

Description

TITLE OF THE INVENTION

Image Processing Method, Image Processing Device and
Surface Inspection Device Using the Image Processing Device

5 TECHNICAL FIELD

[0001]

The present invention relates to an image processing
method and an image processing device for processing an
image including an object surface image represented by
10 pixel-based gray values, and a surface inspection device
using the image processing device.

BACKGROUND ART

[0002]

There has been proposed a surface inspection device
15 for capturing an image of a surface of an object and
inspecting defects on the object surface based on an
obtained image (see patent literature 1). In this surface
inspection device, a surface of an inspected specimen such
as a semiconductor wafer, a liquid crystal glass substrate
20 or the like is scanned by a line sensor and a two-
dimensional surface image of an inspected specimen is
generated based on an imaging signal output from the line
sensor. Respective parts of the surface image are processed
and defects of the specimen surface (thickness unevenness,
25 pattern defect, etc.) are detected based on a state of
shading in the surface image having the respective parts
processed.

PRIOR ART DOCUMENTS

PATENT LITERATURE

30 [0003]

Patent Literature 1

Japanese Unexamined Patent Publication No. 2007-147441

SUMMARY OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

35 [0004]

A filtering process may be performed to emphasize

shading of defect parts in an object surface image as a process performed on the object surface image in a surface inspection device as described above. This filtering process is for emphasizing a gray value of each target pixel in view of gray values of surrounding pixels. In other words, a two-dimensional image processing for successively processing the gray values of a plurality of two-dimensionally arranged pixels (target pixel and its surrounding pixels) is performed on the object surface image.

10 [0005]

However, since the gray value suddenly changes between an inner side of an edge line (edge image) and an outer side of the edge line (background image) in an edge part of the object surface image, a properly processed image cannot be obtained in an area of the edge line by the two-dimensional image processing.

[0006]

The present invention was developed in view of such a situation and aims to provide an image processing method and an image processing device capable of obtaining a properly processed image in an area of an edge part of an object surface image, and a surface inspection device using the image processing device.

MEANS FOR SOLVING PROBLEM

25 [0007]

The present invention is directed to an image processing method, comprising an image obtaining step of obtaining an image to be processed represented by pixel-based gray values and including an object surface image; an edge image specifying step of specifying an image including an edge line of the object surface image set in the image to be processed and located in an area with a predetermined width in a direction orthogonal to the edge line as an edge image; a conversion step of converting the edge image into a rectangular image with a width equivalent to the predetermined width; and an image processing step of

performing a one-dimensional image processing on the rectangular image to successively process the gray values of a plurality of pixels arranged in a direction orthogonal to a width direction of the rectangular image.

5 [0008]

By this construction, the edge image including the edge line of the object surface image set in the image to be processed and located in the area with the predetermined width in the direction orthogonal to the edge line is converted into the rectangular image with the width equivalent to the predetermined width, and the one-dimensional image processing is performed on the rectangular image to successively process the gray values of the plurality of pixels arranged in the direction orthogonal to the width of the rectangular image. Since the gray values of the plurality of pixels arranged in the direction orthogonal to the width direction of the rectangular image are successively processed in the one-dimensional image processing performed on the rectangular image, the rectangular image is successively processed in the direction along a straight line corresponding to the edge line of the object surface image.

[0009]

The image processing method according to the present invention may further comprise an inverse conversion step of generating a processed edge image by inversely converting the rectangular image having the one-dimensional image processing performed thereon into an image in the original area.

30 [0010]

By this construction, the processed edge image is generated by inversely converting the rectangular image having the one-dimensional image processing performed thereon into the image in the original area. Since the one-dimensional image processing is performed on the rectangular image in the direction along the straight line corresponding

to the edge line of the object surface image as described above, the processed edge image obtained by inversely converting the rectangular image having the one-dimensional image processing performed thereon is substantially an image
5 obtained by performing an image processing along the edge line of the object surface image.

[0011]

In the image processing method according to the present invention, an image in an area with a first
10 predetermined width in an inward direction of the object surface image from the edge line and a second predetermined width in an outward direction of the object surface image from the edge line may be specified as the edge image in the edge image specifying step.

15 [0012]

By this construction, the image in the area invariably including the edge of the object surface image can be specified as the edge image even if the edge line precisely matching the edge of the object surface image is not set in
20 the image to be processed.

[0013]

In the image processing method according to the present invention, the conversion step may include a position conversion step of obtaining a position in the edge
25 image corresponding to each pixel of the rectangular image; and a step of determining the gray value of the pixel of the rectangular image corresponding to each obtained position in the edge image based on the gray values of respective pixels in the edge image.

30 [0014]

By this construction, the position in the edge image corresponding to each pixel constituting the rectangular image is obtained and the gray value of the pixel of the rectangular image corresponding to each obtained position in
35 the edge image is determined based on the gray values of the respective pixels in the edge image.

[0015]

If the position in the edge image corresponding to the pixel of the rectangular image matches a pixel position of the edge image, the gray value of the pixel of the rectangular image can be determined as the gray value of the corresponding pixel of the edge image. Further, if the position in the edge image corresponding to the pixel of the rectangular image deviates from the pixel position of the edge image, the gray value of the pixel of the rectangular image can be determined, for example, by an interpolation process based on the gray values of pixels surrounding the corresponding position in the edge image.

[0016]

In the image processing method according to the present invention, a conversion table indicating the positions of the edge image corresponding to the respective pixels of the rectangular image may be generated beforehand; and the positions in the edge image corresponding to the respective pixels of the rectangular image may be obtained using the conversion table in the position conversion step.

[0017]

By this construction, the positions in the edge image corresponding to the respective pixels in the rectangular image can be more quickly obtained since the positions in the edge image corresponding to the respective pixels in the rectangular image are determined using the conversion table.

[0018]

In the image processing method according to the present invention, the inverse conversion step may include a position inverse conversion step of obtaining a position in the rectangular image corresponding to each pixel in the image in the original area; and a step of generating the processed edge image by determining gray values of the pixels in the image in the original area corresponding to the obtained respective positions in the rectangular image based on the gray values of the respective pixels in the

rectangular image having the one-dimensional image processing performed thereon.

[0019]

By this construction, the positions in the rectangular
5 image corresponding to the respective pixels constituting
the image in the original area are obtained and the gray
values of the pixels of the image in the original area
corresponding to the obtained respective positions in the
rectangular image are determined based on the gray values of
10 the respective pixels in the rectangular image having the
one-dimensional image processing performed thereon. The
processed edge image is generated which is represented by
the thus determined gray values of the respective pixels of
the image in the original area.

15 [0020]

If the position in the rectangular image corresponding
to the pixel of the image in the original area matches a
pixel position of the rectangular image, the gray value of
the pixel of the image in the original area can be
20 determined as the gray value of the corresponding pixel of
the rectangular image. Further, if the position in the
rectangular image corresponding to the pixel of the image in
the original area deviates from the pixel position of the
rectangular image, the gray value of the pixel of the image
25 in the original area can be determined, for example, by an
interpolation process based on the gray values of pixels
surrounding the corresponding position of the rectangular
image.

[0021]

30 In the image processing method according to the
present invention, an inverse conversion table indicating
the positions in the rectangular image corresponding to the
respective pixels of the image in the original area may be
generated beforehand; and the positions in the rectangular
35 image corresponding to the respective pixels of the image in
the original image may be obtained using the inverse

conversion table in the position inverse conversion step.

[0022]

By this construction, the positions in the rectangular image corresponding to the respective pixels in the image in the original area can be more quickly obtained since the positions in the rectangular image corresponding to the respective pixels in the image in the original area are determined using the inverse conversion table.

[0023]

10 In the image processing method according to the present invention, an image including a surface image of a disk-shaped semiconductor wafer may be obtained as the image to be processed in the image obtaining step; an entire or partial image in a ring-shaped area with a predetermined width in a direction orthogonal to a circular line along an edge of the semiconductor wafer surface image may be specified as the edge image in the edge image specifying step; and the processed edge image may be generated by inversely converting the rectangular image having the one-dimensional image processing performed thereon into an entire or partial image in the original ring-shaped area in the inverse conversion step.

[0024]

By this construction, it is possible to obtain a processed edge image by successively performing an image processing on an entire or partial image in a ring-shaped area, which is set along an edge of a semiconductor wafer surface image in the image to be processed and includes a circular line, substantially in a direction along the circular line.

[0025]

In the image processing method according to the present invention, an entire or partial image in a ring-shaped area with a first predetermined width at an inner side of the circular line and a second predetermined width at an outer side of the circular line is specified as the

edge image in the edge image specifying step.

[0026]

By this construction, an entire or partial image in a ring-shaped area invariably including the edge of the semiconductor wafer surface image can be specified as an edge image even if a circular line precisely matching the edge of the semiconductor wafer surface image is not set.

[0027]

In the image processing method according to the present invention, in the conversion step, the edge image may be converted into a rectangular image composed of pixels in a rectangular array corresponding to respective positions set at predetermined intervals along one of two partition lines at the opposite sides of and parallel to the edge line of the object image of the edge image and respective positions set at predetermined intervals along normal lines orthogonal to the partition lines from the respective positions up to the other partition line.

[0028]

By this construction, it is possible to obtain a rectangular image in which respective pixels in a rectangular array correspond to positions in an edge image partitioned by two partition lines at the opposite sides of and parallel to an edge line of an object image.

[0029]

In the image processing method according to the present invention, in the conversion step, the edge image may be converted into a rectangular image composed of pixels in a rectangular array corresponding to respective positions set at predetermined intervals along the longer one of the two partition lines at the opposite sides of and parallel to the edge line of the object image of the edge image and respective positions set at predetermined intervals along normal lines orthogonal to the partition lines from the respective positions up to the shorter partition line.

[0030]

By this construction, more positions can be set in the edge image since the respective positions in the edge image are set based on the respective positions set at the predetermined intervals along the longer one of the two partition lines partitioning the edge image. As a result, conversion into a rectangular image composed of more pixels is possible.

[0031]

In the image processing method according to the present invention, a conversion table relating the respective positions along the partition line in the edge image and pixels in one row of the rectangular image corresponding to each of all the positions set on the normal lines passing through the respective positions may be generated beforehand; and the positions in the edge image corresponding to the respective pixels of the rectangular image may be determined using the conversion table in the conversion step.

[0032]

By this construction, a small-sized conversion table can be constructed since the conversion table does not relate all the respective positions in the edge image and the pixels of the rectangular image, but relates the respective positions along the one partition line in the edge image and the pixels in one row of the rectangular image corresponding to each of all the positions set on the normal lines passing through these positions. As a result, the capacity of a memory for storing the conversion table can be reduced.

[0033]

The present invention is also directed to an image processing method, comprising an image obtaining step of obtaining an image to be processed partitioned by two parallel partition lines; and a conversion step of converting the image to be processed into a rectangular image composed of pixels in a rectangular array

corresponding to respective positions set at predetermined intervals along one of the two parallel partition lines of the image to be processed and respective positions set at predetermined intervals along normal lines orthogonal to the
5 partition lines from the respective positions up to the other partition line.

[0034]

By this construction, an image to be processed partitioned by two parallel partition lines can be converted
10 into a rectangular image in which pixels are arranged in a rectangular array.

[0035]

In the image processing method according to the present invention, a conversion table relating the
15 respective positions along the partition line in the image to be processed and pixels in one row of the rectangular image corresponding to each of all the positions set on the normal lines passing through the respective positions may be generated beforehand; and the positions in the image to be
20 processed corresponding to the respective pixels of the rectangular image may be determined using the conversion table in the conversion step.

[0036]

By this construction, a small-sized conversion table
25 can be constructed since the conversion table does not relate all the respective positions in the edge image and the pixels of the rectangular image, but relates the respective positions along the one partition line in the edge image and the pixels in one row of the rectangular
30 image corresponding to each of all the positions set on the normal lines passing through these positions. As a result, the capacity of a memory for storing the conversion table can be reduced.

[0037]

35 The present invention is further directed to an image processing device, comprising an image capturing unit for

capturing an image of a surface of an object; and a processing unit for processing a captured image obtained by the image capturing unit, wherein the processing unit includes image obtaining means for obtaining an image to be
5 processed represented by pixel-based gray values and including a surface image of the object; edge image specifying means for specifying an image including an edge line of the object surface image set in the image to be processed and located in an area with a predetermined width
10 in a direction orthogonal to the edge line as an edge image; conversion means for converting the edge image into a rectangular image with a width equivalent to the predetermined width; and image processing means for performing a one-dimensional image processing on the
15 rectangular image to successively process the gray values of a plurality of pixels arranged in a direction orthogonal to a width direction of the rectangular image.

[0038]

By this construction, a processing unit converts the
20 edge image including the edge line of the object surface image set in the image to be processed and located in the area with the predetermined width in the direction orthogonal to the edge line into the rectangular image with the width equivalent to the predetermined width, and
25 performs the one-dimensional image processing on the rectangular image to successively process the gray values of the plurality of pixels arranged in the direction orthogonal to the width of the rectangular image. Since the gray values of the plurality of pixels arranged in the direction
30 orthogonal to the width direction of the rectangular image are successively processed in the one-dimensional image processing performed on the rectangular image, the rectangular image is successively processed in the direction along a straight line corresponding to the edge line of the
35 object surface image.

[0039]

The image processing device according to the present invention may further comprise inverse conversion means for generating a processed edge image by inversely converting the rectangular image having the one-dimensional image processing performed thereon into an image in the original area.

[0040]

By this construction, the processed edge image is generated by inversely converting the rectangular image that the one-dimensional image processing has been performed into the image in the original area. Since the one-dimensional image processing is performed on the rectangular image in the direction along the straight line corresponding to the edge line set in the object surface image as described above, the processed edge image obtained by inversely converting the rectangular image that the one-dimensional image processing has been performed is substantially an image obtained by performing an image processing along the edge line of the object surface image.

[0041]

In the image processing device according to the present invention, the conversion means may include position conversion means for obtaining a position in the edge image corresponding to each pixel of the rectangular image; and means for determining the gray value of the pixel of the rectangular image corresponding to each obtained position in the edge image based on the gray values of respective pixels in the edge image.

[0042]

By this construction, the processing unit obtains the position in the edge image corresponding to each pixel constituting the rectangular image and determines the gray value of the pixel of the rectangular image corresponding to each obtained position in the edge image based on the gray values of the respective pixels in the edge image.

[0043]

The image processing device according to the present invention may further comprise a storage unit for storing a conversion table indicating the positions in the edge image corresponding to the respective pixels of the rectangular
5 image; and the position conversion means may obtain the positions in the edge image corresponding to the respective pixels of the rectangular image using the conversion table.
[0044]

By this construction, the positions in the edge image
10 corresponding to the respective pixels in the rectangular image can be more quickly obtained in the processing unit since the processing unit obtains the positions in the edge image corresponding to the respective pixels in the rectangular image using the conversion table stored in the
15 storage unit.
[0045]

In the image processing device according to the present invention, the image capturing unit may capture an image of a surface of a disk-shaped semiconductor wafer; the
20 image obtaining means may obtain an image including a surface image of the semiconductor wafer as the image to be processed; the edge image specifying means may specify an entire or partial image in a ring-shaped area with a predetermined width in a direction orthogonal to a circular
25 line along an edge of the semiconductor wafer surface image as the edge image; and the inverse conversion means may generate a processed edge image by inversely converting the rectangular image that the one-dimensional image processing has been performed into an entire or partial image in the
30 original ring-shaped area.
[0046]

By this construction, the processing unit can obtain a processed edge image by successively performing an image processing on an entire or partial image in a ring-shaped
35 area, which is set along an edge of a disk-shaped semiconductor wafer surface image and includes a circular

line, substantially in a direction along the circular line.
[0047]

In the image processing device according to the present invention, the edge image specifying means may
5 specify an entire or partial image in a ring-shaped area with a first predetermined width at an inner side of the circular line and a second predetermined width at an outer side of the circular line as the edge image.
[0048]

10 By this construction, even if a circular line precisely matching an edge of a semiconductor wafer surface image is not set, the processing unit can specify an entire or partial image in a ring-shaped area invariably including the edge of the semiconductor wafer surface image as an edge
15 image.
[0049]

The present invention is further directed to an image processing device, comprising an image capturing unit for capturing an image of a surface of an object; and a
20 processing unit for processing a captured image obtained by the image capturing unit, wherein the processing unit includes image obtaining means for obtaining an image to be processed partitioned by two parallel partition lines from the captured image; and conversion means for converting the
25 image to be processed into a rectangular image composed of pixels in a rectangular array corresponding to respective positions set at predetermined intervals along one of the two partition lines of the image to be processed and respective positions set at predetermined intervals along
30 normal lines orthogonal to the partition lines from the respective positions up to the other partition line.
[0050]

The image processing device according to the present invention may further comprise a storage unit for storing a
35 conversion table relating the respective positions along the partition line in the image to be processed and pixels in

one row of the rectangular image corresponding to each of all the positions set on the normal lines passing through the respective positions; and the conversion means may include a means for determining the positions in the image to be processed corresponding to the respective pixels of the rectangular image using the conversion table.

[0051]

By this construction, a small-sized conversion table can be constructed since the conversion table does not relate all the respective positions in the edge image and the pixels of the rectangular image, but relates the respective positions along the one partition line in the edge image and the pixels in one row of the rectangular image corresponding to each of all the positions set on the normal lines passing through these positions. As a result, the capacity of the storage unit for storing the conversion table can be reduced.

[0052]

The present invention is further directed to a surface inspection device, comprising an image capturing unit for capturing an image of a surface of an object; and a processing unit for detecting a defect on the object surface by processing a captured image obtained by the image capturing unit, wherein the processing unit includes image obtaining means for obtaining an image to be processed represented by pixel-based gray values and including a surface image of the object; edge image specifying means for specifying an image including an edge line of the object surface image set in the image to be processed and located in an area with a predetermined width in a direction orthogonal to the edge line as an edge image; conversion means for converting the edge image into a rectangular image with a width equivalent to the predetermined width; first image processing means for performing a one-dimensional image processing on the rectangular image to successively process the gray values of a plurality of pixels arranged in

a direction orthogonal to a width direction of the rectangular image; inverse conversion means for generating a processed edge image by inversely converting the rectangular image that the one-dimensional image processing has been
5 performed into an image in the original area; second image processing means for generating a processed main image by performing a two-dimensional image processing on a main image obtained by excluding the edge image from the object surface image to successively process the gray values of a
10 plurality of two-dimensionally arranged pixels; and defect specifying means for specifying a defect part in the processed edge image and the processed main image.

[0053]

By this construction, a processing unit converts the
15 edge image including the edge line of the object surface image set in the image to be processed and located in the area with the predetermined width in the direction orthogonal to the edge line into the rectangular image with the width equivalent to the predetermined width, and
20 performs the one-dimensional image processing on the rectangular image to successively process the gray values of the plurality of pixels arranged in the direction orthogonal to the width of the rectangular image. Since the gray values of the plurality of pixels arranged in the direction
25 orthogonal to the width direction of the rectangular image are successively processed in the one-dimensional image processing performed on the rectangular image, the rectangular image is successively processed in the direction along a straight line corresponding to the edge line of the
30 object surface image.

[0054]

Then, the processing unit generates the processed edge image by inversely converting the rectangular image that the one-dimensional image processing has been performed into the
35 image in the original area. Since the one-dimensional image processing performed on the rectangular image is processed

in the direction along the straight line in the rectangular image corresponding to the edge line of the object surface image as described above, the processed edge image obtained by inversely converting the rectangular image that the one-dimensional image processing has been performed is substantially an image successively processed in the direction along the edge line of the object surface image. [0055]

Further, the processing unit generates the processed main image by performing the two-dimensional image processing on the main image obtained by excluding the edge image from the object surface image to successively process the gray values of the plurality of two-dimensionally arranged pixels, and specifies the defect part in the processed edge image and the processed main image. [0056]

As described above, since the defect part is specified with the edge image and the main image of the object surface image already processed, defect parts can be more accurately inspected over the entire object surface. [0057]

In the surface inspection device according to the present invention and according to claim 14 for capturing an image of a surface of a disk-shaped semiconductor wafer by the image capturing unit and detecting a defect on the semiconductor wafer surface by the processing unit, the image obtaining means may obtain an image including a surface image of the semiconductor wafer as the image to be processed; the edge image specifying means may specify an entire or partial image in a ring-shaped area with a predetermined width in a direction orthogonal to a circular line along an edge of the semiconductor wafer surface image as the edge image; the inverse conversion means may generate a processed edge image by inversely converting the rectangular image that the one-dimensional image processing has been performed into an entire or partial image in the

original ring-shaped area; and the second image processing means may generate a processed main image by performing the two-dimensional image processing on the main image obtained by excluding the edge image from the semiconductor wafer
5 surface image.

[0058]

By this construction, defect parts are specified both in the processed edge image obtained by successively performing the image processing in the direction
10 substantially along the circular line on the entire or partial image in the ring-shaped area including the circular line set along the edge of the disk-shaped semiconductor wafer surface image and in the processed main image obtained by performing the two-dimensional image processing on the
15 main image obtained by excluding the edge image from the semiconductor wafer surface image. Thus, defect parts can be more accurately inspected over the entire surface of the semiconductor wafer.

EFFECTS OF THE INVENTION

20 [0059]

According to the image processing methods and devices of the present invention, an edge image including an edge line of an object surface image specified in an image to be processed is converted into a rectangular image and a one-
25 dimensional image processing is performed on this rectangular image. Since gray values of a plurality of pixels arranged in a direction orthogonal to a width direction of the rectangular image are successively processed in the one-dimensional image processing on the
30 rectangular image, the rectangular image that the one-dimensional image processing has been performed corresponds to an image obtained by successively performing an image processing in a direction along the edge line of the object surface image. By inversely converting the processed
35 rectangular image, it is possible to easily obtain an image that the image processing has been properly performed in the

area of the edge part of the object surface image.

BRIEF DESCRIPTION OF DRAWINGS

[0060]

FIG. 1 is a side view showing the structure of a
5 mechanism unit in a surface inspection device for
semiconductor wafers,

FIG. 2 is a front view showing the structure of the
mechanism unit in the surface inspection device for
semiconductor wafers,

10 FIG. 3 is a diagram showing a state of scanning a
semiconductor wafer surface by a camera unit (CCD line
sensor),

FIG. 4 is a block diagram showing a control system in
the surface inspection device for semiconductor wafers,

15 FIG. 5 is a flow chart showing the procedure of a
registration process,

FIG. 6A is a diagram showing an example of a captured
image,

20 FIG. 6B is a diagram showing an example of a position-
corrected captured image,

FIG. 6C is a diagram showing a state where a circular
line is set on an edge of a wafer surface image in a
captured image,

25 FIG. 7 is a diagram showing a ring-shaped area
including an edge line of the wafer surface image set in the
captured image,

FIG. 8 is a diagram showing a pixel configuration of a
rectangular image into which an image in the ring-shaped
area (edge image) should be converted,

30 FIG. 9 is a diagram showing a relationship between the
edge image specified in the captured image and the
rectangular image obtained by converting the edge image,

FIG. 10A is a diagram showing the edge image in a
state where a normal line NL is set at an arbitrary angle
35 position θ ,

FIG. 10B is a diagram enlargedly showing an angle

range of 0° to 90° of FIG. 10A,

FIG. 11A is a diagram enlargedly showing positions set on the outer peripheral edge of the edge image,

FIG. 11B is a diagram showing positions set on the
5 normal line NL,

FIG. 12 is a diagram enlargedly showing the positions set on the normal line NL,

FIG. 13 is tables showing a relationship between respective pixels of the rectangular image and positions of
10 the edge image,

FIG. 14 is a table showing an example of information contents of a conversion table,

FIG. 15 is a diagram showing a relationship between the rectangular image and an image in a ring-shaped area
15 (edge image) obtained by inversely converting the rectangular image,

FIG. 16 is a flow chart showing the procedure of an inspection process,

FIG. 17A is a diagram showing an example of a captured
20 image of a semiconductor wafer to be inspected,

FIG. 17B is a diagram showing an example of a position-corrected captured image,

FIG. 18 is a diagram showing a relationship between an edge image specified in the captured image and a rectangular
25 image obtained by converting the edge image,

FIG. 19 is a diagram showing a rectangular image before a one-dimensional image processing and a rectangular image after the one-dimensional image processing,

FIG. 20 is a diagram showing a relationship between
30 the processed rectangular image and a processed edge image obtained by inversely converting the processed rectangular image, and

FIG. 21 is a diagram showing an example of a wafer surface image showing detected defects.

35 **MODE FOR CARRYING OUT THE INVENTION**

[0061]

Hereinafter, an embodiment of the present invention is described with reference to the drawings.

[0062]

An image processing device in which an image
5 processing in accordance with an image processing method according to the present invention is performed is, for example, constructed in a surface inspection device for semiconductor wafers. A mechanism unit of this surface inspection device is constructed as shown in FIGS. 1 and 2.
10 Note that FIGS. 1 and 2 are a side view and a front view showing the construction of this mechanism unit.

[0063]

In FIGS. 1 and 2, this surface inspection device includes a base 50, and a carriage 60 and a shifting
15 mechanism 70 are provided in the base 50 (particularly see FIG. 1). The shifting mechanism 70 includes a stage 71 and the carriage 60 can move back and forth (movements in a lateral direction in FIG. 1, direction perpendicular to the plane of FIG. 2)) on the stage 71 by self-running. The
20 shifting mechanism 70 also includes a driving unit 72 with a motor, a gear mechanism and the like, and the stage 71 is made movable in a direction (lateral direction in FIG. 2, direction orthogonal to the plane of FIG. 1) orthogonal to a moving direction of the carriage 60 by self-running by this
25 driving unit 72.

[0064]

The carriage 60 is provided with a supporting mechanism 20 for supporting a semiconductor wafer (hereinafter, merely referred to as a wafer) 10 to be
30 inspected, and this supporting mechanism 20 projects from the upper surface of the base 50. The supporting mechanism 20 includes a circular table 21 on which the wafer 10 is to be set, and two supporting legs 22a, 22b which are arranged in a direction orthogonal to the moving direction of the
35 carriage 60 and support the table 21. These supporting legs 22a, 22b are fixed to the carriage 60. Although not shown, a

guiding mechanism for guiding the supporting legs 22a, 22b in the moving direction when the carriage 60 autonomously moves and a shift guiding mechanism for guiding the supporting legs 22a, 22b in a direction orthogonal to a self-running direction of the carriage 60 when the carriage 60 is shifted in this direction by the shifting mechanism 70 are provided on the upper surface of the base 50.

[0065]

An arched frame 55 is provided substantially in a central part of the upper surface of the base 50 in the self-running direction of the carriage 60. A camera unit 30 faced downward is disposed substantially in a central part of this frame 55. Further, an illumination unit 31 is disposed near the disposed position of the camera unit 30 on the frame 55. The illumination unit 31 illuminates a surface of the wafer 10 supported on the supporting mechanism 20 moving below the frame 55.

[0066]

The camera unit 30 includes a line sensor (e.g. linear CCD image sensor) and captures an image of the surface of the wafer 10 supported on the supporting mechanism 20 moved according to a movement of the carriage 60. Specifically, as shown in FIG. 3, the camera unit 30 captures an image of the entire surface of the wafer 10 by performing scanning four times.

[0067]

In FIG. 3, first at a shift initial position Ps1, the camera unit 30 scans the surface of the wafer 10 over a specified width (corresponding to the length of the line sensor) in a direction S1 when the carriage 60 moves in a direction A1. When scanning at the shift initial position Ps1 is completed, the carriage 60 is shifted to a shift position Ps2 in a direction B by the shifting mechanism 70. Subsequently, at the shift position Ps2, the camera unit 30 scans the wafer 10 in a direction S2 (opposite to the direction S1) when the carriage 60 moves in a direction A2

opposite to the direction A1. When scanning at the shift position Ps2 is completed, the carriage 60 is further shifted to a shift position Ps3 in the direction B by the shifting mechanism 70. Then, at the shift position Ps3, the camera unit 30 scans the wafer 10 in the direction S1 when the carriage 60 moves in the direction A1. When scanning at the shift position Ps3 is completed, the carriage is further shifted to a shift position Ps4 by the shifting mechanism 70. At this shift position Ps4, the camera unit 30 scans the wafer in the direction S2 when the carriage 60 moves in the direction A2. In this way, the camera unit 30 scans the surface of the wafer 10 four times for a time during which the carriage 60 is repeatedly shifted in the direction B by the shifting mechanism 70 while moving back and forth in the directions A1, A2 by self-running. In this process, the camera unit 30 captures an image of the surface of the wafer 10 and successively outputs image signals.

[0068]

A control system of the surface inspection device is constructed as shown in FIG. 4.

[0069]

In FIG. 4, a processing unit 100 receives image signals from the camera unit 30 described above and processes the image signals as information representing a surface image of the wafer 10. A drive control unit 120 is connected to the processing unit 100 and controls driving of a moving mechanism 200 including the carriage 60 and the shifting mechanism 70 described above under the control of the processing unit 100. An operation unit 111 and a display unit 112 are also connected to the processing unit 100. Upon receiving an operation signal from the operation unit 111 operated by a user, the processing unit 100 performs various processes based on this operation signal. The processing unit 100 causes the display unit 112 to display various pieces of information such as causing the display unit 112 to display a captured image including a surface image of the

wafer 10 based on image data obtained by processing.

[0070]

Next, a process for detecting a defect of the surface of the wafer 10 is described.

5 [0071]

First, a process relating to registration of various pieces of information on an image processing of the surface image of the wafer 10 (registration process) is performed.

[0072]

10 An image of the surface of the wafer 10 as a representative of wafers to be inspected is captured by the camera unit 30 in the mechanism unit (see FIGS. 1 to 3) and the processing unit 100 that receives image signals from the camera unit 30 performs the process in accordance with the
15 procedure shown in FIG. 5.

[0073]

In FIG. 5, the processing unit 100 converts the image signals successively supplied from the camera unit 30 into image data represented by pixel-based gray values and
20 obtains a captured image including a wafer surface image (data) representing the entire surface of the wafer 10 as an image to be processed (S1). The captured image including this wafer surface image is developed on an image memory (not shown). When obtaining a captured image (image to be
25 processed) I including a wafer surface image I10, for example, as shown in FIG. 6A, the processing unit 100 corrects the position of the captured image I on the image memory based on X (horizontal coordinate axis), Y (vertical coordinate axis) and θ (angle in a counterclockwise
30 direction) (S2). For example, a position correction is so performed that a notched part I11 of the wafer surface image I10 is positioned in a predetermined direction as shown in FIG. 6B. The processing unit 100 causes the display unit 112 to display the captured image I including the position-
35 corrected wafer surface image I10.

[0074]

The user sets a circular line C0 (edge line: see dashed-dotted line) along an edge Edg of the wafer surface image I10 on the captured image I displayed on the display unit 112, for example, as shown in FIG. 6C by operating the operation unit 111. When a predetermined determination operation is performed on the operation unit 111 with the circular line C0 set, the processing unit 100 obtains a radius R and a position (X_0 , Y_0) of a center O of the set circular line C0 (S3). Subsequently, the processing unit 100 sets an inner circular partition line C1 concentric with the circular line C0 specified by the radius R and the position (X_0 , Y_0) of the center O and having a radius ($R-L1$) and an outer circular partition line C2 concentric with the circular line C0 and having a radius ($R+L2$) as shown in FIG. 7. By this, the processing unit 100 recognizes a ring-shaped area E_{Ling} partitioned by the inner and outer circular partition lines C1, C2 at the opposite sides of and parallel to the circular line C0 and having a width L1 and a width L2 from the circular line C0 at an inner side and an outer side of the wafer surface image I10, and specifies an image in the ring-shaped area E_{Ling} in the captured image I as an edge image IE (S4). Note that L1, L2 are, for example, set through the operation of the operation unit 11 by the user. [0075]

Subsequently, the processing unit 100 generates a conversion table (HLUT) to be used for converting the edge image IE in the ring-shaped area E_{Ling} into a rectangular image IR with a width equivalent to the width ($L1+L2$) (S5). This conversion table (HLUT) relates respective positions of the ring-shaped edge image IE having an outer perimeter $2\pi(R+L2)$ (length of the outer circular partition line C2) and an inner perimeter $2\pi(R-L1)$ (length of the inner circular partition line C1) to pixels Px of the rectangular image IR with a length and a width equivalent to the outer perimeter $2\pi(R+L2)$ and the width ($L1+L2$) of the edge image IE as shown in FIG. 8. Specifically, as shown in FIG. 9,

respective positions of a first edge image part IE(1) in a
 first angular range ($0^\circ \leq \theta < 90^\circ$) in the ring-shaped edge
 image IE are related to pixels of a first rectangular image
 part IR(1) with a length equivalent to the first angular
 5 range ($0^\circ \leq \theta < 90^\circ$) out of the length $2\pi(R+L_2)$, and
 respective positions of a second edge image part IE(2) in a
 second angular range ($90^\circ \leq \theta < 180^\circ$) in the ring-shaped edge
 image IE are similarly related to pixels of a second
 rectangular image part IR(2) with a length equivalent to the
 10 second angular range ($90^\circ \leq \theta < 180^\circ$). Further, respective
 positions of a third edge image part IE(3) in a third
 angular range ($180^\circ \leq \theta < 270^\circ$) in the ring-shaped edge image
 IE are related to pixels of a third rectangular image part
 IR(3) with a length equivalent to the third angular range
 15 ($180^\circ \leq \theta < 270^\circ$) out of the length $2\pi(R+L_2)$, and respective
 positions of a fourth edge image part IE(4) in a fourth
 angular range ($270^\circ \leq \theta < 360^\circ, 0^\circ$) in the ring-shaped edge
 image IE are similarly related to pixels of a fourth
 rectangular image part IR(4) with a length equivalent to the
 20 fourth angular range ($270^\circ \leq \theta < 360^\circ, 0^\circ$).
 [0076]

The conversion table indicates the positions of the
 edge image IE corresponding to the respective pixels of the
 rectangular image IR and is generated as follows.

25 [0077]

In the ring-shaped edge image IE having the outer
 peripheral edge (outer circular partition line C2) and the
 inner peripheral edge (inner circular partition line C1) as
 shown in FIGS. 10A and 10B, n positions $P_0 (X_0, Y_0)$, $P_1 (X_1,$
 30 $Y_1)$, ..., $P_{n-1} (X_{n-1}, Y_{n-1})$ are determined at equal intervals δ
 (unit length based on resolution of one pixel) along the
 outer peripheral edge (outer circular partition line C2) as
 shown in FIG. 11A. Note that $n = 2\pi(R+L_2)/\delta$. Subsequently,
 when straight lines (hereinafter, referred to as normal
 35 lines) NL (θ) passing through the respective positions P_j set
 on the outer peripheral edge (outer circular partition line

C2) and orthogonal to the outer peripheral edge (outer circular partition line C2) and the inner peripheral edge (inner circular partition line C1) are set as shown in FIGS. 10A, 10B and 11B, m positions $P_{j1\Delta}$ to $P_{jm\Delta}$ can be set at equal intervals (δ) between an intersection A of the normal line NL (θ) with the outer peripheral edge (C2) and an intersection B thereof with the inner peripheral edge (C1). Note that $m = (L1+L2)/\delta$. Specifically, as shown in FIG. 12, on the normal line NL (θ), the respective positions $P_{j1\Delta}$ to $P_{jm\Delta}$ successively shifted by $\Delta X_j (= \delta \cdot \cos\theta)$ in an X-direction and by $\Delta Y_j (= \delta \cdot \sin\theta)$ in a Y-direction from the position P_j at the point A can be set until reaching the point B. Coordinate values of the respective positions are $P_j (X_j, Y_j)$, $P_{j1\Delta} (X_j - \Delta X_j, Y_j - \Delta Y_j)$, ..., $P_{jm\Delta} (X_j - m\Delta X_j, Y_j - m\Delta Y_j)$.

[0078]

As described above, the respective positions set on the edge image IE are related to the pixels of the rectangular image IR shown in FIG. 8. Specifically, as shown in FIG. 13, n pixels Px_0 to Px_{n-1} arranged along a side V(C2) of the rectangular image IR corresponding to the outer peripheral edge (outer circular partition line C2) of the edge image IE are related to the positions $P_0 (X_0, Y_0)$ to $P_{n-1} (X_{n-1}, Y_{n-1})$ set along the outer peripheral edge (outer circular partition line C2) of the edge image IE, and n pixels Px_{01} to $Px_{(n-1)1}$ arranged at an inner side of the side V(C2) of the rectangular image IR by one pixel are related to the positions $P_{01\Delta} (X_0 - \Delta X_0, Y_0 - \Delta Y_0)$ to $P_{(n-1)1\Delta} (X_{n-1} - \Delta X_{n-1}, Y_{n-1} - \Delta Y_{n-1})$ set at an inner side of the outer peripheral edge (outer circular partition line C2) of the edge image IE by the interval δ . The pixels and the positions are similarly related thereafter until n pixels Px_{0m} to $Px_{(n-1)m}$ arranged along a side V(C1) of the rectangular image IR corresponding to the inner peripheral edge (inner circular partition line C1) of the edge image IE are related to the positions $P_{0m\Delta} (X_0 - m\Delta X_0, Y_0 - m\Delta Y_0)$ to $P_{(n-1)m\Delta} (X_{n-1} - m\Delta X_{n-1}, Y_{n-1} - m\Delta Y_{n-1})$ set along the inner peripheral edge (inner circular partition line C1)

of the edge image IE.

[0079]

The conversion table (HLUT) relates numerical values
($X_0, Y_0, \Delta X_0, \Delta Y_0$), ($X_1, Y_1, \Delta X_1, \Delta Y_1$), ..., ($X_{n-1}, Y_{n-1}, \Delta X_{n-1}, \Delta Y_{n-1}$) including the coordinate values of the respective
5 positions P_0 to P_{n-1} set along the outer peripheral edge
(outer circular partition line C2) of the edge image IE to
the pixels (Px_0 to Px_{0m}), (Px_1 to Px_{1m}), ..., (Px_{n-1} to $Px_{(n-1)m}$) in
one row in the width direction in the rectangular image IR
10 in view of the relationship described above as shown in FIG.
14. By using such a conversion table (HLUT), the respective
positions of the edge image IE corresponding to the
respective pixels (Px_0 to Px_{0m}) in the first row in the width
direction in the edge image IE are determined to be (X_0, Y_0),
15 ($X_0 - \Delta X_0, Y_0 - \Delta Y_0$), ..., ($X_0 - m\Delta X_0, Y_0 - m\Delta Y_0$) and, similarly, the
respective positions of the edge image IE corresponding to
the respective pixels (Px_i to Px_{im}) in an arbitrary $(i+1)^{th}$
row in the width direction are determined to be (X_i, Y_i),
($X_i - \Delta X_i, Y_i - \Delta Y_i$), ..., ($X_i - m\Delta X_i, Y_i - m\Delta Y_i$).

20 [0080]

The conversion table (HLUT) does not relate all the
positions set in the edge image IE and the respective pixels
of the rectangular image IR as shown in FIG. 13, but relates
the respective positions $P_0(X_0, Y_0)$ to $P_{n-1}(X_{n-1}, Y_{n-1})$ along the
25 outer peripheral edge (outer circular partition line C2) in
the edge image IE and the interval Δ of the positions set on
the normal lines passing through the respective positions to
one row of the pixels in the width direction of the
rectangular image IR as shown in FIG. 14. Thus, the
30 conversion table (HLUT) can be formed to be smaller, with
the result that the capacity of a memory for storing this
table can be reduced.

[0081]

Referring back to FIG. 5, when the conversion table
35 (HLUT) indicating the positions of the edge image IE
corresponding to the respective pixels of the rectangular

image IR by the relationship described above is generated,
 the processing unit 100 generates an inverse conversion
 table (NLUT), conversely, indicating the positions of the
 rectangular image IR corresponding to the respective pixels
 5 of the edge image IE (S6). The respective positions of the
 rectangular image IR with the length and width equivalent to
 the length $2\pi(R+L2)$ and the width $(L1+L2)$ as shown in FIG. 8
 are related to the pixels of the image (edge image IE) of
 the original ring-shaped area E_{ring} with the outer perimeter
 10 $2\pi(R+L2)$ and the inner perimeter $2\pi(R-L1)$. Specifically, as
 shown in FIG. 15, the inverse conversion table relates the
 respective positions in the first rectangular image part
 IR(1) with the length equivalent to the first angular range
 ($0^\circ \leq \theta < 90^\circ$) out of the length $2\pi(R+L2)$ to the respective
 15 pixels of the first edge image part IE(1) in the first
 angular range ($0^\circ \leq \theta < 90^\circ$) in the ring-shaped edge image IE
 and, similarly relates the respective positions in the
 second rectangular image part IR(2) with the length
 equivalent to the second angular range ($90^\circ \leq \theta < 180^\circ$) to
 20 the respective pixels of the second edge image part IE(2) in
 the second angular range ($90^\circ \leq \theta < 180^\circ$) in the ring-shaped
 edge image IE. Further, the inverse conversion table relates
 the respective positions in the third rectangular image part
 IR(3) with the length equivalent to the third angular range
 25 ($180^\circ \leq \theta < 270^\circ$) out of the length $2\pi(R+L2)$ to the
 respective pixels of the third edge image part IE(3) in the
 third angular range ($180^\circ \leq \theta < 270^\circ$) in the ring-shaped edge
 image IE and, further, relates the respective positions in
 the fourth rectangular image part IR(4) with the length
 30 equivalent to the fourth angular range ($270^\circ \leq \theta < 360^\circ, 0^\circ$)
 to the respective pixels of the fourth edge image part IE(4)
 in the fourth angular range ($270^\circ \leq \theta < 360^\circ, 0^\circ$) in the ring-
 shaped edge image IE.

[0082]

35 Note that a method for generating this inverse
 conversion table (NLUT) is similar to that for generating

the conversion table (HLUT) described above.

[0083]

When the conversion table (HLUT) and the inverse conversion table (NLUT) are generated, the processing unit
5 100 converts the edge image IE specified in the captured image I including the wafer surface image I10 into the rectangular image IR using the conversion table (HLUT) and further inversely converts the rectangular image IR obtained by the conversion into an image in the original ring-shaped
10 area E_{Ling} (edge image IE) using the inverse conversion table (NLUT) (S7). Then, the captured image I including the image obtained by the inverse conversion is displayed on the display unit 112. The user performs a predetermined operation of executing registration using the operation unit
15 111 unless there is any problem in the captured image I displayed on the display unit 112, particularly in the image part of the ring-shaped area E_{Ling} . Upon receiving an operation signal based on the operation of executing registration from the operation unit 111, the processing
20 unit 100 registers the center position O (X_0 , Y_0) and the radius (R) for specifying the circular line C0 (edge line) along the edge of the wafer surface image I10 set as described above, the widths L1, L2 from the circular line C0 indicating the boundary lines (C1,) of the ring-shaped area
25 E_{Ling} , the conversion table (HLUT), the inverse conversion table (NLUT) and a circular main area obtained by excluding the ring-shaped area E_{Ling} from the circular area of the wafer surface image I10 and having a center position (X_0 , Y_0) and a radius (R-L1) in an internal memory (S8) and finishes the
30 process. This registration process can be performed for each diameter of wafers to be inspected.

[0084]

Note that the user can capture an image of the surface of the wafer 10, determine the circular line C0 and the
35 widths L1, L2 for the wafer surface image I10 and generate the conversion table (HLUT) and the inverse conversion table

(NLUT) again if there is any problem in the captured image I, particularly in the image part in the ring-shaped area E_{Ling} obtained through the conversion and the inverse conversion processes.

5 [0085]

After the registration process is finished as described above, the surface inspection device can inspect a surface of each wafer 10. An image of the surface of the wafer 10 to be inspected is captured by the camera unit 30 in the mechanism unit (see FIGS. 1 to 3) and the processing unit 100 that receives image signals from the camera unit 30 performs a process in accordance with a procedure shown in FIG. 16.

[0086]

15 In FIG. 16, the processing unit 100 converts the image signals successively supplied from the camera unit 30 that captures an image of the surface of the wafer 10 to be inspected into image data represented by pixel-based gray values and obtains a captured image including a wafer surface image (data) representing the entire surface of the wafer 10 as an image to be processed (S11). The captured image including this wafer surface image is developed on the image memory (not shown). When obtaining a captured image I including a wafer surface image I20, for example, as shown in FIG. 17A, the processing unit 100 corrects the position of the captured image I on the image memory based on X (horizontal coordinate axis), Y (vertical coordinate axis) and θ (angle in a counterclockwise direction) (S12). For example, a position correction is so performed that a notched part I21 of the wafer surface image I20 is positioned in a predetermined direction and the wafer surface image I20 is position-corrected similar to the one (see FIGS. 5 and 6B) at the time of the registration process as shown in FIG. 17B, and the captured image I after this position correction is developed on the image memory. Note that, in this case, a defect part D1 is present on an outer

edge part of the wafer surface image I20.

[0087]

The processing unit 100 maps an inspection area in the position-corrected wafer surface image I20 based on the center position O (X_0 , Y_0) and the radius (R) for specifying the registered circular line C0 and the widths L1, L2 for specifying the ring-shaped area E_{Ling} (S13). By this mapping, an image in the ring-shaped area E_{Ling} is specified as an edge image IE and a circular main area (wafer main image with a radius (R-L1)) obtained by excluding the E_{Ling} (edge image IE) from the area of the wafer surface image I20 is specified.

[0088]

Subsequently, the processing unit 100 converts the edge image IE, which is the image in the ring-shaped area E_{Ling} , obtained by the above mapping into a rectangular image IR using the conversion table (HLUT) (see FIGS. 13, 14) described above (S14). In this conversion process, the position in the ring-shaped edge image IE corresponding to each pixel of the rectangular image IR (see FIG. 8) is first obtained from the conversion table (HLUT). Subsequently, the gray value at the obtained position in the edge image IE is obtained and determined as a gray value of the pixel of the rectangular image IR corresponding to this position. If the position in the edge image IE matches the pixel position in the edge image IE, the gray value of this pixel is determined as a gray value of the corresponding pixel in the rectangular image IR. Further, if the position in the edge image IE does not match the pixel position in the edge image IE, the gray value of this pixel is determined by an interpolation process based on the gray values of the pixels surrounding this position, and this gray value is determined as the gray value of the corresponding pixel of the rectangular image IR.

[0089]

The edge image IE is converted into the rectangular image IR by determining the gray values of the respective

pixels in the rectangular image IR as the gray values at the
 positions in the edge image IE related by the conversion
 table (HLUT) in this way. By this conversion process, as
 shown in FIG. 18, a first edge image part IE(1) in a first
 5 angular range ($0^\circ \leq \theta < 90^\circ$) in the edge image IE is
 converted into a first rectangular image part IR(1) with a
 length equivalent to the first angular range ($0^\circ \leq \theta < 90^\circ$)
 out of the length $2\pi(R+L_2)$, and a second edge image part
 IE(2) in a second angular range ($90^\circ \leq \theta < 180^\circ$) in the ring-
 10 shaped edge image IE is similarly converted into a second
 rectangular image part IR(2) with a length equivalent to the
 second angular range ($90^\circ \leq \theta < 180^\circ$). Further, a third edge
 image part IE(3) in a third angular range ($180^\circ \leq \theta < 270^\circ$)
 in the ring-shaped edge image IE is converted into a third
 15 rectangular image part IR(3) with a length equivalent to the
 third angular range ($180^\circ \leq \theta < 270^\circ$) out of the length
 $2\pi(R+L_2)$, and a fourth edge image part IE(4) in a fourth
 angular range ($270^\circ \leq \theta < 360^\circ, 0^\circ$) in the edge image IE is
 similarly converted into a fourth rectangular image part
 20 IR(4) with a length equivalent to the fourth angular range
 ($270^\circ \leq \theta < 360^\circ, 0^\circ$). In this case, a defect part D1 present
 in the second edge image part IE(2) is converted into a
 defect part DR1 of the corresponding second rectangular
 image part IR(2).

25 [0090]

Referring back to FIG. 16, upon generating the
 rectangular image IR, the processing unit 100 applies a one-
 dimensional filtering process to the rectangular image IR to
 emphasize defect parts (S15). In this one-dimensional
 30 filtering process, the gray value of each target pixel is
 determined based on the gray values of the pixels arranged
 before and after the target pixel in a direction orthogonal
 to the width direction of the rectangular image IR, i.e. in
 a direction parallel to a straight line V(C0) (see FIG. 8)
 35 extending in a horizontal direction and corresponding to the
 circular line C0 set as the edge line of the edge image IE.

By such a one-dimensional filtering process, a processed rectangular image IR_p with the emphasized defect parts is obtained. Specifically, as shown in FIG. 19, a first processed rectangular image part $IR_p(1)$ corresponding to the first angular range ($0^\circ \leq \theta < 90^\circ$) is generated from the first rectangular image part $IR(1)$ corresponding to this angular range, a second processed rectangular image part $IR_p(2)$ corresponding to the second angular range ($90^\circ \leq \theta < 180^\circ$) is generated from the second rectangular image part $IR(2)$ corresponding to this angular range, a third processed rectangular image part $IR_p(3)$ corresponding to the third angular range ($180^\circ \leq \theta < 270^\circ$) is generated from the third rectangular image part $IR(3)$ corresponding to this angular range and, further, a fourth processed rectangular image part $IR_p(4)$ corresponding to the fourth angular range ($270^\circ \leq \theta < 360^\circ$, 0°) is generated from the fourth rectangular image part $IR(4)$ corresponding to this angular range. In this case, the defect part $DR1$ included in the second rectangular image part $IR(2)$ is emphasized and generated as a defect part $DR1_p$ in the second processed rectangular image part $IR_p(2)$.

[0091]

When the one-dimensional filtering process is performed on the rectangular image IR to obtain the processed rectangular image IR_p , the processing unit 100 inversely converts the processed rectangular image IR_p into an image in the original ring-shaped area E_{Ling} using the inverse conversion table (NLUT) (S16). In this inverse conversion process, the position of the processed rectangular image IR_p corresponding to each pixel in the original ring-shaped area E_{Ling} is obtained from the inverse conversion table (NLUT). Subsequently, the gray value at the obtained position in the processed rectangular image IR_p is obtained and determined as a gray value of the corresponding pixel in the ring-shaped area E_{Ling} . If the position in the processed rectangular image IR_p matches the pixel position in the processed rectangular image IR_p , the gray value of this

pixel is determined as a gray value of the corresponding
 pixel in the ring-shaped area E_{Ling} . Further, if the position
 in the processed rectangular image IR_P does not match the
 pixel position in the processed rectangular image IR_P , the
 5 gray value at this position is determined by an
 interpolation process based on the gray values of the pixels
 surrounding this position, and this gray value is determined
 as the gray value of the corresponding pixel in the ring-
 shaped area E_{Ling} .

10 [0092]

The processed rectangular image IR_P is converted into
 the image in the ring-shaped area E_{Ling} to obtain a processed
 edge image IE_P by determining the gray value of each pixel in
 the ring-shaped area E_{Ling} as a gray value at the
 15 corresponding position of the processed rectangular image IR_P
 related by the inverse conversion table (NLUT). By this
 inverse conversion process, as shown in FIG. 20, the first
 processed rectangular image part $IR_P(1)$ corresponding to the
 first angular range ($0^\circ \leq \theta < 90^\circ$) is inversely converted
 20 into a first processed edge image part $IE_P(1)$ in the same
 angular range, the second processed rectangular image part
 $IR_P(2)$ corresponding to the second angular range ($90^\circ \leq \theta <$
 180°) is inversely converted into a second processed edge
 image part $IE_P(2)$ in the same angular range, the third
 25 processed rectangular image part $IR_P(3)$ corresponding to the
 third angular range ($180^\circ \leq \theta < 270^\circ$) is inversely converted
 into a third processed edge image part $IE_P(3)$ in the same
 angular range and, further, the fourth processed rectangular
 image part $IR_P(4)$ corresponding to the fourth angular range
 30 ($270^\circ \leq \theta < 360^\circ$, 0°) is inversely converted into a fourth
 processed edge image part $IE_P(4)$ in the same angular range.
 In this case, the defect part DR_{1P} present in the second
 processed rectangular image part $IR_P(2)$ in an emphasized
 manner is converted into a defect part DL_P emphasized in the
 35 second processed edge image part $IE_P(2)$.

[0093]

Referring back to FIG. 16, after generating the processed edge image IE_p described above, the processing unit 100 performs a two-dimensional filtering process on an image in the circular main area obtained by excluding the ring-shaped area E_{Ling} from the area of the wafer surface image $I20$ obtained by the mapping (see S13) (S17). Specifically, the gray value of each target pixel is determined based on the gray values of surrounding two-dimensionally arranged pixels (e.g. eight pixels surrounding the target pixel) in the image (wafer main image) in the circular main area. By performing such a two-dimensional filtering process, a processed wafer main image is obtained. The defect parts are emphasized in this processed wafer main image. Subsequently, the processing unit 100 combines the processed edge image IE_p and the processed wafer main image to generate a single processed wafer surface image $I20_p$ (S18). Then, the processing unit 100 performs a defect detection process on the generated processed wafer surface image $I20_p$ (S19). For example, the defect parts are specified based on a density distribution of the processed wafer surface image $I20_p$. The processing unit 100 generates information for specifying the defect parts detected by the defect detection process, i.e. defect information (e.g. defect numbers (NO.), center coordinates of the defect parts, areas of the defect parts, degrees of flatness of the defect parts, major and minor axes of ellipses approximated to the defect parts, defect classification numbers (NO.), etc.) and stores the defect information together with the processed wafer surface image $I20_p$ (S20). Then, the processing unit 100 causes the display unit 112 to display defect parts $D1_p$, $D2_p$, $D3_p$ and $D4_p$ specified by the defect information together with the processed wafer surface image $I20_p$ as shown in FIG. 21. Note that, in FIG. 21, the defect part $D1_p$ is specified on the processed edge image IE_p and the other defect parts $D2_p$, $D3_p$ and $D4_p$ are specified on the processed wafer main image.

[0094]

In the image processing performed in the wafer surface inspection device described above, the edge image IE including the circular line C0 along the edge of the wafer surface image I10 specified in the captured image I (image to be processed) is converted into the rectangular image IR and the one-dimensional filtering process is performed on this rectangular image IR. Since this one-dimensional filtering process is performed in the direction along the straight line V(Co) corresponding to the circular line Co set for the edge of the wafer surface image I20, the processed edge image IE_p obtained by inversely converting the processed rectangular image IR_p having the one-dimensional filtering process performed thereon is substantially an image obtained by performing the filtering process along the edge line of the wafer surface image I20. Thus, it becomes possible to easily obtain the image (processed edge image IE_p) having the filtering process properly performed thereon in the area of the edge part of the wafer surface image I20. [0095]

Since the image (processed edge image IE_p) having the filtering process properly performed thereon in the area of the edge part of the wafer surface image I20 is obtained, the defect part D1_p located on the edge part of the wafer surface image I20 can also be precisely detected similar to the defect parts D2_p, D3_p and D4_p located in the wafer main image inside. [0096]

Although the edge image IE is set to be the image in the ring-shaped area E_{Ling} including the circular line C0 as the edge line set in the wafer surface image I20 in the embodiment of the present invention described above, it is also possible to process a partial image in the ring-shaped area E_{Ling} as the edge image IE. Even if an edge line of an object surface is not a circular line, but an arbitrary curve, it is also possible to set an edge line along the curve of the edge and specify an image in an area with a

predetermined width in a direction orthogonal to the edge line as an edge image. In this case, the edge image is converted into a rectangular image based on a correspondence between respective positions of the edge image having the
5 arbitrary curved shape and respective pixels of the rectangular image, and a processed rectangular image is inversely converted into an image (processed edge image) in the original curved area.

[0097]

10 In the image processing method and device according to the present invention, the one-dimensional image processing performed on the rectangular image IR is not limited to the filtering process. The one-dimensional image processing is not particularly limited so long as the gray values of a
15 plurality of pixels arranged in the direction orthogonal to the width direction of the rectangular image IR are successively processed.

[0098]

In the embodiment of the present invention described
20 above, after the processed rectangular image IR_p is obtained by performing the one-dimensional image processing (one-dimensional filtering process) on the rectangular image IR converted from the edge image IE, the processed rectangular image IR_p is inversely converted to generate the processed
25 edge image IE_p and defects are detected in the processed edge image IE_p (actually, in the combined image). However, such as in the case of only detecting the presence or absence of defect parts in the image to be processed, particularly in the edge image IE, the processed rectangular image IR_p needs
30 not be inversely converted and the defect detection process can be performed on the processed rectangular image IR_p .

[0099]

Further, although the captured image of the semiconductor wafer is the image to be processed in the
35 embodiment of the present invention described above, the image to be processed is not particularly limited so long as

it includes a surface image of a certain object.

INDUSTRIAL APPLICABILITY

[0100]

5 As described above, the image processing method and
device according to the present invention have an effect of
being able to obtain an image having an image processing
properly performed thereon in an area of an edge part of an
object surface image, are useful as an image processing
10 method and an image processing device for processing an
object surface image represented by pixel-based gray values
and are suitably applied to a surface inspection device.

EXPLANATIONS OF LETTERS OR NUMERALS

15 [0101]

10 wafer
20 supporting mechanism
21 table
22a, 22b supporting leg
20 30 camera unit
31 illumination unit
50 base
55 frame
60 carriage
25 70 shifting mechanism
71 stage
72 driving unit
100 processing unit
111 operation unit
30 112 display unit
120 drive control unit
200 moving mechanism

CLAIMS

1. An image processing method, comprising:
an image obtaining step of obtaining an image to be processed represented by pixel-based gray values and
5 including an object surface image;
an edge image specifying step of specifying an image including an edge line of the object surface image set in the image to be processed and located in an area with a predetermined width in a direction orthogonal to the edge
10 line as an edge image;
a conversion step of converting the edge image into a rectangular image with a width equivalent to the predetermined width; and
an image processing step of performing a one-
15 dimensional image processing on the rectangular image to successively process the gray values of a plurality of pixels arranged in a direction orthogonal to a width direction of the rectangular image.
2. The image processing method according to claim 1,
20 further comprising an inverse conversion step of generating a processed edge image by inversely converting the rectangular image having the one-dimensional image processing performed thereon into an image in the original area.
- 25 3. The image processing method according to claim 1 or 2, wherein an image in an area with a first predetermined width in an inward direction of the object surface image from the edge line and a second predetermined width in an outward direction of the object surface image from the edge
30 line is specified as the edge image in the edge image specifying step.
4. The image processing method according to any one of claims 1 to 3, wherein the conversion step includes:
a position conversion step of obtaining a position in
35 the edge image corresponding to each pixel of the rectangular image; and

a step of determining the gray value of the pixel of the rectangular image corresponding to each obtained position in the edge image based on the gray values of respective pixels in the edge image.

5 5. The image processing method according to claim 4, wherein:

 a conversion table indicating the positions of the edge image corresponding to the respective pixels of the rectangular image is generated beforehand; and

10 the positions in the edge image corresponding to the respective pixels of the rectangular image are obtained using the conversion table in the position conversion step.

 6. The image processing method according to claim 2, wherein the inverse conversion step includes:

15 a position inverse conversion step of obtaining a position in the rectangular image corresponding to each pixel in the image in the original area; and

 a step of generating the processed edge image by determining gray values of the pixels in the image in the
20 original area corresponding to the obtained respective positions in the rectangular image based on the gray values of the respective pixels in the rectangular image having the one-dimensional image processing performed thereon.

 7. The image processing method according to claim 6,
25 wherein:

 an inverse conversion table indicating the positions in the rectangular image corresponding to the respective pixels of the image in the original area is generated beforehand; and

30 the positions in the rectangular image corresponding to the respective pixels of the image in the original image are obtained using the inverse conversion table in the position inverse conversion step.

 8. The image processing method according to claim 1,
35 wherein:

 an image including a surface image of a disk-shaped

semiconductor wafer is obtained as the image to be processed in the image obtaining step; and

an entire or partial image in a ring-shaped area with a predetermined width in a direction orthogonal to a
5 circular line along an edge of the semiconductor wafer surface image is specified as the edge image in the edge image specifying step.

9. The image processing method according to claim 2, wherein:

10 an image including a surface image of a disk-shaped semiconductor wafer is obtained as the image to be processed in the image obtaining step;

an entire or partial image in a ring-shaped area with a predetermined width in a direction orthogonal to a
15 circular line along an edge of the semiconductor wafer surface image is specified as the edge image in the edge image specifying step; and

the processed edge image is generated by inversely converting the rectangular image having the one-dimensional
20 image processing performed thereon into an entire or partial image in the original ring-shaped area in the inverse conversion step.

10. The image processing method according to claim 8 or 9, wherein an entire or partial image in a ring-shaped
25 area with a first predetermined width at an inner side of the circular line and a second predetermined width at an outer side of the circular line is specified as the edge image in the edge image specifying step.

11. The image processing method according to claim 1,
30 wherein, in the conversion step, the edge image is converted into a rectangular image composed of pixels in a rectangular array corresponding to respective positions set at predetermined intervals along one of two partition lines at the opposite sides of and parallel to the edge line of the
35 object image of the edge image and respective positions set at predetermined intervals along normal lines orthogonal to

the partition lines from the respective positions up to the other partition line.

12. The image processing method according to claim 11, wherein, in the conversion step, the edge image is
5 converted into a rectangular image composed of pixels in a rectangular array corresponding to respective positions set at predetermined intervals along the longer one of the two partition lines at the opposite sides of and parallel to the edge line of the object image of the edge image and
10 respective positions set at predetermined intervals along normal lines orthogonal to the partition lines from the respective positions up to the shorter partition line.

13. The image processing method according to claim 11 or 12,
15 a conversion table relating the respective positions along the partition line in the edge image and pixels in one row of the rectangular image corresponding to each of all the positions set on the normal lines passing through the respective positions is generated beforehand; and
20 the positions in the edge image corresponding to the respective pixels of the rectangular image are determined using the conversion table in the conversion step.

14. An image processing method, comprising:
an image obtaining step of obtaining an image to be
25 processed partitioned by two parallel partition lines; and
a conversion step of converting the image to be processed into a rectangular image composed of pixels in a rectangular array corresponding to respective positions set at predetermined intervals along one of the two parallel
30 partition lines of the image to be processed and respective positions set at predetermined intervals along normal lines orthogonal to the partition lines from the respective positions up to the other partition line.

15. The image processing method according to claim 35 14, wherein, in the conversion step, the image to be processed is converted into a rectangular image composed of

pixels in a rectangular array corresponding to respective positions set at predetermined intervals along the longer one of the two partition lines of the image to be processed and respective positions set at predetermined intervals
5 along normal lines orthogonal to the partition lines from the respective positions up to the shorter partition line.

16. The imaging processing method according to claim 14 or 15, wherein:

a conversion table relating the respective positions
10 along the partition line in the image to be processed and pixels in one row of the rectangular image corresponding to each of all the positions set on the normal lines passing through the respective positions is generated beforehand; and

15 the positions in the image to be processed corresponding to the respective pixels of the rectangular image are determined using the conversion table in the conversion step.

17. An image processing device, comprising:
20 an image capturing unit for capturing an image of a surface of an object; and

a processing unit for processing a captured image obtained by the image capturing unit, wherein the processing unit includes:

25 image obtaining means for obtaining an image to be processed represented by pixel-based gray values and including a surface image of the object;

edge image specifying means for specifying an image including an edge line of the object surface image set in
30 the image to be processed and located in an area with a predetermined width in a direction orthogonal to the edge line as an edge image;

conversion means for converting the edge image into a rectangular image with a width equivalent to the
35 predetermined width; and

image processing means for performing a one-

dimensional image processing on the rectangular image to successively process the gray values of a plurality of pixels arranged in a direction orthogonal to a width direction of the rectangular image.

5 18. The image processing device according to claim 17, further comprising inverse conversion means for generating a processed edge image by inversely converting the rectangular image that the one-dimensional image processing has been performed into an image in the original
10 area.

 19. The image processing device according to claim 17 or 18, wherein the conversion means includes:

 position conversion means for obtaining a position in the edge image corresponding to each pixel of the
15 rectangular image; and

 means for determining the gray value of the pixel of the rectangular image corresponding to each obtained position in the edge image based on the gray values of respective pixels in the edge image.

20 20. The image processing device according to claim 19, further comprising a storage unit for storing a conversion table indicating the positions in the edge image corresponding to the respective pixels of the rectangular image, wherein the position conversion unit obtains the
25 positions in the edge image corresponding to the respective pixels of the rectangular image using the conversion table.

 21. The image processing device according to claim 17, wherein:

 the image capturing unit captures an image of a
30 surface of a disk-shaped semiconductor wafer;

 the image obtaining means obtains an image including the semiconductor wafer surface image as the image to be processed;

 the edge image specifying means specifies an entire or
35 partial image in a ring-shaped area with a predetermined width in a direction orthogonal to a circular line along an

edge of the semiconductor wafer surface image as the edge image; and

the inverse conversion means generates a processed edge image by inversely converting the rectangular image that the one-dimensional image processing has been performed
5 into an entire or partial image in the original ring-shaped area.

22. The image processing device according to claim 21, wherein the edge image specifying means specifies an
10 entire or partial image in a ring-shaped area with a first predetermined width at an inner side of the circular line and a second predetermined width at an outer side of the circular line as the edge image.

23. The image processing device according to claim
15 17, wherein the conversion means converts the edge image into a rectangular image composed of pixels in a rectangular array corresponding to respective positions set at predetermined intervals along one of two partition lines at the opposite sides of and parallel to the edge line of the
20 object image of the edge image and respective positions set at predetermined intervals along normal lines orthogonal to the partition lines from the respective positions up to the other partition line.

24. The image processing device according to claim
25 11, wherein the conversion means converts the edge image into a rectangular image composed of pixels in a rectangular array corresponding to respective positions set at predetermined intervals along the longer one of the two partition lines at the opposite sides of and parallel to the
30 edge line of the object image of the edge image and respective positions set at predetermined intervals along normal lines orthogonal to the partition lines from the respective pixels up to the shorter partition line.

25. The image processing device according to claim
35 23 or 24, further comprising a storage unit for storing a conversion table relating the respective positions along the

partition line in the edge image and pixels in one row of the rectangular image corresponding to each of all the positions set on the normal lines passing through the respective positions, wherein the conversion unit includes a unit for determining the positions in the edge image corresponding to the respective pixels of the rectangular image using the conversion table.

26. An image processing device, comprising:
an image capturing unit for capturing an image of a surface of an object; and
a processing unit for processing a captured image obtained by the image capturing unit, wherein the processing unit includes:

image obtaining means for obtaining an image to be processed partitioned by two parallel partition lines from the captured image; and

conversion means for converting the image to be processed into a rectangular image composed of pixels in a rectangular array corresponding to respective positions set at predetermined intervals along one of the two partition lines of the image to be processed and respective positions set at predetermined intervals along normal lines orthogonal to the partition lines from the respective positions up to the other partition line.

27. The image processing device according to claim 26, wherein the conversion means converts the image to be processed into a rectangular image composed of pixels in a rectangular array corresponding to respective positions set at predetermined intervals along the longer one of the two parallel partition lines of the image to be processed and respective positions set at predetermined intervals along normal lines orthogonal to the partition lines from the respective positions up to the shorter partition line.

28. The image processing device according to claim 26 to 27, further comprising a storage unit for storing a conversion table relating the respective positions along the

partition line in the image to be processed and pixels in one row of the rectangular image corresponding to each of all the positions set on the normal lines passing through the respective positions, wherein the conversion means
5 includes a means for determining the positions in the image to be processed corresponding to the respective pixels of the rectangular image using the conversion table.

29. A surface inspection device, comprising:
an image capturing unit for capturing an image of a
10 surface of an object; and

a processing unit for detecting a defect on the object surface by processing a captured image obtained by the image capturing unit, wherein the processing unit includes:

image obtaining means for obtaining an image to
15 be processed represented by pixel-based gray values and including a surface image of the object;

edge image specifying means for specifying an image including an edge line of the object surface image set in the image to be processed and located in an area with a
20 predetermined width in a direction orthogonal to the edge line as an edge image;

conversion means for converting the edge image into a rectangular image with a width equivalent to the predetermined width;

25 first image processing means for performing a one-dimensional image processing on the rectangular image to successively process the gray values of a plurality of pixels arranged in a direction orthogonal to a width direction of the rectangular image;

30 inverse conversion means for generating a processed edge image by inversely converting the rectangular image having the one-dimensional image processing performed thereon into an image in the original area;

second image processing means for generating a
35 processed object surface main image by performing a two-dimensional image processing on a main image obtained by

excluding the edge image from the object surface image to successively process the gray values of a plurality of two-dimensionally arranged pixels; and

defect specifying means for specifying a defect part in the processed edge image and the processed main image.

30. The surface inspection device according to claim 29 for capturing an image of a surface of a disk-shaped semiconductor wafer by the image capturing unit and detecting a defect on the semiconductor wafer surface by the processing unit, wherein:

the image obtaining means obtains an image including a surface image of the semiconductor wafer as the image to be processed;

the edge image specifying means specifies an entire or partial image in a ring-shaped area with a predetermined width in a direction orthogonal to a circular line along an edge of the semiconductor wafer surface image as the edge image;

the inverse conversion means generates a processed edge image by inversely converting the rectangular image having the one-dimensional image processing performed thereon into an entire or partial image in the original ring-shaped area; and

the second image processing means generates a processed main image by performing the two-dimensional image processing on the main image obtained by excluding the edge image from the semiconductor wafer surface image.