and a low reflective part formed on the reflective part and configured to absorb an incident light, in which the low reflective part is a multi-layer structural body having at least two or more layers including an absorption layer and a phase shift layer, the absorption layer and the phase shift layer are deposited in this order on the reflective part, the optical constant to a wavelength of 13.5 nm of a material constituting the absorption layer satisfies an extinction coefficient $k > 0.041$, and the optical constant to the wavelength of 13.5 nm of a material constituting the phase shift layer satisfies a refractive index $n < 0.94$ and the extinction coefficient $k < 0.02$.

[0012]

The absorption layer in the reflective photomask blank according to one aspect of the present disclosure preferably contains a total of 50 at% or more of at least one kind of element selected from the group consisting of tellurium (Te), cobalt (Co), nickel (Ni), platinum (Pt), silver (Ag), tin (Sn), indium (In), copper (Cu), zinc (Zn), and bismuth (Bi), as metals, oxides, nitrides, or oxynitrides thereof.

[0013]

The phase shift layer in the reflective photomask blank according to one aspect of the present disclosure preferably contains a total of 50 at% or more of at least one kind of element selected from the group consisting of molybdenum (Mo), ruthenium (Ru), and

niobium (Nb), as metals, oxides, nitrides, or oxynitrides thereof.

[0014]

The low reflective part containing the absorption layer and the phase shift layer in the reflective photomask blank according to one aspect of the present disclosure preferably has a phase difference of 160 to 200° to the reflective part and a reflectance of 1% to 40% according to a film thickness ratio of the absorption layer and the phase shift layer.

[0015]

A reflective photomask according to one aspect of the present disclosure is a reflective photomask for pattern transfer using an extreme ultraviolet light as a light source, and includes: a substrate; a reflective part formed on the substrate and configured to reflect an incident light; and a low reflective part formed on the reflective part and configured to absorb an incident light, in which the low reflective part is a multi-layer structural body having at least two or more layers including an absorption layer and a phase shift layer, the absorption layer and the phase shift layer are deposited in this order on the reflective part, the optical constant to a wavelength of 13.5 nm of a material constituting the absorption layer satisfies an extinction coefficient $k > 0.041$, and the optical constant to the wavelength of 13.5 nm of a material constituting the phase shift layer satisfies the refractive index $n < 0.94$

18, a material having higher absorptivity to the EUV light than that of a conventional material, i.e., a material having a high extinction coefficient k to a wavelength of 13.5 nm, is preferably applied to the low reflective part 18.

[0027]

FIG. 3 is a graph showing the optical constant to the wavelength of 13.5 nm of the EUV light of each metal material. The horizontal axis of FIG. 3 represents the refractive index n and the vertical axis represents the extinction coefficient k. As illustrated in FIG. 3, the extinction coefficient k of tantalum (Ta), which is a main material of the conventional absorption layer 14, is 0.041. When the main material of the absorption layer 14 is a compound material having the extinction coefficient k larger than that of tantalum (Ta), the thickness of the absorption layer 14 can be further reduced as compared with conventional compound materials, and the shadowing effect can be reduced. When the extinction coefficient k is 0.06 or more, the thickness of the absorption layer 14 can be sufficiently reduced, and the shadowing effect can be reduced.

[0028]

Examples of materials having the extinction coefficient k greater than 0.041 described above include silver (Ag), platinum (Pt), indium (In), cobalt (Co), tin (Sn), nickel (Ni), tellurium (Te), copper (Cu), zinc (Zn), and bismuth (Bi) as illustrated in FIG. 3.

Therefore, materials of the absorption layer 14 preferably contain a total of 50 at% or more of at least one kind of element selected from the group consisting of tellurium (Te), cobalt (Co), nickel (Ni), platinum (Pt), silver (Ag), tin (Sn), indium (In), copper (Cu), zinc (Zn), and bismuth (Bi), as metals, oxides, nitrides, or oxynitrides thereof.

[0029]

In the reflective photomask blank, the absorption layer 14 needs to be easily processable for patterning. Among the materials above, tin oxide is known to be dry-etchable using a chlorine-based gas. It is also known that a tin (Sn) simple substance has a low melting point and poor thermal stability, but its melting point increases when made into tin oxide. Therefore, the absorption layer 14 preferably contains tin (Sn) and oxygen (O) in this embodiment.

[0030]

The reflective photomask is exposed to a hydrogen radical environment, and therefore the photomask cannot withstand long-term use unless the materials of the absorption layer 14 are absorption materials having high hydrogen radical resistance. A material having a film reduction rate of 0.1 nm/s or less under a hydrogen radical environment having a power of 1 kW and a hydrogen pressure of 0.36 mbar or less using a microwave plasma is used as a material having high hydrogen radical resistance. In the materials of the absorption layer 14,

reflected light from the low reflective part is 170 to 190°. The phase shift layer 15 preferably has a refractive index n < 1 and more preferably has the refractive index n < 0.94. When the refractive index n of the phase shift layer 15 is smaller than 1, which is the refractive index in vacuum, the adjustment of the phase difference by the film thickness is facilitated. When the film thickness of the phase shift layer 15 is large, the film thickness of the entire low reflective part 18 is large, deteriorating the resolution due to the shadowing effect.

[0036]

A material of the phase shift layer 15 is preferably a material which can be etched using a fluorine-based gas or a chlorine-based gas because patterning processing is performed in the phase shift layer 15. The material of the phase shift layer 15 is preferably a material having the extinction coefficient k < 0.02 not to affect the shadowing effect. Specifically, the material of the phase shift layer 15 preferably contains at least one kind of element of molybdenum (Mo), ruthenium (Ru), and niobium (Nb), and oxides, nitrides, and oxynitrides thereof. Not to reduce the etching rate, the phase shift layer 15 desirably contains a material containing at least 50% or more of the elements above.

[0037]

When the absorption layer 14 contains tin or indium (In) that can be etched using a chlorine gas, molybdenum

CLAIMS

1. A reflective photomask blank for producing a reflective photomask for pattern transfer using an extreme ultraviolet light as a light source comprising:

a substrate;

a reflective part formed on the substrate and configured to reflect an incident light; and

a low reflective part formed on the reflective part and configured to absorb an incident light, wherein

the low reflective part is a multi-layer structural body having at least two or more layers including an absorption layer and a phase shift layer,

the absorption layer and the phase shift layer are deposited in this order on the reflective part,

an optical constant to a wavelength of 13.5 nm of a material constituting the absorption layer satisfies an extinction coefficient $k > 0.041$, and

the optical constant to the wavelength of 13.5 nm of a material constituting the phase shift layer satisfies a refractive index $n < 0.94$ and the extinction coefficient $k < 0.02$.

2. The reflective photomask blank according to claim 1, wherein the absorption layer contains a total of 50 at% or more of at least one kind of element selected from the group consisting of tellurium (Te), cobalt (Co), nickel (Ni), platinum (Pt), silver (Ag), tin (Sn), indium (In), copper (Cu), zinc (Zn), and bismuth (Bi).

3. The reflective photomask blank according to claim 1 or 2, wherein the phase shift layer contains a total of 50 at% or more of at least one kind of element selected from the group consisting of molybdenum (Mo), ruthenium (Ru), and niobium (Nb).

4. The reflective photomask blank according to any one of claims 1 to 3, wherein the low reflective part including the absorption layer and the phase shift layer has a phase difference of 160 to 200° to the reflective part and a reflectance of 1% to 40% according to a film thickness ratio of the absorption layer and the phase shift layer.

5. A reflective photomask for pattern transfer using an extreme ultraviolet light as a light source comprising:

a substrate;

a reflective part formed on the substrate and configured to reflect an incident light; and

a low reflective part formed on the reflective part and configured to absorb an incident light, wherein

the low reflective part is a multi-layer structural body having at least two or more layers including an absorption layer and a phase shift layer,

the absorption layer and the phase shift layer are deposited in this order on the reflective part,

an optical constant to a wavelength of 13.5 nm of a material constituting the absorption layer satisfies an extinction coefficient $k > 0.041$, and

the optical constant to the wavelength of 13.5 nm of a material constituting the phase shift layer satisfies a refractive index $n < 0.94$ and the extinction coefficient $k < 0.02$.