Wafer defect detection method based on machine vision

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Abstract:

With the development of integrated electronic circuit manufacturing technology, enterprises have put forward higher requirements for the quality of silicon chips. Aiming at the low efficiency of silicon wafer defect detection, this paper proposes an automatic defect detection method based on machine vision. The voiding algorithm based on flood fill can effectively extract the inner contour information of the wafer profile. A rotation correction algorithm is proposed to correct the wafer yaw angle. The actual wafer was used to verify the performance of the proposed method. The results show that the proposed method is effective in detection accuracy.

Keywords: machine vision, flood fill, defect detection, rotation correction

1. Introduction

Wafer manufacturing is the core process of the semiconductor chip industry. The complexity of semiconductor silicon wafer processing technology has led to more and more sources of defects [10], which puts higher requirements on existing detection technologies. The defect detection is done manually under the microscope, which is affected by visual fatigue and human subjective factors. The detection accuracy cannot be guaranteed, and the artificial vision inspection cannot meet the requirements of large-scale production and manufacturing.

The machine vision detection method can largely overcome the shortcomings of the manual detection method such as low accuracy, poor real-time performance, low efficiency, and high labor intensity, and has been widely studied and applied in industrial testing [1]. Li applies machine vision to the detection of surface defects in integrated circuit wafers, and uses fuzzy logic to analyze different shapes of surface pit defects [2]. Barni based on machine vision system for quality testing of chicken. According to the color information of the chicken image, the mathematical problem is used to extract the features of the potential problem area, and then classified according to the predefined list of quality problems [3]. Hoang introduced a method for detecting surface defects in leather, using OTSU method for defect segmentation [4].

With the development of computer technology and image processing technology, computer vision detection technology has been widely studied and applied in various fields. Aiming at surface defects such as dirt and particles generated during the manufacturing process of silicon wafers, this paper makes research on the technology of silicon wafer surface defect detection based on machine vision. The rotation algorithm based on the cumulative Hough linear transformation can correct the declination of the wafer. The adaptive reconstruction grid method is used to reconstruct the wafer grid, which can effectively filter out the information outside the grain.

2. Image acquisition device

The image acquisition device consists of CMOS industrial camera, lens, ring light source, and light source controller. The structure diagram of the image acquisition device is shown in Fig 1.

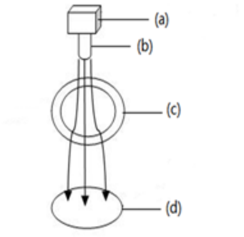


Fig. 1. Structure diagram of the image acquisition device. (a) is the industrial camera. (b) is the lens. (c) is the ring light source. (d) is the silicon wafer.

This device uses a MD-UB1000 CMOS industrial camera. The industrial camera does not need an additional image acquisition card during the image acquisition process, and the camera and the computer can use a professional camera connection cable for data transmission. The camera imager transmits data in parallel at the front end during data transmission, and the bandwidth of the amplifier is very low. The main parameters of the camera include: the pixel size is 1.67um; the effective pixels are 10 million; the resolution ratio is 3664 × 2748; the pixel bit depth is 12 bits. The lens is an MV-JT08 zoom lens. The main parameters include: focal length of 8mm, distortion of less than 1%, closest distance of 0.1m. The ring light source is a FJI-RL150-A00-W ring light source with a diameter of 15cm. The light is radiated vertically from different directions around it. Compared with parallel light, a better quality image can be obtained.

3. Wafer image correction algorithm

There is a deviation in the process of manually placing the wafer, so that the vertical and horizontal intersection lines of the wafer cannot completely match the actual horizontal and vertical directions. In order to accurately locate the grain position coordinates, the tilt angle must be calculated by a certain algorithm, and the wafer is rotated and corrected according to the tilt angle.

Rotation algorithm include graying, thresholding, hole extraction, Hough transform of cumulative probability, and calculation of rotation angle. The flowchart of the algorithm is shown in Fig 2.

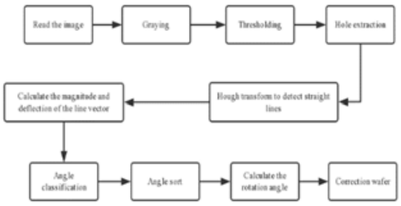


Fig. 2. The flowchart of the algorithm

3.1 Hole filling algorithm

Hough transform requires detection of white straight lines. Hole extraction can turn black grid lines into white and white grains into black. Hole extraction refers to extracting information about the contour of a completely closed contour and filling it with color. The white grid of the image divided by the threshold is used as the outline, and the information of its inner circumference is exacted.

3.1.1 Threshold processing

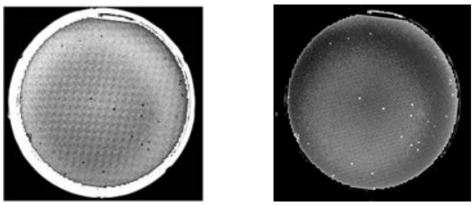
Threshold processing can be regarded as a statistical decision problem, the purpose of which is to minimize the average error introduced in the process of assigning to two or more classes [9,11]. The image has other interference information besides the wafer. Threshold processing of the acquired image can filter out the interference information to obtain the clearest wafer information. Fixed threshold processing is defined as:

$$g(x,y)=\begin{cases} maxval & f(x,y)>T \\ 0 & f(x,y)<T \end{cases} \quad (1)$$

In formula (1), g (x, y) represents the gray value after threshold processing, f (x, y) represents the gray value before threshold processing, and T represents the selected threshold value within the range of pixel gray values. In this paper, the threshold set is T=180.

3.1.2 Flood fill

Flood filling is a method of filling connected areas with a specific color [5-6]. By setting the upper and lower limits of connectable pixels and the connection method, different filling effects are achieved. In order to get the white lines needed for Hough detection, we set the gray value of the fill color to 255. The comparison of the wafer before and after the hole extraction is shown in Fig 3.



(a) (b)

Fig. 3. The comparison of the wafer before and after the hole filling. (a) is threshold image. (b) is hole extraction image

3.2 Hough transform to detect straight lines

Hough transform is a feature extraction technology in image processing [7-8], which is widely used in image analysis and computer vision. In the parameter space, a Hough result is obtained by calculating a local maximum of the accumulated results to obtain a set that conforms to the specific shape. Huff transform uses a transformation between two coordinate systems to map a curve or line with the same shape in one space to a point in another coordinate space to form a peak, thereby transforming the problem of detecting any shape into a statistical peak problem. By performing a Hough transform on the wafer image after the hole filling, the linear distribution of the wafer can be detected.

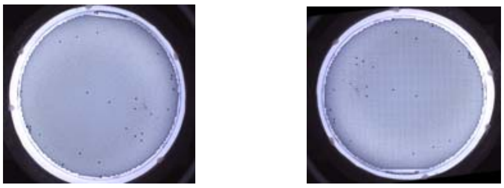
3.3 Angle correction

The coordinates of the two ends of the line segment detected by the Hough transform are subtracted to obtain the size $\mathrm{v}(\mathrm{x1}-\mathrm{x2},\mathrm{y1}-\mathrm{y2})$ of the line segment vector, and the coordinate components v.x and v.y of the vector on the X and Y axes are determined according to the vector size. Let angle be the positive angle of the vector v and the X axis. Then the angle value should satisfy formula (2).

$$\mathrm{angle}=\arctan\left(\frac{v.y}{v.x}\right) \quad (2)$$

The included angle between each line segment and the positive direction of the X axis is not exactly the same, so all the angles need to be further carefully divided. Hierarchical clustering is used to divide a set of data into several categories. After sorting, the angle group containing the largest number of angles is obtained, and the average value of all angles in the array is taken as the final corrected angle.

The affine transformation can realize the rotation correction of the wafer image. Affine transformation refers to the process in which a vector space is transformed into another vector space by completing a linear transformation in geometric space. The affine transformation can maintain the "flatness" and "parallelism" of a two-dimensional image. The comparison before and after correction is shown in Figure 4.



(a) (b)

Fig. 4. The comparison before and after correction. (a) is before correction. (b) is after correction.

4. Wafer grid reconstruction

The number and size of the grains of each wafer are different. Before performing wafer defect detection, different standard templates need to be designed according to the specifications of the grain. The standard template is used as a reference for comparison with the original image during detection. Based on the above problems, this paper proposes an adaptive reconstruction grid method for wafer grid reconstruction. The wafer grid reconstruction algorithm flowchart is shown in Fig 5.

Fig. 5. Wafer grid reconstruction algorithm flowchart

The rule of horizontal clustering is that the Y coordinates at the same point of every two rectangular units are compared, and if the absolute value of the difference between the Y coordinate values is less than 5 pixels, the two rectangles are divided into one class. The rule of vertical clustering is that the X coordinates at the same point of every two rectangular units are compared, and if the absolute value of the difference between the X coordinate values is less than 5 pixels, the two rectangles are divided into one class. Finally, the intersection of the results of horizontal clustering and vertical clustering is taken to complete the grid reconstruction. The effect of wafer grid reconstruction is shown in Fig 6.

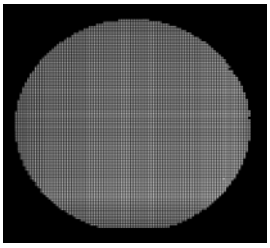


Fig. 6. The effect of wafer grid reconstruction

5. Defect detection

In this paper, a progressive s-shape is used to traverse each grain. The grain defect is composed of a plurality of black pixels in the threshold map. Hole extraction algorithm is performed for each grain to calculate the number of non-zero pixels in the image. The number of pixels in the grain is multiplied by a set threshold, and the number of non-zero pixel points in the grain is more than the number of pixels in the rectangular element, multiplied by the set threshold, the grain is identified as defective.

In this experiment, a total of 1243 grains and 94 defective grains were found in six randomly selected test areas. The total amount of grains and the number of defective grains are different in each test area. The data are shown in Table 1.

Table 1 Statistical results of machine vision detection

Area	Actual defect	Detected defects	Accuracy
1	15	15	100%
2	11	10	90.9%
3	19	18	94.7%
4	20	19	95.0%
5	18	16	88.9%
6	11	11	100%
Total	94	89	94.7%

6. Conclusion

With the rapid development of the semiconductor industry, it is of great significance to apply machine vision technology to detect wafer surface defects. This paper designs an image rotation correction and adaptive grid reconstruction algorithm based on the VS platform and the opencv vision library. The image rotation correction can eliminate the deviation generated in the film placement process and facilitate the positioning of the grain position. Adaptive grid reconstruction algorithm can meet the detection of different specifications of grains. In this paper, the online detection of defective grains is realized, but there are still some shortcomings. Image acquisition is susceptible to interference from the external environment, and the algorithm does not work well for images with uneven light reception.

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