Proceedings of the 7th
World Congress on Intelligent Control and Automation
June 25 - 27, 2008, Chongqing, China

A New Wafer Prealigner Based on Multi-sensor Fusion*

Chunxia Huang, Qixin Cao and Zhuang Fu

Research Institute of Robotics

Shanghai JiaoTong University

Shanghai, China

hcx81314@sjtu.edu.cn

***Abstract*-Aiming to traditional pre-aligners' deficiencies in the precision of prealignment and spacing consuming in the manufacture of integrated circuits, a new wafer prealigner was proposed, which uses a high-precision laser displacement sensor and a low-cost transmission laser sensor as wafer-periphery detectors instead of a CCD linear sensor traditionally used, and correspondingly a precise prealignment algorithm was developed based on the multi-sensor fusion. The eccentricities of the wafer and the notch were calculated by means of centroid acquiring algorithm among one particle system, the micron-rank prealignment precision was achieved at the end. The proposed system has saved the space occupation of the structure and enhanced the systematic prealignment precision. Experimentation has proved the validity and effectiveness of the system.**

Index Terms – Wafer prealigner, Multi-sensor Fusion, Eccentricity calculation

I. INTRODUCTION

In the manufacture of integrated circuits, various processes are required to be performed on the silicon wafer that is the substrate of the chips in order for a circuit pattern to be imprinted thereon. The apparatus that finishes this job is called lithography, of which a prealigner is a crucial subsystem. A prealigner is a device that orients a wafer or a substrate so that its center is set at a predefined place and its flat or notch is set at a predefined angle. A silicon wafer need to be prealigned prior to delivery to the work stage where a circuit pattern imprinted process is implemented. Wafer prealignment is very important because the wafer must be positioned accurately enough to be within the range of the work stage, so that the next procedure can proceed successfully [1-2].

In prior prealigners, the detection of the periphery of the wafer often utilizes a linear CCD array. After the wafer spun about the center axis of the turntable, the prealigner determines the center of the wafer by fitting the current data curve of CCD to the standard curve without offset. Having eliminated the spike in the data caused by the notch, the wafer center may be easily determined using the amplitude and phase of the fitted curve. Then align the wafer center to the position of the turntable center by three vertical pins for separating them and the motion module for alignment. With the centers aligned, the wafer is spun again, then the abrupt change in the curve caused by the notch can be observed. The position of the notch can be determined by calculating the curve apex based on its derivative. Timesaving is an advantage of prior prealigners when prealigning a wafer. However there are the following disadvantages. Firstly, due to the influences brought by the limitation of the sampling frequency and external disturbance, the device has relatively low accuracy, especially in terms of the notch alignment that depends on one apex of the curve. As the line size of wafer features becomes smaller and smaller, its prealignment precision cannot meet the demand of the lithography. Secondly, a CCD array is a bulky component, it may not accommodate the narrow space due to the mechanical dimension limitation of the lithography [3-5].

In this paper, a prealigner based on multi-sensor fusion is proposed. The proposed prealigner integrates the peripheral data of the wafer detected by a high-precision laser displacement sensor and a low-cost transmission sensor to calculate the eccentricities of the wafer and the notch by means of centroid acquiring algorithm among one particle system. The precise prealignment of the center and notch of the wafer is based on the two determined eccentricities. Both of the sensors are small enough to be embedded in the mechanical frame around, so that they hardly occupy any space. And high sampling frequency is available for both sensors so that they can be sampled much more circumferential points on the edge of wafers than a CCD array can under the same circumstances, which enhances the prealignment precision of the system. The proposed prealigner is a 4-axis mechanism, which results in a quick aligning.

II. MECHANISM OF THE WAFER PREALIGNER

The sketch of the mechanism of the system is shown in Fig. 1.

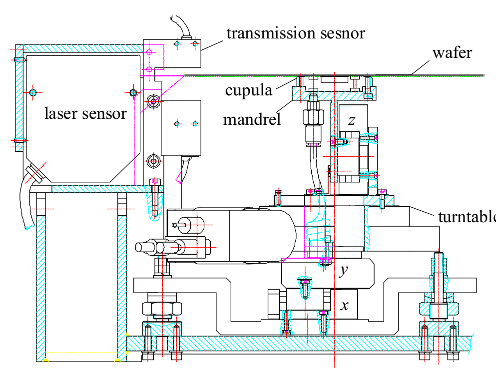

Fig. 1. The sketch of the mechanism of the wafer prealigner

The proposed prealigner is a 4-DOF executive machine. The motion module consists of four stages of x, y, z, r (turntable), implementing rotation and 6 directions of linear movement. X stage is fixed on the bottom board, y stage is

978-1-4244-2114-5/08/$25.00 © 2008 IEEE.

fixed on the x stage, x and y stages can implement linear movement of front and back, left and right respectively, carrying out the center prealignment of the wafer. The turntable is fixed on y stage, rotating the part thereon when sensors detecting the peripheral data of the wafer and when the notch being oriented. Z stage is fixed on the turntable, able to implement linear movement of up and down. Z stage moves when the robot arm handing over the wafer before it prealigned and the deporting arm taking over the wafer after it prealigned. The motion module is controlled by a four-axis controlling card, which can drive 4 axes at most at the same time, thus the center prealignment of the wafer, which involves 2 directions of movements in x and y, can be carried out synchronously.

On the z stage is a mandrel, which is the detective component of the jumpiness error of the turntable. On the mandrel is a cupula absorbing the wafer thereon.

The sensor module consists of two sensors, one is the high-precision laser displacement sensor and the other is the low-cost transmission laser sensor. Their set positions are shown in Fig. 1. The laser from laser sensor projects radially against the edge of the wafer, and then reflects back to the receiver. As for the transmission sensor, its emitter and receiver are set perpendicular to the plane of the wafer, its measuring value depends on how much beam of the light being obstructed.

III. METHOD OF PREALIGNMENT

A. *Wafer Prealignment Based on Multi-sensor Fusion*

Wafer prealignment includes its center prealignment and notch prealignment. The data from the laser sensor can be used to determine the eccentricity of the wafer precisely, which means the laser sensor is competent to provide all the information that center prealignment needs. However in some cases due to the specialties that laser cannot reflect back to the receiver when it beaming radially at the bevel edges of the notch, the laser sensor fails in detecting the notch. Therefore the transmission sensor that can detect the notch successfully under any condition is appended for notch prealignment. So as a matter of fact wafer prealignment is accomplished based on the fusion of the two sensors.

B. *Prealignment Flow*

The process of wafer prealignment includes four steps. The first step, the wafer is spun by one circle, the data sampling card samples the wafer peripheral data from the laser and transmission sensors, triggered by the external clock signal provided by the code signal of the turntable. Therefore each of the sampled point is relative to some angle of the rotation, namely the polar coordinates of each point is determined. The second step, the peripheral data from the laser sensor is used to calculate the eccentricity of the wafer by means of centroid acquiring algorithm among one particle system, at the same time based on the shape of the notch, pick alternative sensor's data to calculate the coarse orientation of the notch. The third step, based on the determined eccentricity of the wafer, x and y stages in motion module align the wafer so that its center can be set at the position of the turntable center. The forth step, the turntable spins the notch under the transmission sensor based on the determined coarse orientation of the notch, and then begins to re-sample the data of the notch part triggered by the signal which is created by multiplying four times of the code signal of the turntable. The re-sampled data of the notch can be used to calculate its eccentricity accurately still by means of centroid acquiring algorithm. The connecting direction from the eccentricity of the notch to the center of the turntable is defined as the notch direction. After it is determined, the turntable spins a certain angle so that the notch direction is set to the desired angle. Thus wafer prealignment is finished.

C. *Eccentricity Calculation Algorithm*

Eccentricity calculation is the key of wafer prealignment. No matter which prealignment it is, center one or notch one, the reference of precise prealignment is eccentricity. So the precision of eccentricity calculation directly decides the precision of prealignment.

The traditional algorithm of eccentricity calculation is data fitting by least square, which requires the calculated object to be round. However, strictly speaking, the wafer with a notch is not a circle, not to mention the notch itself. Therefore, in this paper the eccentricity calculation of the wafer and the notch doesn't use the traditional algorithm, but use centroid acquiring algorithm among one particle system, which can adapt to any object with random figure. Namely the eccentricities of the wafer and the notch can be calculated with the same algorithm.

The centroid of the object is calculated by (1) and (2)

$$\bar{x} = \frac{M_y}{M} = \frac{\sum_{i=1}^{n} m_i x_i}{\sum_{i=1}^{n} m_i} \tag{1}$$

$$\bar{y} = \frac{M_x}{M} = \frac{\sum_{i=1}^{n} m_i y_i}{\sum_{i=1}^{n} m_i} \tag{2}$$

Hereinto, $M = \sum_{i=1}^{n} m_i$ is the total quality of the object, $M_y = \sum_{i=1}^{n} m_i x_i$, $M_x = \sum_{i=1}^{n} m_i y_i$ are the static moments of the x and y axes respectively。

N is the number of the effective points of the wafer circumferential data sampled, each point relative to the code value of the rotation, so that the polar coordinates of each point are (r_i, θ_i). The wafer is divided into n sectors, which is shown in Fig. 2.

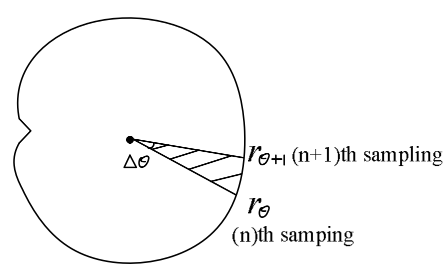

Fig. 2. Data sampling for wafer eccentricity calculation with the centroid acquiring algorithm

Total quality of the wafer is calculated by (3)

$$\sum_{i=1}^{N} \iint_d \rho \cdot r dr d\theta \cdot \tag{3}$$

Static moment of y-axis of the wafer is calculate by (4)

$$\sum_{i=1}^{N}\iint_{d}\rho\cdot r^{2}\cos\theta drd\theta \cdot \tag{4}$$

Static moment of x-axis of the wafer is calculated by (5)

$$\sum_{i=1}^{N}\iint_{d}\rho\cdot r^{2}\sin\theta drd\theta \cdot \tag{5}$$

According to (1) and (2), the coordinates of the wafer eccentricity are calculated as in (6) and (7)

$$\bar{x}=\frac{\sum_{i=1}^{N}\iint_{d}\rho\cdot r^{2}\cos\theta drd\theta}{\sum_{i=1}^{N}\iint_{d}\rho\cdot rdrd\theta}=\frac{\frac{1}{3}\sum_{i=1}^{N}r_{i}^{3}\left[\sin\theta_{i+1}-\sin\theta_{i}\right]}{\frac{1}{2}\sum_{i=1}^{N}r_{i}^{2}\left[\theta_{i+1}-\theta_{i}\right]} \tag{6}$$

$$\bar{y}=\frac{\sum_{i=1}^{N}\iint_{d}\rho\cdot r^{2}\sin\theta drd\theta}{\sum_{i=1}^{N}\iint_{d}\rho\cdot rdrd\theta}=\frac{\frac{1}{3}\sum_{i=1}^{N}r_{i}^{3}\left[\cos\theta_{i+1}-\cos\theta_{i}\right]}{\frac{1}{2}\sum_{i=1}^{N}r_{i}^{2}\left[\theta_{i+1}-\theta_{i}\right]}. \tag{7}$$

In this paper, the notch eccentricity is regarded as the eccentricity of the sector with the notch figure as its contour line, which is shown in Fig. 3. Equations of the coordinates of the notch eccentricity are similar with (6) and (7). The only difference is the range of the integral angle, as for the wafer eccentricity, it's 0~360°, as for the notch eccentricity, the range is within two certain angles represented respectively by the start and end points of the notch.

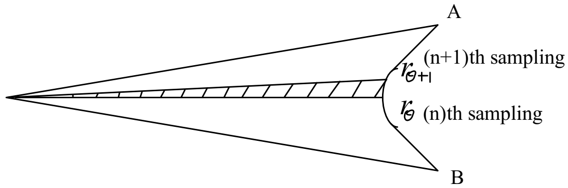

Fig. 3. Data sampling for notch eccentricity calculation with the centroid acquiring algorithm

D. Notch Prealignment

Notch prealignment is the hard part of wafer prealignment, which is way more difficult and complicated than center prealignment. From the prealignment flow, it's known that notch prealignment goes through two steps, one is called the coarse orientation of the notch which aims at the search for the begin and end points of the notch, the other is the precise orientation which involves the aforementioned eccentricity calculation of the notch.

a. the Coarse Orientation of the Notch

The coarse orientation of the notch is calculated as the wafer eccentricity being calculated. Due to the existence of the original random offset of the wafer center, the precision of the coarse orientation of the notch is destined to be out of the required range. However, the information of the coarse orientation is the premise to the precise orientation of the notch afterwards, therefore the search for it is necessary.

In the process of data sampling for the coarse orientation of the notch, the data from two sensors is sampled synchronously. Which sensor's data being used depends on the shape of the notch. The common goal is to find the coarse orientation of the notch as quickly and precisely as possible. The notch is a little slot with almost 1 mm in depth and 1.15° of splaying angle in the periphery of the wafer. Most of them are V-shape, few of them are semicircular. For the laser sensor, when it detecting the notch with V-shape, at the sections of two bevel edges of the notch its reflecting light is unable to return to the receiver, which results to the share of points of the notch being out of range, however it doesn't happen when it detecting the notch with semicircular shape. For the transmission sensor, because its emitter and receiver are set perpendicular to the plane of the wafer, no matter what shape the notch belongs to, it can manage to measure all notch points.

For the notch of V-shape, the feature of the laser sensor being out of range on the sections of the notch bevel edges can be utilized to position the notch coarse orientation very quickly. Specifically speaking, the start and end points of the data segment being out of range are respectively the start and end points of the notch.

For the notch of semicircular shape, both of the sensors can manage to detect the notch, considering the data of the laser sensor includes much more disturbance than the transmission sensor does, for the sake of precision it is the data of the transmission sensor that is utilized to find the coarse orientation of the notch. The method is to calculate the derivative of its sampled peripheral data circularly in one circle. The points of the minimum and the maximum are respectively the start and end points of the notch.

The connecting direction from the start or end point of the notch to the wafer center is then the coarse orientation of the notch.

b. the Precise Orientation of the Notch

As for the precise orientation of the notch, notch eccentricity needs to be calculated using (6) and (7) whose integral angle range depend on the start and end points of the notch. So the precision of the two points' orientation directly decides the precision of the notch orientation. Due to the influence inflicted by the random wafer eccentricity, the precision of the two points' orientation is very low at the moment. So we need to center the wafer first, and then resample the notch data, redetermining the start and end points of the notch with new notch data. Due to the laser sensor's incapability when detecting the V-shape notch, only the notch data from the transmission sensor is re-sampled. The turntable spins the relative angle bringing the coarse start point of the notch to the transmission sensor beginning the process of data re-sampling, then continues to spin until the coarse end point of the notch gets through the sensor, ending the process of data sampling.

The method of redetermining the start and end points of the notch is as follows. After wafer centered, the data from the transmission sensor changes abruptly when the notch part passes through the sensor. The controller of the sensor provides a digital signal whose output is relative to a limitative value which needs to be set beforehand. If the measured data is greater than the set limitation, the digital output will be 1, otherwise it will be 0. With the splaying angle of the notch being about 1. 15° and the sampling frequency being fixed, regardless of the difference of notch shape, the number of data sampling in notch section is relatively invariable, which is 850. The transmission sensor's analog signal represents the peripheral data of the notch and its digital signal includes the information that redetermination of the start and end points of the notch needs. Two signals need to be sampled synchronously. Analyze the digital signal, selecting the point where it changes from 1 to 0 as the start point of the notch, and the point where it changes from 0 to 1 as the end point of the notch. The analog data between the start point and the end point is then the effective data segment for calculating the notch eccentricity as in (6) and (7).

Ⅳ. EXPERIMENTS

For the proposed prealigner, the range of the required center prealignment precision is ± 1.5 μm, and the range of the required notch prealignment precision is ±30 μrad. The following experiment is to prove whether the proposed prealigner has met the required prealignment precision.

The apparatuses which the experiment needs are a wafer prealigner shown in Fig. 4, a 12-inch wafer with markers on it, a CCD camera and a photo sampling card. The set direction of the CCD camera is above the wafer, perpendicular to the plane of the wafer. The CCD camera takes photos of the magnified markers on the wafer as shown in Fig. 5. The measurement method of the experiment is as follows. Prealign the same wafer repeatedly for 25 times, and each time the original positions of the wafer on the prealigner are different. When one prealignment procedure finished, the CCD camera will take a photo of the markers on the wafer. The 25 different photos as a group will be analyzed by the photo analytical software. Specifically speaking, one of those photos is selected as the standard pattern, and then the rest are matched with it, by which 25 groups of the coordinates of pixel are acquired, then the values of 3σ of the x and y coordinates are calculated respectively. Table 1 displays a group of experimental results, where it is shown that the values of 3σ of x and y coordinates have already met the required prealignment precision of micron rank. The experiment has been implemented repeatedly and the same ideal results can be achieved. It has proved that the proposed wafer prealigner has achieved the required prealignment precision of micron rank.

Fig. 4. The proposed wafer prealigner

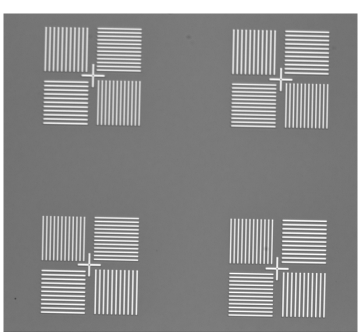

Fig. 5. The CCD photo of the magnified markers on the wafer

TABLE I

RESULTS OF THE EXPERIMENT OF PREALIGNMENT PRECISION (1. 5μm/pixel)

Photo No.	Value of x pixel	Value of y pixel	Photo No.	Value of x pixel	Value of y pixel
1	522.07	514.72	14	523. 29	514.43
2	522.07	514.5	15	523.49	513.7
3	522.1	514.51	16	523.47	514.65
4	522.48	514.63	17	523.4	514.13
5	522.66	514.39	18	523.6	514.43
6	522.51	515.41	19	523.37	513.95
7	522.68	515.14	20	523.66	514. 18
8	522.61	514.56	21	523.63	513. 91
9	522.68	514.21	22	523.93	514. 45
10	522.99	514.89	23	524.06	514. 62
11	523.21	514.57	24	524.05	515. 16
12	523.07	514.63	25	524.17	514. 63
13	523.08	514.01			
$3\sigma(x)$ = 2. 83 μm			$3\sigma(y)$=1. 80 μm		

Ⅳ. CONCLUSION

In this paper, a new wafer prealigner has been established. It integrates the laser sensor and the transmission sensor to detect the periphery of the wafer instead of a CCD linear sensor. Both of the sensors are relatively small in dimension, able to be embedded in the mechanical frame around it, thus having the advantage of space saving. And high sampling frequency is available for both sensors so that they can sample much more points on the periphery of the wafer than a CCD array can under the same circumstances, which enhances the systematic prealingment precision. The prealigner manages to position the wafer achieving the required prealignment precision of micron rank, based on the wafer and notch eccentricities calculated by using the information extracted from the two sensors with centroid acquiring algorithm which is applicable to any object with random figure. Experimentation has proved the validity and effectiveness of the method presented in this paper.

REFERENCES

[1] H.S. Lee, J.W. Jeon, J.W. Kim, et al, "The development of a 12-inch wafer pre-aligner with optical character recognition," the 27th Annual Conference of the IEEE Industrial Electronics Society, 2001, pp. 215-219.

[2] D.N. Galburt, J.D. Buckely, "Universal edged-based wafer alignment apparatus." United States Patent, US4907035, 06/842, 145, March1990.

[3] K.C. Wu, "Wafer aligner," United States Patent, US6932558, 10/190,111, August 2005.

[4] B.R. Spady, W.A. McGahan, J.V. Read, et al, "High precision substrate prealigner," United States Patent, US6836690, 10/199, 278, December 2004.

[5] J.R. Andrews, "Software to determine the position of the center of a wafer," United States Patent, US5706201, 08/643, 908, January 1998.