Key Engineering Materials *Online: 2005-10-15*
ISSN: 1662-9795, Vols. 295-296, pp 107-112
doi:10.4028/www.scientific.net/KEM.295-296.107

A Measurement System for Step Imprint Lithography

H.Z. Liu, B.H. Lu, Y.C. Ding, D.C. Li, Y.P. Tang and T. Jin

Institute of Advanced Manufacturing Technology, Xi'an Jiaotong University, Xi'an, China

Keywords: Step Imprint Lithography, Plane Reflection, 6 DOF Measurement

Abstract. A precision 6-degree-of-freedom measurement system has been developed for simultaneous on-line measurements of imprint lithography stage. To successfully accomplish nanometer-scale pattern transfer from mold to resist film on the wafer, two types of positioning methods, static and dynamic, are used in this system. Two laser interferometers, two optical reflection mirrors and special structure on the stage with 3 elastic tracks are employed in this system to detect the positions and rotations of the stage. Through an algorithm, measurements of pitch, yaw and roll motions can be achieved. This system can realize on-line position detecting. Based on adjusting of PZTs, the detecting precision can reach 10nm and ±3 milli-arcsec, respectively. The measuring range can reach 100mm and ±10 arcsec, respectively.

Introduction

Imprint is well established for microstructure fabrication, e.g. in compact disc moulding and the manufacturing of holographic security features. At present, however, nano-imprint lithography (NIL) [1] has drawn close attention and extensive interest, especially as a low-cost process to make nanometer-scale patterns. To successfully accomplish the nanometer-scale patterns' transfer from mold to resist film on the wafer, the ultra-precision positioning of imprint motion-stage and the alignment of step-imprint are the prerequisite for step imprint process. Considering the stage motion and imprint-head pressing motion in the imprint process, positioning can be divided into two types: static and dynamic. For static type, the main positioning errors are two linear errors (X- or Y-direction), but for dynamic type, the main errors are six-degree-of-freedom (6DOF) errors (X-, Y-, Z- directions and pitch, yaw and roll).

In recent years, some research reports about the precision measurement utilizing multi-error detectors have been published. Fan [2] developed a multi-function error calibration system for NC machine tools, Ni et al. [3,4] employed 4 position sensitive detectors for 5-DOF measurement, Chou et al. [5] replaced quadrant detectors with CCD cameras and successfully developed a 5-DOF measurement system, and Fan and Chen [6] employed 4 laser interferometers and L-shaped mirrors for 6-DOF precision measurement of X-Y stage. The above systems, however, focus only on the multi-error measurements, the principle of measurement and fabrications are complex and expensive. So, in this paper, two types of positioning methods are presented, and a simple and effective measurement system for the step imprint lithography is proposed and designed.

Principle of Measurement

Figure 1(a) shows the schematic diagram of the system. This system is composed of a moving stage, two laser interferometers (model SP 120, SIOS) whose wavelength stability is 0.1 ppm, and three piezo actuators. The moving stage includes of an optical reflection part and positioning device. The optical reflection part consists of two plane mirrors perpendicular to each other, and the positioning device includes of three elastic tracks. The basic principle of measurement is to measure the displacements of X, Y and Yaw laser beams. As shown in Fig. 1 (b), the relationship of the unit normal vector of the mirror (**n**), the unit vector of the beam axis (**b**), and the travel axis (**T**) will affect the accuracy of displacement measurement. The moving stage's displacement from X and Y directions and the measurement errors can be calculated as follows: when the stage moves a vector T_x along X, the length NV equals $(T_x \cdot n_x) / \cos\theta$ or $(T_x \cdot n_x) / (b_x \cdot n_x)$, and the length OV equals

to $NV\cos 2\theta$. Thus the physical optical path (ΔL) measured by Laser interferometer is half of the optical path change and can be expressed as

$$\Delta L = (T_x \cdot n_x)\,(b_x \cdot n_x). \tag{1}$$

This calculation describes the stage moving from M1 to M2 along X. For the displacement along Y, the calculation is the same as that along X.

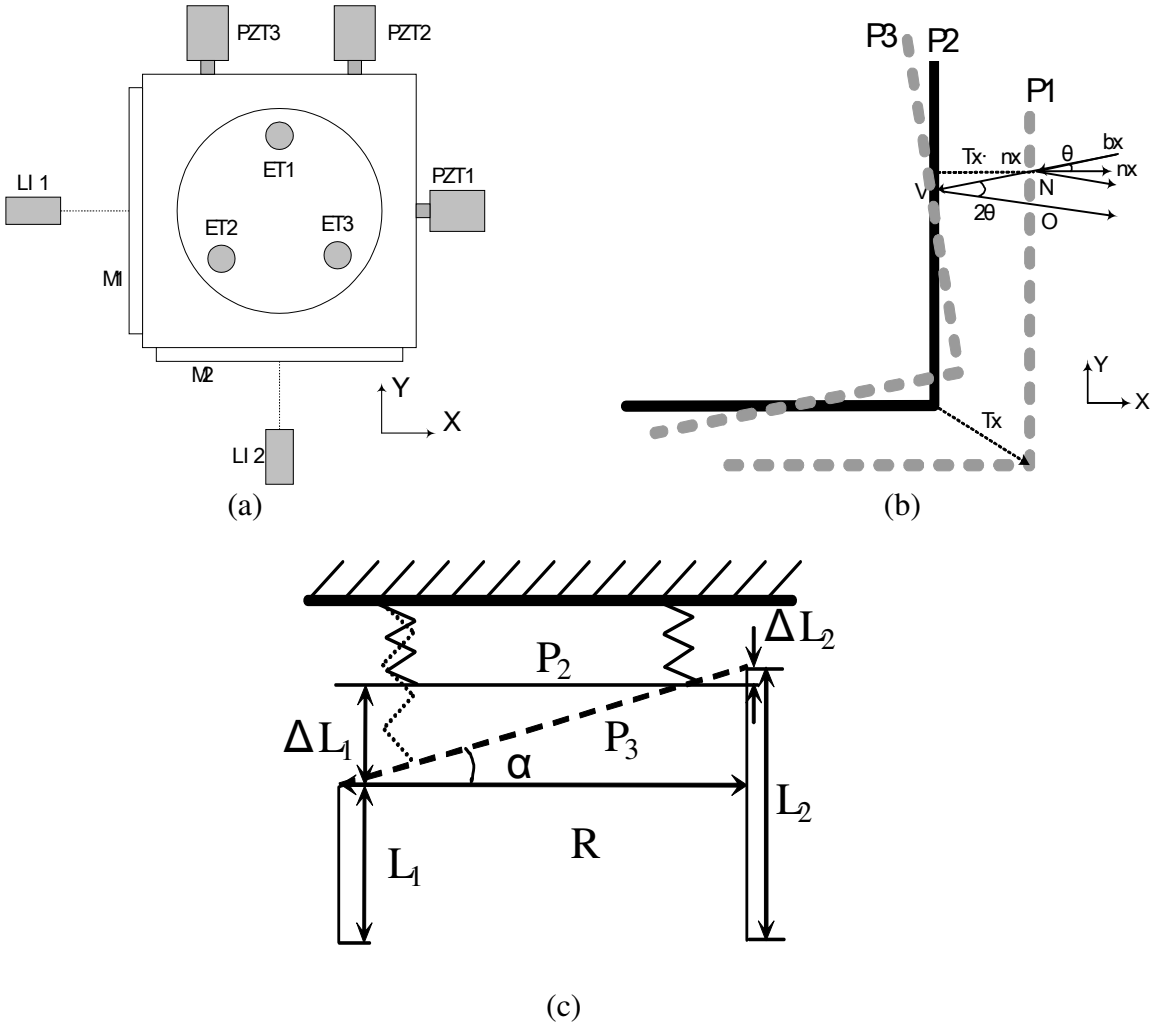


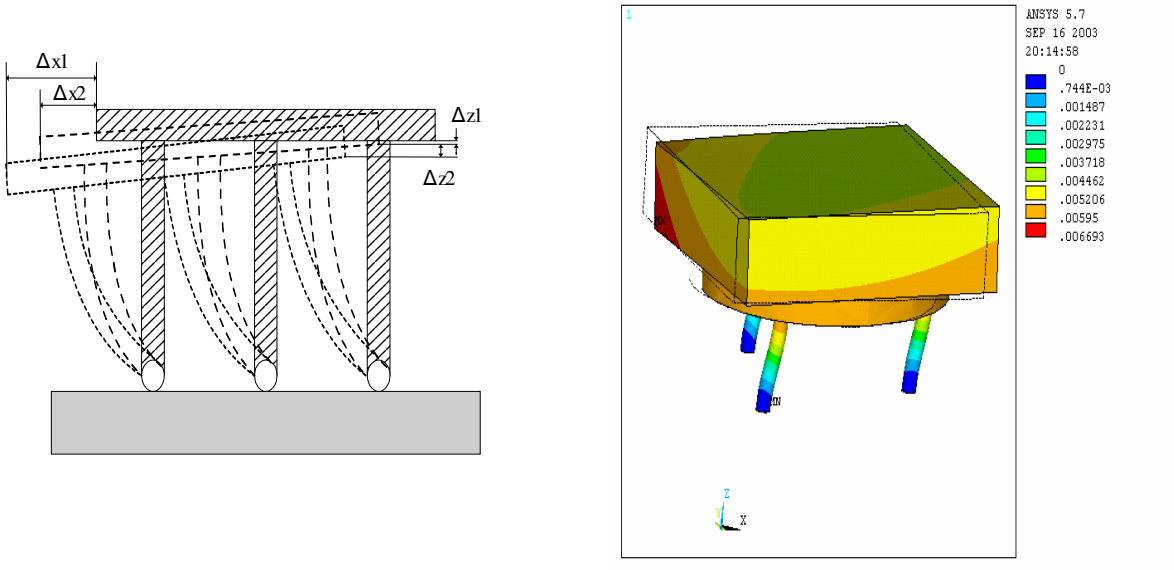
Fig.1 Schematic diagram of the measurement system and principle (a) Measurement system LI1-2: Laser interferometer; P1-2: reflection mirror; PZT1-3: piezo actuator; ET1-3: elastic track, (b) Relations of unit normal vector (n), measurement beam and travel axis, (c) Relations of displacement (X) and rotation (α)

The measurement of Yaw motion and error is as shown in Fig. 1(b) and (c). When the stage motion is only Yaw, e.g. from P2 to P3, measurements have to be conducted on two points. ΔL_1 and ΔL_2 are two displacements measured from two measuring points respectively, and R is the range between two measuring points. So, the angle calculation of Yaw motion is

$$\alpha = \frac{1}{tg\dfrac{\Delta L_1 + \Delta L_2}{R}}. \tag{2}$$

Similarly, the error calculation of displacement is as Eq. (1). The two points measurement is realized by parallel scanning of LI1 or LI2.

The X, Y and Yaw motion measurements shown above are only static, and the dynamic measurement must include 6 DOF motions. In this system, an additional structure (3 elastic tracks) is added to the stage, Fig. 2(a) is the schematic diagram of 6 DOF motion through 3 elastic tracks. $\Delta x1$ and $\Delta x2$ are the displacements through X, and $\Delta z1$, $\Delta z2$ are the displacements through Z. The angle of the roll motion can be calculated by Eq. (2), and the roll error's calculation is the same as Yaw. Similarly, this algorithm can be also used in Pitch motion. Fig. 2(b) is the finite element analysis (FEA) of stage's 6DOF motion. It caused by the press force which acts on the non center place of the stage.



(a) (b)

Fig. 2 (a) Schematic diagram of 6 DOF motion through 3 elastic tracks, (b) FEA result of stage's 6DOF motion

The measuring errors of pitch, yaw and roll can be calculated through the errors of the displacement through X, Y, Z-direction. When the stage has a motion relative to P, the spatial errors can be expressed as

$$\begin{bmatrix} \Delta X_P \\ \Delta Y_P \\ \Delta Z_P \end{bmatrix} = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} + \begin{bmatrix} \theta_x \\ \theta_y \\ \theta_z \end{bmatrix} \times \begin{bmatrix} X_P - X \\ Y_P - Y \\ Z_P - Z \end{bmatrix}, \tag{3}$$

where θ_x, θ_v, θ_z are the pitch, yaw and roll errors of the stage, and ΔX, ΔY, ΔZ are the measured linear errors. Here, × represents the vector cross product, and X_P-X, Y_P-Y, Z_P-Z are offsets from measured points to point P.

Measurement of Positioning Process and Discussion

In positioning process, stage motion can be divided into straight motion and rotary motion. Due to only X, Y-direction displacements can be measured. Fig. 3 is the result of X-direction positioning linear error. As shown in (a), the positioning process includes coarse and fine motions, (b) shows the positioning error is under 10nm [7]. Also, the Y-direction's detecting result is as same as the X-direction. The pitch, yaw and roll motions must be calculated from the straight motion. Following the Eq. (1-3), the rotary motion can be calculated accurately.

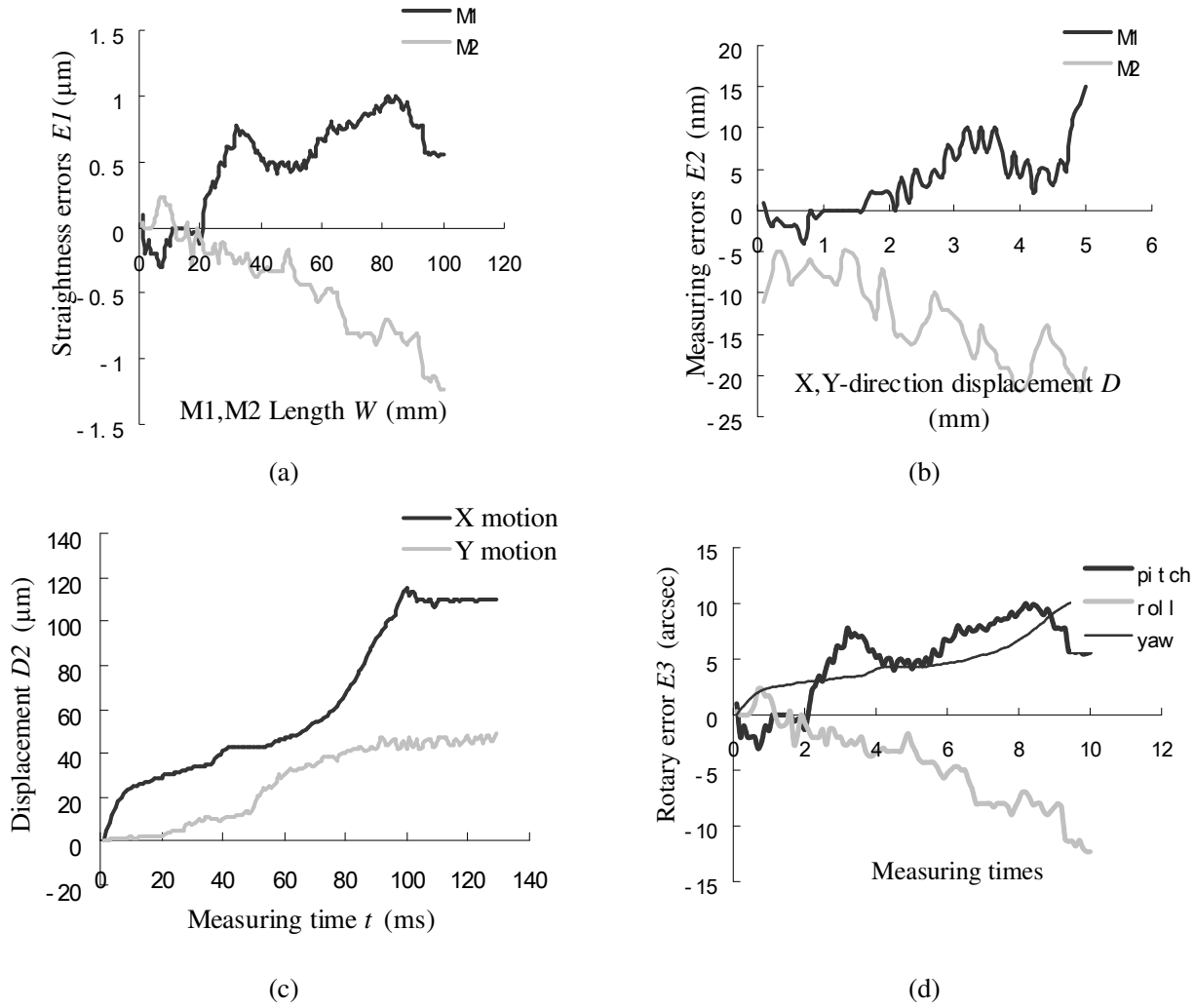


Fig.3 Measurement of positioning process (a) straightness of mirrors M1 and M2, (b) X, Y-direction displacement comes of pitch and roll motion, (c) X, Y-direction displacement comes of yaw and straight motion, (d) measuring result of pitch, yaw, roll motion

As shown in Fig.3, (a) is the straightness of mirrors M1 and M2, which is measured by LI1 and LI2 through scanning measurement of 100 mm range. Using this result of measurement, the compensation of straight motion measurement can be made. During this positioning process, the stage's motion locus is shown in (c). As shown in Fig. 3, the straight motion error is under 10nm, so the motion error is mainly caused by the straightness of the mirrors. The motion locus is recorded by LI1 and LI2. In addition, two measurement results just like (a), and two scan measuring results through Z as (b) can be obtained. The values of (b) are calculated from Eq. (2). After this process, the X, Y and Yaw-direction error can be achieved. The 3DOF motions are actuated by PZTs, it belongs to initiative control.

Considering the press force in imprint process, the preload is exerted by PZTs before stage is moving. Adding or reducing the preload force could adjust the stage position and at the same time the pitch and roll motions of the stage will be compensated. In imprint process, the motion locus along X, Y and displacements of mirror 1 and 2 at different positions could be recorded and measured by LI1 and LI2, which is just like (b), (c). Then, the results of the pitch, yaw and roll motions can be calculated. As shown in (d), it is the results of 10 times measurements of stage rotary position. As shown in (d), every result of measurement only describes the different static position of the stage motion. If the division of the motion range is more denseness, the measuring and calculating result is more close to real value.

Figure 4 is the photo of the stage structure. This stage includes two drive mechanisms, macro-driven by linear motors and micro-driven by PZTs. The base of the measurement system and stages is a granite table to maintain the same reference datum. The whole system is installed in a temperature and humidity-controlled room. Using software compensation, the displacement measurements of LI1 and LI2 are corrected for ambient influence.

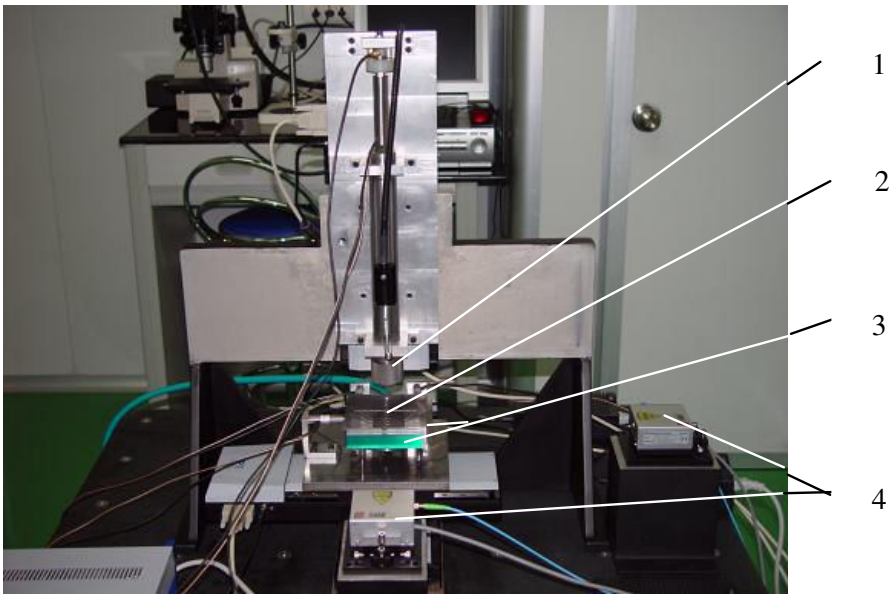


Fig.4 Photo of the experimental setup (1 - press head, 2 - stage, 3 - M1, M2, 4: LI1, LI2)

Conclusions

This paper presents a newly developed system able to measure and calculate the motion errors in 6 DOF of the X-Y stage. The developed system is simple in principle and structure. It can be mounted on a precision stage to provide a real-time compensation for 6 DOF. Its detecting accuracy is 10nm and ±3 milli-arcsec. The measuring range is 100mm and ±10 arcsec respectively. The disadvantage of this system is that the range of pitch, yaw and roll is limited into ±10 arcsec, and hence it needs to be further improved.

References

[1] S.Y. Chou, P.R. Krauss and P.J. Renstrom: Science, Vol. 272 (1996), p. 85.
[2] C.Y. Fang and K.C. Fan: Proc of the Third ROC-ROK Metrology Symposium, Taiwan, Vol. 1 (1990), p. 163.
[3] J. Ni, P.S. Huang and S.M. Wu: J Engng Ind, Trans ASME, Vol. 114 (1992), p. 362.
[4] P.S. Huang and J. Ni: Mach Tools Manufact, Vol. 35 (1995), p. 725.
[5] C. Chou, L.Y. Chou and C.K. Peng: Mach Tools Manufact, Vol. 37 (1997), p. 579.
[6] K.C. Fan and M.J. Chen: Prec Eng, Vol. 24 (2002), p. 15.
[7] H.Z. Liu, B.H. Lu and Y.C. Ding: J. Micromech. Microeng, Vol. 3 (2003), p. 295.