Wafer prealigning robot based on shape center calculation

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Abstract
Purpose – The aim of this paper is to provide a new wafer prealigning robot for the photo-etching facility during the manufacturing of IC products.
Design/methodology/approach – The shape center is measured by a reflection-style laser sensor in the wafer's radial direction, and the position is measured by a penetration-style laser sensor. A dynamic error compensation is applied to eliminate the radial runout and wobble of the rotary stage, which have effects on the measurement of the wafer's shape center.
Findings – It is found that the new wafer prealigning robot can satisfy the accuracy requirement.
Research limitations/implications – The robot requires that the shape center can be accurately calculated.
Practical implications – The robot is applicable to wafer prealigning for the photo-etching facility.
Originality/value – A wafer prealigning robot based on the shape center calculation method has been developed and is described in the paper.

Keywords Robotics, Sensors, Assembly

Paper type Research paper

Introduction

When the wafer is processed through protective coating, masking and photo-etching at different working stages, and the position errors will be generated during the transport process. If the errors are not eliminated, it is unable to guarantee the photo-etching accuracy. Before the photo-etching, a facility is necessary, which aligns the wafer with some high precise sensors and actuators accurately, so as to save the time of the photo-etching process.

The prealigning robots can be classified into the mechanical and the optical types (Yang, 2003). The optical prealigning robot has been widely used with high accuracy (Blaine *et al.*, 2004; Kung, 2005). Usually, it uses a linear charged couple device (CCD) sensor to detect the center and the position of the wafer from its axial direction. For example, the 12-inch wafer prealigning robot designed by Korea uses CCD to get images of a wafer, and then calculate its center and notch position by using the least minimum square method. Finally, the motion module makes an alignment (Lee *et al.*, 2003). But this kind of prealigning robot processes many images and brings out lower efficiency. The prealigning robot of Holland ASML Company calculates the center and the position of a wafer by detecting the variance of CCD optical energy, based on the CCD basic parameters and empirical parameters obtained by experiments (Zhang *et al.*, 2002). In order to leave the space for descending and raising a wafer, there will be a certain distance between CCD and a wafer, which results in optical diffraction and declination between LED and the surface of a wafer. So the effection, radial run-out and wobble of a wafer cannot be eliminated. Additionally, the rotary stage, which rotates a wafer, commonly has 3-10 μm radial run-out and about 70 μrad wobble which belongs to uneliminated random errors. Both of them can effect the measurement of the shape center (Song *et al.*, 2006). So it is necessary to consider a new solution or make a certain compensation to get much higher positioning accuracy.

In this paper, a new wafer prealigning robot is proposed. In the prealigning robot, more precise sensors are used to detect the shape center and the notch position of a wafer from its radial and axial direction, respectively. In addition, a new shafting mechanism is designed, which has higher repeatability positioning accuracy.

The architecture of the robot

As shown in Figure 1, the prealigning robot is made up of the actuator, the detection device and the control module. The actuator has two linear displacement stages X-Y at the basis layer. One is the rotary stage θ and the other is a linear displacement stage Z. The axis θ is in series with the axes X, Y and Z.

A sucker, a gas tube and a tribolet are installed on the Z axis. In the external of the tribolet, the sucker is connected with the gas tube by a soft spiral pipe of SMC. The wafer is sucked by the negative pressure in the sucker. The detection

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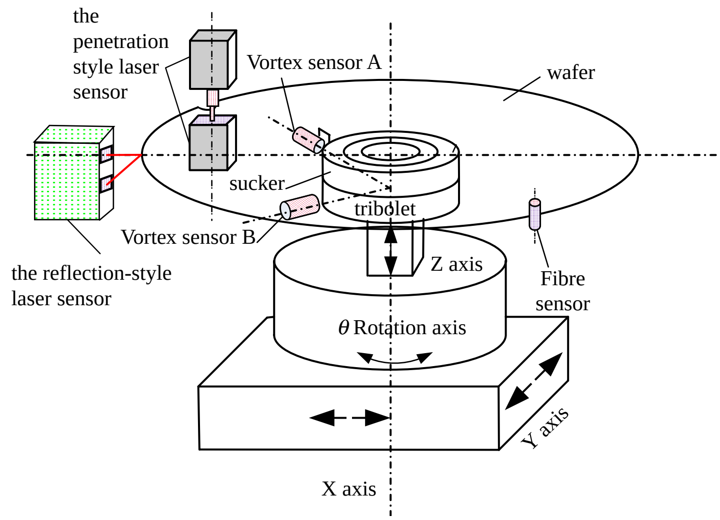
Figure 1 The illustration of the prealigning robot



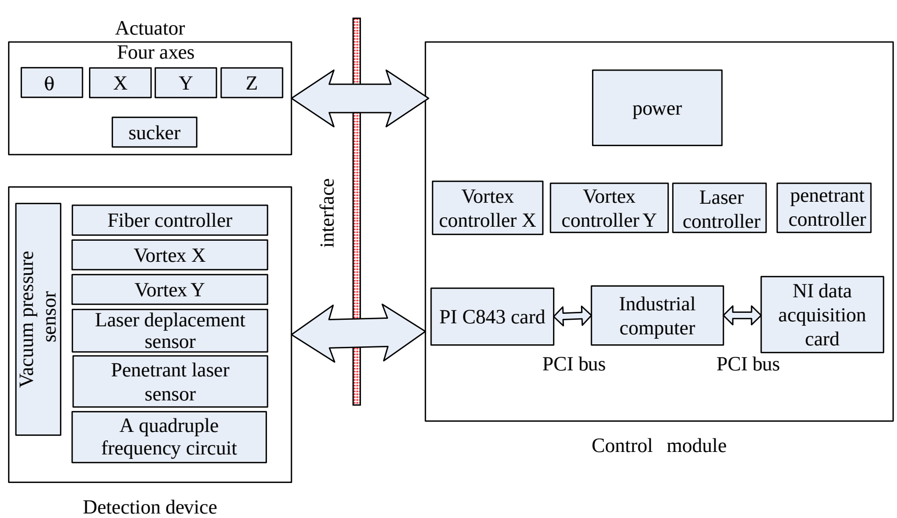
devices mainly include a reflection-style laser sensor, a penetration-style laser sensor and two vortex sensors. The former laser sensor can measure the radial displacement druing the rotation. The latter laser sensor can measure the positon of the notch of the wafer. The two vortex sensors are mounted beside the tribolet with the angle of 90° and relatively still towards rotary stage, and they are used to measure the radial runout of the rotary stage.

As shown in Figure 2, the control module can collect the signals with NI data acquisition card. Besides, it can detect the position of the PI stages and the negative pressure of the valve. These signals will be processed by the control module so as to get the linear displacement along X-Y direction and rotation displacement around the Z axis. The PI card controls the linear movement of X, Y, Z and θ stages to realize the prealignment of the wafer. The aligning process of the wafer prealigning robot is described as follows. Firstly, when the θ stage rotates with high speed in the first circle, the reflection-style laser sensor emits beams to the edge of the wafer to measure the rough position of the shape center and the notch. Then Z axis is descended and the wafer is put on the supporting cushion in order to make it separate compeletely with the sucker of the rotary stage. The X, Y and θ axes will move according to the position of the shape center and the notch. Thus, they make the wafer and the rotary stage concentric and turn to the predefined angle relative to the zero position. Then Z axis moves up, the sucker lifts the wafer from the supporting cushion, and the X, Y, Z and θ axes will return to zero position. Secondly, rotating in the second circle, the reflection-style laser sensor measures the additional eccentricity of the wafer's shape center and removes most of the position errors in that way. Finally, rotating in third circle, the penetration-style laser sensor measures the notch position and aligns the center and notch precisely. In the following parts about the detection device, the control module and the actuator will be introduced in details.

The detection device

The new wafer prealigning robot introduced in this paper can detect the center of a wafer with the reflection-style laser

Figure 2 The proposed control system architecture for a prealigning robot



sensor and also get the angle of the notch with the penetration-style laser sensor. The reflection-style laser sensor detects the radial displacement of the wafer, and prevents the data from fluctuating caused by diffuse reflection of the workpiece's coarse face. The Keyence LX2-11 is chosen as the digitally penetration-style sensor, which can detect the edge of the wafer along the axial direction to ascertain the shape center and the angle of the notch. The geometric information of the notch can be obtained from the light intensity covered with the wafer. In order to ensure the accuracy of the notch, the best way is to take the position feedback pulse of the rotary stage as the triggered signal to detect the position of the notch. However, the fastest output pulses of the rotary stage can only ensure 176,000 per circle, that is to say, one sampling point is collected per 36 μrad. Since the notch is smaller, more sampling points are expected. So a quadruple frequency circuit is added to get the angular resolution of collecting one point per 9 μrad in the new system.

The control module

The control module includes the signal regulators, the power supply, the NI data acquisition card, the PI motion control card, the industrial computer and the interface board. An automatic control software is installed on the industrial computer to control the motion of the four axes, the pneumatic pressure and the transportation of a wafer.

The data acquisition card NI PCI-6229 is used in the control system with five channels. The channels are connected with two laser sensors, two vortex sensors and one rotary stage encoder. The data acquisition card uses one pulse output from the PI rotary stage's encoder as an external clock (35,200 Hz). The sensors are applied on timing mode, which refers to the state of output voltage of the sensor being constant during two timing signals. The timing signal is provided by the encoder of the PI rotary stage. To collect sampling points for calculating shape center, the frequency of the timing signal is 1/128 of that of the PI rotary encoder signal. There are 1,375 sampling points in calculating the shape center during each cycle. In order to get radial run-out data of rotary stage, the vortex sensor needs to collect points during each timing signal. The NI data acquisition card can collect 128 sampling points in one timing signal cycle, and the radial runout data can be got in a filter algorithm, which can greatly reduce the external noise. The PI rotary stage controller, C843 PCI card can simultaneously drive three linear displacement stages and one rotary stage. The card provides motion control functions effectively.

The actuator

The prealigning robot has four axes. The high precise linear displacement stage produced by PI Company is used as X-Y axes, and they are placed under the θ axis. The rotary axis θ is driven by a DC motor decelerated by a super precise gear worm. The axis is also fixed with a spring which can tense the system to eliminate the clearance. A linear displacement stage used as the Z axis is fixed on the rotary stage and connected in series with the θ and X-Y axes, and rotates with it.

The rotary stage's center of the gyration is the reference of the whole system's measurement, so its position should not be changed. But it is inevitable that the rotary stage will have 3-10 μm radial run-out and 70 μrad wobble caused by the connecting portion of the sucker and the gas tube while rotating. When the moving mechanism is higher, the system stiffness will descend. Then it will cause the variance of the center of gyration. For the precise wafer prealigning robot, the higher the center is the more consideration for the error factors is. To eliminate the error, we use the vortex sensor to get the dynamic data of the rotation. Compared with the statical data, we get the radial runout and wobble of the rotary stage, and then subtract them from the data obtained from the laser sensor.

The prealigning algorithm

The calculation method of wafer's shape center

While the wafer is rotating eccentrically, the reflection-style laser sensor can measure the displacement of the edge. As demonstrated in Figure 3, O is the rotational center of rotary stage, O' is the shape center of the wafer when the manipulator transfers a wafer to the vaccum sucker, e is the eccentricity and R the ideal radius.

After establishing the cartesian coordinates through the center of rotary stage, the actual geometric coordinate rotated by θ is (x, y). The x-coordinate offset Ox' is detected by the laser along the fixed X axis. Then there is:

$$\begin{cases} x = e\cos\theta \\ y = e\sin\theta. \end{cases} \quad (1)$$

We can get:

$$Ox' = e\cos\theta + (R^2 - e^2\sin^2\theta)^{1/2}. \quad (2)$$

Equation (1) is the functional relation of the eccentricity, the rotary angle and the edge displacement while the wafer's being rotated eccentrically in an ideal condition. It can be used to verify whether the data are right or not during the detecting process. While being detected in practice, the wafer can be regarded as static, and the sensors rotate around the gyration center of the rotary stage. The method for calculating the shape center of wafer is called the least minimum square method. However, because the roundness tolerance of the 10-inch wafer is ± 0.1 mm, and also the data of positioning notch needs processing individually, the taken method is not the least minimum square one, but a way based on the mass center (Song *et al.*, 2006; Ziger, 2002; Beaulieu, 1987; Fu *et al.*, 2007).

As shown in Figure 4, the data acquisition card synchronously collects the digital signals from the reflection-style laser sensor trigged by the pulse of the rotated table encoder. And we get the

Figure 3 The schematic diagram of the eccentricity of the wafer

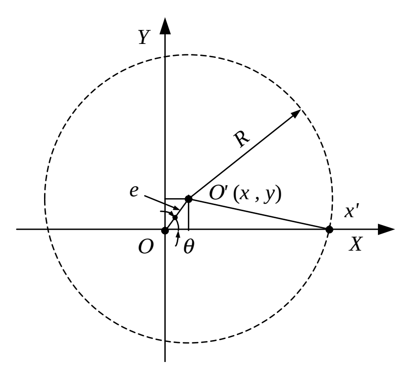


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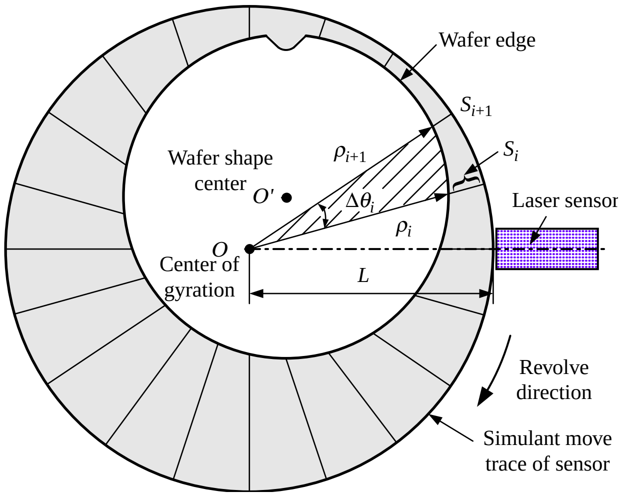
Figure 4 The solution of the polar coordinates of the wafer's shape center



following values: S_i is the distance between sensor and the edge of wafer and θ_i is the revolting angle.

Suppose that ρ_i is the distance between the center of the gyration and the edge of the wafer, $\Delta\theta_i$ is the angle interval with the next sampling point and L is the distance between the laser sensor and the axis of rotary stage.

So we have $\rho_i = L - S_i$.

According to the mass point calculation method of an object with arbitrary shape and uniform mass in two dimension, we can calculate the coordinate of the wafer's shape center O', and get the mass point coordinate. That is the position coordinate of wafer's shape center:

$$O'(\bar{x}, \bar{y}) : \bar{x} = \frac{\int_0^{2\pi}\int_0^{\rho(\theta)} \rho^2 \cos\theta . \mathrm{d}\rho\, \mathrm{d}\theta}{\int_0^{2\pi}\int_0^{\rho(\theta)} \rho . \mathrm{d}\rho\, \mathrm{d}\theta} \quad (3)$$

$$\bar{y} = \frac{\int_0^{2\pi}\int_0^{\rho(\theta)} \rho^2 sin\, \theta . \mathrm{d}\rho\, \mathrm{d}\theta}{\int_0^{2\pi}\int_0^{\rho(\theta)} \rho . \mathrm{d}\rho\, \mathrm{d}\theta} \quad (4)$$

where $\rho(\theta)$ is a function of radius vector about the angle.

Thus, it can be calculated according to the method of the discrete system in mechanics:

$$\bar{x} = \frac{M_y}{M} = \frac{\sum_{i=1}^{n} m_i x_i}{\sum_{i-1}^{n} m_i} \quad (5)$$

$$\bar{y} = \frac{M_x}{M} = \frac{\sum_{i=1}^{n} m_i y_i}{\sum_{i-1}^{n} m_i} \quad (6)$$

where $M = \sum_{i-1}^{n} m_i$is the total mass.

$M_x = \sum_{i=1}^{n} m_i y_i$ and $M_y = \sum_{i=1}^{n} m_i x_i$ are static moments to X and Y axes, respectively.

To solve the shape center of the wafer in the polar coordinates system, we obtain $(\bar{x}, \bar{y})$ as follows:

$$\bar{x} = \frac{\sum_{i=1}^{N} \int_0^{\rho(\theta)} \rho^2 \mathrm{d}\rho \int_{\theta_i}^{\theta_{i+1}} \cos\theta\, \mathrm{d}\theta}{\sum_{i=1}^{N} \int_0^{\rho(\theta)} \rho\, \mathrm{d}\rho \int_{\theta}^{\theta_{i+1}} \mathrm{d}\theta} = \frac{\frac{1}{3}\sum_{i=1}^{N} \rho_i^3 [\sin\theta_{i+1} - \sin\theta_i]}{\frac{1}{2}\sum_{i=1}^{N} \rho_i^2 [\theta_{i+1} - \theta_i]} \quad (7)$$

$$\bar{y} = \frac{\sum_{i=1}^{N} \int_0^{\rho(\theta)} \rho^2 \mathrm{d}\rho \int_{\theta_i}^{\theta_{i+1}} \sin\theta\, \mathrm{d}\theta}{\sum_{i=1}^{N} \int_0^{\rho(\theta)} \rho\, \mathrm{d}\rho \int_{\theta}^{\theta_{i+1}} \mathrm{d}\theta} = \frac{\frac{1}{3}\sum_{i=1}^{N} \rho_i^3 [\cos\theta_{i+1} - \cos\theta_i]}{\frac{1}{2}\sum_{i=1}^{N} \rho_i^2 [\theta_{i+1} - \theta_i]} \quad (8)$$

where, N means the number of the effective sampling points.

The position searching of the wafer notch

In the calculation of the shape center, 176,000 sampling points are collected in total. Some points around the notch show the state of outrange while the rotary stage is revolting with high speed. So the notch points need to be recollected with low rotation speed when the rotary stage rotates to the notch position.

Since the points are on the sloping side of notch, the beam can be reflected. The inlet and outlet points of notch are generally outranged. So the initial position of the notch can be got from this feature.

Rotating with low speed, the nearest point towards the center of the circle can be calculated by the collected points, and the position of the notch is the vector of the nearest point that the center of the circle is towards.

Experiments and result analysis

The wafer prealigning robot is shown in Figure 5.

In experiments, we use an external CCD, which repeated accuracy can be up to ± 60 nm after the template matching, for examining the repeatability position error in the directions x and y. The type of the high resolution CCD is MVS, and the measurement range is 1018 × 1004 pixels.

Before the experiment, we do pre-photo-etching marking image, which is used for testing. After finishing the prealignment, we get the marking image of wafer gap and wafer center. Then, processing the image offline based on the template matching, we get the relative position of the photo-etching marking image to the CCD. In the test, the prealignment operation has been performed for 25 times in a group by the same wafer, which is located randomly. The same action is repeated in four groups. The statistical data are shown in the Table I.

From Table I, we can see the repeatability position precision of directions x and y is up to $\pm 1.5\,\mu$m.

Figure 5 The photo of the wafer prealigning robot

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Table I The test result

Test tool: MVS	Test location: FFU-2 Purge room
Environment temperature: 20.5°C	Humidity: 60 percent RH
Repeatability measurement accuracy: ±60 nm	Vacuity of a wafer sucker: −0.635 bar
3σ (*x*)	2.83 μm
3σ (*y*)	1.80 μm

Conclusions

This paper proposes a new wafer prealigning robot, which is based on the shape center calculation method. The repeatability position precision of the shape center is up to ±1.5 μm. The time of positioning is 50 s. In order to enhance the measurement precision of the shape center, the prealigning robot uses the reflection-style laser sensor to measure the wafer shape center through the wafer radial, and also uses the penetration-style laser sensor to measure the notch angle of the wafer. And the prealigning robot uses the dynamic error compensation for reducing the impact of the radial run-out and wobbles to the shape center measurement. In the process of aligning, first, a coarse adjustment to the wafer shape center and positioning notch angle is taken. Next, a fine adjustment to positioning notch angle is finished. The experiment verifies that the method has improved the positioning precision of the prealigning robot.

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