Laser Diode Feedback Signal for Position Sensing Using Self-Mixing Interference

2009 Jpn. J. Appl. Phys. 48 03A007

(http://iopscience.iop.org/1347-4065/48/3S1/03A007)

Japanese Journal of Applied Physics **48** (2009) 03A007 **REGULAR PAPER**

Laser Diode Feedback Signal for Position Sensing Using Self-Mixing Interference

Meng-Yen Tsai, Tzong-Shi Liu*, and Tuviah E. Schlesinger[1]

Department of Mechanical Engineering, Chiao Tung University, Hsinchu 30010, Taiwan, R.O.C.
[1]*Department of Electrical Engineering, Carnegie Mellon University, Pittsburgh, PA 15213, U.S.A.*

Received September 2, 2008; accepted November 5, 2008; published online March 23, 2009

We modified a digital versatile disk (DVD) pickup head as a DVD actuator with a laser diode package for sensing. Tuning a tilting coil in the DVD actuator causes the tilt of a laser diode to compensate misalignment between a target surface and the laser diode facet. Experimental results show that tuning the tilting coil compensates misalignment between both surfaces to achieve effective self-mixing signal. Furthermore, we present the conformity between the output voltage and the target surface displacement from a laser diode package using the self-mixing effect. The resolution in linear region of self-mixing signal is 100 mV/nm.

DOI: 10.1143/JJAP.48.03A007

1. Introduction

For position sensing, self-mixing interference (SMI) systems constitute an alternative to conventional interferometers, since optical elements such as beam splitter, reference mirror, and photo detector are not required in SMI. Self-mixing interferometry was used to measure distances and displacements.[1)] Fast Fourier transform (FFT) analysis can be used to detect the signal phase and increase the measurement precision of SMI. A distance resolution of 1 mm and displacement resolution down to 10 nm was obtained.[2)]

In contrast to a four-wire actuator in recording storage,[3)] near-field recording is a promising approach to achieving higher storage density. A laser diode (LD) height control system for near-field recording was developed and constructed by using the laser with a photo diode (PD) installed on a conventional digital versatile disk (DVD) pickup head.[4,5)] Experimental results by using a PD at the back facet of the LD show that signal amplitude of a fringe, the slope at the half-maximum level of the laser sensor is 6 mV/nm.[6)] The LDs were mounted on a commercial DVD pickup head and a control system was constructed. The control system could operate both in the near and far fields, and a controlled approach from the far to near field was demonstrated using a fringe jump controller. This height control system based on feedback in a LD was capable of servo control.[7)] A flying slider actuator is another type of recording storage device.[8)] An LD was attached to a flying slider and a semi-transparent rotating disk serves as a mirror for an extremely-short-external-cavity configuration.[9)]

In this paper, we have developed a positioning method based on tuning a tilting coil in DVD actuator for compensating misalignment between a target surface and the laser diode facet. The resolution in linear region of PD signal is 100 mV/nm. The experiment of SMI is described in three parts. First, an experimental setup is described in which the effect of tuning the tilting coil for the PD signal is measured by changing the spacing between the laser diode and a target surface. Then we present the conformity between PD feedback signal and the output voltage of a laser Doppler vibrometer (LDV). Finally, smoothed PD signal is useful to increase signal-to-noise ratio in signal.

2. System Configuration

Figures 1(a) and 1(b) respectively show a sketch and a photo of a laser diode package inside a DVD actuator with a tilting coil. Tilting coil causes both rotations shown bold dashed and bold solid arrows in Fig. 1(a). Whole the DVD actuator with the LD package rotates in the center of the LD package. Hence, the LD package is rotated by tuning the tilting coil in the DVD actuator.

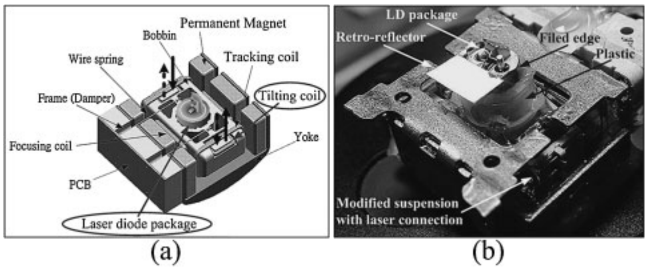

Fig. 1. Modified DVD actuator (a) sketch and (b) photo.

To avoid LD package being attracted by magnet in the DVD actuator, the LD package was filed edge and bound on a plastic cylinder to keep away from effect of magnetic force. The tracking coil connections were rewired to power the LD and provide electric connections to the PD. A retro-reflector depicted in Fig. 1(b) is used to check usefulness of the DVD actuator by using interferometry.

3. Experimental Setup and Results

3.1 Tuning tilting coil effect on PD signal

Experiments were performed in which a silicon surface was brought into close proximity of the laser diode facet. By varying spacing of the silicon surface to facet of the laser diode, feedback signal varies with the spacing.

Figures 2(a) and 2(b) show experimental setups for testing the effect of driving tilting coil on PD signal. A function generator providing tilting coil voltage signal and the connection of oscilloscope (OSC) channel two are the differences of both experimental setups in Figs. 2(a) and 2(b). The LD package attached to the DVD actuator on a three-axis rotary stage was brought close to the surface while allowing observation using an optical microscope. A 4-in. silicon wafer was used as a reflector, held in front of the laser, and attached to a piezoelectric (PZT) actuator on a translation stage. Parameter values are listed in Table I. Input conditions of LD current, PZT driver frequency and voltage are the same in both experimental setups except the tilting coil voltage.

*E-mail address: tsliu@mail.nctu.edu.tw

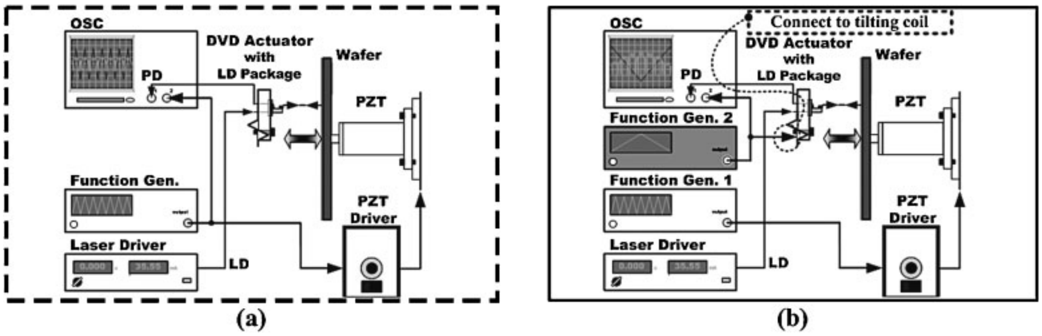

Fig. 2. Experimental setup (a) without tuning tilting coil voltage and (b) with tuning tilting coil voltage.

Table I. Input parameter values in experiment of Fig. 2.

	LD current (mA)	PZT driver frequency (Hz)	PZT driver voltage (mVp)	Tilting coil frequency (Hz)	Tilting coil voltage (mVp)
Figure 2(a)	35.55	1	158	—	—
Figure 2(b)	35.55	1	158	0.15	7

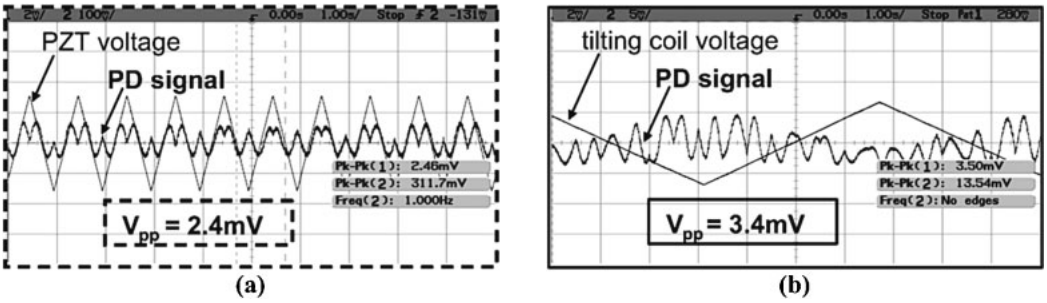

Fig. 3. Experimental results (a) in Fig. 2(a) and (b) in Fig. 2(b).

Figures 3(a) and 3(b) are experimental results of apparatus in Figs. 2(a) and 2(b), respectively. The siganl of OSC Channel one is PD signal in Figs. 3(a) and 3(b), and signals of Channel two represent input voltagse of the PZT driver and tilting coil in Figs. 3(a) and 3(b), respectively. Laser feedback result for $\lambda = 635$ nm laser actuated in front of a silicon surface is shown as PD signal in Figs. 3(a) and 3(b). The photodiode behind the back facet of the diode laser was used to measure the power in the laser cavity. The PD signal variation is plotted together with the PZT driver voltage. As tilting coil voltage is decreased, the PD signal increases as depicted in Fig. 3(b). Peak-to-peak voltage of the PD signal in Fig. 3(b) is larger than that in Fig. 3(a) although PZT driver voltage and LD current are the same in both experimental setups. Effectiveness of tuning tilting coil is verified by noting that peak-to-peak PD voltage signal in Fig. 3(b) reaches higher than that in Fig. 3(a).

If one keeps moving the silicon wafer attached to PZT, fixing LD current, and acquiring interference signal of PD, driving tilting coil in the DVD actuator causes μrad scale rotation of the whole DVD actuator with LD package. Therefore, the misalignment between the LD facet and silicon wafer surface is compensated by tuning tilting coil. The interference signal of PD will be more evident if both surfaces of LD and silicon wafer are parallel. Accordingly, the tilting coil in DVD actuator is a compensator of misalignment between both surfaces and results in high signal-to-noise ratio of PD signal.

3.2 Resolution of PD signal

The present system is measured by means of an actuated surface system, as shown in Fig. 4. The system consists of a DVD actuator containing an LD package with a PD shown in Fig. 1, a target wafer attached to a PZT transducer, and an LDV depicted in Fig. 4. Operation current of the laser driver is 40 mA to enter LD. The voltage amplitude in the function generator is 158.8 mV with triangular waveform and 10 Hz frequency to enter the PZT driver. The signal in oscilloscope (OSC) Channel one is PD signal through an amplifier, and signal in OSC Channel two is LDV signal. Both sensors are used to measure displacement of a silicon wafer attached to the PZT actuator.

Figure 5 shows measured displacement of the silicon wafer where LDV signal in Channel two is 2 μm/V, and the PD signal in Channel one is $\lambda/2$ per complete interference fringe. Therefore, the signal is a periodic function of the distance with the maximum amplitude of 1.69 V and a complete interferometric fringe, corresponds to a displacement of $\lambda/2$, equal to 317.5 nm. Although within a fringe, the signal varies nonlinearly with the displacement, it can be treated as linear region, as shown in Fig. 6. The slope of the linear function represents the sensitivity of the signal with respect to the signal amplitude. The slope in the linear region of this SMI sensing is thus calculated as 100 mV/nm.

3.3 Discussion

The SMI signal contains multi-frequency components as

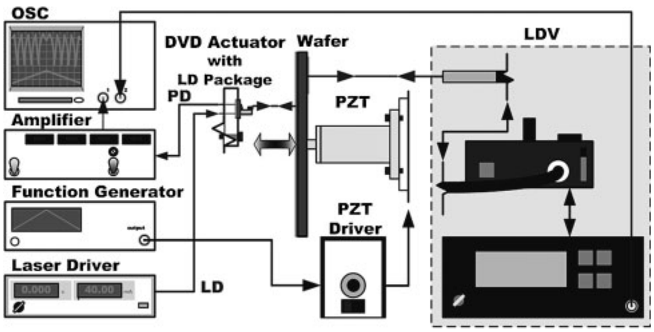

Fig. 4. Experimental setup for feedback signal characterization.

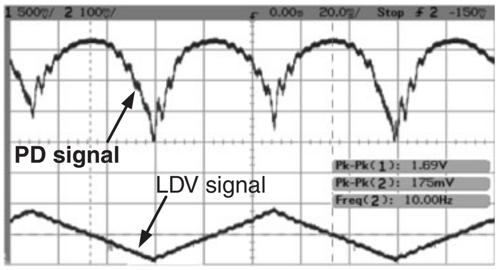

Fig. 5. Measured signals from PD and LDV with tilting DVD actuator and moving PZT.

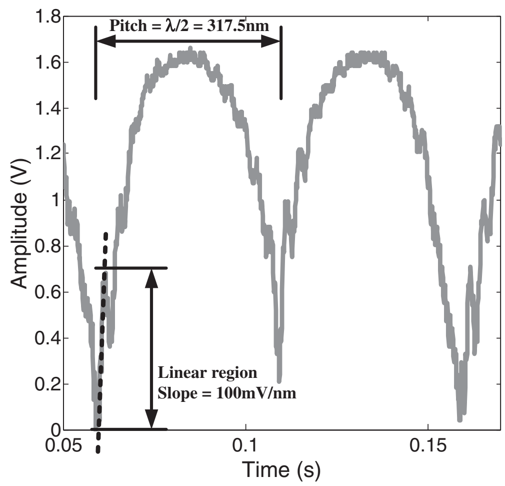

Fig. 6. Part of Fig. 3 after enlargement.

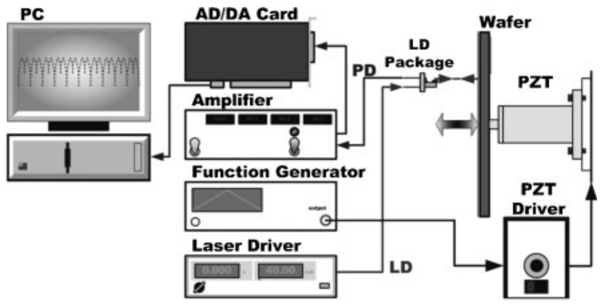

Fig. 7. Experimental setup for feedback signal on AD/DA card.

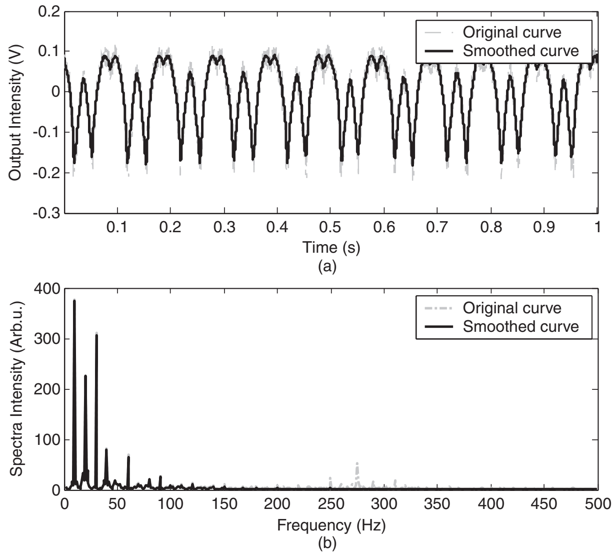

Fig. 8. (a) Interference fringe signal and (b) Fourier spectra of interference fringe signal with moving PZT.

shown in Fig. 6, for which the FFT method can extract the resonant frequencies. An analog-to-digital or digital-to-analog converter (AD/DA) card at 10 kHz sampling rate is used to catch the PD signal. The experimental setup is shown in Fig. 7. Figure 8(b) shows the Fourier spectra of the SMI signal in Fig. 8(a). Original data caught by the AD/DA card shows as gray dash-dotted curve in Fig. 8(a), and that frequency spectrum is gray dash-dot line in Fig. 8(b). Curve of smoothing original data and that frequency shows as black solid line in Figs. 8(a) and 8(b), respectively. The harmonic component corresponding to 10 Hz voltage is imported to PZT driver by a function generator, which are 10, 20, 30, and 40 Hz. Removing high frequency of PD signal increases signal-to-noise ratio of PD signal by smoothing the original. Therefore, in the future we will filter out specific frequencies of PD signal by a notch filter to improve the signal-to-noise ratio of PD feedback signal for positioning control in the future.

4. Conclusions

This paper presents that rotating movement by tuning tilting coil in DVD actuators can compensate SMI signal. Moreover, we have presented the conformity according to Fig. 5 between the output voltage and the target surface displacement from a laser diode package using the SMI, where the linear region accounts for sensing resolution of 100 mV/nm.

Acknowledgement

This research was supported by National Science Council, Taiwan, under Grant No. NSC93-2752-E009-009-PAE.

1) M. Wang: Opt. Laser Technol. **33** (2001) 409.
2) M. Wang and G. Lai: Meas. Sci. Technol. **14** (2003) 1025.
3) C.-P. Chao, J.-S. Huang, C.-W. Chiu, and C.-Y. Shen: Proc. American Control Conference, 2005, p. 2457.
4) J.-Y. Fang, P. Herget, J. A. Bain, and T. E. Schlesinger: Proc. SPIE **6282** (2007) 62820P.
5) J.-Y. Fang, C.-H. Tien, H.-P. D. Shieh, P. Herget, J. A. Bain, and T. E. Schlesinger: J. Lightwave Technol. **25** (2007) 3704.
6) P. Herget, J.-Y. Fang, J. A. Bain, and T. E. Schlesinger: presented at Opt. Data Storage Topical Meet., 2006.
7) P. Herget, T. Ohno, J. A. Bain, K. Takatani, M. Taneya, W. C. Messner, and T. E. Schlesinger: Jpn. J. Appl. Phys. **45** (2006) 1193.
8) C.-C. Hsiao, T.-S. Liu, and S.-H. Chien: Smart Mater. Struct. **15** (2006) 1632.
9) H. Ukita and Y. Karaki: Opt. Rev. **11** (2004) 188.