DESCRIPTION

TITLE OF INVENTION: REFLECTIVE PHOTOMASK BLANK, REFLECTIVE PHOTOMASK, AND REFLECTIVE PHOTOMASK PRODUCTION METHOD

TECHNICAL FIELD

[0001] The present invention relates to a reflective photomask blank, a reflective photomask, and a method for producing a reflective photomask.

BACKGROUND ART

[0002] In the production process of a semiconductor device, a demand for miniaturization by a photolithography technique has been increasing with miniaturization of the semiconductor device. A minimum resolution dimension of a transfer pattern in photolithography largely depends on the wavelength of an exposure light source, and a shorter wavelength enables a smaller minimum resolution dimension. Therefore, in the exposure light source, ArF excimer laser light having a wavelength of 193 nm in the related art has been undergoing replacement with light in an extreme ultraviolet (EUV) region having a wavelength of 13.5 nm.

[0003] Since the light in the EUV region is absorbed by almost all substances at a high ratio, a reflective photomask is used as a photomask (EUV mask) for EUV exposure (see, for example, Patent Literature 1). Patent literature 1 discloses an EUV photomask obtained by forming a reflective layer made of a multilayer film in which a molybdenum (Mo) layer and a silicon (Si) layer are alternately deposited on a glass substrate, forming a light absorption layer containing tantalum (Ta) as a main component thereon, and forming a pattern on the light absorption layer.

[0004] In the EUV lithography, as described above, a refractive optical system using light transmission cannot be used, and thus, an optical system member of an exposure apparatus is not a lens but a reflection type member (mirror). This causes a problem that an incident light on the reflective photomask (EUV mask) and the reflected light from the EUV mask cannot be designed coaxially. Typically, EUV lithography employs a technique of allowing light to be incident with an optical axis inclined by 6 degrees from a direction perpendicular to the EUV mask, and guiding reflected light reflected at an angle of -6 degrees to a semiconductor substrate.

[0005] As described above, in the EUV lithography, the optical axis is inclined via the mirror, and this may cause a problem called “shadowing effect” in which the EUV light incident on the EUV mask forms a shadow of a mask pattern (patterned light absorption layer) of the EUV mask. In a current EUV mask blank, a film having a film thickness of 60 nm to 90 nm and containing tantalum (Ta) as a main component is used as a light absorption layer. When pattern transfer exposure is performed using the EUV mask produced using this mask blank, a contrast might be reduced at an edge portion which is a shadow of a mask pattern, depending on the relationship between the incident direction of the EUV light and the orientation of the mask pattern. In addition, problems may occur, such as an increase in line edge roughness of a transfer pattern on a semiconductor substrate and an inability to form a line width at a target dimension, and these may lead to deterioration in transfer performance.

[0006] Therefore, a reflective photomask blank has been studied in which a light absorption layer is changed from tantalum (Ta) to a material having a high absorptivity (extinction coefficient) with respect to EUV light, or a material having high absorptivity is added to tantalum (Ta). For example, Patent Literature 2 describes a reflective photomask blank in which a light absorption layer is made of an alloy containing at least two materials selected from Pt, Zn, Au, NiO, Ag2O, Ir, Fe, SnO2, Co, and the like.

[0007] However, some materials are difficult to process by dry etching among materials having high absorptivity to EUV light, and this causes a problem in that even when a photomask blank is formed (produced), the light absorption layer included in the photomask blank cannot be patterned.

CITATION LIST

PATENT LITERATURE

[0008] Patent Literature 1: JP5418293B

Patent Literature 2: JP2019-527382A

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0009] An object of the present disclosure is to provide a reflective photomask for pattern transfer using light having a wavelength in an extreme ultraviolet range as a light source, the reflective photomask including an absorption layer having a good pattern processability, a reflective photomask blank used for producing the reflective photomask, and a method for

producing a reflective photomask using the reflective photomask blank.

SOLUTION TO PROBLEM

[0010] The present disclosure has been made to solve the above problem, and the reflective photomask blank according to an aspect of the present disclosure is a reflective photomask blank for producing a reflective photomask for pattern transfer using extreme ultraviolet light as a light source, and the reflective photomask blank includes a substrate, a reflective layer including a multilayer film formed on the substrate, and an absorption layer formed on the reflective layer. The absorption layer is formed of a material containing 50 atom% or more of platinum (Pt) and containing tantalum (Ta) in a range of 5 atom% or more and less than 50 atom%. A film thickness of the absorption layer is in a range of 17 nm or more and 50 nm or less, an extinction coefficient of the absorption layer with respect to EUV light is 0.049 or more, and a surface roughness of the absorption layer is 0.4 nm or less.

[0011] The reflective photomask according to an aspect of the present disclosure is a reflective photomask for pattern transfer using extreme ultraviolet light as a light source, and the reflective photomask includes a substrate, a reflective layer including a multilayer film formed on the substrate, and an absorption pattern layer formed on the reflective layer. The absorption pattern layer is formed of a material containing 50 atom% or more of platinum (Pt) and containing tantalum (Ta) in a range of 5 atom% or more and less than 50 atom%. A film thickness of the absorption pattern layer is in a range of 17 nm or more and 50 nm or less, an extinction coefficient of the absorption layer with respect to EUV light is 0.049 or more, and a surface roughness of the absorption pattern layer is 0.4 nm or less.

[0012] The method for producing a reflective photomask according to an aspect of the present disclosure is a method for producing a reflective photomask for pattern transfer using extreme ultraviolet light as a light source, and the method includes forming, on a substrate, a reflective layer including a multilayer film, and forming an absorption pattern layer on the reflective layer. The absorption pattern layer is formed of a material containing 50 atom% or more of platinum (Pt) and containing tantalum (Ta) in a range of 5 atom% or more and less than 50 atom%. A film thickness of the absorption pattern layer is in a range of 17 nm or more and 50 nm or less, an extinction coefficient of the absorption pattern layer with respect to EUV light is 0.049 or more, and a surface roughness of the absorption pattern layer is 0.4 nm or less.

ADVANTAGEOUS EFFECTS OF INVENTION

[0013] In the reflective photomask blank according to an aspect of the present disclosure, an absorption layer having good pattern processability can be formed. That is, the reflective photomask blank according to an aspect of the present disclosure can provide a reflective photomask blank having excellent pattern processability of the absorption layer. In other words, in the reflective photomask blank according to an aspect of the present disclosure, it is possible to provide a reflective photomask blank including an absorption layer in which favorable pattern processability can be obtained and improvement in transfer performance to a semiconductor substrate can be expected in patterning using light having a wavelength in an extreme ultraviolet range as a light source.

[0014] In the reflective photomask according to an aspect of the present disclosure, a reflective photomask including an absorption layer having good pattern processability can be provided.

In the reflective photomask according to an aspect of the present disclosure, improvement in transfer performance to a semiconductor substrate can be expected in patterning using light having a wavelength in an extreme ultraviolet range as a light source.

In the method for producing a reflective photomask according to an aspect of the present disclosure, a reflective photomask including an absorption layer having good pattern processability can be produced. That is, in the method for producing a reflective photomask according to an aspect of the present disclosure, a reflective photomask can be produced in which improvement in transfer performance to a semiconductor substrate can be expected in patterning using light having a wavelength in an extreme ultraviolet range as a light source.

[0015] As described above, an aspect of the present disclosure allows for providing a reflective photomask for pattern transfer using light having a wavelength in an extreme ultraviolet range as a light source, the reflective photomask including an absorption layer having good pattern processability, a reflective photomask blank to be used for producing the reflective photomask, and a method for producing a reflective photomask using the reflective photomask blank.

BRIEF DESCRIPTION OF DRAWINGS

[0016] FIG. 1 is a schematic cross-sectional view illustrating a structure of a reflective photomask blank according to an embodiment of the present invention.

FIG. 2 is a schematic cross-sectional view illustrating a structure of a reflective

photomask according to an embodiment of the present invention.

FIG. 3 is a graph showing an optical constant of each metal material at a wavelength of EUV light.

FIG. 4 is a schematic cross-sectional view illustrating a structure of a reflective photomask blank according to another embodiment of the present invention.

FIG. 5 is a schematic cross-sectional view illustrating a structure of a reflective photomask blank according to an example of the present invention.

FIG. 6 is a schematic cross-sectional view illustrating a production process of a reflective photomask according to an example of the present invention.

FIG. 7 is a schematic cross-sectional view illustrating a production process of a reflective photomask according to an example of the present invention.

FIG. 8 is a schematic cross-sectional view illustrating a production process of a reflective photomask according to an example of the present invention.

FIG. 9 is a schematic cross-sectional view illustrating a structure of a reflective photomask according to an example of the present invention.

FIG. 10 is a schematic plan view illustrating a shape of a designed pattern in a reflective photomask according to an example of the present invention.

DESCRIPTION OF EMBODIMENTS

[0017] Hereinafter, embodiments of the present invention will be described with reference to the drawings, but the present invention is not limited to the following embodiments.

In the following embodiments, technically preferable limitations are imposed in order to implement the present invention, but this limitation is not an essential requirement of the present invention.

[0018] FIG. 1 is a schematic cross-sectional view illustrating a structure of a reflective photomask blank 10 according to an embodiment of the present invention. FIG. 2 is a schematic cross-sectional view illustrating a structure of a reflective photomask 20 according to an embodiment of the present invention. Here, the reflective photomask 20 according to the embodiment of the present invention shown in FIG. 2 is formed by patterning the absorption layer 4 of the reflective photomask blank 10 according to the embodiment of the present invention shown in FIG. 1.

[0019] (Overall Structure)

As shown in FIG. 1, a reflective photomask blank 10 according to an embodiment of

the present invention includes a substrate 1, a reflective layer 2 formed on the substrate 1, a capping layer 3 formed on the reflective layer 2, and an absorption layer 4 formed on the capping layer 3.

[0020] (Substrate)

As the substrate 1 according to the embodiment of the present invention, for example, a flat Si substrate, a synthetic quartz substrate, or the like can be used. A low thermal expansion glass to which titanium is added can be also used for the substrate 1, but the present invention is not limited thereto as long as a material having a low thermal expansion coefficient is used for the substrate 1.

[0021] (Reflective Layer)

The reflective layer 2 according to the embodiment of the present invention may be a reflective layer that reflects EUV light (extreme ultraviolet light), which is an exposure light, and may be a multilayer reflective film formed of a combination of materials having significantly different refractive indices with respect to EUV light. The reflective layer 2 including the multilayer reflective film may be formed by repeatedly depositing layer pairs such as Mo (molybdenum) and Si (silicon), and Mo (molybdenum) and Be (beryllium) for about 40 periods.

[0022] (Capping Layer)

The capping layer 3 according to the embodiment of the present invention is formed of a material resistant to dry etching performed when a transfer pattern (mask pattern) is formed on the absorption layer 4, and functions as an etching stopper for preventing damage to the reflective layer 2 when the absorption layer 4 is etched. The capping layer 3 is formed of, for example, Ru (ruthenium). Here, the capping layer 3 may not be formed depending on the material and etching conditions of the reflective layer 2. Although not shown, a backside conductive film can be formed on the surface of the substrate 1 on which the reflective layer 2 is not formed. The backside conductive film is a film for fixing the reflective photomask 20 using the principle of an electrostatic chuck when the reflective photomask 20 is set in an exposure apparatus.

[0023] (Absorption Layer)

As shown in FIG. 2, the absorption pattern (absorption pattern layer) 41 of the reflective photomask 20 is formed by removing a part of the absorption layer 4 of the reflective photomask blank 10, that is, by patterning the absorption layer 4. In the EUV lithography, the EUV light is obliquely incident and is reflected by the reflective layer 2, but

the transfer performance on the wafer (semiconductor substrate) may deteriorate due to the shadowing effect in which the absorption pattern 41 interferes with the optical path. The deterioration of the transfer performance is reduced by reducing the thickness of the absorption layer 4 that absorbs EUV light. In order to reduce the thickness of the absorption layer 4, it is preferable to apply a material having higher absorptivity to EUV light than the conventional materials, that is, a material having a high extinction coefficient k to a wavelength of 13.5 nm.

[0024] FIG. 3 is a graph showing an optical constant of each metal material with respect to a wavelength of 13.5 nm of EUV light. In FIG. 3, the horizontal axis represents the refractive index n, and the vertical axis represents the extinction coefficient k. The extinction coefficient k of tantalum (Ta), which is the main material of the conventional absorption layer 4, is 0.041. Compound materials having a larger extinction coefficient k than it, enable reducing the thickness of the absorption layer 4 as compared with the related art.

[0025] Examples of the material satisfying the extinction coefficient k as described above include silver (Ag), platinum (Pt), indium (In), cobalt (Co), tin (Sn), nickel (Ni), and tellurium (Te) as shown in FIG. 3. However, some of these metal materials have a problem that cleaning resistance and/or hydrogen radical resistance required in an environment in which a photomask is used is low. Therefore, even if a reflective photomask blank including an absorption layer formed of these metal materials is produced, a reflective photomask produced using the reflective photomask blank cannot be used in an exposure environment in some cases.

[0026] Even if the materials have no problem in terms of resistance against hydrogen radicals, most of the materials have a problem of poor dry etching properties due to the low volatility of their halides. That is, the absorption layer formed of a material that has resistance to hydrogen radicals but in which halide of the material has low volatility cannot be patterned, and as a result, a problem may occur that the reflective photomask blank cannot be processed into a reflective photomask.

[0027] In order to avoid the above-described defects, the absorption layer 4 of the reflective photomask blank 10 of the present embodiment or the absorption pattern layer 41 of the reflective photomask 20 of the present embodiment is formed of a material (alloy) containing platinum (Pt) and tantalum (Ta). It is known that platinum (Pt) alone has high resistance to a liquid used for cleaning a photomask and has high resistance to hydrogen radicals, but has poor dry etching properties.

The inventors of the present application have found that use of a material containing platinum (Pt) and tantalum (Ta) in a specific ratio as a material for forming the absorption layer 4 and the absorption pattern layer 41 enables the absorption layer 4 to be processed by dry etching and also enables maintaining high hydrogen radical resistance.

[0028] In the present embodiment, "poor dry etching property" refers to a state in which an angle formed by the surface of the reflective layer 2 or the surface of the capping layer 3 and the side surface of the absorption pattern layer 41 in the pattern-formed portion, that is, an elevation angle (also referred to as a sidewall angle) with respect to the surface of the reflective layer 2 or the surface of the capping layer 3, is less than 80°, when the absorption pattern layer 41 is formed.

In the present embodiment, "high hydrogen radical resistance" means that a film loss rate is 0.01 nm/s or less under a hydrogen radical environment in which the hydrogen pressure is 0.36 millibar (mbar) or less at a power of 1 kW using microwave plasma.

[0029] The material constituting the absorption layer 4 contains 50 atom% or more of platinum (Pt) with respect to the total number of constituent atoms in the absorption layer 4. The material constituting the absorption layer 4 preferably contains platinum (Pt) in a range of 50 atom% or more and 95 atom% or less, more preferably contains platinum (Pt) in a range of 55 atom% or more and 90 atom% or less, and still more preferably contains platinum (Pt) in a range of 60 atom% or more and 80 atom% or less, with respect to the total number of constituent atoms in the absorption layer 4.

The absorption layer 4 contains tantalum (Ta) in a range of 5 atom% or more and less than 50 atom% with respect to the total number of constituent atoms in the absorption layer 4. This is because when a component other than platinum (Pt) is contained in the absorption layer 4, the EUV light absorption property may decrease, but when the component other than platinum (Pt) is less than 50 atom%, the reduction in EUV light absorption is very slight, and the performance of the EUV mask as the absorption layer 4 hardly decreases.

[0030] Furthermore, although platinum (Pt) is difficult to process by dry etching as a single substance, the addition of tantalum (Ta) to platinum (Pt) enables improving the processability in dry etching, and allows dry etching using a chlorine-based gas, a fluorine-based gas, or a mixed gas, so that the reflective photomask blank can be processed into a reflective photomask. Specifically, when the content of tantalum (Ta) contained in the absorption layer 4 is in a range of 5 atom% or more and less than 50 atom% with respect to the total number of constituent atoms of the absorption layer 4, the processability of the absorption layer 4 in dry

etching can be improved while maintaining hydrogen radical resistance.

[0031] If the content of tantalum (Ta) is less than 5 atom% with respect to the total number of constituent atoms of the absorption layer 4, the processability of the absorption layer 4 in dry etching may not be improved. If the content of tantalum (Ta) is 50 atom% or more with respect to the total number of constituent atoms of the absorption layer 4, the absorptivity of EUV light in the absorption layer 4 may be reduced and the thinning of the absorption layer 4 may not be expected. Further, if the content of tantalum (Ta) exceeds 50 atom% with respect to the total number of constituent atoms of the absorption layer 4, the contrast under DUV (Deep Ultraviolet) light having a wavelength of 190-260 nm is lowered, and thus the inspectability may be deteriorated.

Therefore, the content of tantalum (Ta) is preferably in a range of 5 atom% or more and less than 50 atom%, more preferably in a range of 10 atom% or more and 45 atom% or less, and still more preferably in a range of 20 atom% or more and 40 atom% or less with respect to the total number of constituent atoms of the absorption layer 4.

[0032] The composition ratio of the materials constituting the absorption layer 4 is calculated based on the analysis result by Rutherford backscattering analysis (RBS), and the content may vary depending on the analysis method. For example, for a material in which the content of platinum (Pt) is 50 atom% to 99 atom% in all metal elements by Rutherford backscattering analysis (RBS), the content of platinum (Pt) may be 40 atom% to 75 atom% in all metal elements as a result of analysis using the X-ray photoelectron spectroscopy (XPS) or may be 45 atom% to 100 atom% in all metal elements as a result of analysis using the energy dispersive X-ray analysis (EDX).

[0033] The crystallinity of the constituent materials also affects the processability of the absorption layer 4. The crystallinity also affects the smoothness of the film and the line edge roughness of the formed absorption pattern layer 41. The absorption layer 4 in the present embodiment is preferably formed of an amorphous film having low crystallinity for the reason above. The surface roughness of a material having high crystallinity increases due to formation of crystal grain boundaries. Therefore, the surface roughness (RMS) of the absorption layer 4 is preferably 0.4 nm or less, and more preferably 0.2 nm or less. Here, “surface roughness (RMS) of the absorption layer 4” means roughness (RMS) on a surface (surface) of the absorption layer 4 (absorption pattern layer 41) opposite to the side of the reflective layer 2.

The surface roughness (RMS) in the present embodiment may be measured using, for

example, an atomic force microscope (AFM).

[0034] As described above, the material constituting the absorption layer 4 preferably contains 50 atom% or more of platinum (Pt) and 5 atom% or more and less than 50 atom% of tantalum (Ta) with respect to the total number of constituent atoms of the absorption layer 4, but the material constituting the absorption layer 4 may further contain, as the material other than platinum (Pt) and tantalum (Ta), one or more elements selected from the group consisting of, for example, ruthenium (Ru), iridium (Ir), titanium (Ti), chromium (Cr), indium (In), nickel (Ni), cobalt (Co), bismuth (Bi), iron (Fe), gold (Au), silver (Ag), iodine (I), tellurium (Te), hafnium (Hf), tungsten (W), palladium (Pd), rhenium (Re), aluminum (Al), nitrogen (N), zinc (Zn), gallium (Ga), and boron (B) (hereinafter referred to as “additive element group” for convenience). That is, the absorption layer 4 may further contain one or more elements selected from the above additive element group in addition to platinum (Pt) and tantalum (Ta).

[0035] For example, among the elements included in the additive element group described above, the addition of tellurium (Te), silver (Ag), nickel (Ni), and/or indium (In) to the absorption pattern layer 41 enables further improving the absorptivity for EUV light and further thinning the film.

Alternatively, among the elements included in the additive element group described above, the addition of iron (Fe), palladium (Pd), gold (Au), cobalt (Co), and/or iridium (Ir) to the absorption pattern layer 41 enables high absorptivity for EUV light and also imparting conductivity to the absorption pattern layer 41. This enables enhancement of the inspectability in the mask pattern inspection.

[0036] Alternatively, among the elements included in the additive element group described above, the addition of nitrogen (N), hafnium (Hf), tungsten (W), iodine (I), chromium (Cr), boron (B), and/or ruthenium (Ru) to the absorption layer 4 enables the film to be more amorphous. This enables improving roughness and in-plane dimensional uniformity of the absorption layer pattern (mask pattern) 41 after dry etching, or in-plane uniformity of a transferred image.

[0037] The total content of the elements included in the additive element group described above may be the same as the content of tantalum (Ta). That is, the absorption layer 4 or the absorption pattern layer 41 may include platinum (Pt), tantalum (Ta), and one or more elements selected from the additive element group described above, and the total content of the elements included in the additive element group described above may be equal to or less than the content of tantalum (Ta). More preferably, the total content of elements included in

the additive element group described above is within a range of 0.9 times or less the content of tantalum (Ta), and more preferably, the total content of elements included in the additive element group described above is within a range of 0.6 times or less the content of tantalum (Ta). The above configuration enables providing excellent transfer performance, and imparting excellent pattern processability and the various functions described above, to the absorption layer 4.

[0038] The OD value in the absorption pattern layer 41 will be described below.

The intensity of the reflected light from a reflective portion, which is the region where the absorption layer 4 is partially removed and the reflective layer 2 and the capping layer 3 are exposed, is defined as Rm, the intensity of the reflected light from an absorption portion, which is the region where the absorption layer 4 remains, is defined as Ra, and the optical density (OD) value, which is an index representing the contrast of the light intensity between the reflective portion and the absorption portion, is defined by (Expression 1). The larger OD value equates to the better contrast and higher transferability. When the OD value is less than 1, sufficient contrast cannot be obtained, and the transfer performance tends to deteriorate. For the pattern transfer, OD > 1 is preferable, and OD is more preferably 1.5 or more.

Therefore, the OD value of the absorption layer 4 (absorption pattern layer 41) on which the transfer pattern is formed is preferably 1.0 or more, and more preferably 1.5 or more.

$$OD = -\log (Ra/Rm) \quad \text{(Expression 1)}$$

[0039] The absorption layer 4 (absorption pattern layer 41) of the conventional EUV reflective photomask is formed of a compound material containing tantalum (Ta) as a main component as described above. In this case, the film thickness of the absorption layer 4 needs to be 40 nm or more for achieving 1 or more of the OD value. The extinction coefficient k of the conventional material is 0.031. On the other hand, by forming the absorption layer 4 with a compound material containing platinum (Pt), which has an extinction coefficient k of 0.058 as a single substance, as a main component, the film thickness of the absorption layer 4 can be reduced to 17 nm for the OD value of 1 or more. However, the extinction coefficient k of the whole absorption layer 4 greatly varies depending on the mixing ratio of tantalum (Ta) to platinum (Pt) and the crystallinity of the deposited material, and when the extinction coefficient k of the whole absorption layer 4 is less than 0.049, a sufficient thinning effect cannot be expected. Therefore, in order to realize a thinner film than in the related art, the

extinction coefficient k of the whole absorption layer 4 is preferably 0.049 or more, and more preferably 0.051 or more.

[0040] Further, when the film thickness of the absorption layer 4 exceeds 50 nm, the absorption layer 4 shows the shadowing effect comparable with an absorption layer having a film thickness of 60 nm formed of a compound material containing tantalum (Ta) as a main component in the related art. When the film thickness of the absorption layer 4 exceeds 50 nm, the pattern processability of the absorption layer 4 may decrease.

Therefore, the film thickness of the absorption layer 4 according to the present embodiment is in the range of 17 nm or more and 50 nm or less. That is, when the film thickness of the absorption layer 4 is in the range of 17 nm or more and 50 nm or less, the shadowing effect can be sufficiently reduced and the transfer performance is improved as compared with the conventional absorption layer formed of a compound material containing tantalum (Ta) as a main component.

The film thickness of the absorption layer 4 is more preferably in the range of 25 nm to 40 nm. When the film thickness of the absorption layer 4 is in the range of 25 nm or more and 40 nm or less, the shadowing effect can be further reduced, and the transfer performance is further improved, as compared with the conventional absorption layer.

The “main component” refers to a component contained in an amount of 50 atom% or more with respect to the total number of atoms of the absorption layer.

[0041] Further, an oxide film (not shown) may be formed by oxidizing the upper surface of the absorption layer 4, or at least one of the upper surface or the side surface of the absorption pattern layer 41. Further, an oxide film (not shown) may be formed additionally on the upper surface of the absorption layer 4, or on at least one of the upper surface or the side surface of the absorption pattern layer 41.

The film thickness of the oxide film is not limited, but is, for example, in the range of 1 nm or more and 5 nm or less.

The above-described oxide film may be a natural oxide film naturally formed when the reflective photomask blank 10 or the reflective photomask 20 is stored or when the reflective photomask blank 10 or the reflective photomask 20 is cleaned.

[0042] (Hard Mask)

As shown in FIG. 4, in the reflective photomask blank 10 according to the embodiment of the present invention, a hard mask 5 may be formed on the absorption layer 4. The hard mask 5 according to the present embodiment has a function of further enhancing the

processability of the absorption layer 4 by being formed on the absorption layer 4.

The material constituting the hard mask 5 is preferably a material that can be dry-etched by a gas different from a gas used for dry-etching the absorption layer 4. That is, when the material containing platinum (Pt) and tantalum (Ta) as the material for forming the absorption layer 4 is etched with a chlorine-based gas, it is preferable to use a gas other than the chlorine-based gas as the etching gas for the hard mask 5. When the material containing platinum (Pt) and tantalum (Ta) as the material for forming the absorption layer 4 is etched with a fluorine-based gas, it is preferable to use a gas other than the fluorine-based gas as the etching gas for the hard mask 5.

[0043] Therefore, the constituent materials of the hard mask 5, preferably include one or more selected from the group consisting of ruthenium (Ru), titanium (Ti), chromium (Cr), nickel (Ni), cobalt (Co), bismuth (Bi), iron (Fe), gold (Au), silver (Ag), hafnium (Hf), tantalum (Ta), aluminum (Al), silicon (Si), and oxides, nitrides, borides, oxynitrides, oxyborides, and oxynitrided borides thereof. That is, the absorption layer 4 may contain platinum (Pt), tantalum (Ta) and one or more elements selected from the above additive element group, and the hard mask 5 may contain one or more selected from the group consisting of ruthenium (Ru), titanium (Ti), chromium (Cr), nickel (Ni), cobalt (Co), bismuth (Bi), iron (Fe), gold (Au), silver (Ag), hafnium (Hf), tantalum (Ta), aluminum (Al), silicon (Si), and oxides, nitrides, borides, oxynitrides, oxyborides, and oxynitrided borides thereof.

[0044] Typically, in dry etching, an introduced gas collides with electrons in a plasma to generate reactive species, such as active radicals and ions produced through various dissociation processes, thereby causing etching. Therefore, a material is more readily etched when volatile reaction products having low boiling points are formed on the etching surface. A indicator of etchability is the boiling point and/or vapor pressure of the reaction product of the material to be etched and the introduced gas. That is, a reaction product having a low boiling point tends to have a higher vapor pressure, making it easier to volatilize and be exhausted.

[0045] In the etching of the absorption layer 4 at the time of producing the reflective photomask 20, the definition of “easily etched” or “not easily etched” is that when the absorption layer is easily etched with the chlorine-based gas, the boiling point of at least one chlorine-based compound generated by etching is 250°C or less, and when the absorption layer is not easily etched with the chlorine-based gas, the boiling point of a stoichiometric form of chloride generated by etching is 300°C or more. The same applies to the fluorine-

based gas.

Therefore, the material used as the hard mask 5 is preferably a material that is easily etched by a fluorine-based gas or a chlorine-based gas, that is, a material in which a fluorine-based compound or a chlorine-based compound has a low boiling point.

[0046] Table 1 shows the boiling point of the metal halogen-based compound. The numerical values in Table 1 summarize values observed on various documents (such as CRC Handbook of Chemistry and Physics, 97th Edition (2016) and websites. As shown in Table 1, examples of mixed materials that are easily etched by the fluorine-based gas include ruthenium (Ru), bismuth (Bi), tantalum (Ta), and silicon (Si). Examples of mixed materials that are easily etched by chlorine-based gas include titanium (Ti), chromium (Cr), gold (Au), tantalum (Ta), aluminum (Al), and silicon (Si). In addition, oxides, nitrides, oxynitrides, and nitrided borides of these mixed materials may be used.

[0047] [Table 1]

	Boiling Point (°C) of Halogen-Based Compound	
Material	Fluorine-based	Chlorine-based
Ru	227	-
Ti	284	136.4
Cr	400	117
Ni	-	973
Co	1400	1049
Bi	230	447
Fe	1100	316
Au	300	200
Ag	1150	1550
Hf	968	316
Ta	229.5	242
Al	-	182.7
Si	-18.9	145

[0048] However, the above-described matters are examples of the etching gas and the reactivity thereof, and the etching gas in the present embodiment is not limited to the two types of the fluorine-based gas and the chlorine-based gas. In addition to the fluorine-based gas and the chlorine-based gas, a mixed gas thereof may be used, and a non-halogen gas such as an oxygen gas or a hydrogen gas may be contained to promote the reaction. Use of the mixed gas enables etching materials in which the fluorine-based compound or the chlorine-based compound has a boiling point higher than 250°C.

[0049] The hard mask 5 needs to remain on the absorption layer 4 until the etching of the absorption layer 4 is completed. However, when the film thickness of the hard mask 5

exceeds 30 nm, it may be difficult to form a fine pattern. If the film thickness of the hard mask 5 is less than 2 nm, the hard mask 5 is too thin and it may be difficult to form a hard mask 5 with a uniform thickness.

Therefore, the film thickness of the hard mask 5 is preferably in the range of 2 nm or more and 30 nm or less, and more preferably in the range of 5 nm or more and 10 nm or less.

The processing of the absorption layer 4 in the present embodiment is not limited to dry etching. For example, the absorption layer 4 may be processed using atomic layer etching (ALE).

[0050] Examples of a reflective photomask blank and a reflective photomask according to the present invention will be described below.

[0051] [Example 1]

First, a method for producing the reflective photomask blank 10 will be described with reference to FIG. 5.

As shown in FIG. 5, on a synthetic quartz substrate 1 having low thermal expansivity, a reflective layer 2 formed by stacking 40 pairs of silicon (Si) and molybdenum (Mo) are paired was formed.

The film thickness of the reflective layer 2 was set to 280 nm.

Next, a capping layer 3 formed of ruthenium (Ru) was formed, as an intermediate film, on the reflective layer 2 so as to have a film thickness of 3.5 nm.

Next, the absorption layer 4 containing platinum (Pt) and tantalum (Ta) was formed on the capping layer 3 so as to have a film thickness of 33 nm.

Composition analysis of the formed absorption layer 4 using Rutherford backscattering analysis (RBS) revealed that the content of platinum (Pt) in the whole absorption layer 4 was 55 atom% and the content of tantalum (Ta) was 45 atom%.

[0052] Further, the surface roughness (RMS) of the absorption layer 4 was measured using the atomic force microscope (AFM), and it was found that the surface roughness was 0.1 nm.

In addition, the crystallinity of the absorption layer 4 was measured by XRD (X-ray diffractometer), and it was found that slight crystallinity was observed but the absorption layer 4 was amorphous.

Next, the backside conductive film 6 formed of chromium nitride (CrN) was formed to a thickness of 100 nm on the surface of the substrate 1 on which the reflective layer 2 was not formed, and the reflective photomask blank 10 of Example 1 was obtained.

A sputtering apparatus was used for forming each film (layer formation) on the

substrate 1. The film thickness of each film was controlled by sputtering time.

[0053] First, a method for producing the reflective photomask 20 will be described with reference to FIGs. 6 to 9.

As shown in FIG. 6, a positive chemically amplified resist (SEBP9012: manufactured by Shin-Etsu Chemical Co., Ltd.) was spin-coated on the absorption layer 4 of the reflective photomask blank 10 to a film thickness of 120 nm, and baked at 110°C for 10 minutes to form a resist film 7.

Next, a predetermined pattern was drawn on the resist film 7 by an electron beam lithography apparatus (JBX3030: manufactured by JEOL Ltd.).

Thereafter, a pre-baking treatment was performed at 110°C for 10 minutes, and then a developing treatment was performed using a spray developer (SFG3000: manufactured by Sigmameltec Ltd.). Thus, as shown in FIG. 7, a resist pattern 71 was formed.

[0054] Next, the absorption layer 4 was patterned by dry etching mainly using a chlorine-based gas and using the resist pattern 71 as an etching mask. Thus, as shown in FIG. 8, an absorption pattern (absorption pattern layer) 41 was formed in the absorption layer 4.

Next, the resist pattern 71 was peeled off in the washing step, and as shown in FIG. 9, the reflective photomask 20 of this example was produced. In the present example, the absorption pattern 41 formed in the absorption layer 4 included a LS (line and space) pattern having a line width of 64 nm on the reflective photomask 20 for transfer evaluation, a LS pattern having a line width of 200 nm for film thickness measurement of the absorption layer by AFM, and an absorption-layer-removed portion having a size of 4 mm square for EUV reflectivity measurement. In the present example, the LS pattern having a line width of 64 nm was designed in each of the x direction and the y direction as shown in FIG. 10 so that the influence of the shadowing effect by the EUV irradiation was readily observed.

[0055] [Example 2-1]

The absorption layer 4 was formed so that the content of platinum (Pt) was 90 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 10 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 28 nm. Further, the surface roughness (RMS) of the absorption layer 4 was measured, and it was found that the surface roughness was 0.3 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Example 2-1 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0056] [Example 2-2]

The absorption layer 4 was formed so that the content of platinum (Pt) was 90 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 10 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 28 nm. Further, the surface roughness (RMS) of the absorption layer 4 was measured, and it was found that the surface roughness was 0.3 nm.

Next, a hard mask (HD: not shown) formed of silicon dioxide (SiO2) was formed on the absorption layer 4 so as to have a film thickness of 10 nm.

A reflective photomask blank 10 of Example 2 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0057] Next, a resist pattern 71 was formed in the same manner as in Example 1. Then, the hard mask was patterned by dry etching mainly using a fluorine-based gas and using the resist pattern 71 as an etching mask.

Then, the absorption layer 4 was patterned by dry etching mainly using a chlorine-based gas and using the patterned hard mask as an etching mask. Thus, an absorption pattern (absorption pattern layer) 41 was formed in the absorption layer 4.

Next, the resist pattern 71 was peeled off in the washing step.

Finally, the hard mask used as an etching mask was removed by dry etching mainly using a fluorine-based gas.

Except for these points, the reflective photomask 20 of Example 2-2 was produced in the same manner as in Example 1.

[0058] [Example 3]

The absorption layer 4 was formed so that the content of platinum (Pt) was 60 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 40 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 39 nm. Further, the surface roughness (RMS) of the absorption layer 4 was measured, and it was found that the surface roughness was 0.1 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Example 3 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0059] [Example 4]

The absorption layer 4 containing platinum (Pt), tantalum (Ta) and hafnium (Hf) was formed on the capping layer 3 so as to have a film thickness of 40 nm. Further, the surface

roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.1 nm. Composition analysis of the formed absorption layer 4 using Rutherford backscattering analysis (RBS) revealed that the content of platinum (Pt) was 60 atom%, the content of tantalum (Ta) was 30 atom%, and the content of hafnium (Hf) was 10 atom%, in the whole absorption layer 4.

A reflective photomask blank 10 and a reflective photomask 20 of Example 4 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0060] [Example 5]

The absorption layer 4 was formed so that the content of platinum (Pt) was 70 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 30 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 19 nm. Further, the surface roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.2 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Example 5 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0061] [Example 6-1]

The absorption layer 4 was formed so that the content of platinum (Pt) was 70 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 30 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 33 nm. Further, the surface roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.1 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Example 6-1 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0062] [Example 6-2]

The absorption layer 4 was formed so that the content of platinum (Pt) was 70 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 30 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 33 nm. Further, the surface roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.1 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Example 6-2 were

produced in the same manner as in Example 2-2 except for matters relating to the formation of the absorption layer 4.

[0063] [Example 7-1]

The absorption layer 4 was formed so that the content of platinum (Pt) was 70 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 30 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 48 nm. Further, the surface roughness (RMS) of the absorption layer 4 was measured, and it was found that the surface roughness was 0.3 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Example 7-1 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0064] [Example 7-2]

The absorption layer 4 was formed so that the content of platinum (Pt) was 70 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 30 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 48 nm. Further, the surface roughness (RMS) of the absorption layer 4 was measured, and it was found that the surface roughness was 0.3 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Example 7-2 were produced in the same manner as in Example 2-2 except for matters relating to the formation of the absorption layer 4.

[0065] [Example 8-1]

The absorption layer 4 was formed so that the content of platinum (Pt) was 90 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 10 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 45 nm. Further, the surface roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.4 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Example 8-1 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0066] [Example 8-2]

The absorption layer 4 was formed so that the content of platinum (Pt) was 90 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 10 atom% of the whole absorption layer 4. The absorption layer 4 was formed to a film thickness of 45 nm.

Further, the surface roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.4 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Example 8-2 were produced in the same manner as in Example 2-2 except for matters relating to the formation of the absorption layer 4.

[0067] [Example 9]

The absorption layer 4 containing platinum (Pt), tantalum (Ta) and iodine (I) was formed on the capping layer 3 so as to have a film thickness of 26 nm. Further, the surface roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.1 nm. Composition analysis of the formed absorption layer 4 using Rutherford backscattering analysis (RBS) revealed that the content of platinum (Pt) was 70 atom%, the content of tantalum (Ta) was 20 atom%, and the content of iodine (I) was 10 atom%, in the whole absorption layer 4.

A reflective photomask blank 10 and a reflective photomask 20 of Example 9 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0068] [Example 10]

The absorption layer 4 containing platinum (Pt), tantalum (Ta) and cobalt (Co) was formed on the capping layer 3 so as to have a film thickness of 36 nm. Further, the surface roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.2 nm. Composition analysis of the formed absorption layer 4 using Rutherford backscattering analysis (RBS) revealed that the content of platinum (Pt) was 60 atom%, the content of tantalum (Ta) was 20 atom%, and the content of cobalt (Co) was 20 atom%, in the whole absorption layer 4.

A reflective photomask blank 10 and a reflective photomask 20 of Example 10 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0069] [Example 11]

The absorption layer 4 containing platinum (Pt), tantalum (Ta) and tellurium (Te) was formed on the capping layer 3 so as to have a film thickness of 24 nm. Further, the surface roughness (RMS) of the absorption layer 4 was measured, and it was found that the surface roughness was 0.3 nm. Composition analysis of the formed absorption layer 4 using Rutherford backscattering analysis (RBS) revealed that the content of platinum (Pt) was 70

atom%, the content of tantalum (Ta) was 15 atom%, and the content of tellurium (Te) was 15 atom%, in the whole absorption layer 4.

A reflective photomask blank 10 and a reflective photomask 20 of Example 11 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0070] [Example 12]

The absorption layer 4 containing platinum (Pt), tantalum (Ta) and boron (B) was formed on the capping layer 3 so as to have a film thickness of 41 nm. Further, the surface roughness (RMS) of the absorption layer 4 was measured, and it was found that the surface roughness was 0.1 nm. Composition analysis of the formed absorption layer 4 using Rutherford backscattering analysis (RBS) revealed that the content of platinum (Pt) was 70 atom%, the content of tantalum (Ta) was 25 atom%, and the content of boron (B) was 5 atom%, in the whole absorption layer 4.

A reflective photomask blank 10 and a reflective photomask 20 of Example 12 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0071] [Example 13]

The absorption layer 4 containing platinum (Pt), tantalum (Ta) and rhenium (Re) was formed on the capping layer 3 so as to have a film thickness of 33 nm. Further, the surface roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.2 nm. Composition analysis of the formed absorption layer 4 using Rutherford backscattering analysis (RBS) revealed that the content of platinum (Pt) was 75 atom%, the content of tantalum (Ta) was 15 atom%, and the content of rhenium (Re) was 10 atom%, in the whole absorption layer 4.

A reflective photomask blank 10 and a reflective photomask 20 of Example 13 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0072] [Comparative Example 1]

The absorption layer 4 was formed so that the content of platinum (Pt) was 45 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 55 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 29 nm. Further, the surface roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.2 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Comparative Example 1 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0073] [Comparative Example 2]

The absorption layer 4 was formed so that the content of platinum (Pt) was 30 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 70 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 28 nm. Further, the surface roughness (RMS) of the absorption layer 4 was measured, and it was found that the surface roughness was 0.3 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Comparative Example 2 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0074] [Comparative Example 3]

The absorption layer 4 was formed so that the content of platinum (Pt) was 70 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 30 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 15 nm. Further, the surface roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.2 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Comparative Example 3 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0075] [Comparative Example 4]

The absorption layer 4 was formed so that the content of platinum (Pt) was 70 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 30 atom% of the whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 55 nm. Further, the surface roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.4 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Comparative Example 4 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0076] [Comparative Example 5]

The absorption layer 4 was formed so that the content of platinum (Pt) was 55 atom% of the whole absorption layer 4 and the content of tantalum (Ta) was 45 atom% of the

whole absorption layer 4, in the absorption layer 4. The absorption layer 4 was formed to a film thickness of 33 nm. Further, the surface roughness (RMS) of the absorption layer 4 was measured, and it was found that the surface roughness was 0.5 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Comparative Example 5 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0077] [Comparative Example 6]

The absorption layer 4 was formed so that the content of platinum (Pt) in the absorption layer 4 was 100 atom% of the whole absorption layer 4. The absorption layer 4 was formed to a film thickness of 33 nm. Further, the surface roughness (RMS) of the absorption layer 4 was measured, and it was found that the surface roughness was 0.6 nm.

A reflective photomask blank 10 and a reflective photomask 20 of Comparative Example 6 were produced in the same manner as in Example 1 except for matters relating to the formation of the absorption layer 4.

[0078] In addition to the above Examples and Comparative Examples, a reflective photomask (existing mask) having an absorption pattern layer composed of TaBO/TaBN, which was a conventional tantalum (Ta)-based absorption pattern layer, was also compared as a reference example. The reflective photomask blank included a reflective layer formed by stacking 40 stacks in which silicon (Si) and molybdenum (Mo) were paired on a synthetic quartz substrate having low thermal expansivity, and a ruthenium (Ru) capping layer 3 having a film thickness of 3.5 nm, as in the above-described Examples and Comparative Examples. The absorption layer 4 formed on the capping layer 3 was obtained by forming a TaBO having a film thickness of 2 nm on a TaBN having a film thickness of 58 nm. Further, the surface roughness (RMS) of the formed absorption layer 4 was measured, and it was found that the surface roughness was 0.1 nm.

In addition, as in the above-described Examples and Comparative Examples, a patterned absorption layer 4 was used for evaluation.

In the Examples and Comparative Examples described above, the film thickness of the absorption layer 4 was measured with a transmission electron microscope.

[0079] Evaluation items for evaluating this Example will be described below.

(Processability)

Examples and Comparative Examples described above were analyzed by SEM to check whether there was a disconnection or a missing defect (so-called pattern defect) in the

pattern in the absorption pattern layer 41. The cross-sectional shape of the pattern in the absorption pattern layer 41 was also checked.

When no abnormality was observed in the formed pattern, the processing suitability (transfer performance) was regarded as acceptable, and was evaluated as "Passed (Δ)" in this evaluation. In addition, when no abnormality was observed in the formed pattern and the sidewall angle (an elevation angle based on the surface of the capping layer 3) that can be confirmed from the cross-sectional image is 80° or more, the processing suitability (transfer performance) was regarded as acceptable, and was evaluated as "Passed (○)" in this evaluation.

That is, it was suggested that, on each embodiment of Examples 2-1, 6-1, 7-1, and 8-1, providing the hard mask (HD) enables improvement of processing suitability (transfer performance).

[0080] (Reflectance)

In the above Examples and Comparative Examples, the reflectance Ra of the absorption pattern layer 41 region (see FIG. 10) of the produced reflective photomask 20 was measured by a reflectance measuring device using EUV light. The reflectance Rm of the reflective portion 8 (see FIG. 10) in which the absorption pattern layer 41 was not formed was measured by a reflectance measuring device using EUV light. In this way, the OD values of the reflective photomask 20 according to Examples and Comparative Examples were calculated using the above Equation 1.

As described above, when the OD value is less than 1.0, sufficient contrast cannot be obtained, and the transfer performance deteriorates.

Therefore, when the OD value was 1.0 or more, the transfer performance was regarded as acceptable, and was evaluated as "Passed" in this evaluation.

[0081] (Wafer Exposure Evaluation)

Using an EUV exposure apparatus (NXE3300B: manufactured by ASML), the absorption pattern 41 of the reflective photomask 20 prepared in Examples and Comparative Examples was exposed and transferred on a semiconductor wafer coated with an EUV positive chemically amplified resist. At this time, the exposure amount was adjusted so that the LS pattern in the x direction shown in FIG. 10 was transferred as designed. Specifically, in this exposure test, exposure was performed such that the LS pattern (line width: 64 nm) in the x direction shown in FIG. 10 formed a pattern having a line width of 16 nm on the semiconductor wafer. The transferred resist pattern was observed and the line width of the

resist pattern was measured by an electron beam dimension measuring machine, and how the HV bias value changes was compared by simulation.

[0082] The HV bias value is a difference between the line width of the transfer pattern depending on the orientation of the mask pattern, that is, the difference between the line width in the horizontal (H) direction and the line width in the vertical (V) direction. The line width in the H direction indicates the line width of the linear pattern orthogonal to the plane formed by the incident light and the reflected light (hereinafter, may be referred to as an "incidence plane"), and the line width in the V direction indicates the line width of the linear pattern parallel to the incidence plane. That is, the line width in the H direction is a length in a direction parallel to the incidence plane, and the line width in the V direction is a length in a direction orthogonal to the incidence plane.

[0083] As the evaluation method, the HV bias value of the existing tantalum (Ta)-based photomask, which was shown as "Existing Mask" in Table 2, was used as a reference, and the HV bias value was evaluated based on the magnitude of the HV bias value. That is, a case in which the LS pattern in the y direction was transferred as designed when the LS pattern in the x direction was adjusted to be transferred as designed, and the HV bias was smaller than that of the existing tantalum (Ta)-based photomask was evaluated as "Passed". A case (a case where the LS pattern in the y direction was not resolved) in which the LS pattern was not transferred as designed when the LS pattern in the x direction was adjusted to be transferred as designed, or a case in which the HV bias was higher than that of the existing tantalum (Ta)-based photomask was evaluated as "Failed".

These evaluation results were shown in the table. In addition to the above evaluation results, the refractive index n and the extinction coefficient k were shown in the table.

[0084] [Table 2]

	Composition	Film thickness	n	k	Surface roughness	Processability	OD value	HV bias	Overall evaluation
Example 1	PtTa(55:45)	33	0.916	0.050	0.1	○	1.67	1.47	○
Example 2-1	PtTa(90:10)	28	0.897	0.056	0.3	No HM: Δ	1.39	1.78	○
Example 2-2	PtTa(90:10)	28	0.897	0.056	0.3	With HM: ○	1.39	-	○
Example 3	PtTa(60:40)	39	0.914	0.051	0.1	○	1.57	1.23	○
Example 4	PtTaHf(60:30:10)	40	0.914	0.051	0.1	○	1.95	1.18	○
Example 5	PtTa(70:30)	19	0.908	0.052	0.2	○	1.02	1.46	○
Example 6-1	PtTa(70:30)	33	0.908	0.052	0.1	No HM: ○	1.74	1.38	○
Example 6-2	PtTa(70:30)	33	0.908	0.052	0.1	With HM: ◎	1.74	-	○
Example 7-1	PtTa(70:30)	48	0.908	0.052	0.3	No HM: Δ	2.67	0.85	○
Example 7-2	PtTa(70:30)	48	0.908	0.052	0.3	With HM: ○	2.67	-	○
Example 8-1	PtTa(90:10)	45	0.897	0.056	0.4	No HM: Δ	1.58	0.77	○
Example 8-2	PtTa(90:10)	45	0.897	0.056	0.4	With HM: ○	1.58	-	○
Example 9	PtTaI(70:20:10)	26	0.912	0.054	0.1	○	1.46	1.43	○
Example 10	PtTaCo(60:20:20)	36	0.910	0.055	0.2	○	1.45	1.62	○
Example 11	PtTaTe(70:15:15)	24	0.912	0.058	0.3	○	1.13	1.44	○
Example 12	PtTaB(70:25:5)	41	0.907	0.053	0.1	○	2.46	1.15	○
Example 13	PtTaRe(75:15:10)	33	0.902	0.054	0.2	○	1.71	1.32	○
Comparative Example 1	PtTa(45:55)	29	0.922	0.048	0.2	○	1.00	1.85	×
Comparative Example 2	PtTa(30:70)	28	0.929	0.045	0.3	×	0.98	-	×
Comparative Example 3	PtTa(70:30)	15	0.908	0.052	0.2	×	0.57	-	×
Comparative Example 4	PtTa(70:30)	55	0.908	0.052	0.4	×	2.45	0.81	×
Comparative Example 5	PtTa(55:45)	33	0.916	0.050	0.5	×	1.67	1.47	×
Comparative Example 6	Pt	33	0.391	0.058	0.6	×	1.74	0.98	×
Existing mask	Existing TaBO/TaBN	2/58nm	0.953	0.031	0.1	○	1.69	1.80	△

[0085] Table 2 shows comparison of OD values of Examples and Comparative Examples. As described above, when the OD value is less than 1, sufficient contrast cannot be obtained, and the transfer performance deteriorates.

While the OD value of the reflective photomask in the related art (existing reflective photomask) having a tantalum (Ta)-based absorption pattern layer having a film thickness of 60 nm was 1.69, the OD value of the reflective photomask 20 of Example 1 was 1.67, the OD value of the reflective photomask 20 of Example 2-1 and Example 2-2 was 1.39, the OD value of the reflective photomask 20 of Example 3 was 1.57, the OD value of the reflective photomask 20 of Example 4 was 1.95, the OD value of the reflective photomask 20 of Example 5 was 1.02, the OD value of the reflective photomask 20 of Example 6-1 and Example 6-2 was 1.74, the OD value of the reflective photomask 20 of Example 7-1 and Example 7-2 was 2.67, the OD value of the reflective photomask 20 of Example 8-1 and Example 8-2 was 1.58, the OD value of the reflective photomask 20 of Example 9 was 1.46, the OD value of the reflective photomask 20 of Example 10 was 1.45, the OD value of the reflective photomask 20 of Example 11 was 1.13, the OD value of the reflective photomask 20 of Example 12 was 2.46, and the OD value of the reflective photomask 20 of Example 13 was 1.71. In the Comparative Examples, the OD value of the reflective photomask 20 of Comparative Example 1 was 1.00, the OD value of the reflective photomask 20 of Comparative Example 2 was 0.98, the OD value of the reflective photomask 20 of Comparative Example 3 was 0.57, the OD value of the reflective photomask 20 of Comparative Example 4 was 2.45, the OD value of the reflective photomask 20 of Comparative Example 5 was 1.67, and the OD value of the reflective photomask 20 of Comparative Example 6 was 1.74. Thus, Comparative Examples 2 and 3 had an OD value of less than 1.0, and did not satisfy the “Passed” criterion in this evaluation.

[0086] Table 2 shows comparison of the HV bias of Examples and Comparative Examples.

As a result of patterning with EUV light a reflective photomask including a conventional tantalum (Ta)-based absorption pattern layer having a film thickness of 60 nm, the HV bias was 1.80 nm. On the other hand, the HV bias of Example 1 was 1.47 nm, the HV bias of Example 2-1 was 1.78 nm, the HV bias of Example 3 was 1.23 nm, the HV bias of Example 4 was 1.18 nm, the HV bias of Example 5 was 1.46 nm, the HV bias of Example 6-1 was 1.38 nm, the HV bias of Example 7-1 was 0.85 nm, the HV bias of Example 8-1 was 0.77 nm, the HV bias of Example 9 was 1.43 nm, the HV bias of Example 10 was 1.62 nm, the HV bias of Example 11 was 1.44 nm, the HV bias of Example 12 was 1.15 nm, and the HV bias of Example 13 was 1.32 nm. In the Comparative Examples, the HV bias of Comparative Example 4 was 0.81 nm, the HV bias of Comparative Example 5 was 1.47 nm, the HV bias of Comparative Example 6 was 0.98 nm, and these Comparative Examples met the “Passed”

criterion in this evaluation.

[0087] On the other hand, the HV bias of Comparative Example 1 was 1.85 nm. That is, as a result of the patterning using EUV light, the transferability of Comparative Example 1 deteriorated as compared with the conventional tantalum (Ta)-based photomask.

As for Comparative Examples 2 and 3, their OD values were small, pattern processing of the absorption layer 4 could not be performed, and the HV bias could not be measured.

[0088] In the Examples, the HV bias was not evaluated for each embodiment of Examples 2-2, 6-2, 7-2, and 8-2 (that is, the embodiment including the hard mask). This is because each embodiment of Examples 2-1, 6-1, 7-1, and 8-1 (that is, the form without the hard mask) had excellent processability and met the “Passed” criterion in the HV bias evaluation and thus in even the embodiments further including the hard mask, the HV bias value does not decrease and the HV bias is not evaluated as “Failed”.

That is, the HV bias value of each embodiment (Example 2-2, Example 6-2, Example 7-2, and Example 8-2) including the hard mask is equivalent to the HV bias value of each embodiment (Example 2-1, Example 6-1, Example 7-1, and Example 8-1) not including the hard mask, and thus the description thereof is omitted in Table 2.

[0089] Table 2 shows overall evaluation of processability, OD value, and HV bias. For the reflective photomask 20 in which the shadowing effect was suppressed or reduced and the absorption layer had the processability, the “evaluation” column was denoted by “○”. For the reflective photomask 20 in which the shadowing effect could not be suppressed or reduced or the absorption layer had the poor processability, the “evaluation” column was denoted by “×”. Since the conventional tantalum (Ta)-based photomask is a comparison target, the “evaluation” column was denoted by “△”.

[0090] Furthermore, the surface roughness (RMS) of Examples 1-13 and Comparative Examples 1-6 was also confirmed supplementarily. An atomic force microscope (AFM) was used for the measurement. In order to reduce the influence of the reflectance of EUV light, the RMS of 0.4 nm or less was evaluated as "Passed". In this case, the reflective photomask 20 of Examples 1-13 and Comparative Examples 1-4 met the "Passed" criterion in the present evaluation, and Comparative Examples 5 and 6 met the “Failed” criterion.

[0091] Accordingly, the reflective photomask exhibited the good processability (pattern processability), good optical density (OD value), and good HV bias of the absorption layer 4, where the absorption pattern layer 41 was formed of a material containing 50 atom% or more

of platinum (Pt) and containing tantalum (Ta) in a range of 5 atom% or more and less than 50 atom%, the film thickness of the absorption pattern layer 41 was in a range of 17 nm or more and 50 nm or less, the extinction coefficient of the absorption pattern layer 41 with respect to EUV light was 0.049 or more, and the surface roughness of the absorption pattern layer 41 was 0.4 nm or less. Thus, the transfer pattern was reliably formed on such a reflective photomask blank, the shadowing effect was reduced, and the transfer performance was high.

[0092] For example, the reflective photomask blank, the reflective photomask, and the method for producing the reflective photomask according to the present disclosure may have the following configurations.

(1)

A reflective photomask blank for producing a reflective photomask for pattern transfer using extreme ultraviolet light as a light source, including: a substrate; a reflective layer including a multilayer film formed on the substrate; and an absorption layer formed on the reflective layer, wherein the absorption layer is formed of a material containing 50 atom% or more of platinum (Pt) and containing tantalum (Ta) in a range of 5 atom% or more and less than 50 atom%, a film thickness of the absorption layer is in a range of 17 nm or more and 50 nm or less, an extinction coefficient of the absorption layer with respect to EUV light is 0.049 or more, and a surface roughness of the absorption layer is 0.4 nm or less.

(2)

The reflective photomask blank according to the above (1), wherein the absorption layer is formed of a material containing tantalum (Ta) in a range of 20 atom% or more and 40 atom% or less.

(3)

The reflective photomask blank according to the above (1) or (2), wherein the absorption layer further contains one or more elements selected from the group consisting of ruthenium (Ru), iridium (Ir), titanium (Ti), chromium (Cr), indium (In), nickel (Ni), cobalt (Co), bismuth (Bi), iron (Fe), gold (Au), silver (Ag), iodine (I), tellurium (Te), hafnium (Hf), tungsten (W), palladium (Pd), rhenium (Re), aluminum (Al), nitrogen (N), zinc (Zn), gallium (Ga), and boron (B).

(4)

The reflective photomask blank according to any one of the above (1) to (3), further comprising a hard mask on the absorption layer, wherein a film thickness of the hard mask is in a range of 2 nm or more and 30 nm or less.

(5)

The reflective photomask blank according to the above (4), wherein the hard mask is made of one or more selected from the group consisting of ruthenium (Ru), titanium (Ti), chromium (Cr), nickel (Ni), cobalt (Co), bismuth (Bi), iron (Fe), gold (Au), silver (Ag), hafnium (Hf), tantalum (Ta), aluminum (Al), silicon (Si), and oxides, nitrides, borides, oxynitrides, oxyborides, and oxynitrided borides thereof.

(6)

The reflective photomask blank according to any one of the above (1) to (5), further comprising an oxide film on the absorption layer.

(7)

The reflective photomask blank according to any one of the above (1) to (6), wherein a capping layer is formed between the reflective layer and the absorption layer.

(8)

A reflective photomask for pattern transfer using extreme ultraviolet light as a light source, including: a substrate; a reflective layer including a multilayer film formed on the substrate; and an absorption pattern layer formed on the reflective layer, wherein the absorption pattern layer is formed of a material containing 50 atom% or more of platinum (Pt) and containing tantalum (Ta) in a range of 5 atom% or more and less than 50 atom%, a film thickness of the absorption pattern layer is in a range of 17 nm or more and 50 nm or less, an extinction coefficient of the absorption layer with respect to EUV light is 0.049 or more, and a surface roughness of the absorption pattern layer is 0.4 nm or less.

(9)

The reflective photomask according to the above (8), wherein the absorption pattern layer is formed of a material containing tantalum (Ta) in a range of 20 atom% or more and 40 atom% or less.

(10)

The reflective photomask according to the above (8) or (9), wherein the absorption pattern layer further contains one or more elements selected from the group consisting of ruthenium (Ru), iridium (Ir), titanium (Ti), chromium (Cr), indium (In), nickel (Ni), cobalt (Co), bismuth (Bi), iron (Fe), gold (Au), silver (Ag), iodine (I), tellurium (Te), hafnium (Hf), tungsten (W), palladium (Pd), rhenium (Re), aluminum (Al), nitrogen (N), zinc (Zn), gallium (Ga), and boron (B).

(11)

The reflective photomask according to any one of the above (8) to (10), further comprising an oxide film on at least one of an upper surface of the absorption pattern layer or a side surface of the absorption pattern layer.

(12)

The reflective photomask according to any one of the above (8) to (11), wherein a capping layer is formed between the reflective layer and the absorption pattern layer.

(13)

A method for producing a reflective photomask for pattern transfer using extreme ultraviolet light as a light source, the method comprising forming, on a substrate, a reflective layer including a multilayer film, and forming an absorption pattern layer on the reflective layer, wherein the absorption pattern layer is formed of a material containing 50 atom% or more of platinum (Pt) and containing tantalum (Ta) in a range of 5 atom% or more and less than 50 atom%, a film thickness of the absorption pattern layer is in a range of 17 nm or more and 50 nm or less, an extinction coefficient of the absorption pattern layer with respect to EUV light is 0.049 or more, and a surface roughness of the absorption pattern layer is 0.4 nm or less.

INDUSTRIAL APPLICABILITY

[0093] The reflective photomask according to the present invention can be suitably used to form a fine pattern by EUV exposure in a production process of a semiconductor integrated circuit or the like.

REFERENCE SIGNS LIST

[0094]

1 ... Substrate
2 ... Reflective layer
3 ... Capping layer
4 ... Absorption layer
41 ... Absorption pattern (Absorption pattern layer)
5 ... Hard mask
10 ... Reflective photomask blank
20 ... Reflective photomask
6 ... Backside conductive film

7 ... Resist film

71 ... Resist pattern

8 ... Reflective portion