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Development of an Optical Pickup System for Measuring the Displacement of the Micro Cantilever in Scanning Probe Microscope

Kuang-Yuh Huang, En-Te Hwu and Hsin-Yi Chow
Department of Mechanical Engineering
National Taiwan University
1. Sec. 4, Roosevelt Road,10764, Taipei, Taiwan
d92522029@ntu.edu.tw

Shao-Kan Hung
Department of Electrical Engineering
National Taiwan University
1. Sec. 4, Roosevelt Road,10764, Taipei, Taiwan
skhung@ntu.edu.tw

***Abstract*— This paper is to present the development and the verification of a compact optical sensor system for measuring the displacement of the micro cantilever in scanning probe microscope (SPM). An optical pickup head of commercial compact disc (CD)/disk versatile disc (DVD) read only memory (ROM) drive is applied in this displacement sensor system. For fulfilling our tight measuring requirements of sensibility and reliability, the build-in detection device is replaced with a four-quadrant photodiode. The developed system is well functionally verified by measuring calibration sample of 463 nm (pitch) x 30nm (height).**

Index Terms - CD, DVD, Pickup head, SPM

I. INTRODUCTION

The pursuit of high speed and high precision is the current trend of the rapid technological development. And dimensional shape and surface topography are two crucial aspects for quality assessment of high-precision parts. The growing demand for dimensional measurements has led to numerous researches and developments of methods and instruments for profile and surface inspection. Because of non-contact and high resolution measuring characteristic, the optical measuring principles are still the main stream.

The compact and inexpensive optical pickup head of commercial compact disc (CD)/digital versatile disc (DVD) read only memory (ROM) drive is provided with the necessary features for measuring confocal displacement. The 3D optical profilometers based on the optical pickup head have found widespread applications for precision profile and surface roughness measurements [1]-[6]. However, the significant disadvantage for many optical measuring principles comes from too huge focal spot of micro-meter range, which restricts the horizontal resolution of measurement. Armstrong and Fitzgerald established a small compact autocollimator based on the laser head of a CD optical pickup head [7]. Quericioli and Tiribilli [8] applied the CD pickup head to monitor the vertical displacement of the cantilever in an atomic force microscope (AFM) [9].

In order to improving compactness and sensing functions of our developed scanning probe microscope (SPM), we apply the optical pickup head to measure the bending displacement of the micro cantilever. The compact and integrated construction of the pickup head simplifies the adjustment effort during the instrument assembly and can also bring out positive effect on minimizing sensing error induced by thermal gradient.

II. EXPERIMENTAL SETUP

Our developed SPM comprises a probe holder with probe, a scanning actuator, a positioning actuator, a holder for testing piece, a precision X-Y stage, an optical displacement measuring system and a base with vibration isolator. The main function of the optical displacement measuring system is to measure the displacement of the micro cantilever on the probe, and its functional elements include a laser diode, a photodiode, some adjusting elements and a signal processing circuit. The setup of the optical system is decisive for the functional quality of SPM. Instead of assembly and adjustment of separate parts, a compact and integrated optical pickup head can certainly bring out many advantages for instrument development and applications.

Figure 1 shows schematically the inside construction and the working principle of a typical optical pickup head of a CD/ DVD ROM drive. The laser beam from a stabilized laser diode is first collimated and diffracted into three beams, which are then actively focused onto the disc surface by magnetic actuators. The reflected beams from the disc surface are then directed back through the pickup head and turned to the photodiodes via a beam splitter. A quarter wave plate ensures that only return beams with specific polarization are selectively turned to the photodiode IC. The photodiodes (A, B,C and D) detects the position and the focusing performance of the central beam, while the other photodiodes E and F on both sides detect two other diffracted beams for tracking control.

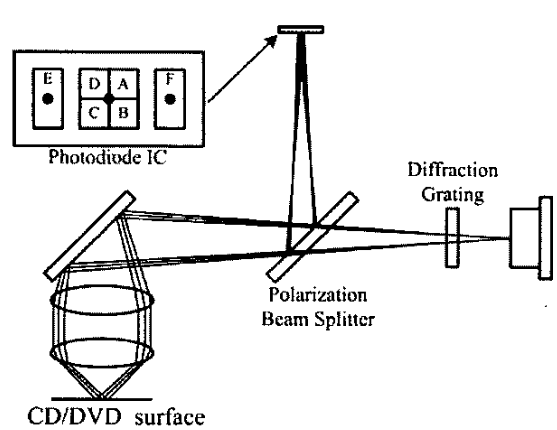


Fig. 1 Inside buildup and working principle of a typical optical pickup head of a CD/DVD ROM drive.

The laser diode emits light at a wavelength of 650±10nm. The objective lens has a numerical aperture of 0.6 with a free working distance of 1.5 mm. The size of focal spot is proportional to the wavelength λ of laser as follows:

$$D = 0.52\frac{\lambda}{NA} \quad (1)$$

Where D is the full-width half maximum (FWHM) of focal spot. Therefore, our setup generates a laser spot with *D=554~572 nm* theoretically. For our measuring purpose with a fixed focusing range in SPM, the active focusing function of pickup head is useless and is blockaded by epoxy resin. The micro cantilevers (BudgeSensors BS-Tap300Al) with size of 125 μm ×30 μm × 4 μm is driven by a frequency of ca. 300 kHz. And the sensing probe of the micro cantilever has an apex radius of 10nm.

In SPM, the atomic force induced by testing surface acts on the sensing probe and makes the micro cantilever deform. In order to adapt to the required displacement sensing range of SPM, a four-quadrant photodiode (PIN-SPOT 4D) is used to replace the built-in photodiode IC inside the optical pickup head (DPD-20482, TENTATIVE). Fig. 2 shows the schema and the principal algorithms of signal processing. The torsional deformation of the micro cantilever is derived by the signal X from Eq.(2), while the bending deformation is acquired by the signal Y from Eq.(3).

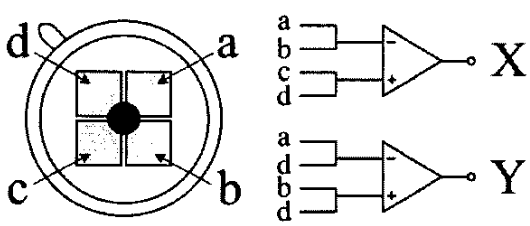


Fig.2 Schema and principal signal processing of four-quadrant Photodetector.

$$X = (a+b)-(c+d). \quad (2)$$

$$Y = (a+d)-(b+c). \quad (3)$$

For realizing optimal signal output, the laser spot must be focused on the end of the micro cantilever. A three-axis precision stage is utilized to bring the micro cantilever to the

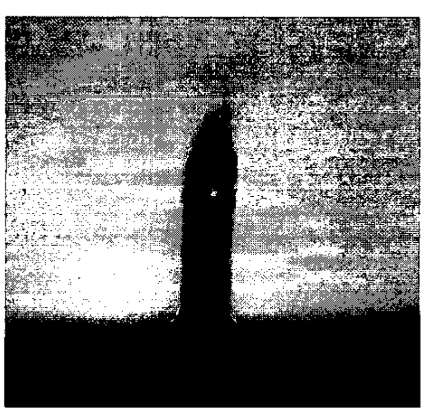


Fig.3 Focused laser spot on a micro cantilever.

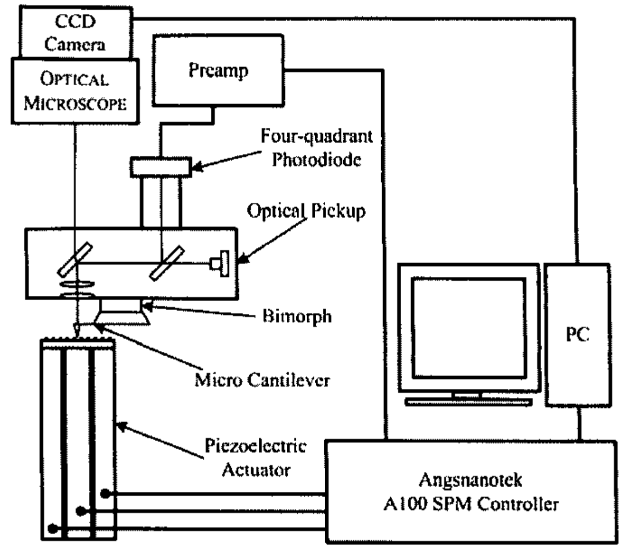


Fig.4 Layout of experimental setup.

focusing position of the pickup head. For ensuring their relative positions after the fine adjustment, the micro cantilever with a piezoelectric bimorph actuator is directly adhered to the pickup head by using epoxy resin. Fig. 3 presents the focused laser spot on the end of the micro cantilever.

Fig. 4 shows the layout of experimental setup. In order to enlarge the optical lever, the spacer is applied between the photodiode and the optical pickup. The laser spot reflected from beam splitter strikes the center of photodiode, which is well positioned by the three-axis precision stage. A microscope with a CCD camera is coupled to the optical pickup head to simultaneously monitoring the alignment of the laser spot. The micro cantilever is vibrational stimulated by the attached piezoelectric bimorph actuator. The testing piece is mounted on a piezoelectric scanner, which can bring the testing piece into three-dimensional motion of $x=y=100\mu m$ and $z=5\mu m$. For signal processing and actuating control, a SPM controller (AngsNanoTek A100) is applied. All sensing signals and the monitoring visual signal are captured and processed in the computer.

III. EXPERIMENTAL RESULTS

When the vibrating cantilever comes close to the testing surface, its amplitude and phase are influenced by the atomic force between the probe and the surface. The force between probe and surface [10] is approximately described by the Eq. (4):

$$F_{ts}(z_c, z) = -\frac{HR}{6a_0^2} + \bar{E}\sqrt{R}(a_0 - d)^{\frac{3}{2}} \quad (4)$$

Where $\bar{E}$ is the reduced elastic modulus of probe and sample. H is the Hamaker constant, R the probe radius, a_0 the intermolecular distance, z_c the rest probe-surface sparation, z the instaneous probe position and $d=z_c+z$. The probe-surface

F_{ts} contains long range van der Waal forces and short range repulsive forces. The equation that describes the cantilever motion is independent of the environment, however, the probe's final motion is sensitive to both tip-surface and tip environment interactions. Operation of SPM is usually performed with an amplitude modulation feedback.

The optical pickup head is used to measure vibrating changes. The amplitude and phase spectrum of a vibrating micro cantilever is shown in Fig. 5, it has a distinct resonance peak at the frequency of 300 *kHz*. The changes of cantilever vibrations are measured to generate an atomic force topography of the testing surface. According to the measuring signals, the SPM controller undertakes a stabilization function for vibrating amplitude or phase.

For functional verification and performance testing, a testing sample with diffraction grating of 2160 lines/mm (pitch=463 nm and height= 30 nm) was used. Fig. 6 shows the measuring result of the modified micro cantilever sensing system. The surface texture of the testing sample can be very detected and reconstructed as shown in Fig. 6(a), a more detailed quantitative evaluation can be done by inspecting the cross-sectional intensity profiles as shown in Fig. 6(b).

The measured pitch of grating is ca. 471 nm, while the measured height is ca. 31 nm. The intensity curves can deliver quantitative data for the surface texture. However, the lateral resolution of our developed sensing system is limited by the apex radius of the probe.

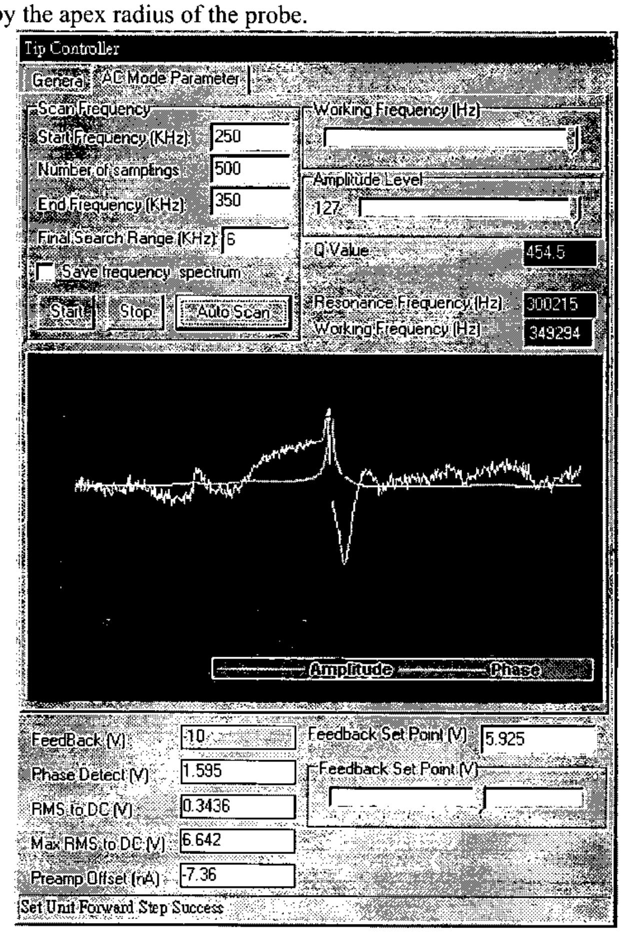
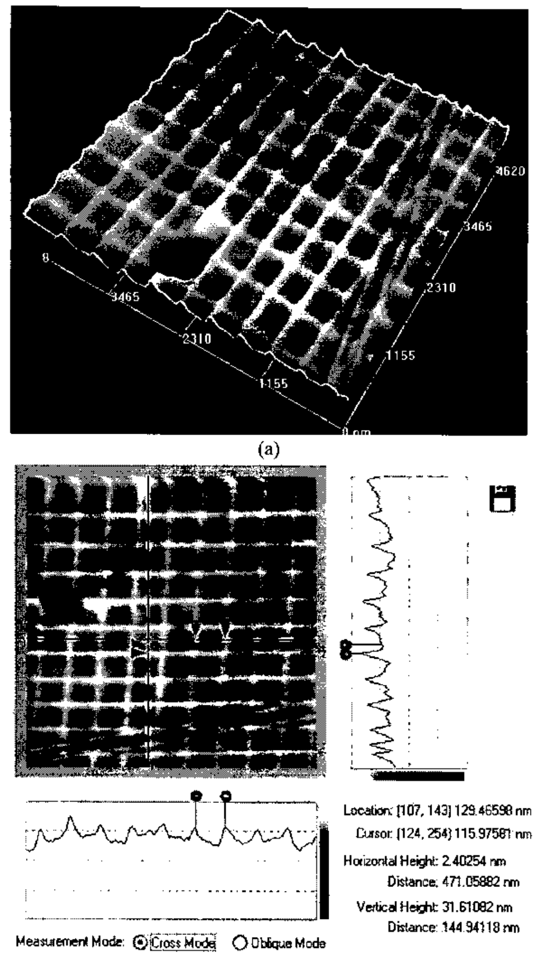


Fig.5 Measuring data and signals of the micro cantilever and the control data of the SPM controller.



(a)

(b)

Fig.6 Reconstructed image of a testing sample with diffraction grating. (a) 3D image, (b) Cross-sectional intensity profiles.

IV. Discussion

An optical pickup head of commercial CD/DVD ROM drive applied to detect the micro cantilever displacement in SPM was demonstrated. This system is well functionally verified by measuring calibration sample of 463 nm (pitch) × 30nm (height). With some small modifications and skillful adjustment technique, the optical pickup head has achieved all functional requirements at preliminary tests. In terms of compactness, low cost, and high vertical sensing resolution in nanometer range, it can make our developed SPM instruments more reliable and flexible in their applications. Based on the basic design concept with the commercial pickup head, a further refined development with advanced modifications is already in progress.

V. Acknowledgments

The authors would like to thank the AngsNanoTek Co. who supplied the SPM controller to establish this research. We would also like to acknowledge the TENTATIVE Co. who providing the CD/DVD PUH used in these measurements and for the information allowing us to drive the laser diode.

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