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Wafer Pre-Aligner System Based on Vision Information Processing

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Abstract: Wafer pre-alignment is one of the most difficult and important part in wafer transmitting system. The key point of alignment is the position identification and information process. It is explored in this paper to use a new algorithm of vision information processing to obtain the special area of wafer edge and then concentrate to some feature points of wafer by which the wafer can be located. The basis principle of algorithm is to integrate least squares regression fitting, weighted means and compromise of wavelet coefficient method together in vision part. Also a new mechanical structure and vision system has been established to process the data and locate wafer. Experimental test is given showing that the system can carry out the alignment of wafer well and accurately by using the proposed algorithm and structure.

Key words: Pre-aligner system, edge identification, vision system, light intensity, information processing

INTRODUCTION

Wafer pre-alignment system is a sort of high-precision alignment device, which integrates with the subject of mechanics, electronics, optics and computer science and can automatically detects information and locates the position of geometric centre and notch on wafer avoiding offset errors when transported to the wafer stage. It is called pre-alignment since the motion of alignment coming up before the process of wafer mask alignment (Canny, 1986).

The research of wafer pre-alignment system experiences two developing stages which named mechanical pre-alignment and optical pre-alignment. In the mechanical stage, the device mainly used the special mechanism structures or tools to finish alignment. The information collection is not necessary. But during the stage of optical alignment, it is quite different that all the work will be accomplished by the help of information, clouding collection, processing and analysis.

The mechanical pre-alignment applies complicated machine to touch silicon wafer directly and makes the wafer placed passively. It is mainly applied to micro-sized machine which doesn't require superior transmission precision during process. The mechanical pre-alignment is not a proper pre-alignment system but a pre-orientation system in that it cannot meet the requirements of the complete machine precision.

Along with the development of nano-sized machine, optical pre-alignment has become the primary method of pre-alignment. It applies optical tester to detect and record wafer position and transmits feedback information to the controller of system which then fixes the geometric centre and notches of wafer by sending the orders. The methods that are popularly used in international scope mainly consist of edge-detecting alignment, imaging-contrast alignment and photoelectric sensor alignment. For example, pre-alignment tool IPA-300VS-1 made in ISEL-ROBOTIK and wafer pre-alignment system BX (Inenaga *et al*., 2004) made in Berkeley Process Control are typical devices of wafer pre-aligner.

At same time, vision information becomes to the main data of wafer edge detection and the processing capacity of which affects the performance of system evidently. Information processing is customarily assumed to involve at least three stages: identification, filtering and screening and analysis and synthesis.

At present, the 12 inch wafer with feature size of 90 or 65 nm is the mainstream of wafer technology. In order to meet the new requirements such as reducing the response time, improving the precision of alignment and simplify the structure of system and motion control, new mechanical structures and information processing methods are needed and brought forward continuously (Li *et al*., 2004). In this research, a wafer pre-alignment system which could meet the technology of 12 inch with 90 nm is proposed. The new system is based on the algorithm of edge visual detection and the method of vision information processing which contains many key technologies such as vision acquisition of signal, fitting of geometrical element, method of wavelet-threshold de-noising and etc. With the application of new method in system, it successfully achieves the goals to reduce the response time and increase accuracy as well as simplifying the structure and motion control. However, with the help of new method applying in wafer

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pre-alignment system, high precision positioning has been realized before the process of wafer mask alignment and the operational capability has been ultimately enhanced.

THE SYSTEM

Wafer pre-aligner system is a vacuum type and has three degrees of freedom for aligning a wafer. The automatic positioning system entirely reaches a new level in accuracy which can locate wafer in 300 mm size precisely (Ming *et al.*, 2005). The architecture of system is mainly built up with basic machine, vision module and motion control system.

The basis machine: In Fig. 1, the basic machine of wafer pre-alignment system consists of rotational support part and horizontal alignment part. The horizontal alignment part includes one pallet, two linear motion guide ways and three join columns and has one degree of freedom at Y-direction. The rotational support part has two degrees of freedom, this part can rotate in X-Y plane and lift in Z-direction. The motion process of basic machine mainly contain three steps. First, the rotational part rotate the wafer in order to find the position of maximum eccentric dot and notch, then align them to Y-direction. Second, the horizontal alignment part move the displacement as same as the maximum eccentric measure in Y-direction to realize the alignment of wafer. Finally, the rotational part is rotated at certain degree to make the notch to correct direction.

The vision system: The information of wafer is detected and collected by the vision system. After screening and information filtering, the key data of wafer will be got which is the fundament to pre-aliment. The vision part of system sets Complex Programmable Logic Device (CPLD) as control centre, using CCD image sensors to collect dates and an A/D converter to translate them (Cong Ming *et al.*, 2006). The collection, translation and storage of date from CCD are all commanded by CPLD chip.

The working processes of visual system are as the following: the background light emitted by LED array illuminations will be centralized by cylindrical lens and then the parallel light is projected to the wafer and CCD sensor as well as bringing light charge. The CCD image sensor receives the different signal data of wafer by edge detecting unit and sends the detected value of the wafer edge through the data transfer unit to system controller PC. The PC controller stores the value and records the corresponding position at the same time. Then the system repeats the operation until all the information is stored in memory waiting to be analysed and processed. The principle of visual system (Fig. 2).

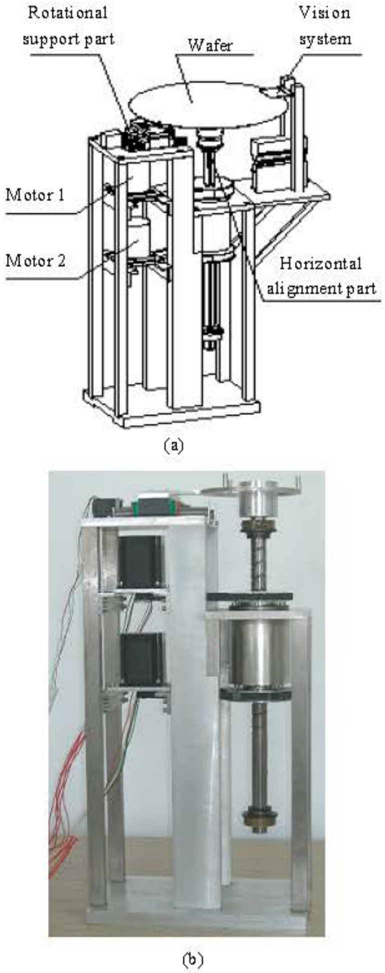

Fig. 1: The basic machine of wafer pre-aligner system (a) architecture and (b) Prototype

The motion control system: The motion control part of wafer pre-alignment system depends on visual basic working environment based on windows development platform (Russoe, 1998). It has been operated by the way of PC + MPC07 motion control card founded on PCI bus (Fig. 3). The entire control system consists of a control part to generate control signal for motors, memory and other chips, a communication part to make an interface to access A/D converter through PCI bus and vacuum system. After receiving the signal from vision system, CPU can deal with the data information and control the motors after converting the data into effective order.

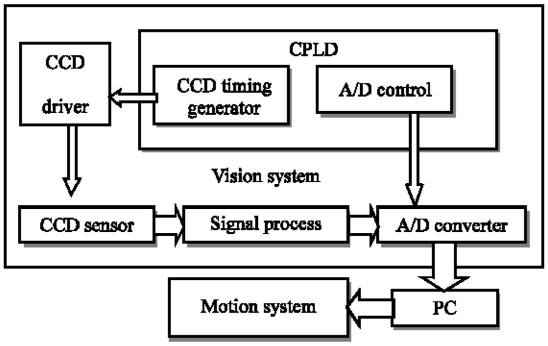

Fig. 2: The working process of visual system

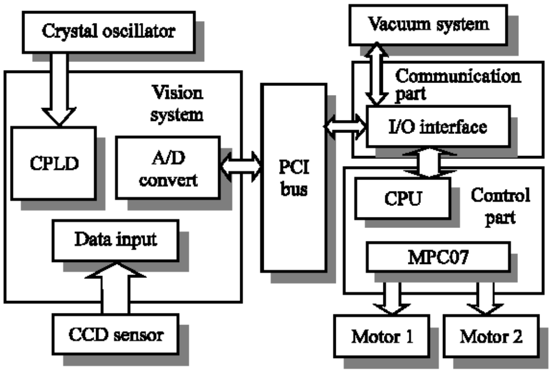

Fig. 3: The motion control system architecture

GENERAL PRINCIPLES OF PRE-ALIGNER

Vision identification of edge: In wafer pre-alignment system, the position of wafer is mainly determined by edge information which will be detected through the magnitude of light transmission from the edge (Law *et al.*, 1996). Based on the principle of image edge detection (Kamaled *et al.*, 1999), CCD image sensor identify the wafer by the light intensity of different region on edge, then the PC can calculate the position of maximum eccentric dot and notch on wafer by a series of algorithms. Guided by method of least-squares fitting regression, we can get a continuous function curve which figures different light gradation beyond wafer edge by continuum technique dealing with discrete CCD voltage signal. The principle of vision identification (Fig. 4). The light intensity is different among the notch, middle region and max offset region and distribute around the wafer circumference uniformly.

Furthermore, the application of de-noise method based on compromise algorithm between soft-threshold and hard-threshold of wavelet coefficient make it possible to eliminate the bad points in the function curve and get rid of the noise interference brought by dark current, so the precision of vision system would be heighten.

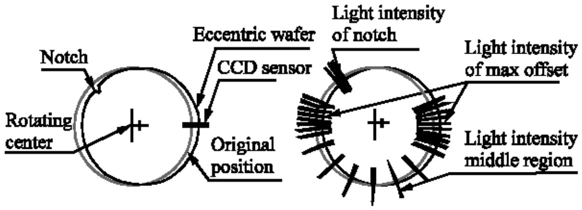

Fig. 4: The vision identification of wafer edge

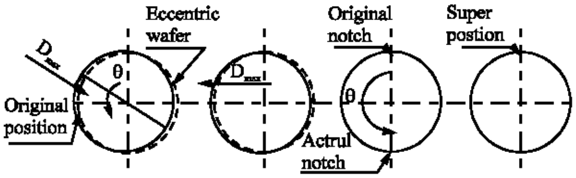

Fig. 5: The principle of wafer alignment

Alignment principle: In wafer pre-alignment system, the working process of alignment includes two steps (Mard *et al.*, 2001; Dellecker, 2001). First, CCD image sensor receives light signal not shielded by wafer from LED and translates them to voltage signal, then A/D converter translates voltage signal to digital signal which transmitted to computer while support part rotating for one cycle. If the geometric centre of wafer is eccentric, the light received from different part of wafer edge will not be symmetrical (Feddema *et al.*, 1998). So the voltage curve should be changed continuously going with wafer rotation and the deviation of wafer centre can be located. Secondly, rotate the support part again, since there is a notch on wafer, the light beyond this part is stronger than other part of wafer and it would be clearly shown from voltage signal curve (Popa *et al.*, 2002). Find out the angle of notch and locate wafer to initial position by rotating the wafer for one circle again. Figure 5 shows the alignment principle of wafer.

Technical indexes: Technical indexes of wafer pre-alignment system are present in Table 1.

VISION INFROMATION PROCESSING

Based on the general principles of pre-aligner above (Nelson *et al.*, 1998), a new method of vision information processing used to alignment, which made up of detection of wafer centre and notch, de-noised, fitting of signal and screening of important data, is put forward.

Table 1: Indexes of system

Diameter (mm)	Accuracy of alignment				
	Notch (°)	Centre (mm)	Time (sec)	Range (mm)	Speed of operation
300	±0.02	±0.025	≤5	Y: ±10 Z: ±10	Y: 100 mm sec^{-1} Z: 100 mm sec^{-1} 60 r min^{-1}

The basis of this method is the analysis and synthesis of visual information, it applying least squares regression fitting, weighted means and compromise of wavelet coefficient method etc. in vision part to locate wafer well and accurately.

Filtering and screening: The discrete wavelet transform represents a one-dimensional signal f in terms of shifted versions of a dilated low-pass scaling function φ and shifted and dilated versions of a band-pass wavelet function Ψ. In case of orthonormal wavelets (Chelbeyd, 1996; Neil, 2000), this gives

$$f = \sum_{i \in z} \left\langle f, \varphi_i^n \right\rangle \varphi_i^n + \sum_{j=-\infty}^{n} \sum_{i \in z} \left\langle f, \psi_i^j \right\rangle \psi_i^j \tag{1}$$

Where, $\psi_i^j = 2^{-j/2}\psi(2^{-j}s - i)$ and $\langle \cdot, \cdot \rangle$ denotes the inner product in $L_2(\Re)$. If the measurement f is corrupted by moderate white Gaussian noise, then this noise is contained to a small amount in all wavelet coefficients $\langle f, \Psi_i^j \rangle$, while the original is in general determined by a few significant wavelet coefficients. Therefore, wavelet shrinkage attempts to eliminate noise from the wavelet coefficients by the following three-step procedures (Huang *et al.*, 2002; Mallat and Wangw, 1992; Kawamura *et al.*, 1998):

- **Analysis:** Transform the noisy data f to the wavelet coefficients $d_i^j = \langle f, \Psi_i^j \rangle$ and scaling function coefficients $c_i^n = \langle f, \varphi_i^n \rangle$ according to Eq. 2.
- **Shrinkage:** Apply a shrinkage function s_θ with a threshold parameter θ to the wavelet coefficients, i.e.

$$s_\theta\left(d_i^j\right) = s_\theta\left(\left\langle f, \psi_i^j \right\rangle\right) \tag{2}$$

- Synthesis: reconstruct the de-noised version u of f from the shrunken wavelet coefficients:

$$y = \sum_{i \in z} \left\langle f, \varphi_i^n \right\rangle \varphi_i^n + \sum_{j=-\infty}^{n} \sum_{i \in z} s_\theta \left\langle f, \psi_i^j \right\rangle \psi_i^j \tag{3}$$

In this, study we restrict our attention to compromise of wavelet coefficient. The wavelet function and shrinkage function are given respectively by:

$$\psi(x) = 2^{-j/2} \sum_{n=0}^{N-1} f(n)\psi(2^{-j}n - k) \tag{4}$$

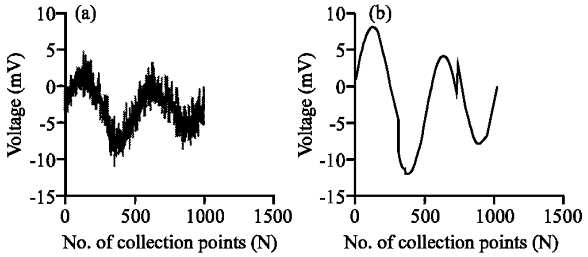

Fig. 6: The contrast of CCD signal by using compromise of wavelet coefficient de-noising (a) the signal with noise and (b) the signal after de-noising

$$S_\theta = \sigma\sqrt{2\log(N)} \tag{5}$$

Where:

σ = The standard deviation of noise.

So reconstructed wavelet function is

$$\varphi(x) = \alpha S_\theta \tag{6}$$

Where, α = 0.5 denotes the compromise threshold coefficient.

As the contrast of CCD signal shown in Fig. 6, the method of compromise of wavelet coefficient, which improves the effectiveness of soft and hard shrinkage on the side of de-noising, make it possible to eliminate the bad points in function curve and get rid of the interference brought by white noise.

Analysis: In wafer pre-alignment system, the technology of collecting and fitting signal beyond wafer edge is the most important (Donoho, 1995). By the method of least square fitting, the discrete data groups can be fitted to a smooth curve of quadratic function describing the relationship between time and voltage (t-V).

The working time of system was set as T, so the CCD sensor can receive and send about 2/T voltage signal in one cycle of detection. After that the computer can get a series of (t-V) data as (t_1, V_1), (t_2, V_2), ····· (T_s, V_s), ·····.

Supposing that the function of voltage which is going to be fitted is:

$$V(t) = a_3t^3 + a_2t^2 + a_1t + a_0 \tag{7}$$

By substituting the (t-V) data into this function, a fitting function can be made as follow:

$$V_i(t) = a_3 t_i^3 + a_2 t_i^2 + a_1 t_i + a_0 \tag{8}$$

Where, i = 1'.... 2' .... s' .....

and

$$\delta_i = \left[V_i(t) - V_i\right]^2 = (a_3 t_i^3 + a_2 t_i^2 + a_1 t_i + a_0 - V_i)^2 \tag{9}$$

$$\delta = \sum_{i=1}^{s} \delta_i \tag{10}$$

To minimize the value of above function, calculate the differentiation and make them equal to 0.

$$\frac{\partial \delta}{\partial a_k} = \sum_{i=1}^{s} \frac{\partial \delta_i}{\partial a_k} = 0 \tag{11}$$

So we can get the final equations as:

$$\sum_{i=1}^{s} (a_3 t_i^3 + a_2 t_i^2 + a_1 t_i + a_0 - V_i) t_i^k = 0 \tag{12}$$

Where, k = 0, 1, 2, 3

By calculation of above equations, the fitting curves of cubic function have been got finally. Figure 7a and b represent the voltage curves of wafer edge and notch, respectively. The fitting curve can help the vision system to get more valuable datum of edge, by which the dealing centre can find the key positions of wafer and make it possible to locate the wafer correctly.

Synthesis: Since the voltage signal of CCD V_j is proportional to the radiant energy E_l which is shown in Eq. 13, the signal of CCD can linearly represent the magnitude of light projected from the edge (Hansen and Yu, 2000). Then the vision system will figure out the position changes of wafer edge and consequently locate the wafer.

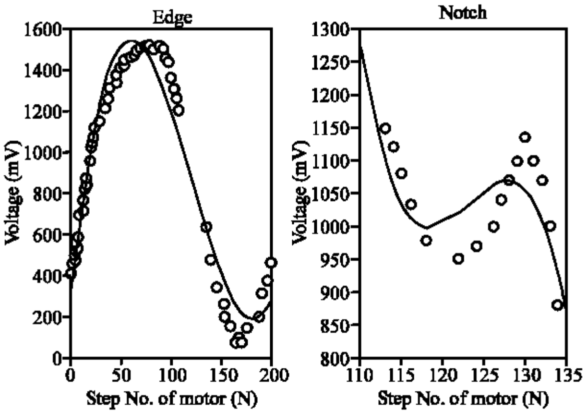

Fig. 7: The fitting curve of edge and notch

$$V_i(x_c) = S\int \left| \int_{x_{1i}}^{x_{ni}} E_l(x_c, x)\,dx \right| dt \tag{13}$$

According to the theory talking about above, if the peak value of the fitting curve is found out, the maximum offset and the coordinate of wafer will be confirmed. First get many groups of point coordinates as possible which are symmetrically picked out from the fitting curve. Then figure out the average value of X-coordinates by using the corresponding Y-coordinates as the weight. At last, the X -coordinate of peak value X'_{mid} will be got by Eq. 14.

$$X'_{mid} = X_{mid} + \sum_i \left[\frac{Y_i - Y_{min}}{Y_{max} - Y_{min}} (X_{mid} - X_i) \right] / n \tag{14}$$

Where:

n = The No. of groups

(X_i, Y_i) = The coordinate of point.

After several times of calculation by bring the data among $0.4\ Y_{max} \le Y_i \le 0.8\ Y_{max}$ into formula, we could get final results of the wafer offset coordinate X_{max} and the notch coordinate X_{notch}. The X_{max} and X_{notch} are the key parameters for motion system through which the motor can complete the alignment of wafer.

TESTS AND RESULTS

Positioning error of wafer center and notch influences alignment precision severely. Since the coordinates of max eccentricity and notch are fitted by computer not got by practically accurate measurement, it becomes the main source of alignment errors.

During the tests, we use the Raster Indicator Verification Instrument (RIVI) to test the repeatability positioning accuracy of wafer and the stopwatch to compute the alignment time respectively. The degree precision of notch is got by counter in vision system which can reach to 0.001°. The resolution of RIVI is 0.1 μm and the measuring scope is 0 to 10 mm. The least time that stopwatch can record is 0.1 sec.

Group 1 to 9 are the coordinates of key point extracted from the fitting curve of edge and notch. From that we can get the modify values of X_{max} and X_{notch} shown as Table 2 and 3.

Table 2: The modify values of edge (X_{max})

Groups	(x_i, y_i)	Modify value
Group 1 a	(8,673)	2.468
b	(13,711)	
c	(132,825)	
d	(129,845)	
Group 2 a	(13,764)	-0.200
b	(14,821)	
c	(127,860)	
d	(125,900)	
Group 3 a	(15,847)	0.959
b	(16,870)	
c	(124,930)	
d	(122,950)	
Group 4 a	(20,959)	3.087
b	(21,1027)	
c	(118,980)	
d	(116,1030)	
Group 5 a	(22,1044)	3.112
b	(23,1075)	
c	(115,1080)	
d	(114,1120)	
Group 6 a	(24,1115)	1.906
b	(30,1150)	
c	(113,1150)	
d	(110,1200)	
Average of value		2.833

Table 3: The modify values of notch (X_{notch})

Groups	(x_i, y_i)	Modify value
Group 7 a	(126,1000)	0.588
b	(127,1040)	
c	(133,1000)	
d	(134,880)	
Group 8 a	(127,1040)	0.118
b	(128,1070)	
c	(132,1070)	
d	(133,1000)	
Group 9 a	(128,1070)	0.001
b	(129,1100)	
c	(131,1100)	
d	(132,1070)	
Average of value		0.226

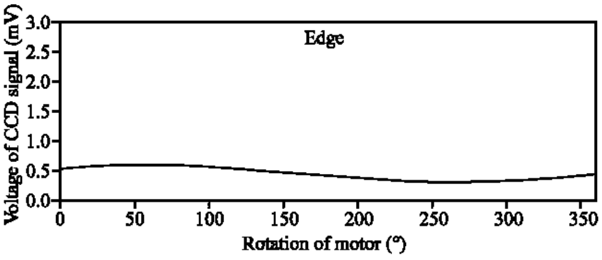

Fig. 8: The CCD signal of wafer edge after alignment

By using the modify values of X_{max} and X_{notch} to align the wafer, we finish the pre-alignment process and test at the same time. The test results were got that the error of wafer centre coincidence is λ = 7.8 μm, the notch alignment precision is λ = 0.014° and the alignment time is 3.7 sec.

Figure 8 has shown the CCD signal of wafer edge collected after pre-alignment. In the chart, the value of CCD voltage changed in a very little rage about 0.4 to 0.52 mv. In other words, the effect of pre-alignment is quite well and the system based on algorithm of vision edge detection locates wafer well within the range of guideline and reduces the working time.

CONCLUSIONS

In this study, a pre-aligner system designed for 12 inch wafer with 90 nm technology is developed. While CCD camera and the complex algorithm of circle fitting have been used in existing pre-aligner system, a vision system with linear CCD senor and a simple algorithm of vision information processing is implemented in the proposed pre-aligner. By the help of mathematic method integrated with least squares regression fitting and weighted means, the system can rapidly find the geometrical feature elements of wafer such as the centre, maximum offset and notch through the vision information processing and finally complete the work of alignment. According to the experimental results, as the simplicity of both the structure and processing method, the proposed system locates wafer well within alignment accuracy requirement, reduces the pre-alignment time than other aligner system and promotes the efficiency of working system successfully.

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