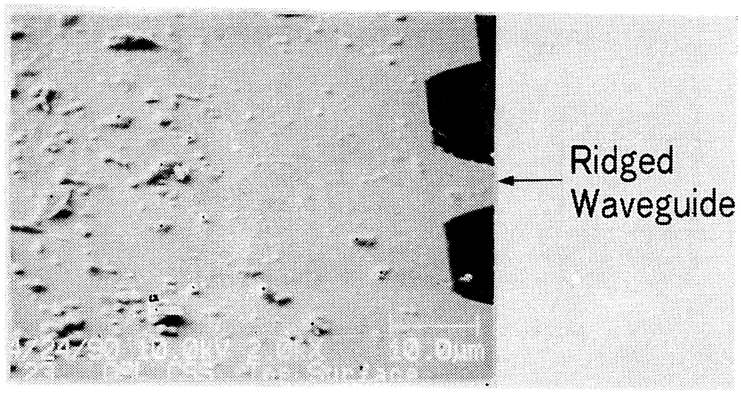


Fig. 18. SEM photograph of LD facet after 10,000 contact start/stop cycles in an office environment (class 350,000). The disk has SiN / SbTeGe / SiN / plastic substrate structure and used at low rotation of 900 rpm to accelerate the head/disk interface reliability test.

produced even if scratch on the medium can't be seen with an optical microscope.

5.3. Reliability test

The LD-PD reliability and the dust in the air is evaluated by free-running test at 3600 rpm, 4mW light power, and with h_0 =1 µm in an experimental room environment (class 30,000). Figure 19 shows the bias current for a constant signal amplitude versus running time. This head has a lifetime (before bias current increases by 20%) of 2040 hours. This corresponds to 4.4×10^8 passes, which is much more than the several million passes of a magnetic floppy disk lifetime.

Figure 20 shows a sample of contact start/stop (CSS) test: bias current for constant signal amplitude versus the number of CSS cycles. This figure shows that the head signal is still good after more than 50,000 cycles in a class 30,000 environment (30,000 particles larger than 0.5 µm / ft^3).

The main factors contributing to the high reliability of the head/medium interface are the oxidation-free InGaAsP LD-PD, the high thermal conductivity of the slider, and the low residual stress and high adhesion strength of the SiN protective layer on the recording medium. Moreover, as the laser diode facet is about 1 µm behind the slider surface, it does't directly contact the medium.

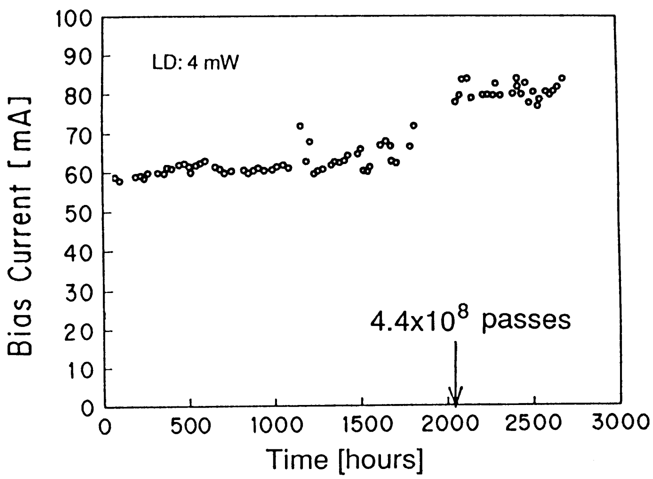


Fig. 19. Bias current for constant head signal amplitude vs. running time for a rotating disk of 3600 rpm in an experimental room environment (class 30,000).

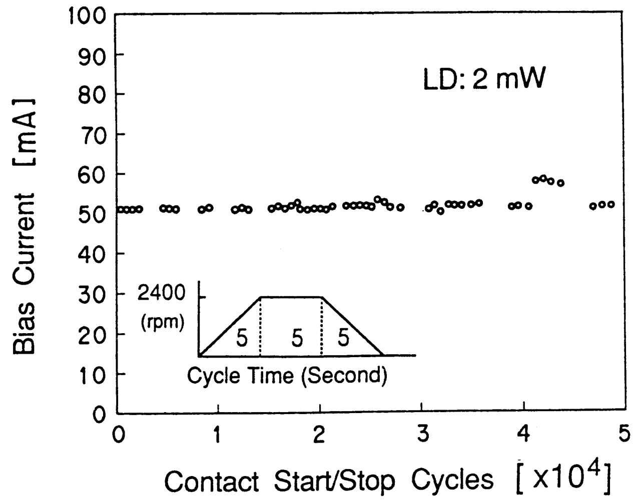


Fig. 20. Bias current for constant head signal amplitude vs. number of contact start/ stop cycles in an experimental room environment (class 30,000).

6. DISCUSSION ON THE FLYING OPTICAL HEAD APPLICATION

For high-capacity low-traffic random-access file storage of multimedia data, an optical disk is more effective than a magnetic disk.[16] The slow access of conventional optical disks is mainly due to the size and mass of the optical head. Fast access and high-speed data transfer are nevertheless important, especially for computer periheral data storage.

The flying optical head is free from the head-size problem arising from substrate thickness. The thinness and low cost of a flying optical head makes it possible to have stacked several disks, each surface of which has more than one head, on a single spindle. The flying head's near field recording, however, makes it difficult to use removable media because dust in the air must be avoided.

This feasibility examination and analysis will open a way to designing the following storage devices:

1) a super-thin and small optical disk drive.
2) a high-performance stacked-type optical disk drive.

The former will compete with 2 ~ 3.5 inch magnetic disks (MDK). But, it will be able to exceed MDK performance by using removable recording media. The latter should be combined in a sealed disk drive and, hence, used in the same fields that presently use the MDK. Compared with the present MDK, this ODK has (1) a ten times higher flying height, which makes it more reliable, and (2) a five times higher area recording density, which lowers bit cost.

Our present ODK has almost the same recording density as today's ODK and will soon have almost the same access time as today's MDK. Track following, however, is slow (900 rpm). Product manufactureres say that introducing a completely new system to the marketplace requires a performance level an order of magnitude higher than that of the conventional system. Before the flying optical head can provide this kind of performance, some problems must be solved:

1) track following at more than 3,000 rpm.

2) assuring the future growth in recording density.

3) ascertaining the applications not only for the phase-change medium[17] but also for the magneto-optical medium.

7. CONCLUSIONS

A super-small optical head with only a laser diode/photodiode on a slider shows excellent read/write characteristics and reliability. An antireflection-coated laser diode combined with a taper-ridged waveguide has a high-SNR readout and high-resolution write-down performance. An oxidation-free InGaAsP laser diode (λ=1.3 μm), a high-thermal-conductivity AlN slider, and an SiN protective layer (0.24 μm) on a phase-change recording medium contribute to the high reliability of this flying optical head.

Demonstration of this flying optical head's performance shows the feasibility of the following type disk drives: a super-thin and low-cost type for personal use, and a multiple-platter high-capacity type for high-performance use. For personal use, some kind of cartridge mechanism or dust-wiping method should be developed to allow removal and replacement of the recording medium. For high-performance use, a high-speed track following method and/or a multibeam head should be developed.

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9. REFERENCES

1. H. Ukita, Y. Isomura and H. Tanaka, "An optically switched laser (OSL) head for optical recording," Proc. SPIE **1139**, *Optical Storage and Scanning Technology*, pp.142-148, 1989.

2. H. Nishihara, "Recent studies of miniaturization of optical disk pickup in Japan," Proc. SPIE **1248**, *Storage and Retrieval Systems and Applications*, pp.88-95, 1990.

3. U. Durig, D.W.Pohl, and F. Rohner, "Near-field optical-scanning microscopy," J. Appl. Phys. **59** (10), pp.3318-3327, 1986.

4. M. Ueki et al, "Laser Monolithically Integrated with a Photo-detector (1)," Natl. Conf. Rec. IEICE, C-192, p.4-132, 1989 (In Japanese).

5. Y. Uenishi, Y. Isomura, R. Sawada, H. Ukita and T. Toshima, " Beam Converging Laser Diode by Taper Ridged Waveguide," Electronics Letters, **24**, 10, pp.623-624, 1988.

6. Y. Sugiyama, S.Fujimori, H.Yamazaki and I. Hatakeyama, "Protective films prepared by the electron resonance plasma chemical vapor deposition technique for phase-change type optical disks," Appl. Phys. Lett., **56** (15), pp.1403-1405, 1990.

7. H. Ukita, Y. Katagiri and Y. Uenishi, "Readout Characteristics of Micro-optical Head Operated in Bi-stable Mode ", *Proc. Int. Symp. on Optical Memory,* Jpn. J. Appl. Phys., Suppl. **26-4**, pp.111-116, 1987.

8. Y. Katagiri and H. Ukita, "Improvement in signal-to-noise ratio of longitudinally-coupled cavity laser by internal facet reflectivity reduction," *Proc. Int. Symp. on Optical Memory,* Jpn. J. Appl. Phy., Suppl. **28-3**, pp.177-182, 1989.

9. Y. Katagiri and H. Ukita, "Ion beam sputtered $(SiO_2)_x(Si_3N_4)_{1-x}$ antireflection coating on laser facets produced by using O_2-N_2 discharges," Appl. Opt. **29**, 34, pp.5074-5079, 1990.

10. M. Ettenberg, H. S. Sommers, Jr., H. Kressel ang H. F. Lockwood, " Control of Facet Damage in GaAs Laser Diodes," Appl. Phys. Lett. **18**, 12, pp.571-573, 1971.

11. N. Eguchi, M. Tobita and M. Ogawa, "An 86 mm Magnetio-Optical Disk Drive with Compact and Fast-Seek time Optical Head," *Conference Digest of Optical Data Storage Topical Meeting*, pp.2-5, 1990.

12. H. Ukita, Y. Katagiri and S. Fujimori, "Supersmall Flying Optical Head for Phase Change Recording Media," Appl. Opt. **28**, 20, pp.4360-4365, 1989.

13. I. P. Kaminow, G. Eisenstein and L. W. Stulz, " Measurement of the Modal Reflectivity of an Antireflection Coating on a Superluminescent Diode," IEEE J. Quantum Electron., **QE-19**, pp. 493-495, 1983.

14. H. Nakada, R. Sawada, Y. Isomura and S. Hara, "Fine Precision Bonding Machine for Optical Parts," *Proc. of JSPE Autumn Meeting,* H31, pp.777-778, 1990 (In Japanese).

15. to be published in Appl. Opt., 1991.

16. K. Ishii, T. Takeda, K. Itao and R. Kaneko, " Mass Storage Technology in Networks," Proc. SPIE **1248**, *Storage and Retrieval System and Applications*, pp.2-9, 1990.

17. M. Terao, Y. Miyauchi, K. Ando, H. Yasuoka, and R. Tamura, " Progress of Phase-Change Single-Beam Overwrite Technology," Proc. SPIE **1078**, *Optical Data Storage Topical Meeting*, pp.2-10, 1989.

Flying head read/write characteristics using a monolithically integrated laser diode/photodiode at a wavelength of 1.3 μm

Q: What CNR is now being obtained for a given mark length and data rate? What are the specific tracking issues that need to be addressed and solved for 3600 RPM? Is contamination a serious issue, in practice, for your flying head?

A: We have obtained, for example, 50 dB for a 7-μm bit length at 1 MHz. We haven't tried to obtain the maximum value yet.

I can only provide a partial answer to the second question. We have two ideas: one is a fine micro-actuator, such as a PZT, on the slider or on the arm of the main actuator for track seek. The other is to use a laser diode with beam deflector. I think an electric actuator, such as a laser beam deflector, is preferable to a mechanical actuator, such as a PZT.

As for the last question, contamination may be a problem for removable media, but personall I think it can be avoided if we apply some kind of wiping mechanism and head lifting mechanism. For more prctical applications, the thinness and low cost of the flying head make it possible to have several disks stacked on a single spindle in a sealed disk drive just like a magnetic disk.

Q: Is there any particular reason why you work in the 1.3 μm region other than the technology availability? Is there any plan to change the wavelength region later?

A: We used a 1.3-μm long-wavelength Indium Gallium Arsenic Phosphorus laser diode because it is stable and oxidation-free in air and its spot diameter (near field pattern) is mainly constrained by the shape of the ridged waveguide. The oxidation-free characteristics are very important, especially when the laser diode is used at a high power output for thermal writing.

A 0.8-μm-wavelength Gallium Aluminum Arsenic laser diode could be used if its facets were covered with dielectric protective film to prevent oxidation in air because the shorter the wavelength, the greater the recording density.