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Improvement in Lasing Properties of an Integrated Flying Optical Head with a Diamond-Film-Coated Slider

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The heat dissipation in a junction-up mounted 1.3-μm-wavelength InGaAsP laser diode/photodiode on a flying optical head slider is analyzed by infrared microscopy. The temperature rise is reduced by about 50% for a slider with a diamond film. This reduction corresponds to a 27-fold increase (31°C temperature drop) in the lifetime of the laser diode and confirms the possibility of head operability in multilaser diodes on a slider.

KEYWORDS: integrated flying optical head, diamond-film-coated slider, 1.3-μm-wavelength InGaAsP, thermal conductivity, multibeam, laser power increase, lifetime, optical disk memory

§1. Introduction

Optical recording technology has been applied to specific areas such as (1) document/image file systems[1)] for office, medical and ethnology use, (2) network file systems[2)] and (3) cards as portable medical records.[3)] It, however, has not yet replaced magnetic recording technology. The main reasons for this are due to its low performance in high-end applications, high price and large size for low-end applications. In order to replace magnetic recording devices, optical recording devices must provide such specifications as high-speed access for magnetic disks, a high data transfer rate for magnetic tapes, and a low price for floppy disks.

One of the candidates for facilitating this change is the integrated flying optical head used with a phase-change recording medium.[4)] We have already reported on its high-quality read/write and reliability characteristics.[5)] This supersmall flying optical head operates like a magnetic head: air-bearing technology is used to stabilize the slider flying height at about 1 μm for autofocusing, and a track-seeking actuator controlled by a sampled servo track error signal is used for following the track. The slider is also used as the heat sink of a laser diode. Heat dissipation is essential to the slider to increase the laser power, to prolong the laser diode lifetime and to increase the bit transfer rate by a multibeam operation.

The present work examines the feasibility of a flying head with a diamond-film-coated slider for heat dissipation. We examine its cooling effect with air flow, read/write operation, and 20,000-cycle contact start/stop operation.

§2. Light Power Increase for a Flying Optical Head

The typical construction of an integrated flying optical head is shown in Fig. 1. A monolithically integrated laser diode/photodiode (LD-PD) chip with a wavelength of 1.3 μm is mounted junction-up at the tailing edge of the flying slider. Full widths at half-maxima of a taper-ridged waveguide laser[6)] in the near field are approximately 1 μm on the recording medium. Laser light output power is limited by the temperature due to the heat produced in the active region of the laser diode.

Figure 2 shows the dependence of LD-PD light output on the head-medium spacing for aluminum nitride (AlN) and sapphire sliders. The light output is higher for the slider with the higher thermal conductivity (AlN) than that with the lower thermal conductivity (sapphire). 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

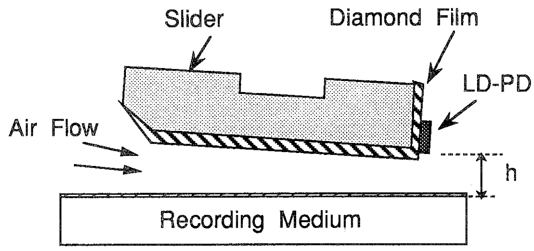

Fig. 1. Cross-sectional view of an integrated flying optical head with a diamond-film-coated slider.

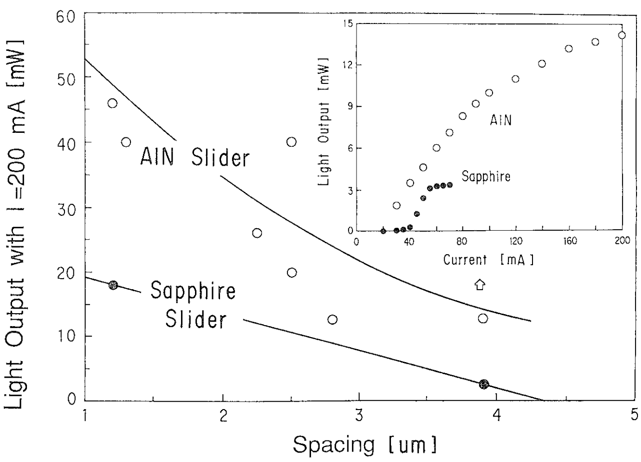

Fig. 2. Flying head light output vs laser diode-medium spacing for sapphire and AlN sliders. The reflectivity of both laser diode facets is 0.32 and the reflectivity of the recording medium is 0.35.

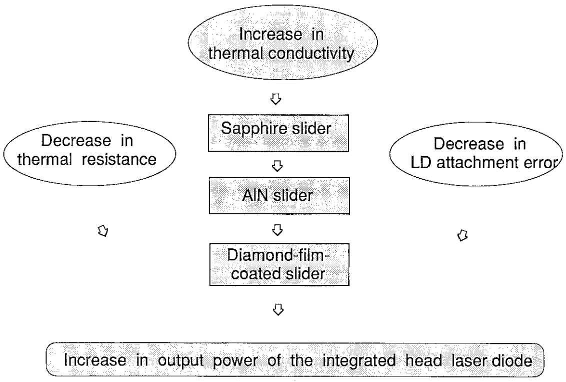

Fig. 3. Method of increasing laser diode output power for an integrated flying optical head.

Table I. Thermal conductivity of slider materials.

Material	Thermal conductivity (W/mK)
Diamond	2000
SiC	270
AlN	180–260
Sapphire	30

diameter below 1 μm, is the sum of slider flying height h_0, LD-PD attachment error h_1 (facet-to-slider surface error due to mismounting), and medium 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.*

Laser power density on the medium is increased not only by the thermal resistance and laser diode attachment error decrease but also by the thermal conductivity increase of the slider (heat sink), as shown in Fig. 3. Table I shows the thermal conductivity of slider materials. We expect the diamond film on the slider to be effective in dissipating heat.

§3. Flying Optical Head with a Diamond Film Coated Slider

3.1 *Diamond film preparation*

Figure 4 shows the slider fabricated with a diamond film. The diamond film was evaporated by heat filament chemical vapor deposition (CVD)[7] using CH_3OH and H_2 gas mixtures both on the flying surface where air passes through and at the trailing edge where an LD-PD (heat source) was attached (Fig. 1). Note that the tantalum (Ta) filament temperature may reach 2000°C and the slider surface temperature may be 700–1000°C due to the effect of radiation. The diamond film growth speed was about 10 μm/hr. On the surface of the diamond film, a good adhesive strength sputtered metallized layer (Ti/Pt/Au: 1 μm thick) and an evaporated solder layer (AuSn: 4 μm thick, melting point: 280°C) were prepared before the LD-PD was bonded.

*H. Nakada, R. Sawada, Y. Isomura and S. Hara: *Proc. of JSPE Autumn Meeting*, H31 (1990) p. 777 [in Japanese].

3.2 *Observation of diamond film surface*

Figure 5 shows the diamond surface roughness (a) before and (b) after mechanical lapping/polishing with diamond powders of 2/0.5 μm. The surface roughness was much improved by the polishing from 5 μmRmax to 0.1 μmRmax. The diamond film thickness was estimated to be about (a) 50 μm and (b) 25 μm, respectively.

3.3 *Optical head performance*

Figure 6 shows (a) the flying surface of the integrated optical head and (b) the reproduced signals obtained by the head. The slider corners were not rectangular because

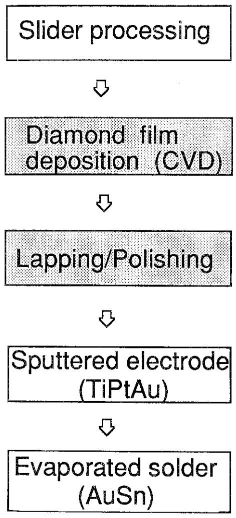

Fig. 4. Fabrication process of a diamond-film-coated slider.

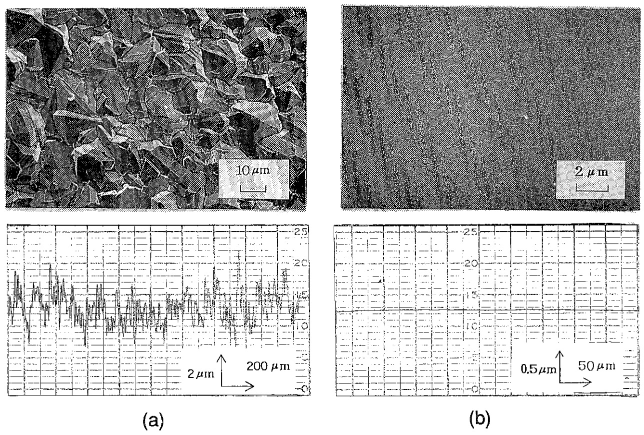

Fig. 5. Observation of the slider/surface (a) before and (b) after mechanical polishing.

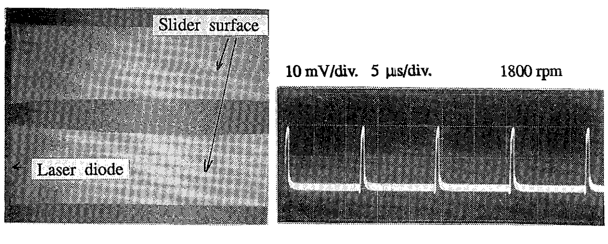

Fig. 6. Photograph of an integrated optical head with a diamond-film-coated slider and its reproduced signals.

the slider edges were not lapped in this case. These bits are read out at 1800 rpm with a high signal-to-noise ratio, using the optically switched laser diode, due to medium reflectivity change. As for the contact start/stop test using a diamond-coated slider and silicon nitride(SiN)-coated SbTeGe recording film[8] on a glass substrate, we obtained 20,000 cycles. From the result obtained above, we found that the diamond-film-coated slider can be applied to a flying optical head if its surface is polished before use.

§4. Thermal Analysis with an Infrared Microscope

Theoretical thermal analysis[9,10] in a laser diode and experimental temperature measurement in it using laser Raman spectroscopy[11] were made for an ordinary heat sink, but neither was performed for the flying-type slider heat sink. In this section, experimental thermal analyses for various kinds of sliders are carried out using infrared microscopy to remove the heat generated by a laser diode.

4.1 *Thermography*

The temperature on a laser diode facet and on a slider surface was measured with an infrared microscope, as shown in Fig. 7. The measurement was made without contact by collecting the infrared radiance at each point (painted black) through raster scanning.

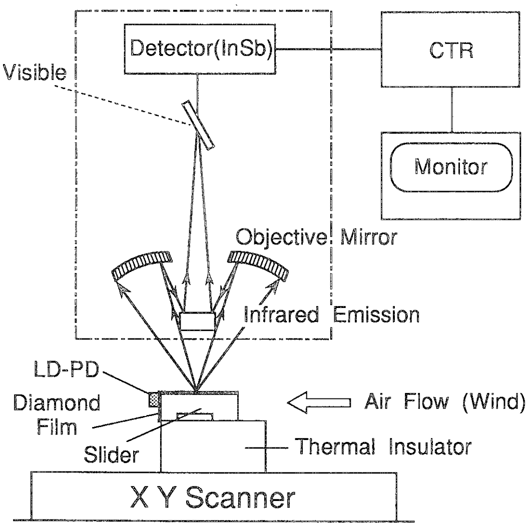

Fig. 7. Optical layout of the experimental system for measuring temperature distribution in a head slider under a cooling wind corresponding to the air flow between the slider and the recording medium.

Figure 8 shows an infrared microscope temperature image on a sapphire slider surface (a) without air flow and (b) with air flow at a drive current of 100 mA. The laser facet can be seen at the lower left portion (cross mark, point i) in each figure, and it has the maximum temperature because of the heat generation at the point. It can be seen from the photograph that the temperature is greatly reduced and becomes almost uniform over the entire slider surface as a result of the air flow.

4.2 *Temperature pattern analysis*

Figure 9 shows a thermal profile of a 1.3-μm-wavelength InGaAsP laser diode facet and of an AlN slider surface with a spatial resolution of 20 μm. The temperature decreases rapidly from the junction-up mounted laser diode active region and reaches an almost constant value over the entire slider surface. The temperature difference between the active region and the slider surface was found to be about 20°C for the sapphire slider, and about 10°C for the AlN slider when $I=100$ mA. These values were almost the same in the respective cases, regardless of the air flow (wind velocity v). Great temperature uniformity (±1°C) was obtained on the large conductivity heat sink of AlN.

As for current, temperature was a linear function of the laser diode drive current (Fig. 10).

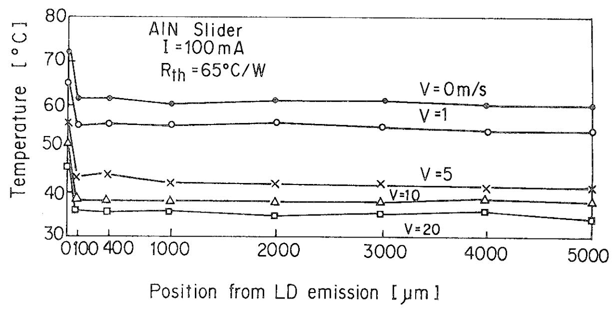

Fig. 9. Temperature distribution on a laser diode facet and on a diamond-film-coated slider.

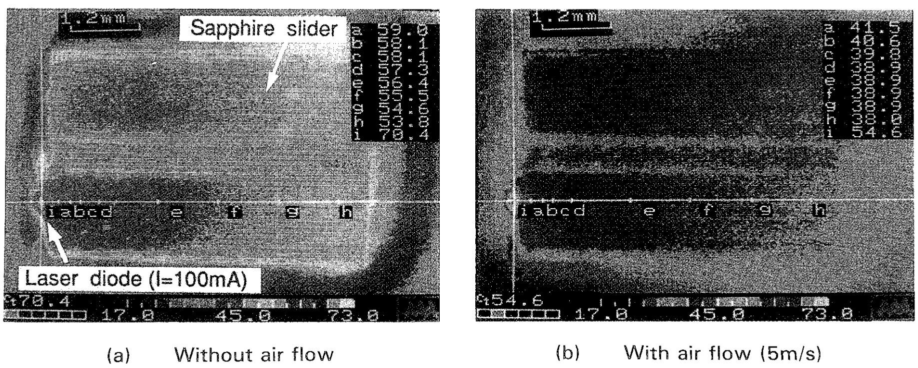

Fig. 8. Thermal profile on an integrated flying optical head (a) without air flow and (b) with air flow ($v=5$ m/s).

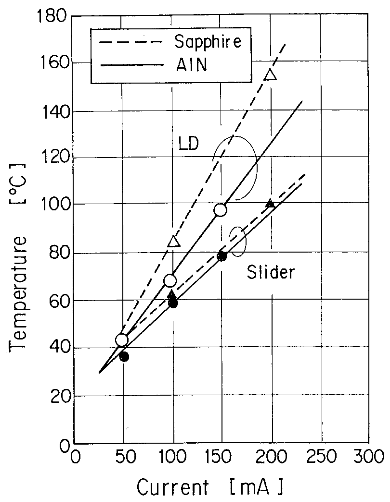

Fig. 10. Temperature vs drive current for sapphire and AlN sliders.

4.3 *Air flow effect*

Air flow occurs due to the rotation of an optical disk. The temperature decrease for various air flow velocities (-wind velocity v) on the laser diode (LD) junction and on the slider surface is shown in Fig. 11. The air flow effect was found to be very effective even for a slow wind velocity (rapid temperature decrease occurrence at less than 5 m/s).

4.4 *Use of a diamond-film-coated slider*

The above experimental results provide the following thermal dissipation image. First of all, the heat flux from the laser diode active region reaches the slider (heat sink), then spreads over the entire surface because of high thermal conductivity, and finally is removed by the air flow due to disk rotation. The much-higher-conductivity diamond film on the surface of the slider is expected to be more effective in dissipating heat. It can be seen from Fig. 12 that temperature is nearly equal for diamond-coated sliders with different thermal conductivities of

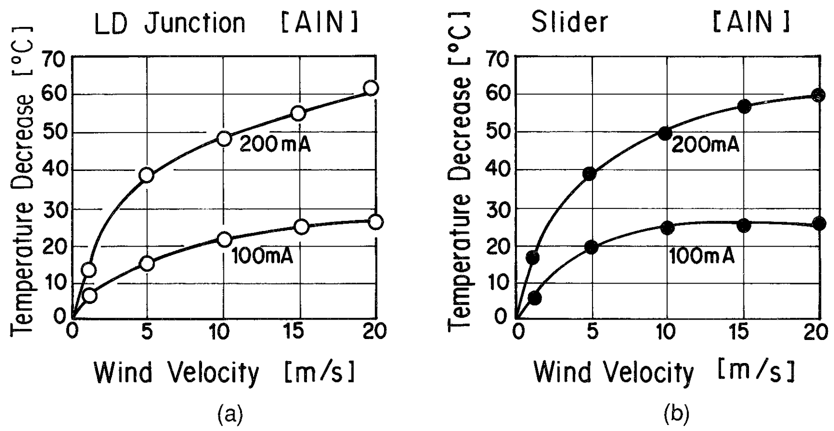

Fig. 11. The effect of air flow on temperature decrease on (a) the laser diode facet and on (b) the slider surface.

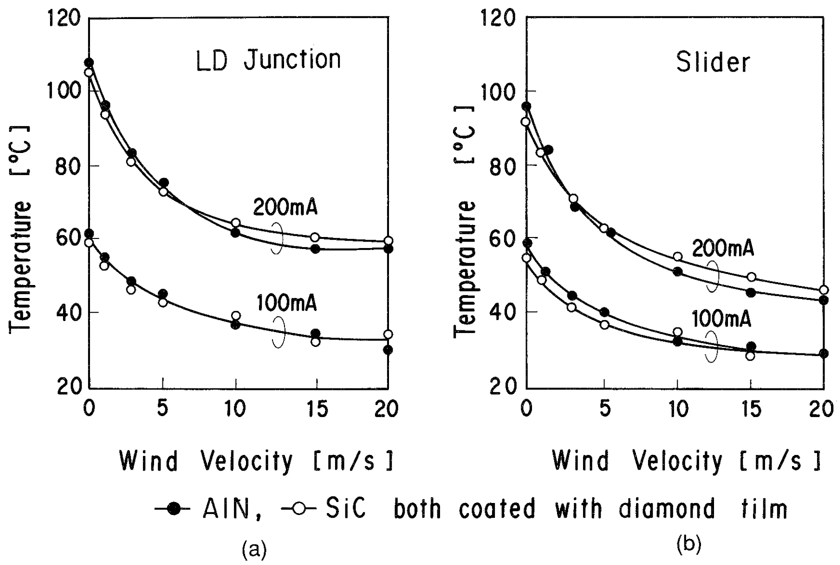

Fig. 12. Temperature vs wind velocity for (a) the LD junction and (b) the slider. Temperature is nearly equal for diamond-film-coated sliders with different thermal conductivities. Diamond film plays the main role in removing heat.

AlN and SiC. Diamond film plays the main role in removing heat.

Figure 13 shows the laser diode junction (LD) temperature versus wind velocity for sapphire, AlN, and diamond-film-coated AlN sliders. About a 10°C temperature drop occurs for each slider due to the thermal conductivity difference (Table I). Figure 14 shows the temperature decrease in (a) the laser diode junction and in (b) the slider with different materials. The notation is shown in the upper right portion of the figure. A junction temperature decrease of 31°C was obtained when a diamond film was coated on an AlN slider where $I=200$ mA and $v=20$ m/s. According to Arrhenius' equation for a 0.8 eV activation energy, this temperature decrease corresponds to a 27-fold increase in the lifetime of the laser diode.

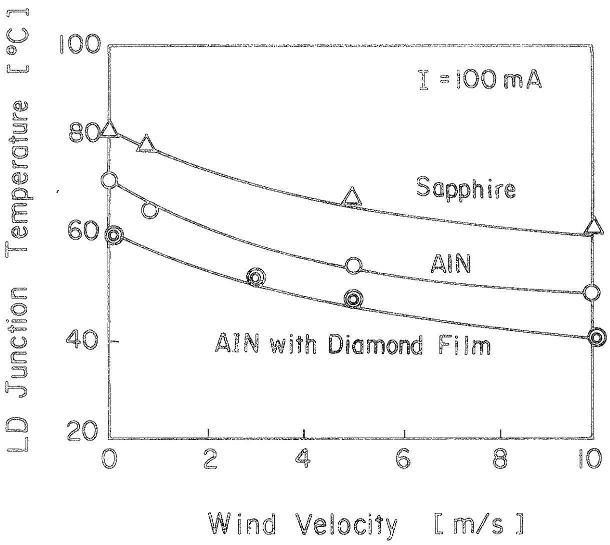

Fig. 13. Laser diode (LD) junction temperature vs wind velocity for sapphire, AlN, and diamond-film-coated AlN sliders.

§5. Conclusions

A significant reduction in temperature rise was achieved through the spreading of heat using a diamond film on a slider surface. A high-thermal-conductivity diamond-coated slider allows us to operate a laser diode on a flying optical head at less than 50°C (compared to 81°C for an AlN slider without diamond film), at a drive current of 200 mA and at a medium velocity of 20 m/s. If operated at 70 mA, more than three laser diodes can be located on the same slider. Demonstration of the diamond-film-coated slider head's read/write operation shows the feasibility of a multibeam head for high-performance optical disks.

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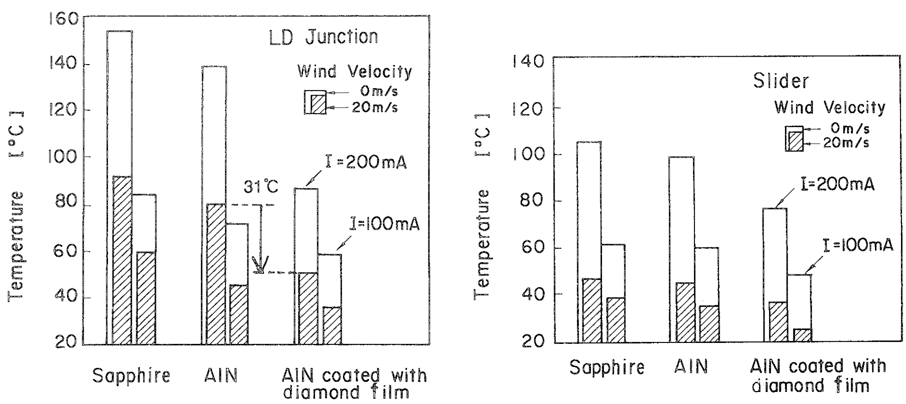

Fig. 14. The effect of slider material and wind velocity on temperature rise in (a) the laser diode junction and in (b) the slider for two drive currents.