

[DESCRIPTION]

[Title of Invention]

PHASE SHIFT MASK BLANK, PHASE SHIFT MASK AND
MANUFACTURING METHOD FOR PHASE SHIFT MASK

[Technical Field]

[0001]

The present invention relates to a phase shift mask blank, a phase shift mask and a manufacturing method for a phase shift mask, and specifically, relates to a phase shift mask used for fabricating a semiconductor integrated circuit, a CCD (charge coupled device), a color filter for an LCD (liquid crystal display), a magnetic head and so on.

[Background Art]

[0002]

Recently, along with the miniaturization of semiconductor devices, high resolution of projection exposure is demanded. Therefore, in the field of photomasks, a phase shift method has been developed as a means for enhancing resolution of a transfer pattern. A principle of the phase shift method is to perform adjustment so that a phase of a transmitted light having passed through a phase shift portion arranged adjacent to an opening portion is reversed with a phase of the transmitted light passing through the opening, such that light intensity of the portion where the transmitted lights mutually interfere is weakened (phase shift effect), and as a result, the resolution of the transfer pattern is improved. Photomasks using this principle are referred to as phase shift masks in general.

[0003]

A mainstream of a phase shift mask blank used for the phase shift mask is a structure where a phase shift film and a light shielding film are laminated sequentially on a transparent substrate such as a glass substrate. The film thickness and composition of the phase shift film are adjusted so that desired phase difference and transmittance are realized, wherein if the phase difference is between 175 and 180 degrees and the transmittance is between 5 and 7 %, it is common to form the film using a monolayer or a multilayer film using MoSi-based material with a film thickness of 60 to 80 nm. Further, the film thickness and composition of the light shielding film are adjusted so that a desired OD value (optical density) is realized in combination with the phase shift film, so that if the OD value combined with the above-described phase shift film is 2.8 or greater, it is common to form the film using a

monolayer or a multilayer film using a chromium-based material having a film thickness of 40 to 60 nm.

[0004]

A general method for forming a phase shift mask pattern involves forming a resist film on a light shielding film of a phase shift mask blank, drawing a pattern on the resist film using a laser beam or an electron beam, forming a resist pattern by developing the same, forming a light shielding film pattern by etching the light shielding film using the resist pattern as a mask, etching the phase shift film using the light shielding film pattern as mask, and thereafter removing the resist film and the light shielding film to form a phase shift film pattern.

[0005]

In a phase shift mask requiring a high accuracy pattern to be formed, dry etching using gas plasma for etching is the mainstream. Oxygen-containing chlorine-based etching (Cl/O based) is the mainstream of dry etching of a light shielding film using a chromium-based material, and fluorine-based etching (F based) is the mainstream of dry etching of a phase shift film using a MoSi-based material.

[0006]

Meanwhile, along with the refinement of the semiconductor device, there are demands for a technique for forming a microscopic photomask pattern used as an original plate. Especially, an assist pattern for assisting transfer property of a main pattern of the photomask must be formed smaller than the main pattern so that it will not be transferred on the wafer during exposure. A dimension of the assist pattern for a generation of logic device of 28 nm or smaller, or for a generation of a memory device of 30 nm or smaller, is required to realize a resolution of 60 nm or smaller.

[0007]

One effective means for improving the resolution of a photomask pattern is thinning of film thickness of the resist film. By lowering an aspect ratio (film thickness / width) of the resist film, collapsing or cut-out failure of the resist pattern during development can be reduced.

[0008]

In the phase shift mask, thinning of the resist film has been performed to realize improvement of resolution of the pattern, too. However, the resist film is also damaged during dry etching of the light shielding film having a film thickness of 40 to 60 nm, so that there was a limit in the thinning of the resist film considering tolerance during etching of the light shielding film.

[0009]

Therefore, a phase shift mask blank has been proposed where an etching mask film is formed on the light shielding film (Patent Literatures 1 and 2). It is the mainstream to use MoSiN and SiON which are silicon-based compounds to achieve sufficient tolerance to light shielding film etching of a chromium-based material as a lower layer. The mainstream film thickness is 3 to 30 nm, which is thinner than the light shielding film, enabling resist damage during dry etching to be suppressed compared to the light shielding film, by which further thinning of the resist film is realized.

[0010]

During fabrication of a phase shift mask using the phase shift mask blank with this etching mask film, there may be a case where the dimensions of the etching mask film and the light shielding film are not identical, and that an undercut is generated on the light shielding film as lower layer. The reason is that, in an etching mask film formed of a silicon-based compound and processed by fluorine-based etching (F based), and a light shielding film formed of a chromium-based material and formed of an oxygen-containing chlorine-based etching (Cl/O based), the dimension of a line pattern of the light shielding film becomes thinner because lateral etching thereof tends to advance. The amount of undercut of the light shielding film is generally adjusted by dry etching of the light shielding film, but since the amount of advancement of etching to the lateral direction differs depending on the width and area of the pattern area to be etched, it is extremely difficult to eliminate undercut of the light shielding film in all patterns.

[0011]

One of the indispensable steps for fabricating a phase shift mask using this phase shift mask blank with an etching mask film is a step of removing the etching mask film simultaneously when dry-etching the phase shift film, since both the etching mask film and the phase shift film are processed by fluorine-based etching (F based). During this step, if the above-mentioned undercut of the light shielding film has occurred, at the initial stage of etching the phase shift film, the dimension of the phase shift film is determined by the etching mask film, but after the etching mask film having a thin film thickness is lost in midway, the dimension of the phase shift film is determined by the exposed light shielding film as lower layer. That is, since the dimension of the phase shift film changes before and after elimination of the etching mask film, a step occurs to the phase shift film, and it becomes impossible to obtain a uniform dimension.

[0012]

Further, there is a phase shift mask blank where the same chromium-based material is used to form the etching mask film and a part of the light shielding film. In this type of phase shift mask blank, if the etching mask film is to be etched by oxygen-containing chlorine-based etching (Cl/O based), undercuts may be formed on the light shielding film, and if the light shielding film is to be etched by oxygen-containing chlorine-based etching (Cl/O based), the etching mask film may also be removed simultaneously, causing a problem in that processing becomes difficult.

[0013]

Further, the silicon compound constituting the etching mask film has less adhesion property with the resist film than chromium-based materials. Therefore, even if the thinning of the resist film is realized by the etching mask film, the deterioration of adhesion property with the resist film may cause collapsing of the resist pattern.

[0014]

Since etching shape of phase shift film and depth of transparent substrate of the opening portion must be controlled during dry etching of the phase shift film, conditions only suited for the removal of the etching mask film that is performed simultaneously cannot be selected, thereby causing residue (remaining after removal) of etching mask film and lower layer light shielding film. Further, since residue of the etching mask film can only be removed by fluorine-based etching (F based), and the phase shift film or the transparent substrate also receives damage simultaneously, this residue cannot be corrected by dry etching.

[Citation List]

[Patent Literature]

[0015]

[PTL 1] Japanese Patent Application Laid-Open Publication No. 2005-62884

[PTL 2] International Patent Application Publication No. 2004-090635

[Summary of Invention]

[Technical Problem]

[0016]

In consideration of the problems described above, the present invention aims at providing a phase shift mask blank, a phase shift mask and a manufacturing method for a phase shift mask, that is capable of correcting defects easily, that realizes both improvement of resolution and improvement of dimension of the phase shift mask pattern, and that enables to suppress

residue of etching mask film and light shielding film and also enables to correct the residue of the etching mask film and the light shielding film by dry etching.

[Solution to Problem]

[0017]

A phase shift mask blank according to one aspect of the present invention includes, on a substrate transparent to an exposure wavelength, a phase shift film, a light shielding film, and an etching mask film laminated in a named order, wherein the phase shift film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by fluorine-based etching (F based), the light shielding film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and is capable of being etched by non-oxygen-containing chlorine-based etching (Cl based), the etching mask film has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by oxygen-containing chlorine-based etching (Cl/O based), and wherein an etching stopper layer is not arranged between the phase shift film and the substrate.

[0018]

A phase shift mask blank according to one aspect of the present invention includes, on a substrate transparent to an exposure wavelength, a phase shift film, a lower layer light shielding film, an upper layer light shielding film, and an etching mask film laminated in a named order, wherein the phase shift film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by fluorine-based etching (F based), the lower layer light shielding film has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by oxygen-based etching (O based), the upper layer light shielding film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and is capable of being etched by either one of or both fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based), and the etching mask film has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O-based) and is capable of being etched by oxygen-containing chlorine-based etching (Cl/O based).

[0019]

Further, it is preferable that the lower layer light shielding film has a film thickness of 2 nm or greater and 30 nm or smaller and is composed of a simple substance of ruthenium or a ruthenium compound containing 50 atomic percent or higher ruthenium content.

[0020]

A phase shift mask according to one aspect of the present invention includes, on a substrate transparent to an exposure wavelength, a plurality of films including a phase shift film, a light shielding film, and an etching mask film laminated in a named order, on which a circuit pattern is formed by removing a portion of the films selectively, wherein the phase shift film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by fluorine-based etching (F based), the light shielding film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and is capable of being etched by non-oxygen-containing chlorine-based etching (Cl based), the etching mask film has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by oxygen-containing chlorine-based etching (Cl/O based), and wherein an etching stopper layer is not arranged between the phase shift film and the substrate.

[0021]

Further, a phase shift mask according to one aspect of the present invention includes, on a substrate transparent to an exposure wavelength, a plurality of films including a phase shift film, a lower layer light shielding film, an upper layer light shielding film, and an etching mask film laminated in a named order, on which a circuit pattern is formed by removing a portion of the films selectively, wherein the phase shift film has resistance to oxygen-containing chlorine-based etching (Cl/O based), non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O based) and is capable of being etched by fluorine-based etching (F based), the lower layer light shielding film has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by oxygen-based etching (O based), the upper layer light shielding film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and is capable of being etched by either one of or both fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based), and the etching mask film has resistance to fluorine-based etching (F based), non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O-based) and is

capable of being etched by oxygen-containing chlorine-based etching (Cl/O based).

[0022]

Further, it is preferable that the lower layer light shielding film has a film thickness of 2 nm or greater and 30 nm or smaller and is composed of a simple substance of ruthenium or a ruthenium compound containing 50 atomic percent or higher ruthenium content.

[0023]

Further, a manufacturing method for a phase shift mask using the phase shift mask blank according to one aspect of the present invention includes a step of forming a resist pattern on the etching mask film; a step of forming a pattern on the etching mask film by oxygen-containing chlorine-based etching (Cl/O based); a step of forming a pattern on the light shielding film using both or either one of non-oxygen-containing chlorine-based etching (Cl based) and fluorine-based etching (F based); a step of forming a pattern on the phase shift film by fluorine-based etching (F based); a step of removing the etching mask film from the pattern formed on the light shielding film by oxygen-containing chlorine-based etching (Cl/O based); and a step of removing the light shielding film from the pattern formed on the phase shift film by either non-oxygen-containing chlorine-based etching (Cl based) or both non-oxygen-containing chlorine-based etching (Cl based) and fluorine-based etching (F based).

[0024]

Further, a manufacturing method for a phase shift mask using the phase shift mask blank according to one aspect of the present invention includes a step of forming a resist pattern on the etching mask film; a step of forming a pattern on the etching mask film by oxygen-containing chlorine-based etching (Cl/O based); a step of forming a pattern on the upper layer light shielding film using both or either one of non-oxygen-containing chlorine-based etching (Cl based) and fluorine-based etching (F based); a step of forming a pattern on the lower layer light shielding film using oxygen-based etching (O based); a step of forming a pattern on the phase shift film by fluorine-based etching (F based); a step of removing the etching mask film from the pattern formed on the upper layer light shielding film by oxygen-containing chlorine-based etching (Cl/O based); a step of removing the upper layer light shielding film by either one of or both non-oxygen-containing chlorine-based etching (Cl based) and fluorine-based etching (F based); and a step of removing the lower layer light shielding film from the pattern formed on the phase shift film by oxygen-based etching (O based).

[0025]

In the phase shift mask blank according to one aspect of the present invention, the above-described film formed of the chromium-based material where lateral etching advances easily and processed by oxygen-containing chlorine-based etching (Cl/O based) exists only on an uppermost layer as the etching mask film. Therefore, an undercut is not generated in the upper layer light shielding film, the lower layer light shielding film or the antireflection film disposed as lower layers therefrom, and a phase shift mask having improved dimension can be acquired.

[0026]

Since the etching mask film is only required to have a thin film thickness, improvement of dimension by shortening of etching time and improvement of resolution by thinning of the resist film can be realized. Further, since the chromium-based material constituting the etching mask film has better adhesion with the resist film compared to the conventional silicon compound, the collapsing of the resist pattern can be suppressed.

[0027]

According to one aspect of the present invention, it is preferable that the lower layer light shielding film has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by oxygen-based etching (O based). Materials having such characteristics include a simple substance of ruthenium or a ruthenium compound.

[0028]

Further according to one aspect of the present invention, the films and substrates other than the etching mask film have tolerance to oxygen-containing chlorine-based etching (Cl/O based) for removing the etching mask film. That is, the lower layer light shielding film has resistance to oxygen-containing chlorine-based etching (Cl/O based). Further, the films and substrates other than the upper layer light shielding film have tolerance to non-oxygen-containing chlorine-based etching (Cl based) for removing the upper layer light shielding film. Furthermore, the films and substrates other than the lower layer light shielding film have tolerance to oxygen-based etching (O based) for removing the lower layer light shielding film. Therefore, it becomes possible to set conditions suitable for removal of the film without being limited by the damaging, dimension control and depth control of other films and substrate, which was the case according to the prior art phase shift mask with an etching mask, realizing reduction of residue of the etching mask

film, the upper layer light shielding film and the lower layer light shielding film. Moreover, in correcting the residue of the etching mask film, the upper layer light shielding film and the lower layer light shielding film by dry etching, the residue of the etching mask film is removed by oxygen-containing chlorine-based etching (Cl/O based), the residue of the upper layer light shielding film is removed by non-oxygen-containing chlorine-based etching (Cl based) and the residue of the lower layer light shielding film is removed by oxygen-based etching (O based), such that only residues can be corrected without causing damage to the phase shift film and the substrate.

[Advantageous Effects of Invention]

[0029]

The present invention enables to provide a phase shift mask blank, a phase shift mask and a manufacturing method for a phase shift mask that enable to correct defects easily, that realize both resolution improvement and dimension improvement of the phase shift mask pattern, that suppress residue of the etching mask film and the light shielding film, and that enables to correct residue of the etching mask film and the light shielding film by dry etching.

[Brief Description of Drawings]

[0030]

[FIG. 1] FIG. 1 is a schematic cross-sectional view illustrating a phase shift mask blank according to a first embodiment.

[FIG. 2] FIG. 2 is a schematic cross-sectional view illustrating a phase shift mask blank according to a second embodiment.

[FIG. 3] FIG. 3 is a schematic cross-sectional view illustrating a phase shift mask blank according to a third embodiment.

[FIG. 4] FIG. 4 is a schematic cross-sectional view illustrating a phase shift mask blank according to a fourth embodiment.

[FIG. 5] FIG. 5 is a schematic cross-sectional view illustrating a phase shift mask blank according to a fifth embodiment.

[FIG. 6] FIG. 6 is a schematic cross-sectional view illustrating a phase shift mask blank according to a sixth embodiment.

[FIG. 7] FIG. 7 is a schematic diagram having enlarged an effective area of a phase shift mask blank according to a comparison example 1 in which an etching stopper layer is provided.

[FIG. 8] FIG. 8 is a schematic diagram having enlarged an effective area of a phase shift mask according to a comparison example 2 in which an etching stopper layer is provided interposing a phase shift film.

[FIG. 9] FIG. 9 is a view similar to FIG. 8 according to the present embodiment.

[FIG. 10] FIG. 10 is a schematic cross-sectional view illustrating respective steps of a manufacturing method for a phase shift mask using the phase shift mask blank according to the first embodiment.

[FIG. 11] FIG. 11 is a schematic cross-sectional view illustrating respective steps of a manufacturing method for a phase shift mask using the phase shift mask blank according to the second embodiment.

[FIG. 12] FIG. 12 is a schematic cross-sectional view illustrating respective steps of a manufacturing method for a phase shift mask using the phase shift mask blank according to the third embodiment.

[FIG. 13] FIG. 13 is a schematic cross-sectional view illustrating respective steps of a manufacturing method for a phase shift mask using the phase shift mask blank according to the fourth embodiment.

[FIG. 14] FIG. 14 is a schematic cross-sectional view illustrating respective steps of a manufacturing method for a phase shift mask using the phase shift mask blank according to the fifth embodiment.

[FIG. 15] FIG. 15 is a schematic cross-sectional view illustrating respective steps of a manufacturing method for a phase shift mask using the phase shift mask blank according to the sixth embodiment.

[FIG. 16] FIG. 16 is an enlarged schematic cross-sectional view illustrating a method for correcting residue on an etching mask film and a light shielding film of the phase shift mask using the phase shift mask blank according to the present embodiment.

[FIG. 17] FIG. 17 is an enlarged schematic cross-sectional view illustrating a method for correcting residue on an etching mask film and a light shielding film of the phase shift mask using the phase shift mask blank according to the present embodiment.

[Description of Embodiments]

[0031]

Embodiments for carrying out the present invention will be described below with reference to drawings. The schematic cross-sectional view does not accurately reflect actual dimension ratios or number of patterns, and amount of engraving of the substrate and amount of damage of the films are not shown.

[0032]

The phase shift mask blank according to the embodiment illustrated below is a halftone phase shift mask blank used for fabricating a phase shift mask to which exposure light with a wavelength of 20 nm or greater and 200 nm or

smaller is applied, at least having laminated on a substrate transparent to an exposure wavelength without interposing other films, a phase shift film having resistance to oxygen-containing chlorine-based etching (Cl/O based), non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O based) and capable of being etched by fluorine-based etching (F based), an upper layer light shielding film formed on the phase shift film and having resistance to oxygen-containing chlorine-based etching (Cl/O based) and capable of being etched by fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and an etching mask film formed on an upper layer than the upper layer light shielding film and having resistance to fluorine-based etching (F based), non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O based) and capable of being etched by oxygen-containing chlorine-based etching (Cl/O based). However, there is no etching stopper layer provided between the phase shift film and the substrate.

[0033]

According further to the phase shift mask blank of the present embodiment, a lower layer light shielding film having resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and capable of being etched by oxygen-based etching (O based), is disposed between the phase shift film and the upper layer light shielding film. This lower layer light shielding film contains ruthenium and has a film thickness of 2 nm or greater and 30 nm or smaller.

[0034]

The lower layer light shielding film and the upper layer light shielding film exert a light shielding function. That is, since the lower layer light shielding film is provided, the film thickness of the upper layer light shielding film can be thinned in correspondence therewith. For example, if the upper layer light shielding film contains tantalum, the film is not easily etched by oxidation, so that etching generally takes time. In that case, if the film thickness of the upper layer light shielding film can be thinned corresponding to the lower layer light shielding film, processing efficiency can be enhanced and probability of residue can be improved.

[0035]

FIG. 1 is a schematic cross-sectional view illustrating a phase shift mask blank according to a first embodiment. A phase shift mask blank 10 according to FIG. 1 includes a substrate 11 transparent to exposure wavelength, a phase shift film 12 formed on the substrate 11, a light shielding film (also referred to

as upper layer light shielding film) 13 formed on the phase shift film 12, and an etching mask film 14 formed on the light shielding film 13. There is no etching stopper layer formed between the substrate 11 and the phase shift film 12. In the phase shift mask using the phase shift mask blank 10, a portion of the etching mask film 14 is not removed and remains on the mask.

[0036]

FIG. 2 is a schematic cross-sectional view illustrating a phase shift mask blank according to a second embodiment. The phase shift mask blank 10 of FIG. 2 includes a substrate 11 transparent to exposure wavelength, a phase shift film 12 formed on the substrate 11, a lower layer light shielding film 18 formed on the phase shift film 12, an upper layer light shielding film 13 formed on the lower layer light shielding film 18, and an etching mask film 14 formed on the upper layer light shielding film 13. There is no etching stopper layer provided between the substrate 11 and the phase shift film 12. In the phase shift mask using the phase shift mask blank 10, a portion of the etching mask film 14 is not removed and remains on the mask.

[0037]

FIG. 3 is a schematic cross-sectional view illustrating a phase shift mask blank according to a third embodiment. A phase shift mask blank 20 of FIG. 3 includes a substrate 21 transparent to exposure wavelength, a phase shift film 22 formed on the substrate 21, a light shielding film (also referred to upper layer light shielding film) 23 formed on the phase shift film 22, and an etching mask film 24 formed on the light shielding film 23. There is no etching stopper layer formed between the substrate 21 and the phase shift film 22. In the phase shift mask using the phase shift mask blank 20, the etching mask film 24 is completely removed and does not remain on the mask.

[0038]

FIG. 4 is a schematic cross-sectional view illustrating a phase shift mask blank according to a fourth embodiment. A phase shift mask blank 20 of FIG. 4 includes a substrate 21 transparent to exposure wavelength, a phase shift film 22 formed on the substrate 21, a lower layer light shielding film 28 formed on the phase shift film 22, an upper layer light shielding film 23 formed on the lower layer light shielding film 28, and an etching mask film 24 formed on the upper layer light shielding film 23. There is no etching stopper layer formed between the substrate 21 and the phase shift film 22. In the phase shift mask using the phase shift mask blank 20, the etching mask film 24 is completely removed and does not remain on the mask.

[0039]

There is no special limitation to the substrates 11 and 21 transparent to exposure wavelength, and materials such as quartz glass or CaF_2 or aluminosilicate glass is generally used.

[0040]

Further, the phase shift films 12 and 22 contain silicon and also contain one or more kinds selected from transition metal, nitrogen, oxygen and carbon, and specifically, they are a monolayer of oxide film, nitride film or oxynitride film formed of silicon, or of oxide film, nitride film or oxynitride film formed of silicon and transition metal, or a multilayer film or gradient film thereof, wherein the transmittance and phase difference with respect to the exposure wavelength can be adjusted by arbitrarily selecting the composition and film thickness thereof. Molybdenum, titanium, vanadium, cobalt, nickel, zirconium, niobium, hafnium and the like can be used as transition metal, but molybdenum is preferable.

[0041]

The value of transmittance is 3 % or greater and smaller than 100 % with respect to the transmittance of the substrate when the final phase shift mask is completed, and the most appropriate transmittance with respect to a desired wafer pattern can be arbitrarily selected, but the transmittance is generally 5 % or greater and 40 % or smaller. The value of phase difference should preferably be 170 degree or greater and 190 degrees or smaller, especially 175 degrees or greater and 180 degrees or smaller when the final phase shift mask is completed. In etching the phase shift film 12 or 22, the substrate is generally engraved simultaneously for approximately 1 to 3 nm, so as to prevent cut-out failure of the phase shift film and to perform fine adjustment of phase difference. Therefore, the phase shift film 12 or 22 must be formed with a smaller phase difference than the value desired when the mask is completed, in consideration of the amount of engraving of the substrate.

[0042]

The composition of the phase shift film 12 or 22 varies according to the combination of desired transmittance and phase difference. For example, in the case of an oxynitride film of silicon and molybdenum having a transmittance of 6 % and a phase difference of 177 degrees, in order to realize tolerance to oxygen-containing chlorine-based etching (Cl/O based), non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O based), processability to fluorine-based etching (F based) and tolerance to various chemical cleaning, it is preferable that the content of silicon is 20 atomic percent or greater and 60 atomic percent or smaller, especially 30

atomic percent or greater and 50 atomic percent or smaller, molybdenum is 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller, oxygen is 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller, and nitrogen is 30 atomic percent or greater and 80 atomic percent or smaller, especially 40 atomic percent or greater and 70 atomic percent or smaller.

[0043]

Further, if the phase shift film is a multilayer film or a gradient film, it is preferable that a silicon compound film containing little or no transition metal having strong tolerance to non-oxygen-containing chlorine-based etching (Cl based) or oxygen-based etching (O based) applied to remove the light shielding film, is formed at an uppermost surface. Specifically, it is preferable to form SiO_2 or SiON on the outermost surface of the phase shift film. Especially in the phase shift film 12 or 22 without an etching stopper layer formed as a lower layer, even if the SiO_2 or the SiON serving as the outermost surface is damaged by strong cleaning or application of strong etching condition in removal of the etching mask film, the substrate having an equivalent composition is also damaged at the same time, so that variation of phase difference or transmittance with respect to the substrate can be suppressed.

[0044]

Moreover, the upper layer light shielding film 13 or 23 is formed of a tantalum compound containing no silicon, and it is a monolayer containing one or more kinds selected from nitrogen, boron, oxygen and carbon, or a multilayer film or a gradient film thereof, and preferably, it is a film containing tantalum nitride as the main component. It does not contain silicon so as to prevent SiO_2 and SiN which are difficult to process by non-oxygen-containing chlorine-based etching (Cl based) from mixing into the film.

[0045]

The film thickness of the upper layer light shielding film 13 varies according to the transmittance of phase shift film. It is adjusted so that an OD (Optical Density) to exposure wavelength of the light shielding film (including the lower layer light shielding film, if any, the same applies hereafter), the phase shift film and the etching mask film combined, is 2.5 or greater, more preferably, 2.8 or greater. For example, if the transmittance of the phase shift film is 6 %, the film thickness of the upper layer light shielding film 13 (if there is a lower layer light shielding film 18, the total thereof, the same applies hereafter)

should preferably be 10 nm or greater and 35 nm or smaller, especially 15 nm or greater and 30 nm or smaller.

[0046]

Meanwhile, the film thickness of the upper layer light shielding film 23 (if there is a lower layer light shielding film 28, the total thereof, the same applies hereafter) also varies according to the transmittance of the phase shift film. Since the etching mask film 24 does not remain on the phase shift mask in the end, the OD (Optical Density) with respect to the exposure wavelength is adjusted so that the sum of the light shielding film and the phase shift film combined is 2.5 or greater, more preferably 2.8 or greater. For example, if the transmittance of the phase shift film is 6 %, the film thickness of the light shielding film should preferably be 15 nm or greater and 50 nm or smaller, especially 20 nm or greater and 45 nm or smaller.

[0047]

Further, the upper layer light shielding film 23 can function as an antireflection layer. In this case, the reflectivity to exposure wavelength should preferably be suppressed to 45 % or smaller, especially 30 % or smaller, so as to suppress multiple reflection between phase shift mask and projection exposure surface during exposure. Further, it is preferable to suppress reflectivity with respect to the wavelength (such as 257 nm) used for reflection testing of the phase shift mask blank or the phase shift mask to 30 % or smaller, for example, so as to detect defect with high accuracy. In order to enhance the effects of these antireflection layers, it is common to adopt a method to increase the gas content on the surface of the light shielding film to realize higher refractive index and lower extinction coefficient.

[0048]

The composition of the upper layer light shielding film 13 should preferably contain 50 atomic percent or greater and 100 atomic percent or smaller, especially 60 atomic percent or greater and 90 atomic percent or smaller tantalum, 0 atomic percent or greater and 70 atomic percent or smaller, especially 10 atomic percent or greater and 60 atomic percent or smaller nitrogen, 0 atomic percent or greater and 10 atomic percent or smaller, especially 0 atomic percent or greater and 5 atomic percent or smaller oxygen, 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller carbon, and 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller boron, in order to realize tolerance to oxygen-containing chlorine-based etching (Cl/O based),

processability to non-oxygen-containing chlorine-based etching (Cl based), and tolerance to various chemical cleaning. Further, the composition of the upper layer light shielding film 23 should preferably contain 40 atomic percent or greater and 90 atomic percent or smaller, especially 50 atomic percent or greater and 80 atomic percent or smaller tantalum, 10 atomic percent or greater and 70 atomic percent or smaller, especially 10 atomic percent or greater and 60 atomic percent or smaller nitrogen, 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller oxygen, 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller carbon, and 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller boron, in order to realize tolerance to oxygen-containing chlorine-based etching (Cl/O based), processability to non-oxygen-containing chlorine-based etching (Cl based), effect as antireflection layer and tolerance to various chemical cleaning.

[0049]

Further, the upper layer light shielding film should preferably be formed of tantalum compound or silicon compound. The tantalum compound should preferably contain one or more kinds selected from tantalum, nitrogen, boron, silicon, oxygen and carbon. The silicon compound contains silicon, and should preferably contain one or more kinds selected from molybdenum, titanium, vanadium, cobalt, nickel, zirconium, niobium, hafnium, nitrogen, oxygen and carbon.

[0050]

The lower layer light shielding film 18 or 28 is a simple substance of ruthenium, or a ruthenium compound having a ruthenium content of 50 atomic percent or greater, and specifically, it is preferably composed of a simple substance of ruthenium, or either one or more materials selected from ruthenium, nitrogen, boron, carbon and oxygen or one or more materials selected from niobium and zirconium, or a compound of both materials. The film thickness of the lower layer light shielding film 18 or 28 should preferably be 2 nm or greater and 30 nm or smaller, especially 5 nm or greater and 20 nm or smaller to realize sufficient etching tolerance and light shielding property. The etching of the lower layer light shielding film 18 or 28 can be performed by oxygen-based dry etching (oxygen-based), and it is also possible mix inert gas such as argon gas or helium gas as needed to the oxygen gas. Further, the

lower layer light shielding film 18 or 28 has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based). [0051]

Further, the etching mask film 14 or 24 is a monolayer containing a single substance of chromium or one or more kinds selected from chromium, nitrogen, oxygen and carbon, or a multilayer film or a gradient film thereof. The film thickness of the etching mask film 14 should preferably be 2 nm or greater and 30 nm or smaller, especially 20 nm or smaller to reduce resist damage during dry etching of the etching mask film and realize a thin resist. The etching mask film 14 may also have a function as an antireflection layer. In that case, the reflectivity to exposure wavelength should preferably be suppressed to 45 % or smaller, especially 30 % or smaller, to suppress multiple reflection between the phase shift mask and the projection exposure surface during exposure. Further, the reflectivity to the wavelength (such as 257 nm) used for reflection testing of the phase shift mask blank or the phase shift mask should preferably be suppressed to 30 % or smaller to enable defects to be detected with high accuracy. The film thickness of the etching mask film 14 in a case where it is provided with a function as an antireflection layer should preferably be 5 nm or greater to ensure sufficient antireflection effect. Meanwhile, the film thickness of the etching mask film 24 should preferably be 2 nm or greater and 30 nm or smaller, especially 15 nm or smaller so as to reduce resist damage during dry etching of the etching mask film and realize a thin resist, and 3 nm or greater so as to prevent pin holes during film formation and loss of film during etching and cleaning. [0052]

The composition of the etching mask film 14 should preferably contain 30 atomic percent or greater and 100 atomic percent or smaller, especially 35 atomic percent or greater and 50 atomic percent or smaller chromium, 0 atomic percent or greater and 60 atomic percent or smaller, especially 20 atomic percent or greater and 60 atomic percent or smaller oxygen, 0 atomic percent or greater and 50 atomic percent or smaller, especially 0 atomic percent or greater and 30 atomic percent or smaller nitrogen, and 0 atomic percent or greater and 30 atomic percent or smaller, especially 0 atomic percent or greater and 20 atomic percent or smaller carbon, so as to realize tolerance to fluorine-based etching (F based), non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O based), processability to oxygen-containing chlorine-based etching (Cl/O based), effect as an antireflection layer, and tolerance to various chemical cleaning.

[0053]

Further, the composition of the etching mask film 24 should preferably contain 30 atomic percent or greater and 100 atomic percent or smaller, especially 50 atomic percent or greater and 100 atomic percent or smaller chromium, 0 atomic percent or greater and 50 atomic percent or smaller, especially 0 atomic percent or greater and 40 atomic percent or smaller oxygen, 0 atomic percent or greater and 50 atomic percent or smaller, especially 0 atomic percent or greater and 40 atomic percent or smaller nitrogen, and 0 atomic percent or greater and 30 atomic percent or smaller, especially 0 atomic percent or greater and 20 atomic percent or smaller carbon, so as to realize tolerance to fluorine-based etching (F based), non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O based), processability to oxygen-containing chlorine-based etching (Cl/O based), and tolerance to various chemical cleaning.

[0054]

Next, a phase shift mask blank according to fifth and sixth embodiments will be described. The phase shift mask blank according to fifth and sixth embodiments differs from the phase shift mask according to first to fourth embodiments in that there is an antireflection film layer disposed between the light shielding film and the etching mask film.

[0055]

FIG. 5 is a schematic cross-sectional view illustrating a phase shift mask blank according to the fifth embodiment. A phase shift mask blank 10' according to FIG. 5 includes a substrate 11' that is transparent to exposure wavelength, a phase shift film 12' formed on the substrate 11', a light shielding film (also referred to as an upper layer light shielding film) 13' formed on the phase shift film 12', an antireflection film 14' formed on the light shielding film 13', and an etching mask film 15' formed on the antireflection film 14'. There is no etching stopper layer provided between the substrate 11' and the phase shift film 12'. According to the phase shift mask using the phase shift mask blank 10', the etching mask film 15' is completely removed and does not remain on the mask.

[0056]

FIG. 6 is a schematic cross-sectional view illustrating a phase shift mask blank according to the sixth embodiment. A phase shift mask blank 10' according to FIG. 6 includes a substrate 11' that is transparent to exposure wavelength, a phase shift film 12' formed on the substrate 11', a lower layer light shielding film 18' formed on the phase shift film 12', an upper layer light

shielding film 13' formed on the lower layer light shielding film 18', an antireflection film 14' formed on the upper layer light shielding film 13', and an etching mask film 15' formed on the antireflection film 14'. There is no etching stopper layer provided between the substrate 11' and the phase shift film 12'. According to the phase shift mask using the phase shift mask blank 10', the etching mask film 15' is completely removed and does not remain on the mask. [0057]

There is no special limitation to the substrate 11' that is transparent to exposure wavelength, and generally, quartz glass, CaF_2 or aluminosilicate glass is used.

[0058]

Further, the phase shift film 12' contains silicon, and also contains one or more kinds selected from transition metal, nitrogen, oxygen and carbon, specifically it is a monolayer of an oxide film, a nitride film or an oxynitride film of silicon, or a monolayer of an oxide film, a nitride film or an oxynitride film of silicon and transition metal, or a multilayer film or a gradient film thereof, wherein the composition and film thickness are selected arbitrarily to adjust the transmittance and phase difference with respect to exposure wavelength. Molybdenum, titanium, vanadium, cobalt, nickel, zirconium, niobium, hafnium and the like can be used as the transition metal, but molybdenum is preferable.

[0059]

The value of transmittance is 3 % or greater and smaller than 100 % with respect to the transmittance of substrate at the time of completion of the final phase shift mask, and a most appropriate transmittance can be selected arbitrarily according to the desired wafer pattern. A transmittance of 5 % or greater and 40 % or smaller is popular. The value of the phase difference should preferably be 170 degrees or greater and 190 degrees or smaller, especially 175 degrees or greater and 180 degrees or smaller at the time of completion of the final phase shift mask. The substrate 11' is finally engraved for approximately 5 nm to 20 nm during the mask fabrication processing of patterning the phase shift film 12' using fluorine-based etching (F based) and removal of the antireflection film 14'. Therefore, the phase shift film 12' must be formed with a shallower phase difference than the value desired during completion of the mask, considering the amount of engraving of the substrate. The film thickness of the phase shift film varies according to the combination of the desired transmittance and phase difference, and for example, if a phase shift film having 6 % transmittance and 177-degree phase difference is to be

formed, the film thickness should preferably be 60 nm or greater and 80 nm or smaller.

[0060]

The composition of the phase shift film 12' varies according to the combination of desired transmittance and phase difference. For example, in order to form an oxynitride film of silicon and molybdenum having a 6 % transmittance and 177-degree phase difference, it should preferably contain 20 atomic percent or greater and 60 atomic percent or smaller, especially 30 atomic percent or greater and 50 atomic percent or smaller silicon, 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller molybdenum, 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller oxygen, and 30 atomic percent or greater and 80 atomic percent or smaller, especially 40 atomic percent or greater and 70 atomic percent or smaller nitrogen, so as to realize tolerance to oxygen-containing chlorine-based etching (Cl/O based), non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O based), processability to fluorine-based etching (F based), and tolerance to various chemical cleaning.

[0061]

If the phase shift film is a multilayer film or a gradient film, it is preferable to form a silicon compound film that contains little or no transition metal having stronger tolerance to non-oxygen-containing chlorine-based etching (Cl based) used for removal of the light shielding film, on the outermost surface. Especially in the phase shift film 12' having no etching stopper layer as the underlayer, even if the SiO₂ or SiON on the outermost layer is damaged by application of a strong cleaning or a strong etching condition for removal of the etching mask film, the substrate having a similar composition is damaged at the same time, so that fluctuation of phase difference and transmittance with respect to the substrate can be suppressed.

[0062]

Further, the light shielding film 13' is a monolayer composed of a tantalum compound containing no silicon and containing one or more kinds selected from nitrogen, boron, oxygen and carbon, or a multilayer film or a gradient film thereof, and it is preferably a film containing tantalum nitride as main component. It does not contain silicon so as to prevent SiO₂ or SiN which are difficult to process by non-oxygen-containing chlorine-based etching (Cl based) from being mixed in the film. The film thickness of the light shielding film 13'

(including, if any, the lower layer light shielding film 18', the same applies hereafter) varies according to transmittance of the phase shift film, and it is adjusted so that the OD (optical density) with respect to the exposure wavelength combining the antireflection film, the light shielding film and the phase shift film is 2.5 or higher, more preferably, 2.8 or higher. For example, if the transmittance of the phase shift film is 6 %, the film thickness of the light shielding film 13' should preferably be 10 nm or greater and 35 nm or smaller, especially 15 nm or greater and 30 nm or smaller.

[0063]

The composition of the light shielding film 13' should preferably contain 50 atomic percent or greater and 100 atomic percent or smaller, especially 60 atomic percent or greater and 90 atomic percent or smaller tantalum, 0 atomic percent or greater and 70 atomic percent or smaller, especially 10 atomic percent or greater and 60 atomic percent or smaller nitrogen, 0 atomic percent or greater and 10 atomic percent or smaller, especially 0 atomic percent or greater and 5 atomic percent or smaller oxygen, 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller carbon, and 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller boron, so as to realize tolerance to oxygen-containing chlorine-based etching (Cl/O based), processability to non-oxygen-containing chlorine-based etching (CL based), and tolerance to various chemical cleaning.

[0064]

The lower layer light shielding film 18' is a simple substance of ruthenium, or a ruthenium compound having a ruthenium content of 50 atomic percent or greater, and specifically, it is preferably composed of a simple substance of ruthenium, or either one or more materials selected from ruthenium, nitrogen, boron, carbon and oxygen, or one or more materials selected from niobium and zirconium, or a compound of both materials. The film thickness of the lower layer light shielding film 18 or 28 should preferably be 2 nm or greater and 30 nm or smaller, especially 5 nm or greater and 20 nm or smaller to realize sufficient etching tolerance and light shielding property. The film is formed through sputter processing using an ion sputtering device with the above-described simple substance of ruthenium or ruthenium compound as target. The etching of the lower layer light shielding film 18' can be performed by oxygen-based dry etching (oxygen-based), and it is also possible mix inert gas such as argon gas or helium gas as needed to the oxygen gas. Further, the

lower layer light shielding film 18' has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based).

[0065]

Further, the antireflection film 14' is a monolayer formed of a tantalum compound containing no silicon and containing one or more kinds selected from nitrogen, boron, oxygen and carbon, or a multilayer film or a gradient film thereof, and it is preferably a film containing tantalum oxide as the main component. Therefore, the film can be formed continuously in a same film deposition chamber without changing the target from a sputter film deposition of the light shielding film. Regarding the antireflection function, the reflectivity with respect to exposure wavelength should preferably be suppressed to 45 % or below, for example, especially 30 % or below, to suppress multiple reflection between the phase shift mask and the projection exposure surface during exposure. Further, it is preferable to suppress the reflectivity with respect to the wavelength (257 nm, for example) used for reflection testing of the phase shift mask blank or the phase shift mask to 30 % or smaller, for example, from the viewpoint of detecting defects with high accuracy. The film thickness of the antireflection film 14' should preferably be 2 nm or greater and 20 nm or smaller, especially 15 nm or smaller to achieve a sufficient antireflection effect. Further, the film thickness should preferably be 3 nm or greater to prevent pinholes during film formation or loss of film during etching and cleaning.

[0066]

The composition of the antireflection film 14' should preferably contain 10 atomic percent or greater and 70 atomic percent or smaller, especially 20 atomic percent or greater and 60 atomic percent or smaller tantalum, 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller nitrogen, 40 atomic percent or greater and 90 atomic percent or smaller, especially 50 atomic percent or greater and 80 atomic percent or smaller oxygen, 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller carbon, and 0 atomic percent or greater and 20 atomic percent or smaller, especially 0 atomic percent or greater and 10 atomic percent or smaller boron, so as to realize tolerance to oxygen-containing chlorine-based etching (Cl/O based) and non-oxygen-containing chlorine-based etching (Cl based), processability to fluorine-based etching (F based), and tolerance to various chemical cleaning.

[0067]

The above-described etching mask film 15' is a monolayer containing a single substance of chromium or one or more kinds selected from chromium, nitrogen, oxygen and carbon, or a multilayer film or a gradient film thereof. The film thickness of the etching mask film 15' should preferably be 2 nm or greater and 30 nm or smaller, especially 15 nm or smaller to reduce resist damage during dry etching of the etching mask film and realize a thin resist. Further, the film thickness should preferably be 3 nm or greater to prevent pinholes during film formation or loss of film during etching and cleaning.

[0068]

The composition of the etching mask film 15' should preferably contain 30 atomic percent or greater and 100 atomic percent or smaller, especially 50 atomic percent or greater and 100 atomic percent or smaller chromium, 0 atomic percent or greater and 50 atomic percent or smaller, especially 0 atomic percent or greater and 40 atomic percent or smaller oxygen, 0 atomic percent or greater and 50 atomic percent or smaller, especially 0 atomic percent or greater and 40 atomic percent or smaller nitrogen, and 0 atomic percent or greater and 30 atomic percent or smaller, especially 0 atomic percent or greater and 20 atomic percent or smaller carbon, so as to realize tolerance to fluorine-based etching (F based), non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O based), processability to oxygen-containing chlorine-based etching (Cl/O based), and tolerance to various chemical cleaning.

[0069]

The phase shift film, the light shielding film, the antireflection film and the etching mask film of the phase shift mask blank according to the various embodiments described above can be formed by known methods. The most preferable method for achieving a film having superior homogeneity easily is a sputtering film deposition method, but the present invention is not necessary limited to sputtering film deposition method.

[0070]

The target and sputtering gas are selected by film composition. For example, as a method for forming a film containing chromium, there is a method of performing reactive sputtering using target containing chromium in only an inert gas such as argon gas etc., or in only a reactive gas such as oxygen etc., or in a mixed gas of the inert gas and the reactive gas. The flow rate of sputtering gas should preferably be adjusted according to film property, and it can be constant during film deposition, or it can be varied according to the target composition if the amount of oxygen or amount of nitrogen should

preferably be changed in a thickness direction of the film. Moreover, the applied power to the target, the distance between target and substrate, or the pressure within the film deposition chamber can be adjusted. Further, for example, in depositing a film containing silicon and metal, a target in which the content ratio of silicon and metal is adjusted can be used independently as the target, or a plurality of targets can be selected arbitrarily among targets composed of a silicon target, a metal target or a target composed of silicon and metal.

[0071]

The phase shift mask is obtained can be obtained by patterning or removing various films included in the phase shift mask blank according to the various embodiments mentioned above to a desired pattern.

[0072]

Now, the effect of not providing an etching stopper layer on the substrate will be described. FIG. 7 is a schematic diagram in which an effective area of the phase shift mask blank according to comparison example 1 provided with an etching stopper layer is shown in enlarged view. In FIG. 7, an etching stopper layer 2 is formed on a substrate 3, and a phase shift film 1 is formed on the etching stopper layer 2.

[0073]

The etching stopper layer 2 is formed, for example, of a mixed film containing silicon and aluminum. As illustrated in FIG. 7, there may be a case where a defect C exists within the film. In that case, if the defect C exists in an area where exposure light DUV passes, a portion of exposure light passing the etching stopper layer 2 may be interrupted and high accuracy exposure may not be performed.

[0074]

Similarly, if a defect such as damage A or protrusion B has occurred to the surface of the substrate 3, it may interfere with the passing of exposure light DUV. If the surface of the substrate 3 is exposed, such defect can be corrected, such as by filling damage A with transparent material and removing protrusion B. However, if an etching stopper layer 2 is formed on the substrate 3, the above-described correction becomes impossible, so that the phase shift mask blank with such defect must be discarded and yield rate is deteriorated. In contrast, if an etching stopper layer is not provided as according to the present embodiment, the above-described defect will not occur.

[0075]

Next, the effect of using a simple substance of ruthenium or ruthenium compound as the lower layer light shielding film will be described. In embodiments 2, 4 and 6, a lower layer light shielding film is provided between the phase shift film and the upper layer light shielding film. Therefore, the film thickness of the upper layer light shielding film can be thinned corresponding to the thickness of the lower layer light shielding film. For example, in a case where the upper layer light shielding film is formed of a compound including tantalum, the coating is hardened by oxidation caused by cleaning, etching, natural oxidation and the like, so that a relatively long time is required for removal. In contrast, the use of a simple substance of ruthenium or a ruthenium compound enables to shorten the processing time. The lower layer light shielding film which becomes unnecessary in the end will be etched together with the upper layer light shielding film and removed, so that there is an effect of not interfering with the correction of the phase shift film by fluorine-based gas.

[0076]

FIG. 8 is a schematic diagram having enlarged the effective area of a phase shift mask according to comparison example 2 in which an etching stopper layer is provided interposing the phase shift film. In FIG. 8, an etching stopper lower layer 2 is formed on the substrate 3, a phase shift film 1 is formed on an etching stopper lower layer 2, and an etching stopper upper layer 2 is formed on the phase shift film 1. Now, it is assumed that the two etching stopper layers 2 are formed using an aluminum compound, for example.

[0077]

In FIG. 8, it is assumed that in a state where the phase shift mask whose processing has been completed was examined, due to a presence of a microscopic foreign matter, for example, a defect D has been generated at a position that was supposed to be removed. In this case, it is necessary to remove the defect D by correction processing, and normally, the correction is performed by fluorine gas-assisted electric beam irradiation. However, according to the configuration of FIG. 8, the etching stopper upper layer 2 is formed at a position where the electric beam is to be irradiated, so that the phase shift film 1 arranged below the layer cannot be removed. Thus, processing becomes difficult and yield rate is deteriorated.

[0078]

In contrast, in the case of a phase shift mask according to the embodiment illustrated in FIG. 9, the lower layer light shielding film is removed at the end and only the phase shift film 1 will remain on the substrate 3, so that

irradiation of fluorine gas-assisted electric beam will not be interfered, and removal of the defect D can be performed easily.

[0079]

In the present embodiment, a lower layer light shielding film using a simple substance of ruthenium or a ruthenium compound is used as an etching stopper layer of upper layer light shielding film using a tantalum compound. Therefore, the etching tolerance differs, and the lower layer light shielding film can be used as a stopper layer for correcting the upper layer light shielding film. Further, light shielding effect can be exerted by both the upper layer light shielding film and the lower layer light shielding film. That is, the lower layer light shielding film exerts both a light shielding function and an etching suppressing function.

[0080]

Next, a preferred embodiment of a phase shift mask fabricated by a phase shift mask blank according to the first to sixth embodiments and a manufacturing method for a phase shift mask will be described.

[0081]

FIG. 10 is a schematic cross-sectional view sequentially illustrating a manufacturing method of a phase shift mask 100 using the phase shift mask blank 10 illustrated in FIG. 1. The components denoted by the reference numbers already described are the same as FIG. 1. FIG. 10(a) illustrates a step of applying a resist film on the etching mask film 14, drawing thereon, performing a developing process thereto, and forming a resist pattern 15. FIG. 10(b) illustrates a step of patterning the etching mask film 14 by oxygen-containing chlorine-based dry etching (Cl/O based) along the resist pattern 15. FIG. 10(c) illustrates a step of separating and removing the resist pattern 15 that remains, and then performing cleaning. FIG. 10(d) illustrates a step of patterning the light shielding film 13 along the pattern of the etching mask film 14 using both or either one of a non-oxygen-containing chlorine-based dry etching (Cl based) and fluorine-based etching (F based).

[0082]

FIG. 10(e) illustrates a step of patterning the phase shift film 12 along the pattern of the etching mask film 14 and the light shielding film 13 by fluorine-based dry etching (F based). FIG. 10(f) illustrates a step of newly forming a second resist pattern 16. FIG. 10(g) illustrates a step of removing the etching mask film 14 of the area not covered by the second resist pattern 16 by oxygen-containing chlorine-based dry etching (Cl/O based). FIG. 10(h) illustrates a step of removing the light shielding film 13 of the area not covered by the

second resist pattern 16 by non-oxygen-containing chlorine-based dry etching (Cl based), or by both non-oxygen-containing chlorine-based dry etching (Cl based) and fluorine-based etching (F based). FIG. 10(i) illustrates a step of separating and removing the second resist pattern 16 that remains, and then performing cleaning. By executing the steps described above, the phase shift mask 100 is fabricated.

[0083]

In the phase shift mask 100, a portion of the etching mask film 14 is not removed and remains on the mask. Further, in FIG. 10(i), the area denoted by reference number 101 indicates an area where a circuit pattern formed on the phase shift mask 100 is arranged (hereinafter, this area is called “effective area 101”), and the area denoted by reference number 102 indicates an area where a pattern is arranged to surround the effective area 101 in which the circuit pattern is arranged, and in the following description, this area is referred to as “periphery portion 102”. The same definitions of the effective area and the periphery portion apply to the phase shift mask illustrated in FIGs. 11 through 15 described below. In the example of the phase shift mask 100 illustrated in FIG. 10, the pattern formed in the effective area 101 is composed only of the substrate 11 and the phase shift film 12, and the pattern further laminating the light shielding film 13 and the etching mask film 14 thereon exists only in the periphery portion 102. However, as a different embodiment, a pattern in which the substrate 11, the phase shift film 12, the light shielding film 13 and the etching mask film 14 are laminated can be formed within the effective area 101.

[0084]

FIG. 11 is a schematic cross-sectional view in which manufacturing methods of the phase shift mask 100 using the phase shift mask blank 10 illustrated in FIG. 2 are sequentially illustrated. The members denoted by already described reference numbers are the same as FIG. 2. FIG. 11(a) illustrates a step of applying a resist film on the etching mask film 14, drawing thereon, performing a developing process thereto, and forming the resist pattern 15. FIG. 11(b) illustrates a step of patterning the etching mask film 14 by oxygen-containing chlorine-based dry etching (Cl/O based) along the resist pattern 15. FIG. 11(c) illustrates a step of separating and removing the resist pattern 15 that remains, and then performing cleaning. FIG. 11(d) illustrates a step of patterning the upper layer light shielding film 13 along the pattern of the etching mask film 14 using both or either one of a non-oxygen-containing chlorine-based dry etching (Cl based) and fluorine-based etching (F based).

FIG. 11(e) illustrates a step of etching the lower layer light shielding film 18 by oxygen-based etching (O based) along the pattern of the etching mask film 14 and the upper layer light shielding film 13.

[0085]

FIG. 11(f) illustrates a step of patterning the phase shift film 12 by fluorine-based dry etching (F based). FIG. 11(g) illustrates a step of newly forming a second resist pattern 16. FIG. 11(h) illustrates a step of removing the etching mask film 14 of the area not covered by the second resist pattern 16 by oxygen-containing chlorine-based dry etching (Cl/O based). FIG. 11(i) illustrates a step of removing the upper layer light shielding film 13 of the area not covered by the second resist pattern 16 by both or either one of non-oxygen-containing chlorine-based dry etching (Cl based) and fluorine-based etching (F based).

FIG. 11(j) illustrates a step of removing the lower layer light shielding film 18 of the area not covered by the second resist pattern 16 by oxygen-based etching (O based). FIG. 11(k) illustrates a step of separating and removing the second resist pattern 16 that remains, and then performing cleaning. By executing the steps described above, the phase shift mask 100 is fabricated.

[0086]

In the phase shift mask 100, a portion of the etching mask film 14 is not removed and remains on the mask. Further, in FIG. 11(k), the area denoted by reference number 101 indicates an effective area, and the area denoted by reference number 102 indicates a periphery portion. In the example of the phase shift mask 100 illustrated in FIG. 11(k), the pattern formed in the effective area 101 is composed only of the substrate 11 and the phase shift film 12. And the laminated pattern of the upper layer light shielding film 13, the lower layer light shielding film 18 and the etching mask film 14, exists only in the periphery portion 102. However, as a different embodiment, a pattern in which the substrate 11, the phase shift film 12, the upper layer light shielding film 13, the lower layer light shielding film 18 and the etching mask film 14 are laminated can be formed within the effective area 101.

[0087]

FIG. 12 is a schematic cross-sectional view in which manufacturing methods of a phase shift mask 200 using the phase shift mask blank 20 illustrated in FIG. 3 are sequentially illustrated. The members denoted by already described reference numbers are the same as FIG. 3. FIG. 12(a) illustrates a step of applying a resist film on the etching mask film 24, drawing thereon, performing a developing process thereto, and forming a resist pattern 25. FIG. 12(b) illustrates a step of patterning the etching mask film 24 by oxygen-

containing chlorine-based dry etching (Cl/O based) along the resist pattern 25. FIG. 12(c) illustrates a step of separating and removing the resist pattern 25 that remains, and then performing cleaning. FIG. 12(d) illustrates a step of patterning the light shielding film 23 along the pattern of the etching mask film 24 using both or either one of a non-oxygen-containing chlorine-based dry etching (Cl based) and fluorine-based etching (F based).
[0088]

FIG. 12(e) illustrates a step of patterning the phase shift film 22 by fluorine-based dry etching (F based) along the pattern of the etching mask film 24 and the light shielding film 23. FIG. 12(f) illustrates a step of removing the etching mask film 24 by oxygen-containing chlorine-based dry etching (Cl/O based). FIG. 12(g) illustrates a step of newly forming a second resist pattern 26. FIG. 12(h) illustrates a step of removing the light shielding film 23 of the area not covered by the second resist pattern 26 by non-oxygen-containing chlorine-based dry etching (Cl based) or by both non-oxygen-containing chlorine-based dry etching (Cl based) and fluorine-based dry etching (F based). FIG. 12(i) illustrates a step of separating and removing the second resist pattern 26 that remains, and then performing cleaning. By executing the steps described above, the phase shift mask 200 is fabricated.
[0089]

In the phase shift mask 200, the etching mask film 24 is completely removed and does not remain on the mask. Further, in FIG. 12(i), the area denoted by reference number 201 indicates an effective area, and the area denoted by reference number 202 indicates a periphery portion. In the example of the phase shift mask 200 illustrated in FIG. 12(i), the pattern formed in the effective area 201 is composed only of the substrate 21 and the phase shift film 22, and the pattern further laminating the light shielding film 23 thereon exists only in the periphery portion 202. However, as a different embodiment, a pattern in which the substrate 21, the phase shift film 22, and the light shielding film 23 are laminated can be formed within the effective area 201.
[0090]

Next, FIG. 13 is a schematic cross-sectional view in which manufacturing methods of a phase shift mask 200 using the phase shift mask blank 20 illustrated in FIG. 4 are sequentially illustrated. The members denoted by already-described reference numbers are the same as FIG. 4. FIG. 13(a) illustrates a step of applying a resist film on the etching mask film 24, drawing thereon, performing a developing process thereto, and forming a resist pattern 25. FIG. 13(b) illustrates a step of patterning the etching mask film 24 by

oxygen-containing chlorine-based dry etching (Cl/O based) along the resist pattern 25. FIG. 13(c) illustrates a step of separating and removing the resist pattern 25 that remains, and then performing cleaning. FIG. 13(d) illustrates a step of patterning the upper layer light shielding film 23 along the pattern of the etching mask film 24 using both or either one of a non-oxygen-containing chlorine-based dry etching (Cl based) and fluorine-based etching (F based). FIG. 13(e) illustrates a step of etching the lower layer light shielding film 28 by oxygen-based etching (O based) along the pattern of the etching mask film 24 and the upper layer light shielding film 23.

[0091]

FIG. 13(f) illustrates a step of patterning the phase shift film 22 along the pattern of the etching mask film 24 and the light shielding film 23 and the lower layer light shielding film 28 by fluorine-based dry etching (F based). FIG. 13(g) illustrates a step of removing the etching mask film 24 by oxygen-containing chlorine-based dry etching (Cl/O based). FIG. 13(h) illustrates a step of newly forming a second resist pattern 26. FIG. 13(i) illustrates a step of removing the light shielding film 23 of the area not covered by the second resist pattern 26 by both or either one of non-oxygen-containing chlorine-based dry etching (Cl based) and fluorine-based etching (F based). FIG. 13(j) illustrates a step of removing the lower layer light shielding film 28 of the area not covered by the second resist pattern 26 by oxygen-based etching (O based). FIG. 13(k) illustrates a step of separating and removing the second resist pattern 26 that remains, and then performing cleaning. By executing the steps described above, the phase shift mask 200 is fabricated.

[0092]

In the phase shift mask 200, the etching mask film 24 is completely removed and does not remain on the mask. Further, in FIG. 13(k), the area denoted by reference number 201 indicates an effective area, and the area denoted by reference number 202 indicates a periphery portion. In the example of the phase shift mask 200 illustrated in FIG. 13(k), the pattern formed in the effective area 201 is composed only of the substrate 21 and the phase shift film 22, and the pattern further laminating the upper layer light shielding film 23 and the lower layer light shielding film 28 thereon exists only in the periphery portion 202. However, as a different embodiment, a pattern in which the substrate 21, the phase shift film 22, the upper layer light shielding film 23 and the lower layer light shielding film 28 are laminated can be formed within the effective area 201.

[0093]

In the steps illustrated in FIGs. 10(a), 11(a), 12(a) and 13(a), material of the resist film can either be a positive resist or a negative resist, but it is preferable to use a chemically amplified resist for drawing a pattern using electron beams that enables to form a pattern with high accuracy. The film thickness of the resist film is in a range of 50 nm or greater and 200 nm or smaller, for example. Specifically, in fabricating a phase shift mask in which a microscopic pattern formation is required, the resist film must be thinned so as not to increase the aspect ratio of the resist pattern from the viewpoint of preventing collapsing of pattern, and a film thickness of 150 nm or smaller is preferred. Meanwhile, the minimum level of film thickness of the resist film is determined by comprehensively considering conditions such as tolerance to etching of the resist material being used, and a thickness of 60 nm or greater is preferred. If a chemically amplified resist for drawing a pattern using electron beams is used as the resist film, energy density of the electron beams for drawing is within the range of 10 to 100 $\mu\text{C}/\text{cm}^2$, and after the drawing step, a heating step and a developing step are performed to obtain a resist pattern.

[0094]

In the steps illustrated in FIGs. 10(b), 11(b), 12(b) and 13(b), the conditions of the oxygen-containing chlorine-based dry etching (Cl/O based) for patterning the etching mask film can be well-known conditions used conventionally for dry etching a chromium compound film. Chlorine gas and oxygen gas may be used with inert gas such as nitrogen gas or helium gas mixed as needed. The light shielding film as lower layer has resistance to oxygen-containing chlorine-based dry etching (Cl/O based), so that in the present steps, they remain without being removed or patterned.

[0095]

Further, in the steps of FIGs. 10(c), 11(c), 12(c) and 13(c), the separating and removing of the resist pattern can be performed by dry etching, but in general, they are subjected to wet stripping using a stripping solution.

[0096]

Further, in the steps of FIGs. 10(d), 11(d), 12(d) and 13(d), the conditions of non-oxygen-containing chlorine-based dry etching (Cl based) for patterning the upper layer light shielding film can adopt. Chlorine gas may be used with inert gas such as nitrogen gas and helium gas mixed as needed. The etching mask film on the upper layer and the lower layer light shielding film have resistance to non-oxygen-containing chlorine-based dry etching (Cl based), so in the present steps, they remain without being removed or patterned. Further, if the composition of the outermost surface of the upper layer light shielding film

varies by etching or cleaning and etching rate using non-oxygen-containing chlorine-based etching (Cl based) is deteriorated, fluorine-based etching (F based) can be added prior to non-oxygen-containing chlorine-based dry etching (Cl based) to more efficiently remove the light shielding film on the outermost surface.

[0097]

Further, in the steps of FIGs. 11(e) and 13(e), the oxygen-based dry etching (O based) for patterning the lower layer light shielding film can use oxygen gas, or oxygen gas with inert gas such as argon gas and helium gas mixed as needed. The etching mask film, the upper layer light shielding film and the phase shift film have resistance to oxygen-based dry etching (O based), so that in the present step, they remain without being removed or patterned.

[0098]

In the steps of FIGs. 10(e), 11(f), 12(e) and 13(f), the conditions of fluorine-based dry etching (F based) for patterning the phase shift film can be a known condition conventionally used for dry etching the silicon-based compound film. CF_4 , C_2F_6 or SF_6 as fluorine-based gas is generally used, with inert gas such as nitrogen gas or helium gas mixed as needed.

[0099]

The etching mask film on the uppermost layer has resistance to fluorine-based dry etching (F based), so that in the present step, it remains without being removed or patterned together with the light shielding film. In FIGs. 10(e), 11(f), 12(e) and 13(f), generally, the substrate is engraved simultaneously for 1 to 3 nm so as to prevent cut-out failure of the phase shift film and also perform fine adjustment of phase difference.

[0100]

In the steps of FIGs. 10(f), 11(g), 12(g) and 13(h), the drawing method can adopt a laser drawing method which has lower accuracy than electron beam drawing method, wherein by applying a resist film, performing electron beam drawing or laser beam drawing and thereafter performing a developing process, the second resist pattern is obtained.

[0101]

According to the steps of FIGs. 12(f) and 13(g), the conditions of oxygen-containing chlorine-based dry etching (Cl/O based) for removing the etching mask film can be a well-known condition conventionally used for removal of the chromium compound film. Chlorine gas and oxygen gas is used with inert gas such as nitrogen gas and helium gas mixed as needed. The lower layer light shielding film, the phase shift film and the substrate all have resistance

to oxygen-containing chlorine-based dry etching (Cl/O based), so that in the present embodiment, they remain without being removed or patterned. Therefore, an etching condition allowing lateral direction etching to proceed and suppress residue (remaining after removal) of the etching mask film can be selected. Etching conditions in which etching in the lateral direction tends to advance preferably adopts a higher pressure (low vacuum) and greater over-etching amount than the etching conditions used for the steps of FIGs. 12(b) and 13(b). Over-etching amount described here is the ratio of etching time performed in extension with respect to an etching time required to completely remove the film.

[0102]

In the steps of FIGs. 10(h), 11(i), 12(h) and 13(i), the conditions of non-oxygen-containing chlorine-based dry etching (Cl based) for removing the upper layer light shielding film can mix inert gas such as nitrogen gas and helium gas to the chlorine gas as needed. The lower layer light shielding film as underlayer, the phase shift film and the substrate all have resistance to non-oxygen-containing chlorine-based dry etching (Cl based), so that in the present steps, they remain without being removed or patterned.

[0103]

In the steps of FIGs. 11(j) and 13(j), the conditions for oxygen-based dry etching (O based) for removing the lower layer light shielding film can use oxygen gas, or oxygen gas with inert gas such as argon gas or helium gas mixed as needed. The phase shift film as underlayer and the substrate both have resistance to oxygen-based dry etching (O based), so that in the present steps, they remain without being removed or patterned.

[0104]

Therefore, an etching condition allowing lateral direction etching to proceed and suppress residue (remaining after removal) of the etching mask film can be selected. Etching conditions in which etching in the lateral direction tends to advance preferably adopts a higher pressure (low vacuum) and greater over-etching amount than the etching conditions used for the steps of FIGs. 10(d), 11(d), 11(e), 12(d), 13(d) and 13(e). Over-etching amount described here is the ratio of etching time performed in extension with respect to an etching time required to completely remove the film.

[0105]

In the steps of FIGs 10(i), 11(k), 12(i) and 13(k), the separating and removing of the resist pattern can be performed by dry etching, but in general, they are removed through wet stripping by stripping solution.

[0106]

Next, a phase shift mask fabricated from a phase shift mask blank and a manufacturing method for a phase shift mask according to fifth and sixth embodiments are illustrated. FIG. 14 is a view illustrating a manufacturing method of a phase shift mask 100' using the phase shift mask blank 10' illustrated in FIG. 5. The components denoted by the reference numbers already described are the same as FIG. 5. FIG. 14(a) illustrates a step of applying a resist film on an etching mask film 15', drawing thereon, performing a developing process thereto, and forming a resist pattern 16'. FIG. 14(b) illustrates a step of patterning the etching mask film 15' by oxygen-containing chlorine-based dry etching (Cl/O based) along the resist pattern 16'. FIG. 14(c) illustrates a step of separating and removing the resist pattern 16' that remains, and then performing cleaning. FIG. 14(d) illustrates a step of patterning the antireflection film 14' along the pattern of the etching mask film 15' using fluorine-based dry etching (F based). FIG. 14(e) illustrates a step of patterning the light shielding film 13' along the pattern of the etching mask film 15' and the antireflection film 14' by using both or either one of non-oxygen-containing chlorine-based dry etching (Cl based) and fluorine-based etching (F based).

[0107]

FIG. 14(f) illustrates a step of patterning the phase shift film 12' by fluorine-based dry etching (F based) along the pattern of the etching mask film 15', the antireflection film 14' and the light shielding film 13'. FIG. 14(g) illustrates a step of removing the etching mask film 15' by oxygen-containing chlorine-based dry etching (Cl/O based). FIG. 14(h) illustrates a step of newly forming a second resist pattern 17'. FIG. 14(i) illustrates a step of removing the antireflection film 14' of the area not covered by the second resist pattern 17' by fluorine-based dry etching (F based). FIG. 14(j) illustrates a step of removing the light shielding film 13' of the area not covered by the second resist pattern 17' by non-oxygen-containing chlorine-based dry etching (Cl based) or by non-oxygen-containing chlorine-based dry etching (Cl based), or by both non-oxygen-containing chlorine-based dry etching (Cl based) and fluorine-based etching (F based). FIG. 14(k) illustrates a step of separating and removing the second resist pattern 17' that remains, and then performing cleaning. By executing the steps described above, the phase shift mask 100' is fabricated.

[0108]

In the phase shift mask 100', the etching mask film 15' is completely removed and does not remain on the mask. Further, in FIG. 14(k), the area denoted by reference number 101' indicates an effective area, and the area denoted by reference number 102' indicates a periphery portion. In the example of the phase shift mask 100' illustrated in FIG. 14(k), the pattern formed in the effective area 101' is composed only of the substrate 11' and the phase shift film 12', and the pattern further laminating the light shielding film 13' and the antireflection film 14' thereon exists only in the periphery portion 102'. However, as a different embodiment, a pattern in which the substrate 11', the phase shift film 12', the light shielding film 13' and the antireflection film 14' are laminated can be formed within the effective area 101'.

[0109]

FIG. 15 is a view illustrating a manufacturing method of the phase shift mask 100' using the phase shift mask blank 10' illustrated in FIG. 6. The members denoted by already-described reference numbers are the same as FIG. 6. FIG. 15(a) illustrates a step of applying a resist film on the etching mask film 15', drawing thereon, performing a developing process thereto, and forming a resist pattern 16'. FIG. 15(b) illustrates a step of patterning the etching mask film 15' by oxygen-containing chlorine-based dry etching (Cl/O based) along the resist pattern 16'. FIG. 15(c) illustrates a step of separating and removing the resist pattern 16' that remains, and then performing cleaning. FIG. 15(d) illustrates a step of patterning the antireflection film 14' along the pattern of the etching mask film 15' using fluorine-based dry etching (F based). FIG. 15(e) illustrates a step of patterning the upper layer light shielding film 13' along the pattern of the etching mask film 15' and the antireflection film 14' by both or either one of non-oxygen-containing chlorine-based dry etching (Cl based) and fluorine-based etching (F based). FIG. 15(f) illustrates a step of patterning the lower layer light shielding film 18' along the pattern of the etching mask film 15', the antireflection film 14' and the upper layer light shielding film 13' by oxygen-based dry etching (O based).

[0110]

FIG. 15(g) illustrates a step of patterning the phase shift film 12' along the pattern of the etching mask film 15', the antireflection film 14', the lower layer light shielding film 13' and the lower layer light shielding film 18' by fluorine-based dry etching (F based). FIG. 15(h) illustrates a step of removing the etching mask film 15' by oxygen-containing chlorine-based dry etching (Cl/O based). FIG. 15(i) illustrates a step of newly forming a second resist pattern

17'. FIG. 15(j) illustrates a step of removing the antireflection film 14' of the area not covered by the second resist pattern 17' by fluorine-based dry etching (F based). FIG. 15(k) illustrates a step of removing the upper layer light shielding film 13' of the area not covered by the second resist pattern 17' by both or either one of non-oxygen-containing chlorine-based dry etching (Cl based) and fluorine-based etching (F based). FIG. 15(l) illustrates a step of removing the lower layer light shielding film 18' of the area not covered by the second resist pattern 17' by oxygen-based etching (O based). FIG. 15(m) illustrates a step of separating and removing the second resist pattern 17' that remains, and then performing cleaning. By executing the steps described above, the phase shift mask 100' is fabricated.

[0111]

In the phase shift mask 100', the etching mask film 15' is completely removed and does not remain on the mask. Further, in FIG. 15(m), the area denoted by reference number 101' indicates an effective area, and the area denoted by reference number 102' indicates a periphery portion. In the example of the phase shift mask 100' illustrated in FIG. 15(m), the pattern formed in the effective area 101' is composed only of the substrate 11' and the phase shift film 12', and the pattern further laminating the upper layer light shielding film 13', the lower layer light shielding film 18' and the antireflection film 14' thereon, exists only in the periphery portion 102'. However, as a different embodiment, a pattern in which the substrate 11', the phase shift film 12', the upper layer light shielding film 13', the lower layer light shielding film 18' and the antireflection film 14' are laminated can be formed within the effective area 201.

[0112]

In the steps illustrated in FIGs. 14(a) and 15(a), material of the resist film can either be a positive resist or a negative resist, but it is preferable to use a chemically amplified resist for drawing a pattern using electron beams that enables to form a pattern with high accuracy. The film thickness of the resist film is in a range of 50 nm or greater and 200 nm or smaller, for example. Specifically, in fabricating a phase shift mask in which a microscopic pattern formation is required, the resin film must be thinned so as not to increase the aspect ratio of the resist pattern from the viewpoint of preventing collapsing of pattern, and a film thickness of 150 nm or smaller is preferred. Meanwhile, the minimum level of film thickness of the resist film is determined by considering conditions such as tolerance to etching of the resist material being used, and a thickness of 60 nm or greater is preferred. If a chemically

amplified resist for drawing a pattern using electron beams is used as the resist film, energy density of the electron beams for drawing is within the range of 10 to 100 $\mu\text{C}/\text{cm}^2$, and after the drawing step, a heating step and a developing step are performed to obtain a resist pattern.

[0113]

In the steps illustrated in FIGs. 14(b) and 15(b), the conditions of the oxygen-containing chlorine-based dry etching (Cl/O based) for patterning the etching mask film can be well-known conditions used conventionally for dry etching a chromium compound film. Chlorine gas and oxygen gas are used with inert gas such as nitrogen gas or helium gas mixed as needed. The lower layer antireflection film has resistance to oxygen-containing chlorine-based dry etching (Cl/O based), so that in the present steps, they remain without being removed or patterned.

[0114]

Further, in the steps of FIGs. 14(c) and 15(c), the separating and removing of the resist pattern can be performed by dry etching, but in general, they are subjected to wet stripping using a stripping solution.

[0115]

Further, in the steps of FIGs. 14(d) and 15(d), the conditions of fluorine-based dry etching (F based) for patterning the antireflection film generally adopts CF_4 , C_2F_6 and SF_6 as fluorine-based gas, and inert gas such as nitrogen gas or helium gas can be mixed as needed. The etching mask film on the upper layer has resistance to fluorine-based dry etching (F based), so that in the present step, it remains together with the light shielding film without being removed or patterned. Further, since the light shielding film as lower layer can also be processed by fluorine-based dry etching (F based), the light shielding pattern can be patterned in the present step without removing all the film.

[0116]

Further, in the steps of FIGs. 14(e) and 15(e), the non-oxygen-containing chlorine-based dry etching (Cl based) for patterning the upper layer light shielding film can use chlorine gas, or chlorine gas with inert gas such as nitrogen gas and helium gas mixed as needed. The etching mask film on the uppermost layer and the phase shift film as lower layer have resistance to non-oxygen-containing chlorine-based dry etching (Cl based), so that in the present step, they remain without being removed or patterned.

[0117]

Further, in the step of FIG. 15(f), the oxygen-based dry etching (O based) for patterning the lower layer light shielding film can use oxygen gas, or oxygen gas with inert gas such as argon gas and helium gas mixed as needed. The upper layer light shielding film and the phase shift film as lower layer have resistance to oxygen-based dry etching (O based), so that in the present step, they remain without being removed or patterned.

[0118]

In the steps of FIGs. 14(f) and 15(g), the conditions of fluorine-based dry etching (F based) for patterning the phase shift film can be a known condition conventionally used for dry etching the silicon-based compound film, which uses CF_4 , C_2F_6 or SF_6 as fluorine-based gas, with inert gas such as nitrogen gas or helium gas mixed as needed. The etching mask film on the uppermost layer has resistance to fluorine-based dry etching (F based), so that in the present step, it remains together with the antireflection film and the light shielding film without being removed or patterned. In FIGs. 14(f) and 15(g), generally, the substrate is engraved simultaneously for 1 to 3 nm so as to prevent cut-out failure of the phase shift film and also perform fine adjustment of phase difference.

[0119]

According to the steps of FIGs. 14(g) and 15(h), the conditions of oxygen-containing chlorine-based dry etching (Cl/O based) for removing the etching mask film can be a well-known condition conventionally used for removal of the chromium compound film. Chlorine gas and oxygen gas are used with inert gas such as nitrogen gas and helium gas mixed as needed. The antireflection film on the lower layer, the light shielding film, the phase shift film and the substrate all have resistance to oxygen-containing chlorine-based dry etching (Cl/O based), in the present embodiment, they remain without being removed or patterned. Therefore, an etching condition allowing lateral direction etching to proceed and residue (remaining after removal) of the etching mask film to be suppressed can be selected. Etching conditions in which etching in the lateral direction tends to advance preferably adopts a higher pressure (low vacuum) and greater over-etching amount than the etching conditions used for the steps of FIGs. 14(b) and 15(b). Over-etching amount described here is the ratio of etching time performed in extension with respect to an etching time required to completely remove the film.

[0120]

In the steps of FIGs. 14(h) and 15(i), the drawing method can adopt a laser drawing method which has lower accuracy than electron beam drawing

method, wherein by applying a resist film, performing electron beam drawing or laser beam drawing and thereafter performing a developing process, the second resist pattern is obtained.

[0121]

In the steps of FIGs. 14(i) and 15(j), the conditions of fluorine-based dry etching (F based) for removing the antireflection film can generally use CF_4 , C_2F_6 or SF_6 as fluorine-based gas, with inert gas such as nitrogen gas or helium gas mixed as needed. The lower layer light shielding film can also be removed by fluorine-based dry etching (F based), so that a portion or all of the film can be removed in the present step. In FIGs. 14(i) and 15(j), the substrate is also engraved simultaneously. Therefore, in order to completely remove the antireflection film and to realize a desired phase difference, the final amount of engraving of the substrate together with the amount of engraving in FIGs. 14(g) and 15(h) can preferably be adjusted between 5 and 20 nm.

[0122]

In the steps illustrated in FIGs. 14(j) and 15(k), the conditions of the non-oxygen-containing chlorine-based dry etching (Cl based) for removing the upper layer light shielding film can use chlorine gas, or chlorine gas with inert gas such as nitrogen gas or helium gas mixed as needed. The lower layer light shielding film, the phase shift film and the substrate as lower layers all have resistance to non-oxygen-containing chlorine-based dry etching (Cl based), so that in the present steps, they remain without being removed or patterned.

[0123]

In the step illustrated in FIG. 15(l), the conditions of the oxygen-based dry etching (O based) for removing the lower layer light shielding film can use oxygen gas, or oxygen gas with inert gas such as argon gas or helium gas mixed as needed. The phase shift film as lower layer and the substrate both have resistance to oxygen-based dry etching (Cl based), so that in the present steps, they remain without being removed or patterned.

[0124]

Therefore, an etching condition allowing lateral direction etching to proceed and residue (remaining after removal) of the light shielding film to be suppressed can be selected. Etching conditions in which etching in the lateral direction tends to advance preferably adopts a higher pressure (low vacuum) and greater over-etching amount than the etching conditions used for the steps of FIGs. 14(e), 15(e) and 15(f). Over-etching amount described here is the ratio of etching time performed in extension with respect to an etching time required to completely remove the film.

[0125]

In the steps of FIGs. 14(k) and 15(m), the separating and removing of the resist pattern can be performed by dry etching, but in general, they are subjected to wet stripping using a stripping solution.

[0126]

The method for fabricating a phase shift mask using the phase shift mask blank according to the respective embodiments have been described, but in the case where a defect has been detected by mask inspection, a step may be added to correct the defect in midway of the method described above. There are various methods for correcting defects depending on the variety and size of the defects. In the case of a black defect in which a portion of the phase shift film becomes greater than a desired size, it is common to adopt a correction method (electron beam correction), in which an electron beam is irradiated to a defect portion while supplying fluorine-based gas to etch and remove only the defect portion with high accuracy. According to the present embodiment, the lower layer light shielding film using the simple substance of ruthenium or the ruthenium compound is finally removed, so that it does not interfere with electron beam correction.

[0127]

Next, a preferred embodiment of a method for correcting residue in a case where residue of etching mask film and upper layer light shielding film (and lower layer light shielding film) occurs to a phase shift mask fabricated by the steps described above will be illustrated.

[0128]

FIG. 16 is an enlarged schematic cross-sectional view illustrating a method for correcting residue of an etching mask film and a light shielding film of the phase shift mask 100 using the phase shift mask blank 10 illustrated in FIG. 1. FIG. 16(a) illustrates a state of a portion of a mask where a residue 14a of an etching mask film and a residue 13a of a light shielding film exist on the phase shift film 12.

[0129]

Next, FIG. 16(b) illustrates a step of newly forming a resist pattern 17 for correcting residue so as not to cover the area where the residues 13a and 14a have occurred. In the present step, after forming the resist film, subjecting the same to electron beam drawing or laser beam drawing and then performing developing process, the resist pattern 17 is obtained. Further, the resist pattern 17 can be obtained by subjecting the area where the residues 13a and

14a have occurred to spot exposure and then subjecting the same to developing process.

[0130]

Next, FIG. 16(c) illustrates a step of removing the residue 14a of the etching mask film of the area not covered by the resist pattern 17 by oxygen-containing chlorine-based dry etching (Cl/O based). The residue 13a of the light shielding film, the phase shift film 12 and the substrate 11 have resistance to oxygen-containing chlorine-based dry etching (Cl/O based), in the present step, they remain without being removed or patterned. The etching conditions should preferably be selected to allow advancement of etching in the lateral direction to remove the residue 14a of the etching mask film. The conditions in which etching easily advances in the lateral direction are similar to the conditions of the step illustrated in FIG. 10(g).

[0131]

Next, FIG. 16(d) illustrates a step of removing the residue 13a of the light shielding film of the area not covered by the resist pattern 17 by non-oxygen-containing chlorine-based dry etching (Cl based). The phase shift film 12 and the substrate 11 have resistance to non-oxygen-containing chlorine-based dry etching (Cl based), so that in the present step, they remain without being removed or patterned. The etching conditions should preferably be selected to allow advancement of etching in the lateral direction to remove the residue 13a of the light shielding film. The conditions that allow advancement of etching in the lateral direction are similar to the conditions of step illustrated in FIG. 10(h).

[0132]

Next, FIG. 16(e) illustrates a step of separating and removing the remaining resist pattern 17, and then cleaning the same. The separating and removing can be performed by dry etching, but generally, it is performed by wet stripping using a stripping solution. According to this step, correction of residue of the etching mask film and the light shielding film of the phase shift mask 100 is completed.

[0133]

FIG. 17 is an enlarged schematic cross-sectional view illustrating a method for correcting residue of an etching mask film and a light shielding film of the phase shift mask 100 using the phase shift mask blank 10 illustrated in FIG. 2. FIG. 17(a) illustrates a state of a portion of a mask where a residue 14a of an etching mask film, a residue 13a of an upper layer light shielding film and a residue 18a of a lower layer light shielding exist on the phase shift film 12.

[0134]

Next, FIG. 17(b) illustrates a step of newly forming a resist pattern 17 for correcting residue so as not to cover the area where the residues 13a, 14a and 18a have occurred. In the present step, after forming a resist film, subjecting the same to electron beam drawing or laser beam drawing and then performing developing process, the resist pattern 17 is obtained. Further, the resist pattern 17 can be obtained by subjecting the area where the residues 13a, 14a and 18a have occurred to spot exposure and then subjecting the same to developing process.

[0135]

Next, FIG. 17(c) illustrates a step of removing the residue 14a of the etching mask film of the area not covered by the resist pattern 17 by oxygen-containing chlorine-based dry etching (Cl/O based). The residue 13a of the upper layer light shielding film, the residue 18a of the lower layer light shielding film, the phase shift film 12 and the substrate 11 have resistance to oxygen-containing chlorine-based dry etching (Cl/O based), so that in the present step, they remain without being removed or patterned. The etching conditions should preferably be selected to allow advancement of etching in the lateral direction to remove the residue 14a of the etching mask film. The conditions in which etching easily advances in the lateral direction are similar to the conditions of the step illustrated in FIG. 11(h).

[0136]

Next, FIG. 17(d) illustrates a step of removing the residue 13a of the upper layer light shielding film of the area not covered by the resist pattern 17 by non-oxygen-containing chlorine-based dry etching (Cl based). The residue 18a of the lower layer light shielding film, the phase shift film 12 and the substrate 11 have resistance to non-oxygen-containing chlorine-based dry etching (Cl based), so that in the present step, they remain without being removed or patterned. The etching conditions should preferably be selected to allow advancement of etching in the lateral direction to remove the residue 13a of the upper layer light shielding film. The conditions in which etching easily advances in the lateral direction are similar to the conditions of the step illustrated in FIG. 11(i).

[0137]

Next, FIG. 17(e) illustrates a step of removing the residue 18a of the lower layer light shielding film of the area not covered by the resist pattern 17 by oxygen-based dry etching (O based). The phase shift film 12 and the substrate 11 have resistance to oxygen-based dry etching (O based), so that in the

present step, they remain without being removed or patterned. The etching conditions should preferably be selected to allow advancement of etching in the lateral direction to remove the residue 18a of the lower layer light shielding film. The conditions in which etching easily advances in the lateral direction are similar to the conditions of the step illustrated in FIG. 11(j).

[0138]

Next, FIG. 17(f) illustrates a step of separating and removing the remaining resist pattern 17, and then cleaning the same. The separating and removing can be performed by dry etching, but generally, it is performed by wet stripping using a stripping solution. According to this step, correction of residue of the etching mask film and the light shielding film of the phase shift mask 100 is completed.

[0139]

Next, a preferred embodiment of a method for correcting residue in a case where residue of etching mask film occurs during fabrication of a phase shift mask fabricated according to steps illustrated in FIGs. 14 and 15 will be described.

[0140]

The removal of the etching mask film is performed by steps illustrated in FIGs 14(g) and 15(h). If a portion of the etching mask film remains on the antireflection film without being removed completely, the residue can be detected by performing reflection mask inspection after the step illustrated in FIGs. 14(g) and 15(h).

[0141]

Next, the residue of the etching mask film being detected is removed by oxygen-containing chlorine-based dry etching (Cl/O based). The antireflection film, the upper layer light shielding film, the lower layer light shielding film, the phase shift film and the substrate all have resistance to oxygen-containing chlorine-based dry etching (Cl/O based), so that in the present step, they remain without being removed or patterned. The etching conditions should preferably be selected to allow advancement of etching in the lateral direction to remove the residue of the etching mask film. The conditions in which etching easily advances in the lateral direction are similar to the conditions of the step illustrated in FIGs.14(g) and 15(h).

[0142]

Next, it is confirmed that the residue of the etching mask film detected by reflection mask inspection or SEM observation had been completely removed. By the present step, residue correction of etching mask film of the phase shift

mask is completed. Hereafter, the steps following FIGs. 14(h) and 15(i) may be performed to continue fabrication of the phase shift mask.

[Examples]

[0143]

The present embodiments will be described further specifically according to examples, but the present invention is not limited to the examples illustrated below.

[0144]

(Example 1)

A DC sputtering device adopting two targets was used to form a phase shift film formed of silicon, molybdenum, oxygen and nitrogen to a thickness of 66 nm on a quartz substrate. Molybdenum and silicon were used as the target, and argon, oxygen and nitrogen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:Mo:O:N = 40:8:7:45 (atomic percent ratio).

[0145]

A light shielding film formed of tantalum and nitrogen was formed on the phase shift film to a thickness of 28 nm using a DC sputtering device. Tantalum was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:N = 85:15 (atomic percent ratio).

[0146]

An etching mask film formed of chromium, oxygen and nitrogen was formed on the light shielding film to a thickness of 18 nm using the DC sputtering device. Chromium was used as the target, and argon, oxygen and nitrogen were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:O:N = 45:45:10 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described etching mask film with the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 3.2.

[0147]

As described, a phase shift mask blank having a phase shift film formed of silicon, molybdenum, oxygen and nitrogen, a light shielding film formed of tantalum and nitrogen and an etching mask film formed of chromium, oxygen and nitrogen with laminated on a quartz substrate, was obtained.

[0148]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 150 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of $35 \mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110°C , developing was performed for 90 seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0149]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0150]

Next, a light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the lower layer light shielding film is narrowed compared to the upper layer etching mask film.

[0151]

Next, a phase shift film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 2 nm in average.

[0152]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0153]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0154]

Next, the light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0155]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 6.1 %, and the phase difference was 180 degrees. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 2 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 5 % compared to the phase shift mask using the conventional silicon compound film as etching mask film.

[0156]

Next, a positive-type resist film was spin-coated on the phase shift mask according to the present embodiment where residue of the etching mask film and the light shielding film was detected by defect inspection, and drawing was carried out by a laser drawing apparatus to only a surrounding area of the residue portion. Thereafter, developing was performed and a resist pattern where only the residue portion is opened was formed.

[0157]

Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0158]

Next, the residue of the light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0159]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and residue correction of the etching mask film and the light shielding film of the phase shift mask according to the present embodiment was completed. The phase shift mask was subjected to defect inspection, and it was confirmed that the residue of the etching mask film and the light shielding film was completely removed.

[0160]

(Example 2)

A DC sputtering device adopting two targets was used to form a phase shift film formed of silicon, molybdenum, oxygen and nitrogen to a thickness of 66 nm on a quartz substrate. Molybdenum and silicon were used as the target, and argon, oxygen and nitrogen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:Mo:O:N = 40:8:7:45 (atomic percent ratio).

[0161]

A lower layer light shielding film formed of ruthenium was formed on the phase shift film to a thickness of 10 nm using an ion sputtering device. Ruthenium was used as the target, and xenon was used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ru = 100 (atomic percent ratio).

[0162]

An upper layer light shielding film formed of tantalum and nitrogen was formed on the lower layer light shielding film to a thickness of 18 nm using the DC sputtering device. Tantalum was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:N = 85:15 (atomic percent ratio).

[0163]

An etching mask film formed of chromium, oxygen and nitrogen was formed on the light shielding film to a thickness of 18 nm using the DC sputtering device. Chromium was used as the target, and argon, oxygen and nitrogen were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:O:N = 45:45:10 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described etching mask film with the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 3.2.

[0164]

As described, a phase shift mask blank having a phase shift film formed of silicon, molybdenum, oxygen and nitrogen, a lower layer light shielding film formed of ruthenium, an upper layer light shielding film formed of tantalum and nitrogen, and an etching mask film formed of chromium, oxygen and nitrogen with laminated on a quartz substrate, was obtained.

[0165]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 150 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of $35 \mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110°C , developing was performed for 90 seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0166]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0167]

Next, an upper layer light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the upper layer light shielding film is narrowed compared to the upper layer etching mask film.

[0168]

Next, a lower layer light shielding film was patterned using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the lower layer light shielding film is narrowed compared to the upper layer light shielding film.

[0169]

Next, a phase shift film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP

power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 2 nm in average.

[0170]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0171]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0172]

Next, the upper layer light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0173]

Next, the lower layer light shielding film was removed using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0174]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 6.1 %, and the phase difference was 180 degrees. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 2 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 7 % compared to the phase shift mask using the conventional silicon compound film as etching mask film. Wince the

upper layer light shielding film was thinned, the improvement rate was improved compared to Example 1.

[0175]

Next, a positive-type resist film was spin-coated on the phase shift mask according to the present embodiment where residue of the etching mask film and the upper and lower light shielding films was detected by defect inspection, and drawing was carried out by a laser drawing apparatus to only a surrounding area of the residue portion. Thereafter, developing was performed and a resist pattern where only the residue portion is opened was formed.

[0176]

Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0177]

Next, the residue of the upper layer light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0178]

Next, the residue of the lower layer light shielding film was removed using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0179]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and residue correction of the etching mask film and the light shielding film of the phase shift mask according to the present embodiment was completed. The phase shift mask was subjected to defect inspection, and it was confirmed that the residue of the etching mask film and the light shielding film was completely removed.

[0180]

(Example 3)

A DC sputtering device was used to form a phase shift film formed of silicon and nitrogen to a thickness of 68 nm on a quartz substrate. Silicon was used as the target, and argon and nitrogen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:N = 50:50 (atomic percent ratio).

[0181]

A light shielding film formed of tantalum and nitrogen was formed on the phase shift film to a thickness of 26 nm using the DC sputtering device. Tantalum was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:N = 70:30 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 2.9.

[0182]

An etching mask film formed of chromium and nitrogen was formed on the light shielding film to a thickness of 13 nm using a DC sputtering device. Chromium was used as the target, and argon and nitrogen were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:N = 90:10 (atomic percent ratio).

[0183]

As described, a phase shift mask blank having a phase shift film formed of silicon and nitrogen, a light shielding film formed of tantalum and nitrogen, and an etching mask film formed of chromium and nitrogen with laminated on a quartz substrate, was obtained.

[0184]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 150 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of 35 $\mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110 °C, developing was performed for 90 seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0185]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0186]

Next, a light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the lower layer light shielding film is narrowed compared to the upper layer etching mask film.

[0187]

Next, a phase shift film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 2 nm in average.

[0188]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0189]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0190]

Next, the light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0191]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 5.5 %, and the phase difference was 180 degrees. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 3 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the

etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 5 % compared to the phase shift mask using the conventional silicon compound film as etching mask film.

[0192]

Next, a positive-type resist film was spin-coated on the phase shift mask according to the present embodiment where residue of the etching mask film and the light shielding film was detected by defect inspection, and drawing was carried out by a laser drawing apparatus to only a surrounding area of the residue portion. Thereafter, developing was performed and a resist pattern where only the residue portion is opened was formed.

[0193]

Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0194]

Next, the residue of the light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0195]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and residue correction of the etching mask film and the light shielding film of the phase shift mask according to the present embodiment was completed. The phase shift mask was subjected to defect inspection, and it was confirmed that the residue of the etching mask film and the light shielding film was completely removed.

[0196]

(Example 4)

A DC sputtering device was used to form a phase shift film formed of silicon and nitrogen to a thickness of 61 nm on a quartz substrate. Silicon was used as the target, and argon and nitrogen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:N = 50:50 (atomic percent ratio).

[0197]

A lower layer light shielding film formed of ruthenium compound was formed on the phase shift film to a thickness of 17 nm using the ion sputtering device. Ruthenium was used as the target, and xenon and nitrogen were used

as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ru:N = 95:5 (atomic percent ratio).

[0198]

An upper layer light shielding film formed of tantalum and nitrogen was formed on the lower layer light shielding film to a thickness of 10 nm using the DC sputtering device. Tantalum was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the upper layer light shielding film was analyzed by ESCA, and the result was Ta:N = 70:30 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 2.9.

[0199]

An etching mask film formed of chromium and nitrogen was formed on the light shielding film to a thickness of 13 nm using a DC sputtering device. Chromium was used as the target, and argon and nitrogen were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:N = 90:10 (atomic percent ratio).

[0200]

As described, a phase shift mask blank having a phase shift film formed of silicon and nitrogen, a lower layer light shielding film formed of ruthenium compound, an upper layer light shielding film formed of tantalum and nitrogen, and an etching mask film formed of chromium and nitrogen with laminated on a quartz substrate, was obtained.

[0201]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 150 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of 35 $\mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110 °C, developing was performed for 90 seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0202]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then,

the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0203]

Next, an upper layer light shielding film was patterned using the dry etching device. CF_4 and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 20 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the upper layer light shielding film is narrowed compared to the upper layer etching mask film.

[0204]

Next, a lower layer light shielding film was patterned using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the lower layer light shielding film is narrowed compared to the upper layer light shielding film.

[0205]

Next, a phase shift film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 2 nm in average.

[0206]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0207]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0208]

Next, the upper layer light shielding film was removed using the dry etching device. CF_4 and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 20 W. Over-etching was stopped when the quartz substrate was engraved for 18 nm in average. Thereby, in addition to the thickness of the phase shift film being set to 61 nm, a desired phase difference was realized.

[0209]

Next, the lower layer light shielding film was removed using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0210]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 7.4 %, and the phase difference was 180 degrees. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 3 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 9 % compared to the phase shift mask using the conventional silicon compound film as etching mask film. Since the upper layer light shielding film was thinned, the improvement rate was improved compared to Example 3.

[0211]

Next, a positive-type resist film was spin-coated on the phase shift mask according to the present embodiment where residue of the etching mask film and the light shielding film was detected by defect inspection, and drawing was carried out by a laser drawing apparatus to only a surrounding area of the residue portion. Thereafter, developing was performed and a resist pattern where only the residue portion is opened was formed.

[0212]

Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0213]

Next, the residue of the upper layer light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas

pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0214]

Next, the residue of the upper layer light shielding film was removed using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0215]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and residue correction of the etching mask film and the light shielding film of the phase shift mask according to the present embodiment was completed. The phase shift mask was subjected to defect inspection, and it was confirmed that the residue of the etching mask film and the light shielding film was completely removed.

[0216]

(Example 5)

A DC sputtering device adopting two targets was used to form a first phase shift film formed of silicon, molybdenum, oxygen and nitrogen to a thickness of 62 nm on a quartz substrate. Molybdenum and silicon were used as the target, and argon, oxygen and nitrogen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:Mo:O:N = 40:8:7:45 (atomic percent ratio). Thereafter, a second phase shift film formed of silicon and oxygen was formed on the first phase shift film to a thickness of 10 nm using a DC sputtering device. Silicon was used as the target, and argon and oxygen were used as the sputtering gas. The composition of the phase shift film was analyzed by ESCA, and the result was Si:O = 33:67 (atomic percent ratio).

[0217]

A light shielding film formed of tantalum and nitrogen was formed on the phase shift film to a thickness of 28 nm using a DC sputtering device. Tantalum was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:N = 85:15 (atomic percent ratio).

[0218]

An etching mask film formed of chromium, oxygen and nitrogen was formed on the light shielding film to a thickness of 18 nm using the DC sputtering device. Chromium was used as the target, and argon, oxygen and nitrogen were used as the sputtering gas. The composition of the etching mask film was

analyzed by ESCA, and the result was Cr:O:N = 45:45:10 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described etching mask film with the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 3.1.

[0219]

As described, a phase shift mask blank having a first phase shift film formed of silicon, molybdenum, oxygen and nitrogen, a second phase shift film formed of silicon and oxygen, a light shielding film formed of tantalum and nitrogen and an etching mask film formed of chromium, oxygen and nitrogen with laminated on a quartz substrate, was obtained.

[0220]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 150 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of $35 \mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110°C , developing was performed for 90 seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0221]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0222]

Next, a light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the lower layer light shielding film is narrowed compared to the upper layer etching mask film.

[0223]

Next, first and second phase shift films were patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry

etching was stopped when the quartz substrate was engraved for 2 nm in average.

[0224]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0225]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0226]

Next, the light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0227]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 7.2 %, and the phase difference was 180 degrees. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 2 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 5 % compared to the phase shift mask using the conventional silicon compound film as etching mask film.

[0228]

Next, a positive-type resist film was spin-coated on the phase shift mask according to the present embodiment where residue of the etching mask film and the light shielding film was detected by defect inspection, and drawing was carried out by a laser drawing apparatus to only a surrounding area of the

residue portion. Thereafter, developing was performed and a resist pattern where only the residue portion is opened was formed.

[0229]

Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0230]

Next, the residue of the light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 60 W. According to this etching condition, it has been confirmed by evaluation performed in advance that the quartz substrate receives 2 nm of damage.

[0231]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and residue correction of the etching mask film and the light shielding film of the phase shift mask according to the present embodiment was completed. The phase shift mask was subjected to defect inspection, and it was confirmed that the residue of the etching mask film and the light shielding film was completely removed. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, and it has been confirmed that they have not been varied from the value prior to correction of residue.

[0232]

(Example 6)

A DC sputtering device adopting two targets was used to form a first phase shift film formed of silicon, molybdenum, oxygen and nitrogen to a thickness of 62 nm on a quartz substrate. Molybdenum and silicon were used as the target, and argon, oxygen and nitrogen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:Mo:O:N = 40:8:7:45 (atomic percent ratio). Thereafter, a second phase shift film formed of silicon and oxygen was formed on the first phase shift film to a thickness of 10 nm using a DC sputtering device. Silicon was used as the target, and argon and oxygen were used as the sputtering gas. The composition of the phase shift film was analyzed by ESCA, and the result was Si:O = 33:67 (atomic percent ratio).

[0233]

A lower layer light shielding film formed of ruthenium compound was formed on the phase shift film to a thickness of 5 nm using an ion sputtering device. Ruthenium was used as the target, and xenon and boron were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ru:B = 80:20 (atomic percent ratio).
[0234]

An upper layer light shielding film formed of tantalum and nitrogen was formed on the lower layer light shielding film to a thickness of 24 nm using the DC sputtering device. Tantalum was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:N = 85:15 (atomic percent ratio).
[0235]

An etching mask film formed of chromium, oxygen and nitrogen was formed on the light shielding film to a thickness of 18 nm using the DC sputtering device. Chromium was used as the target, and argon, oxygen and nitrogen were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:O:N = 45:45:10 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described etching mask film with the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 3.1.
[0236]

As described, a phase shift mask blank having a first phase shift film formed of silicon, molybdenum, oxygen and nitrogen, a second phase shift film formed of silicon and oxygen, a lower layer light shielding film formed of ruthenium compound, an upper layer light shielding film formed of tantalum and nitrogen, and an etching mask film formed of chromium, oxygen and nitrogen with laminated on a quartz substrate, was obtained.
[0237]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 150 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of 35 $\mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110 °C, developing was performed for 90 seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon

compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0238]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0239]

Next, the upper layer light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the upper layer light shielding film is narrowed compared to the upper layer etching mask film.

[0240]

Next, a lower layer light shielding film was patterned using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the lower layer light shielding film is narrowed compared to the upper layer light shielding film.

[0241]

Next, first and second phase shift films were patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 2 nm in average.

[0242]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0243]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0244]

Next, the upper layer light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0245]

Next, the lower layer light shielding film was removed using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0246]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 7.2 %, and the phase difference was 180 degrees. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 2 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 6 % compared to the phase shift mask using the conventional silicon compound film as etching mask film. Since the upper layer light shielding film was thinned, the improvement rate was improved compared to Example 5.

[0247]

Next, a positive-type resist film was spin-coated on the phase shift mask according to the present embodiment where residue of the etching mask film and the light shielding film was detected by defect inspection, and drawing was carried out by a laser drawing apparatus to only a surrounding area of the residue portion. Thereafter, developing was performed and a resist pattern where only the residue portion is opened was formed.

[0248]

Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas

pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0249]

Next, the residue of the upper layer light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0250]

Next, the lower layer light shielding film was removed using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0251]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and residue correction of the etching mask film and the light shielding film of the phase shift mask according to the present embodiment was completed. The phase shift mask was subjected to defect inspection, and it was confirmed that the residue of the etching mask film and the light shielding film was completely removed. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, and it has been confirmed that they have not been varied from the value prior to correction of residue.

[0252]

(Example 7)

A DC sputtering device adopting two targets was used to form a first phase shift film formed of silicon, molybdenum, oxygen and nitrogen to a thickness of 59 nm on a quartz substrate. Molybdenum and silicon were used as the target, and argon, oxygen and nitrogen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:Mo:O:N = 40:8:7:45 (atomic percent ratio).

[0253]

A light shielding film formed of tantalum and nitrogen was formed on the phase shift film to a thickness of 20 nm using a DC sputtering device. Tantalum was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:N = 85:15 (atomic percent ratio).

[0254]

An antireflection film formed of tantalum and oxygen was formed on the light shielding film to a thickness of 10 nm using the DC sputtering device. Tantalum was used as the target, and xenon and oxygen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:O = 35:65 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described antireflection film with the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 3.0.

[0255]

An etching mask film formed of chromium and nitrogen was formed on the antireflection film to a thickness of 13 nm using the DC sputtering device. Chromium was used as the target, and argon and nitrogen were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:N = 90:10 (atomic percent ratio).

[0256]

As described, a phase shift mask blank having a phase shift film formed of silicon, molybdenum, oxygen and nitrogen, a light shielding film formed of tantalum and nitrogen, an antireflection film formed of tantalum and oxygen, and an etching mask film formed of chromium and nitrogen with laminated on a quartz substrate, was obtained.

[0257]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 150 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of 35 $\mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110 °C, developing was performed for 90 seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0258]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0259]

Next, the antireflection film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 20 W. Dry etching was stopped when the light shielding film was engraved for 5 nm in average.

[0260]

Next, a light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the antireflection film and the light shielding film as lower layers is narrowed compared to the upper layer etching mask film.

[0261]

Next, phase shift films were patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 2 nm in average.

[0262]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0263]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0264]

Next, the antireflection film was removed using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 15 nm in average.

[0265]

Next, the light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0266]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained.

Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 8.1 %, and the phase difference was 180 degrees. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 3 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 7 % compared to the phase shift mask using the conventional silicon compound film as etching mask film.

[0267]

Next, prior to the step of removing the above-mentioned etching mask film, particles of Si_3N_4 were scattered on the mask surface, and thereafter, the step of removing the etching mask film was performed and particles were removed by cleaning, by which a residue of etching mask film was generated intendedly on the antireflection film. Next, a reflection mask inspection was performed, and detection of this residue has been confirmed. Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 100 %. Next, the area where occurrence of residue has been detected was observed by SEM, and complete removal of the residue was confirmed.

[0268]

(Example 8)

A DC sputtering device adopting two targets was used to form a phase shift film formed of silicon, molybdenum, oxygen and nitrogen to a thickness of 59 nm on a quartz substrate. Molybdenum and silicon were used as the target, and argon, oxygen and nitrogen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:Mo:O:N =40:8:7:45 (atomic percent ratio).

[0269]

A lower layer light shielding film formed of ruthenium compound was formed on the phase shift film to a thickness of 10 nm using an ion sputtering device. Ruthenium - niobium alloy was used as the target, and xenon was

used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ru:Nb = 85:15 (atomic percent ratio).
[0270]

An upper layer light shielding film formed of tantalum and nitrogen was formed on the lower layer light shielding film to a thickness of 12 nm using a DC sputtering device. Tantalum was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:N = 85:15 (atomic percent ratio).
[0271]

An antireflection film formed of tantalum and oxygen was formed on the light shielding film to a thickness of 10 nm using the DC sputtering device. Tantalum was used as the target, and xenon and oxygen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:O = 35:65 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described antireflection film with the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 3.0.
[0272]

An etching mask film formed of chromium and nitrogen was formed on the antireflection film to a thickness of 13 nm using the DC sputtering device. Chromium was used as the target, and argon and nitrogen were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:N = 90:10 (atomic percent ratio).
[0273]

As described, a phase shift mask blank having a phase shift film formed of silicon, molybdenum, oxygen and nitrogen, a lower layer light shielding film formed of ruthenium compound, an upper layer light shielding film formed of tantalum and nitrogen, an antireflection film formed of tantalum and oxygen, and an etching mask film formed of chromium and nitrogen with laminated on a quartz substrate, was obtained.
[0274]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 150 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of 35 $\mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110 °C, developing was performed for 90 seconds by paddle development, and a resist pattern was formed. The

resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0275]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0276]

Next, the antireflection film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 20 W. Dry etching was stopped when the light shielding film was engraved for 5 nm in average.

[0277]

Next, an upper layer light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the antireflection film and the upper layer light shielding film as lower layers is narrowed compared to the upper layer etching mask film.

[0278]

Next, a lower layer light shielding film was patterned using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the lower layer light shielding film is narrowed compared to the upper layer etching mask film.

[0279]

Next, the phase shift film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 2 nm in average.

[0280]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to

10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0281]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0282]

Next, the antireflection film was removed using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 15 nm in average.

[0283]

Next, the upper layer light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0284]

Next, the lower layer light shielding film was removed using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0285]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 8.1 %, and the phase difference was 180 degrees. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 3 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 8 % compared to the phase shift mask using the conventional silicon compound film as etching mask film. Since the

upper layer light shielding film was thinned, the improvement rate was improved compared to Example 7.

[0286]

Next, prior to the step of removing the above-mentioned etching mask film, particles of Si_3N_4 were scattered on the mask surface, and thereafter, the step of removing the etching mask film was performed and particles were removed by cleaning, by which a residue of etching mask film was generated intendedly on the antireflection film. Next, a reflection mask inspection was performed, and detection of this residue has been confirmed. Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 100 %. Next, the area where occurrence of residue has been detected was observed by SEM, and complete removal of the residue was confirmed.

[0287]

(Example 9)

A DC sputtering device was used to form a phase shift film formed of silicon and nitrogen to a thickness of 64 nm on a quartz substrate. Silicon was used as the target, and argon and nitrogen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:N = 50:50 (atomic percent ratio).

[0288]

A light shielding film formed of tantalum, nitrogen and oxygen was formed on the phase shift film to a thickness of 30 nm using the DC sputtering device. Tantalum was used as the target, and xenon, nitrogen and oxygen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:N:O = 85:10:5 (atomic percent ratio).

[0289]

An antireflection film formed of tantalum and oxygen was formed on the light shielding film to a thickness of 6 nm using the DC sputtering device. Tantalum was used as the target, and xenon and oxygen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:O = 30:70 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described antireflection film, the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 3.0.

[0290]

An etching mask film formed of chromium and nitrogen was formed on the antireflection film to a thickness of 4 nm using the DC sputtering device. Chromium was used as the target, and argon and nitrogen were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:N = 90:10 (atomic percent ratio).

[0291]

As described, a phase shift mask blank having a phase shift film formed of silicon and nitrogen, a light shielding film formed of tantalum, nitrogen and oxygen, an antireflection film formed of tantalum and oxygen, and an etching mask film formed of chromium and nitrogen with laminated on a quartz substrate, was obtained.

[0292]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 80 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of 37 $\mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110 °C, developing was performed for 60 seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0293]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric acid and hydrogen peroxide mixture.

[0294]

Next, an antireflection film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 5 nm in average.

[0295]

Next, the light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the

dimension of line pattern of the antireflection film and the light shielding film as lower layers is narrowed compared to the upper layer etching mask film.
[0296]

Next, a phase shift film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 1 nm in average.
[0297]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.
[0298]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.
[0299]

Next, an antireflection film was removed using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 8 nm in average.
[0300]

Next, the light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.
[0301]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 6.8 %, and the phase difference was 180 degrees. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 4 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to

defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 3 % compared to the phase shift mask using the conventional silicon compound film as etching mask film.

[0302]

Next, prior to the step of removing the above-mentioned etching mask film, particles of Si_3N_4 were scattered on the mask surface, and thereafter, the step of removing the etching mask film was performed and particles were removed by cleaning, by which a residue of etching mask film was generated intendedly on the antireflection film. Next, a reflection mask inspection was performed, and detection of this residue was confirmed. Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 100 %. Next, the area where occurrence of residue has been detected was observed by SEM, and complete removal of the residue was confirmed.

[0303]

(Example 10)

A DC sputtering device was used to form a phase shift film formed of silicon and nitrogen to a thickness of 64 nm on a quartz substrate. Silicon was used as the target, and argon and nitrogen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was $\text{Si:N} = 50:50$ (atomic percent ratio).

[0304]

A lower layer light shielding film formed of ruthenium compound was formed on the phase shift film to a thickness of 10 nm using the ion sputtering device. Ruthenium was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was $\text{Ru:N} = 80:20$ (atomic percent ratio).

[0305]

An upper layer light shielding film formed of tantalum, nitrogen and oxygen was formed on the lower layer light shielding film to a thickness of 23 nm using the DC sputtering device. Tantalum was used as the target, and xenon, nitrogen and oxygen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was $\text{Ta:N:O} = 85:10:5$ (atomic percent ratio).

[0306]

An antireflection film formed of tantalum and oxygen was formed on the light shielding film to a thickness of 6 nm using the DC sputtering device. Tantalum was used as the target, and xenon and oxygen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:O = 30:70 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described antireflection film, the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 3.0.

[0307]

An etching mask film formed of chromium and nitrogen was formed on the antireflection film to a thickness of 4 nm using the DC sputtering device. Chromium was used as the target, and argon and nitrogen were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:N = 90:10 (atomic percent ratio).

[0308]

As described, a phase shift mask blank having a phase shift film formed of silicon and nitrogen, a lower layer light shielding film formed of ruthenium compound, an upper layer light shielding film formed of tantalum, nitrogen and oxygen, an antireflection film formed of tantalum and oxygen, and an etching mask film formed of chromium and nitrogen with laminated on a quartz substrate, was obtained.

[0309]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 80 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of 37 $\mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110 °C, developing was performed for 60 seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0310]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0311]

Next, an antireflection film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 5 nm in average.

[0312]

Next, the upper layer light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the antireflection film and the upper layer light shielding film as lower layers is narrowed compared to the upper layer etching mask film.

[0313]

Next, the lower layer light shielding film was patterned using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the lower layer light shielding film is narrowed compared to the upper layer light shielding film.

[0314]

Next, a phase shift film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 1 nm in average.

[0315]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0316]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0317]

Next, the antireflection film was removed using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP

power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 8 nm in average.

[0318]

Next, the upper layer light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0319]

Next, the lower layer light shielding film was removed using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0320]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 6.8 %, and the phase difference was 180 degrees. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 4 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 5 % compared to the phase shift mask using the conventional silicon compound film as etching mask film. Since the upper layer light shielding film was thinned, the improvement rate was higher than Example 9.

[0321]

Next, prior to the step of removing the above-mentioned etching mask film, particles of Si_3N_4 were scattered on the mask surface, and thereafter, the step of removing the etching mask film was performed and particles were removed by cleaning, by which a residue of etching mask film was generated intendedly on the antireflection film. Next, a reflection mask inspection was performed, and detection of this residue was confirmed. Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and

helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 100 %. Next, the area where occurrence of residue has been detected was observed by SEM, and complete removal of the residue was confirmed.

[0322]

(Example 11)

An RF sputtering device adopting two targets was used to form a phase shift film formed of silicon and oxygen to a thickness of 169 nm on a quartz substrate. Silicon was used as the target, and argon and oxygen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:O = 33:67 (atomic percent ratio).

[0323]

A light shielding film formed of tantalum and nitrogen was formed on the phase shift film to a thickness of 48 nm using the DC sputtering device. Tantalum was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:N = 85:15 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described etching mask film with the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 2.9.

[0324]

An etching mask film formed of chromium, nitrogen and carbon was formed on the light shielding film to a thickness of 10 nm using the DC sputtering device. Chromium was used as the target, and argon, nitrogen and carbon were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:N:C = 85:10:5 (atomic percent ratio).

[0325]

As described, a phase shift mask blank having a phase shift film formed of silicon and oxygen, a light shielding film formed of tantalum and nitrogen, and an etching mask film formed of chromium, nitrogen and carbon with laminated on a quartz substrate, was obtained.

[0326]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 120 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of 36 $\mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110 °C, developing was performed for 70

seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0327]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0328]

Next, the light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the lower layer light shielding film is narrowed compared to the upper layer light shielding film.

[0329]

Next, the phase shift film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 2 nm in average.

[0330]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0331]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0332]

Next, the light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0333]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 98 %, and the phase difference was 180 degrees. The phase difference of this phase shift mask was measured for the whole mask surface, and it was confirmed that there was no phase difference error caused by pattern dependency or mask position dependency. Further, a program defect portion where black defect of the phase shift film was intentionally arranged was corrected by electron beam, and it was confirmed that it could be corrected with good shape. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 2 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 2 % compared to the phase shift mask using the conventional silicon compound film as etching mask film.

[0334]

Next, a positive-type resist film was spin-coated on the phase shift mask according to the present embodiment where residue of the etching mask film and the light shielding film was detected by defect inspection, and drawing was carried out by a laser drawing apparatus to only a surrounding area of the residue portion. Thereafter, developing was performed and a resist pattern where only the residue portion is opened was formed.

[0335]

Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0336]

Next, the residue of the light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0337]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and residue correction of the etching mask film and the light shielding film of the phase shift mask according to the present embodiment was completed. The phase shift mask was subjected to defect inspection, and it was confirmed that the residue of the etching mask film and the light shielding film was completely removed.

[0338]

(Example 12)

An RF sputtering device adopting two targets was used to form a phase shift film formed of silicon and oxygen to a thickness of 169 nm on a quartz substrate. Silicon was used as the target, and argon and oxygen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:O = 33:67 (atomic percent ratio).

[0339]

A lower layer light shielding film formed of ruthenium compound was formed on the phase shift film to a thickness of 20 nm using the ion sputtering device. Ruthenium was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ru:N = 90:10 (atomic percent ratio).

[0340]

An upper layer light shielding film formed of tantalum and nitrogen was formed on the lower layer light shielding film to a thickness of 32 nm using the DC sputtering device. Tantalum was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:N = 85:15 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described etching mask film with the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 2.9.

[0341]

An etching mask film formed of chromium, nitrogen and carbon was formed on the light shielding film to a thickness of 10 nm using the DC sputtering device. Chromium was used as the target, and argon, nitrogen and carbon were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:N:C = 85:10:5 (atomic percent ratio).

[0342]

As described, a phase shift mask blank having a phase shift film formed of silicon and oxygen, a lower layer light shielding film formed of ruthenium

compound, an upper layer light shielding film formed of tantalum and nitrogen, and an etching mask film formed of chromium, nitrogen and carbon with laminated on a quartz substrate, was obtained.

[0343]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 120 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of $36 \mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110°C , developing was performed for 70 seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0344]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0345]

Next, the upper layer light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the upper layer light shielding film is narrowed compared to the upper layer etching mask.

[0346]

Next, the lower layer light shielding film was patterned using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the lower layer light shielding film is narrowed compared to the upper layer light shielding film.

[0347]

Next, the phase shift film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 2 nm in average.

[0348]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0349]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0350]

Next, the upper layer light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0351]

Next, the lower layer light shielding film was removed using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0352]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 98 %, and the phase difference was 180 degrees. The phase difference of this phase shift mask was measured for the whole mask surface, and it was confirmed that there was no phase difference error caused by pattern dependency or mask position dependency. Further, a program defect portion where black defect of the phase shift film was intentionally arranged was corrected by electron beam, and it was confirmed that it could be corrected with good shape. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 2 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed

that occurrence of residue was improved by 4 % compared to the phase shift mask using the conventional silicon compound film as etching mask film. Since the upper layer light shielding film was thinned, the improvement rate was improved compared to Example 11.

[0353]

Next, a positive-type resist film was spin-coated on the phase shift mask according to the present embodiment where residue of the etching mask film and the light shielding film was detected by defect inspection, and drawing was carried out by a laser drawing apparatus to only a surrounding area of the residue portion. Thereafter, developing was performed and a resist pattern where only the residue portion is opened was formed.

[0354]

Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0355]

Next, the residue of the upper layer light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0356]

Next, the lower layer light shielding film was removed using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0357]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and residue correction of the etching mask film and the light shielding film of the phase shift mask according to the present embodiment was completed. The phase shift mask was subjected to defect inspection, and it was confirmed that the residue of the etching mask film and the light shielding film was completely removed.

[0358]

(Example 13)

A DC sputtering device adopting two targets was used to form a first phase shift film formed of silicon, molybdenum and oxygen to a thickness of 56 nm on a quartz substrate. Molybdenum and silicon were used as the target, and

argon, oxygen and nitrogen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:Mo:O:N = 40:8:7:45 (atomic percent ratio). Thereafter, the DC sputtering device was used to form a second phase shift film formed of silicon and oxygen to a thickness of 8 nm on the first phase shift film. Silicon was used as the target, and argon and oxygen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:O = 33:67 (atomic percent ratio).

[0359]

A light shielding film formed of tantalum and nitrogen was formed on the phase shift film to a thickness of 20 nm using the DC sputtering device. Tantalum was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:N = 85:15 (atomic percent ratio).

[0360]

An antireflection film formed of tantalum and oxygen was formed on the light shielding film to a thickness of 10 nm using the DC sputtering device. Tantalum was used as the target, and xenon and oxygen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:O = 35:65 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described antireflection film with the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 2.9.

[0361]

An etching mask film formed of chromium and nitrogen was formed on the antireflection film to a thickness of 13 nm using the DC sputtering device. Chromium was used as the target, and argon and nitrogen were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:N = 90:10 (atomic percent ratio).

[0362]

As described, a phase shift mask blank having a first phase shift film formed of silicon, molybdenum, oxygen and nitrogen, a second phase shift film formed of silicon and oxygen, a light shielding film formed of tantalum and nitrogen, an antireflection film formed of tantalum and oxygen, and an etching mask film formed of chromium and nitrogen with laminated on a quartz substrate, was obtained.

[0363]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 150 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of $35 \mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110°C , developing was performed for 90 seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0364]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0365]

Next, the antireflection film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 20 W. Dry etching was stopped when the light shielding film was engraved for 5 nm in average.

[0366]

Next, the light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the antireflection film and the light shielding film as lower layers is narrowed compared to the upper layer etching mask film.

[0367]

Next, the first and second phase shift films were patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 2 nm in average.

[0368]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0369]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0370]

Next, the antireflection film was removed using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 15 nm in average.

[0371]

Next, the light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0372]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 9.3 %, and the phase difference was 180 degrees. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 3 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 7 % compared to the phase shift mask using the conventional silicon compound film as etching mask film.

[0373]

Next, prior to the above-mentioned step of removing the etching mask film, particles of Si_3N_4 were scattered on the mask surface, and thereafter, the step of removing the etching mask film was performed and particles were removed by cleaning, by which a residue of etching mask film was generated intendedly on the antireflection film. Next, a reflection mask inspection was performed, and detection of this residue has been confirmed. Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen

and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 100 %. Next, the area where occurrence of residue has been detected was observed by SEM, and complete removal of the residue was confirmed.

[0374]

Next, a phase shift mask was fabricated in which an additional dry etching was added after the above-mentioned removal step of the light shielding film. Chlorine and helium were used as etching gas of the additional dry etching, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 60 W. According to this etching condition, it has been confirmed by evaluation performed in advance that the quartz substrate receives 2 nm of damage. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, and it has been confirmed that they have not been varied from the value of the phase shift mask which had not been subjected to additional dry etching.

[0375]

(Example 14)

A DC sputtering device adopting two targets was used to form a first phase shift film formed of silicon, molybdenum, oxygen and nitrogen to a thickness of 56 nm on a quartz substrate. Molybdenum and silicon were used as the target, and argon, oxygen and nitrogen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:Mo:O:N = 40:8:7:45 (atomic percent ratio). Thereafter, the DC sputtering device was used to form a second phase shift film formed of silicon and oxygen to a thickness of 8 nm on the first phase shift film. Silicon was used as the target, and argon and oxygen were used as the sputtering gas. Composition of the phase shift film was analyzed by ESCA, and the result was Si:O = 33:67 (atomic percent ratio).

[0376]

A lower layer light shielding film formed of ruthenium compound was formed on the phase shift film to a thickness of 10 nm using the ion sputtering device. Ruthenium was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ru:N = 80:20 (atomic percent ratio).

[0377]

An upper layer light shielding film formed of tantalum and nitrogen was formed on the lower layer light shielding film to a thickness of 11 nm using the

DC sputtering device. Tantalum was used as the target, and xenon and nitrogen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:N = 85:15 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the etching mask film with the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 2.9.

[0378]

An antireflection film formed of tantalum and oxygen was formed on the light shielding film to a thickness of 10 nm using the DC sputtering device. Tantalum was used as the target, and xenon and oxygen were used as the sputtering gas. The composition of the light shielding film was analyzed by ESCA, and the result was Ta:O = 35:65 (atomic percent ratio). Further, an optical density (OD value) by exposure wavelength (193 nm) of ArF excimer laser combining the above-described antireflection film with the light shielding film and the phase shift film was measured by a spectrophotometer, and the result was 2.9.

[0379]

An etching mask film formed of chromium and nitrogen was formed on the antireflection film to a thickness of 13 nm using the DC sputtering device. Chromium was used as the target, and argon and nitrogen were used as the sputtering gas. The composition of the etching mask film was analyzed by ESCA, and the result was Cr:N = 90:10 (atomic percent ratio).

[0380]

As described, a phase shift mask blank having a first phase shift film formed of silicon, molybdenum, oxygen and nitrogen, a second phase shift film formed of silicon and oxygen, a lower layer light shielding film formed of ruthenium alloy, an upper layer light shielding film formed of tantalum and nitrogen, an antireflection film formed of tantalum and oxygen, and an etching mask film formed of chromium and nitrogen with laminated on a quartz substrate, was obtained.

[0381]

Next, a negative chemical amplification type electron beam resist was spin-coated to a film thickness of 150 nm on the above-described etching mask film, a pattern was drawn by electron beams with a dosage of 35 $\mu\text{C}/\text{cm}^2$, heating was performed for ten minutes at 110 °C, developing was performed for 90 seconds by paddle development, and a resist pattern was formed. The resolution of the resist pattern was compared with the resist pattern in which

similar processing had been performed on the etching mask film on a silicon compound subjected to HMDS processing, and it was confirmed that collapsing of the resist pattern had been improved by 10 nm.

[0382]

Next, an etching mask film was patterned using a dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. Then, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture.

[0383]

Next, the antireflection film was patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 20 W. Dry etching was stopped when the light shielding film was engraved for 5 nm in average.

[0384]

Next, the upper layer light shielding film was patterned using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the antireflection film and the upper layer light shielding film as lower layers is narrowed compared to the upper layer etching mask film.

[0385]

Next, the lower layer light shielding film was patterned using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 40 W. After the processing of dry etching, there was no occurrence of undercut where the dimension of line pattern of the lower layer light shielding film is narrowed compared to the upper layer etching mask film.

[0386]

Next, the first and second phase shift films were patterned using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 2 nm in average.

[0387]

Next, the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to

10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0388]

Next, a positive-type resist film was spin-coated and drawing was performed using a laser drawing apparatus. Thereafter, developing was performed to form a resist pattern.

[0389]

Next, the antireflection film was removed using the dry etching device. CF_4 and oxygen were used as etching gas, gas pressure was set to 5 mTorr, ICP power was set to 400 W, and bias power was set to 20 W. Dry etching was stopped when the quartz substrate was engraved for 15 nm in average.

[0390]

Next, the upper layer light shielding film was removed using the dry etching device. Chlorine and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0391]

Next, the lower layer light shielding film was removed using the dry etching device. Oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 200 %.

[0392]

Next, the resist pattern was subjected to peeling and cleaning by sulfuric-acid and hydrogen-peroxide mixture, and a phase shift mask was obtained. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, wherein the transmittance of the phase shift film portion with respect to the transmittance of the quartz substrate at exposure wavelength (193 nm) of ArF excimer laser was 9.3 %, and the phase difference was 180 degrees. Further, pattern density dependence of the pattern dimension of the phase shift mask was compared with a phase shift mask where a conventional silicon compound film was used as the etching mask film, and an improvement of 3 nm was confirmed. Further, a plurality of these phase shift masks was fabricated and subjected to defect inspection to inspect the probability of occurrence of residue of the etching mask film and the light shielding film, and it has been confirmed that occurrence of residue was improved by 8 % compared to the phase shift mask using the conventional silicon compound film as etching mask film. Since the

upper layer light shielding film was thinned, the improvement rate was higher than Example 13.

[0393]

Next, prior to the step of removing the above-mentioned etching mask film, particles of Si_3N_4 were scattered on the mask surface, and thereafter, the step of removing the etching mask film was performed and particles were removed by cleaning, by which a residue of etching mask film was generated intendedly on the antireflection film. Next, a reflection mask inspection was performed, and detection of this residue has been confirmed. Next, the residue of the etching mask film was removed using the dry etching device. Chlorine, oxygen and helium were used as etching gas, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 10 W. Over-etching was performed for 100 %. Next, the area where occurrence of residue has been detected was observed by SEM, and complete removal of the residue was confirmed.

[0394]

Next, a phase shift mask was fabricated in which an additional dry etching was added after the above-mentioned removal step of the light shielding film. Chlorine and helium were used as etching gas of the additional dry etching, gas pressure was set to 10 mTorr, ICP power was set to 500 W, and bias power was set to 60 W. According to this etching condition, it has been confirmed by evaluation performed in advance that the quartz substrate receives 2 nm of damage. Transmittance and phase difference of the phase shift mask were measured using MPM 193, a product of Lasertec Corporation, and it has been confirmed that they have not been varied from the value of the phase shift mask which had not been subjected to additional dry etching.

[Industrial Applicability]

[0395]

In the present invention, the composition, film thickness and laminated structure of the phase shift mask blank, and manufacturing steps and conditions of the phase shift mask using the same are selected within an appropriate range, so that a phase shift mask having a microscopic pattern formed with high accuracy that corresponds to manufacturing logic devices of 28 nm or smaller or memory devices of 30 nm or smaller is provided.

[Reference Signs List]

[0396]

10, 20: phase shift mask blank, 11, 21: substrate (substrate transparent to exposure wavelength), 12, 22: phase shift film, 13, 23: light shielding film or

upper layer light shielding film, 14, 24: etching mask film, 15, 25: resist pattern, 16, 26: second resist pattern, 13a: residue (residue of upper layer light shielding film), 14a: residue (residue of etching mask film), 18a: residue (residue of lower layer light shielding film), 17: resist pattern, 18, 28: lower layer light shielding film, 100, 200: phase shift mask, 10': phase shift mask blank, 11': substrate (substrate transparent to exposure wavelength), 12': phase shift film, 13': light shielding film or upper layer light shielding film, 14': antireflection film, 15': etching mask film, 16': resist pattern, 17': second resist pattern, 18': lower layer light shielding film, 100' phase shift mask

[CLAIMS]

[Claim 1]

A phase shift mask blank comprising, on a substrate transparent to an exposure wavelength, a phase shift film, a light shielding film, and an etching mask film laminated in a named order,

wherein the phase shift film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by fluorine-based etching (F based),

the light shielding film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and is capable of being etched by non-oxygen-containing chlorine-based etching (Cl based),

the etching mask film has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by oxygen-containing chlorine-based etching (Cl/O based), and

wherein an etching stopper layer is not arranged between the phase shift film and the substrate.

[Claim 2]

The phase shift mask blank according to claim 1,

wherein the light shielding film is composed of a tantalum compound containing no silicon, and the tantalum compound containing no silicon contains, in addition to tantalum, one or more kinds selected from nitrogen, boron, oxygen and carbon.

[Claim 3]

The phase shift mask blank according to claim 2,

wherein the light shielding film comprises tantalum nitride as a main component.

[Claim 4]

The phase shift mask blank according to any one of claims 1 through 3,

wherein the etching mask film contains a single substance of chromium, or contains, in addition to chromium, one or more kinds selected from nitrogen, oxygen and carbon.

[Claim 5]

The phase shift mask blank according to any one of claims 1 through 4,

wherein the phase shift film comprises a function to provide a predetermined amount of phase change to a transmitted exposure light, and contains one or more kinds selected from transition metal, nitrogen, oxygen and carbon, and

the transition metal is one or more kinds selected from molybdenum, titanium, vanadium, cobalt, nickel, zirconium, niobium and hafnium.

[Claim 6]

The phase shift mask blank according to any one of claims 1 through 5, wherein an antireflection film having resistance to oxygen-containing chlorine-based etching (Cl/O based) and non-oxygen-containing chlorine-based etching (Cl based) and capable of being etched by fluorine-based etching (F based) is laminated between the light shielding film and the etching mask film.

[Claim 7]

The phase shift mask blank according to claim 6, wherein the antireflection film comprises tantalum oxide as a main component.

[Claim 8]

A phase shift mask blank comprising, on a substrate transparent to an exposure wavelength, a phase shift film, a lower layer light shielding film, an upper layer light shielding film, and an etching mask film laminated in a named order,

wherein the phase shift film has resistance to oxygen-containing chlorine-based etching (Cl/O based), non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O based) and is capable of being etched by fluorine-based etching (F based),

the lower layer light shielding film has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by oxygen-based etching (O based),

the upper layer light shielding film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and is capable of being etched by either one of or both fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based), and

the etching mask film has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O-based) and is capable of being etched by oxygen-containing chlorine-based etching (Cl/O based).

[Claim 9]

The phase shift mask blank according to claim 8, wherein the lower layer light shielding film has a film thickness of 2 nm or greater and 30 nm or smaller and is composed of a simple substance of ruthenium or a ruthenium compound containing 50 atomic percent or higher ruthenium content.

[Claim 10]

The phase shift mask blank according to claim 8 or claim 9,
wherein the upper layer light shielding film is composed of a tantalum compound or a silicon compound.

[Claim 11]

The phase shift mask blank according to claim 10,
wherein the tantalum compound contains tantalum, and one or more kinds selected from nitrogen, boron, silicon, oxygen and carbon.

[Claim 12]

The phase shift mask blank according to claim 10,
wherein the silicon compound contains silicon, and one or more kinds selected from molybdenum, titanium, vanadium, cobalt, nickel, zirconium, niobium, hafnium, nitrogen, oxygen and carbon.

[Claim 13]

The phase shift mask blank according to any one of claims 8 through 12,
wherein the etching mask film contains a single substance of chromium, or in addition to chromium, contains one or more kinds selected from nitrogen, oxygen and carbon.

[Claim 14]

The phase shift mask blank according to any one of claims 8 through 13,
wherein the phase shift film comprises a function to provide a predetermined amount of phase change to a transmitted exposure light, and contains silicon and one or more kinds selected from transition metal, nitrogen, oxygen and carbon, and
the transition metal is one or more kinds selected from molybdenum, titanium, vanadium, cobalt, nickel, zirconium, niobium and hafnium.

[Claim 15]

The phase shift mask blank according to any one of claims 8 through 14,
wherein an antireflection film having resistance to oxygen-containing chlorine-based etching (Cl/O based) and non-oxygen-containing chlorine-based etching (Cl based) and capable of being etched by fluorine-based etching (F based) is laminated between the upper layer light shielding film and the etching mask film.

[Claim 16]

The phase shift mask blank according to claim 15,
wherein the antireflection film comprises tantalum oxide as a main component.

[Claim 17]

A phase shift mask on which a circuit pattern is formed by selectively removing a portion of a film of a phase shift mask blank, comprising, on a substrate transparent to an exposure wavelength, a plurality of films including a phase shift film, a light shielding film, and an etching mask film laminated in a named order,

wherein the phase shift film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by fluorine-based etching (F based),

the light shielding film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and is capable of being etched by non-oxygen-containing chlorine-based etching (Cl based),

the etching mask film has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by oxygen-containing chlorine-based etching (Cl/O based), and

wherein an etching stopper layer is not arranged between the phase shift film and the substrate.

[Claim 18]

The phase shift mask according to claim 17,

wherein the light shielding film is composed of a tantalum compound containing no silicon, and the tantalum compound containing no silicon contains, in addition to tantalum, one or more kinds selected from nitrogen, boron, oxygen and carbon.

[Claim 19]

The phase shift mask according to claim 18,

wherein the light shielding film comprises tantalum nitride as a main component.

[Claim 20]

The phase shift mask according to any one of claims 17 through 19,

wherein the etching mask film contains a single substance of chromium, or contains, in addition to chromium, one or more kinds selected from nitrogen, oxygen and carbon.

[Claim 21]

The phase shift mask according to any one of claims 17 through 20,

wherein the phase shift film comprises a function to provide a predetermined amount of phase change to a transmitted exposure light, and contains silicon and one or more kinds selected from transition metal, nitrogen, oxygen and carbon, and

the transition metal is one or more kinds selected from molybdenum, titanium, vanadium, cobalt, nickel, zirconium, niobium and hafnium.

[Claim 22]

The phase shift mask according to any one of claims 17 through 21, wherein an antireflection film having resistance to oxygen-containing chlorine-based etching (Cl/O based) and non-oxygen-containing chlorine-based etching (Cl based) and capable of being etched by fluorine-based etching (F based) is laminated between the light shielding film and the etching mask film.

[Claim 23]

The phase shift mask according to claim 22, wherein the antireflection film comprises tantalum oxide as a main component.

[Claim 24]

A phase shift mask on which a circuit pattern is formed by selectively removing a portion of a film of a phase shift mask blank, comprising, on a substrate transparent to an exposure wavelength, a plurality of films including a phase shift film, a lower layer light shielding film, an upper layer light shielding film, and an etching mask film laminated in a named order,

wherein the phase shift film has resistance to oxygen-containing chlorine-based etching (Cl/O based), non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O based) and is capable of being etched by fluorine-based etching (F based),

the lower layer light shielding film has resistance to fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based) and is capable of being etched by oxygen-based etching (O based),

the upper layer light shielding film has resistance to oxygen-containing chlorine-based etching (Cl/O based) and is capable of being etched by either one of or both fluorine-based etching (F based) and non-oxygen-containing chlorine-based etching (Cl based), and

the etching mask film has resistance to fluorine-based etching (F based), non-oxygen-containing chlorine-based etching (Cl based) and oxygen-based etching (O-based) and is capable of being etched by oxygen-containing chlorine-based etching (Cl/O based).

[Claim 25]

The phase shift mask according to claim 24, wherein the lower layer light shielding film has a film thickness of 2 nm or greater and 30 nm or smaller and is composed of a simple substance of

ruthenium or a ruthenium compound containing 50 atomic percent or higher ruthenium content.

[Claim 26]

The phase shift mask according to claim 24 or claim 25,
wherein the upper layer light shielding film is composed of a tantalum compound or a silicon compound.

[Claim 27]

The phase shift mask according to claim 26,
wherein the tantalum compound contains tantalum, and one or more kinds selected from nitrogen, boron, silicon, oxygen and carbon.

[Claim 28]

The phase shift mask according to claim 26,
wherein the silicon compound contains silicon, and one or more kinds selected from molybdenum, titanium, vanadium, cobalt, nickel, zirconium, niobium, hafnium, nitrogen, oxygen and carbon.

[Claim 29]

The phase shift mask according to any one of claims 24 through 28,
wherein the etching mask film contains a single substance of chromium, or in addition to chromium, contains one or more kinds selected from nitrogen, oxygen and carbon.

[Claim 30]

The phase shift mask according to any one of claims 24 through 29,
wherein the phase shift film comprises a function to provide a predetermined amount of phase change to a transmitted exposure light, and contains silicon and one or more kinds selected from transition metal, nitrogen, oxygen and carbon, and

the transition metal is one or more kinds selected from molybdenum, titanium, vanadium, cobalt, nickel, zirconium, niobium and hafnium.

[Claim 31]

The phase shift mask according to any one of claims 24 through 30,
wherein an antireflection film having resistance to oxygen-containing chlorine-based etching (Cl/O based) and non-oxygen-containing chlorine-based etching (Cl based) and capable of being etched by fluorine-based etching (F based) is laminated between the upper layer light shielding film and the etching mask film.

[Claim 32]

The phase shift mask according to claim 31,

wherein the antireflection film comprises tantalum oxide as a main component.

[Claim 33]

A manufacturing method for a phase shift mask using the phase shift mask blank according to any one of claims 1 through 7, the manufacturing method comprising:

- a step of forming a resist pattern on the etching mask film;
- a step of forming a pattern on the etching mask film by oxygen-containing chlorine-based etching (Cl/O based);
- a step of forming a pattern on the light shielding film using both or either one of non-oxygen-containing chlorine-based etching (Cl based) and fluorine-based etching (F based);
- a step of forming a pattern on the phase shift film by fluorine-based etching (F based);
- a step of removing the etching mask film from the pattern formed on the light shielding film by oxygen-containing chlorine-based etching (Cl/O based);
- and
- a step of removing the light shielding film from the pattern formed on the phase shift film by either non-oxygen-containing chlorine-based etching (Cl based) or both non-oxygen-containing chlorine-based etching (Cl based) and fluorine-based etching (F based).

[Claim 34]

The manufacturing method for a phase shift mask according to claim 33, comprising either one of a correcting step of removing only a residue of the etching mask film formed on the light shielding film by oxygen-containing chlorine-based etching (Cl/O based) and a correcting step of removing only a residue of the light shielding film formed on the phase shift film by non-oxygen-containing chlorine-based etching (Cl based).

[Claim 35]

A manufacturing method for a phase shift mask using the phase shift mask blank according to any one of claims 8 through 16, the manufacturing method comprising:

- a step of forming a resist pattern on the etching mask film;
- a step of forming a pattern on the etching mask film by oxygen-containing chlorine-based etching (Cl/O based);
- a step of forming a pattern on the upper layer light shielding film using both or either one of non-oxygen-containing chlorine-based etching (Cl based) and fluorine-based etching (F based);

a step of forming a pattern on the lower layer light shielding film using oxygen-based etching (O based);

a step of forming a pattern on the phase shift film by fluorine-based etching (F based);

a step of removing the etching mask film from the pattern formed on the upper layer light shielding film by oxygen-containing chlorine-based etching (Cl/O based);

a step of removing the upper layer light shielding film from the pattern formed on the lower layer light shielding film by either one of or both non-oxygen-containing chlorine-based etching (Cl based) and fluorine-based etching (F based); and

a step of removing the lower layer light shielding film from the pattern formed on the phase shift film by oxygen-based etching (O based).

[Claim 36]

The manufacturing method for a phase shift mask according to claim 35, comprising

any one of a correcting step of removing only a residue of the etching mask film formed on the upper layer light shielding film by oxygen-containing chlorine-based etching (Cl/O based), a correcting step of removing only a residue of the upper layer light shielding film formed on the lower layer light shielding film by non-oxygen-containing chlorine-based etching (Cl based), and a correcting step of removing only a residue of the lower layer light shielding film formed on the phase shift film by oxygen-based etching (O based).