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Wafer focusing measurement of optical lithography system based on Hartmann–Shack wavefront testing

Xianchang Zhu*, Song Hu, Lixin Zhao

State Key Laboratory of Optical Technologies for Microfabrication, Institute of Optics and Electronics, The Chinese Academy of Science, Chengdu, Sichuan 610209, China

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ABSTRACT

To improve the focusing measurement precision of wafer in optical lithography instrument (OLI), a method based on Hartmann–Shack (HS) testing principle is introduced. Defocus of wafer is immediately detected by measuring the image change between plane and spherical wavefront. As defocus is measured by every sub-lens of microlens array (MLA), serials of defocus position are calculated at single shot of CCD sensor. Choose the average in this measurement the outstanding advantage of this technology is the high accuracy and efficiency. With an experiment to validate the feasibility, the accuracy of focusing measurement is indicated as 20 nm.

1. Introduction

In order to adjust wafer at the focal plane of projection lens, wafer focusing technique (WFT) [1,2] is a key technology in OLI [3]. Focusing precision of wafer affect the finally exposure effect [4]. Based on triangle method, defocus of wafer is detected by measuring the image remove of gap in CCD sensor [5] or position sensitive detector (PSD) [6] with micron precision in traditional OLI.

In recent times, resolution and exposure field of view (FOV) of OLI is increased [7]. While on one hand, the improvement of resolution reduces the depth of focus of OLI; on the other hand, large exposure FOV needed higher focusing measurement precision, WFT have been of interest and investigated widely [8,9]. Diffractive grating [10] is applied for focusing testing based on Talbot-moiré effect [11,12] and interferometry-spatial-phase imaging [13], probe beam scanner [14,15] are also introduced. Although these WFT have nanometer precision, the measurement system is complex and the measurement efficiency for large FOV need be improved.

In this paper, a simple WFT based on HS wavefront testing principle [16] is proposed. With a simple measurement system composed by MLA and CCD sensor, wafer position is immediately detected by measuring the image change between plane and spherical wavefront.

2. Methodology

The focusing measurement system introduced in this paper is composed by light source, beam expander and collimate system, 4f-optical system, MLA and CCD sensor, shown in Fig. 1

Plane wavefront from the beam expander and collimator system was transformed by 4f optical system and imaged by MLA in CCD sensor. When wafer position at the co-focal plane of 4f optical system, the wavefront measured by MLA is exactly plane wavefront and diffractive light intensity distribute as Bessel function:

$$I=\sum I_0\left[\frac{2J_1(Z)}{Z}\right]=\sum_{n=1}^{N}\sum_{m=1}^{M} I_0\left[\frac{2J_1\left(kd\sqrt{(x-nd)^2+(y-md)^2}/2f_2\right)}{kd\sqrt{(x-nd)^2+(y-md)^2}/2f_2}\right] \tag{1}$$

In this equation f_2 and d are the focal length and diameter of sub-lens in MLA, M and N are the row and column number of these sub-lenses. When wafer placed at a defocus position of projection lens, the wavefront measured by MLA is spherical wavefront and the defocus is calculated in Fig. 1

$$\begin{cases} s_1 = 2h\sin\alpha \\ s_2 = 2h\cos\alpha \end{cases} \tag{2}$$

Based on the triangle method, defocus of wafer h result in axis-defocus s_1 and vertical axis-defocus s_2. To analyze defocus of wafer, MLA and CCD position shown in Fig. 2

* Corresponding author.
E-mail address: zhuxianchang@126.com (X. Zhu).

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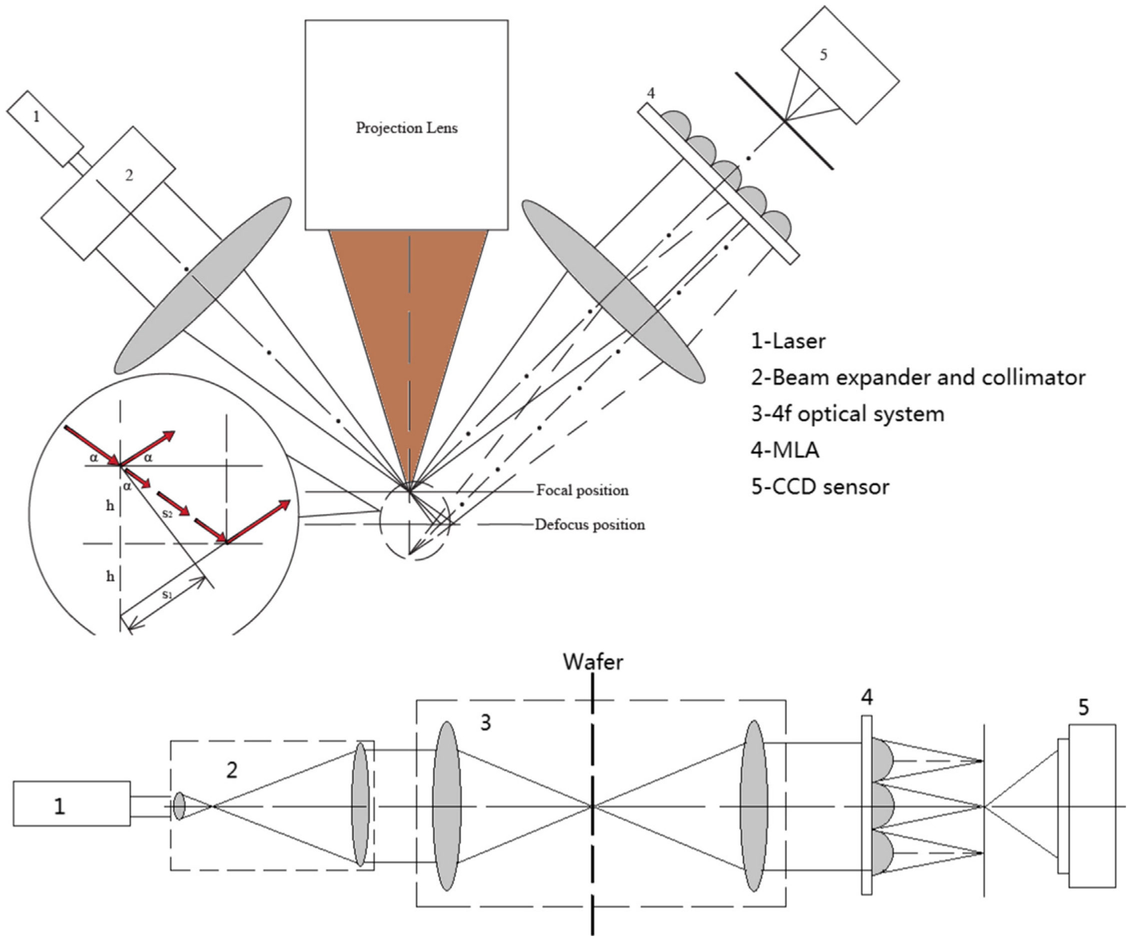

Fig. 1. Illustration of focusing measurement system.

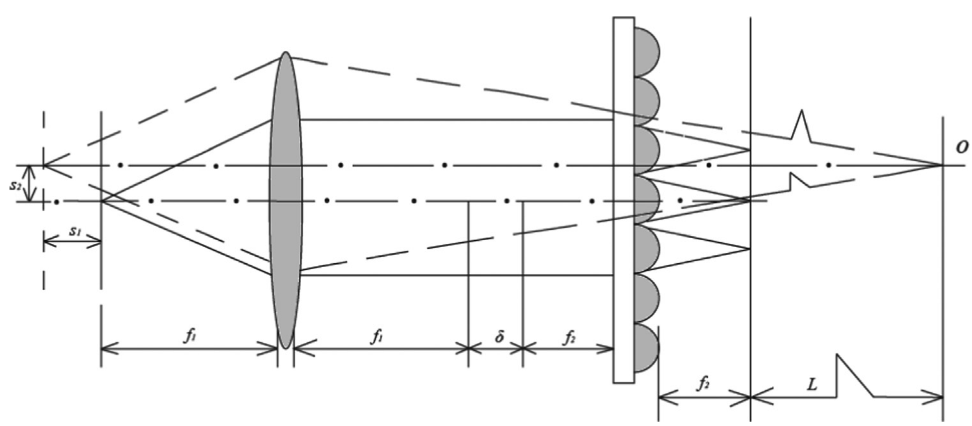

Fig. 2. Illumination of component position in measurement system.

Calculated by Newton equation in geometrical optics:

$$L = \frac{f_1^2}{s_1} - \delta - 2f_2 \tag{3}$$

In this equation, f_1 and f_2 is the focal length of 4f system; s_1 is the axis-defocus; and δ is the distance between 4f system and MLA. And for the spherical wavefront measurement, every sub-wavefront subdivided by MLA is calculated as plane wavefront, which means: the curvature center of wavefront under testing O, center of sub-lens P in MLA and image spot center of this sub-lens in CCD sensor M are on the same line, showed in Fig. 3

Neglected the thickness of MLA Δf, the difference of image spot between plane and spherical wavefront is calculated:

$$\frac{d_s}{L} = \frac{d}{z+L} = \frac{d}{f_2+L} \tag{4}$$

While d_s is the distance between image spot of spherical wavefront and light axis. Composited all these analysis, defocus of wafer is detected actual time:

$$h = \frac{1}{MN} \sum_{m=1}^{M} \sum_{n=1}^{N} \frac{f_1^2}{2\left((d_{smn} f_2 / d_{mn} - d_{smn}) + \delta + 2f_2\right) \sin\,\alpha} \tag{5}$$