

TITLE OF THE INVENTION

METHOD FOR INSPECTING SUBSTRATE WITH
MULTI-LAYER REFLECTION FILM AND METHOD FOR
MANUFACTURING REFLECTIVE MASK BLANK

5

TECHNICAL FIELD

[0001]

The disclosure herein generally relates to
a method of inspecting a substrate with a multi-
10 layer reflection film and a method for manufacturing
a reflective mask blank.

BACKGROUND ART

[0002]

15

Along with the recent miniaturization of
semiconductor devices, an EUV lithography (EUVL), an
exposure technology using Extreme Ultra-Violet (EUV)
light, has been developed. The EUV light includes a
soft X-ray and a vacuum ultraviolet light, and
20 specifically has a wavelength of from 0.2 nm to 100
nm. At present, EUV light with a wavelength of
about 13.5 nm is mainly studied.

[0003]

In the EUVL, a reflective mask is used.
25 The reflective mask includes a substrate, such as a
glass substrate, a multi-layer reflection film
formed on the substrate, and an absorption film
formed on the multi-layer reflection film. An
opening pattern is formed in the absorption film.
30 In the EUVL, the opening pattern of the absorption
film is transferred to a semiconductor substrate.

[0004]

In the manufacturing process of reflective

masks, it is important to detect a defect and specify a position of the defect in the multi-layer reflection film before forming the absorption film on the multi-layer reflection film. It is difficult
5 to repair or remove a defect in the multi-layer reflection film. Therefore, a technique for correcting the opening pattern of the absorption film has been developed so that a defect in the multi-layer reflection film is covered by the
10 absorption film. This technique is called mitigation.

[0005]

WO 2020/095959 discloses a technique for improving an accuracy of conversion of a coordinate
15 system of a defect inspection device to a coordinate system of an electron beam lithography device. The electron beam lithography device draws a pattern on a resist film formed on the absorption film. The resist film is then developed and an opening pattern
20 is formed on the absorption film using the developed resist film.

SUMMARY OF THE INVENTION

[Problem to be solved by the invention]

25 [0007]

Defects in substrates with multi-layer reflection films are roughly classified into amplitude defects and phase defects. The amplitude defect may change an amplitude of the EUV. On the
30 other hand, the phase defect may change a phase of the EUV. The amplitude defects are mainly formed on a surface of the multi-layer reflection film, while the phase defects are mainly formed on a surface of

the substrate or inside the multi-layer reflection film. Since the amplitude defect and the phase defect exist at different depths, they are detected using different types of defect inspection device, and their positions are specified in coordinates of coordinate systems which are set separately from each other.

[0008]

Conventionally, when the coordinate of the defect is transformed from one coordinate system to another coordinate system, errors have occurred. Moreover, since the inspection of defects is performed for an entire quality assurance region of the substrate, it has been difficult to achieve both reducing the inspection time and improvement of the positional accuracy. For example, if the defect is imaged during the movement of the substrate, the inspection time can be reduced, but the positional accuracy of the defect may be degraded. On the other hand, if the defect is imaged while the movement of the substrate stops, the positional accuracy of the defect can be improved, but an area that can be inspected at one time becomes narrow and the inspection time may become longer.

[0009]

An aspect of the present disclosure provides a technique for accurately detecting coordinates of an amplitude defect and a phase defect in a short time.

[Means for Solving Problems]

[0010]

According to an aspect of the present

disclosure, a method for inspecting a substrate with a multi-layer reflection film including a substrate; and a multi-layer reflection film that reflects EUV light and is formed on the substrate includes steps
5 (A) to (D).

Step (A) is imaging the substrate with a multi-layer reflection film while moving the substrate with a multi-layer reflection film at a first movement speed using a first defect inspection device, to
10 detect an amplitude defect present in the substrate with a multi-layer reflection film, and to acquire a coordinate of the amplitude defect in a first coordinate system set by the first defect inspection device.

15 Step (B) is imaging the substrate with a multi-layer reflection film while moving the substrate with a multi-layer reflection film at a second movement speed using a second defect inspection device, which is different from the first defect inspection
20 device, to detect a phase defect present in the substrate with a multi-layer reflection film, and to acquire a coordinate of the phase defect in a second coordinate system set by the second defect inspection device.

25 Step (C) is transforming the coordinate of the amplitude defect from the first coordinate system to the second coordinate system.

Step (D) is imaging the coordinate of the amplitude defect and the coordinate of the phase defect in the
30 second coordinate system using the second defect inspection device while moving the substrate with a multi-layer reflection film at a third movement speed that is lower than the first movement speed

and the second movement speed or while stopping the movement of the substrate with a multi-layer reflection film, to detect again the amplitude defect and the phase defect and acquire again the coordinate of the amplitude defect and the coordinate of the phase defect.

[0011]

According to another aspect of the present disclosure, a method for inspecting a substrate with a multi-layer reflection film including a substrate; and a multi-layer reflection film that reflects EUV light and is formed on the substrate includes steps (E) to (H).

Step (E) is imaging the substrate with a multi-layer reflection film while moving the substrate with a multi-layer reflection film at a first movement speed using a first defect inspection device, to detect an amplitude defect present in the substrate with a multi-layer reflection film, and to acquire a coordinate of the amplitude defect in a first coordinate system set by the first defect inspection device.

Step (F) is imaging the substrate with a multi-layer reflection film while moving the substrate with a multi-layer reflection film at a second movement speed using a second defect inspection device, which is different from the first defect inspection device, to detect a phase defect present in the substrate with a multi-layer reflection film, and to acquire a coordinate of the phase defect in a second coordinate system set by the second defect inspection device.

Step (G) is transforming the coordinate of the phase

defect from the second coordinate system to the first coordinate system.

Step (H) is imaging the coordinate of the amplitude defect and the coordinate of the phase defect in the first coordinate system using the first defect inspection device while moving the substrate with a multi-layer reflection film at a third movement speed that is lower than the first movement speed and the second movement speed, or while stopping the movement of the substrate with a multi-layer reflection film, to detect again the amplitude defect and the phase defect and acquire again the coordinate of the amplitude defect and the coordinate of the phase defect.

[0012]

According to yet another aspect of the present disclosure, a method for inspecting a substrate with a multi-layer reflection film including a substrate; and a multi-layer reflection film that reflects EUV light and is formed on the substrate includes steps (I) to (L).

Step (I) is imaging the substrate with a multi-layer reflection film while moving the substrate with a multi-layer reflection film at a first movement speed using a first defect inspection device, to detect an amplitude defect present in the substrate with a multi-layer reflection film, and to acquire a coordinate of the amplitude defect in a first coordinate system set by the first defect inspection device.

Step (J) is imaging the substrate with a multi-layer reflection film while moving the substrate with a multi-layer reflection film at a second movement

speed using a second defect inspection device, which is different from the first defect inspection device, to detect a phase defect present in the substrate with a multi-layer reflection film, and to
5 acquire a coordinate of the phase defect in a second coordinate system set by the second defect inspection device.

Step (K) is transforming the coordinate of the amplitude defect from the first coordinate system to
10 a third coordinate system, which is different from the first coordinate system and the second coordinate system, and transforming the coordinate of the phase defect from the second coordinate system to the third coordinate system.

15 Step (L) is imaging the coordinate of the amplitude defect and the coordinate of the phase defect in the third coordinate system using a third defect inspection device, which is different from the first defect inspection device and the second
20 defect inspection device, while moving the substrate with a multi-layer reflection film at a third movement speed that is lower than the first movement speed and the second movement speed, or while stopping the movement of the substrate with a multi-
25 layer reflection film, to detect again the amplitude defect and the phase defect and acquire again the coordinate of the amplitude defect and the coordinate of the phase defect.

30 [Effects of the Invention]
[0013]

According to an aspect of the present disclosure, an amplitude defect and a phase defect

are imaged while moving a substrate with a multi-layer reflection film at high movement speed, to specify an approximate coordinate of the amplitude defect and an approximate coordinate of the phase defects, and then the amplitude defect and the phase defect are imaged again while moving the substrate with a multi-layer reflection film at a low movement speed, or while stopping the movement of the substrate with a multi-layer reflection film.

Therefore, the coordinate of the amplitude defect and the coordinate of the phase defect can be detected with high accuracy in a short period of time.

BRIEF DESCRIPTION OF DRAWINGS

[0014]

FIG. 1 is a flow chart illustrating a method for manufacturing a reflective mask blank according to an embodiment;

FIG. 2 is a cross-sectional view depicting an example of a substrate of a reflective mask blank according to the embodiment;

FIG. 3 is a plan view depicting an example of the substrate shown in FIG. 2;

FIG. 4 is a cross-sectional view depicting an example of the reflective mask blank;

FIG. 5 is a cross-sectional view depicting an example of a reflective mask;

FIG. 6 is a cross-sectional view illustrating an example of a defect in a substrate with a multi-layer film;

FIG. 7 is a cross-sectional view illustrating an example of an opening pattern of an

absorption film overlying the defect shown in FIG. 6;

FIG. 8 is a flowchart illustrating a method for inspecting the substrate with a multi-layer film according to the embodiment;

FIG. 9 is a diagram depicting an example of a coordinate of an amplitude defect in a first coordinate system;

FIG. 10 is a diagram depicting an example of a coordinate of a phase defect in a second coordinate system;

FIG. 11 is a diagram illustrating the first coordinate system and the second coordinate system, the origin of the first coordinate system shown in FIG. 9 being superimposed with the origin of the second coordinate system shown in FIG. 10; and

FIG. 12 is a diagram illustrating an example of a result of transforming the coordinate of the amplitude defect from the first coordinate system to the second coordinate system.

MODE FOR CARRYING OUT THE INVENTION

[0015]

In the following, embodiments of the present disclosure will be described with reference to the accompanying drawings. In each drawing, to the same or corresponding configurations, the same reference numeral will be assigned, and an explanation may be omitted. In the specification, a symbol "-" representing a numerical range indicates that values before and after the symbol are included as a lower limit value and an upper limit value,

respectively.

[0016]

As shown in FIG. 1, a manufacturing method for a reflective mask blank includes steps S1 to S7.
5 For example, a substrate 2 shown in FIG. 2 and FIG. 3 is used for manufacturing a reflective mask blank. The substrate 2 has a first main surface 21, and a second main surface 22 opposite to the first main surface 21. The first main surface 21 has a
10 rectangular shape. In the specification of the present application, the rectangular shape includes a corner chamfered shape. The rectangular shape also includes a square. The second main surface 22 is opposite to the first main surface 21. The
15 second main surface 22 also has a rectangular shape, similar to the first main surface 21.

[0017]

The substrate 2 also includes four end faces 23, four first chamfered surfaces 24, and four
20 second chamfered surfaces 25. The end faces 23 are perpendicular to the first main surface 21 and the second main surface 22. The first chamfered surface 24 is formed at the boundary between the first main surface 21 and the end face 23. The second
25 chamfered surface 25 is formed at the boundary between the second main surface 22 and the end face 23. The first chamfered surface 24 and the second chamfered surface 25 are so-called C chamfered surfaces in the present embodiment, but may be R
30 chamfered surfaces.

[0018]

The substrate 2 is, for example, a glass substrate. A glass of the substrate 2 is preferably

quartz glass containing TiO_2 . The quartz glass has a smaller coefficient of linear expansion and smaller dimensional changes due to temperature changes than those of the typical soda lime glass.

5 Quartz glass may contain from 80% to 95% by mass of SiO_2 and from 4% to 17% by mass of TiO_2 . When the TiO_2 content is between 4% and 17% by mass, the linear expansion coefficient around room temperature is almost zero, and there is little dimensional
10 change around room temperature. Quartz glass may contain a third component or impurity other than SiO_2 and TiO_2 .

[0019]

The size of the substrate 2 is, for
15 example, 152 mm in length and 152 mm in width in a plan view. The longitudinal dimension and the lateral dimension may be greater than 152 mm.

[0020]

The substrate 2 has a central region 27
20 and a peripheral region 28 on the first main surface 21. The central region 27 is a square region with a length of 142 mm and a width of 142 mm, excluding a rectangular frame-like peripheral region 28 surrounding the central region 27, which is
25 processed to a desired flatness by steps S1 to S4, and is a quality assurance region. The four sides of the central region 27 are parallel to the four end faces 23. The center of the central region 27 coincides with the center of the first main surface
30 21.

[0021]

Although not shown, the second main surface 22 of the substrate 2 also has a central

region and a peripheral region, similar to those of the first main surface 21. The central region of the second main surface 22 is a square region with a length of 142 mm and a width of 142 mm, which is
5 processed to the desired flatness by steps S1 to S4 of FIG. 1, similar to the central region of the first main surface 21, and is a quality assurance region.

[0022]

10 First, in step S1, the first main surface 21 and the second main surface 22 of the substrate 2 are polished. The first main surface 21 and the second main surface 22 are polished simultaneously by using a double-sided polisher, which is not
15 shown, in the present embodiment. Alternatively, the surfaces may be polished sequentially by a single-sided polisher, which is not shown. In step S1, the substrate 2 is polished while a polishing slurry is supplied between a polishing pad and the
20 substrate 2.

[0023]

The polishing pads include, for example, urethane polishing pads, non-woven polishing pads, suede polishing pads, or the like. The polishing
25 slurry includes an abrasive and a dispersion medium. The abrasive includes, for example, cerium oxide particles. The dispersion medium includes, for example, water or an organic solvent. The first main surface 21 and the second main surface 22 may
30 be polished multiple times with abrasives of different materials or different grain sizes.

[0024]

The abrasive used in step S1 is not

limited to cerium oxide particles. The abrasive used in step S1 includes, for example, silicon oxide particles, aluminum oxide particles, zirconium oxide particles, titanium oxide particles, diamond
5 particles, silicon carbide particles, or the like.
[0025]

Next, in step S2, a surface geometry of the first main surface 21 and the second main surface 22 of the substrate 2 is measured. For
10 example, a non-contact measuring device, such as a laser interference type, is used to measure the surface geometry so that the surface is not damaged. The measuring device measures the surface geometry of the central region 27 of the first main surface
15 21 and the central region of the second main surface 22.
[0026]

Next, in step S3, the first main surface 21 and the second main surface 22 of the substrate 2
20 are locally machined in order to improve the flatness, according to results of the measurement in step S2. The first main surface 21 and the second main surface 22 are locally machined in sequence. Either of the surfaces may be machined first, i.e.
25 the order is not particularly limited. The local machining method includes, for example, the GCIB (Gas Cluster Ion Beam) method or the PCVM (Plasma Chemical Vaporization Machining) method. The method of local machining may be a polishing method using a
30 magnetic fluid, a polishing method using a rotary polishing tool, or the like.
[0027]

Then, in step S4, the finish polishing of

the first main surface 21 and the second main surface 22 of the substrate 2 is performed. The first main surface 21 and the second main surface 22 are polished simultaneously with a double-sided
5 polisher, which is not shown. Alternatively, the surfaces may be polished sequentially by a single-sided polisher, which is not shown. Either of the surfaces may be polished first, i.e. the order is not particularly limited. In step S4, the substrate
10 2 is polished while a polishing slurry is supplied between the polishing pad and the substrate 2. The polishing slurry includes an abrasive. The abrasive is, for example, colloidal silica particles.
[0028]

15 Next, in step S5, a conductive film 5 shown in FIG. 4 is formed in the central region 27 of the first main surface 21 of the substrate 2. The conductive film 5 is used to adsorb a reflective mask to an electrostatic chuck of an exposure
20 device. The conductive film 5 is formed of, for example, chromium nitride (CrN). For example, a sputtering method is used for forming the conductive film 5.
[0029]

25 Next, in step S6, a multi-layer reflection film 3 shown in FIG. 4 is formed in the central region of the second main surface 22 of the substrate 2. The multi-layer reflection film 3 reflects EUV light. The multi-layer reflection film
30 3 is formed, for example, by alternately laminating a high refractive index layer and a low refractive index layer. The high refractive index layer is formed, for example, of silicon (Si), and the low

refractive index layer is formed, for example, of molybdenum (Mo). For example, a sputtering method such as an ion beam sputtering method or a magnetron sputtering method is used for the film formation of the multi-layer reflection film 3.

[0030]

Finally, in step S7, an absorption film 4 shown in FIG. 4 is formed on the multi-layer reflection film 3 formed in step S6. The absorption film 4 absorbs EUV light. The absorption film 4 is formed of, for example, a single metal containing at least one element selected from tantalum (Ta), chromium (Cr), and palladium (Pd), an alloy thereof, a nitride thereof, an oxide thereof, an oxynitride thereof, or the like. For the film formation of the absorption film 4, for example, a sputtering method is used.

[0031]

Steps S6 to S7 are performed after step S5 in the present embodiment, but may be performed before step S5.

[0032]

According to steps S1 to S7, described as above, the reflective mask blank 1 shown in FIG. 4 is provided. The reflective mask blank 1 has a first main surface 11, and a second main surface 12 opposite to the first main surface 11, and has the conductive film 5, the substrate 2, the multi-layer reflection film 3, and the absorption film 4 from the first main surface 11 side to the second main surface 12 side in this order.

[0033]

The reflective mask blank 1, although not

shown, has a central region and a peripheral region on the first main surface 11, similar to the substrate 2. The central region is a square area with a length of 142 mm and a width of 142 mm, excluding a rectangular frame-like peripheral region surrounding the central region, and is a quality assurance region. Similarly to the substrate 2, the reflective mask blank 1 has a central region and a peripheral region also on the second main surface 12. The central region is a square area with a length of 142 mm and a width of 142 mm, excluding a rectangular frame-like peripheral region surrounding the central region, and is a quality assurance region.

[0034]

The reflective mask blank 1 may include another film in addition to the conductive film 5, the substrate 2, the multi-layer reflection film 3, and the absorption film 4.

[0035]

For example, the reflective mask blank 1 may further include a low reflection film. The low reflection film is formed on the absorption film 4. Thereafter, an opening pattern 41 is formed on both the low reflection film and the absorption film 4. The low reflection film is used to inspect the opening pattern 41 and has a lower reflection characteristic to test light than that of the absorption film 4. The low reflection film may be formed of, for example, TaON, TaO, or the like. For example, a sputtering method is used for forming the low-reflection film.

[0036]

The reflective mask blank 1 may further include a protection film. The protection film is formed between the multi-layer reflection film 3 and the absorption film 4. The protection film protects
5 the multi-layer reflection film 3 so that the multi-layer reflection film 3 is not etched when the absorption film 4 is etched to form the opening pattern 41 on the absorption film 4. The protection film may be formed of, for example, Ru, Si, or TiO₂.
10 For forming the protection film, for example, a sputtering method is used.

[0037]

As shown in FIG. 5, the reflective mask is obtained by forming the opening pattern 41 on the
15 absorption film 4. The opening pattern 41 is formed by using a photolithography method and an etching method. Thus, a resist film used to form the opening pattern 41 may be included in the reflective mask blank 1.

20 [0038]

FIG. 6 shows a substrate 7 with a multi-layer reflection film. Hereinafter, the substrate 7 with a multi-layer reflection film is simply referred to as the substrate 7. The substrate 7 has
25 at least the substrate 2 and the multi-layer reflection film 3. In manufacturing a reflective mask, it is important to specify a position of a defect in the multi-layer reflection film 3 before forming the absorption film 4 on the multi-layer
30 reflection film 3.

[0039]

It is difficult to repair or remove the defect in the multi-layer reflection film 3.

Therefore, as shown in FIG. 7, a technique for correcting the opening pattern 41 of the absorption film 4 has been developed so that the defect in the multi-layer reflection film 3 is covered by the absorption film 4. This technique is called mitigation.

[0040]

The defects in the substrate 7 are roughly classified into amplitude defects 31 and phase defects 32. The amplitude defect 31 changes an amplitude of EUV light. The phase defect 32, on the other hand, changes a phase of the EUV light. The amplitude defects 31 are formed mainly on the surface of the multi-layer reflection film 3, while the phase defects 32 are formed mainly on the surface of the substrate 2 or inside the multi-layer reflection film 3. Because the amplitude defects 31 and the phase defects 32 are located at different depths, they are detected using different defect inspection devices and positions are specified with coordinates in separately set coordinate systems.

[0041]

Conventionally, errors have occurred in transforming a coordinate of a defect from one coordinate system to another coordinate system. Moreover, since the defect inspection is performed throughout the quality assurance region of the substrate 7, it has been difficult to achieve both reducing the inspection time and improvement of the positional accuracy. For example, if the defect is imaged during high-speed movement of the substrate 7, the inspection time can be reduced, but the positional accuracy of the defect may be degraded.

On the other hand, if the defect is imaged during low-speed movement of the substrate 7 or the movement is stopped, the positional accuracy of the defect can be improved, but an area that can be
5 inspected at one time is narrow and the inspection time becomes longer.

[0042]

Next, a method for inspecting a substrate with a multi-layer reflection film according to the
10 present embodiment will be described with reference to FIGS. 8 to 13. The inspection method includes steps S101 to S104. The order of step S101 and step S102 may be reversed, and step S101 may be performed after step S102.

15 [0043]

First, in step S101, when a first defect inspection device (not shown) is used to image the substrate 7 while the substrate 7 is moved at a first movement speed V_1 , an amplitude defect 31
20 existing in the substrate 7 is detected, and a coordinate of the amplitude defect 31 in a first coordinate system set by the first defect inspection device to the substrate 7 is acquired. It should be noted that the substrate 7 may be imaged during the
25 movement of the substrate 7, and detection (image processing) of the amplitude defect 31 and specification of the coordinate of the amplitude defect 31 may not be performed during the movement of the substrate 7.

30 [0044]

As the first defect inspection device, a commercially available device, such as a laser inspection device, is used. The first defect

inspection device is more suitable for detecting amplitude defects 31 than phase defects 32. However, the first defect inspection device can detect the phase defects 32 as well as the amplitude defects 31.

[0045]

The first defect inspection device includes, for example, an inspection stage, a transfer mechanism, a position measuring instrument, an irradiator, a detector, and an image processing device. The inspection stage holds the substrate 7 horizontally from below with the multi-layer reflection film 3 facing upward. The transfer mechanism moves the inspection stage horizontally.

The position measuring instrument measures a position of the inspection stage. The position measuring instrument may be, for example, a laser displacement gauge.

[0046]

The irradiator illuminates the substrate 7 held in the inspection stage. The wavelength of light is not particularly limited, and is, for example, from 193 nm to 532 nm. Light with wavelength of from 193 nm to 532 nm is suitable for inspecting a surface of the multi-layer reflection film 3 and for detecting amplitude defects 31.

[0047]

The detector receives reflected light or scattered light of light emitted from the irradiator onto the multi-layer reflection film 3. The detector is an area sensor in which a plurality of light receiving elements are arranged in a matrix, but may be a line sensor in which a plurality of

light receiving elements are arranged in a line, or a sensor consisting of a single light receiving element. For example, a CCD image sensor or a CMOS image sensor may be used as the area sensor. When
5 the sensor consisting of a single light receiving element is used, for example, light illuminated on the multi-layer reflection film 3 by the irradiator is scanned by a galvanomirror or a polygon mirror, and the sensor receives reflected or scattered
10 light. For example, a PMT (Photomultiplier Tube) or an APD (Avalanche Photodiode) may be used as the single light receiving element.
[0048]

The image processing device processes an
15 image imaged by the detector and detects an amplitude defect 31. The image processing device acquires a coordinate of the amplitude defect 31 in a first coordinate system set to the substrate 7 from a coordinate of the amplitude defect 31 in the
20 image and a position of the inspection stage when the image is imaged.
[0049]

As shown in FIG. 9, the origin of the first coordinate system (XY coordinate system) is
25 set to a center of a quality assurance region 77 of the substrate 7, for example. The quality assurance region 77 is a square area, 142 mm in length and 142 mm in width, for example, that is processed to a desired flatness by steps S1 to S4 of FIG. 1.
30 [0050]

The first coordinate system is a two-dimensional orthogonal coordinate system. The X-axis direction and the Y-axis direction are

perpendicular to each other, and both are horizontal. The plurality of light receiving elements constituting the detector are arranged in a matrix, for example, the row direction is in the X-axis direction and the column direction is in the Y-axis direction. As described above, the plurality of light receiving elements may be arranged in a line. The detector may be a single light receiving element if the detector scans light emitted to the multi-layer reflection film 3 by the irradiator in the X-axis direction or the Y-axis direction.

[0051]

The image processing device processes the image imaged by the detector and detects a reference mark 71. The reference mark 71 is formed on the substrate 2 or the multi-layer reflection film 3. The image processing device detects the center of the quality assurance region 77 by detecting the reference mark 71.

[0052]

The reference mark 71 is formed, for example, outside the quality assurance region 77. The number of reference marks 71 is four in FIG. 9, but may be more than one. In FIG. 9, the reference mark 71 has a cross shape, but the shape is not limited to a cross shape.

[0053]

In step S101, the substrate 7 is imaged while the inspection stage and the substrate 7 are moved at the first movement speed V1. Therefore, compared to the case where the substrate 7 is moved at a third movement speed V3 which is less than V1 and will be described later, or the substrate 7 is

imaged while the movement is stopped, the entire quality assurance region 77 can be imaged in a short time, thereby shortening the inspection time. In step S101, an approximate coordinate of the amplitude defect 31 can be acquired.

[0054]

The first movement speed V1 may be, for example, from 10 mm/sec to 1000 mm/sec, and preferably from 50 mm/sec to 200 mm/sec. The third movement speed V3 is, for example, from 0 mm/sec to 50 mm/sec, and preferably from 0 mm/sec to 10 mm/sec.

[0055]

The pixel resolution of the image acquired in step S101 is lower than the pixel resolution of the image acquired in step S104, which will be described later. The pixel resolution is, for example, from 50 nm to 1000 nm, and preferably from 50 nm to 400 nm. The pixel resolution is an actual size (a dimension in the X-axis direction or a dimension in the Y-axis direction) of an object to be imaged by one light receiving element, and is the maximum value among the dimension in the X-axis direction and the dimension in the Y-axis direction.

[0056]

Next, in step S102, when a second defect inspection device (not shown) is used to image the substrate 7 while the substrate 7 is moved at a second movement speed V2, a phase defect 32 existing in the substrate 7 is detected, and a coordinate of the phase defect 32 in a second coordinate system set by the second defect inspection device to the substrate 7 is acquired. It should be noted that

the substrate 7 may be imaged during the movement of the substrate 7, and detection of the phase defect 32 (image processing) and specification of the coordinate of the phase defect 32 may not be performed during the movement of the substrate 7.
[0057]

As the second defect inspection device, a commercially available device, such as an ABI (Actinic Blank Inspection) device manufactured by Lasertech Corporation, is used. The second defect inspection device is more suitable for detecting phase defects 32 than amplitude defects 31. However, the second defect inspection device can detect the amplitude defects 31 as well as the phase defects 32.
[0058]

The second defect inspection device, like the first defect inspection device, includes, for example, an inspection stage, a transfer mechanism, a position measuring instrument, an irradiator, a detector, and an image processing device. The inspection stage holds the substrate 7 horizontally from below with the multi-layer reflection film 3 facing upward. The transfer mechanism moves the inspection stage horizontally. The position measuring instrument measures a position of the inspection stage. The position measuring instrument may be, for example, a laser displacement gauge or a laser interferometer.
[0059]

The irradiator illuminates the substrate 7 held in the inspection stage. The wavelength of light is not particularly limited, and is, for

example, from 10 nm to 20 nm. Light with wavelength of from 10 nm to 20 nm is suitable for inspecting an interior of the multi-layer reflection film 3 and for detecting phase defects 32.

5 [0060]

The detector receives reflected light or scattered light of light emitted from the irradiator onto the multi-layer reflection film 3. The detector is an area sensor in which a plurality of
10 light receiving elements are arranged in a matrix, but may be a line sensor in which a plurality of light receiving elements are arranged in a line. For example, a CCD image sensor or a CMOS image sensor may be used as the area sensor.

15 [0061]

The image processing device processes an image imaged by the detector and detects a phase defect 32. The image processing device acquires a coordinate of the phase defect 32 in a second
20 coordinate system set to the substrate 7 from a coordinate of the phase defect 32 in the image and a position of the inspection stage when the image is imaged.

[0062]

25 As shown in FIG. 10, the origin of the second coordinate system (UV coordinate system) is set to the center of the quality assurance region 77 of the substrate 7, for example. The second coordinate system is a two-dimensional orthogonal
30 coordinate system. The U-axis direction and the V-axis direction are perpendicular to each other, and both are horizontal. The plurality of light receiving elements constituting the detector are

arranged in a matrix, for example, the row direction is in the U-axis direction and the column direction is in the V-axis direction. As described above, the plurality of light receiving elements may be

5 arranged in a line.

[0063]

The image processing device processes the image imaged by the detector and detects the reference mark 71.

10 [0064]

In step S102, the substrate 7 is imaged while the inspection stage and the substrate are moved at the second movement speed V2. Therefore, compared to the case where the substrate 7 is moved at the third movement speed V3 which is less than V2 or the substrate 7 is imaged while the movement is stopped, the entire quality assurance region 77 can be imaged in a short time, thereby shortening the inspection time. In step S102, an approximate coordinate of the phase defect 32 can be obtained.

20

[0065]

The second movement speed V2 may be, for example, from 10 mm/sec to 1000 mm/sec, and preferably from 50 mm/sec to 200 mm/sec. On the other hand, the third movement speed V3 is, for example, from 0 mm/sec to 50 mm/sec, and preferably from 0 mm/sec to 10 mm/sec, as described above.

25

[0066]

The pixel resolution of the image acquired in step S102 is lower than the pixel resolution of the image acquired in step S104, which will be described later. The pixel resolution is, for example, from 100 nm to 1000 nm, and preferably from

30

100 nm to 500 nm. The pixel resolution is an actual size (a dimension in the U-axis direction or a dimension in the V-axis direction) of an object to be imaged by one light receiving element, and is the maximum value among the dimension in the U-axis direction and the dimension in the V-axis direction. [0067]

FIG. 11 is a diagram in illustrating the first coordinate system and the second coordinate system, the origin of the first coordinate system shown in FIG. 9 being superimposed with the origin of the second coordinate system shown in FIG. 10. In FIG. 11, dashed lines represent the first coordinate system and solid lines represent the second coordinate system. A contour of the substrate 7 in the first coordinate system is deviated from a contour of the substrate 7 in the second coordinate system. In addition, the reference mark 71 in the first coordinate system is shifted from the reference mark 71 in the second coordinate system. [0068]

In step S103, a coordinate transformation that transforms the coordinate of the amplitude defect 31 from the first coordinate system to the second coordinate system is performed. The coordinate transformation is performed, for example, on the basis of the plurality of reference marks 71, for example, by translating, rotating, or scaling the first coordinate system such that the reference marks 71 in the first coordinate system coincide with the reference marks 71 in the second coordinate system.

[0069]

The coordinate transformations include, for example, a Helmert transformation, an affine transformation, and a projection transformation.

5 The Helmert transformation is performed based on two or more reference marks 71. The affine transformation is performed based on three or more reference marks 71. The projection transformation is performed based on four or more reference marks
10 71.

[0070]

It should be noted that the coordinate transformation may be performed using a common defect instead of the reference mark 71. The common
15 defect is a defect that is the phase defect 32 and also the amplitude defect 31. The common defect is detected in both step S101 and step S102.

[0071]

When the coordinate of the amplitude
20 defect 31 is transformed from the first coordinate system to the second coordinate system according to the process in step S103, the coordinate of the amplitude defect 31 and the coordinate of the phase defect 32 can be acquired in the same coordinate
25 system, i.e., the second coordinate system, as shown in FIG. 12.

[0072]

In step S104, the second defect inspection device is used to image the coordinate of the
30 amplitude defect 31 and the coordinate of the phase defect 32 (for example, the coordinates shown in FIG. 12) in the second coordinate system while the substrate 7 is moved at the third movement speed V3,

which is less than V1 and V2, or while the movement is stopped, to detect again the amplitude defect 31 and the phase defect 32 and acquire again the coordinate of the amplitude defect 31 and the
5 coordinate of the phase defect 32. Thus, errors caused by the coordinate transformation can be eliminated. In addition, since the approximate coordinate of the amplitude defect 31 and the approximate coordinate of the phase defect 32 have
10 been specified before step S104, the number of images to be imaged while the substrate 7 is moved slowly or the movement is stopped can be reduced, and the inspection time can be reduced. In addition, since the substrate 7 is imaged while the
15 substrate 7 is moved slowly or while the movement is stopped, a clear image can be acquired and the coordinate of the defect can be obtained with high accuracy.

[0073]

20 The pixel resolution of the image acquired in step S104 is, for example, from 5 nm to 100 nm, and preferably from 5 nm to 20 nm. The pixel resolution is an actual size (a dimension in the U-axis direction or a dimension in the V-axis
25 direction) of an object to be imaged by one light receiving element and is the maximum value among the dimension in the U-axis direction and the dimension in the V-axis direction.

[0074]

30 In step S104, an integrated dose of light per unit area may be increased compared to that in step S102. Thus, a clearer image can be acquired and the coordinate of the defect can be obtained more

precisely. The integrated dose of light per unit area is controlled by an output power of the light source, the irradiation time of light, and the like. [0075]

5 The coordinate of the amplitude defect 31 and the coordinate of the phase defect 32 specified before step S104 are of low accuracy. Thus, in step S104, when the coordinates specified prior to step S104 are imaged, an amplitude defect 31 or a phase
10 defect 32 may not be detected. In this case, step S104 includes shifting the coordinate to be imaged, and imaging the coordinate again. For example, imaging is performed again for an area adjacent to the area previously imaged. Reimaging for an image
15 may be performed until an amplitude defect 31 or a phase defect 32 is detected or may be performed within a predetermined area. [0076]

 The inspection method according to the
20 present disclosure is not limited to the above-described inspection method. For example, in step S103, a coordinate transformation that transforms the coordinate of the phase defect 32 from the second coordinate system (UV coordinate system) to
25 the first coordinate system (XY coordinate system) may be performed. In this case, in step S104, while the substrate 7 is moved at the third speed or while the movement of the substrate 7 is stopped, the coordinate of the amplitude defect 31 and the
30 coordinate of the phase defect 32 in the first coordinate system are imaged using the first defect inspection device, to acquire again the coordinate of the amplitude defect 31 and the coordinate of the

phase defect 32.

[0077]

Alternatively, in step S103, a coordinate transformation for transforming the coordinate of the amplitude defect 31 from the first coordinate system (XY coordinate system) to a third coordinate system, and transforming the coordinate of the phase defect 32 from the second coordinate system (UV coordinate system) to the third coordinate system may be performed. The third coordinate system is a coordinate system set to the substrate 7 by a third defect inspection device which is different from the first defect inspection device and the second defect inspection device.

[0078]

In this case, in step S104, while the substrate 7 is moved at the third movement speed or the movement of the substrate 7 is stopped, the coordinate of the amplitude defect 31 and the coordinate of the phase defect 32 in the third coordinate system are imaged using the third defect inspection device, to acquire again the coordinate of the amplitude defect 31 and the coordinate of the phase defect 32. The third defect inspection device includes, for example, an inspection stage, a transfer mechanism, a position measurement instrument, an irradiator, a detector, and an image processing device. The inspection stage holds the substrate 7 horizontally from below with the multi-layer reflection film 3 facing upward. The transfer mechanism moves the inspection stage horizontally. The position measuring instrument measures a position of the inspection stage. The position

measuring instrument may be, for example, a laser displacement gauge.

[0079]

5 The irradiator illuminates the substrate 7 held in the inspection stage. The wavelength of light is not particularly limited, and is, for example, from 10 nm to 532 nm. The wavelength of light may be from 10 nm to 20 nm or may be from 193 nm to 532 nm. The third defect inspection device
10 may have two light sources of different wavelengths. Moreover, each of the first defect inspection device and the second defect inspection device may also have two light sources of different wavelengths.

[0080]

15 The detector receives reflected light or scattered light of light emitted from the irradiator onto the multi-layer reflection film 3. The detector is an area sensor in which a plurality of light receiving elements are arranged in a matrix,
20 but may be a line sensor in which a plurality of light receiving elements are arranged in a line. For example, a CCD image sensor or a CMOS image sensor may be used as the area sensor.

[0081]

25 The image processing device processes an image imaged by the detector and detects an amplitude defect 31 and a phase defect 32. The image processing device acquires a coordinate of the amplitude defect 31 and a coordinate of the phase
30 defect 32 in the third coordinate system set to the substrate 7 from a coordinate of the amplitude defect 31 and a coordinate of the phase defect 32 in the image and a position of the inspection stage

when the image is imaged.

[0082]

As described above, the method for inspecting a substrate with a multi-layer reflection
5 film and the method for manufacturing a reflective mask blank in accordance with the present disclosure have been described. However, the present disclosure is not limited to the above-described
10 embodiments. Various variations, modifications, substitutions, additions, deletions, and combinations are possible within the scope of claims. They are also of course within the technical scope of the present disclosure.

This application is based on Japanese
15 Patent Application No. 2021-070482, filed April 19, 2021, the content of which is incorporated herein by reference.

[Reference signs list]

20 [0083]

- 2 Substrate
- 3 Multi-layer reflection film
- 4 Absorption film

25

WHAT IS CLAIMED IS

1. A method for inspecting a substrate with a multi-layer reflection film including a
5 substrate; and a multi-layer reflection film that reflects EUV light and is formed on the substrate, the method comprising:

a step of imaging the substrate with a multi-layer reflection film while moving the
10 substrate with a multi-layer reflection film at a first movement speed using a first defect inspection device, to detect an amplitude defect present in the substrate with a multi-layer reflection film, and to acquire a coordinate of the amplitude defect in a
15 first coordinate system set by the first defect inspection device;

a step of imaging the substrate with a multi-layer reflection film while moving the
20 substrate with a multi-layer reflection film at a second movement speed using a second defect inspection device, which is different from the first defect inspection device, to detect a phase defect present in the substrate with a multi-layer reflection film, and to acquire a coordinate of the
25 phase defect in a second coordinate system set by the second defect inspection device;

a step of performing a coordinate transformation that transforms the coordinate of the amplitude defect from the first coordinate system to
30 the second coordinate system; and

a step of imaging the coordinate of the amplitude defect and the coordinate of the phase defect in the second coordinate system using the

second defect inspection device while moving the substrate with a multi-layer reflection film at a third movement speed that is lower than the first movement speed and the second movement speed or
5 while stopping the movement of the substrate with a multi-layer reflection film, to detect again the amplitude defect and the phase defect and acquire again the coordinate of the amplitude defect and the coordinate of the phase defect.

10

2. The method for inspecting a substrate with a multi-layer reflection film according to claim 1, wherein

15

a pixel resolution of an image obtained by imaging while moving the substrate with a multi-layer reflection film at the second movement speed using the second defect inspection device is lower than a pixel resolution of an image obtained by
20 imaging using the second defect inspection device while moving the substrate with a multi-layer reflection film at the third movement speed or while stopping the movement of the substrate with a multi-layer reflection film.

25

3. The method for inspecting a substrate with a multi-layer reflection film according to claim 1 or 2, wherein

30

the movement of the substrate with a multi-layer reflection film is stopped while the coordinate of the amplitude defect and the coordinate of the phase defect in the second

coordinate system are imaged.

4. The method for inspecting a substrate
5 with a multi-layer reflection film according to
claim 3, wherein

when the coordinate of the amplitude
defect and the coordinate of the phase defect in the
second coordinate system are imaged using the second
10 defect inspection device while the movement of the
substrate with a multi-layer reflection film is
stopped and the amplitude defect or the phase defect
is not detected, the coordinate of the defect which
is not detected is shifted and imaged again.

15

5. A method for inspecting a substrate
with a multi-layer reflection film including a
substrate; and a multi-layer reflection film that
20 reflects EUV light and is formed on the substrate,
the method comprising:

a step of imaging the substrate with a
multi-layer reflection film while moving the
substrate with a multi-layer reflection film at a
25 first movement speed using a first defect inspection
device, to detect an amplitude defect present in the
substrate with a multi-layer reflection film, and to
acquire a coordinate of the amplitude defect in a
first coordinate system set by the first defect
30 inspection device;

a step of imaging the substrate with a
multi-layer reflection film while moving the
substrate with a multi-layer reflection film at a

second movement speed using a second defect inspection device, which is different from the first defect inspection device, to detect a phase defect present in the substrate with a multi-layer
5 reflection film, and to acquire a coordinate of the phase defect in a second coordinate system set by the second defect inspection device;

a step of performing a coordinate transformation that transforms the coordinate of the
10 phase defect from the second coordinate system to the first coordinate system; and

a step of imaging the coordinate of the amplitude defect and the coordinate of the phase defect in the first coordinate system using the
15 first defect inspection device while moving the substrate with a multi-layer reflection film at a third movement speed that is lower than the first movement speed and the second movement speed, or while stopping the movement of the substrate with a
20 multi-layer reflection film, to detect again the amplitude defect and the phase defect and acquire again the coordinate of the amplitude defect and the coordinate of the phase defect.

25

6. The method for inspecting a substrate with a multi-layer reflection film according to claim 5, wherein

a pixel resolution of an image obtained by
30 imaging while moving the substrate with a multi-layer reflection film at the first movement speed using the first defect inspection device is lower than a pixel resolution of an image obtained by

imaging using the first defect inspection device while moving the substrate with a multi-layer reflection film at the third movement speed or while stopping the movement of the substrate with a multi-layer reflection film.

7. The method for inspecting a substrate with a multi-layer reflection film according to claim 5 or 6, wherein

the movement of the substrate with a multi-layer reflection film is stopped while the coordinate of the amplitude defect and the coordinate of the phase defect in the first coordinate system are imaged.

8. The method for inspecting a substrate with a multi-layer reflection film according to claim 7, wherein

when the coordinate of the amplitude defect and the coordinate of the phase defect in the first coordinate system are imaged using the first defect inspection device while the movement of the substrate with a multi-layer reflection film is stopped and the amplitude defect or the phase defect is not detected, the coordinate of the defect which is not detected is shifted and imaged again.

30

9. A method for inspecting a substrate with a multi-layer reflection film including a substrate; and a multi-layer reflection film that

reflects EUV light and is formed on the substrate,
the method comprising:

5 a step of imaging the substrate with a
multi-layer reflection film while moving the
substrate with a multi-layer reflection film at a
first movement speed using a first defect inspection
device, to detect an amplitude defect present in the
substrate with a multi-layer reflection film, and to
10 acquire a coordinate of the amplitude defect in a
first coordinate system set by the first defect
inspection device;

a step of imaging the substrate with a
multi-layer reflection film while moving the
substrate with a multi-layer reflection film at a
15 second movement speed using a second defect
inspection device, which is different from the first
defect inspection device, to detect a phase defect
present in the substrate with a multi-layer
reflection film, and to acquire a coordinate of the
20 phase defect in a second coordinate system set by
the second defect inspection device;

a step of performing a coordinate
transformation that transforms the coordinate of the
amplitude defect from the first coordinate system to
25 a third coordinate system, which is different from
the first coordinate system and the second
coordinate system, and transforms the coordinate of
the phase defect from the second coordinate system
to the third coordinate system; and

30 a step of imaging the coordinate of the
amplitude defect and the coordinate of the phase
defect in the third coordinate system using a third
defect inspection device, which is different from

the first defect inspection device and the second defect inspection device, while moving the substrate with a multi-layer reflection film at a third movement speed that is lower than the first movement speed and the second movement speed, or while stopping the movement of the substrate with a multi-layer reflection film, to detect again the amplitude defect and the phase defect and acquire again the coordinate of the amplitude defect and the coordinate of the phase defect.

10. The method for inspecting a substrate with a multi-layer reflection film according to claim 9, wherein

a pixel resolution of an image obtained by imaging while moving the substrate with a multi-layer reflection film at the first movement speed using the first defect inspection device and

a pixel resolution of an image obtained by imaging while moving the substrate with a multi-layer reflection film at the second movement speed using the second defect inspection device

are lower than a pixel resolution of an image obtained by imaging using the third defect inspection device while moving the substrate with a multi-layer reflection film at the third movement speed or while stopping the movement of the substrate with a multi-layer reflection film.

11. The method for inspecting a substrate

with a multi-layer reflection film according to claim 9 or 10, wherein

the movement of the substrate with a multi-layer reflection film is stopped while the coordinate of the amplitude defect and the coordinate of the phase defect in the third coordinate system are imaged.

12. The method for inspecting a substrate with a multi-layer reflection film according to claim 11, wherein when the coordinate of the amplitude defect and the coordinate of the phase defect in the third coordinate system are imaged using the third defect inspection device while the movement of the substrate with a multi-layer reflection film is stopped and the amplitude defect or the phase defect is not detected, the coordinate of the defect which is not detected is shifted and imaged again.

13. The method for inspecting a substrate with a multi-layer reflection film according to any one of claims 1 to 12, wherein the first defect inspection device images the amplitude defect with reflected light or scattered light with a wavelength of from 193 nm to 532 nm.

14. The method for inspecting a substrate with a multi-layer reflection film according to any

one of claims 1 to 13, wherein

the second defect inspection device images the phase defect with reflected light or scattered light with a wavelength of from 10 nm to 20 nm.

5

15. The method for inspecting a substrate with a multi-layer reflection film according to any one of claims 9 to 12, wherein

10 the third defect inspection device images the amplitude defect and the phase defect with reflected light or scattered light with a wavelength of from 10 nm to 532 nm.

15

16. The method for inspecting a substrate with a multi-layer reflection film according to any one of claims 1 to 15, wherein

20 a pixel resolution of an image obtained by imaging while moving the substrate with a multi-layer reflection film at the third movement speed or while stopping the movement of the substrate with a multi-layer reflection film is from 5 nm to 100 nm.

25

17. The method for inspecting a substrate with a multi-layer reflection film according to any one of claims 1 to 16, wherein

30 the substrate with a multi-layer reflection film is provided with a plurality of reference marks on the substrate or on the multi-layer reflection film, and

the coordinate transformation is performed

on the basis of the plurality of reference marks.

18. The method for inspecting a substrate
5 with a multi-layer reflection film according to any
one of claims 1 to 17, wherein
the substrate with a multi-layer
reflection film is provided with a plurality of
common defects, each of which is a phase defect and
10 also an amplitude defect, and
the coordinate transformation is performed
on the basis of the plurality of common defects.

19. The method for inspecting a substrate
15 with a multi-layer reflection film according to any
one of claims 1 to 18, wherein
the coordinate transformation is a Helmert
transformation, an affine transformation, or a
20 projection transformation.

20. A method for manufacturing a
reflective mask blank comprising:
25 a step of forming an absorption film on
the multi-layer reflection film of the substrate
with a multi-layer reflection film inspected by
using the method for inspecting a substrate with a
multi-layer reflection film according to any one of
30 claims 1 to 19.