A compact Robot-based defect detection device design for silicon wafer

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Abstract. With the development of semiconductor chips manufacturing, the quality of chips are required to a higher level. At present, as a key element of chip produce process, wafer surface defect detection is a hard challenge for operators, as manual detection accuracy and efficiency are depend on such factors as visual fatigue and inspection error. This paper proposes a defect detection approach for silicon wafer and designs a control system. The system takes PLC as the control core in charge the communication of the PC and the robots, which carries out the logical control instruction. The silicon wafer images are taken by a high precision camera, and processed by the algorithms and the defect elements central coordinates are output to robots. The four-axis robots are driven by the servo motors to mark the defective elements. In order to improve work efficiency, two robots were designed to cooperate to realize wafer transplanting and marking. The device runs smoothly and efficiently, and has prospecting application future.

1. Introduction

Under the background of China increasing emphasis on the semiconductor industry with the release of "Made in China 2025", and as the demand for semiconductor chips increases year by year while the scale of wafer production continues to expand, semiconductor intelligent manufacturing has entered a stage of rapid development. In industrial manufacturing, quality control is crucial to ensure the reliability of the end product [1]. At present, the inspection of wafers is still in the stage of manual detection in some small scale factories. Due to the disadvantages of low precision, low strength and low efficiency of manual wafer detection, the quality and efficiency of products cannot be guaranteed [2], it is unable to meet the needs of industrial large-scale production.

Detection device for silicon wafer has a long history of research and application abroad. The world's first probe platform, EG2001, was developed and commercialized in US at 1963; UF3000 automatic probe station can automatically detect 300mm wafers with a movement accuracy of 2μm developed by Japanese. The Z-801 made in China, a fully automatic probe test bench with automatic loading and unloading, automatic alignment and test marking function, can test 200mm wafers.

In this paper, a new compact silicon wafer defect detection device is designed. It combines a PLC controller with a four-axis robot to replace manual inspection and marking of defective wafer, increasing the level of automation in wafer production. It has a positive role in promoting the development of the domestic semiconductor processing device industry.

2. Structure Design

We propose a device structure composed by four functional zones. It includes (1) storing zone, in which store the raw wafers and the marked wafers, and can move up and down driven by servo motors, (2) transplanting function, which is executed out a four-axis transplanting robot. The wafer is sucked by the robot from the raw storing house and put on a vacuum platform, after wafer marking, the robot move it back to the marked storing house. (3) image acquisition area, in which an industrial vision camera is responsible for acquiring image information; (4) marking function, a four-axis robot with a probe is used to marking the defective particle according to the central coordinates calculated by the detection algorithms. Both robots are driven by a servo motor with an encoder. Figure 1 shows the structure of the defect detection device for silicon wafer consisting of a storing mechanism, a transplanting robot, an image acquisition area, and a marking robot.

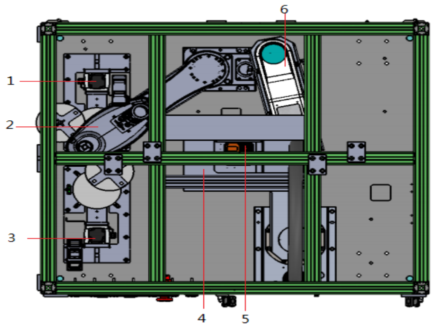

Figure 1. Schematic diagram of the defect detection device for silicon wafer
1. Supply platform 2. Transplanting four-axis robot 3. Recycling platform
4. Vacuum platform 5. Vision camera 6. Marking four-axis robot

2.1. Mechanism for storing wafers

The two storing platforms are respectively composed of chain, limit sensor, guide column, pressure sensor, support plate. The mechanical structure of the storing wafer (1 and 3 in Figure 1) is shown clearly in Figure 2.

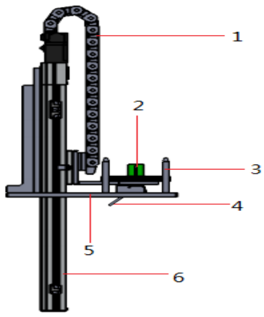

Figure 2. Mechanical structure diagram of the mechanism for storing wafers
1. Chain 2. Limit sensor 3. Guide column 4. Pressure sensor
5. Pallet 6. Support pole

2.2. Transplanting mechanism

The transplanting mechanism consists of a four-axis robot and two vacuum nozzles. The main task is to move the wafer waiting to be detected to the vacuum platform while removing the wafer that has been marked. The transplanting mechanism is 2 in Figure 1, and its mechanical structure is shown in Figure 3.

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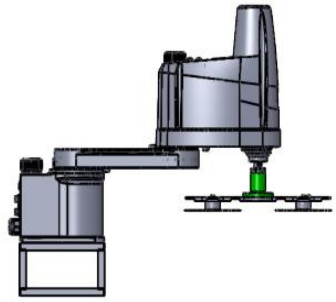

Figure 3. Structure diagram of the transplanting mechanism

2.3. Marking mechanism

The mechanism consists of a four-axis robot, an airway and a marker probe. The main task is to mark the defective particle based on the coordinates. The marking mechanism is 6 in Fig. 1, and its mechanical structure is shown in Figure 4.

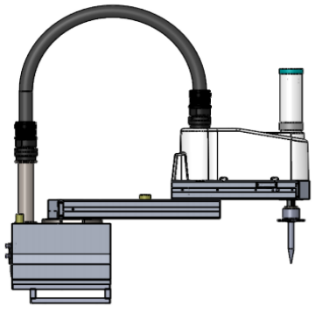

Figure 4. Structure of the marking mechanism

3. Control system design

The wafer transplanting and defect marking are accomplished by four-axis robots instead of manual. The four-axis robot can operate stably and efficiently under complex environments and high-intensity conditions. After receiving the signal returned by the sensor and the actuator, the PLC outputs a control command signal or a certain number of pulse signals to drive the actuator according to the control instructions. The four-axis robot is under controlling of a sequence pulse signals, the position is controlled by the number of pulses, and the speed is controlled by the pulse frequency.

3.1. Control process of Defect detection

The control process of the defect detection device for silicon wafer is shown in Figure 5. The specific implementation steps are as follows:

Step 1: The device is powered up and the system is self-testing. The parameter initialization is to eliminate the alarm information and the variable parameter information, and the servo motor returns its coordinate origin through the travel switch. After initialization, the image processing and wafer detection platform control processes enter their respective threads.

Step 2: The PLC sends an operation command to the transplanting four-axis robot. The transplanting four-axis robot puts the marked wafer into the recycling platform, and places the wafer to be detected on the vacuum platform and returns a signal to the PLC.

Step 3: The PLC sends an operation command. The industrial camera collects image information. And the computer detects whether the particle has defects, while outputting the defect particle coordinates through an image processing algorithm. The computer returns a signal to the PLC.

Step 4: The PLC sends an operation command to the marking four-axis robot. The marking four-axis robot marks the defective particles according to the coordinate position. After marking, the four-axis robot back to the origin position and returns a signal to the PLC.

Step 5: Repeat Steps 2, 3, and 4. When all wafer inspections are completed, the PLC sends a stop command and warns the worker to replace the wafer.

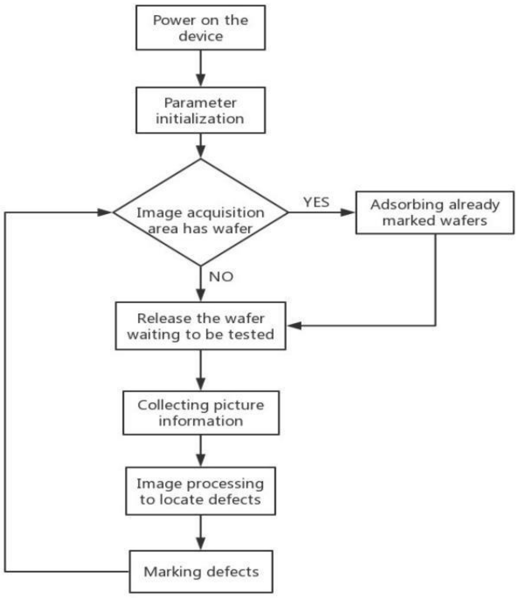

Figure 5. Control process of defect detection device for silicon wafer

3.2. Control process of transplanting

The control process of wafer transplanting is shown in Figure 6. The specific implementation steps are as follows:

Step 1: After receiving the no-wafer signal from the limit sensor in the supply wafer platform, the PLC sends a pulse to the servo motor raising the wafer in Z-axis direction. The limit sensor detects the wafer and sends a signal to the PLC, wafer stops rising.

Step 2: The transplanting robot has two suction nozzles located separately at the two ends of a robot bridge. The PLC outputs an operation command to drive the transplanting four-axis robot move to the top of the storage wafer mechanism and simultaneously one suction nozzle suck up the raw wafer. The transplanting four-axis robot moves over the image acquisition area, and the other suction nozzle picks up the marked wafer on the vacuum platform. Rotating 180 degrees of the robot, the raw wafer is placed on the vacuum platform.

Step 3: The transplanting four-axis robot returns to the top of the storage wafer area and releases the marked wafer to the recovery platform. The PLC sends a pulse after receiving a signal from the limit sensor in the recovery platform. The servo motor drives the recovery platform down in Z-axis.

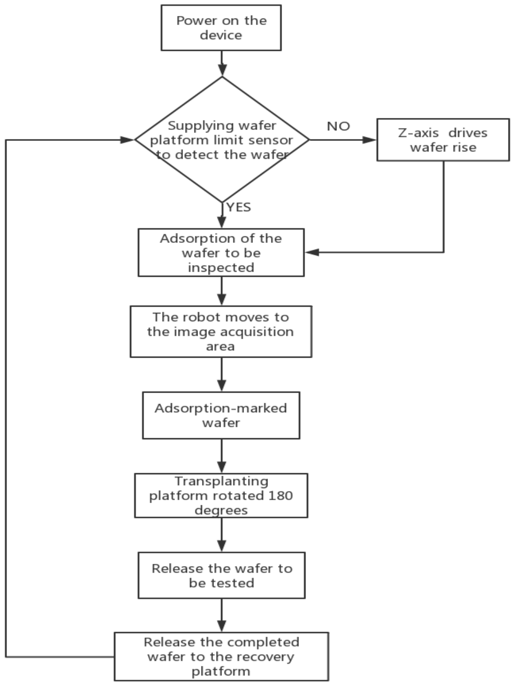

Figure 6. Control process of Wafer transfer

4. Assembling and testing

According to the structural design, each mechanism elements are assembled together compactly. The silicon wafer defect detecting device is built up within a sealed uncontaminated cabinet. The device uses socket to realize bidirectional data communication between PLC, four-axis robot and PC.

When the power supplies, the whole device is in stand-by status. Once the “start” command from operator is send the machine, it works at the sequence programmed in the PLC. The robots work at right time sequence. The speed of the whole machine reaches 16s/piece. Each piece of wafer contains 3500 particles around, which means the marking speed is 219 particles per second. The 5*5 pixels defect can be identified within 28*28 images. The operation of the device is stable during the overall debugging process.

5. Conclusion

The compact robot-based defect detection device for silicon wafer is designed. The use of two four-axis robots in coordination with the control method can replace manual operation. The control system based on image processing and four-axis manipulator effectively solves the problem of low accuracy caused by visual fatigue in manual detection. The compact robot-based defect detection device for silicon wafer greatly reduces the production cost of the enterprise, and has a large development space.

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