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High Resolution Detection of Synchronously Determining Tilt Angle and Displacement of Test Plane by Blu-Ray Pickup Head

Yan-Nan Lin, Wen-Shing Sun*

Department of Optics and Photonics, National Central University, 32001 Chungli, Taiwan(R. O. C.)

Abstract

We present an optical design for Blu-ray pickup head that can synchronously detect a linear displacement and two-dimensional (2D) angular tilt of the test plane. In order to enhance the accuracy of tilt angle and discriminate more tilted orientations, a high resolution detector (177×177 pixels) is used as the photo detector of the Blu-ray pickup head. The horizontal beam expander is used to make the laser beam be more uniform to improve the accuracy of signal at the photo detector. The signal at the high resolution detector of the pickup head used astigmatic detection is comprised of two displacement signals and one angular signal. The displacement of the test plane is ascertained from the rate of change in the length of semi-major and semi-minor axis for elliptical beam shape on the high resolution detector. The tilt of the test plane is obtained from the brightest position of beam shape. It is not only able to judge the tilt angle for four orientations (α , β , 45° and 135°), but also the tilt angle for four orientations (30°, 60°, 120° and 150°). The smaller pixel size will help to improve the accuracy in the 2D angle measurement further.

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1. Introduction

As technology advanced, optical non-contact profile measurement techniques are becoming increasingly important for industrial applications. Many optical inspection methods including interferometry, holography, and fiber optical probes have been widely used in the field of precision measurement. The significant advantage for using optical non-contact properties is not damage to the measured object due to the absence of contacting force. Among these optical inspection methods, optical pickup head has been successfully applied in precision measurement, including scanning optical microscopes [1], autocollimators [2], optical profilometers [3], and AFM [4]. These precision measurement using commercial pickup heads can synchronously detected displacement and tilt angle of surface of measured object to build its profile.

For optical pickup head devices, a quadrant detector is used to detect the relative relationship of the V_A , V_B , V_C , and V_D output signals which can be used to measure the displacement and tilt angle on disc. However, the accuracy

* Corresponding author. Tel.: +886-422-7151 ext65259 ; fax: +886-3-4252897.

E-mail address: wssun@dop.ncu.edu.tw.

of displacement and tilt angle would be directly affected from the precision of each signal (V_A , V_B , V_C , V_D) of a quadrant detector when the normalized focus error signal (NFES) and angular signal are calculated by the V_A , V_B , V_C , and V_D output signals. The tilt angles of four orientations (α , β , 45° , 135°) can be distinguished by the angular signal from a quadrant detector, but the tilt angles of other orientations cannot be distinguished [5]. In order to further improve the disadvantage described above, we used a high resolution detector in optical pickup head to detect the intensity distribution on it. Then the displacement signal was defined by the rate of change in the length of semi-major and semi-minor axis for elliptical beam shape on the high resolution detector; the angular signal was defined by the centroid of the beam shape on the high resolution detector. Thus, the accuracy of displacement and tilt angle would be most affected from pixel size of the high resolution detector, not from the precision of each signal. However, to ensure the accuracy of the displacement signal, the beam intensity distribution in the vertical and horizontal direction must be same. We used two cylindrical lenses as a horizontal beam expander [6] to transform the elliptical beam emitted from a laser diode into a circular and symmetric beam and to enhance the measurement accuracy or reduce the signal reading error.

2. System description

Figure 1 shows a optical layout of a laser expander for Blu-ray pickup head. A Blu-ray pickup head with laser expander is mainly composed of an objective lens, a collimating lens, a beam-splitter (BS), a horizontal beam expander, a cylindrical lens, a corrected plate, a test plane, and a high resolution detector. The laser beam is emitted from the laser diode and the beam shape is elliptic distribution. Because the vertical divergent angle of beam emitted from laser diode is larger than horizontal divergent angle of it and the beam shape on the test plane is circular, the design of the traditional pickup head give up the laser energy which the divergent angle is larger than 7.161 degree, the horizontal divergent angle corresponding to the relative intensity being $1/e^2$. In order to ensure the accuracy of the displacement signal, two cylindrical lenses as a horizontal beam expander [7] were used to transform the elliptical beam into a circular and symmetric beam. When the light is passed through the collimating lens and a horizontal beam expander, the light forms a parallel beam. It is then reflected by a mirror, after which it passes through the objective lens and corrected plate to focus on the test plane. After being reflected from the test plane the beam follows the opposite optical path back to be reflected by the BS. The light beam then passes through the cylindrical lens which induces the astigmatism before reaching the high resolution detector.

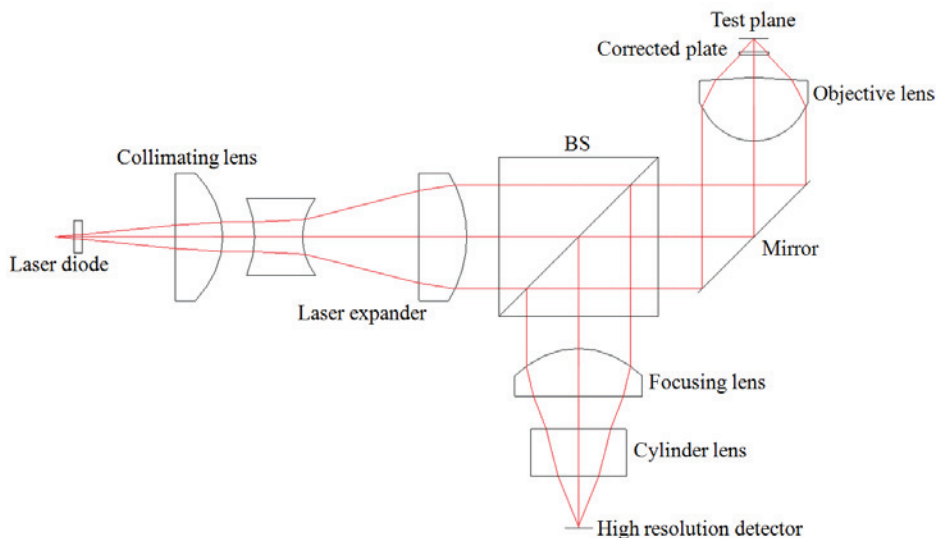


Fig. 1 A schematic diagram of a Blu-ray pickup head with laser expander.

A cylindrical lens is added in the backward path and it is used to induce astigmatic detection in the Blu-ray pickup head. The reflected light beam reaches at the high resolution detector with its axis oriented at 45° along the backward path. The pixel size and effective working area of the high resolution detector are $1.7 \mu\text{m} \times 1.7 \mu\text{m}$ and

300μm × 300μm, respectively. In order to avoid the disadvantage of determining the tilt angle and displacement of the test plane by the signals calculated from the output voltages on the PDIC, we define new displacement and 2D angular signals by the high resolution detector. The displacement signal is composed of defocus_A signal and defocus_B signal and they are combined to calculate the displacement of the test plane. The defocus_A signal and the defocus_B signal are defined by

$$defocus_A = \frac{r_a - r_o}{r_o}, \tag{2}$$

$$defocus_B = \frac{r_b - r_o}{r_o}, \tag{3}$$

where r_a and r_b are semi-major or semi-minor length in 45° and -45° direction, r_o is radius of the beam shape which the test plane is located on the focal point of the objective lens, as shown in Fig. 2. If the signals are defocus_A < 0 and defocus_B > 0, it means that the test plane is positioned in front of the focal point of the objective lens, and the beam shape is an ellipse with its major axis in the -45° direction. If the signals are defocus_A = 0 and defocus_B = 0, it means that the test plane is located on the focal point of the objective lens, and the beam shape is a circle. If the signals are defocus_A > 0 and defocus_B < 0, it indicates that the test plane is located behind the focal point of the objective lens, and the beam shape becomes ellipsoidal with its major axis in the +45° direction.

In this 2D angle measurement, the laser beam is projected onto the plane mirror, and the reflected laser beam is then focused at the center of the high resolution detector. A change in the angle of the test plane causes a corresponding shift in the position of the focused light spot on the high resolution detector [5]. According to describe above, the centroid position of the beam shape at the high resolution detector represents the brightest position in the light pattern, and it is defined as the angular signal. Therefore, the accuracy of tilt angle would be depend on the pixel size of the high resolution detector, rather than the precision of the photo detector.

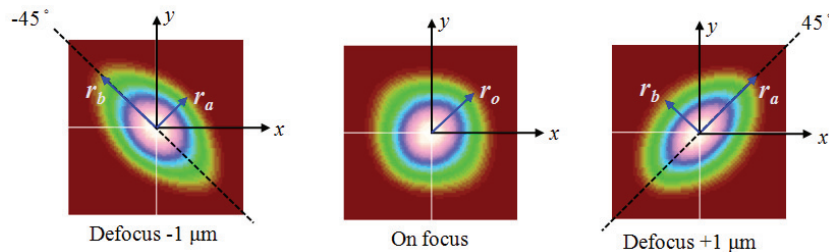


Fig. 2 The variations of the beam shape on the high resolution detector with different displacement.

The orientations on the test plane are defined in Fig. 3. The sign of the tilt angle is positive in the anticlockwise direction. The X-axis indicates the α orientation, and the Y-axis shows the β orientation. The orientations of the X-axis at 30°, 45°, 60°, 120°, 135°, and 150° are defined as the 30°-orientation, 45°-orientation, 60°-orientation, 120°-orientation, 135°-orientation, and 150°-orientation, respectively. The variation in the tilt angle is set to be ±2.5°.

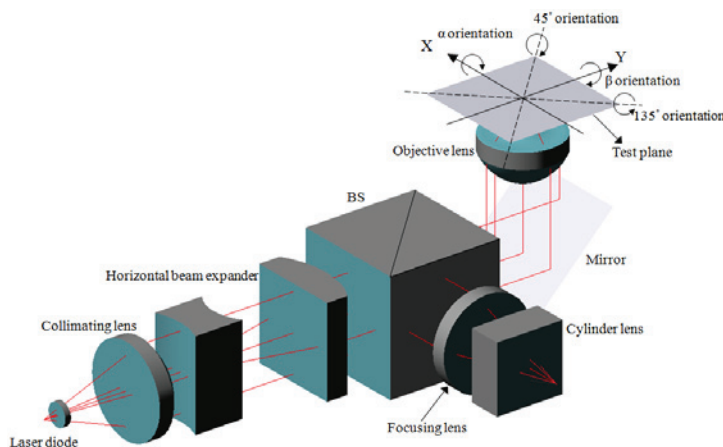


Fig. 3 Layout of the Blu-ray pickup head with laser expander and the orientation tilt at the test plane.

3. Simulation results and analysis

In the simulated displacement measurement, Figure 4 (a) shows the defocus_A signal and defocus_B signal with respect to different displacements (from -10 μm to 10 μm) on the test plane. Both the value zero of the defocus_A signal and defocus_B signal represent that the test plane is on focus. If the value of the defocus_A signal or defocus_B signal is -1, it represents that the test plane is on sagittal line focus and tangential line focus [8], respectively. And the linear range can be extended to 4.5 μm . Compare with using the NFES method by a quadrant detector, the linear range is only 2.1 μm , as shown in Fig. 4 (b).

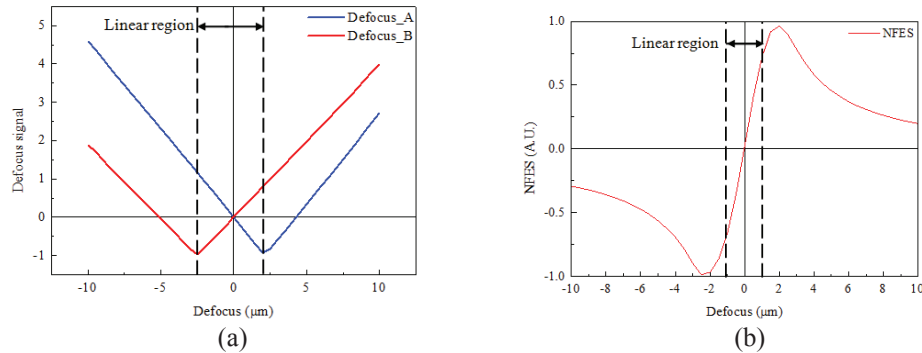


Fig 4 (a) The defocus_A signal and defocus_B signal variations at the high resolution detector with varied displacement of the test plane. (b) The s-curve using the NFES method by a quadrant detector.

In this 2D angle measurement, Fig. 5 shows the variations in the brightest position at the high resolution detector when the test plane is on focus as detected. We defined the center of the high resolution detector as position zero. Each blue lattice represents the pixel of the high resolution detector, and squares of different colors represent the tilt of different orientations. The A to K in each square represent that the tilt angle of the test plane is from $+2.5^\circ$ to -2.5° . The centroid of the beam shape represents the brightest position in the light pattern. In this way, the entire tilt angles within $\pm 2.5^\circ$ for different orientations can be detected by the angular signal. When the tilt angle of α orientation is from $+2.5^\circ$ to -2.5° , the brightest positions are all formed a straight line. Same is true for β , 45° , and 135° orientations. However, the brightest positions cannot form straight lines because of the pixel size at the high resolution detector for the tilt angle of the 30° , 60° , 120° , and 150° orientations. That means that the error of the brightest position in the light pattern is within the square area of a pixel at the high resolution detector. Therefore, the smaller pixel size will help to improve the accuracy in the 2D angle measurement.

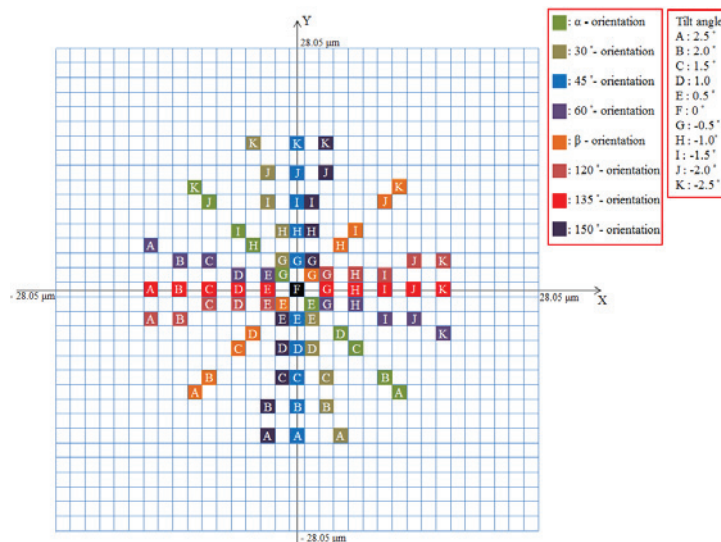


Fig. 5 The brightest position variation at the high resolution detector with varied tilt in different orientations of the test plane.

4. Acknowledge

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