

DESCRIPTION

Title of the Invention: Substrate-Conveying Robot System
and Substrate Detection Method

Technical Field

[0001]

The present disclosure relates to a substrate-conveying robot system and a substrate detection method.

Background Art

[0002]

A measurement device for measuring deformation of a semiconductor wafer has been disclosed in the art. A measurement device disclosed in Japanese Patent Publication No. JP 7169994 measures deformation of a semiconductor wafer by analyzing an image in which a geometric illumination pattern reflected from the semiconductor wafer is captured. The measurement device described in Japanese Patent Publication No. JP 7169994 captures an image of a semiconductor wafer that is placed on a turntable in a vacuum chamber while processing is being performed. Since processing in the vacuum chamber is performed while rotating the turntable, a reflected image of the entire semiconductor wafer is captured even when the semiconductor wafer has a large size. In addition, Japanese Patent Publication No. JP 7169994 describes an example in which, outside the vacuum chamber,

a reflected image of the entire semiconductor wafer is captured by linearly moving the semiconductor wafer by a translation means.

Prior Art

Patent Document

[0003]

Patent Document 1: Japanese Patent Publication No. JP 7169994

Summary of the Invention

[0004]

However, as in Japanese Patent Publication No. JP 7169994, when an image of a substrate placed on a turntable in a vacuum chamber is captured in order to detect a state of the substrate such as deformation of a semiconductor wafer, it is difficult to adjust the position of the substrate to be imaged because the turntable performs only movement in a rotational direction. In addition, even in a case in which a reflected image of an entire substrate is captured by linearly moving the substrate using a translation means arranged outside a vacuum chamber, it is difficult to adjust the position of the substrate to be imaged because the substrate is only moved linearly. When it is difficult to adjust the position of the substrate to be imaged, it is difficult to detect the state of the

substrate with higher accuracy. For this reason, when detecting a state of a substrate by imaging the substrate, it is desired to detect the state of the substrate with higher accuracy by adjusting the position of the substrate.

[0005]

The present disclosure is intended to solve the above problems, and one object of the present disclosure is to provide a substrate-conveying robot system and a substrate detection method capable of detecting a state of a substrate with higher accuracy.

[0006]

A substrate-conveying robot system according to a first aspect of the present disclosure includes a robot that conveys a substrate; a light irradiator that irradiates a main surface of the substrate held by the robot with detection light having a predetermined shape; an image capturer that captures an image of the detection light reflected on the main surface of the substrate by capturing an image of the substrate; and a controller that detects a state of the substrate based on the captured image of the detection light captured by the image capturer.

[0007]

In the substrate-conveying robot system according to

a first aspect of the present disclosure, as discussed above, a main surface of the substrate held by the robot is irradiated with detection light having a predetermined shape. In addition, a state of the substrate is detected based on the captured image of the detection light captured by the image capturer. Accordingly, since the substrate to be imaged is held by the robot that conveys the substrate, a position of the substrate can be easily adjusted by an operation of the robot. As a result, by the operation of the robot, the substrate can be easily arranged at an appropriate position for detecting the state of the substrate, and thus the state of the substrate can be detected with higher accuracy.

[0008]

A substrate detection method according to a second aspect of the present disclosure includes capturing, by capturing an image of a substrate held by a robot that conveys the substrate, detection light having a predetermined shape reflected on a main surface of the substrate; and detecting a state of the substrate based on the captured image of the detection light that has been captured.

[0009]

In the substrate detection method according to the second aspect of the present disclosure, as discussed

above, an image of a substrate held by a robot is captured, and a state of the substrate is detected based on the captured image of the detection light that has been captured. Accordingly, since the substrate to be imaged is held by the robot that conveys the substrate, a position of the substrate can be easily adjusted by an operation of the robot. As a result, since, by the operation of the robot, the substrate can be easily arranged at an appropriate position for detecting the state of the substrate, it is possible to provide a substrate detection method capable of detecting a state of the substrate with higher accuracy.

[0010]

According to the present disclosure, a state of a substrate can be detected with higher accuracy.

Brief Description of the Drawings

[0011]

FIG. 1 is a top view showing a substrate processing system in which a substrate-conveying robot system according to a first embodiment of the present disclosure is arranged.

FIG. 2 is a perspective view illustrating a configuration of a substrate.

FIG. 3 is a block diagram showing a configuration of the substrate-conveying robot system according to the

first embodiment of the present disclosure.

FIG. 4 is a perspective view schematically showing the configuration of the substrate-conveying robot system.

FIG. 5 is a view showing an exemplary captured image of detection light captured by an image capturer.

FIG. 6 is a view showing an exemplary captured image captured while a substrate is moved along a plurality of moving directions.

FIG. 7 is a diagram illustrating learning of a learned model.

FIG. 8 is a flowchart illustrating a substrate detection method according to the first embodiment.

FIG. 9 is a perspective view schematically showing a configuration of a substrate-conveying robot system according to a second embodiment of the present disclosure.

FIG. 10 is a perspective view schematically showing a configuration of a substrate-conveying robot system according to a third embodiment of the present disclosure.

Modes for Carrying Out the Invention

[0012]

[First Embodiment]

The following description will describe a first embodiment of the present disclosure embodying the present disclosure with reference to the drawings.

[0013]

The following description describes a substrate-conveying robot system 100 according to a first embodiment with reference to FIGS. 1 to 7.

[0014]

(Substrate Processing System)

As shown in FIG. 1, the substrate-conveying robot system 100 is arranged in a substrate processing system 400. The substrate processing system 400 includes a processing device 401 that performs processing on a substrate 101. The processing device 401 includes a robot 402, load locks 403, processing modules 404, and a transfer chamber 405. The robot 402 is a horizontal multi-joint robot that conveys the substrate 101. The load locks 403 are chambers for loading the substrate 101 into the processing device and unloading the substrate 101 from the processing device. Accordingly, the load locks 403 are chambers in which the substrate 101 is placed in order to transfer the substrate 101 to the processing device 401. The processing device 401 of the substrate processing system 400 includes two load locks 403. The load locks 403 are connected to the substrate-conveying robot system 100. In the processing module 404, processing such as resist application and etching is performed on the substrate 101. The robot 402 is arranged

in the transfer chamber 405. In the transfer chamber 405, the robot 402 conveys the substrate 101 between the load locks 403 and the processing modules 404.

[0015]

The substrate-conveying robot system 100 conveys the substrate 101 between FOUPs 110 (Front Opening Unify Pod) and the processing device 401 in the substrate processing system 400, in which processing is performed on the substrate 101. The substrate-conveying robot system 100 is an EFEM (Equipment Front End Module). The FOUPs 110 are containers in which a plurality of substrates 101 are stored. In each FOUP 110, a plurality of substrates 101 are arranged in an upward/downward direction. The FOUPs 110 are examples of a substrate storage container.

[0016]

As shown in FIG. 2, the substrate 101 is, for example, a silicon wafer having a disk shape. The substrate 101 has a mirror-finished main surface 101a. The substrate 101 also has a notch 101b that indicates an orientation of the substrate 101. The notch 101b is a V-shaped groove arranged on an outer peripheral edge of the substrate 101 to indicate a crystal orientation of the substrate 101.

[0017]

(Substrate-Conveying Robot System)

As shown in FIG. 3, the substrate-conveying robot system 100 includes a transfer chamber 10, a robot 20, an aligner 30, an image capturer 40, a light irradiator 50, and a controller 60. The robot 20 includes a horizontal multi-joint robot arm 21 and a substrate holding hand 22. The aligner 30 is an example of an adjustment device.

[0018]

As shown in FIG. 4, the transfer chamber 10 is a housing having a rectangular box shape. The transfer chamber 10 has a front surface 11 on a Y1 direction side and a rear surface 12 on a Y2 direction side. The transfer chamber 10 also has a top surface 13 on a vertically upper side, which is a Z1 direction side. In the transfer chamber 10, conveyance of the substrate 101 is performed. The transfer chamber 10 houses the robot 20, the aligner 30, the image capturer 40, the light irradiator 50, and the controller 60. On the front surface 11 of the transfer chamber 10 on the Y1 direction side, three load ports 11a to which FOUPs 110 are attached are arranged side by side along a horizontal direction. Each load port 11a includes an opening and closing mechanism. Each load port 11a opens and closes the door of the attached FOUP 110. On the rear surface 12 of the transfer chamber 10 on the Y2 direction side, two load locks 403 are connected. An opening and closing mechanism

is also arranged between each load lock 403 and the rear surface 12. In FIG. 4, a state is shown in which a FOUP 110 is attached to one load port 11a located on an X1 direction side among the three load ports 11a.

[0019]

The robot 20 is arranged in the transfer chamber 10 in which conveyance of the substrate 101 between the FOUP 110 and the load locks 403 is performed. The robot 20 performs a conveying operation of the substrate 101 in the transfer chamber 10. Specifically, in the robot 20, a substrate holding hand 22, which is an end-effector that holds the substrate 101, is arranged at a distal end of the robot arm 21. The robot 20 performs the conveying operation of the substrate 101 between the FOUP 110 attached to the load ports 11a and the load locks 403. The robot 20 conveys the substrate 101 while holding the substrate 101 along a horizontal plane by the substrate holding hand 22. The substrate holding hand 22 is a passive-type hand that holds the substrate 101 without fixing the substrate.

[0020]

The aligner 30 aligns the substrate 101 conveyed by the robot 20. The aligner 30 adjusts an orientation of the substrate 101 to a predetermined orientation. The aligner 30 is arranged in the transfer chamber 10 closer

to an X2 direction side, which is one side in an X direction that is a rightward/leftward direction. The aligner 30 includes a substrate placement portion 30a on which the substrate 101 is placed. The aligner 30 detects a notch 101b of the substrate 101 from an outer peripheral edge of the substrate 101 by rotating the substrate 101 placed on the substrate placement portion 30a along a horizontal plane. Then, the aligner 30 adjusts the orientation of the substrate 101 to the predetermined orientation by rotating the substrate 101 along the horizontal plane and aligning a rotational position along a circumferential direction of the main surface 101a of the substrate 101, based on a position of the notch 101b detected from the outer peripheral edge. The aligner 30 also detects a center position of the substrate 101.

[0021]

In the substrate-conveying robot system 100, the substrate 101 before processing, which is held by the robot 20, is conveyed from the FOUP 110 to the aligner 30. Then, the substrate 101 aligned by the aligner 30 is conveyed again to the load lock 403 by the robot 20. Further, the substrate 101 after processing performed in the processing device 401 is conveyed from the load lock 403 to the FOUP 110 by the robot 20. The conveying operation of the substrate 101 by the robot 20 includes,

with respect to each of the FOUP 110 and the load locks 403, both an unloading operation of unloading the substrate 101 and a loading operation of loading the substrate 101.

[0022]

The image capturer 40 is, for example, a two-dimensional camera. The image capturer 40 includes an imaging element such as a CCD (Charge Coupled Device) and a CMOS (Complementary Metal Oxide Semiconductor). The image capturer 40 is arranged at a position facing the substrate 101 held by the robot 20. The image capturer 40 captures an image of the substrate 101 while the substrate 101 is held by the robot 20. In the first embodiment, the image capturer 40 is arranged above the robot 20 in the transfer chamber 10. For example, the image capturer 40 is arranged inside the transfer chamber 10 on the top surface 13 of the transfer chamber 10. The image capturer 40 is arranged at a position for capturing an image of the substrate 101 unloaded from the FOUP 110. Three image capturers 40 are arranged so as to correspond to the three load ports 11a to which the FOUPs 110 are attached.

[0023]

The light irradiator 50 irradiates, with detection light L1, the main surface 101a of the substrate 101 whose at least one of a relative position or a relative angle

with respect to the light irradiator is changed. In the first embodiment, the light irradiator 50 irradiates the main surface 101a of the substrate 101 with detection light L1 having a predetermined shape onto the main surface 101a of the substrate 101, which is held by the robot 20 and is relatively moved along a predetermined moving direction. The light irradiator 50 irradiates the main surface of the substrate with line-shaped detection light L1 along a direction intersecting a moving direction in a change of a relative position of the substrate 101 with respect to the light irradiator 50. The light irradiator 50 includes, for example, an LED (Light-Emitting Diode) that emits a red line-shaped light as the detection light L1. The term "line-shaped" light herein means that, when a plane such as the main surface 101a of the substrate 101 is irradiated with the detection light L1, the detection light L1 has a shape extending in a line on the irradiated plane. The light irradiator 50 irradiates the substrate 101 with the detection light L1 at a timing at which an image capturing operation is performed by the image capturer 40. The light irradiator 50 is arranged above the robot 20 in the transfer chamber 10. For example, the light irradiator 50 is arranged inside the transfer chamber 10 on the top surface 13 of the transfer chamber 10. Similar to the image capturer

40, three light irradiators 50 are arranged so as to correspond to the three load ports 11a to which the FOUPs 110 are attached.

[0024]

As shown in FIG. 1, controller 60 includes a machine learning portion 61. The controller 60 controls operations of respective parts of the substrate-conveying robot system 100. In the first embodiment, the controller 60 also serves as a robot controller that controls an operation of the robot 20. In other words, the controller 60 is a robot controller. The controller 60 also controls an operation of the aligner 30. The controller 60 also controls operations of the image capturer 40 and the light irradiator 50. For example, the controller 60 includes an arithmetic unit such as a CPU (Central Processing Unit). The controller 60 also includes memory such as RAM (Random Access Memory) and ROM (Read Only Memory) and storage devices such as a hard disk. The controller 60 executes control processing by the arithmetic unit based on programs and parameters stored in the storage devices.

[0025]

(Generation of Captured Images)

As shown in FIG. 5, a captured image 71 is acquired through image capturing performed by the image capturer 40. The captured image 71 captured by the image capturer

40 is transmitted to the controller 60. By capturing an image of the substrate 101, the image capturer 40 captures the detection light L1 reflected on the main surface 101a of the substrate 101. When image capturing of the detection light L1 is performed by the image capturer 40, the robot 20 changes a position of the substrate 101 relative to the light irradiator 50. Specifically, when image capturing of the detection light L1 is performed by the image capturer 40, the robot 20 moves the substrate 101 along a predetermined moving direction, thereby moving the substrate 101 relative to the light irradiator 50. The light irradiator 50 irradiates, with the detection light L1, the main surface 101a of the substrate 101 that is moving relative to the light irradiator 50 by an operation of the robot 20. Then, the image capturer 40 captures, a plurality of times, the detection light L1 reflected on the main surface 101a of the substrate 101, in accordance with relative movement of the substrate 101 by the robot 20, which is a change in a relative position of the substrate 101 with respect to the light irradiator 50. The controller 60 generates a captured image 71 by capturing the reflected detection light L1 a plurality of times through a plurality of image capturing operations performed by the image capturer 40. More specifically, the controller 60 generates one captured image 71 based on

a plurality of captured images 70 acquired through a plurality of image capturing operations performed by the image capturer 40, such that the detection light L1 reflected over an entirety of the substrate 101 is synthesized.

[0026]

For example, by an operation of the robot 20, the substrate 101 before processing performed by the processing device 401 is moved along a Y2 direction, as indicated by dotted arrows in FIG. 5, after being unloaded from the FOUP 110. At a timing at which the substrate 101 unloaded from the FOUP 110 is being moved by the robot 20, the light irradiator 50 continuously irradiates, a plurality of times, line-shaped detection light L1 extending along an X direction orthogonal to the Y2 direction, which is a moving direction, onto the main surface 101a of the substrate 101. The image capturer 40 captures, continuously a plurality of times, the detection light L1 reflected on the main surface 101a of the substrate 101, in accordance with movement of the substrate 101 in the Y2 direction by the robot 20. The controller 60 generates one captured image 71 by synthesizing the captured images 70 continuously captured by the image capturer 40 during movement in the Y2 direction, which is one moving direction. For example, in

order to generate one captured image 71, the controller 60 moves the substrate 101 by the robot 20 at a fixed speed and synthesizes the captured images 70 captured continuously a plurality of times by the image capturer 40 at fixed time intervals. Synthesis of the captured images 70 is performed such that a plurality of captured images 70 are superimposed on each other in a state shifted from each other in a Y direction, so as to correspond to movement of the substrate 101. That is, one captured image 71 is generated so as to be an image in which a plurality of detection lights L1 are reflected over an entirety of the main surface 101a of the substrate 101 along a moving direction of the substrate 101. Since no light source other than the light irradiator 50 is arranged inside the transfer chamber 10, an interior of the transfer chamber 10 is in a relatively dark state. Accordingly, each of the plurality of captured images 70 is captured so as to be an image in which only the detection light L1 reflected on the main surface 101a of the substrate 101 is extracted. In other words, the captured image 71 is an image captured such that the detection light L1 reflected in accordance with a shape of the substrate 101 is extracted.

[0027]

As shown in FIG. 6, the controller 60 generates a

captured image 72 by capturing the substrate 101 by the image capturer 40 while moving the substrate 101 along a moving direction different from a moving direction used to generate the one captured image 71. In other words, in the first embodiment, the robot 20 moves the substrate 101 along a plurality of moving directions different from each other when image capturing operations for capturing the detection light L1 are performed by the image capturer 40. Then, the controller 60 generates a captured image 71 and a captured image 72 in which the detection light L1 is captured by the image capturer 40, each corresponding to a respective moving direction along which the substrate 101 is moved by the robot 20. For example, the controller 60 generates two captured images 71 and 72 by moving the substrate 101 along two moving directions, namely, a first moving direction of the substrate 101 that is a Y2 direction for generating the captured image 71, and a second moving direction different from the Y2 direction for generating the captured image 72. The captured image 72, similarly to the captured image 71, is generated by synthesizing a plurality of captured images 70 captured continuously a plurality of times.

[0028]

(Control Process for Detection of Substrate State)

As shown in FIG. 7, in the first embodiment, the

controller 60 detects a state of the substrate 101 based on the captured image 71 and the captured image 72 of detection light L1 captured by the image capturer 40 in the transfer chamber 10, by using a learned model 62 generated by machine learning. The controller 60 detects, based on the captured image 71 and the captured image 72, the state of the substrate 101 including a position of the substrate 101 and an orientation of the substrate 101. The state of the substrate 101 detected by the controller 60 includes abnormalities of the substrate 101, including warpage, deformation, chipping, cracking, and scratches of the substrate 101. The learned model 62 is generated by machine learning so as to output an identification result 75 obtained by identifying the state of the substrate 101 based on reflected images of the detection light L1 in the captured image 71 and the captured image 72. The learned model 62 is generated in advance by the machine learning portion 61 of the controller 60 and is stored in a storage device of the controller 60.

[0029]

<Generation of Learned Model>

The controller 60 generates the learned model 62 by machine learning in the machine learning portion 61 based on input teacher images 80 that are learning data. The learned model 62 is generated by machine learning using a

dataset in which the teacher images 80 are used as input and output teacher data 85 are used as output. For example, the learned model 62 is learned so as to output, as an identification result 75, coordinates representing a position of the substrate 101 and an orientation of the substrate 101 indicated by a position of a notch 101b, by using each of the captured image 71 and the captured image 72 as input. When an abnormality such as warpage occurs in the substrate 101, a shape of the detection light L1 in each of the captured image 71 and the captured image 72 is different from a shape in a normal case. In the first embodiment, the learned model 62 is generated by machine learning so that an abnormality of the substrate 101 is identified based on reflected images of the detection light L1 in the captured image 71 and the captured image 72. The learned model 62 is learned so as to output, by using each of the captured image 71 and the captured image 72 as input, an identification result 75 including a likelihood representing a certainty of whether or not the substrate 101 includes an abnormality.

[0030]

The teacher images 80 include the captured images 71 and 72 obtained by capturing the detection light L1 reflected on the main surface 101a of each of a plurality of types of substrates 101 having different states or

presence or absence of an abnormality of the substrates 101, such as different positions and orientations . That is, the captured images 71 and 72 captured in a state in which a plurality of types of substrates 101, including substrates 101 that are known to be normal with no abnormality and substrates 101 that are known to include an abnormality, are arranged in a plurality of types of positions and orientations are acquired as a plurality of types of teacher images 80. The output teacher data 85 indicating a state of the substrate 101 in each of the plurality of types of teacher images 80 are obtained, and each of the plurality of types of teacher images 80 and corresponding output teacher data 85 are stored in a storage device of the controller 60 in an associated state. The output teacher data 85 include, as information indicating the state of the substrate 101, information indicating a position of the substrate 101, information indicating an orientation of the substrate 101, and information indicating whether or not the substrate 101 includes an abnormality.

[0031]

The machine learning portion 61 performs machine learning for generating the learned model 62 by using the plurality of teacher images 80 as input teacher data and using the plurality of output teacher data 85 associated

with the plurality of teacher images 80 as output teacher data. The machine learning portion 61 generates the learned model 62 by machine learning using deep learning. The machine learning portion 61 generates, for example, the learned model 62 by machine learning based on a Fully Convolution Network (FCN).

[0032]

By using the learned model 62 generated by machine learning as described above, the controller 60 obtains the identification results 75 from the captured image 71 and the captured image 72. The controller 60 detects the state of the substrate 101 by, for example, calculating an average of the identification results 75 obtained based on the captured image 71 and the identification results 75 obtained based on the captured image 72.

[0033]

<Correction of Positional Deviation>

In the first embodiment, the controller 60 detects a positional deviation of the substrate 101 with respect to the substrate holding hand 22 based on the detected state of the substrate 101. For example, capturing of the detection light L1 in each of the captured images 71 and 72 is performed at a timing at which the substrate holding hand 22 is in a predetermined position, based on control amounts of the robot 20. Accordingly, by detecting, as

the state of the substrate 101, information indicating positions of the substrate 101 based on each of the captured images 71 and 72, magnitudes and direction of a positional deviation of a position at which the substrate 101 is held with respect to a position of the substrate holding hand 22 of the robot 20 are detected. The controller 60 acquires an average of a magnitude and a direction of the positional deviation detected based on the captured image 71 and a magnitude and a direction of the positional deviation detected based on the captured image 72 as a detected magnitude and direction of the positional deviation, and corrects a conveying operation of the robot 20 so as to correct the positional deviation of the substrate 101, based on the acquired magnitude and direction of the positional deviation.

[0034]

As an example, when the captured images 71 and 72 are obtained by capturing the substrate 101 unloaded from the FOUP 110, and based on each of the captured images 71 and 72, it is detected that the substrate 101 is positionally deviated by +2 cm in the X direction and -1 cm in the Y direction with respect to the substrate holding hand 22, the controller 60 corrects the conveying operation of the substrate 101 so that the substrate 101 is placed at a position displaced by -2 cm in the X

direction and +1 cm in the Y direction from a teaching position set as a position of the substrate placement portion 30a of the aligner 30. Specifically, the controller 60 corrects the conveying operation of the robot 20 by correcting drive signals output to drivers such as the servo motors that serve as drive sources to drive the robot arm 21 and the substrate holding hand 22. [0035]

<Assistance of Aligner>

In the first embodiment, the controller 60 controls an operation of the aligner 30 using a state of the substrate 101 detected based on the captured image 71 and the captured image 72. Specifically, the controller 60 detects an orientation of the substrate 101 held by the substrate holding hand 22 based on the detected state of the substrate 101. The controller 60 detects the notch 101b of the substrate 101 based on an identification result 75 from the learned model 62 obtained as the state of the substrate 101 detected based on the captured image 71 and the captured image 72. For example, the controller 60 acquires, as a detected position of the notch 101b, an average position of a position of the notch 101b detected based on the captured image 71 and a position of the notch 101b detected based on the captured image 72. Then, the controller 60 causes the aligner 30 to perform an

operation for adjusting the orientation of the substrate 101. Based on a position of the notch 101b of the substrate 101 detected using the captured image 71 and the captured image 72, the controller 60 rotates the substrate 101 along a horizontal plane so that not an entire outer peripheral edge of the substrate 101 but a portion of the outer peripheral edge of the substrate 101 including the detected position of the notch 101b is set as a detection target range. That is, after roughly detecting the orientation of the substrate 101 by detecting the state of the substrate 101 based on the captured image 71 and the captured image 72, the controller 60 detects the orientation of the substrate 101 in detail by the aligner 30. In other words, the controller 60 detects the state of the substrate 101 in advance based on the captured image 71 and the captured image 72 so as to assist the operation of the aligner 30.

[0036]

<Detection of Abnormality of Substrate>

In the first embodiment, the controller 60 detects an abnormality of the substrate 101 unloaded from the FOUP 110 based on the captured image 71 and the captured image 72 of the detection light L1 captured at a timing at which the substrate 101 is unloaded from the FOUP 110 in a conveying operation of the robot 20. The controller 60

determines that an abnormality is detected in the substrate 101 when a likelihood indicating a certainty of whether or not the substrate 101 includes an abnormality, which is included in the identification result 75 output as an inference result by the learned model 62, is greater than a predetermined threshold. For example, when the likelihood included in the identification result 75 is a value from 0 to 1, detection of an abnormality of the substrate 101 is determined by setting 0.8 as the predetermined threshold. For example, the controller 60 determines detection of an abnormality of the substrate 101 based on an average value of a likelihood included in the identification result 75 obtained based on the captured image 71 and a likelihood included in the identification result 75 obtained based on the captured image 72.

[0037]

When an abnormality of the substrate 101 is detected, the controller 60 outputs abnormality detection information indicating that an abnormality of the substrate 101 has been detected to the outside. For example, the controller 60 outputs the abnormality detection information to a higher-level control device that controls an entirety of the substrate processing system 400. As an example, when an abnormality of the

substrate 101 is detected, the controller 60 causes the robot 20 to store the substrate 101 back into the FOUP 110 based on a signal from the higher-level control device. When the controller 60 does not obtain a signal from the higher-level control device instructing the controller to store the substrate 101 back into the FOUP 110, the controller 60 stops a conveying operation of the substrate 101 and waits in a standby state. In addition, notification that an abnormality of the substrate 101 has been detected may be provided by displaying information indicating that the abnormality detection information has been obtained on a display device. For example, when processing of the substrate 101 is performed in the processing device 401 by sequentially conveying a plurality of substrates 101 stored in the FOUP 110 to the processing device 401, the controller 60 controls a conveying operation of the robot 20 to convey the substrates 101 one by one to the load lock 403 via the aligner 30. The controller 60 acquires the captured images 71 and 72 in conveying of each of the plurality of substrates 101, and detects an abnormality of the substrate 101 based on the acquired captured images 71 and 72 by using the learned model 62 generated and stored in advance. When an abnormality is detected in one of the plurality of substrates 101, the controller 60 outputs the

abnormality detection information and stores the substrate 101 back into the FOUP 110 so that the substrate 101 in which the abnormality has been detected is returned to its original position, based on a signal from the higher-level control device. Then, the controller 60 conveys a substrate 101 next to the substrate 101 in which the abnormality has been detected to the load lock 403 while similarly detecting an abnormality.

[0038]

(Substrate Detection Method)

The following description describes a control process of a substrate detection method by the substrate-conveying robot system 100 according to the first embodiment with reference to FIG. 8. The control process of the substrate detection method according to the first embodiment is executed by the controller 60 of the substrate-conveying robot system 100.

[0039]

First, in step S1, a learned model 62 is generated. Specifically, a teacher image 80 and output teacher data 85 are acquired. Then, using the teacher image 80 and the output teacher data 85 as a data set, the learned model 62 is generated by machine learning such that a state of the substrate 101 is detected based on each of captured images 71 and 72. The generated learned model 62 is stored in a

storage device of the controller 60.

[0040]

Next, in step S2, a conveying operation of the substrate 101 is started. Specifically, an operation of the robot 20 is controlled such that the substrate 101 arranged in the FOUP 110 is held by the substrate holding hand 22 of the robot 20.

[0041]

Next, in step S3, the substrate 101 is unloaded from the FOUP 110. With the substrate 101 being held by the substrate holding hand 22, one substrate 101 before processing is conveyed from the FOUP 110 into the transfer chamber 10.

[0042]

Next, in step S4, the captured images 71 and 72 in which detection light L1 reflected on the main surface 101a of the substrate 101 is captured are acquired by capturing, by the image capturer 40, the substrate 101 that is held by the robot 20 and that is moving relative to the image capturer along a predetermined moving direction. Specifically, the light irradiator 50 irradiates the main surface 101a of the substrate 101 with the detection light L1, and the detection light L1 reflected on the main surface 101a is captured by the image capturer 40, thereby acquiring the captured images

71 and 72 of the detection light L1.

[0043]

Next, in step S5, a state of the substrate 101 is detected based on each of the captured images 71 and 72 of the detection light L1 that have been captured, by using the learned model 62 generated by machine learning. For example, the state of the substrate 101 is detected, the state including a position of the substrate 101 with respect to the substrate holding hand 22, an orientation of the substrate 101, and whether or not an abnormality has occurred in the substrate 101.

[0044]

Then, in step S6, it is determined whether or not an abnormality of the substrate 101 has been detected, based on the detected state of the substrate 101. When it is determined that an abnormality of the substrate 101 has been detected, the process proceeds to step S7. When it is not determined that an abnormality of the substrate 101 has been detected, the process proceeds to step S8.

[0045]

In step S7, abnormality detection information indicating that an abnormality of the substrate 101 has been detected is output, on the assumption that an abnormality of the substrate 101 has been detected. For example, when a signal instructing that the substrate 101

in which an abnormality has been detected is to be stored back into the FOUP 110 is acquired, an operation of the robot 20 is controlled such that the substrate 101 is stored back into the FOUP 110 without being processed by the processing device 401. Then, the control process of the substrate detection method is ended.

[0046]

In step S8, a positional deviation of the substrate 101 at the substrate holding hand 22 is corrected. Specifically, on the assumption that no abnormality has been detected in the substrate 101, a conveying operation of the substrate 101 is continued, and a positional deviation of the substrate 101 with respect to the substrate holding hand 22 is detected based on a position of the substrate 101 detected as the state of the substrate 101 in step S5. Then, based on the detected positional deviation of the substrate 101, the conveying operation of the substrate 101 by the robot 20 to the aligner 30 is corrected.

[0047]

Then, in step S9, an orientation of the substrate 101 by the aligner 30 is adjusted to a predetermined orientation. Specifically, a position of the notch 101b on an outer peripheral edge of the substrate 101 is detected based on the state of the substrate 101 detected

in step S5. Then, based on the detected position of the notch 101b, a detection range for detecting the orientation of the substrate 101 in the aligner 30 is set. Then, within the set detection range, the notch 101b is detected by the aligner 30 without using the captured images 71 and 72, and a rotational position of the substrate 101 is adjusted such that the substrate 101 is oriented in the predetermined orientation.

[0048]

Then, in step S10, the substrate 101 is conveyed by the robot 20 from the aligner 30 to the load lock 403 so that processing by the processing device 401 is performed. Then, the control process of the substrate detection method is ended.

[0049]

When the control process of the substrate detection method is continuously executed for a plurality of substrates 101, generation of the learned model 62 in step S1 is performed only once, and the control processes from step S2 to step S10 are repeatedly executed for each substrate 101. Further, the control processes in steps S6 to S8 may be performed in any order.

[0050]

[Advantages of First Embodiment]

As described above, in the substrate-conveying robot

system 100, the main surface 101a of the substrate 101 held by the robot 20 is irradiated with detection light L1 having a predetermined shape. In addition, a state of the substrate 101 is detected based on each of captured images 71 and 72 of the detection light L1 captured by the image capturer 40. Accordingly, since the substrate 101 to be imaged is held by the robot 20 that conveys the substrate 101, a position of the substrate 101 can be easily adjusted by an operation of the robot 20. As a result, by the operation of the robot 20, the substrate 101 can be easily arranged at an appropriate position for detecting the state of the substrate 101, and thus the state of the substrate 101 can be detected with higher accuracy.

[0051]

Further, in the first embodiment, since the substrate 101 held by the robot 20 is imaged in order to detect a state of the substrate 101 while a conveying operation of the substrate 101 is being performed by the robot 20, unlike a case in which the substrate 101 is placed on a placement portion exclusively for imaging that is arranged separately from the robot 20 in order to image the substrate 101, or a case in which the substrate 101 is moved by a moving mechanism such as a translation means arranged separately from the robot 20, it is possible to suppress complication of an apparatus configuration for

detecting the state of the substrate 101 with higher accuracy. Further, since imaging of the substrate 101 for detecting the state of the substrate 101 is performed while the conveying operation of the substrate 101 is being performed, it is possible to reduce a workload as compared with a case in which detection of the state of the substrate 101 is performed separately from conveyance of the substrate 101.

[0052]

Further, in the first embodiment, the light irradiator 50 irradiates, with detection light L1, the main surface 101a of the substrate 101 whose at least one of a relative position or a relative angle with respect to the light irradiator is changed. The image capturer 40 captures, a plurality of times, the detection light L1 reflected on the main surface 101a of the substrate 101, in accordance with a change in at least one of a relative position and a relative angle of the substrate 101 relative to the light irradiator 50. The controller 60 detects a state of the substrate 101 based on each of one captured image 71 and one captured image 72 that are generated by capturing reflected detection light L1 a plurality of times through a plurality of image capturing operations performed by the image capturer 40. Accordingly, even when only a part of the main surface

101a of the substrate 101 is irradiated with the detection light L1, by performing a plurality of image capturing operations in accordance with the change in at least one of a relative position or a relative angle of the substrate 101, it is possible to capture reflected images of the detection light L1 reflected over an entirety of the main surface 101a of the substrate 101. As a result, even when only a part of the main surface 101a of the substrate 101 is irradiated with the detection light L1, it is possible to detect an overall state of the substrate 101 with high accuracy.

[0053]

Further, in the first embodiment, the robot 20 changes at least one of a position or an angle of the substrate 101 relative to the light irradiator 50 when an image capturing operation for capturing the detection light L1 is performed by the image capturer 40. Accordingly, by changing at least one of a position or an angle of the substrate 101 relative to the image capturer by the robot 20, the substrate 101 can be imaged by the image capturer 40 while accurately adjusting at least one of a position or an angle of the substrate 101 relative to the image capturer 40. As a result, a state of the substrate 101 can be detected with even higher accuracy.

[0054]

In the first embodiment, the light irradiator 50 irradiates the substrate with line-shaped detection light L1 along a direction intersecting a moving direction in a change of a relative position of the substrate 101 with respect to the light irradiator 50. Accordingly, since the line-shaped detection light L1 can be reflected on the main surface 101a of the substrate 101, a state of the substrate 101 in a continuous region from one end to another end of the substrate 101 can be acquired based on reflected images of the line-shaped detection light L1. As a result, based on each of captured images 71 and 72 obtained by capturing the detection light L1 reflected on the main surface 101a of the substrate 101, the state of the substrate 101 can be detected with even higher accuracy.

[0055]

Further, in the first embodiment, the robot 20 moves the substrate 101 along a plurality of moving directions different from each other when image capturing operations for capturing the detection light L1 are performed by the image capturer 40. The controller 60 detects a state of the substrate 101 based on each of the captured images 71 and 72 obtained in respective movements of the substrate 101 along a plurality of moving directions of the robot 20. Accordingly, by acquiring captured images 71 and 72

obtained in respective movements of the substrate 101 along the plurality of moving directions different from each other, it is possible to acquire a plurality of captured images 71 and 72 obtained in moving directions of the substrate 101 at the time of image capturing different from each other. As a result, since a state of the substrate 101 can be detected based on a plurality of types of captured images 71 and 72 obtained in moving directions of the substrate 101 different from each other, the state of the substrate 101 can be detected with even higher accuracy.

[0056]

In the first embodiment, the controller 60 detects a state of the substrate 101, including at least one of a shape, a position, an orientation of the substrate 101, or an abnormality occurring in the substrate 101, based on each of the captured images 71 and 72. Accordingly, it is possible to detect a state of the substrate 101, including at least one of a shape, a position, an orientation of the substrate 101, or an abnormality occurring in the substrate 101, based on each of the captured images 71 and 72 with higher accuracy.

[0057]

In the first embodiment, the controller 60 detects the notch 101b or an orientation flat indicating an

orientation of the substrate 101 by detecting a state of the substrate 101 based on the captured image 71 and the captured image 72. Accordingly, since the notch 101b or the orientation flat can be detected based on each of the captured images 71 and 72, an orientation of the substrate 101 can be easily detected based on each of the captured images 71 and 72.

[0058]

In the first embodiment, the controller 60 detects a state of the substrate 101 based on each of the captured images 71 and 72 captured by the image capturer 40, using the learned model 62 generated by machine learning. Here, in machine learning, by learning a plurality of types of states of substrates 101, the learned model 62 can be learned so as to detect also a state of the substrate 101 having a form different from the learned states of the substrates 101. For example, when an abnormality of warpage of the substrate 101 is detected using the learned model 62 generated by machine learning, using the learned model 62 that has been learned by learning warpage at a plurality of positions and in a plurality of directions as abnormalities, it is possible to accurately detect also warpage at a position different from learned positions or warpage in a direction different from learned directions. As a result, by detecting the state of the substrate 101

based on each of the captured images 71 and 72 using the learned model 62 generated by machine learning, it is possible to detect a plurality of types of states of the substrate 101 with higher accuracy.

[0059]

In the first embodiment, the robot 20 is arranged in the transfer chamber 10 in which the substrate 101 is conveyed to and from the FOUP 110 as a substrate storage container in which the substrate 101 is stored. The light irradiator 50 is arranged above the robot 20 in the transfer chamber 10 and irradiates the main surface 101a of the substrate 101 with detection light L1. The image capturer 40 is arranged above the robot 20 in the transfer chamber 10 and captures the detection light L1 reflected on the main surface 101a of the substrate 101. The controller 60 detects a state of the substrate 101 based on each of the captured images 71 and 72 captured in the transfer chamber 10. Accordingly, while a conveying operation of the substrate 101 to the FOUP 110 is performed by the robot 20, a state of the substrate 101 can be detected based on each of the captured images 71 and 72. As a result, as compared with a case in which conveyance of the substrate 101 to the FOUP 110 and detection of a state of the substrate 101 are performed separately, it is possible to suppress an increase in

working time required to detect the state of the substrate 101.

[0060]

In the first embodiment, the substrate-conveying robot system 100 includes the aligner 30 as an adjustment device that adjusts an orientation of the substrate 101 to a predetermined orientation. The controller 60 controls an operation of the aligner 30 using a state of the substrate 101 detected based on each of the captured images 71 and 72. Accordingly, since a state of the substrate 101 can be detected in advance based on each of the captured images 71 and 72, orientation adjustment of the substrate 101 by the aligner 30 can be performed in a state in which an approximate orientation of the substrate 101 has been detected in advance. As a result, it is possible to shorten a time required for adjusting the orientation of the substrate 101 by the aligner 30.

[0061]

In the first embodiment, the robot 20 includes the substrate holding hand 22 for holding the substrate 101. The controller 60 also serves as a robot controller that controls a conveying operation of the robot 20. The controller 60 detects, based on the detected state of the substrate 101, a deviation in at least one of a position or an orientation of the substrate 101 with respect to the

substrate holding hand 22, and corrects, in the conveying operation of the robot 20, the detected deviation in at least one of a position or an orientation of the substrate 101. Accordingly, since the conveying operation of the robot 20 can be corrected by detecting a state of the substrate 101 based on each of the captured images 71 and 72, the conveying operation by the robot 20 can be performed with higher accuracy.

[0062]

[Second Embodiment]

The following description describes a configuration of a substrate-conveying robot system 200 according to a second embodiment with reference to FIG. 9. In a second embodiment, the substrate-conveying robot system 200, unlike the substrate-conveying robot system 100 according to the first embodiment including the light irradiator 50 that irradiates the main surface of the substrate with one line of detection light L1, includes a light irradiator 250 that irradiates the main surface of the substrate with two lines of detection light L11 and L12. The same components as those of the aforementioned first embodiment are denoted by the same reference numerals, and their description is omitted.

[0063]

As shown in FIG. 9, the substrate-conveying robot

system 200 according to the second embodiment includes a light irradiator 250 and a controller 260. The light irradiator 250 irradiates, onto the main surface 101a of the substrate 101, line-shaped detection light L11 and line-shaped detection light L12 different from each other. For example, the light irradiator 250 irradiates, onto the main surface 101a of the substrate 101, two lines of detection light L11 and detection light L12 that extend in directions parallel to each other and that have a common color and a common shape such as a width. Here, the detection light L11 and the detection light L12 are examples of a "first detection light" and a "second detection light," respectively.

[0064]

Similar to imaging of detection light L1 in the first embodiment, the image capturer 40 captures, a plurality of times, the detection light L11 and the detection light L12 reflected on the main surface 101a of the substrate 101, in accordance with movement of the substrate 101 by the robot 20. The controller 260 acquires one captured image, similar to the captured image 71 and the captured image 72 in the first embodiment, by capturing the reflected detection light L11 and the reflected detection light L12 a plurality of times through a plurality of image capturing operations performed by the

image capturer 40. That is, a captured image in the second embodiment includes both the detection light L11 and the detection light L12. Then, similar to the captured image 71 and the captured image 72 in the first embodiment, the controller 260 detects a state of the substrate 101 based on the acquired captured images.

[0065]

For example, in the second embodiment, the controller 260 sets an operation speed of the robot 20, when image capturing by the image capturer 40 is performed, to a speed that is twice an operation speed of the robot 20 in the first embodiment. The controller 260 captures both the detection light L11 and the detection light L12 in one captured image. That is, even when the operation speed of the robot 20 is doubled, the controller 260 irradiates the main surface 101a of one substrate 101 with both the detection light L11 and the detection light L12, and captures both the reflected detection light L11 and the reflected detection light L12 by one image capturer 40, thereby making a total number of captured lines of the detection light L11 and captured lines of the detection light L12 included in one captured image equal to a number of captured lines of the detection light L1 in the first embodiment. The other configuration of the second embodiment is similar to that of the first

embodiment.

[0066]

[Advantages of Second Embodiment]

In the substrate-conveying robot system 200 according to the second embodiment, as described above, the light irradiator 250 irradiates the main surface of the substrate with detection light including detection light L11 as first detection light and detection light L12 as second detection light, which are mutually different lines of detection light. The controller 260 detects a state of the substrate 101 based on one captured image generated through a plurality of image capturing operations performed by the image capturer 40 and including the detection light L11 and the detection light L12. Accordingly, since two lines of detection light, namely the detection light L11 and the detection light L12 reflected on the main surface 101a of the substrate 101, can be captured by capturing one reflected image, as compared with a case in which one line-shaped detection light is reflected, it is possible to reduce the number of reflected images to be captured required to capture the line-shaped detection lights L11 and L12 reflected over an entirety of the main surface 101a of the substrate 101. As a result, it is possible to shorten a time required for detecting a state of the substrate 101. Also, the other

advantages of the second embodiment are similar to those of the first embodiment.

[0067]

[Third Embodiment]

The following description describes a configuration of a substrate-conveying robot system 300 according to a third embodiment with reference to FIG. 10. In the substrate-conveying robot system 300 according to the third embodiment, the robot 320 moves a held substrate 101 so as to change an angle of the substrate with respect to a horizontal plane. The same components as those of the aforementioned first embodiment are denoted by the same reference numerals, and their description is omitted.

[0068]

As shown in FIG. 10, the substrate-conveying robot system 300 according to the third embodiment includes a robot 320, a light irradiator 350, and a controller 360. The robot 320 includes a robot arm 321 and a substrate holding hand 322. The light irradiator 350 irradiates line-shaped detection light L21 along a YZ plane onto the substrate 101. That is, the light irradiator 350 irradiates line-shaped detection light L21 that extends along a Y direction on the main surface 101a of the substrate 101. In the third embodiment, the light irradiator 350 irradiates, with the detection light L21,

the main surface 101a of the substrate 101 whose angle is changed relative to the light irradiator. When image capturing of the detection light L21 is performed by the image capturer 40, the robot 320 changes an angle of the substrate 101 relative to the light irradiator 350. The robot 320 includes a rotation drive mechanism that rotates the substrate holding hand 322 along a θ direction, with a direction from a proximal end toward a distal end of the substrate holding hand 322 as a rotation axis line. For example, at a distal end of a horizontal multi-joint robot arm 321, a rotation drive mechanism such as a servo motor that rotates the substrate holding hand 322, which is an end effector, is arranged. The light irradiator 350 irradiates line-shaped detection light L21 along a direction of the rotation axis line of a rotation operation in changing a relative angle of the substrate 101 with respect to the light irradiator 350. "Along the direction of the rotation axis line" includes a direction parallel to the rotation axis line and a direction inclined from a direction parallel to the rotation axis line. In other words, the light irradiator 350 irradiates line-shaped detection light L21 that extends in a direction not orthogonal to the rotation axis line of the substrate holding hand 322. Specifically, the detection light L21 extends, on the main surface 101a of the

substrate 101, in a direction parallel to the rotation axis line in a rotational movement of the substrate holding hand 322. In the third embodiment, similar to the first embodiment, a state of the substrate 101 is detected based on a captured image of the detection light L21 reflected on the main surface 101a of the substrate 101. When image capturing of the detection light L21 is performed by the image capturer 40, the robot 320 moves the substrate 101 along a predetermined moving direction so as to change an angle of the substrate 101 held by the substrate holding hand 322 with respect to a horizontal plane. That is, in the third embodiment, the θ direction is an example of the predetermined moving direction.

[0069]

In order to detect a state of the substrate 101, the controller 360 conveys, by the robot 320, the substrate 101 to a predetermined position at which an image of the substrate 101 is captured by the image capturer 40. Then, the controller 360 rotationally moves the substrate 101 by tilting the substrate 101 so as to change an angle of the substrate 101 with respect to a horizontal plane along the θ direction, without changing a position of the substrate 101 in an XY plane. As an example, the controller 360 rotationally moves the substrate 101 along the θ direction within a range from -5 degrees to +5 degrees, with a state

in which the main surface 101a of the substrate 101 extends along the horizontal plane as a reference. The image capturer 40 captures, a plurality of times, the detection light L21 reflected on the main surface 101a of the substrate 101, in accordance with movement of the substrate 101 along the θ direction, which is a change in a relative angle of the substrate 101 with respect to the light irradiator 350. Similar to the first embodiment, the controller 360 detects a state of the substrate 101 based on one captured image that is generated by capturing reflected detection light L21 a plurality of times through a plurality of image capturing operations performed by the image capturer 40. Detection of the state of the substrate 101 based on a captured image of the detection light L21 is similar to detection of the state of the substrate 101 based on each of the captured images 71 and 72 in the first embodiment. The other configuration of the third embodiment is similar to that of the first embodiment. For example, the controller 360 generates a plurality of captured images by changing an orientation of the substrate holding hand 322 to change an orientation of a rotation axis line. Then, the controller detects a state of the substrate 101 based on a plurality of captured images in which orientations of the rotation axis line are different from each other.

[0070]

[Advantages of Third Embodiment]

In the third embodiment, as described above, the light irradiator 350 irradiates line-shaped detection light L21 along a direction of the rotation axis line of a rotation operation in changing a relative angle of the substrate 101 with respect to the light irradiator 350. Accordingly, since the line-shaped detection light L21 can be reflected on the main surface 101a of the substrate 101, a state of the substrate 101 in a continuous region from one end to another end of the substrate 101 can be acquired based on reflected images of the line-shaped detection light L21. As a result, based on a captured image obtained by capturing the detection light L21 reflected on the main surface 101a of the substrate 101, the state of the substrate 101 can be detected with even higher accuracy.

[0071]

Further, in the third embodiment, as described above, the robot 320 changes an angle of the substrate 101 with respect to a horizontal plane when an image capturing operation for capturing the detection light L21 is performed by the image capturer 40. Accordingly, since the angle of the substrate 101 with respect to the horizontal plane can be changed by the robot 320, an

irradiation angle of the detection light L21 with which the substrate 101 is irradiated can be changed three-dimensionally. Accordingly, since the detection light L21 can be reflected on the main surface 101a of the substrate 101 from various irradiation directions, and a state of the substrate 101 can be detected based on a captured image obtained by capturing reflected detection light L21, the state of the substrate 101 can be detected with even higher accuracy. Also, the other advantages of the third embodiment are similar to those of the first embodiment.

[0072]

[Modified Embodiments]

Note that the embodiment disclosed this time must be considered as illustrative in all points and not restrictive. The scope of the present disclosure is not shown by the above description of the embodiments but by the scope of claims for patent, and all modifications (modified embodiments) within the meaning and scope equivalent to the scope of claims for patent are further included.

[0073]

For example, while the example in which a state of the substrate 101 is detected based on one captured image that is generated by capturing reflected detection light line-shaped reflected detection light L1, L11 and L21, or

L21 a plurality of times through a plurality of image capturing operations performed by the image capturer 40 has been shown in the aforementioned first, second, and third embodiments, the present disclosure is not limited to this. In the present disclosure, a state of the substrate may be detected based on a captured image of detection light captured by a single image capturing operation. For example, when the detection light is not line-shaped but is a plurality of point light sources arranged in a grid pattern, a state of the substrate is detected by capturing, in a single image capturing operation, detection light reflected over an entirety of a main surface of the substrate. In addition, a shape of the detection light with which the main surface of the substrate is irradiated is not limited to a line shape and a grid shape, and may have a predetermined geometric shape such as a concentric shape. Further, the light irradiator may irradiate the main surface of the substrate with detection light having a predetermined color and a predetermined shape by using a projector device or the like that projects an image. Further, a captured image as a single moving image may be acquired by a plurality of image capturing operations performed by the image capturer, and a state of the substrate may be detected based on the captured image as a moving image.

[0074]

While the example in which a state of the substrate 101 is detected based on one captured image including detection light L11 as first detection light and detection light L12 as second detection light, which are line-shaped, parallel to each other, have the same shape, and are emitted by the light irradiator 250 for irradiation has been shown in the aforementioned second embodiment, the present disclosure is not limited to this. In the present disclosure, when the main surface of the substrate is irradiated with a first detection light and a second detection light, which are two forms of light, the first detection light and the second detection light may have different shapes from each other, or may have different colors from each other. Further, when the first detection light and the second detection light are both line-shaped, the first detection light and the second detection light may be emitted so as to intersect with each other for irradiation. Further, three or more lines of detection light different from each other may be emitted for irradiation. Further, when a plurality of forms of detection light are emitted for irradiation, a plurality of light irradiators may be separately arranged.

[0075]

While the example in which, by using the learned

model 62, based on each of captured images of the detection light L1, L11, L12, or L21, a position of the substrate 101, an orientation of the substrate 101, and an abnormality of the substrate 101 are detected as states of the substrate 101 has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, a state of the substrate detected based on a captured image may be at least one of a shape of the substrate, a position of the substrate, an orientation of the substrate, or an abnormality of the substrate. In other words, the shape of the substrate may be detected as the state of the substrate. For example, a shape of a contour line of the substrate may be detected based on a captured image, and a coordinate of a center position of the substrate and a notch or an orientation flat may be detected based on the detected shape of the substrate, thereby detecting a position and an orientation of the substrate. In addition, an abnormality of the substrate detected as a state of the substrate may be one of warpage, deformation, chipping, cracking, and scratching of the substrate, or may be any two or more of them. For example, only warpage of the substrate may be detected as an abnormality. In addition, a state of the substrate may be detected without using a learned model. For example, a

state of the substrate may be detected by detecting a linear structure from captured images by using a predetermined algorithm other than a learned model, based on each of captured images obtained by capturing line-shaped detection light a plurality of times in accordance with movement of the substrate. In this case, for example, the line-shaped detection light may be detected by extracting a position of a center in a width direction of the line-shaped detection light included in the captured images.

[0076]

While the example in which based on each of captured images 71 and 72 captured at a timing at which the substrate 101 is unloaded from the FOUP 110 as a substrate storage container, in accordance with movement of the substrate 101 by the robot 20 or 320, an abnormality of the substrate 101 is detected as a state of the substrate 101, and the substrate 101 in which an abnormality is detected is stored back into the FOUP 110 has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, a state of a substrate may be detected based on a captured image obtained by capturing an image of the substrate that is not being moved by a robot and is in a stopped state. For example, the substrate held by

the robot may be moved relative to the light irradiator by operating the light irradiator so as to change at least one of an irradiation direction or a position of the light irradiator. A predetermined detection position may be set in advance, and an abnormality of the substrate may be detected based on a captured image obtained by capturing an image of the substrate that has been moved to the predetermined detection position by the robot. In addition, when a captured image is captured by the image capturer, at least one of a relative position or a relative angle of the substrate with respect to the light irradiator may be configured not to be changed. For example, the image capturer may capture detection light with which the substrate is irradiated by the light irradiator in a stationary state and which is reflected on the substrate in a stationary state while being held by the robot. Also, the image capturer may be moved. In addition, a state of the substrate may be detected based on a captured image captured at a timing at which the substrate after processing by the processing device is stored in the substrate storage container. Also, a substrate in which an abnormality is detected may not be stored back into the substrate storage container. For example, the substrate in which an abnormality is detected may be placed in a container different from the substrate

storage container from which the substrate has been unloaded, or at a placement position. In addition, when an abnormality of the substrate is detected, processing for detecting a state of the substrate using the learned model may be performed again by performing image capturing again by the image capturer. When image capturing is performed again, a position, an orientation, or a moving direction of the substrate may be changed from those in the first image capturing. In addition, a signal indicating the detected state of the substrate may be output to the processing device or the like. In addition, by arranging a notifier that performs notification, such as a display device, on a front side of the transfer chamber, information indicating the detected state of the substrate may be notified by displaying text information and outputting audio information or the like.

[0077]

While the example in which a captured image 71 is obtained during movement of the substrate 101 along a predetermined moving direction, and a captured image 72 is obtained during movement of the substrate 101 along a different moving direction that is different from the predetermined moving direction along which the captured image 71 is obtained has been shown in the aforementioned first and second embodiments, the present disclosure is

not limited to this. In the present disclosure, a state of a substrate may be detected based on one captured image captured during movement of the substrate along one moving direction, or captured images may be obtained in three or more moving directions different from each other. Also, even when a plurality of captured images are obtained, the plurality of captured images may be obtained while moving the substrate along a common moving direction to each other. In addition, image capturing may be performed in a state in which a relative angle between the substrate and the light irradiator is made different from each other.

[0078]

While the example in which a state of the substrate 101 is detected based on each of captured images obtained by capturing the detection light L21 a plurality of times, in accordance with a rotational movement that changes an angle of the substrate 101 with respect to a horizontal plane along a θ direction without changing a position of the substrate 101 in an XY plane has been shown in the aforementioned third embodiment, the present disclosure is not limited to this. In the present disclosure, by moving a substrate along a horizontal plane with different angles from each other with respect to the horizontal plane, a plurality of captured images of a substrate at the different angles may be obtained. In this case, moving

directions of the substrate along the horizontal plane may be made different from each other. That is, both a relative position and a relative angle of the substrate with respect to the light irradiator may be changed. In this case, both the relative position and the relative angle of the substrate with respect to the light irradiator may be changed by the robot. Detection light with which the substrate is irradiated by the light irradiator may be line-shaped detection light extending along a direction intersecting a moving direction in a change of a relative position of the substrate with respect to the light irradiator, and line-shaped detection light extending along a direction of a rotation axis of a rotational motion in a change of a relative angle of the substrate with respect to the light irradiator.

[0079]

While the example in which the notch 101b indicating an orientation of the substrate 101 is detected by detecting a state of the substrate 101 has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, an orientation flat arranged on a substrate may be detected by detecting a state of the substrate.

[0080]

While the example in which a conveying operation of the robot 20 or 320 is corrected so as to correct a deviation of at least one of a position or an orientation of the substrate 101 detected based on a detected state of the substrate 101, and an operation of the aligner 30 as an adjustment device is controlled based on the detected state of the substrate 101 has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, a conveying operation of the robot may be corrected based on a detected state of a substrate so as to correct a deviation of at least one of a position or an orientation of the substrate. That is, the conveying operation of the robot may be corrected based on the detected state of the substrate so as to correct a deviation of the orientation of the substrate. For example, when an orientation of the substrate held by the substrate holding hand is different from a predetermined orientation that is set in advance, an operation of the robot may be corrected based on the detected state of the substrate so that the substrate is conveyed to the predetermined orientation. Also, when an operation of the aligner as an adjustment device is controlled based on the detected state of the substrate, the adjustment device may perform only an adjustment operation of a position in a

rotational direction of the substrate without detecting the orientation of the substrate. Also, when the operation of the aligner as the adjustment device is controlled based on the detected state of the substrate, a notch or an orientation flat indicating the orientation of the substrate may be detected as the state of the substrate based on each of captured images of detection light, and a rotational direction of the substrate in the aligner may be set in accordance with a position of the detected notch or orientation flat. In this case, since the substrate placed on the aligner can be rotated in a direction close to the notch or the orientation flat in the aligner, a time required for an operation for detecting the orientation of the substrate in the aligner can be shortened.

[0081]

While the example in which the robot 20 or 320 including the horizontal multi-joint robot arm 21 or 321 is provided has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, a robot arm including a vertical multi-joint robot arm instead of the horizontal multi-joint robot arm may be provided. In addition, the robot may include a linear movement mechanism such as a slide mechanism. In addition, the

substrate holding hand may be an active-type hand that fixes and holds a substrate by vacuum or a chuck. In addition, detection light reflected on each of main surfaces on both sides of a substrate may be captured by rotating the substrate so as to be inclined with respect to a horizontal plane while a position of the substrate is fixed.

[0082]

While the example in which the substrate-conveying robot system 100 according to the present disclosure is an EFEM that conveys the substrate 101 to the processing device 401 has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, the substrate-conveying robot system may be other than an EFEM. For example, the substrate-conveying robot system may be a stocker or a sorter that conveys a substrate from a substrate storage container to a substrate storage container. Also, the substrate-conveying robot system may convey a substrate that has been conveyed by a belt conveyor or the like, instead of a substrate storage container, to a substrate storage container or a substrate placement portion. Also, detection of a state of a substrate according to the present disclosure may be applied to a system that conveys a substrate on a

processing device side. That is, when conveying a substrate between a load lock and a processing module, a state of the substrate may be detected by the substrate detection method according to the present disclosure.

[0083]

While the example in which the controller 60, 260, or 360 of the substrate-conveying robot system 100 executes generation of the learned model 62, detection of an abnormality of the substrate 101 based on each of captured images 71 and 72, and control of operations of the robot 20 or 320 has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, at least one of generation of a learned model or control of an operation of a robot may be executed by a control device different from a controller that performs detection of an abnormality of a substrate based on each of captured images. For example, generation of the learned model may be executed by a control device that is arranged separately from the robot. That is, a learned model may be generated by performing machine learning by a control device that is arranged separately from the substrate-conveying robot system such as an EFEM. Also, a controller that executes detection of a state of a substrate based on each of captured images may be arranged

separately from a robot controller that controls an operation of the robot.

[0084]

While the example in which the image capturer 40 and the light irradiators 50, 250, or 350 are arranged inside the transfer chamber 10 has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, any one of a marker member, the image capturer, and the light irradiator may be arranged outside the transfer chamber in which a substrate is conveyed. For example, when an abnormality of a substrate is detected in the transfer chamber of a processing device that performs processing on the substrate, a ceiling portion of the transfer chamber of the processing device may be formed of a transparent member such as glass, and the marker member, the image capturer, and the light irradiator may be arranged above and outside the transfer chamber.

[0085]

While the example in which the light irradiator 50, 250 or 350 irradiates a substrate with detection light L1, L11, L12, or L21 at a timing at which image capturing is performed by the image capturer 40 has been shown in the aforementioned first, second and third embodiments, the

present disclosure is not limited to this. In the present disclosure, the light irradiator may continuously irradiate a substrate with illumination light. Also, irradiation with the illumination light may be controlled by control processing performed by a controller based on a captured image. For example, the control processing may be performed to change a light amount, a wavelength, or the like of the illumination light based on a luminance value or the like of the captured image. Also, when an abnormality of a substrate is detected, detection of an abnormality of the substrate using the learned model may be performed again by controlling the illumination light and capturing a captured image again in a state in which a light amount, a wavelength, or the like of the illumination light is changed. Also, an illuminator that irradiates a substrate with illumination light may be arranged separately from the light irradiator in the transfer chamber.

[0086]

While the example in which the light irradiator 50, 250, or 350 including LEDs that emit red light as detection light L1, L11, L12, or L21 is provided has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, the light irradiator may

include a light source other than LEDs. Also, illumination light by the light irradiator may have a wavelength of a predetermined color other than red. Also, the illumination light may be light having a wavelength other than visible light, such as infrared light. Also, the number of light irradiators may be one or may be three or more.

[0087]

While the example in which three FOUPs 110 as substrate storage containers are attached to the transfer chamber 10 of the substrate-conveying robot systems 100, 200, or 300, and three image capturers 40 and three light irradiators 50, 250, and 350 are arranged so as to correspond to the FOUPs 110 has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, the number of substrate storage containers attached to the transfer chamber may be two or less, or may be four or more. Also, one image capturer and one light irradiator may be arranged for a plurality of substrate storage containers. In this case, a common image capturer may capture images of substrates conveyed to the plurality of substrate storage containers. Also, the number of image capturers and the number of light irradiators may be different from each other.

[0088]

While the example in which the learned model 62 is generated by machine learning of deep learning using a fully convolutional network has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, machine learning for generating the learned model may be other than deep learning. Also, machine learning for generating the learned model may be machine learning using a convolutional neural network other than a fully convolutional network. Also, machine learning for generating the learned model may be machine learning other than machine learning using a convolutional neural network.

[0089]

While the example in which the substrate 101 is a silicon wafer having a disk shape has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, the substrate 101 may be made of a material other than silicon. Also, a state of a rectangular substrate on which electronic components are mounted, instead of a disk-shaped substrate, may be detected. In this case, a state of the substrate including an orientation and a position of the substrate may be

detected by detecting sides of the rectangular shape.

[0090]

While the example in which an abnormality of the substrate 101 is detected by using the learned model 62 that outputs an identification result 75 with captured images of detection lights L1, L11, L12, or L21 captured by the image capturer 40 as inputs has been shown in the aforementioned first, second and third embodiments, the present disclosure is not limited to this. In the present disclosure, image processing such as noise removal, edge enhancement, and contrast change may be performed in advance on captured images input to a learned model for detecting an abnormality of a substrate, before the captured images are input to the learned model.

[0091]

Functions of elements disclosed in this specification can be realized by a circuit or processing circuit including a general purpose processor, a dedicated processor, an integrated circuit, ASIC (Application Specific Integrated Circuits), a conventional circuit and/or combination of them configured or programmed to realize the disclosed functions. A processor is considered a processing circuit or circuits because it contains transistors and other circuitry. In the present disclosure, a circuit, a unit, or a means is hardware that

performs an enumerated function or is hardware programmed to perform an enumerated function. The hardware may be the hardware disclosed herein or any other known hardware that is programmed or configured to perform the enumerated functions. If the hardware is a processor, which is considered a type of circuit, the circuit, means, or unit is a combination of hardware and software, and software is used to configure the hardware and/or processor.

[0092]

[Embodiments]

The aforementioned exemplary embodiment will be understood as concrete examples of the following Embodiments by those skilled in the art.

[0093]

(Embodiment 1)

A substrate-conveying robot includes a robot that conveys a substrate; a light irradiator that irradiates a main surface of the substrate held by the robot with detection light having a predetermined shape; an image capturer that captures an image of the detection light reflected on the main surface of the substrate by capturing an image of the substrate; and a controller that detects a state of the substrate based on the captured image of the detection light captured by the image capturer.

[0094]

(Embodiment 2)

In the substrate-conveying robot system according to Embodiment 1, the light irradiator irradiates the main surface of the substrate with the detection light, while at least one of a relative position or a relative angle of the substrate relative to the light irradiator is changed; the image capturer captures, a plurality of times, the detection light reflected on the main surface of the substrate, in accordance with a change in at least one of a relative position or a relative angle of the substrate relative to the light irradiator; and the controller detects a state of the substrate based on one captured image generated by capturing the reflected detection light a plurality of times through a plurality of image capturing operations performed by the image capturer.

[0095]

(Embodiment 3)

In the substrate-conveying robot system according to Embodiment 2, the robot changes at least one of a position or an angle of the substrate relative to the light irradiator when an image capturing operation for capturing the detection light is performed by the image capturer.

[0096]

(Embodiment 4)

In the substrate-conveying robot system according to Embodiment 2 or 3, the light irradiator irradiates the main surface of the substrate with at least one of line-shaped detection light extending along a direction intersecting a moving direction in a change of a relative position of the substrate with respect to the light irradiator, or line-shaped detection light extending along a direction of a rotation axis of a rotational motion in a change of a relative angle of the substrate with respect to the light irradiator.

[0097]

(Embodiment 5)

In the substrate-conveying robot system according to Embodiment 3, the robot moves the substrate along a plurality of moving directions different from each other when image capturing operations for capturing the detection light are performed by the image capturer; and the controller detects a state of the substrate based on each of captured images obtained in respective movements of the substrate along the plurality of moving directions of the robot.

[0098]

(Embodiment 6)

In the substrate-conveying robot system according to Embodiment 3, the robot changes an angle of the substrate

with respect to a horizontal plane when an image capturing operation for capturing the detection light is performed by the image capturer.

[0099]

(Embodiment 7)

In the substrate-conveying robot system according to any of Embodiments 1 to 6, the controller detects a state of the substrate including at least one of a shape, a position, an orientation of the substrate, or an abnormality occurring in the substrate, based on the captured image.

[0100]

(Embodiment 8)

In the substrate-conveying robot system according to Embodiment 7, the controller detects a notch or an orientation flat indicating an orientation of the substrate by detecting a state of the substrate based on the captured image.

[0101]

(Embodiment 9)

In the substrate-conveying robot system according to any of Embodiments 1 to 8, the controller detects a state of the substrate based on the captured image captured by the image capturer, using a learned model generated by machine learning.

[0102]

(Embodiment 10)

In the substrate-conveying robot system according to any of Embodiments 2 to 6, the light irradiator irradiates the main surface of the substrate with the detection light including a first line-shaped detection light and a second line-shaped detection light different from each other; and the controller detects a state of the substrate based on the one captured image generated through the plurality of image capturing operations performed by the image capturer and including the first detection light and the second detection light.

[0103]

(Embodiment 11)

In the substrate-conveying robot system according to any of Embodiments 1 to 10, the robot is arranged in a transfer chamber in which the substrate is conveyed to and from a substrate storage container in which the substrate is stored; the light irradiator is arranged above the robot in the transfer chamber and irradiates the main surface of the substrate with the detection light; the image capturer is arranged above the robot in the transfer chamber and captures the detection light reflected on the main surface of the substrate; and the controller detects a state of the substrate based on the captured image

captured in the transfer chamber.

[0104]

(Embodiment 12)

In the substrate-conveying robot system according to any of Embodiments 1 to 11, an adjustment device that adjusts an orientation of the substrate to a predetermined orientation is further provided; and the controller controls an operation of the adjustment device using the state of the substrate detected based on the captured image.

[0105]

(Embodiment 13)

In the substrate-conveying robot system according to any of Embodiments 1 to 12, the robot includes a substrate holding hand that holds the substrate; and the controller serves as a robot controller that controls a conveying operation of the robot, detects, based on the detected state of the substrate, a deviation in at least one of a position or an orientation of the substrate with respect to the substrate holding hand, and corrects, in the conveying operation of the robot, the detected deviation in at least one of a position or an orientation of the substrate.

[0106]

(Embodiment 14)

A substrate detection method includes capturing, by capturing an image of a substrate held by a robot that conveys the substrate, detection light having a predetermined shape reflected on a main surface of the substrate; and detecting a state of the substrate based on the captured image of the detection light that has been captured.

CLAIMS

[Claim 1]

A substrate-conveying robot system comprising:

 a robot that conveys a substrate;

 a light irradiator that irradiates a main surface of the substrate held by the robot with detection light having a predetermined shape;

 an image capturer that captures an image of the detection light reflected on the main surface of the substrate by capturing an image of the substrate; and

 a controller that detects a state of the substrate based on the captured image of the detection light captured by the image capturer.

[Claim 2]

The substrate-conveying robot system according to claim 1, wherein

 the light irradiator irradiates the main surface of the substrate with the detection light, while at least one of a relative position or a relative angle of the substrate relative to the light irradiator is changed;

 the image capturer captures, a plurality of times, the detection light reflected on the main surface of the substrate, in accordance with a change in at least one of

a relative position or a relative angle of the substrate relative to the light irradiator; and

the controller detects a state of the substrate based on one captured image generated by capturing the reflected detection light a plurality of times through a plurality of image capturing operations performed by the image capturer.

[Claim 3]

The substrate-conveying robot system according to claim 2, wherein the robot changes at least one of a position or an angle of the substrate relative to the light irradiator when an image capturing operation for capturing the detection light is performed by the image capturer.

[Claim 4]

The substrate-conveying robot system according to claim 2, wherein the light irradiator irradiates the main surface of the substrate with at least one of line-shaped detection light extending along a direction intersecting a moving direction in a change of a relative position of the substrate with respect to the light irradiator, or line-shaped detection light extending along a direction of a rotation axis of a rotational motion in a change of a relative angle of the substrate with respect to the light

irradiator.

[Claim 5]

The substrate-conveying robot system according to claim 3, wherein

the robot moves the substrate along a plurality of moving directions different from each other when image capturing operations for capturing the detection light are performed by the image capturer; and

the controller detects a state of the substrate based on each of captured images obtained in respective movements of the substrate along the plurality of moving directions of the robot.

[Claim 6]

The substrate-conveying robot system according to claim 3, wherein the robot changes an angle of the substrate with respect to a horizontal plane when an image capturing operation for capturing the detection light is performed by the image capturer.

[Claim 7]

The substrate-conveying robot system according to claim 1, wherein the controller detects a state of the substrate including at least one of a shape, a position, an

orientation of the substrate, or an abnormality occurring in the substrate, based on the captured image.

[Claim 8]

The substrate-conveying robot system according to claim 7, wherein the controller detects a notch or an orientation flat indicating an orientation of the substrate by detecting a state of the substrate based on the captured image.

[Claim 9]

The substrate-conveying robot system according to claim 1, wherein the controller detects a state of the substrate based on the captured image captured by the image capturer, using a learned model generated by machine learning.

[Claim 10]

The substrate-conveying robot system according to claim 2, wherein

the light irradiator irradiates the main surface of the substrate with the detection light including a first line-shaped detection light and a second line-shaped detection light different from each other; and

the controller detects a state of the substrate

based on the one captured image generated through the plurality of image capturing operations performed by the image capturer and including the first detection light and the second detection light.

[Claim 11]

The substrate-conveying robot system according to claim 1, wherein

the robot is arranged in a transfer chamber in which the substrate is conveyed to and from a substrate storage container in which the substrate is stored;

the light irradiator is arranged above the robot in the transfer chamber and irradiates the main surface of the substrate with the detection light;

the image capturer is arranged above the robot in the transfer chamber and captures the detection light reflected on the main surface of the substrate; and

the controller detects a state of the substrate based on the captured image captured in the transfer chamber.

[Claim 12]

The substrate-conveying robot system according to claim 1 further comprising an adjustment device that adjusts an orientation of the substrate to a predetermined

orientation, wherein

the controller controls an operation of the adjustment device using the state of the substrate detected based on the captured image.

[Claim 13]

The substrate-conveying robot system according to claim 1, wherein

the robot includes a substrate holding hand that holds the substrate; and
the controller serves as a robot controller that controls a conveying operation of the robot,

detects, based on the detected state of the substrate, a deviation in at least one of a position or an orientation of the substrate with respect to the substrate holding hand, and

corrects, in the conveying operation of the robot, the detected deviation in at least one of a position or an orientation of the substrate.

[Claim 14]

A substrate detection method comprising:

capturing, by capturing an image of a substrate held by a robot that conveys the substrate, detection light having a predetermined shape reflected on a main surface

of the substrate; and

detecting a state of the substrate based on the captured image of the detection light that has been captured.