Key Engineering Materials Vol. 339 (2007) pp. 200-205
online at http://www.scientific.net

A High Precision Focus Probe for the Quality Assessment of Grating Pitches

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Keywords: DVD pickup head, Focus probe, FES (Focus error signal), Grating pitches

Abstract. An innovative high precision optical focus probe has been developed to measure the grating pitches. This probe uses characteristics of FES (focus error signal) of the modified DVD pickup head. Experimental tests showed the linear range of FES of this probe to the gratings was 5µm, the resolution was less than 1nm, the time stability was 5nm in 10 minutes, and positioning repeatability was better than 12nm. This system was applied to measure the grating pitch of 1200 lines per 1mm. The quality of the grating was assessed by the average of sampled pitches and its standard deviation. The inspected results can be an index to improve the process control of the grating fabrication.

Introduction

With the development of micro system technology and the increasing market needs of various tiny objects, such as micro channels, micro molds, micro optical components, etc., ultra precision micro/nano linear stages have been widely adopted for use in recent years. The high-density gratings are fundamental sensors for position detection of the nano-resolution stage. For those grating pitches more than 1000 line/mm, the fabrication process can be made by either the hologram technology or direct laser writer. The line width (pitch) and line depth are two major parameters to assess the quality of the grating. In order to measure these parameters, a high precision micro 3D profile measuring probe has to be used.

The micro-grating profile measurement methods may include: traditional diffraction method, mechanical contact probe method [2], optical focus probe method [3], optical interference method, SEM (Scanning Electronic Microscope), and SPM (Scanning Probe Microscope) method [4], etc. Among which, AFM (Atom Force Microscope) is often adopted to measure the surface profile and grating pitch [5, 6], while STM (Scanning Tunnel Microscope) or XRL (X-ray interferometer) is used to measure the standard pitch of some specimens [7]. The DVD pickup head adopted in this research is a micro optic-mechanical-electronic system. On the basis of astigmatic principle, the FES (focus error signal) of the pickup head is used and modified to develop an innovative non-contact detection system to measure the 3D surface profile of any microstructure. The detection system is low cost and easy to operate. The focused optical spot is less than 1µm, which can probe the direct profile of high density gratings. In this study, the system is used to calibrate and measure the grating pitches.

DVD Pickup Head

The Operational Theory. As shown in Figure 1, the auto power control technology is applied to make laser diode producing a 0.5mW and 650nm wavelength stable red laser beam. The laser beam passing through a grating the light diffracts into three beams. These beams pass through a polarized beam splitter, a quarter waveplate, and a collimator lens to transform the laser beams into a collimated beam. The collimated laser beam is then passed through a holographic Fresnel lens with concentric circular groves of tens to hundreds µm interval. Reflecting from the disk surface the beams pass through the original path and a cylindrical lens, and finally project onto the four-quadrant photodiode, which will output A, B, C, D signals. According to the beam spot distribution among four quadrants, after proper signal processing, the FES (Focus Error Signal, (B+D)-(A+C)) is used to drive the voice coil motor (VCM) to shift the objective lens until the focal point is set on the disk surface and achieve the autofocusing process [8]. When the objective lens is fixed, the FES of the probe can be directly obtained as a focus probe [9]. Because of the high resolution and accuracy of FES curve, the probe is adopted to develop the precision profile measurement system.

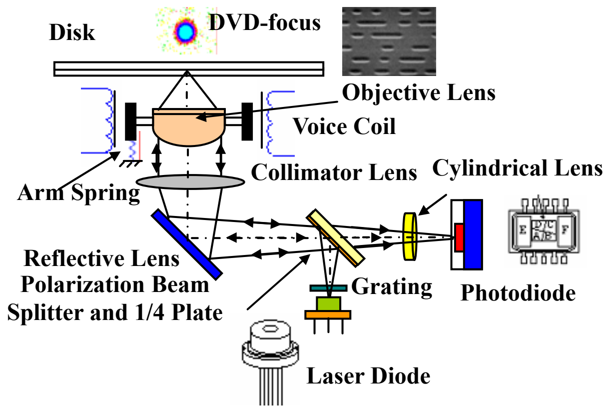

Fig.1 DVD pick-up configuration sketch

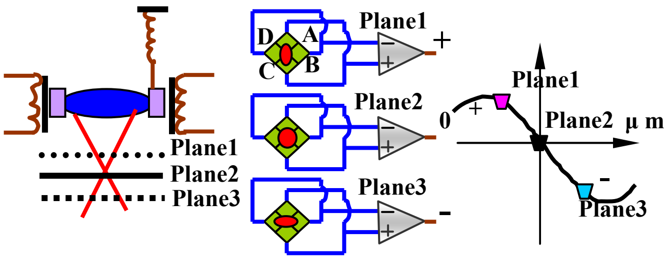

Fig. 2 The S-curve of FES

The FES theory of DVD pickup head. As shown in Figure 2, when reflective plane locates on the focus point (plane2), the image of laser beam spot on the four-quadrant photodiode is perfectly circular, so the FES is zero. When the reflective plane is away from the focus position (plane1 or plane3), the beam spot on the quadrant detector performs elliptical shape. The corresponding FES from four-quadrant photodiode is not zero. The continuous variation of the FES between Plane 1 and Plane 3 shows a S-curve form.

The probe structure reconfiguration. The DVD pick-up head system is often integrated into usual DVD-ROM so the head is in flat shape, which is not convenient to be built into most measuring probes. In this research a new head configuration was reconstructed so as to extend the objective lens out of the probe case and forms like a probe tip. The prototype of the improved probe (94x50x27mm) is shown in Figure 3.

Fig.3 The prototype of designed probe.

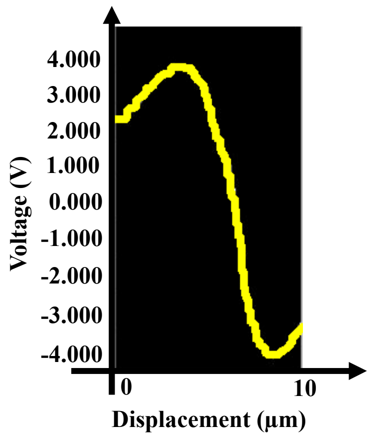

Fig.4 Calibrated FES S-curve

The Calibration of FES. In this paper, the FES curve of the probe was calibrated by a laser interferometer on an optical mirror. The measurement setup is shown in Figure 5. The probe is fixed, and the precise stage with reflective mirror 10 is driven from far position to approach the focus spot. The displacement of the stage is detected by the laser interferometer. Meanwhile, the FES voltage after signal process is acquired by a precise digital multimeter, and transmitted into the process program of a PC via the serial communication interface. The characteristic curve of the output FES voltage to the displacement of stage is shown in Figure 4, which performs the S-shape curve. The linear part of FES curve from –3V to +3V is stable and the corresponding displacement is 4.557µm with the resolution to 0.8nm/mV after a 6-1/2 digital multimeter.

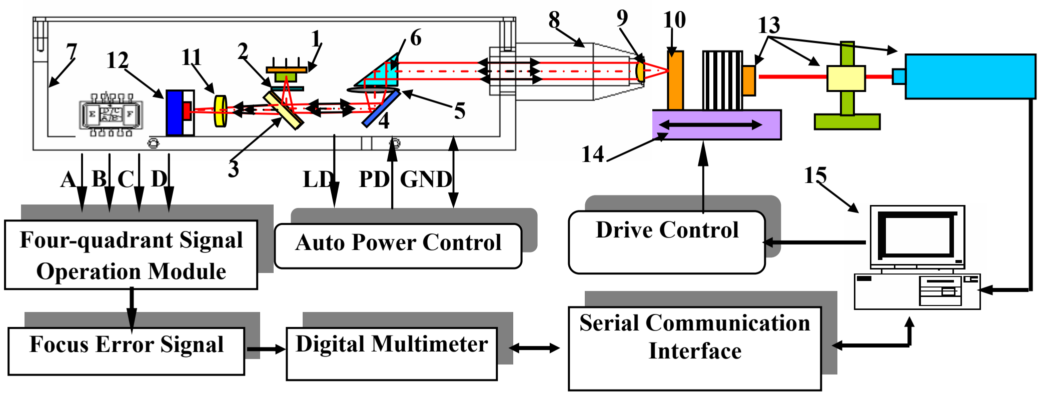

Fig.5 The setup of measuring FES curve. (1 laser diode, 2 grating, 3 polarized beam splitter&1/4 wave plate, 4 reflector, 5 collimation lens, 6 transition reflector, 7 probe case, 8 head case, 9 holographic Fresnel lens, 10 optical reflector, 11 cylindrical lens, 12 four-quadrant photodiode, 13 laser interferometer, 14 precision stage, 15 PC)

The Repeatability and Stability Tests of the Probe. To test the repeatability of FES, we also used the same setup as in Figure 5. Initially, we moved the precise stage and the fixed reflector to reach the zero voltage of FES, and reset the reading of the interferometer. The stage was then moved away with random distances and back to the zero voltage point repeatedly for 7 times. Table 1 shows good repeatability errors of within 12nm. For the stability tests, the probe and the stage were all fixed for 11 minutes. A promising result of 5nm stability error within 10 minutes was obtained, as given in Table 2.

Table1 the repeatability errors of probe

FES Voltage (V)	Repeatability （nm）
0	0
0	-5
0	-10
0	-12
0	1
0	8
0	6

Table2 the stability errors of probe

Time (minute)	Voltage (mV)	Stability Error (nm)
0	-1544.9	0
5	-1544.7	0.16
6	-1544.4	0.4
8	-1542.7	1.76
11	-1537.7	5.76

Grating Pitch Measurement. Linear gratings are commonly used for the position feedback sensor of linear stages. Conventional grating with 10 to 20 µm pitch width can only provide up to submicron resolution after signal subdivision process. For stages with nanometer resolution the pitch of the grating is normally selected less than 2µm so that after 10-bit electronic interpolation the resolution can reach to 1 nm. Since the pitch width (or line space) is the unit dimension of stage displacement, it must be very accurate. The calibration of grating pitch error is therefore very important to ensure the quality of the fabrication process. Figure 6 illustrates the schematic diagram of the grating pitch calibration setup system. The grating plate is moved with the motorized stage of which its real time position is detected by a laser interferometer. The focusing probe is fixed to continuously scan the variation of the grate profile and output corresponding analog voltage. Six places along the moving axis are sampled, each with a random short distance. Measured data are given in Figures 7 to 12 (grating 1), which show the pitch cycles and pitch depths respectively. By calculating the average grating pitch of above six sections to get the overall average error, this study chose the whole integral number of periods in each section from the corresponding recorded length readings of the laser interferometer. The total displacement divided by the cycle number is the average grating pitch, as shown in Table 3 (grating 1) and Table 4 (grating 2). The maximum error between the measured data and the nominal pitch is about 5nm. The overall average grating pitch error of the entire length is less than 1nm and the standard deviation is about 3.7nm.

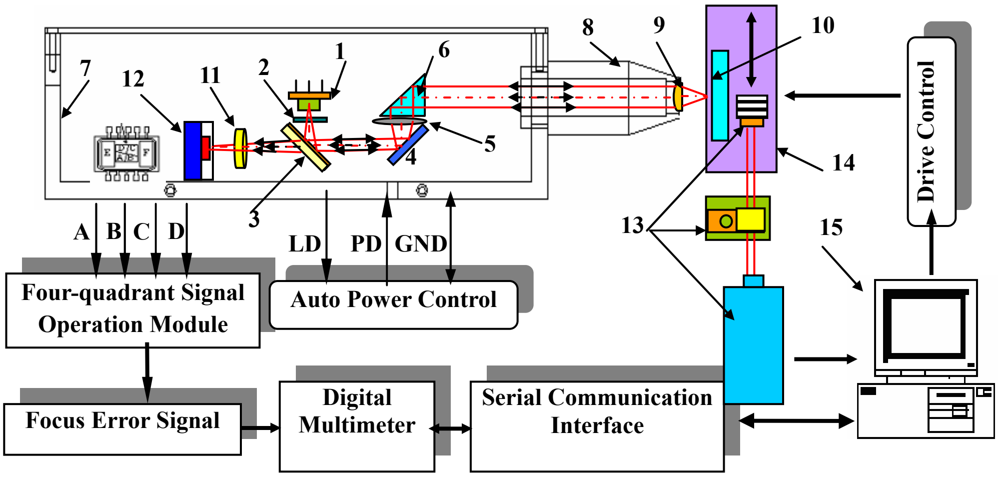

Fig.6 Schematic of grating pitch measurement. (10 grating plate, other components are the same as Figure 4)

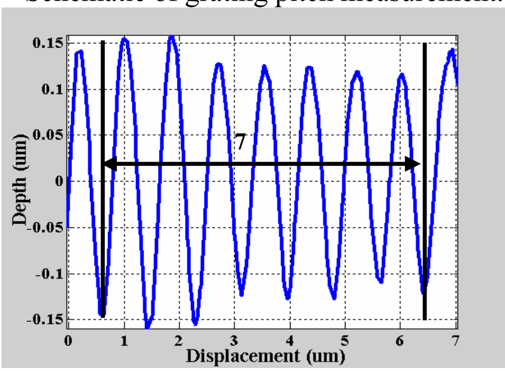

Fig.7 the first section grating signal

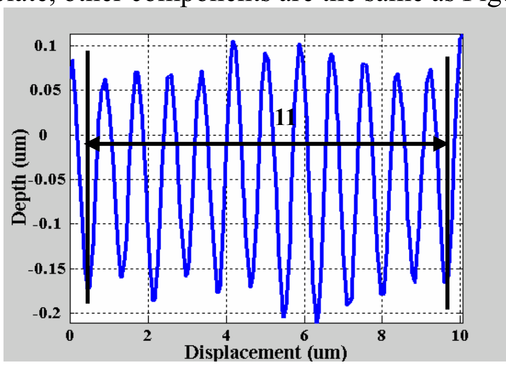

Fig.8 the second section grating signal

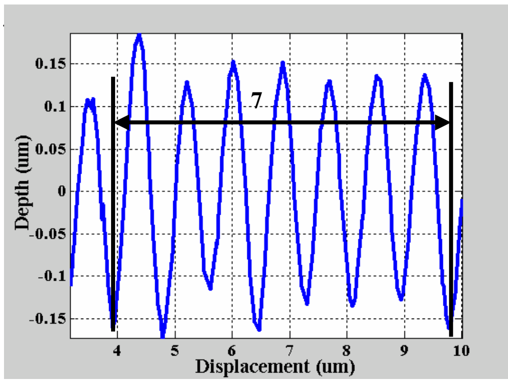

Fig.9 the third section grating signal

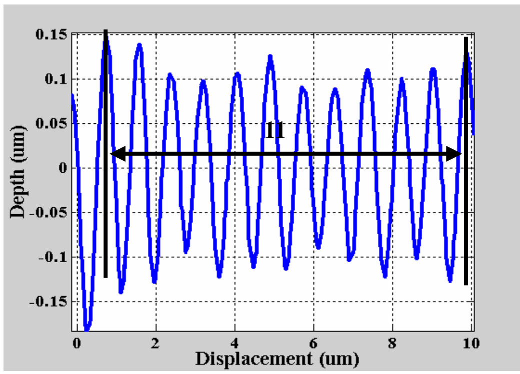

Fig.10 the fourth section grating signal

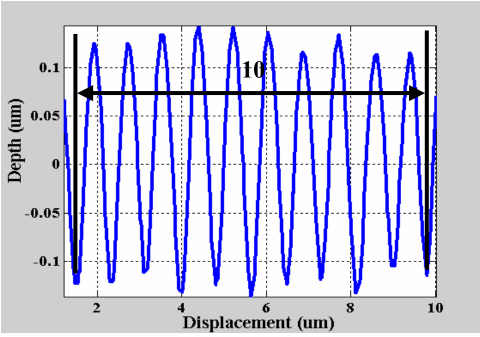

Fig.11 the fifth section grating signal

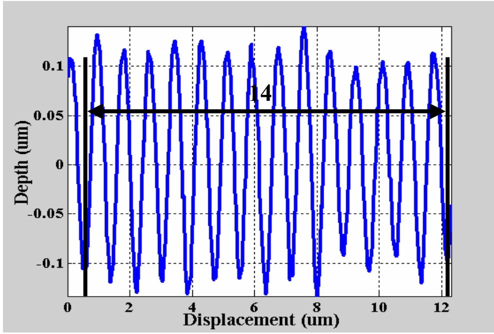

Fig.12 the sixth section grating signal

Table 3 (Grating 1) measurement value VS theory value of grating pitch (theory value: 0.833 μm)

Section number	Laser interferometer data (μm)	Cycle number of grating	Average grating pitch (μm)	Error (μm)
1	5.793	7	0.828	-0.005
2	9.148	11	0.832	-0.001
3	5.850	7	0.836	0.003
4	9.130	11	0.830	-0.002
5	8.279	10	0.828	-0.005
6	11.705	14	0.836	0.003
Average value			0.832	-0.001
Standard deviation				0.0037

Table 4 (Grating 2) measurement value VS theory value of grating pitch (theory value: 0.833 μm)

Section number	Laser interferometer data (μm)	Period number of grating	Average grating pitch (μm)	Error (μm)
1	9.136	11	0.831	-0.002
2	9.165	11	0.833	-0.000
3	9.138	11	0.831	0.002
4	9.152	11	0.832	-0.001
5	9.539	11.5	0.829	-0.004
6	34.153	41	0.833	0.000
Average value			0.8315	-0.0015
Standard deviation				0.0015

Summary

This paper reports the development of a precision focusing probe directly taken from a commercially available DVD pickup head. Having calibrated this probe has proven to be a very good sensor for profile measurement of surface variation in a few micrometers. Utilizing the S-curve of the probe, this study has proved the feasibility of application to the grating pitch measurement. The calibrated results can provide an index of the fabrication quality of the grating pitches.

Acknowledge

This paper is supported by NNSFC (National Natural Science Foundation of China: 50275048)

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