Laser Diode Active Height Control System for Data Storage Applications

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ABSTRACT

We describe and characterize an active height control system for near-field data storage applications using a commercial laser diode as a direct position sensor. The self-mixing interference signal was experimentally characterized and the effective spot size of the laser sensor was also measured. A control system utilizing interference in the laser as feedback signal was constructed to drive a conventional DVD pickup with the laser sensor mounted. The residual position error is ±9nm when the rotation speed of a glass disk was 1500rpm and the vertical runout was 16μm. The approach limit was estimated to be 25nm when the laser size is reduced to 100μm.

Keywords: Nano-scale control, self-mixing effect, near-field recording, optical recording

1. INTRODUCTION

Near-field recording is a promising approach to achieving higher storage densities. However this requires that either a light source or an objective lens must approach the medium to within nanometer distances. Therefore, for a removable medium storage system, servo control is a critical technology to maintain the nano-scale distance of separation between objective lens or light source and the medium. Both Sony and Philips have demonstrated servo control systems for solid immersion lenses that operate in the near-field with a constant air gap of less than 30nm [1-5].

We have proposed an alternative solution using direct laser diode feedback [6]. By employing the self-mixing effect [7], the laser diode functions as a position sensor to detect the distance between the laser and the target surface. This method not only eliminates the optical path but may also be integrated with near-field light sources such as sub-wavelength apertures and very small aperture lasers (VSAL) [8-10].

In this paper, we describe our active height control system employing a conventional commercial laser diode and DVD biaxial pickup. The characteristics of the laser diode as position sensor are investigated, we describe the servo signal characteristics and characterize the effective spot size. Finally, the minimum laser to surface distance that this system can achieve is estimated.

2. SYSTEM CONFIGURATION

A laser diode may be used as a position sensor by employing and sensing self-mixing interferometry. In the system configuration shown in Fig. 1(a), the disk surface and the laser diode output facet function as an external cavity Fabry-Perot interferometer. A part of the light emission from the laser is reflected by the disk surface and then injected back into the laser cavity. The reflected beam is mixed with the optical field inside the cavity. This self-mixing effect causes strong modulation of the optical output power, and is dependant on the distance between the reflecting surface and the laser and is detectable by the photodiode in the laser package. Therefore, the laser diode itself can function as a direct high-accuracy position sensor and thus no external optical interferometer is required. Given the highly sensitive correspondence between the gap width and the optical power output, this laser position sensor can be used to determine

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the gap width with nanometer scale precision. The monitor current from the photodiode is used as the feedback signal to control the pickup and hence gap distance.

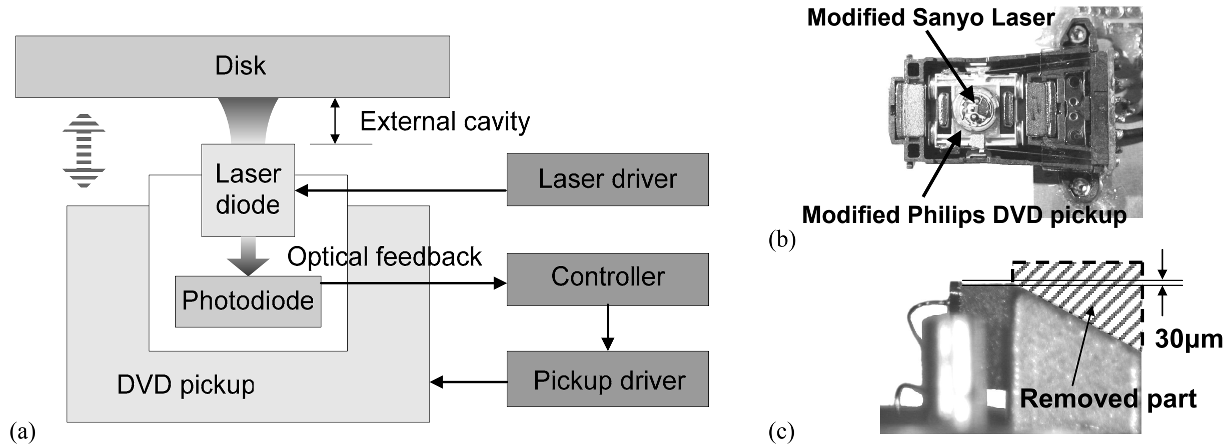

Fig. 1 (a) System configuration, (b) photo of the pickup with laser diode mounted and (c) side view of modified laser package

This system comprised, a commercial Sanyo laser diode, DL3148-025, with λ=635nm and a maximum output power of 5mW mounted on a conventional DVD pickup provided by Philips, as shown in Fig. 1(b). The laser was driven by a Melles Griot laser diode driver, 06 DLD 203A, and the signal from the photodiode was sent to the analog-to-digital input port of a dSPACE DS1103 system in which the controller was implemented. To actuate the pickup the drive signal from the dSPACE system was converted into a current signal by the pickup drive circuit.

To bring the laser close to the disk surface and into the near field, some modifications were made to the commercial laser mount. Fig. 1(c) shows a side view of the modified laser diode mount. In addition to the cap that was removed from the standard package, the corner of the stem was filed to obtain a 30-μm clearance between the package and the top of the laser.

3. LASER CHARACTERIZATION

3.1 Feedback signal characterization

To characterize the feedback signal, a silicon wafer coated with an aluminum film was placed in close proximity to the output facet of the laser diode. The laser diode was fixed in a mount attached to a piezo actuator that provided a back-and-forth motion to generate the interference signal waveforms. The experimental setup is shown in Fig. 2(a). According to the optical alignment method that we developed, angular alignment precision between the two surfaces was within 50μrad.

The monitor current of the photodiode was converted into a voltage signal and then displayed and saved by the digital oscilloscope. The measured result is shown in Fig. 2(b) when the operating current was 35mA and the sampling rate was 10ks/s. The signal is a periodic function of the distance with the maximum amplitude of 0.37V and the pitch, a complete interferometric fringe, corresponds to a displacement of $\lambda/2$, which is 317.5nm in this case. The asymmetry in the shape of the signal identifies the direction of motion. Although within a fringe, the signal varies nonlinearly with respect to the displacement, it can be approximated as a linear function in the middle half region, as indicated in Fig. 2(b). The slope of the linear function represents the sensitivity of the signal with respect to the distance variation and also implies the distance resolution that the laser sensor can achieve. According to the signal amplitude and the pitch, the slope in the linear region of this laser sensor is 6mV/nm. Compared to the noise level of this system, a theoretical accuracy of less than ±1nm can be achieved.

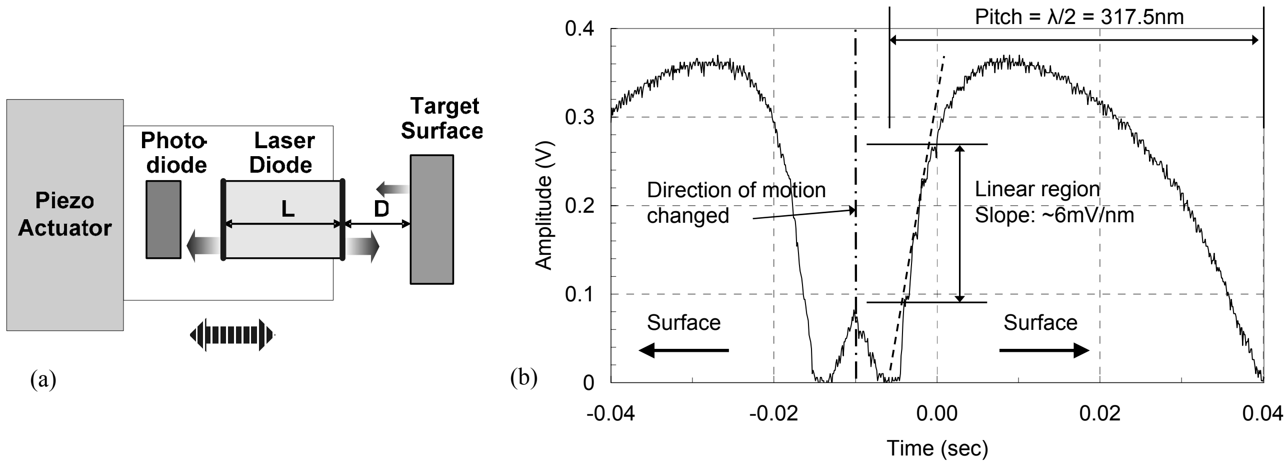

Fig. 2 (a) Experimental setup for feedback signal characterization and (b) measured signal from the photodiode

3.2 Effective spot size measurement

Because of the divergence of the laser beam, only part of reflected beam can be reflected back into the laser diode cavity. Therefore, another characteristic that is of interest is the area on the target surface that contributes to the feedback signal. Here we refer to this area as the effective spot size of the laser position sensor.

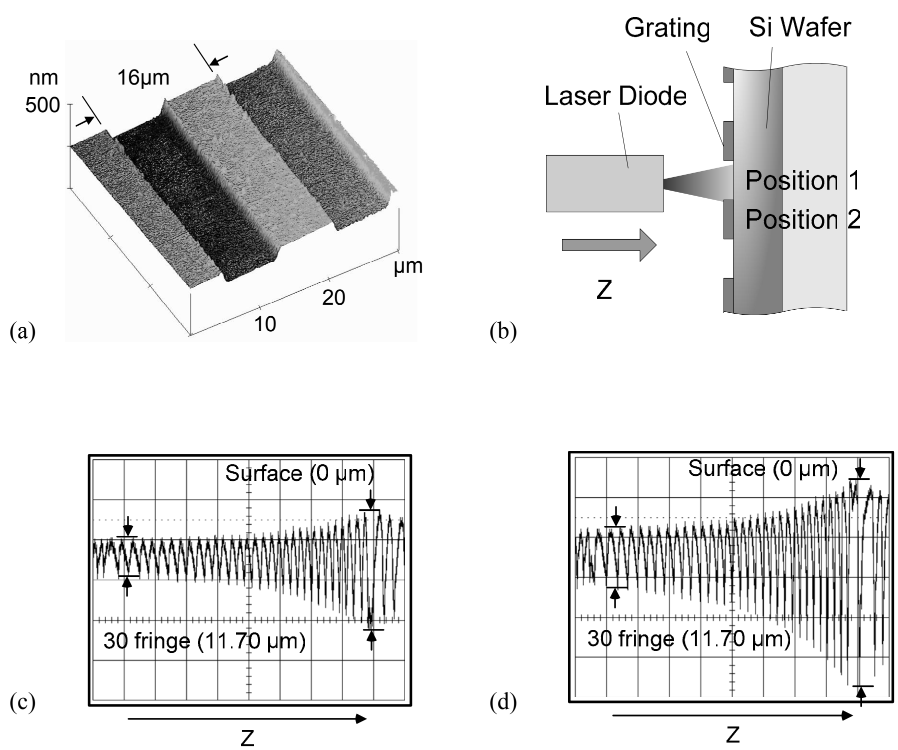

Fig. 3 (a) AFM measurement of the silicon grating, (b) configuration of experimental setup, and interferometric fringe signal at position 1 (c) and position 2 (d) on the grating

To measure the effective spot size, a silicon grating with a pitch of 16μm, as shown in Fig. 3(a), was brought in front of the laser diode and aligned parallel to the laser output facet. The experimental setup is shown in Fig. 3(b). The laser was moved back and forth along the z axis to generate the interferometric fringe while the silicon grating was at different transverse positions with respect to the motion of the laser. Two examples of the fringes measured at different positions on the grating are presented in Fig. 3(c) and (d). We measured the peak-to-peak amplitude of the signals obtained for laser motion along the z-axis for different positions of the laser spot on the grating. The peak-to-peak amplitude as a function of the spot positions on the grating was obtained for a number of z-axis distances, as shown in Fig. 4. Using the change in the amplitude as the laser spot crossed the edges of the rulings of the grating, the effective spot size was calculated. The effective spot size was estimated to be about 1μm and independent of the distance of the laser from the surface up to 12μm. The result indicates that the laser sensor can detect changes such as reflectivity and surface structure with at least a 1-μm spatial resolution. In addition, the independence of the effective spot size from the distance also implies that the spatial resolution remains constant from the far field to the near field.

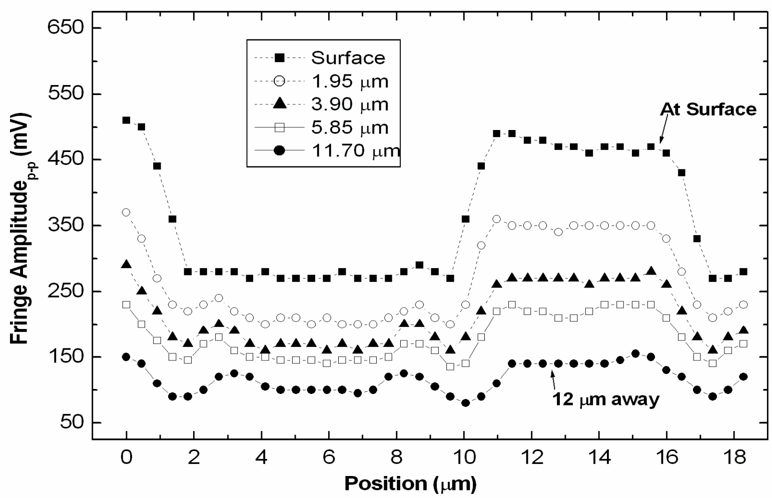

Fig. 4 Peak-to-peak fringe amplitude as a function of position on grating with various distances between the laser and grating

4. ACTIVE HEIGHT CONTROL SYSTEM DESIGN

4.1 Actuator modification

Prior to the controller design, the open-loop frequency response of the actuator, consisting of the pickup with the laser sensor installed and the pickup drive circuit, was measured. As shown in Fig. 5(a), the first resonance frequency is 42Hz and the transfer function of the actuator was modeled accordingly. Then the step response of the pickup was calculated, as shown in Fig. 5(b). From these results, it is clear that both the settling time and the overshoot can not meet the system requirements. The dynamic performance which determines the control precision was degraded because the laser diode doubles the weight of the moving part of the pickup.

To improve the frequency characteristics, high-viscosity resin was added in the damping area of the suspension wires of the pickup. As a result, the damping coefficient was increased by 200% which was accompanied by a 15% increase in the spring constant. Compared to the initial pickup the response shown in Fig. 5(b) was obtained. The modification reduced the overshoot by 40% and the settling time by 70% while the first resonance frequency was moved to a slightly higher frequency of 43Hz.

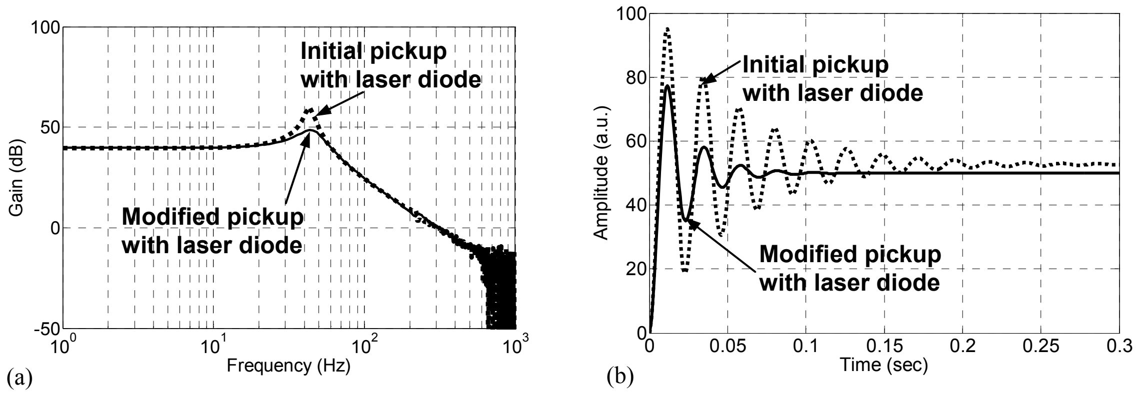

Fig. 5 (a) Measured open-loop frequency response of the actuator and (b) calculated step response of the actuator according to the modeling transfer function

4.2 Controller design

Using a linear approximation of the feedback signal and given the frequency response of the actuator, a proportional integral (PI) controller was designed to actively control the distance of the laser from a spinning disk at a rotation speed of 1200rpm or greater and with runout of 20μm or less. The controller was digitally implemented in a dSPACE DS1103 system at a sampling rate of 100 kHz. In Fig. 6, the dashed curve shows the open-loop dynamic characteristics of the active height controller system as designed. From the calculated data, the bandwidth is 6 kHz and the phase and gain margins are 52° and -24dB, respectively. To evaluate the performance of the entire system, the controller was implemented in the dSPACE system and then the open-loop frequency response was measured. Compared to the designed characteristic, it is clear that the controller meets the design requirements and the frequency response agrees well with the design.

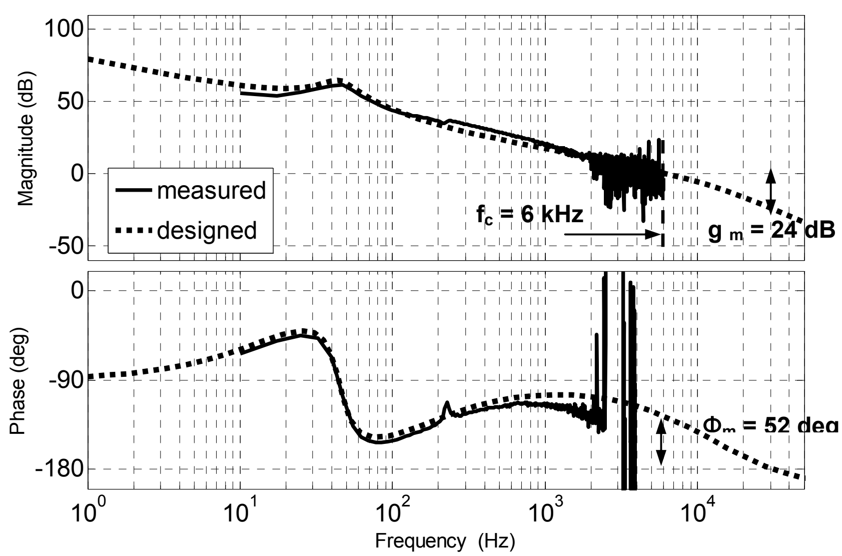

Fig. 6 Open-loop frequency response of the active height control system

4.3 Servo performance

To evaluate the control system and avoid having the laser diode crash into the disk surface, an actuated surface test was employed prior to operation under a spinning disk. The configuration of the actuated surface test system is shown in Fig. 7(a). A silicon wafer coated with an aluminum film was attached onto a piezo actuator in proximity to the laser sensor and the two surfaces were aligned to be parallel. A Polytech OFV-3001 laser interferometer was used to detect the real-time vertical movement of a spinning glass disk with an aluminum film coating at a radial position of 50mm. The detected signal from the interferometer was sent to the piezo driver to synchronize its movement to the silicon wafer.

At a rotation speed of 1500rpm, the vertical runout at the radial position of 50mm is measured to be around 16μm, as shown by the results in Fig. 7(b). Due to the gains of the interferometer and the piezo actuator, the actual displacement of the silicon wafer was around 4.8μm. From the experimental result shown in Fig. 7(c), when the servo was turned on, the control system was able to precisely follow the motion of the silicon wafer and reduce the residual position error to ±3nm.

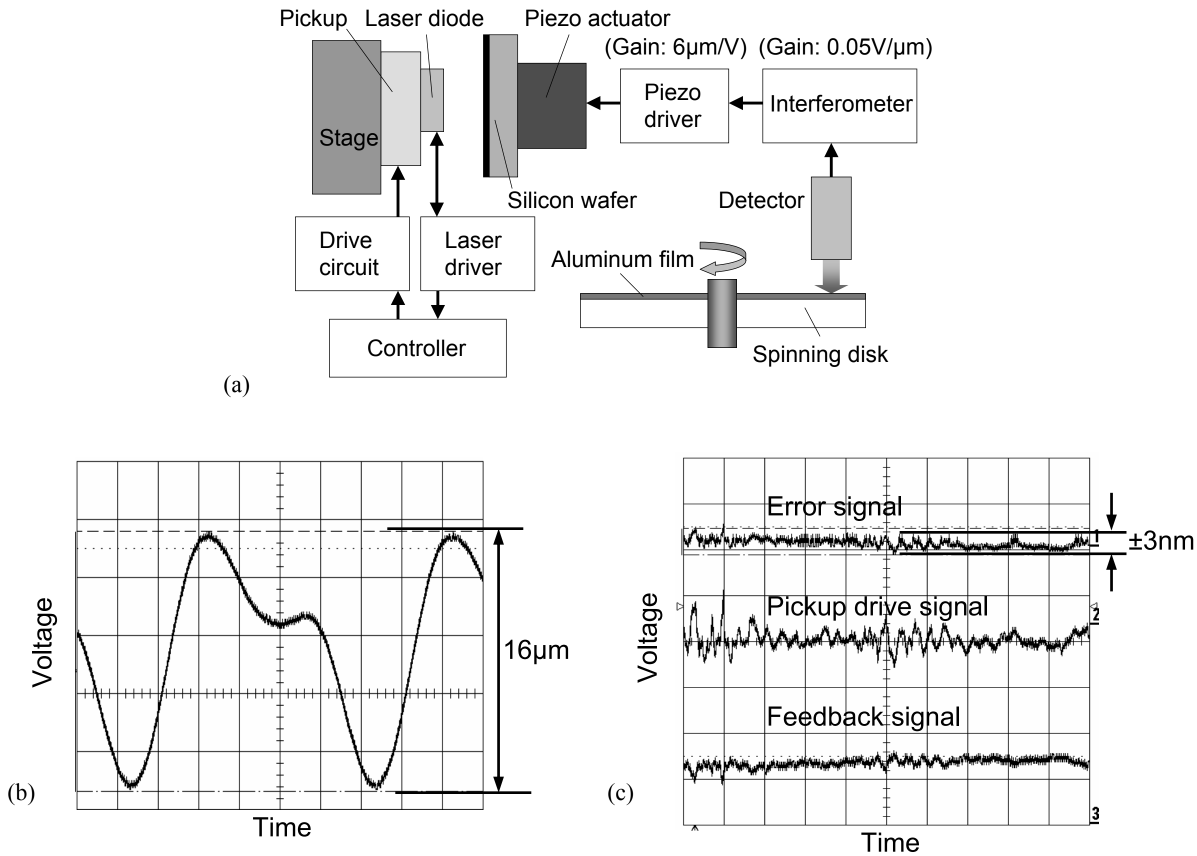

Fig. 7 (a) Configuration of actuated surface test system, (b) the measured vertical vibration of a spinning disk with the runout of 16μm at 1500rpm and (c) experimental results when the displacement is 4.8μm at 1500rpm

Finally, the control system was tested under a spinning disk. The configuration of the disk test system is shown in Fig. 8(a). The pickup with the laser sensor installed was mounted on a stage that provided 3-axis positioning and 2-axis tilt adjustment which can compensate the angular variation of the disk surface. A 120mm diameter glass disk coated with an aluminum film was clamped on an air-bearing spindle. In order to align the laser to the disk surface, a laser beam was used to illuminate an open window at the disk edge. Through the open window, the incident light was split into two beams at the glass-air interface. One was reflected by the interface and the transmitted light was reflected by the laser diode. The orientation of the pickup was adjusted until these two reflected beams were parallel ensuring alignment of the laser to the disk surface.

The system was tested at rotation speeds ranging from 200rpm to 1500rpm. Fig. 8(b) illustrates the error signal, pickup drive signal and feedback signal when the servo was in closed-loop operation at rotation speeds up to 1500rpm. From the data, the residual position error was about ±9nm when the vertical runout was 16μm and the linear velocity at the servo radius was about 7.8m/s. The residual error is much larger than the actuated SIL has achieved and we believe that this is due to noise in the electrical system which may yet be reduced.

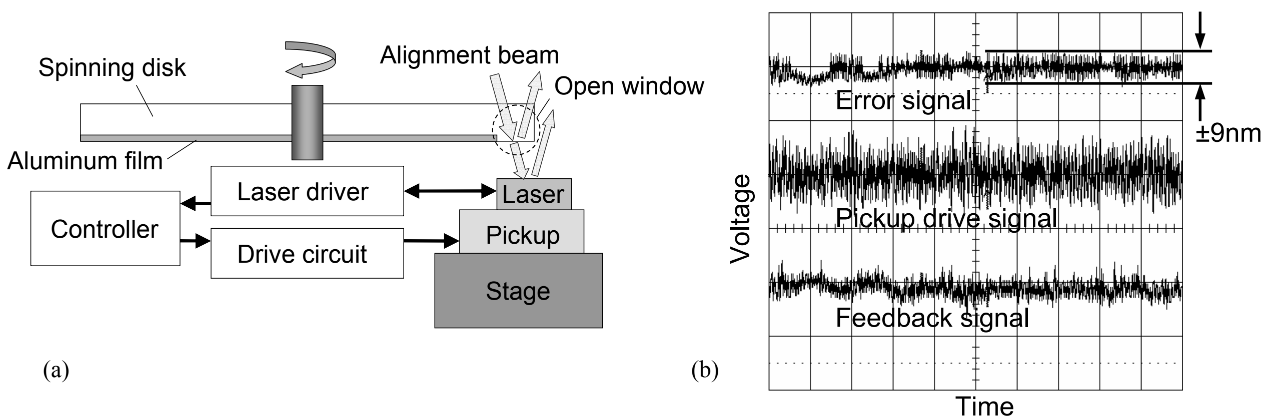

Fig. 8 (a) Configuration of spinning disk test system and (b) experimental results with the runout of 16μm at 1500rpm

5. APPROACH LIMIT

Due to the angular variation of a spinning disk shown schematically in Fig. 9(a), there will be mechanical interference between the laser diode and the disk when the laser approaches the surface. Therefore, we define the approach limit as the closest distance that the laser can achieve without mechanical interference. If the disk surface is assumed to be planar locally then from the geometry, the approach limit at a radial position is determined by the maximum angular variation in a revolution and the size of the laser. To measure the angular variation, a laser beam along the tangential or radial direction of the measured disk illuminated the disk surface and the reflected beam was projected onto a screen. Using the optical lever method, the angular variation was obtained by measuring the position of the reflected beam on the screen. From the measured angular variation of the disk at different radial positions shown in Fig. 9(b), the approach limit is around 75nm when the laser size is 300μm. To approach to the near field, the laser size should be reduced to less than 100μm to achieve an approach limit of less than 25μm.

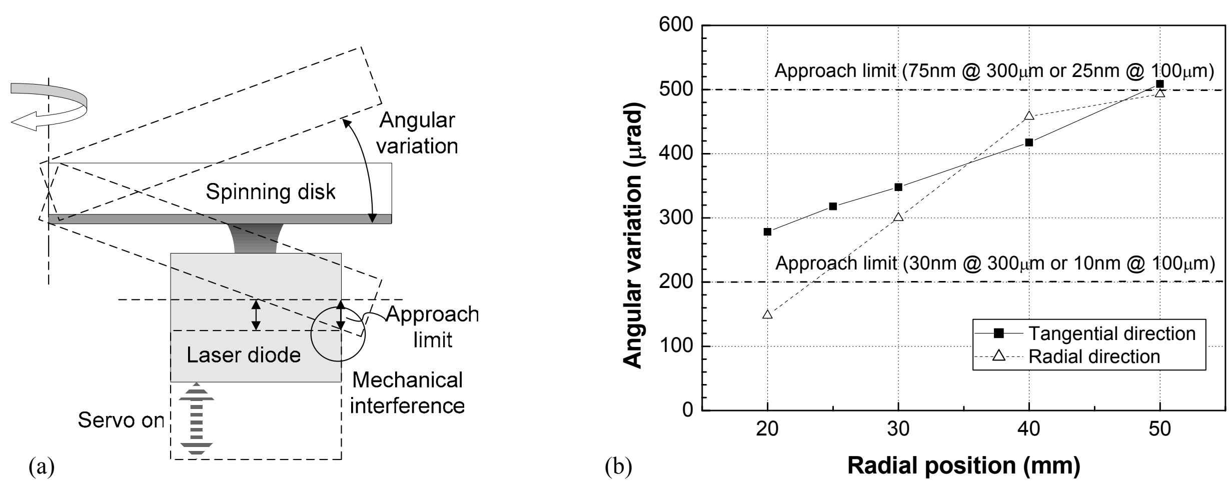

Fig. 9 (a) Angular variation of the disk and the laser size determines the approach limit and (b) the measured angular variation of the glass disk at different radial position along tangential and radial direction

6. CONCLUSION

The correspondence between the output power and the target surface distance from a laser diode as a result of the self-mixing effect was characterized. The laser diode can function as a compact and highly precise position sensor. Furthermore, the effective spot size of this laser sensor is around 1μm for the laser used and independent of the separation of the two surfaces. A laser diode active height control system for near-field recording was developed and constructed by using the laser position sensor installed on a conventional biaxial DVD pickup. A position accuracy of ±9nm was achieved when a glass disk with a runout of 16μm rotating at a speed of 1500rpm. The approach limit that the laser can achieve is estimated to be around 25nm when the laser size is reduced to 100μm.

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