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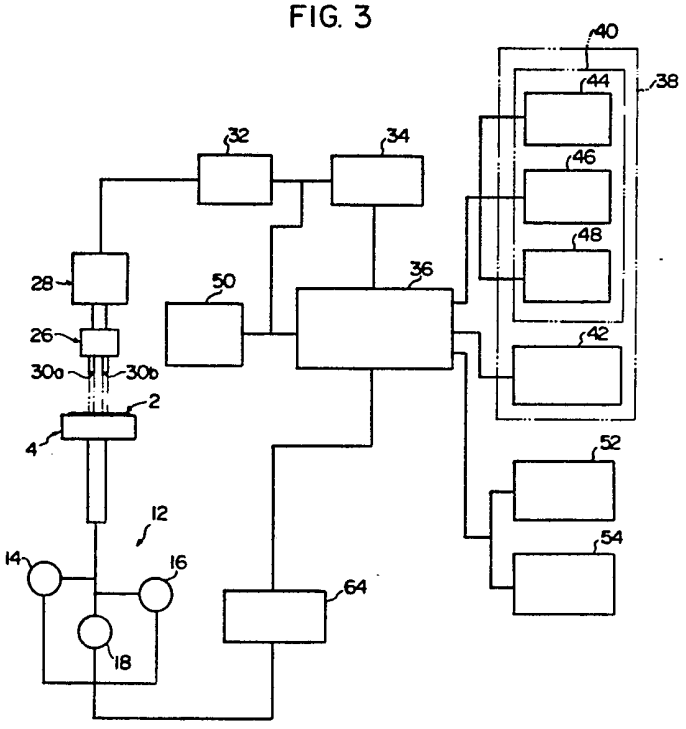
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(58) Field of search
G1A
G2A
G3N

# (54) Automatic alignment system

(57) An accurate alignment system, for positioning a semiconductor wafer (2) at a required position, comprises holding means (4) for holding the wafer (2), moving means (12) for moving the holding means (4), a camera (28) for taking at least a part of the image of the surface of the wafer (2) held on the holding means and outputting analog signals showing the densities of x-y matrix arrayed pixels. An A/D converter means (32) converts the analog signals outputted by the camera into multi-value digital signals. The system further comprises non-pattern matching type (38) and pattern matching type (54) position detecting means for detecting the positions of the straight-line areas on the wafer by using the multi-value digital signals, and movement control means (64) for actuating the moving means (12) according to the detected positions of the straight-line areas and thus positioning the wafer held on the holding means at the required position.

FIG. 3




GB 2 139 348 A

FIG. 1

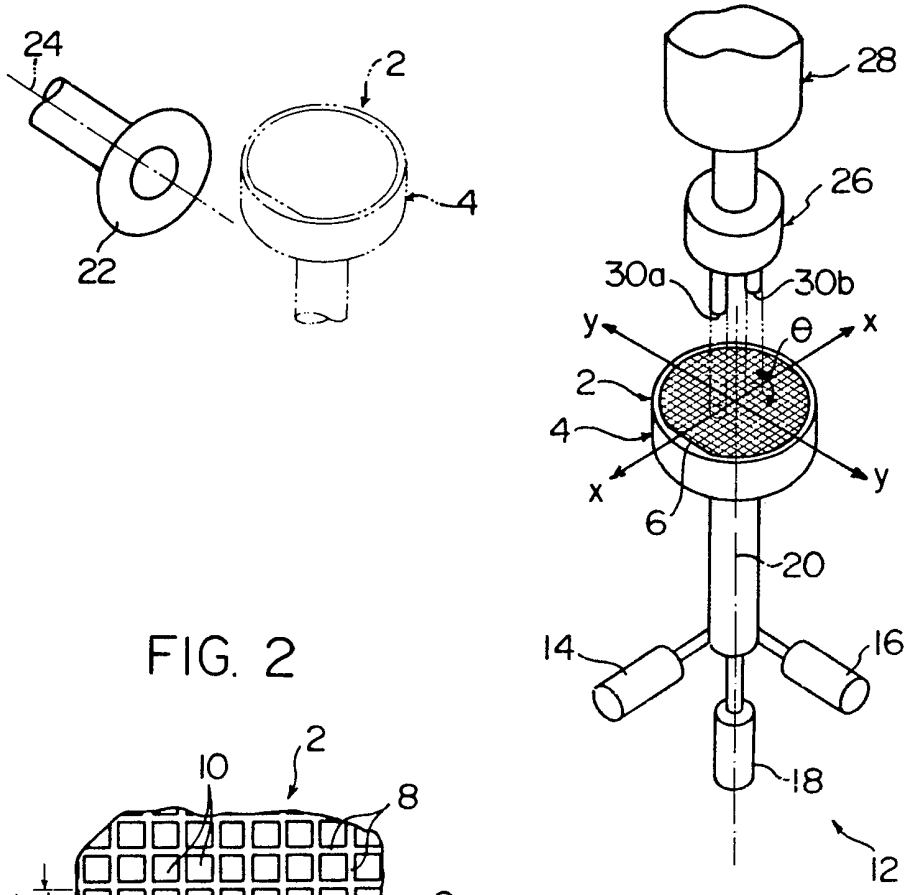



FIG. 2

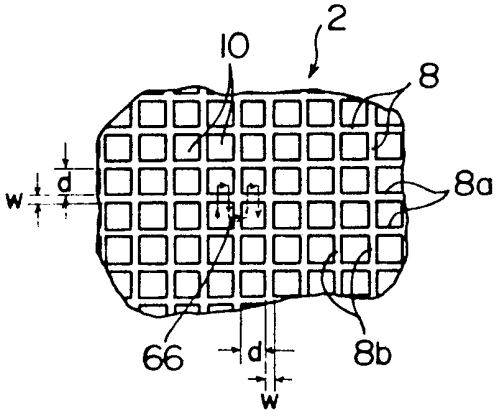


FIG. 3

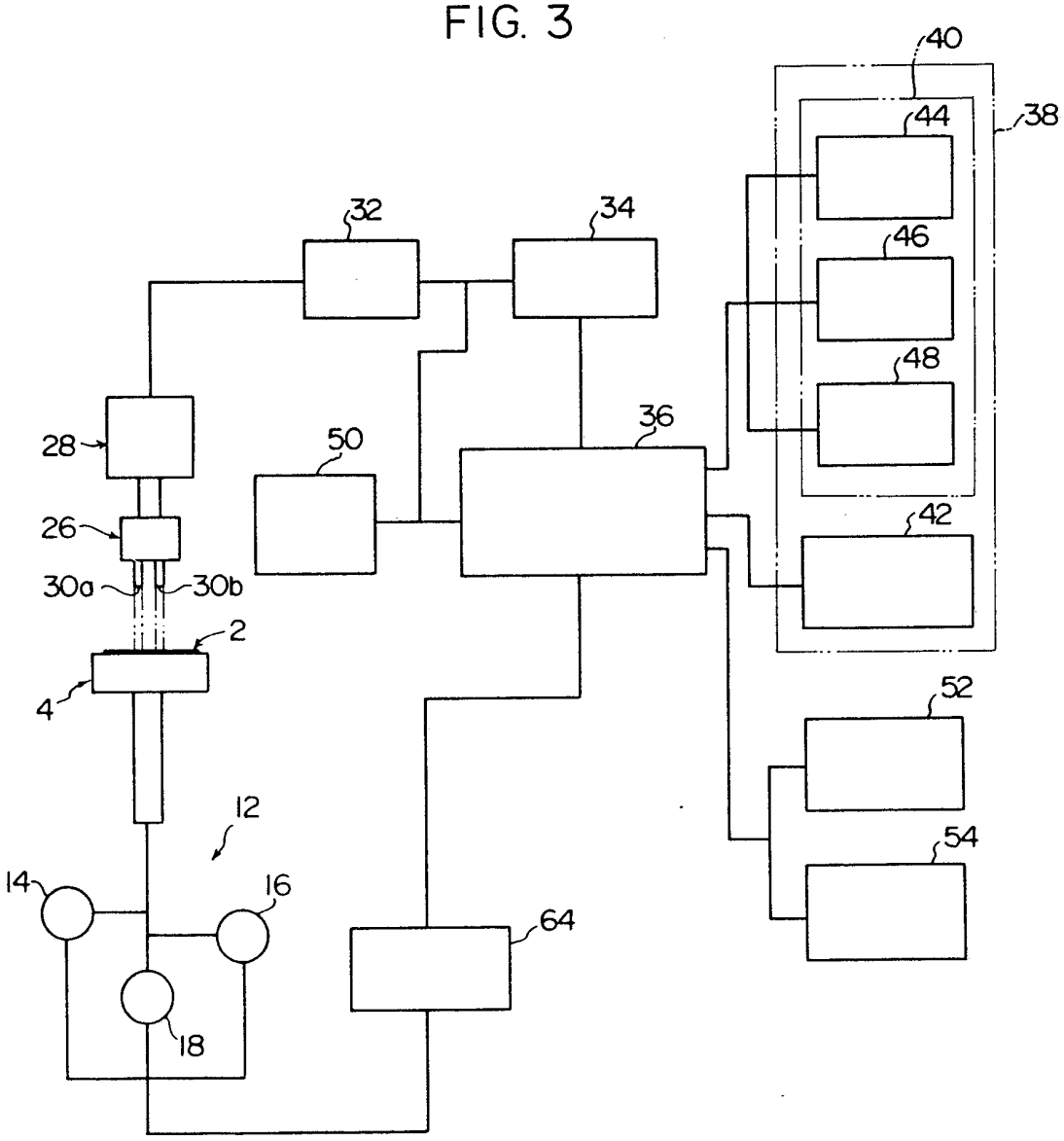


FIG. 4

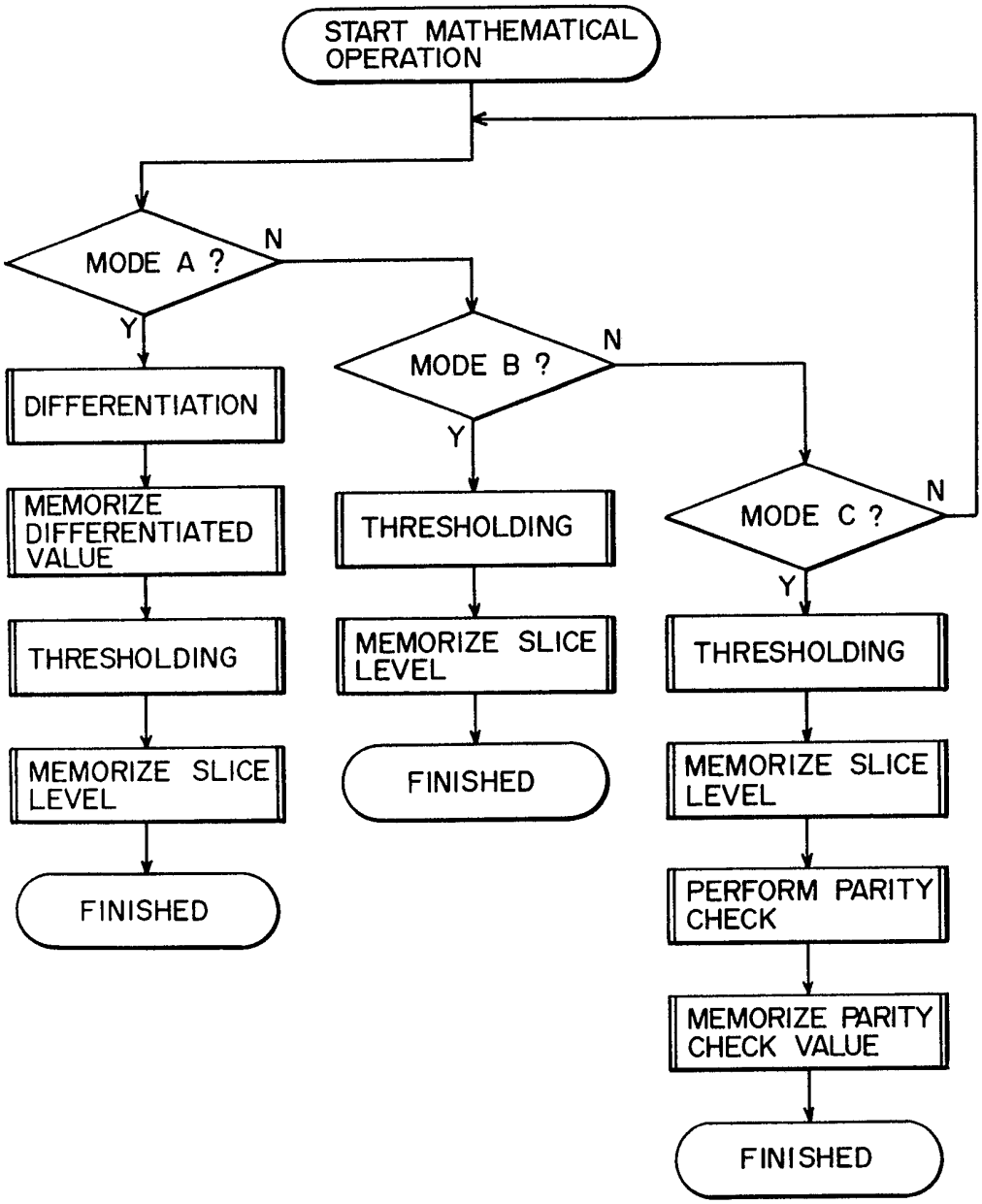

START MATHEMATICAL OPERATION
MODE A ?
N
Y
DIFFERENTIATION
MEMORIZE DIFFERENTIATED VALUE
THRESHOLDING
MEMORIZE SLICE LEVEL
FINISHED
MODE B ?
N
Y
THRESHOLDING
MEMORIZE SLICE LEVEL
FINISHED
MODE C ?
N
Y
THRESHOLDING
MEMORIZE SLICE LEVEL
PERFORM PARITY CHECK
MEMORIZE PARITY CHECK VALUE
FINISHED

FIG. 5-A

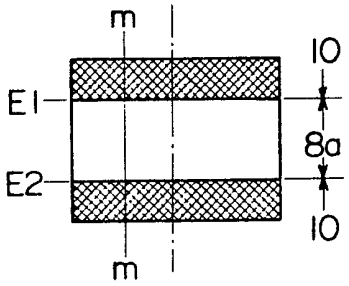



FIG. 5-B

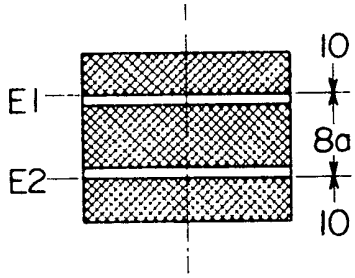



FIG. 6-A

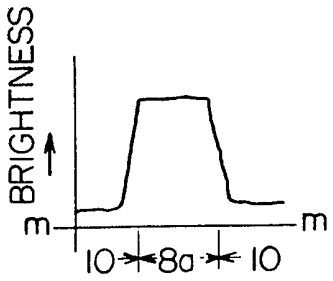



FIG. 6-B

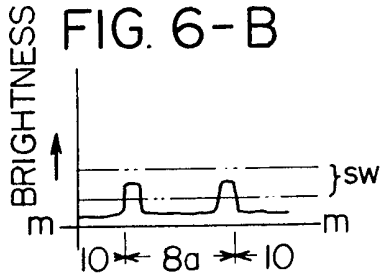



FIG. 6-C

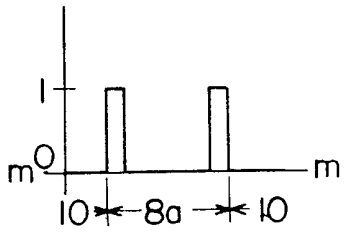


FIG. 7-A

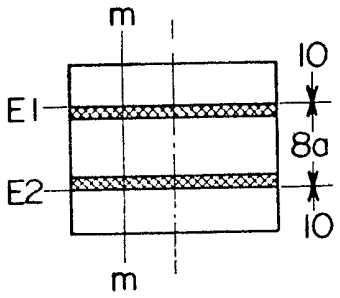



FIG. 8-A

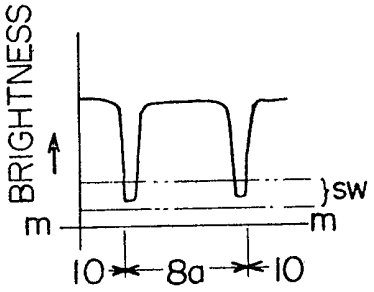



FIG. 7-B

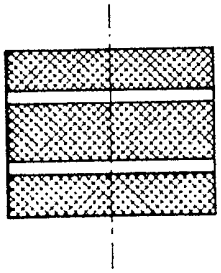


FIG. 8-B

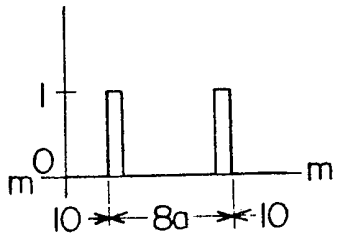


FIG. 9-A

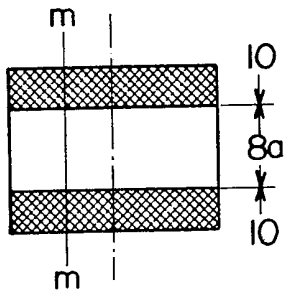



FIG. 9-B

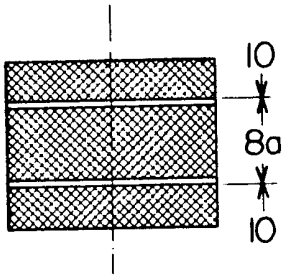



FIG. 10-A

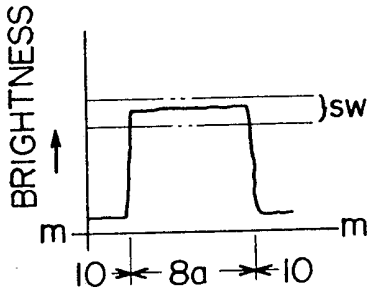



FIG. 10-B

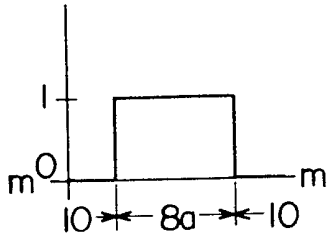



FIG. 10-C

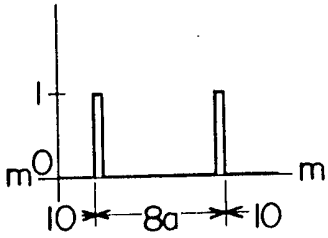


FIG. 11

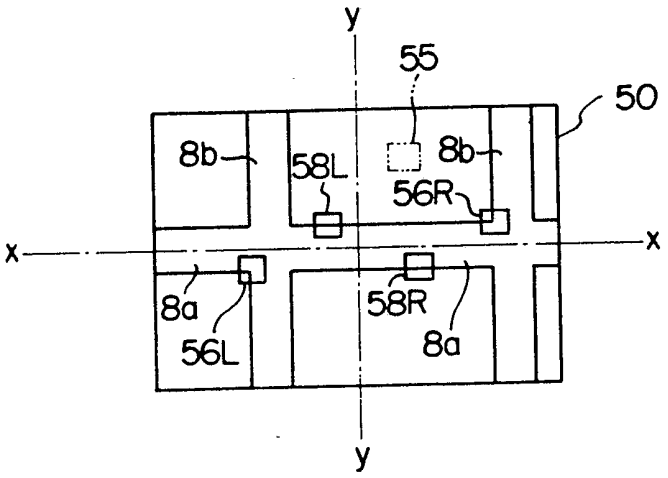

y
55
50
8b
58L
8b
56R
x
x
8a
56L
58R
8a
y

FIG. 12

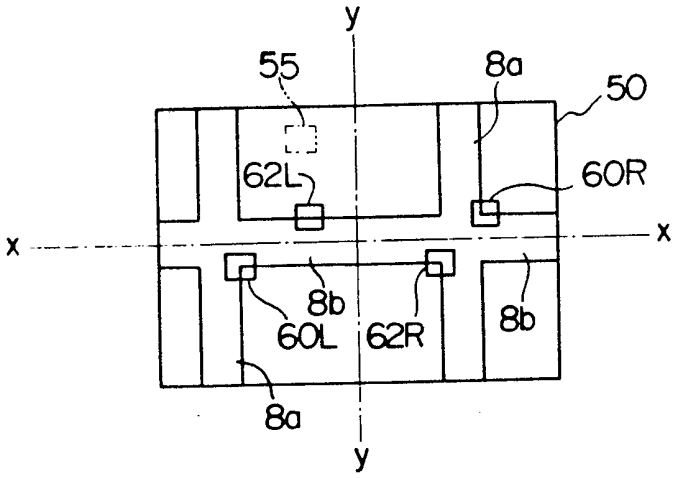
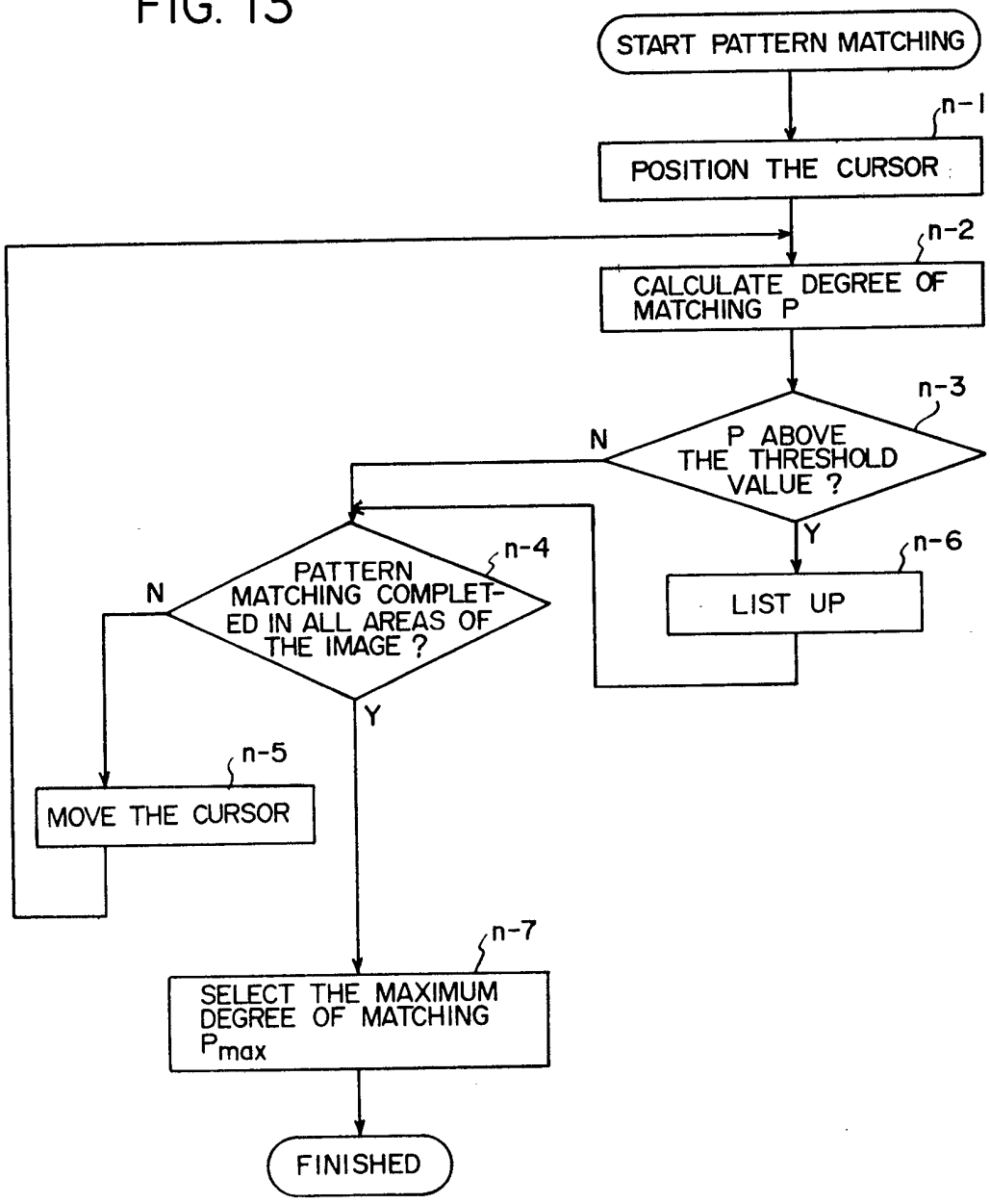

y
55
8a
50
62L
60R
x
x
8b
60L
62R
8b
8a
y

FIG. 13


START PATTERN MATCHING
n-1
POSITION THE CURSOR
n-2
CALCULATE DEGREE OF MATCHING P
n-3
P ABOVE THE THRESHOLD VALUE ?
N
Y
n-4
PATTERN MATCHING COMPLETED IN ALL AREAS OF THE IMAGE ?
N
Y
n-5
MOVE THE CURSOR
n-6
LIST UP
n-7
SELECT THE MAXIMUM DEGREE OF MATCHING Pmax
FINISHED

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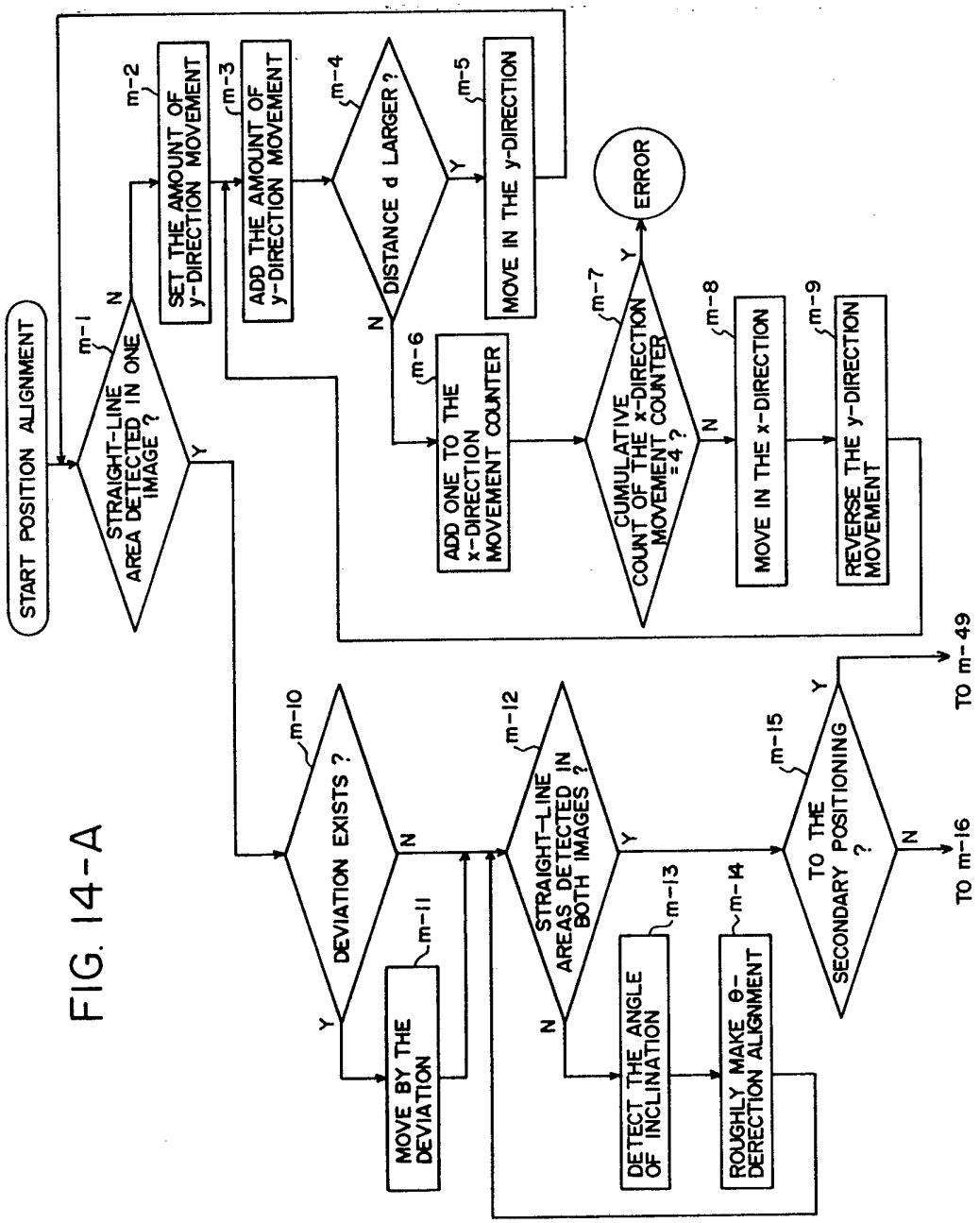



FIG. 14-A

FIG. 14-B

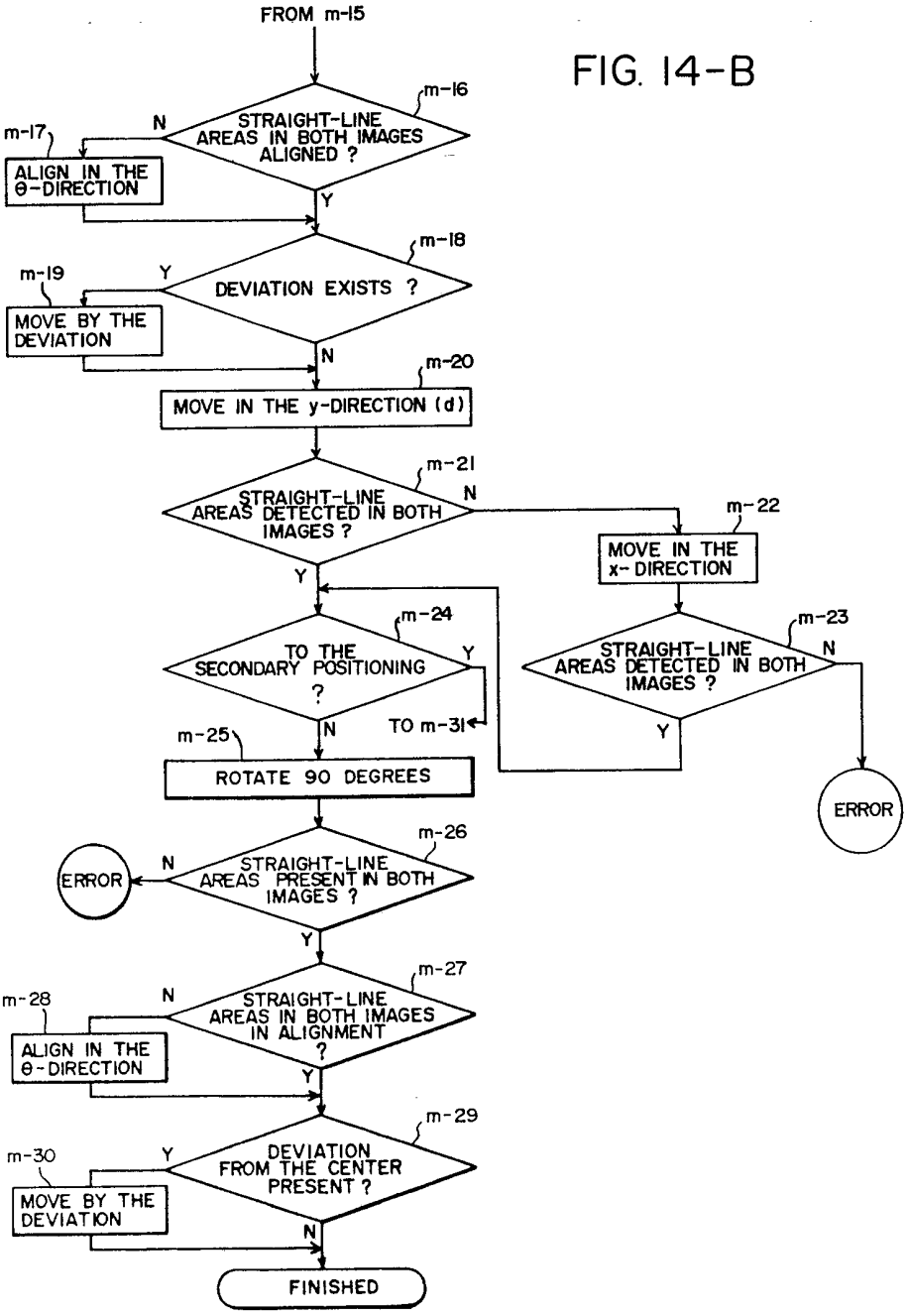

FROM m-15
m-16
STRAIGHT-LINE AREAS IN BOTH IMAGES ALIGNED ?
N
m-17
ALIGN IN THE θ-DIRECTION
Y
m-18
DEVIATION EXISTS ?
Y
m-19
MOVE BY THE DEVIATION
N
m-20
MOVE IN THE y-DIRECTION (d)
m-21
STRAIGHT-LINE AREAS DETECTED IN BOTH IMAGES ?
N
m-22
MOVE IN THE x-DIRECTION
Y
m-24
TO THE SECONDARY POSITIONING ?
Y
TO m-31
m-23
STRAIGHT-LINE AREAS DETECTED IN BOTH IMAGES ?
N
Y
ERROR
N
m-25
ROTATE 90 DEGREES
m-26
ERROR
N
STRAIGHT-LINE AREAS PRESENT IN BOTH IMAGES ?
Y
m-27
m-28
N
STRAIGHT-LINE AREAS IN BOTH IMAGES IN ALIGNMENT ?
ALIGN IN THE θ-DIRECTION
Y
m-29
m-30
Y
DEVIATION FROM THE CENTER PRESENT ?
MOVE BY THE DEVIATION
N
FINISHED

FIG. 14-C

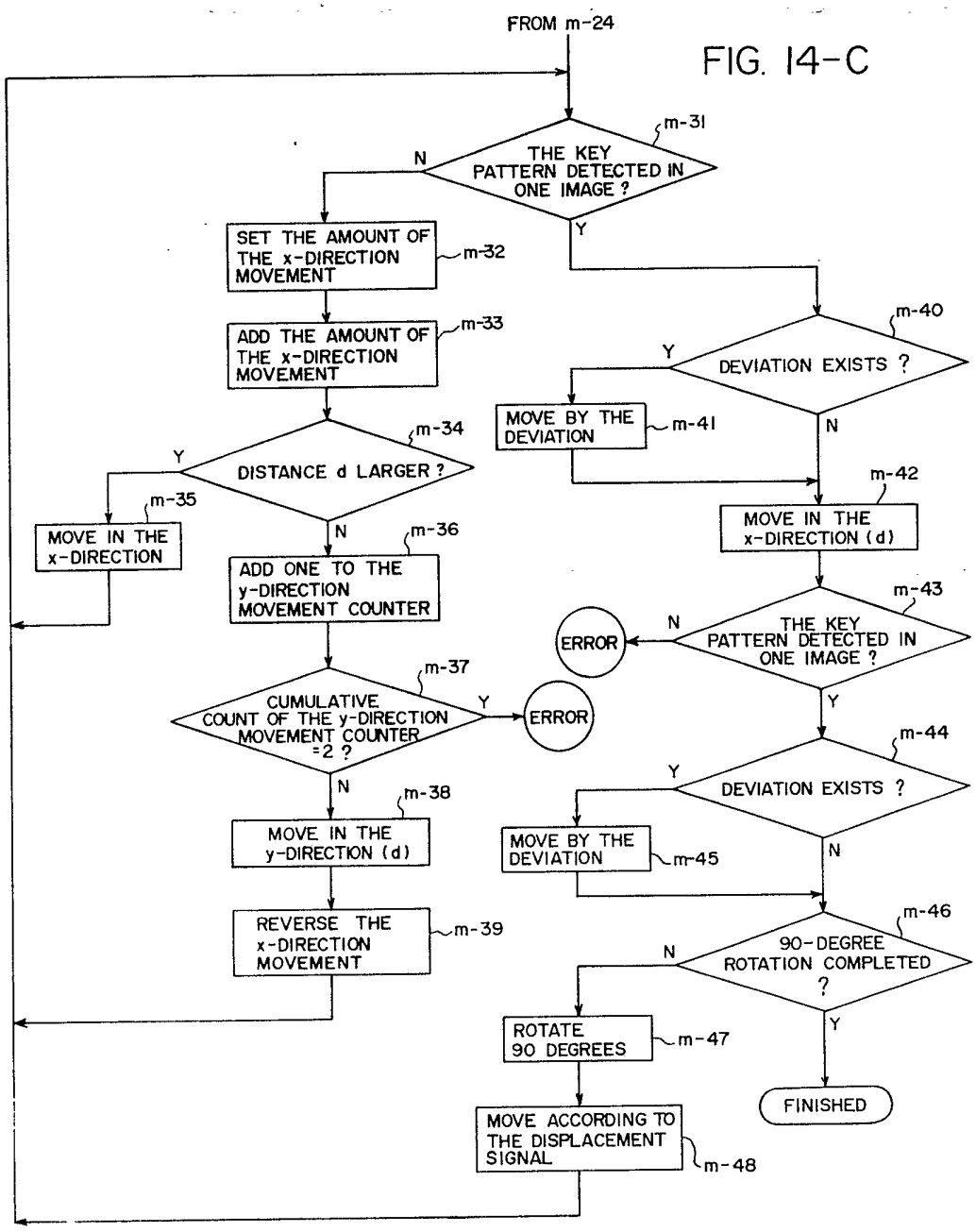
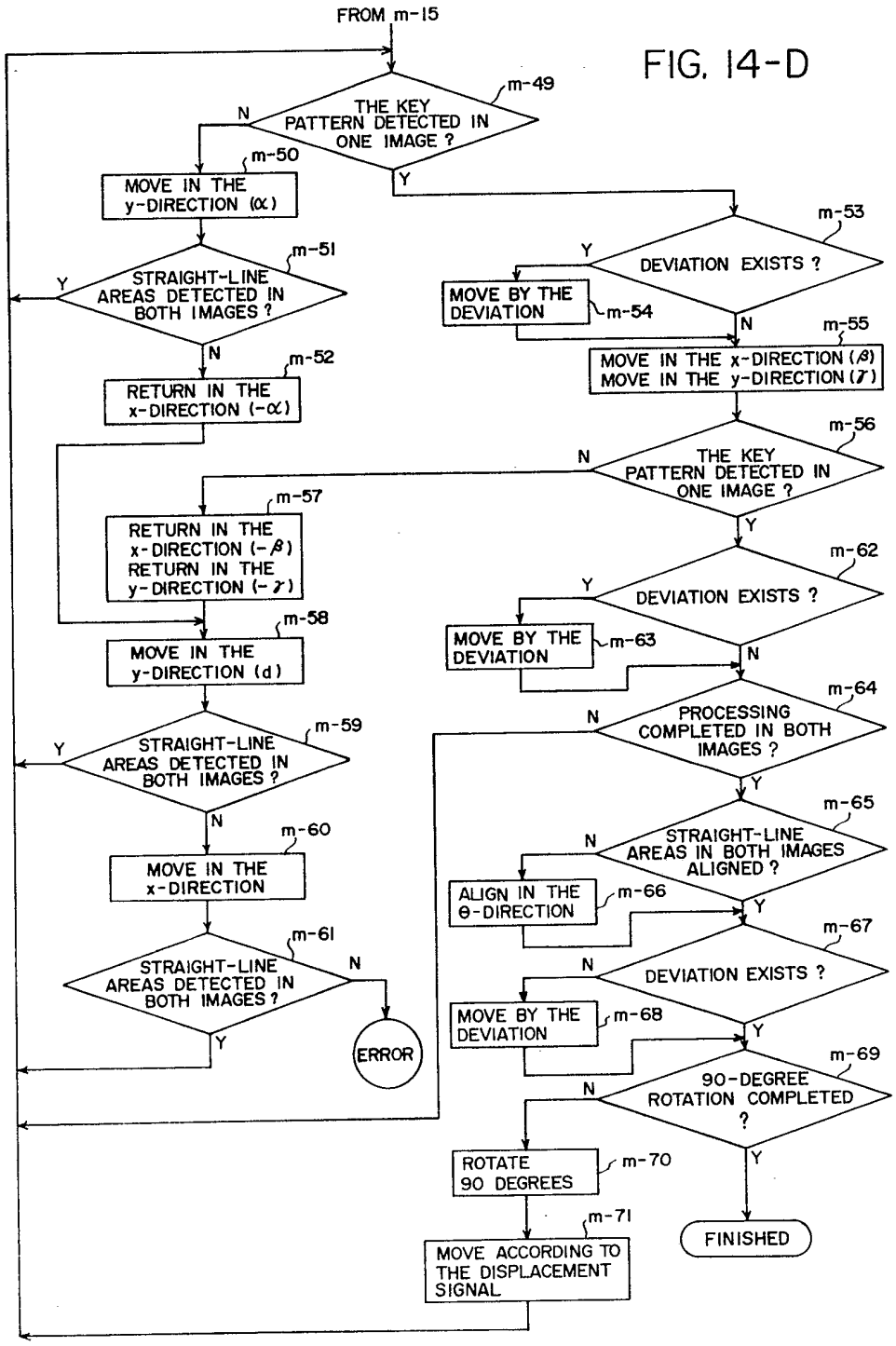

FROM m-24
m-31
THE KEY PATTERN DETECTED IN ONE IMAGE ?
N
Y
SET THE AMOUNT OF THE x-DIRECTION MOVEMENT
m-32
ADD THE AMOUNT OF THE x-DIRECTION MOVEMENT
m-33
m-34
DISTANCE d LARGER ?
Y
N
m-35
MOVE IN THE x-DIRECTION
m-36
ADD ONE TO THE y-DIRECTION MOVEMENT COUNTER
m-37
CUMULATIVE COUNT OF THE y-DIRECTION MOVEMENT COUNTER =2 ?
Y
ERROR
N
m-38
MOVE IN THE y-DIRECTION (d)
REVERSE THE x-DIRECTION MOVEMENT
m-39
m-40
DEVIATION EXISTS ?
Y
N
MOVE BY THE DEVIATION
m-41
m-42
MOVE IN THE x-DIRECTION (d)
m-43
THE KEY PATTERN DETECTED IN ONE IMAGE ?
N
ERROR
Y
m-44
DEVIATION EXISTS ?
Y
N
MOVE BY THE DEVIATION
m-45
m-46
90-DEGREE ROTATION COMPLETED ?
N
Y
ROTATE 90 DEGREES
m-47
MOVE ACCORDING TO THE DISPLACEMENT SIGNAL
m-48
FINISHED

FIG. 14-D


FROM m-15
m-49
THE KEY PATTERN DETECTED IN ONE IMAGE ?
N
Y
m-50
MOVE IN THE y-DIRECTION (α)
m-51
STRAIGHT-LINE AREAS DETECTED IN BOTH IMAGES ?
Y
N
m-52
RETURN IN THE x-DIRECTION (-α)
m-53
DEVIATION EXISTS ?
Y
N
MOVE BY THE DEVIATION
m-54
m-55
MOVE IN THE x-DIRECTION (β)
MOVE IN THE y-DIRECTION (γ)
m-56
THE KEY PATTERN DETECTED IN ONE IMAGE ?
N
Y
m-57
RETURN IN THE x-DIRECTION (-β)
RETURN IN THE y-DIRECTION (-γ)
m-58
MOVE IN THE y-DIRECTION (d)
m-59
STRAIGHT-LINE AREAS DETECTED IN BOTH IMAGES ?
Y
N
m-60
MOVE IN THE x-DIRECTION
m-61
STRAIGHT-LINE AREAS DETECTED IN BOTH IMAGES ?
N
Y
ERROR
m-62
DEVIATION EXISTS ?
Y
N
MOVE BY THE DEVIATION
m-63
m-64
PROCESSING COMPLETED IN BOTH IMAGES ?
N
Y
m-65
STRAIGHT-LINE AREAS IN BOTH IMAGES ALIGNED ?
N
Y
ALIGN IN THE θ-DIRECTION
m-66
m-67
DEVIATION EXISTS ?
N
Y
MOVE BY THE DEVIATION
m-68
m-69
90-DEGREE ROTATION COMPLETED ?
N
Y
ROTATE 90 DEGREES
m-70
m-71
MOVE ACCORDING TO THE DISPLACEMENT SIGNAL
FINISHED

SPECIFICATION

**Automatic alignment system**

This invention relates to an automatic alignment system which is suitable, although not exclusively, for the automatic accurate alignment of a semiconductor wafer having a given circuit pattern applied to its surface.

As is well known, a plurality of straight-line areas with predetermined widths which are arranged in a lattice pattern at predetermined intervals exist on the surface of a semiconductor wafer. These straight-line areas are generally called streets. A circuit pattern is applied to a plurality of rectangular areas defined by these straight-line areas. The semiconductor wafer is cut at these straight-line areas to separate the individual rectangular areas having a circuit pattern applied thereto. These separated rectangular areas are generally called chips. It is important that cutting of the semiconductor wafer should bve carried out fully accurately at the aforesaid straight-line areas. The width of each of the staight-line areas is very narrow, and is generally about several tens of $\mu$m. Hence, when such a semiconductor wafer is to be cut by a cutting means such as a diamond blade, it is necessary to align the semiconductor wafer extremely accurately with respect to the cutting means.

Automatic accurate alignment systems of various types have already been proposed and come into commercial acceptance to position a semiconductor wafer fully precisely at a required position for cutting purposes or otherwise. Such automatic accurate alignment systems are generally adapted to detect fully accurately the positions of the straight-line areas existing on the surface of a semiconductor wafer held by a holding means and move the holding means on the basis of the detected positions thereby setting the semiconductor wafer at the required position. Examples of means for detecting the positions of the straight-line areas used in the conventional automatic accurate alignment systems include (a) means utilizing laser beams, and (b) means utilizing pattern matching.

According to the means (a), laser beams are irradiated on the surface of the semiconductor wafer, and based on the difference in the state of reflection between the staight-line areas and the rectangular areas having a circuit pattern applied thereto, the positions of the straight-line areas are detected. In ordinary semiconductor wafers, the laser beams are reflected to the same path as the incident ones in the straight-line areas, whereas the laser beams are scattered on the rectangular area because of the circuit pattern applied thereto. The means (b), on the other hand, involves memorizing the pattern of a specified characteristic area. i.e. the key pattern, on the surface of a semiconductor wafer located at a predetermined position, and the position of the key pattern, and detecting the same pattern as the above pattern on the surface of the semiconductor wafer to be aligned, thereby detecting the position of a straight-line area.

The means (a), however, has the following defect or problem. Recent semiconductors include those which are dry-etched at their surfaces, or have a special test pattern or the like applied also to the aforesaid straight-line areas. In such semiconductor wafers, laser beams are scattered on the straight-line areas, and therefore, it is extremely difficult, or impossible to detect the positions of the straight-line areas.

The means (b), on the other hand, has the following defect or problem. To detect the relative position of the straight-line areas properly, pattern matching needs to be carried out over a relatively broad range on the surface of the semiconductor wafer. Hence, a considerably long period of time is required, and this becomes an obstacle to increasing of the speed of such an operation as cutting in the step of processing the semiconductor wafer.

It is a primary object of the present invention to provide a novel automatic alignment system suitable, although not exclusively, for automatic accurate alignment of a semiconductor wafer having a given pattern to its surface, which at least partly eliminates the defects or problems of conventional automatic alignment systems, especially means therein for detecting the positions of straight-line areas.

According to one aspect of this invention, there is provided an automatic accurate alignment system for positioning at a required position an object to be worked which has on its surface straight-line areas whose image density changes relatively abruptly at both side edges, said system comprising

holding means for holding the object to be worked,

moving means for moving the holding means,

camera means for taking at least a part of the image of the surface of the object held on the holding means and outputting analog signals representative of the densities of x-y matrix arrayed pixels,

A/D converter means for converting the analog signals outputted by the camera means into multi-value digital signals,

operation means for performing a mathematical operation on the multi-value digital signals to produce binary digital signals,

detecting means for detecting the position of at least one side edge of a straight-line area, and thus the position of the straight-line area, on the basis of the binary digital signals, and

movement control means for actuating the moving means according to the detected position of the straight-line area and thus positioning the object held on the holding means at the required position.

According to another aspect of this invention, there is provided an automatic accurate alignment system for positioning at a required position a semiconductor wafer having a plurality of straight-line areas arranged in a lattice pattern on its surface and a circuit pattern applied to each of a plurality of rectangular areas defined by the straight-line areas, said system comprising

holding means for holding the semiconductor wafer,

moving means for moving the holding means,

camera means for taking at least a part of the image of the surface of the semiconductor wafer held on the holding means and outputting analog signals showing the densities of x-y matrix arrayed pixels,

an image frame memory for memorizing signals corresponding to the analog signals outputted by the camera means,

a key pattern memory for memorizing signal showing a key pattern corresponding to a specified area on said surface of the semiconductor wafer located at a predetermined position and a signal showing the position of the key pattern,

pattern matching-type position detecting means for detecting the position of a straight-line area by detecting the same pattern as the key pattern in the image taken by the camera means on the basis of the signals stored in the image frame memory and the key pattern signal stored in the key pattern memory,

non-pattern matching type position detecting means for detecting the position of a straight-line area by methods other than pattern matching, and

movement control means for primarily positioning the semiconductor wafer held on the holding means by actuating the moving means according to the detection of the position of the straight-line area by the non-pattern matching type position detecting means and thereafter secondarily positioning the semiconductor wafer held on the holding means by actuating the moving means according to the detection of the position of the straight-line area by the pattern matching-type position detecting means.

A feature of this invention is the ability to provide an automatic alignment system which can detect accurately the position of straight-line areas on the surface of a semiconductor wafer even when the wafer has a dry-etched surface.

Another feature of this invention is the ability to provide an automatic alignment system which can detect accurately the positions of straight-line areas on the surface of a semiconductor wafer even when the wafer has a special test pattern or the like applied to its straight-line areas on the surface.

Another feature of this invention is the ability to provide an automatic alignment system which can detect very accurately the positions of straight-line areas present on the surface of an object to be processed such as a semiconductor wafer even when some change has occurred in the illuminating conditions, etc.

A further feature of this invention is the ability to provide an automatic alignment system which can relatively rapidly detect the positions of straight-line areas present on the surface of an object to be processed such as a semiconductor wafer.

A still further feature of this invention is the ability to provide an automatic alignment system which can align an object to be processed such as a semiconductor wafer at a required position more accurately and surely than conventional automatic accurate alignment systems.

An additional feature of this invention is the ability to provide an automatic alignment system which can position a semiconductor wafer fully rapidly at a required position while reducing the occurrence of an error substantially to zero.

The invention is described further hereinafter, by way of example only, with reference to the accompanying drawings, in which:—

*Figure 1* is a simplified perspective view schematically showing a part of a semiconductor wafer cutting apparatus equipped with one embodiment of the automatic accurate alignment system constructed in accordance with this invention;

*Figure 2* is a partial top plan view showing a part of the surface of a typical semiconductor wafer;

*Figure 3* is a block diagram showing one embodiment of the automatic accurate alignment system constructed in accordance with this invention;

*Figure 4* is a flow chart showing the procedure of a mathematical operation performed by the mathematical operation means in the automatic accurate alignment system of Fig. 3;

*Figures 5-A and 5-B* are simplified views which show the visual display by display means of typical examples of digital signals before and after the mathematical operation performed in mode A;

*Figures 6-A, 6-B and 6-C* are diagrams graphically showing typical examples of digital signals before, during and after the mathematical operation performed in mode A in Fig. 4;

*Figures 7-A and 7-B* are simplified views which show the visual display by display means of typical examples of digital signals before and after the mathematical operation performed in mode B in Fig. 4;

*Figures 8-A and 8-B* are diagrams graphically showing typcial examples of digital signals before and after the mathematical operation performed in mode B in Fig. 4;

*Figures 9-A and 9-B* are simplified view which show the visual display by display means of typical examples of digital signals before and after the mathematical operation performed in mode C in Fig. 4;

*Figures 10-A, 10-B and 10C* are diagrams graphically showing typical examples of digital signals before, during and after the mathematical operation performed in mode C in Fig. 4;

*Figures 11 and 12* are simplified views illustrating the designated positions of a specified area and a subsidiary specified area on a display panel by display means;

*Figure 13* is a flow chart showing one example of the procedure of pattern matching-type position detection performed by the pattern matching-type position detecting means in the automatic accurate alignment system of Fig. 3; and

*Figures 14-A, 14-B, 14-C and 14-D* are flow charts showing the procedure of alignment performed by the automatic accurate alignment system of Fig. 3.

## *DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS*

Now, referring to the accompanying drawings, one embodiment of the automatic accurate alignment system constructed in accordance with this invention will be described in detail.

Fig. 1 schematically shows a part of semiconductor wafer cutting apparatus equipped with one embodiment of the automatic accurate alignment system constructed in accordance with this invention. A semiconductor wafer 2 to be cut is supplied by a suitable supply means (not shown) of a type known *per se* and placed on a holding means 4. At this time, the wafer 2 is placed on the holding means 4, not fully accurately but within a certain range of errors, for example, by utilizing an orientation flat 6 present in the wafer 2. In more detail, as shown in Fig. 2, a plurality of straight-line areas 8 arranged in a lattice pattern exist on the surface of the wafer 2. These straight-line areas 8, or known in the art as streets, are arranged at a predetermined distance d from each other with a predetermined width w. The width of a straight-line area 8a extending in a given direction does not have to be always substantially equal to that of a straight-line area 8b extending in a direction perpendicular to the given direction, but the width of any of these streets is generally on the order of several tens of $\mu$m. Furthermore, the distance between the adjoining straight-line areas 8a extending in the given direction need not to be always equal to that between the adjoining straight-line areas 8b extending in a direction perpendicular to the given direction. Thus, in an ordinary wafer 2, a plurality of rectangular areas 10 are defined by the straight-line areas 8 (8a and 8b). A required circuit pattern is applied to these rectangular areas 10. By utilizing the orientation flat 6, the wafer 2 is placed on the holding means 4 such that either the straight-line areas 8a or the straight-line areas 8b (the straight-line areas 8a in the illustrated embodiment) are within an inclination angle range of, for example, about $\pm 1.5$ to $\pm 3.0$ degrees to a predetermined reference direction, i.e., the x-direction (Fig. 1).

Further, with reference to Fig. 1, the holding means 4 which may be of a known type surely holds the wafer 2 onto its surface by vacuum attraction, etc. The holding means 4 is mounted by a suitable supporting mechanism (not shown) so that it can move freely in the x-, y- and $\theta$-directions. A moving means 12 is drivingly connected to the holding means 4 to move it very precisely in a required manner. In the illustrated embodiment, the moving means 12 is comprised of an x-direction moving source 14, a y-direction moving source 16 and a $\theta$-direction moving source 18. The x-direction moving source 14 conveniently constructed of a pulse motor, when actuated, moves the holding means 4 a predetermined distance in the x-direction with an accuracy of, for example, about 1$\mu$m. The y-direction moving means conveniently constructed of a pulse motor, when actuated, moves the holding means a predetermined distance in the y-direction, i.e. a direction perpendicular to the x-direction, with an accuracy of, for example, about 1$\mu$m. The $\theta$-direction moving source 18 which is likewise constructed conveniently of a pulse motor moves the holding means 4 by a given angle, namely rotates the holding means 4 about its central axis 20, with an accuracy of, for example, 0.0015° when it is actuated.

A rotating blade 22 preferably formed of bonded diamond abrasive is provided in the illustrated semiconductor wafer cutting apparatus. The rotating blade 22 constituting wafer cutting means is mounted such that it can freely rotate about the central axis 24 which is substantially parallel to the y-direction, and can freely move in the x-direction. It is rotated at a predetermined speed by a suitable drive source (not shown) such as an AC motor, and is reciprocated in the x-direction at a predetermined speed by a suitable drive source (not shown) such as a DC motor.

In the illustrated semiconductor wafer cutting apparatus, the wafer 2 is placed on the holding means 4 by the supply means (not shown) while the holding means 4 is disposed in a supply and discharge zone which corresponds to the position shown by a solid line in Fig. 1 or its vicinity. Then, as will be described in detail hereinafter the position of the holding means 4 is finely adjusted so that the wafer 2 held on the holding means 4 is aligned very accurately at a predetermined position with respect to the rotating blade 22. Then, the holding means 4 is advanced a predetermined distance in the y-direction to position the holding means 4 and the wafer 2 held on its upper surface at a cutting start zone adjacent to the rotating blade 22 as shown by chain lines in Fig. 1. Thereafter, while the rotating blade 22 is rotated, a cutting movement in the x-direction by which the wafer 2 is put in condition for undergoing the action of the blade 22 being rotated, and a so-called index movement by which the holding means 4 is moved in the y-direction by an amount corresponding to the distance d + w (Fig. 2) between the adjoining straight-line areas 8 existing on the surface of the wafer 2 are alternately effected. As a result, the wafer 2 is cut along the straight-line areas 8b (or 8a) existing on its surface. Subsequently, the holding means 4 is moved by an angle of 90 degrees in the $\theta$-direction about the central axis 20, and then the cutting movement and the index movement are performed alternately to cut the wafer 2 along the straight-line areas 8a (or 8b) existing on its surface. The holding means 4 is then moved backward a predetermined distance in the y-direction and returned to the supply and discharge zone. The cut wafer 2 is discharged from the holding means 4 by a suitable discharge means (not shown) which may be of any type known *per se*, and the next wafer 2 is placed on the holding means 4 by the supply means (not shown). As is well known to those skilled in the art, the cutting of the wafer 2 by the rotating blade 22 is performed not over the entire thickness of the wafer 2 but in such a manner as to leave a very small non-cut thickness, whereby the rectangular areas 10 (Fig. 2) can be prevented from being completely separated from each other (in which case subsequent application of some force breaks the remaining non-cut portion to separate the rectangular areas 10 completely and form chips). Alternatively, an adhesive tape may be applied in advance to the back surface of the wafer 2 so that even when the wafer 2 is cut over its entire thickness, the rectangular areas 10 will not be separated from each other (in which case subsequent peeling of the adhesive tape results in complete separation of the rectangular areas and formation of chips).

Further, with reference to Fig. 1, the illustrated embodiment includes a stationary magnifying optical means 26 located above the holding means 4 and the wafer 2 held on its surface when the holding means 4 is disposed in the supply and discharge zone, and a camera means 28 optically connected to the magnifying optical means 26. The magnifying optical means 26 illustrated in the drawing is constructed of a binocular microscope having two light-incoming openings 30a and 30b spaced from each other a suitable distance of, for example, about 40 mm in the x-direction. Hence, the images of two portions of the surface of the wafer 2 on the holding means 4 which are spaced from each other in the x-direction by a predetermined distance are input into the magnifying optical means 26 through the openings 30a and 30b, magnified at a predetermined ratio and sent to the camera means 28 as split images. The magnification ratio achieved by the magnifying optical means 26 may be about 20, for example. If desired, a variable magnification optical means may be used which can vary the magnification stepwise or continuously. The camera means 28 may be of any type which can output an analog signal showing the density of x-y matrix arranged pixels according to the images taken. Preferably, it is constructed of a solid-state camera, particularly a solid camera having a plurality of image sensor elements such as CCDs, CPDs or MOSs arranged in an x-y matrix. In the illustrated embodiment, the camera means 28 is constructed as a solid-state camera having 256 × 256 CCDs arrayed in a matrix. The image which has entered the left opening 30a of the magnifying optical means 26 is input into the 128 × 256 CCDs located on the left half portion of the 256 × 256 CCDs, and the image which has entered the right opening 30b is input into the remaining 128 × 256 CCDs located in the right half portion. Each of the 256 × 256 CCDs produces an analog signal having a voltage corresponding to the grey level of a pixel input thereinto. Conveniently, an automatic gain adjusting means (not shown) known *per se* and capable of automatically adjusting the gain of an output analog signal according to the actual density of the image taken by the camera means is built in, or attached to, the solid-state camera having 256 × 256 CCDs.

With reference to Fig. 3 which is a block diagram showing various electronic or electrical means provided in relation to the camera means 28, output analog signals of the camera means 28 are input into an A/D (analog/digital) converter means 32 which convert the input analog signals into multi-value digital signals which may, for example, be 8-bit digital signals (therefore, $2^8 = 256$ levels). The multi-value digital signals are fed to an image frame memory 34 and memorized there. The image frame memory 34 in the illustrated embodiment is comprised of RAM which as a storage capacity of at least 256 × 256 × 8 bits and therefore can memorize 256 × 256 eight-bit digital signals corresponding respectively to the densities of 256 × 256 pixels input into 256 × 256 CCDs in the solid-state camera constituting the camera means 28.

In the illustrated embodiment, a central processing unit (CPU) 36 which may be a microprocessor having a plurality of RAMs built therein is connected to the image frame memory 34, and a non-pattern matching type position detecting means shown generally at 38 is connected to the central processing unit 36.

The illustrated non-pattern matching type position detecting means 38 includes an operation means 40 and a straight-line area detecting means 42. The operation means 40 includes a differentiation circuit 44, a thresholding circuit 46 and a parity check circuit 48. The operation means 40 performs a mathematical operation on the aforesaid multi-value digital signals in the image frame memory 34 by any one mode selected by the operator from modes A, B and C to be described below.

With reference to Fig. 4, which is a flow chart of a mathematical operation, taken in conjunction with Fig. 3, the mathematical operation will be described. When mode A is selected, the multi-value digital signals memorized in the image frame memory 34 are first differentiated by the differentiation circuit 44 in order to emphasize changes in the densities of the images taken by the camera means. The differentiation can be performed by any of various differentiation methods capable of emphasizing changes in density in the x-direction and/or y-direction, or in other directions, for example a differentiation method using any one of the various first-order differentiation operators, i.e. so-called differentiation masks described at pages 46–48 of "Theory of Image Recognition" (Japanese-language publication), by Makoto Nagao, in Information Engineering Lecture 16, published by Corona Sha. As one example of a differentiating procedure which is relatively simple and therefore can be performed at fully high speeds and can fully achieve the desired object, there can be cited a differentiation procedure by which a change in density in either one of the x-direction and the y-direction (the y-direction in the illustrated embodiment) is emphasized. In this differentiation procedure, the following typical differentiation mask can be used.

| | | |
|---|---|---|
| −1 | −1 | −1 |
| 0 | 0 | 0 |
| 1 | 1 | 1 |

According to the differentiation procedure using this differentiation mask, when the values of the multi-value digital signals memorized in the image frame memory 34 are as shown below

| y \ x | m − 1 | m | m + 1 |
|---|---|---|---|
| n − 1 | A | B | C |
| n | D | E | F |
| n + 1 | G | H | I |

$f(m, n) = |-A-B-C+G+H+I|$ is calculated as a differentiated value f(m, n) at address (x = m, y = n). Thus, the 256 × 256 multi-value digital signals stored in the image frame memory 34 are converted to 254 × 254 differentiated values f(m, n). The 254 × 254 differentiated values so calculated are, for example, 8-bit multi-value digital signals. These differentiated multi-value digital signals are memorized by accumulating them in the image frame memory 34 in place of the multi-value digital signals stored in the image frame memory 34. If desired, a memory having a memory capacity of at least 254 × 254 × 8 bits may be provided independently of the image frame memory 34, and the differentiated multi-value digital signals may be memorized in this different memory.

Then, the thresholding circuit 46 thresholds the differentiated multi-value digital signals memorized in the image frame memory 34 with a predetermined slice level to form binary digital signals. The binary digital signals so formed are memorized together with their addresses in the x-direction and the y-direction in RAM built in the central processing unit 36. The slice level at the time of thresholding can be preset by the operator. Or it is possible to detect the maximum of the 254 × 254 differentiated values so that the maximum of these may be extracted, and automatically set a slice level ranging from a value slightly smaller than the maximum value to a value slightly larger than the maximum value. In this case, if the slice

center level is too large, straight lines cannot be detected in the operation of detecting straight-line areas to be described hereinafter. If, on the other hand, the slice center level is too small, many pseudo straight lines are detected in the operation of detecting straight-line areas to be described hereinafter. Accordingly, by changing the slice level little by little, the optimum slice level can be automatically selected (self-learning of the system). Once the optimum slice level has been selected, it does not need to be varied unless the wafer 2 (Fig. 1) to be aligned is changed to another type.

In the illustrated embodiment, a display means 50 is also provided which is constructed conveniently of a cathode ray tube (CRT). The display means visually displays selectively an image corresponding to the multi-value digital signal outputted by the A/D converter means 32, the binary digital signal stored in RAM in the central processing unit 36 or the signal stored in the key pattern memory to be described, according to the manual operation of a switching means (not shown). The illustrated display means 50 displays at its left half portion an image corresponding to the image input into the camera means 28 from the left-side opening 30a of the magnifying optical means 26 and at its right half portion an image corresponding to the image input into the camera means 28 from the right-side opening 30b of the magnifying optical means 26, each in a total magnification of about 260.

For better understanding, the above mathematical operation in mode A will be described below in relation to the images displayed on the display means 50. As a typical example, let us consider the case wherein an image displayed on the screen of the display means 50 as an image corresponding to the multi-value digital signal output by the A/D converter means 32 (hence, an image to be taken by the camera means 28) contains a straight-line area 8a located nearly centrally in the y-direction, and the density of the image is relatively low in the straight-line area 8a and is relatively high in the parts above and below the straight-line area 8a, i.e. the rectangular areas 10 having a given circuit pattern applied thereto, because of the pattern applied, as shown in Fig. 5-A (in Fig. 5-A, cross hatchings are used to show a high image density). In this case, the multi-value digital signals output by the A/D converter means 32 which are along the line m-m of Fig. 5-A, i.e. along addresses in which the address in the x-direction is $x = m$ and remains unchanged and the address in the y-direction varies from $y = 1$ to $y = 256$, are as graphically displayed in Fig. 6-A. When these multi-value digital signals are differentiated in order to emphasize changes in density in the y-direction, the multi-value digital data shown in Fig. 6-A are converted to differentiated multi-value digital signals graphically displayed in Fig. 6-B. Such differentiated multi-value digital signals are relatively large in both side edges of the straight-line area 8a i.e. the upper side edge E1 and the lower side edge E2, where the change of the density in the y-direction is abrupt, and are relatively small in the other parts where the change of the density in the y-direction is relatively slow or substantially absent. When the differentiated multi-value digital signals shown in Fig. 6-B are then thresholded with a predetermined slice level sw to produce binary digital signals, they become "1" in the upper side edge E1 and the lower side edge E2 of the straight-line area 8a, and "0" in the other parts, as graphically displayed in Fig. 6-C. When the binary digital signals obtained by thresholding with the predetermined slice level sw, i.e. signals memorized in RAM built in the central processing unit 36, are sent to the display means 48 and visually displayed, there appears an image which has a low image density, and therefore a high brightness, only at the upper side edge E1 and the lower side edge E2 of the straight-line area 8a, and a high image density, and therefore a low brightness, at the other parts, as shown in Fig. 5-B (in Fig. 5-B, too, cross hatchings are used to show a high image density).

In the mathematical operation in mode A described hereinabove, differentiation is performed to emphasize a change in the density of an image taken by the camera means, and by thresholding the differentiated multi-value digital signals, binary digital signals are produced which clearly show the upper side edge E1 and the lower side edge E2 of the straight-line area 8a. It will be readily seen therefore that even when the conditions for illuminating the surface of the wafer 2 (Fig. 1) held on the holding means 4 or the reflectance of the surface of the wafer 2 slightly changes and the absolute value of the density of the input image changes, binary digital signals can be surely produced which clearly show the upper side edge E1 and the lower side edge E2 of the straight-line area 8a. As another noteworthy point, when a special test pattern is applied to the straight-line area 8a or when straight lines or straight-line areas which abruptly change in density exist in the circuit pattern applied to the rectangular area 10, the aforesaid binary digital signals clearly show not only the upper side edge E1 and the loweer side edge E2 but also pseudo straight lines. It has been confirmed by the experiments of the present inventors, however, that when an operation of detecting the position of a straight-line area is performed in the manner to be described below subsequent to the mathematical operation in mode A, it is possible to detect the upper side edge E1 and the lower side edge E2 of the straight-line area 8a, therefore the position of the straight-line area 8a, surely and easily even in the above case with wafers in which the image density changes relatively abruptly in both side edges E1 and E2 of the straight-line area 8a, therefore with most of the wafers now in

existence.

When mode B is selected, it will be understood from the flow chart shown in Fig. 4 that the 256 × 256 multi-value digital signals input into the image frame memory 34 from the A/D converter means 32 and memorized in the memory 34 are directly thresholded with a predetermined slice level by the thresholding circuit 46, and as a result, 256 × 256 binary digital signals are produced. The binary digital signals are memorized together with their addresses in the x-direction and y-direction in RAM built in the central processing unit 36. The slice level at the time of thresholding can be pre-set by the operator. Or the optimum slice level can be automatically selected also by the self-learning of the system.

In relation to an image displayed on the display means 50, the mathematical operation in mode B is described below. The mathematical operation in mode B which is performed more rapidly and in a much simpler manner than the operation in mode A is especially effective when an image displayed on the screen of the display means 50 as an image corresponding to the multi-value digital signal output by the A/D converter means 32 (therefore, an image to be taken by camera means 28) has a relatively high (or low) density only at both side edges, i.e. the upper side edge E1 and the lower side edge E2, of the straight-line area 8a, and a relatively low (or high) density at the other parts, i.e. the central portion of the straight-line area 8a and the rectangular areas 10 existing above and below the straight-line area 8a, as shown in Fig. 7-A (in Fig. 7-A, cross hatchings are used to show a high image density). In the case of the image shown in Fig. 7-A, the multi-value digital signals output by the A/D converter means 32 which are along the line m-m in Fig. 7-A, i.e. along addresses in which the address in the x-direction is $x = m$ and does not vary but the address in the y-direction varies from $y - 1$ to $y = 256$, are as graphically shown in Fig. 8-A. When such multi-value digital signals are directly thresholded with a predetermined slice level sw, they become "1" only at the upper side edge E1 and the lower side edge E2 of the straight-line area 8a, and "0" at the other parts. When the binary digital signals obtained by thresholding with the predetermined slice level sw, i.e. the signals memorized in RAM built in the central processing unit 36, are sent to the display means 50 and visually displayed, there appears an image which, as shown in Fig. 7-B, has a low density, and therefore a high brightness, only at the upper side edge E1 and the lower side edge E2 of the straight-line area 8a, and a high image density, and therefore a low brightness, at the other parts (in Fig. 7-B, cross hatchings are applied to show a high image density).

The mathematical operation in mode B described above has the advantage of being much simpler and more rapid than the mathematical operation in mode A described earlier. Experiments of present inventors, however, have shown that the operation in mode B is effective for a specific type of wafers in which as shown in Fig. 7-A, the image density at the upper side edge E1 and the lower side edge E2 of the straight-line area 8a differ comparatively markedly from that at the other parts, but when it is applied to other various types of wafers, it is impossible or considerably difficult to detect the positions of the upper side edge E1 and the lower side edge E2 of the straight-line area 8a, and therefore the position of the straight-line area 8a. Furthermore, as will be readily seen, when the conditions for illuminating the surface of the wafer 2 (Fig. 1) held on the holding means 4 or the reflectance of the surface of the wafer 2 changes to a comparatively great extent and the absolute value of the density of the image taken by the camera means changes, it tends to become impossible or considerably difficult according to mode B to detect the position of the straight-line area 8a.

The operation according to mode C will now be described. In this mode, as shown in the flow chart of Fig. 4, the 256 × 256 multi-value digital signals input into the image frame memory 34 from the A/D converter means 32 and memorized in the memory 34 are first threshold with a predetermined slice level by the thresholding circuit 46 to produce 256 × 256 intermediate binary digital signals. The 256 × 256 intermediate binary digital signals are memorized together with addresses in the x-direction and y-direction in RAM built in the central processing unit 36. The slice lelvel during the thresholding can be preset by the operator as in modes A and B, or the optimum slice level can be automatically selected by the self-learning of the system. In mode C, the parity check circuit 48 performs parity check on the intermediate binary digital signals memorized in RAM3 so as to extract parts at which the intermediate binary digital signals change from "1" to "0" or from "0" to "1". When the intermediate binary digital signals memorized in RAM3 have the following numerical values

| y \ x | m | m + 1 |
|---|---|---|
| n | A | B |
| n + 1 | C | |

the parity check calculates "0" only when A = B = C and "1" in other cases as a parity check value P(m, n) at address (x = m, y = n). Thus, the 256 × 256 intermediate binary digital signals memorized in RAM are converted to 255 × 255 binary digital signals by the parity check. The 255 × 255 binary digital signals obtained by the parity check are memorized by accumulating then in RAM in place of the binary digital signals before the parity check memorized in RAM. If desired, separate RAMs may be used, instead of one common RAM, to store the binary digital signals before and after the parity check.

The mathematical operation in mode C will be described in relation to the image displayed on the display means 50. The mathematical operation in mode C is based on so-called boundary extraction, and is especially effective when an image displayed on the screen of the display means 50 as an image corresponding to the multi-value digital signal output by the A/D converter means 32 (hence, the image to be taken by the camera means 28) has a sufficiently uniform image density throughout the straight-line area 8a and shows a comparatively marked difference in image density between the straight-line area 8a and the rectangular areas 10 existing above and below it, as illustrated in Fig. 9-A. In the image shown in Fig. 9-A, the straight-line area 8a has a sufficiently uniform relatively low image density throughout and the rectangular area 10 has a relatively high image density (in Fig. 9-A, cross hatching are used to show a high image density). In the case of the image shown in Fig. 9-A, the multi-value digital signals output by the A/D converter means 32 which are along the line m-m of Fig. 9-A, i.e. along addresses in which the address in the x-direction is x = m and does not vary but the address in the y-direction varies from y = 1 to y − 256, are as graphically displayed in Fig. 10-A. When these multi-value digital signals are converted to the intermediate binary digital signals by thresholding with the predetermined slice level sw, they become "1" in the straight-line area 8a and "0" in the rectangular area 10, as graphically shown in Fig. 10-B. When the intermediate binary digital signals are then subjected to parity check as stated above, they become "1" only at the upper side edge E1 and the lower side edge E2 of the straight-line area 8a and "0" at the other parts as graphically shown in Fig. 10-C. When the binary digital signals obtained by the parity check and memorized in RAM built in the central processing unit 36 are fed to the display means 50 and visually displayed, there appears an image which has a low image density, and therefore a high brightness, only at the upper side edge E1 and the lower side edge E2, and a high image density, and therefore a low brightness, at the other parts as shown in Fig. 9-B (in Fig. 9-B, cross hatchings are used to show a high image density).

Experiments by the present inventors have shown that for wafers in which no specil test pattern is applied to straight-line areas 8a and the straight-line areas 8a have a sufficiently uniform image density throughout, selection of mode C generally permits simpler and more rapid detection of the positions of the upper side edge E1 and the lower side edge E2, and therefore the position of the straight-line area 8a, in the operation of detecting the position of a straight-line area to be described hereinafter than does selection of mode A. However, when mode C is selected for wafers in which a special test pattern is applied to straight-line areas 8a, selection of mode C makes it impossible or considerably difficult to detect the position of the straight-line area 8a. Furthermore, it will be readily understood that when mode C is selected, the detection of the position of the straight-line area 8a tends to become impossible or considerably difficult when the conditions for illuminating the surface of the wafer 2 (Fig. 1) held on the holding means 4 change relatively greatly and the absolute value of the density of the image taken by camera means changes.

In the illustrated embodiment, after the mathematical operation in mode A, B or C, the straight-line area position detecting means 42 (Fig. 3) controlled by the central processing unit 36 detects at least one side edge E1 or E2 of the straight-line area 8a on the basis of the binary digital signals memorized in RAM included in the central processing unit 36, and thus determines the position of the straight-line area 8a.

In the illustrated embodiment, the images of the two portions of the surface of the wafer 2 which are spaced from each other by a predetermined distance in the x-direction are taken by the camera means 28. Detection of the position of a straight-line area is carried out on each of the images of the two portions. In the binary digital signals memorized in RAM in the central processing unit as a result of the mathematical operation in mode A, mode B or mode C

described above, signal "ones" corresponding to the upper side edge E1 and the lower side edge E2 of the straight-line area 8a exist continuously in a predetermined direction. Based on this fact, the detecting means 42 first scans the binary digital signals stored in RAM built in the central processing unit 36 to examine whether a predetermined number or more of signal "ones" exist continuously in a predetermined direction, thus detects candidate lines of the upper side edge E1 and/or the lower side edge E2 of the straight-line area 8a, i.e. the position at which a predetermined number or more of signal "ones" exist continuously, and memorizes the positions of the candidate lines in other RAM built in the central processing unit 36. In the illustrated embodiment, there is a possibility that the straight-line areas 8a existing on the surface of the wafer 2 held on the holding means 4 are inclined at an inclination angle range of, for example, about $\pm 1.5$ to $\pm 3.0$ degrees with respect to the x-direction (Fig. 1). Accordingly, the above examination of whether signal "ones" exist continuously in a predetermined number is carried out not only by scanning the binary digital signals in the x-direction or more specifically by increasing the address in the x-direction for each address in the y-direction, but also in a region inclined by an angle range of, for example, about $\pm 1.5$ to $\pm 3.0$ degrees with respect to the x-direction. This inclination examination can be achieved by performing so-called approximate $\theta$ scan by which a plurality of addresses in the x-direction are increased for each increment of the address in the y-direction. In the illustrated embodiment, for example, the approximate $\theta$ scan by which

$$\frac{1}{\tan 0.5^\circ} = 115$$

addresses are increased in the x-direction every time one address is increased in the y-direction is a scan having an inclination angle of about 0.5 degree to the x-direction, and the approximate $\theta$ scan is carried out by changing the inclination angle for each 0.5 degree or so to the x-direction within the allowable inclination angle range of, for example, $\pm 1.5$ to $\pm 3.0$ degrees. The predetermined number of signal "ones" continuously present can be properly preset by the operator. It may, for example, be about 80 when there are 128 pixels in the x-direction of each image, as in the illustrated embodiment.

Frequently, straight-line areas exist in a circuit pattern applied to the rectangular areas 10 (Fig. 2) on the surface of the wafer 2 or a special test pattern applied to the straight-line areas 8a (or 8b) of the wafer 2. Hence, candidate lines detected as described above frequently contain not only the upper side edge E1 and the lower side edge E2 of the straight-line area 8a but also the edges of the straight-line areas of the aforesaid circuit pattern or test pattern. Hence, the detecting means 42 then determines whether each detected candidate line is actually the upper side edge E1 or the lower side edge E2 of the straight-line area 8a. If it can so determine, the position of the upper side edge E1 or the lower side edge E2 is memorized in other RAM built in the central processing unit 36. Whether a detected candidate lin is actually the upper side edge E1 or the lower side edge E2 of the straight-line area 8a can be determined in the following manner. If the detected candidate line is actually the upper side edge E1 or the lower side edge E2 of the straight-line area 8a, there naturally exists the lower side edge E2 or the upper side edge E1 of a straight-line area 8a which extends parallel to the detected candidate line and is spaced therefrom in the y-direction by a distance corresponding to the width w (Fig. 2) of the straight-line area 8a, and therefore, another detected candidate line corresponding to it exists. Based on this fact, the detecting means 42 detects the presence or absence of another candidate line extending substantially parallel and spaced by a distance corresponding to the width w of the straight-line area 8a in the y-direction, with respect to each of the candidate line memorized in RAM. Thus, the detecting means 42 determines whether each of such candidate lines is actually the upper side edge E1 or the lower side edge E2 of the straight-line area 8a. When the position of the upper side edge E1 and/or the lower side edge E2 of the straight-line area 8a is thus detected and confirmed, the detection of the position of the straight-line 8a necessarily follows.

Again, with reference to Fig. 3, a key pattern memory 52 and a pattern matching-type position detecting means 54 are also connected to the central processing unit 36.

The key pattern memory 52 which may be constructed of RAM memorizes a signal showing the pattern of a specified area on the surface of the wafer 2, i.e. the key pattern, and a signal showing the position of the key pattern. One example of a method of inputting signals into the key pattern memory 52 is as follows: In inputting signals into the key pattern memory 52, the sample wafer is placed on the holding means 4, and then the holding means 4 is moved by properly actuating an x-direction moving source 14, a y-direction moving source 16 and a $\theta$-direction moving source 18 by hand, thereby positioning the sample wafer 2 on the holding means 4 at a required position with respect to the magnifying optical means 28. In performing

this manual positioning, the multi-value digital signals outputted by the A/D converter means 32 are visually displayed by the display means 50. The operator observes the image displayed on the display means 50 and thus positions the sample wafer 2 so that as schematically shown in Fig. 11, the center line of the straight-line area 8a in the surface of the sample wafer 2 substantially corresponds with the transverse center line of the displayed image on the display means 50, i.e. the x-x line. Then in each of the left half portion and the right half portion of the displayed image on the display means 50, cursors 55 are manually positioned respectively at specified areas 56L and 56R. The cursors 55, and therefore the specified areas 56L and 56R designated by the cursors 55, may, for example, be in the form of a square having a size corresponding to $32 \times 32$ pixels (corresponding to $32 \times 32$ CCDs in the camera means 28). The specified areas 56L and 56R designated by the cursors 55 are preferably areas having a marked characteristic, for example areas located at the crossing of the straight-line area 8a and the straight-line area 8b. Then, those multi-value digital signals stored in the image frame memory 34 which correspond to $32 \times 32 = 1024$ pixels existing in the specified areas 56L and 56R are fed to, and stored in, the key pattern memory 52. Simultaneously, signals showing the positions (i.e., x- and y-coordinates) of the specified areas 56L and 56R in the image displayed on the display means 50 are also fed to, and stored in, the key pattern memory 52. Thus, the key pattern memory 52 memorizes the multi-value digital signals showing the patterns of the specified areas 56L and 56R, i.e. the key patterns, and the x- and y-coordinate signals showing the positions of the key patterns.

In a preferred embodiment, an operation of memorizing subsidiary key patterns is carried out after the aforesaid operation of memorizing the key patterns. In the operation of memorizing the subsidiary key pattern, the cursors 55 are manually positioned at suitable areas, i.e. subsidiary specified areas 58L and 58R, which are different from the specified areas 56L and 56R, at the left half portion and the right half portion of the displayed image on the display means 50, respectively. Thereafter, as in the key pattern memorizing operation described above, multi-value digital signals showing the subsidiary specified areas 58L and 58R, i.e. the subsidiary key patterns, are memorized in the key pattern memory 52. Furthermore, x- and y-coordinate signals showing the positions of the subsidiary key patterns are stored in the key pattern memory 52.

After the aforesaid operations of storing the key patterns and the subsidiary key patterns are over, the $\theta$-direction moving source 18 is manually operated to rotate the sample wafer 2 held on the holding means 4 through 90 degrees. Then, by properly actuating the x-direction moving source 14 and the y-direction moving source 16 manually as required, the sample wafer 2 is positioned so that as schematically shown in Fig. 12, the center line of the straight-line area 8b in the surface of the sample wafer 2 corresponds with the transverse center line of the displayed image on the display means 50, i.e. the x-x line. The same key pattern memorizing operation as described above is carried out. Specifically, in the left half portion and the right half portion of the displayed image on the display means 50, the cursors 55 are positioned manually at specified areas 60L and 60R respectively, and multi-value digital signals showing the patterns of the specified areas 60L and 60R, i.e. the key patterns, are memorized in the key pattern memory 52. Furthermore, x- and y-coordinate signals showing the positions of the key patterns are memorized also in the key pattern memory 52. In addition, signal showing the amounts of movements in the x- and y-directions performed in order to position the sample wafer 2 in the state shown in Fig. 12 after its rotation through 90 degrees are memorized as rotating displacement signals in RAM built in the central processing unit 36 (or in the key pattern memory 52).

In a preferred embodiment, the same subsidiary key pattern memorizing operation as described above is performed after the key pattern memorizing operation. Specifically, in the left half portion and the right half portion of the display image on the display means 50, the cursors 55 are manually positioned at subsidiary specified areas 62L and 62R which are different from the specified areas 60L and 60R, and then multi-value digital signals showing the patterns of the subsidiary specified areas 62L and 62R, i.e. the subsidiary key patterns, are memorized in the key pattern memory 52, and x- and y-coordinate signals showing the positions of the subsidiary key patterns are also memorized in the key pattern memory 52.

The pattern matching-type position detecting means 54 detects the same patterns as the key patterns or the subsidiary key patterns in the image taken by the camera means 28, i.e. the image displayed on the display means 50, on the surface of the wafer 2 held on the holding means 4 and adapted to be automatically positioned at a required position, and thus detects the position of the straight-line area 8a or 8b. One example of such pattern matching-type position detection will be described below.

With reference to the flow chart shown in Fig. 13, a description will be made of the case of detecting the same pattern as the key pattern of the specified area 56L in the image inputted into the camera means 28 from the left-side light-incoming opening 30a of the magnifying optical means 26, i.e. in the image displayed in the left half portion of the displayed image on the display means 50. First, in step n-1, the cursor 55 is positioned at a specified site, for

example the left top corner of the displayed image on the display means 50, thereby defining a collation area to be collated with the key pattern. Then, step n-2 sets in, and the degree of matching, P, between the collation area and the key pattern is calculated. The degree of matching, P, can be calculated on the basis of the multi-value digital signals showing the key pattern, i.e. 32 × 32 multi-value digital signals showing the densities of 32 × 32 pixels in the specified areas 56L, which are stored in the key pattern memory 52, and 32 × 32 multi-value digital signals showing the densities of 32 × 32 pixels in the collation area which are among those multi-value signals which have been inputted into the image frame memory 34 from the camera means 28 via the A/D converter means 32. The degree of matching, P, itself can be calculated, for example, in accordance with the following equation A.

$$P = \sum_{i,j} |[f(i,j)-\bar{f}]-[g(i,j)-\bar{g}]| \ldots A$$

wherein f is a value corresponding to the density of each of 16 × 16 pixels in the collation area, $\bar{f}$ is an average of f values, g is a value corresponding to the density of each of 32 × 32 pixels in the key pattern, $\bar{g}$ is an average of g values, (i,j) show the row and column of each pixel, and therefore i = 1 – 32, j = 1 – 32.

In the calculation of the degree of matching, P, in accordance with the equation A, the differences between the deviated values of the densities of the individual pixels in the collation area (i.e., the values obtained respectively by subtracting the average density value from the actual density values) and the deviated values of the densities of the individual pixels of the key pattern are added up. Accordingly, variations in a so-called density gain ascribable, for example, to variations in illuminance in the collation area are excluded, and a fully reliable degree of matching, P, can be obtained.

For simplification of the mathematical operation, the degree of matching, P, can also be calculated on the basis of the following equation

$$P = \sum_{i,j} |U[f(i,j)-\bar{f}]-U[g(i,j)-\bar{g}]| \ldots B$$

wherein U means binarization, and U(x) = 1 when x>0, and U(x) = 0 when x≦0, which result from binarization of $[f(i,j)-\bar{f}]$ and $[g(i,j)-\bar{g}]$ in the above equation A.

To increase the reliability of the matching degree P further, the degree of matching, P, can also be obtained in accordance with the following equation C

$$P = \frac{\sum_{i,j}[f(i,j)-\bar{f}] \times [g(i,j)-\bar{g}]}{\sqrt{\sum_{i,j}[f(i,j)-\bar{f}]^2 \times \sum_{i,j}[g(i,j)-\bar{g}]^2}} \ldots C$$

on the basis of so-called normalizing correlation.
wherein f, $\bar{f}$, g, $\bar{g}$ and (i,j) are the same as defined for equation A.

In calculating the degree of matching, P, on the basis of equation A, B or C above, the correlation treatment may be carried out only on a plurality of specified pixels in the collation area, for example, only 32 specified pixels selected on the basis of one from each row and one from each column, instead of performing it on all of the pixels (32 × 32 = 1024) in the collation area, in order to increase the operating speed. In particular, it has been ascertained that when the degree of matching, P, is to be calculated on the basis of equation C, sufficient and good results can be obtained with regard to most semiconductor wafers even when the correlation treatment is carried out only on a plurality of specified pixels in the collation area.

After the calculation of the degree of matching, P, it is judged in step n-3 whether the calculated degree of matching, P, is above a predetermined threshold value. The predetermined threshold value may be properly set by the operator (for example, on a trial-and-error basis), and stored in the key pattern memory 52 or the RAM in the central processing unit 36. When the calculated degree of matching, P, is not above the predetermined threshold value (i.e., when the degree of matching is relatively low), step n-4 sets in, and it is determined whether the cursor 55 has been moved over the entire area of an image inputted into the camera means 28 from the left-side light-incoming opening 30a of the magnifying optical means 26, namely an image displayed in the left half portion of the display panel of the display means 50. When the movement of the cursor 55 over the entire area of the aforesaid image has not yet been completed, step n-5 sets in, and the cursor 55 is moved by one pixel in the x-direction and/or y-direction to the next collation area. Thereafter, the degree of matching, P, is calculated in step n-2, and it is judged in step n-3 whether the calculated degree of matching, P, is above a

predetermined threshold value. When the calculated egree of matching, P, is above the predetermined threshold value (i.e., when the degree of matching is relatively high), step n-3 is followed by step n-6 in which the position of the collation area and the degree of matching, P, are memorized in RAM built in the pattern matching-type position detecting means 54 (or RAM built in the central processing unit 36) and listed up. Then, step n-4 sets in. When the degree of matching, P, has been calculated, and it has been judged whether the calculated degree of matching, P, is above the predetermined threshold value, over the entire area of the image inputted into the camera means 28 from the left-side light-incoming opening 30a of the magnifying optical means 26, namely the image displayed in the left-half portion of the display panel of the display means 50, step n-4 is followed by step n-7 in which the largest of the degrees of matching, P, listed up in step n-6 is selected, and it is determined that a collation area which has the largest degree of matching, $P_{max}$, is the same as the key pattern, i.e., the specified area 56L. Thus, the position of the straight-line area 8a is detected necessarily from the position (x- and y- coordinate position) of the collation area having the highest degree of matching $P_{max}$ and the position (x- and y-coordinate position) of the key pattern, i.e. the specified area 56L. The same procedure as described above with reference to the flow chart shown in Fig. 13 may be taken when it is desired to detect the same pattern as the subsidiary key pattern of subsidiary specified area 58L, the key pattern of the specified area 60L, or the subsidiary key pattern of the specified area 62L, in an image inputted into the camera means 28 from the left-side light-incoming opening 30a of the magnifying optical means 26, or the same pattern as the key pattern of the specified area 56R, the subsidiary key pattern of the subsidiary specified area 58R, the key pattern of the specified area 60R, the subsidiary key pattern of the subsidiary specified area 62R in an image inputted into the camera means 28 from the right-side light-incoming opening 30b.

The automatic accurate alignment system constructed in accordance with this invention also includes a movement control means 64 adapted to control the operation of the moving means 12, more specifically the x-direction moving source 14, the y-direction moving source 16 and the $\theta$-direction moving source 18, and to position the wafer 2 held on the holding means 4 at a required position. The movement control means 64 actuates the moving means 12 on the basis of the detection of the position of the straight-line area 8a and/or 8b by the non-pattern matching type position detecting means 38, and thus positions the wafer 2. Alternatively, the movement control means 64 actuates the moving means 12 on the basis of the detection of the position of the straight-line area 8a (or 8b) by the non-pattern matching type position detecting means 38 and thus positions the wafer primarily, and thereafter actuates the moving means according to the detection of the relative position of the straight-line areas 8a (and 8b) by the pattern matching-type position detecting means 54 and thus positions the wafer 2 secondarily.

Figs. 14-A to 14-D show one example of a flow chart showing position alignment by the moving means 64.

With reference to Fig. 14-1, it is judged in step m-1 whether the non-pattern matching type position detecting means 38 can detect the straight-line area 8a in one of two images inputted into the camera means, i.e. the image inputted from the left-side light-incoming opening 30a of the magnifying optical means 26 and the image inputted from the right-side light-incoming opening 30b, for example the former. If no straight-line area 8a exists within the image owing, for example, to an error in positioning the wafer 2 on the holding means 4 or the straight-line area 8a has locally disappeared owing, for example, to poor printing, and the non-pattern matching type position detecting means 38 cannot detect the straight-line area 8a, step m-2 sets in and the central processing unit 36 prescribes the amount of y-direction movement. This amount of y-direction movement may be a suitable amount smaller than the distance d between the straight-line areas 8a, for example about 300 $\mu$m. Then, step m-3 sets in, and the amount of y-direction movement is added to the present position in the y-direction of the holding means 4 and the wafer 2 held thereon. In the next place, step m-4 sets in, and the amount of y-direction movement added is compared with the distance d. If the distance d is larger (when the amount of y-direction movement is further added after the y-direction movement has been repeated a plurality of times, the distance d becomes smaller), step m-5 sets in, and the movement control means 64 drives the y-direction movement source 16 to move the holding means 4 and the wafer 2 held thereon in the y-direction by the amount of y-direction movement. Thereafter, step m-1 again sets in.

On the other hand, in step m-4, if the distance d becomes larger than the amount of y-direction movement added as a result of adding the amount of y-direction movement a plurality of times, and therefore, the total amount of y-direction movement exceeds the distance d upon movement of the holding means 4 and the wafer 2 thereon in the y-direction by the aforesaid amount of y-direction movement, step m-6 sets in, and one is added to an x-direction movement amount counter built in the central processing unit 36. Then, step m-7 sets m, and it is determined whether the cumulative count of the x-direction movement amount counter Cx is 4 or not (in other words, whether the x-direction movement has been repeated three times). When

the cumulative count of the x-direction movement amount counter is not 4, step m-8 sets in, and the movement control means 64 drives the x-direction movement source 14 to move the holding means 4 and the wafer 2 held thereon in the x-direction by a predetermined amount which may, for example, be about 170 $\mu$m. Then, step m-9 sets in, and the y-direction movement is set in a reverse direction (if the previous y-direction movement is in a positive direction, it is then set in a negative direction). Thereafter, step m-3 again sets in. It will be understood therefore that in the illustrated embodiment when the straight-line area 8a cannot be detected, the detection of the straight-line area 8a is repeated by moving the holding means 4 and the wafer 2 held thereon in a zigzag fashion in the y-direction and the x-direction (the movement in the x-direction is performed three times at most) as shown by arrow 66 in Fig. 2.

When the non-pattern matching type position detecting means 38 detects the straight-line area 8a in step m-1, step m-10 sets in, and it is judged whether there is a deviation between the y-direction center (the x-x line in Fig. 11) of the image taken by the camera means and the center of the straight-line area 8a. When there is a deviation, step m-11 sets in, and the movement control means 64 actuates the y-direction moving source 16 to cause it to move the holding means 4 and the wafer 2 thereon in the y-direction by an amount corresponding to the deviation, and thus to position the straight-line area 8a at the y-direction center of the image taken by the camera means. Thereafter, step m-12 sets in, and it is judged whether the non-pattern matching type detecting means 38 detects the straight-line area 8a in the other of the two images inputted into the camera means 28 (namely in both of the two images inputted into the camera means 28). If the straight-line area 8a does not exist in the other of the two images owing, for example, to the inclination of the straight-line area 8a at a relatively large angle to the x-x line (Fig. 11), and therefore the non-pattern matching type position detecting means 38 cannot detect the straight-line area 8a in both of the two images mentioned above, step m-13 sets in, and the angle of inclination of the straight-line area 8a detected in one of the two images to the x-direction is detected. The detection of the inclination angle can be conveniently carried out by moving the holding means 4 and the wafer 2 held thereon in the x-direction by a predetermined distance at least once, and utilizing the difference between the y-direction position of the straight-line area 8a before the movement and that after the movement. In the illustrated embodiment, a three-point checking method is employed, and the inclination angle is detected on the basis of the difference among the y-direction position of the straight-line area 8a in the image before movement, the y-direction position of the straight-line area 8a after the x-direction driving source 14 is driven to move the holding means 4 and the wafer 2 thereon in the x-direction by a predetermined distance which may, for example, be about 2 mm, and the y-direction position of the straight-line area 8b after the x-direction drive source 18 has been driven to move the holding means 4 and the wafer 2 thereon further in the x-direction by the aforesaid predetermined amount. When the inclination angle has been detected as above, step m-14 sets in, and rough alignment in the $\theta$-direction is carried out according to the inclination angle detected. Specifically, according to the detected inclination angle, the movement control means 64 drives the $\theta$-direction moving source 18 to move the holding means 4 and the wafer 2 thereon in the $\theta$-direction, more specifically rotate them about the central axis 20 (Fig. 1), whereby the straight-line area 8 is kept nearly parallel to the x-x line (Fig. 11). It will be readily understood that when this rough alignment in the $\theta$ direction is carried out, a straight-line area 8a exists in both of the two images taken by the camera means 28.

When in step m-12, the non-pattern matching type position detecting means 38 detects the straight-line area 8a in both of the two images, step m-15 sets in. In step m-15, it is judged which of a plurality of (three in the illustrated embodiment as will be described below) position matching procedures that can be properly selected by the operator according to the characteristics of the wafer 2 to be subjected to position alignment is selected. Specifically, it is judged in step m-15 whether the primary positioning based on the detection of the straight-line area 8a and/or 8b by the non-pattern matching type position detecting means 38 should be continued, or whether the primary positioning based on the detection of the straight-line area 8a and/or 8b by the non-pattern matching type position detecting means 38 should be terminated and followed by the secondary positioning based on the detection of the straight-line area 8a and 8b by the pattern matching-type position detecting means 54. With reference to Fig. 14-B, when the former is selected, step m-16 sets in, and it is judged whether the y-direction positions of the straight-line areas 8a detected by the non-pattern matching type position detecting means 38 in the two images respectively inputted into the camera means 28 are in alignment. It will be easily understood that when the straight-line area 8a is not kept parallel to the x-direction sufficiently accurately, there is a difference between the y-direction positions of the straight-line areas 8a detected in the two images spaced from each other a predetermined distance in the x-direction. If this difference exists, step m-17 sets in, and alignment in the $\theta$-direction is carried out sufficiently accurately. Specifically, the movement control means 64 drives the $\theta$-direction movement source 18 according to the aforesaid difference to move the holding means 4 and the wafer 2 thereon in the $\theta$-direction, whereby the staight-line area 8a is maintained parallel to

the x-direction sifficiently accurately. Then, step m-18 sets in, and the central processing unit 36 judges whether or not there is a deviation between the center in the y-direction of the image taken by the camera means (which is the x-x line in Fig. 11) and the center of the straight-line area 8a. When there is a deviation step m-19 sets in, and the movement control means 64 drives the y-direction moving source 16 to move the holding means 4 and the wafer 2 thereon in the y-direction by an amount corresponding to the deviation and thus position the straight-line area 8a sufficiently accurately at the center in the y-direction of the image taken by the camera means. Thereafter, step m-20 sets in, and the movement control means 64 drives the y-direction moving source 16 to move the holding means 4 and the wafer 2 thereon in the y-direction by an amount corresponding to the distance d (Fig. 2) between the straight-line areas 8a. Then, step m-21 sets in, and again it is confirmed whether the non-pattern matching type position detecting means 38 detects the straight-line area 8a in both of the two images inputted into the camera means 28. Since the amount of y-direction movement of the holding means 4 and the wafer 2 held thereon is the distance *d* between the straight-line areas 8a, the non-pattern matching type position detecting means 38 normally detects the straight-line area 9a in both of the two images mentioned above. However, when owing to poor printing, etc., it is impossible to confirm that the non-pattern matching type position detecting means 38 detects the straight-line area 8a in both of the two images, step m-22 sets in. In step m-22, the movement control means 64 drives the x-direction moving source 14 to move the holding means 4 and the wafer 2 thereon in the x-direction by a predetermined distance which may, for example, be about 200 $\mu$m. Thereafter, step m-23 sets in, and it is again confirmed whether the non-pattern matching type position detecting means 38 detects the straight-line area 8a in both of the two images.

When it is confirmed in step m-21 or m-23 that the non-pattern matching type position detecting means 38 detects the straight-line area 8a in both of the two images, step m-24 sets in and it is again judged which of the plurality of (three in the illustrated embodiments) position aligning procedures that can be properly selected by the operator is selected. Specifically, it is judged in step m-24 whether the primary positioning based on the detection of the straight-line area 8a and/or 8b by the non-pattern matching type position detecting means 38 should be continued, or whether the primary positioning based on the detection of the straight-line area 8a and/or by the non-pattern matching type position detecting means 38 should be terminated and followed by the secondary positioning based on the detection of the straight-line areas 8a and 8b by the pattern matching-type position detecting means 54. If the former is selected, step m-25 sets in. In step m-25, the movement control means 64 drives the $\theta$-direction moving source 18 to move the holding means 4 and the wafer 2 thereon by an angle of 90 degrees in the $\theta$-direction, namely to rotate them 90 degrees about the central axis 20 (Fig. 1). It will be readily seen that as a result, instead of the straight-line area 8a, the straight-line area 8b crossing it at right angles becomes parallel to the x-direction sufficiently accurately and is positioned at the center of each of the images of the two parts. Then, step m-26 sets in, and it is determined whether or not the straight-line area 8b exists in both of the two images. Subsequently, step m-27 sets in, and it is determined whether the y-direction positions of the straight-line areas 8b detected in the two images of the two parts are aligned. If the straight-line area 8b is not maintained fully accurately parallel to the x-direction and there is a difference between the y-direction positions of the straight-line areas 8b detected in the two images of the two parts, step m-28 sets in, and the movement control means 64 drives the $\theta$-direction moving source 18 on the basis of this difference to move the holding means 4 and the wafer 2 thereon in the $\theta$-direction, whereby the straight-line area 8b is maintained parallel to the x-direction fully accurately. Thereafter, step m-29 sets in, and it is judged whether there is a deviation between the center in the y-direction of the image taken by the camera means (which is the x-x line in Fig. 11) and the center of the straight-line area 8b. If there is a deviation, step m-30 sets in, and the movement control means 64 drives the y-direction moving source 16 to move the holding means 4 and the wafer 2 thereon in the y-direction by an amount corresponding to the above deviation, and thus position the straight-line area 8b fully accurately at the center in the y-direction of the image taken by the camera means. Thus, the wafer 2 held on the holding means 4 is aligned fully accurately and surely at a predetermined position with respect to the rotating blade (Fig. 1). After the accurate alignment described above is completed, the wafer 2 can be cut as described hereinabove with reference to Fig. 1.

The aforesaid position matching procedure is carried out only on the basis of the detection of the straight-line areas 8a and 8b by the non-pattern matching type position detecting means 38. It will be easily understood that the detection of the positions of the straight-line areas 8a and 8b by the non-pattern matching type position detecting means 38 can be effected at an exceedingly high speed, and therefore by the aforesaid position matching procedure, the position alignment can be carried out accurately at a very high speed. However, if for example, many straight lines similar to the side edges of the straight-line areas 8a and 8b exist in a circuit pattern applied to a rectangular area 10 defined by the straight-line areas 8a and 8b, the above

accurate alignment based only on the detection of the straight-line areas 8a and 8b by the non-pattern matching type position detecting means 38 may result in detecting such straight lines errneously as the side edges of the straight-line areas 8a and 8b and in producing an error in positioning the wafer 2, although this possibility is extremely small. If there is such a likelihood, the primary positioning based on the detection of the position of the straight-line area 8a and/or 8b by the non-pattern matching type position detecting means 38 is followed by the secondary positioning based on the detection of the positions of the straight-line areas 8a and 8b by the pattern matching-type position detecting means 54 in step m-15 in Fig. 14-A or step m-24 in Fig. 14-B. By so doing, the occurrence of an error in detection in the primary positioning can be compensated for by the secondary positioning, and the time required for the secondary positioning can be considerably shortened by the primary positioning. Consequently, the occurrence of an error can be substantially reduced to nought, and the wafer 2 can be accurately held at the required position sufficiently rapidly.

When the secondary positioning is to be carried out in step 24 in Fig. 14-B, step m-31 in Fig. 14-C sets in. In step m-31, it is judged whether the pattern matching-type position detecting means 54 detects the same pattern as the key pattern, i.e. the pattern of the specified area 56L (Fig. 11), in one (or both) of the two images inputted into the camera means 28, for example in the image inputted into the camera means 28 from the left-side light-incoming opening 30a of the magnifying optical means 26. When the pattern matching-type position detecting means 54 does not detect the same pattern as the key pattern, step m-32 sets in, and the central processing unit 36 prescribes the amount of x-direction movement. The amount of x-direction movement may be a suitable value smaller than the distance *d* between the straight line areas 8b, for example about 300 $\mu$m. Then, step m-33 sets in, and the amount of the x-direction movement is added to the present x-direction position of the holding means 4 and the wafer 2 thereon. Then, in step m-34, the added amount of x-direction movement is compared with the distance *d*. When the distance *d* is found to be larger (when the amout of x-direction movement is added after repeating the x-direction movement several times, the distance *d* becomes smaller), step m-35 sets in. In step m-35, the movement control means 64 actuates the x-direction moving source 14 to cause it to move the holding means and the wafer 2 held thereon in the x-direction by the aforesaid amount of x-direction movement. Thereafter, one returns to step m-31. When in step m-34, the distance *d* is smaller and x-direction movement of the holding means 4 and the wafer 2 thereon in the x-direction by the aforesaid amount of x-direction movement makes the total amount of x-direction movements larger than the distance *d*, step m-36 sets in. In step m-36, the y-direction movement counter built in the central processing unit 36 adds one. Then, in step m-37, it is judged whether the cumulative count of the y-direction movement counter is 2 or not (namely whether or not the y-direction movement has laready been effected once). When the cumulative count of the y-direction movement counter is not 2, the movement control means 64 actuates the y-direction moving source 16 to cause the holding means 4 and the wafer 2 thereon to move in the y-direction by the distance *d* between the straight-line areas 8a. Then, step m-39 sets in, and the x-direction movement is set in a reverse direction (namely, when the x-direction movement is carried out in a positive direction, it is set so that thereafter it is effected in a negative direction). Thereafter, one returns to step m-31. Thus, when the pattern matching-type detecting means 54 does not detect the same pattern as the key pattern in step m-31, the holding means 4 and the wafer 2 held thereon are caused to make a zigzag movement in the x- and y-directions (movement in the y-direction is only once) and detection of the same pattern as the key pattern is repeated nearly as in steps m-1 to m-9.

At a time when one goes to step m-31 from step m-24, the primary positioning based on the detection of the relative position of the straight-line area 8a by the non-pattern matching type position detecting means 38 has been completed sufficiently accurately. Accordingly, except in a rare case in which, for example, the non-pattern matching type position detecting means 38 has committed an error in detection, the pattern matching-type position detecting means 54 immediately detects the same pattern as the key pattern in step m-31. When the pattern matching-type position detecting means 54 detects the same pattern as the key pattern, step m-40 sets in and it is judged whether there is a deviation between the y-direction center (x-x line in Fig. 11) of the image taken by the camera means and the center of the straight-line area 8a. If there is a deviation, step m-41 sets in, and the movement control means 64 actuates the y-direction moving source 16 to position the straight-line area 8a sufficiently accurately at the y-direction center of the image taken by the camera means. Thereafter, step m-42 sets in, and the movement control means 64 actuates the x-direction moving source 14 to cause it to move the holding means 4 and the wafer 2 held thereon in the x-direction by the distance *d* between the straight-line areas 8b. Then, one goes to step m-43, in which it is confirmed whether the pattern matching-type position detecting means 54 detects the same pattern as the key pattern in one (or both) of the two images inputted into the camera means 28. When it has been confirmed that the pattern matching-type position detecting means 54 detects the same pattern as the key

pattern, step m-44 sets in, and it is judged whether there is a deviation between the y-direction center (x-x line in Fig. 11) of the image taken by the camera means and the center of the straight-line area 8a. When there is a deviation, step m-45 sets in, and the movement control means 64 actuates the y-direction moving source 16 to position the straight-line area 8a fully accurately at the y-direction center of the image taken by the camera. Thereafter, one goes to step m-46, and it is judged whether the holding means 4 and the wafer 2 thereon have been rotated through 90 degrees. When the 90-degree rotation has not yet been carried out, step m-47 sets in, and the movement control means 64 actuates the $\theta$-direction moving source 18 to cause it to rotate the holding means 4 and the wafer 2 thereon through 90 degrees. Then, step m-48 sets in, and the movement control means 64 actuates the x-direction moving source 14 and the y-direction moving source 16 to cause them to move the holding means 4 and the wafer 2 thereon in the x- and y-directions by amounts of movement corresponding to the aforesaid rotating displacement signal memorized in RAM in the central processing unit 36 (or the key pattern memory 52), i.e. to the amounts of x- and y-direction movements after the 90-degree rotation of the sample wafer 2 in the key pattern memorizing operation. Thus, it is ensured that the same patterns as the key patterns of the specified areas 60L and 60R shown in Fig. 12 (and the subsidiary specified areas 62L and 62R) exist in the images inputted in the camera means 28. Thereafter, one goes back to step m-31. After returning to step m-31 via steps m-47 and m-48, it is judged in steps m-31 and m-43 whether the pattern matching-type position detecting means 54 detects the same pattern as the key pattern of the specified area 60L (or 60R) instead of the specified area 56L (or 56R).

The primary and secondary positionings are effected as described above, and consequently, the wafer 2 can be positioned at a required position fully repidly and fully accurately while reducing an error in position substantially to nought.

On the other hand, when the primary positioning is followed by the secondary positioning in step m-15 in Fig. 14-A, step m-49 in Fig. 14-D sets in. In step m-49, it is judged whether the pattern matching-type position detecting means 54 detects the same pattern as the key pattern of the specified area 56L (Fig. 11) in one of the two images inputted into the camera means 28, for example, in the image inputted into the camera means 28 from the left side light-incoming opening 30a of the magnifying optical means 26.

When the pattern matching-type positioning means 54 does not detect the same pattern as the key pattern in step m-49, starting of the secondary positioning is stopped, and the primary positioning is again carried out. Specifically, one goes to step m-50, and the movement control means 64 actuates the x-direction moving source 14 to cause it to move the holding means 4 and the wafer 2 thereon in the x-direction by a predetermined amount $\alpha$. The predetermined amount $\alpha$ may, for example, be about 170 $\mu$m. Then, step m-51 sets in, and it is judged whether the non-pattern matching type position detecting means 38 detects the straight-line area 8a in both of the two images inputted into the camera means 28. When the non-pattern matching type position detecting means 38 detects the straight-line area 8a in both of the two images in step m-51, one returns to step m-49. On the other hand, when the non-pattern matching type position detecting means 38 does not detect the straight-line area 8a in both of the two images in step m-51, step m-52 sets in, and the movement control means 64 actuates the x-direction moving source 14 to cause it to move the holding means 4 and the wafer 2 thereon in the x-direction by a predetermined amount $\alpha$ (namely, it returns them to the position before movement by the amount $\alpha$ in step m-49). Thereafter, step m-58 to be described below sets in.

When the pattern matching-type postion detecting means 54 detects the same pattern as the key pattern in step m-49, step m-53 sets in, and it is judged whether there is a deviation between the y-direction center (x-x line in Fig. 11) of the image taken by the camera means and the center of the straight-line area 8a. If there is, step m-54 sets in, and the movement control means 64 actuates the y-direction moving source 16 to position the straight-line area 8a fully accurately at the y-direction center of the image taken by the camera means. Then, one goes to step m-55, and the movement control means 64 actuates the x-direction moving source 14 and the y-direction moving source 16 to cause them to move the holding means 4 and the wafer 2 thereon in the x- and y-directions by the x-direction distance $\beta$ and the y-direction $\gamma$ between the key pattern of the specified area 56L (Fig. 11) and the subsidiary key pattern of the specified area 58L (Fig. 11). Then step m-56 sets in, and it is judged whether the pattern matching-type position detecting means 54 detects the same pattern as the subsidiary key pattern of the subsidiary specified area 58L (Fig. 11) in one of the two images inputted into the camera means 28.

When the position detecting means 54 does not detect the same pattern as the subsidiary key pattern in step m-56, the secondary positioning is stopped, and the primary positioning is again carried out. In other words, one goes to step m-57, and the movement control means 64 actuates the x-direction moving source 14 and the y-direction moving source 16 to cause them to move the holding means 4 and the wafer 2 thereon in the x-direction by a predetermined

distance $\beta$ and in the y-direction by a predetermined distance $\gamma$. Thus they are returned to the position before the x-direction movement and the y-direction movement in step m-55. Then, one goes to step m-58, and the movement control means 64 actuates the y-direction moving source 16 to cause it to move the holding means 4 and the wafer 2 thereon in the y-direction by the distance $d$ between the straight-line areas 8a. Thereafter step m-59 sets in, and it is judged whether the non-pattern matching type position detecting means 38 detects the straight-line area 8a in both of the two images inputted into the camera means 28. When in step m-59, the non-pattern matching type position detecting means 38 detects the straight-line area 8a in both of the two images, one returns to step m-49. On the other hand, when the position detecting means 38 does not detect the straight-line area 8a in both of the two images in step m-59, one goes to step m-60. In step m-60, the movement control means 64 actuates the x-direction moving source 14 to cause it to move the holding means 4 and the wafer 2 thereon in the x-direction by a predetermined amount which may, for example, be about 170 $\mu$m. Thereafter, step m-61 sets in, and again it is judged whether the non-pattern matching type position detecting means 38 detects the straight-line area 8a in both of the two images inputted into the camera means 28. When the position detecting means 38 detects the straight-line area 8a in both of the two images in step m-61, one returns to step m-49.

When in step m-56 the pattern matching-type position detecting means 54 detects the same pattern as the subsidiary key pattern, step m-62 sets in, and it is confirmed whether there is a deviation between the y-direction center line (the line x-x in Fig. 11) of the image taken by the camera means and the center of the straight-line area 8a. If there is a deviation, step m-63 sets in, and the movement control means 64 actuates the y-direction moving source 16 to position the straight-line area 8s fully accurately at the y-direction center of the image taken by the camera. Then, step m-64 sets it, and it is judged whether the aforesaid steps m-49 to m-63 have been carried out with regard to the other of the two images inputted into the camera means 28, i.e. the image inputttted through the right-side light-incoming opening 30b of the magnifying optical means 26. When the steps m-49 to m-63 have not been performed on the other image, one goes back to step m-49, and the steps m-49 to m-63 are carried out on the other image. On the other hand, when the steps m-49 to m-63 have been carried out on the other image, step m-65 sets in, and it is judged whether the y-direction positions of the straight-line areas 8a detected by the pattern matching-type position detecting means 54 in the two images inputted into the camera means are in alignement. When there is a difference in y-direction position between the straight-line areas 8a detected in the two images, step m-66 sets in, and in the same way as in step m-17, $\theta$-direction alignment is carried out fully accurately. Thereafter, step m-67 sets in, and it is confirmed whether there is a deviation between the y-direction center (the line x-x in Fig. 11) of the image taken by the camera and the center of the straight-line area 8a. If there is, step m-68 sets in, and the movement control means 64 actuates the y-direction moving source 16 to position the straight-line area 8a fully accurately in the y-direction center of the image taken by the camera. Thereafter, one goes to step m-69 in which it is judged whether the holding means 4 and the wafer 2 thereon have already been rotated through 90 degrees. When this 90-degree rotation has not yet been carried out, step m-70 sets in, and the movement control means 64 actuates the $\theta$-direction moving source 18 to cause it to rotate the holding means 4 and the wafer 2 thereon through 90 degrees. Then, step m-71 sets in, and in the same way as in step m-48, the holding means 4 and the wafer 2 thereon are moved in the x- and y- directions by amounts of x-direction and y-direction movements based on the aforesaid rotating displacement signal. Thereafter, one returns to step m-49. After returning to step m-49 via the steps m-70 and 71, it is judged in step 49 whether the same pattern as the key pattern of the specified area 60L or (60R) instead of the specified area 56L (or 56R) is detected, and in step m-56, it is judged whether the same pattern as the subsidiary key pattern of not the subsidiary specified area 58L (or 58R) but the subsidiary specified area 62L (or 62R) is detected.

In the aforesaid manner, the secondary positioning subsequent to the primary positioning is carried out, and consequently, the wafer 2 is positioned at a required position very rapidly and accurately while reducing the occurrence of an error in positioning substantially to zero.

While the present invention has been described in detail hereinabove with reference to the accompanying drawings showing specific embodiments of the automatic accurate alignment system, it should be understood that the invention is not limited to these specific embodiments, and various changes and modifications are possible without departing from the scope of this invention as defined by the following claims.

CLAIMS

1. An alignment system for positioning at a required position an object to be worked which has on its surface straight-line areas whose image density changes relatively abruptly at both side edges, said system comprising

holding means for holding the object to be worked,

moving means for moving the holding means,

camera means for taking at least a part of the image of the surface of the object held on the holding means and outputting analog signals representative of the densities of x-y matrix arrayed pixels,

A/D converter means for converting the analog signals outputted by the camera means into multi-value digital signals,

operation means for performing a mathematical operation on the multi-value digital signals to produce binary digital signals,

detecting means for detecting the position of at least one side edge of a straight-line area, and thus the position of the straight-line area, on the basis of the binary digital signals, and

movement control means for actuating the moving means according to the detected position of the straight-line area and thus positioning the object held on the holding means at the required position.

2. A system as clamed in claim 1 wherein the object to be worked is a semiconductor wafer having on its surface a plurality of straight-line areas of predetermined widths arranged in a lattice pattern at predetermined intervals.

3. A system as claimed in claim 1 or 2 wherein the moving means includes an x-direction moving source for moving the holding means in the x-direction, a y-direction moving source for moving the holding means in the y-direction and a $\theta$-direction moving source for moving the holding means in the $\theta$-direction.

4. A system as claimed in any of claims 1 to 3 wherein the camera means comprises a solid-state camera having a plurality of image sensor elements arrayed in an x-y matrix.

5. A system as claimed in any of claims 1 to 4 wherein a magnifying optical means is disposed between the surface of the object to be worked and the camera means, and the image of at least a part of the surface of the object is enlarged at a predetermined magnification by the magnifying optical means, and input into the camera means.

6. A system as claimed in any of claims 1 to 5 wherein the camera means is arranged to receive the images of two parts of the surface of the object which are spaced from each other.

7. A system as claimed in claim 6 wherein the two parts are spaced from each other either in the x-direction or the y-direction.

8. A system as claimed in any of claims 1 to 7 wherein the operation means performs differentiation on the multi-value digital signals in order to emphasize a change in density in the image taken to produce differentiated multi-value digital signals, and thresholds the differentiated multi-value digital signals with a predetermined slice level to produce the binary digital signals.

9. A system as claimed in claim 8 wherein the differentiation emphasizes a change in the density of the image either in the x-direction or the y-direction.

10. A system as claimed in claim 9 wherein the differentiation is performed by using the following differentiation mask:

| | | |
|---|---|---|
| −1 | −1 | −1 |
| 0 | 0 | 0 |
| 1 | 1 | 1 |

11. A system as claimed in any of claims 1 to 7 wherein the operation means thresholds the multi-value digital signals with a predetermined slice level to produce the binary digital signals.

12. A system as claimed in any of claims 1 to 7 wherein the operation means thresholds the multi-value digital signals with a predetermined slice level to produce intermediate binary digital signals, and then subjects the intermediate binary digital signals to a parity check to produce the binary digital signals.

13. A system as claimed in claim 12 wherein the parity check produces processed values which distinguish the case where the intermediate binary digital signals are the same at three addresses, i.e. $(x = m, y = n)$, $(x - m + 1, y = m)$, and $(x = m, y = n + 1)$, from the case where they are not.

14. A system as claimed in any of claims 8 to 13 wherein the detecting means detects the position of at least one side edge of the straight-line area on the basis of the detection of whether a predetermined number or more of digital signals "1" exist in a predetermined direction.

15. A system as claimed in claim 14 wherein whether a predetermined number or more of digital signals "1" exist or not is detected in either the x-direction or the y-direction and in a plurality of directions inclined thereto within a predetermined angular range.

16. A system as claimed in claim 14 or 15 wherein the detecting means detects whether the other side edge of the straight-line area is disposed at a position spaced a predetermined distance from one detected side edge of the straight-line area, and thus determines whether the detected one side edge is actually the one side edge of the straight-line area.

17. An automatic alignment system for positioning at a required position a semiconductor wafer having a plurality of straight-line areas arranged in a lattice pattern on its surface and a circuit pattern applied to each of a plurality of rectangular areas defined by the straight-line areas, said system comprising

holding means for holding the semiconductor wafer,

moving means for moving the holding means,

camera means for taking at least a part of the image of the surface of the semiconductor wafer held on the holding means and outputting analog signals showing the densities of x-y matrix arrayed pixels,

an image frame memory for memorizing signals corresponding to the analog signals outputted by the camera means,

a key pattern memory for memorizing a signal showing a key pattern corresponding to a specified area on said surface of the semiconductor wafer located at a predetermined position and a signal showing the position of the key pattern,

pattern matching-type position detecting means for detecting the position of a straight-line area by detecting the same pattern as the key pattern in the image taken by the camera means on the basis of the signals stored in the image frame memory and the key pattern signals stored in the key pattern memory,

non-pattern matching type position detecting means for detecting the position of a straight-line area by methods other than pattern metching, and

movement control means for primarily positioning the semiconductor wafer held on the holding means by actuating the moving means according to the detection of the position of the straight-line area by the non-pattern matching type position detecting means and thereafter secondarily positioning the semiconductor wafer held on the holding means by actuating the moving means according to the detection of the position of the straight-line area by the pattern matching-type position detecting means.

18. A system as claimed in claim 17 wherein the key pattern memory memorizes at least one key pattern corresponding to at least one specified area on said surface of the semiconductor wafer when the semiconductor wafer is at a first predetermined position and at least one key pattern corresponding to at least one specified area on said surface of the semiconductor wafer when the semiconductor wafer is at a second predetermined position by being rotated through 90 degrees with respect to the first predetermined position; and in the secondary positioning, the movement control means performs positioning with regard to the first predetermined position, then rotates the holding means through 90 degrees, and thereafter performs positioning with regard to the second predetermined position.

19. A system as claimed in claim 17 or 18 wherein said camera means includes an A/D converter means for converting said analog signals to multi-value digital signals, and the image frame memory memorizes the multi-value digital signals generated by the A/D converter means.

20. A system as claimed in claim 19 wherein the non-pattern matching type position detecting means includes a mathematical operation means for performing mathematical operations on the multi-value digital signals memorized in the image frame memory to generate binary digital signals, and a straight-line area detecting means for detecting the position of at least one side edge of the straight-line area on the basis of the binary digital signals and thus detecting the relative position of the straight-line area.

21. A system as claimed in claim 19 or 20 wherein the signal showing the key pattern and stored in the key pattern memory is a multi-value digital signal corresponding to the densities of a plurality of pixels in the key pattern.

22. A system as claimed in claim 21 wherein the pattern matching-type position detecting means calculates the degree of matching, P, on the basis of the following equation

$$P = \sum_{i,j} |[f(i,j)-\bar{f}]-[g(i,j)-\bar{g}]|$$

wherein f is a value corresponding to the density of each of a plurality of pixels in a collation area on the surface of the semiconductor wafer held on the holding means, $\bar{f}$ is an average of f values, g is a value corresponding to the density of each of a plurality of pixels in the key pattern, and $\bar{g}$ is an average of g values.

23. A system as claimed in claim 21 wherein the pattern matching-type position detecting means calculates the degree of matching, p, on the basis of the following equation

$$P = \sum_{i,j} |U[f(i,j)-\bar{f}]-U[g(i,j)-\bar{g}]|$$

wherein f is a value corresponding to the density of each of a plurality of pixels in a collation area on the surface of the semiconductor wafer held on the holding means, $\bar{f}$ is an average of f value, g is a value corresponding to the density of each of a plurality of pixels in the key pattern, $\bar{g}$ is an average of g values, and U means binarization.

24. A system as claimed in claim 21 wherein the pattern matching-type position detecting means calculates the degree of matching, P, on the basis of the following equation

$$P = \frac{\sum_{i,j}[f(i,j)-\bar{f}] \times [g(i,j)-\bar{g}]}{\sqrt{\sum_{i,j}[f(i,j)-\bar{f}]^2 \times \sum_{i,j}[g(i,j)-\bar{g}]^2}} \ldots C$$

wherein f is a value corresponding to the density of each of a plurality of pixels in a collation area on the surface of the semiconductor wafer held on the holding means, $\bar{f}$ is an average of f values, g is a value corresponding to the density of each of a plurality of pixels in the key pattern, and $\bar{g}$ ia an average of g values.

25. A system as claimed in any of claims 17 to 24 wherein the camera means comprises a solid-state camera having a plurality of image sensor elements arrayed in an x-y matrix.

26. A system as claimed in any of claims 17 to 25 wherein a magnifying optical means is disposed between the surface of the semiconductor wafer and the camera means, and the image of at least a part of the surface of the semiconductor wafer is enlarged at a predetermined magnification by the magnifying optical means, and input into the camera means.

27. A system as claimed in any of claims 17 to 26 wherein the camera means takes the images of two parts of the surface of the semiconductor wafer which are spaced from each other.

28. A system as claimed in claim 27 wherein the two parts are spaced from each other either in the x-direction or the y-direction.

29. A system as claimed in claim 28 wherein the movement control means performs the primary positioning such that at least the straight-line areas exist in both of the two portions taken by the camera means.

30. An alignment system substantially as hereinbefore described with reference to the accompanying drawings.

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