Focusing and leveling system for optical lithography using linear CCD

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ABSTRACT

This paper proposes a focusing and leveling technique for optical lithography tools using linear CCD and image processing method. A double telecentric optical system is designed, which projects an aperture onto the surface of the wafer at a large incident angle, and then the reflected beam results in a spot image onto a linear CCD. A mathematical model relating the spot lateral displacement to the change of wafer height is established. Two image processing algorithms for displacement detection of the spot image measured by the linear CCD are also proposed. A lot of experiments including the system calibration conducted on a test rig confirm that the proposed technique is feasible and effective. The repetitive height measurement accuracy of the system is verified to be more than 200 nm within a wide band measurement range of 1 mm.

Keywords: lithography, focusing and leveling, image processing, linear CCD

1. INTRUDUCTION

The focusing and leveling system is one of the key parts in optical lithography tools, and it can compensate the influence of focus error factors, and thus ensuring the exposure quality. Recent years, the wafer position is mainly detected by photo-electric sensors and signal processing units. Some optical detection techniques have been proposed by many researchers [1-7]. Oshida et al have developed an optical interference system [2, 3], Kim et al [4] and Delguchi et al [5] have used a type of position sensitive device (PSD), and Derwerf has adopted an image grating method [7]. Monochromatic light, for example, He-Ne laser, light emitting diode (LED), or laser diode (LD), was employed as an illumination light source in some types of optical focusing and leveling systems. This paper proposes a focusing and leveling technique using linear CCD and image processing method. A halogen light with band wide spectra is used as the illumination light source and a linear CCD is used as the detection sensor. The linear CCD based systems can work in both of global and field-by-field modes. In global mode the position of the wafer is measured by the indirect metrology which is calibrated at three points by the systems, and in field-by-field mode the position of the wafer is measured in each exposure field. The design and implementation of the system is described in detail in this paper and is demonstrated to be capable of measuring the wafer focus position for a micro-lithography application. The repetitive height measurement accuracy of the system is verified to be more than 200 nm within a wide band measurement range of 1 mm.

2. METHODOLOGY

2.1 Principle in field-by-field mode

As illustrated in Fig.1, linear CCDs in a field-by-field mode are used to detect the position of a wafer in the focusing and leveling system. A beam is reflected off the wafer surface at a large incident angle α (70º<α<88º) and is detected by a liner CCD. The illumination beam is projected onto the wafer through a collimator lens, an aperture, and a telecentric projection lens, then is reflected from the photoresist on the wafer, and finally results in a spot spot image onto the liner CCD through a telecentric imaging lens. The change of wafer height is transformed into a lateral displacement of the

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spot on the liner CCD. Hence, defocusing information Δz can be obtained from the displacement of the spot in CCD imaging surface Δx by Equation (1) where α is incident angle and γ is magnification factor of the imaging lens.

$$\Delta x = \frac{\Delta z \cdot \gamma}{\cos\alpha} \sin 2(90^\circ - \alpha) \approx 2\Delta z \cdot \gamma \sin\alpha \tag{1}$$

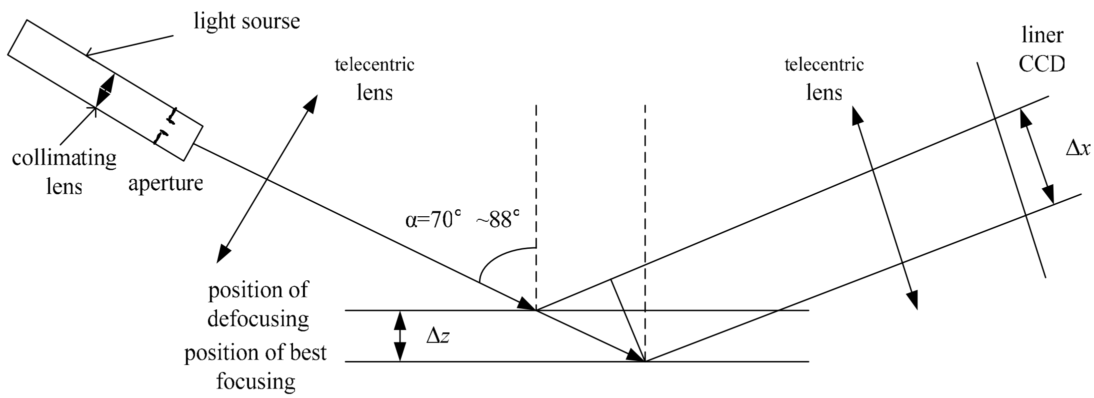


Fig.1 The principle of focusing and leveling system using linear CCD

The displacement of the spot in CCD Δx can be further calculated from the pixel offset of the spot Δn as in Equation (2), where d is effective size of a pixel in the linear CCD (in μm/pixel). Equation (2) establishes a direct relationship between Δz and Δn, which means that the change of wafer height Δz can be directly obtained from the pixel offset of the spot Δn.

$$\Delta n = \frac{\Delta x}{d} = \frac{2\gamma}{d} \Delta z \sin\alpha \tag{2}$$

2.2 Principle in global mode

In global leveling mode, the positions of three points on the wafer will be measured. As shown in Fig.2, three points A, B, C compose an equilateral triangle where D is the midpoint of BC and O is the midpoint of AD which is also the center of the wafer. The distance between B and C is $2b$ and the distance between A and D is $2c$.

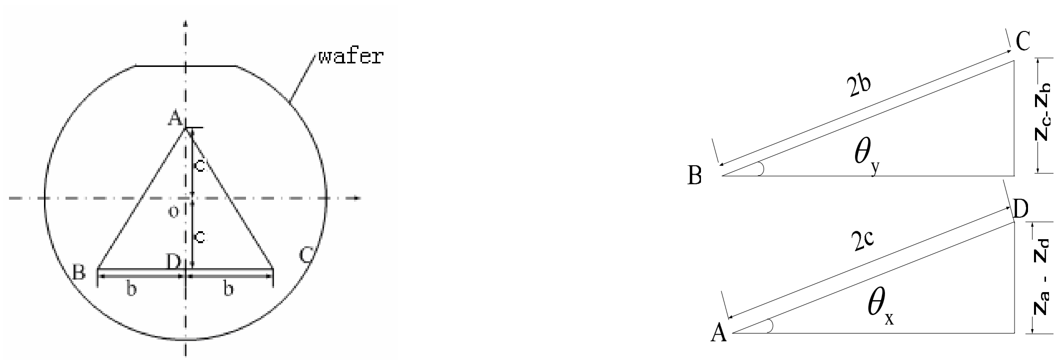


Fig. 2 Principle of focusing and leveling system using linear CCD in global mode

Assume the measured height in Z direction of the three points are z_a, z_b, z_c,, the defocus and the tilt angle in X and Y directions of the wafer can be calculated as in Equations (3), (4) and (5), respectively.

$$\Delta z = \frac{z_b + z_c + 2z_a}{4} \tag{3}$$

$$\theta_x \approx \frac{z_a - z_d}{2c} = \frac{z_a - \frac{z_b + z_c}{2}}{2c} = \frac{2z_a - z_b - z_c}{4c} \tag{4}$$

$$\theta_y \approx \frac{z_c - z_b}{2b} \tag{5}$$

2.3 Spot location detection algorithm

There are two algorithms for the detection of the spot location. One algorithm is looking for the center of spot edges. After finding the two edges of the image, their average gives the center of the spot image. Edge is defined as a gray-scale image of the dramatic changes in the border region. Edge detection is traditionally implemented by convolving the signal with some form of linear filter, usually a filter that approximates a first or second derivative operator [8]. The most methods of edge detection may be grouped into two categories, i.e., gradient (Roberts, Prewitt, Sobel) and Laplacian (Marr-Hildreth). The gradient method detects the edges using the extreme in the first derivative of the image. The Marr-Hildreth method uses the Gaussian smoothing operator to improve the response to noise and searches for zero-crossings in the second derivative of the image to find edges. The zero crossings of a signal always form closed contours. This is nice if one is trying to separate out objects in the scene. By differentiation the Laplacian of Gaussian is called the Log operator [9]. The Log operator is a symmetric filter and the maxima in the output of this operator corresponds to tangent discontinuities, often referred to as bars*,* or line*s*.

The other algorithm for the detection of spot location is looking for the center of gravity of the spot. In a gray-level image, the center of gravity resulting in a sub-pixel estimate of the central position of an object is defined as in Equation (6), where D is a contiguous domain of pixel coordinates x_i that satisfies the threshold condition: $h_i >= h_t$, which is the gray threshold of background and has influence on detecting the gravity center of spot.

$$x_g = \frac{\sum_{x_i \in D} x_i h_i}{\sum_{x_i \in D} h_i} \tag{6}$$

2.4 Calibration method

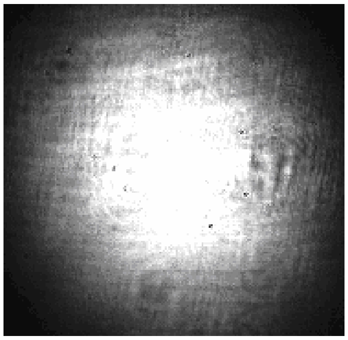
Calibration of the linear CCD in the focusing and leveling system is a process to determine the relationship between wafer height and the spot offset in pixels on the linear CCD [10]. A nanopositioning vertical stage is used here to help form a table which maps a series of spot image offsets on the linear CCD into a series of Z direction displacements of the wafer stage in a step way. Usually, Δz is mapped into Δn using equation (7), and more accuracy with cross terms and high order terms can be achieved. After calibration, the vertical displacement from the position of best focus can be obtained from any measurement spot offset in pixels.

$$\Delta z = a_0 + a_1 \Delta n \tag{7}$$

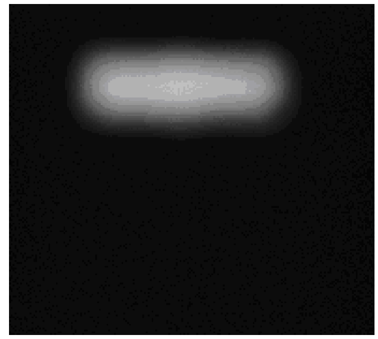
3. EXPERIMENTS

A test rig was set up to verify the proposed method and system. The main hardware components of the system include a light source, a projection lens, an aperture, an imaging lens, a liner CCD camera, and an image grabber. The liner CCD is an Atmel CCD monochrome linescan camera with the model of AVIIVA M2 CL 4010. The resolution of linear CCD is 4096 pixels with a pixel size of about 10μm. The aperture is adjustable from 0.01mm to 1mm. The telecentric lens is Moritex MML1-110. A high-performance image grabber, Euresys GrabLink Expert 2 cPCI, is used to obtain the spot imaging. The nanopositioning stage is actuated by M-451.1DG and P-518.TCD from PI and is measured with a resolution of 0.1nm. The entire focusing and leveling system is isolated from the ground vibration by an active damping system STACIS2000 from TMC.

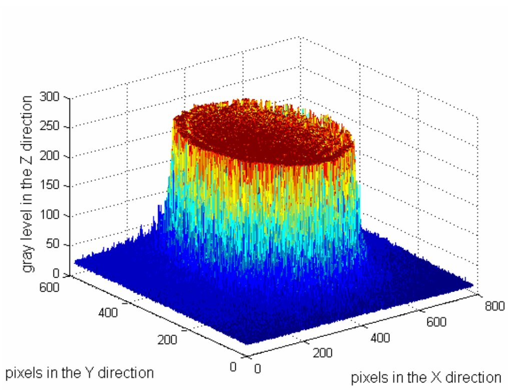
The spot images with a He-Ne laser and a halogen light measured by an array CCD are shown in Fig.3(a) and Fig.3(b), respectively, and the gray-value analysis of the corresponding spot images are shown in Fig.3(c) and Fig.3(d), respectively. Although the laser spot has a higher brightness, the gray-linearity of edge is very poor. On the contrary, the edge of the halogen spot has a very good linear gray-scale distribution. So we chose the halogen light as the illumination light source.



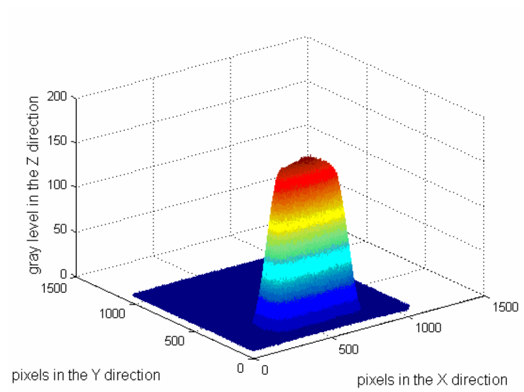
(a) spot image of helium-neon laser



(b) spot image of halogen light



(c) gray-value analysis of helium-neon laser



(d) gray-value analysis of halogen light

Fig.3 Analysis of the spot images using different light source

Figure 4 shows an acquired image from the linear CCD with 300 lines using the halogen light. The width of the spot image is about 100 pixels. Figure 5 depicts the results of the spot image by different edge detection operators, which clearly shows that the Log operator is the best way to detect the center of the spot edges.

Fig.4 The spot image on linear CCD using halogen light

(a) Roberts operator

(b) Prewitt operator

(c) Sobel operator

(d) Log operator

Fig.5 The output of the spot image by different edge detection operators

Table 1 shows some mapping data in the process of calibration where the nanopositioning stage moves with a step of about 1µm. Ten times of measurements were performed to give a mean value for each step of movement while the stage keeps no movement during the measurement.

Table 1 some mapping data in the calibration process

Position of stage (µm)	Gravity center of spot (pixels)	Edge center of spot (pixels)	Position of stage (µm)	Gravity center of spot (pixels)	Edge center of spot (pixels)
-0.0004	2213.2842	2212.0151	11.0011	2214.4779	2213.1586
1.0001	2213.3916	2212.1163	11.9996	2214.5921	2213.2741
1.9989	2213.5023	2212.2193	12.9988	2214.7078	2213.3627
2.9997	2213.5926	2212.2928	13.9988	2214.8184	2213.4523
3.9997	2213.6975	2212.3831	15.0005	2214.9255	2213.5352
5.0005	2213.8026	2212.4848	16.0035	2215.0334	2213.6173
6.0022	2213.9144	2212.5805	16.9991	2215.1312	2213.7352
7.0002	2214.0167	2212.7419	18.0023	2215.2381	2213.8400
7.9991	2214.1315	2212.8424	19.0033	2215.3355	2213.9307
9.0013	2214.2399	2212.9596	20.0032	2215.44176	2214.0632
9.9971	2214.3565	2213.0625			

Figure 6 and Figure 7 show the calibration curves with different spot detection algorithms. The max error of the gravity detection algorithm is 0.019 pixels while that of the edge detection algorithm is 0.042 pixels, which demonstrates that the gravity detection method is better than the edge detection method in this situation. As the effective size of one pixel in the linear CCD is 10µm/pixel, the max error of the gravity detection algorithm is within 200nm.

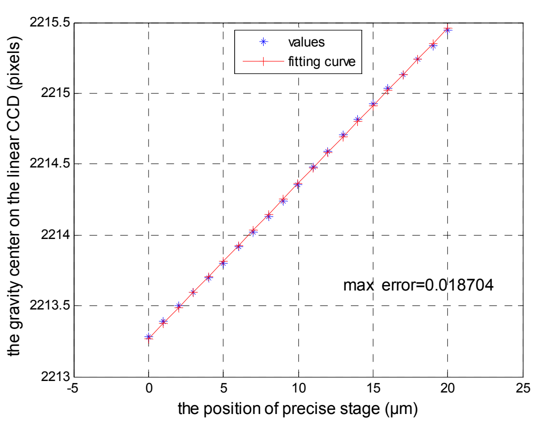


Fig.6 Calibration curve by the gravity detection algorithm

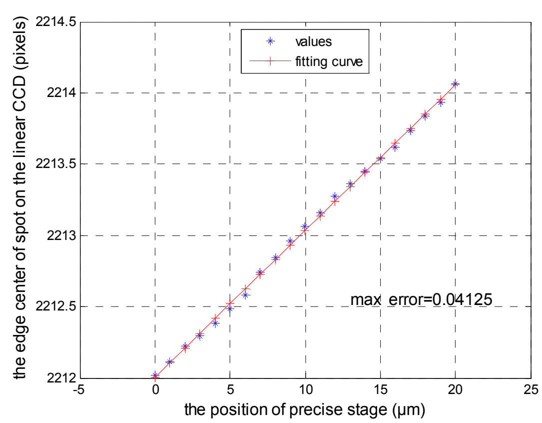


Fig.7 Calibration curve by the edge detection algorithm

The repeatability test results for a single measurement session of displacement are also shown in Fig.8. The mean value of the spot location is 2214.0186 pixels, which is equivalent to a mean stage position of 6.850µm and a position error within ±0.20µm after calibration. Almost all the measurement data are within the range of ±0.20µm and the 3σ value is well below the specification of 0.2µm. These results indicate a consistent ability to achieve the system specifications.

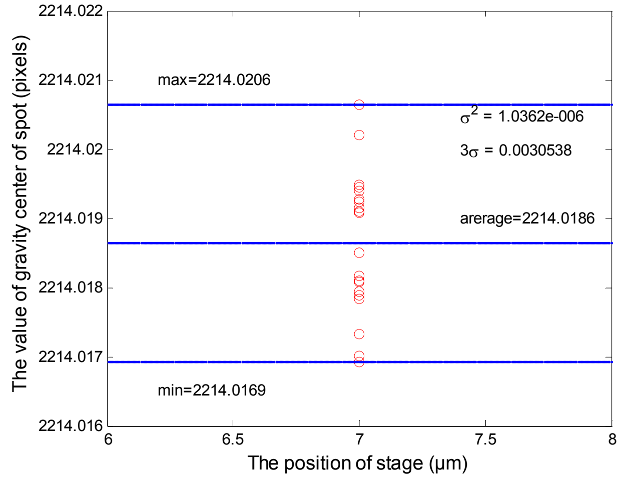


Fig.8 Repeatability test results for a single measurement session of displacement

4. CONCLUSIONS

A focusing and leveling system using linear CCD has been designed for measuring and maintaining the wafer at the position of best focus for the optics in a micro-lithography tool. The repetitive height measurement accuracy of the system is verified to be more than 200 nm. It is expected that this technique will be simple to implement and will provide a useful practical tool the focusing and leveling in product optical lithography tools as well as other applications.

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