nanometer order from being damaged. The vent hole needs to be provided with a filter. Since the space in which the pellicle is located is significantly restricted, there is also a significant restriction on the height of the frame. Therefore, for attaching the filter to the frame, an unconventional design is necessary.

[0012]

Embodiments of the present invention provide a pellicle for extreme ultraviolet light lithography, a production method thereof, and an exposure method.

[0013]

In a pellicle for extreme ultraviolet light lithography, a very thin pellicle film is bonded to a frame. Therefore, if the pellicle film is bonded to the photomask from above the frame with a force as conventionally done, the pellicle film may be broken. For this reason, the pellicle for extreme ultraviolet light lithography needs to be bonded to the photomask in a non-contact manner by use of a dedicated bonding device. Herein, the term "non-contact manner" indicates that no strong force is applied from above the frame, and the "strong force" is at least about 1 kgf, which is used for conventional bonding of a photomask. Embodiments of the present invention also provide a pellicle for extreme ultraviolet light lithography that is bondable to a photomask in a non-contact manner, and a production method thereof.

SOLUTION TO PROBLEM

[0014]

According to a first aspect of the present invention, there is provided a pellicle including a first frame having a pellicle film located thereon; a second frame including a thick portion including a first surface carrying a surface of the first frame opposite to a surface on which the pellicle film is located, and also including a second surface connected with the first surface and carrying a side surface of

the first frame, the second frame enclosing the pellicle film and the first frame; a through-hole provided in the thick portion of the second frame; and a filter located on an outer side surface of the second frame and covering the through-hole, the outer side surface crossing the surface of the first frame on which the pellicle film is located.

[0015]

In an embodiment of the above-described pellicle, the second surface, engaged with the first frame, of the second frame may be perpendicular to the surface of the first frame on which the pellicle film is located.

[0016]

In an embodiment of the above-described pellicle, the second surface, engaged with the first frame, of the second frame may be inclined inward with respect to the surface of the first frame on which the pellicle film is located.

[0017]

In an embodiment of the above-described pellicle, the second frame may further include a third surface connected with the first surface and facing the second surface; and the third surface of the second frame may be located to face an inner side surface of the first frame.

[0018]

In an embodiment of the above-described pellicle, third surface, engaged with the first frame, of the second frame may be perpendicular to the surface of the first frame on which the pellicle film is located.

[0019]

In an embodiment of the above-described pellicle, the third surface, engaged with the first frame, of the second frame may be inclined such that a distance between the third surface and the second surface increases toward the surface of the first frame on which the pellicle film is located.

[0020]

In an embodiment of the above-described pellicle, first frame and the thick portion of the second frame may be bonded to each other with an adhesive layer.

[0021]

In an embodiment of the above-described pellicle, the pellicle film may have a transmittance of 90.0% or greater with respect to light having a wavelength of 5 nm or longer and 30 nm or shorter, and may have a thickness of 20 nm or greater and 50 nm or less.

[0022]

In an embodiment of the above-described pellicle, a total of a height of the second frame and a height of an adhesive layer located on a bottom surface of the second frame may be 2 mm or less.

[0023]

In an embodiment of the above-described pellicle, the first frame may be formed of a material selected from the group consisting of silicon, sapphire and silicon carbide.

[0024]

In an embodiment of the above-described pellicle, a total area size of a gas passage portion of the filter may have a ratio of, with respect to an inner volume of the pellicle, 0.007 mm^{-1} or greater and 0.026 mm^{-1} or less.

[0025]

According to a second aspect of the present invention, there is provided a method for producing a pellicle including forming a pellicle film on a substrate; shaping the substrate into a frame to expose the pellicle film, thereby forming a first frame; preparing a second frame including a thick portion including a first surface carrying a surface of the first frame opposite to a surface on which the pellicle film is located, and also including a second surface connected with the

first surface and carrying a side surface of the first frame; forming a through-hole in the thick portion in the second frame; bonding a filter covering the through-hole on an outer surface of the second frame, the outer surface being parallel to a height direction of the second frame; and securing the first frame to the second frame with an adhesive layer such that the second frame encloses the first frame.

[0026]

In an embodiment of the above-described method for producing a pellicle, the pellicle film may be exposed by dry etching, the second frame including the second surface perpendicular to the surface of the first frame on which the pellicle film is formed may be prepared, and the first frame may be secured to the second frame with the adhesive layer.

[0027]

In an embodiment of the above-described method for producing a pellicle, the pellicle film may be exposed by wet etching, the second frame including the second surface inclined inward with respect to the surface of the first frame on which the pellicle film is formed may be prepared, and the first frame may be secured to the second frame with the adhesive layer.

[0028]

In an embodiment of the above-described method for producing a pellicle, the pellicle film may be exposed by dry etching, the second frame including the second surface and a third surface connected with the first surface and facing the second surface may be prepared, the second surface and the third surface being perpendicular to the surface of the first frame on which the pellicle film is formed, and the first frame may be secured to the second frame with the adhesive layer.

[0029]

In an embodiment of the above-described method for producing a pellicle, the pellicle film may be exposed by wet etching, the second frame including the second surface

and a third surface may be prepared, the second surface being inclined inward with respect to the surface of the first frame on which the pellicle film is formed, the third surface being inclined such that a distance between the third surface and the second surface increases toward the surface of the first frame on which the pellicle film is located, and the first frame may be secured to the second frame with the adhesive layer.

[0030]

In an embodiment of the above-described method for producing a pellicle, the pellicle film having a thickness of 20 nm or greater and 50 nm or less may be formed on the substrate; and the pellicle film may have a transmittance of 90.0% or greater with respect to light having a wavelength of 5 nm or longer and 30 nm or shorter.

[0031]

In an embodiment of the above-described method for producing a pellicle, a total of a height of the second frame and a height of an adhesive layer located on a bottom surface of the second frame may be 2 mm or less.

[0032]

In an embodiment of the above-described method for producing a pellicle, the first frame may be selected from the group consisting of a silicon substrate, a sapphire substrate and a silicon carbide substrate.

[0033]

In an embodiment of the above-described method for producing a pellicle, a total area size of a gas passage portion of the filter may have a ratio of, with respect to an inner volume of the pellicle, 0.007 mm^{-1} or greater and 0.026 mm^{-1} or less.

[0034]

According to a third aspect of the present invention, is there is provided an exposure method including locating the above pellicle on a reticle surface of a photomask; locating the photomask at a predetermined position in an exposure device and causing the pellicle to be

accommodated in a gap having a distance of 3 mm or less from the reticle surface; directing, in vacuum, light having a wavelength of 5 mm or longer and 30 nm or shorter toward the photomask having the pellicle located thereon; and exposing light output from the reticle surface of the photomask having the pellicle located thereon toward a substrate having a resist layer formed thereon.

ADVANTAGEOUS EFFECTS OF INVENTION

[0035]

Embodiments of the present invention provide a pellicle for extreme ultraviolet light lithography, a production method thereof, and an exposure method. Embodiments of the present invention also provide a pellicle for extreme ultraviolet light lithography that is bondable to a photomask in a non-contact manner, and a production method thereof.

[0036]

Embodiments of the present invention provide a pellicle for extreme ultraviolet light lithography that alleviates deterioration of an adhesive layer caused by extreme ultraviolet light, a production method thereof, and an exposure method.

BRIEF DESCRIPTION OF DRAWINGS

[0037]

[FIG. 1] FIG. 1 is a schematic view (perspective view) of a pellicle 100 in an embodiment.

[FIG. 2] FIG. 2 is a cross-sectional view of pellicle 100 in an embodiment, taken along line A-A' in FIG. 1.

[FIG. 3] FIG. 3 provides enlarged views of a frame of the pellicle 100 in an embodiment shown in FIG. 2; and FIG. 3(a) is an enlarged view of the frame, and FIG. 3(b) is a schematic view showing a structure of a gas passage portion 135 and a bonding portion 137 of a filter 131.

$$I = I_0 exp(-\mu\rho d) \cdots (2)$$

[0040]

In expression (2), the density ρ is the density inherent to the material forming the pellicle film. The mass absorption coefficient μ in expression (2) is found as follows. In the case where the optical energy is greater than about 30 eV and the photon energy is sufficiently far from the atomic absorption edge, the mass absorption coefficient μ does not depend on the inter-atom bonding state or the like. The photon energy of a wavelength of 13.5 nm is around 92.5 eV, and is also sufficiently far from the atomic absorption edge. Therefore, the mass absorption coefficient μ does not depend on the inter-atom bonding state of a compound forming the pellicle film. Thus, the mass absorption coefficient μ of the pellicle film is found by the following expression (3) from the mass absorption coefficient μ_1 of each of elements forming the pellicle film (1, 2, ..., i) and the mass fraction W_i of each element.

$$\mu = \mu_1 W_1 + \mu_2 W_2 + \ldots \mu_i W_i \cdots (3)$$

W_i is a value found by $W_i = n_i A_i / \Sigma n_i A_i$. A_i is the atomic weight of each element i, and n_i is the number of atoms of each element i.

[0041]

For the mass absorption coefficient μ_i of each element in expression (3), the values in the following reference document provided by Henke, et al. may be referred to. (B. L. Henke, E. M. Gullikson, and J. C. Davis, "X-Ray Interactions: Photoabsorption, Scattering, Transmission, and Reflection at E = 50-30,000 eV, Z = 1-92," At. Data Nucl. Data Tables 54, 181 (1993). The latest numerical values are described in http://www.cxro.lbl.gov/optical_constants/.)

[0042]

Once the mass absorption coefficient μ, the density ρ and the thickness d of the pellicle film are specified, the transmittance of the pellicle film with respect to light having a wavelength of 13.5 nm is calculated based on expressions (1)

to each other with no contact with the front surface or the rear surface of the pellicle 700 or the photomask 3500. Thus, the pellicle 700 and the photomask 3500 are bonded to each other while any foreign object is suppressed from being attached to the pellicle 700 or the photomask 3500. The order of the operations may be exchanged appropriately.

[0197]

(Exposure method)

The pellicle in any of the embodiments described above may be used to realize microscopic processing by extreme ultraviolet lithography. The pellicle according to the present invention is located on a reticle surface of the photomask, and the photomask is located at a predetermined position in the exposure device. The pellicle is accommodated in a gap having a distance of 3 mm or less from the reticle surface. In vacuum, light of 5 nm or longer and 30 nm or shorter is directed toward the photomask having the pellicle located thereon, and light output from the reticle surface of the photomask having the pellicle located thereon is directed toward a substrate on which a resist layer is formed. Thus, a pattern is exposed to the resist layer.

[0198]

The pellicle film of the pellicle according to the present invention is an unconventionally thin film having a thickness of 20 nm or greater and 50 nm or less. Therefore, it is difficult to secure the pellicle to a photomask like a conventional pellicle. Thus, a dedicated bonding device is needed to bond the pellicle to the photomask in a non-contact manner.

[0199]

The photomask having the pellicle bonded thereto according to the present invention is located at a predetermined position in the exposure device. The pellicle is accommodated in a gap having a distance of 3 mm or less, especially 2.5 mm, from the reticle surface.

[0200]

The substrate having the resist layer formed thereon is introduced into the exposure device, and the inside of the exposure device is put into a vacuum state of about 10^{-4} to about 10^{-6} Pa. At this point, air flows out from the pellicle, according to the present invention, bonded to the photomask. As described above, the pellicle according to the present invention includes the second frame having an L-shaped cross-section, and the height of the filter is made approximately equal to the height of the second frame. Thus, the filter is located with a sufficient adhesiveness with no gap, other than the through-hole, being formed in a rear surface of the filter. Therefore, the inside of the pellicle is put into a vacuum state with no damage on the pellicle film.

[0201]

Then, EUV light of 5 nm or longer and 30 nm or shorter is directed toward the photomask having the pellicle located thereon. The photomask includes a multi-layer reflective film below the reticle surface. Therefore, the EUV light incident on the reticle surface is reflected by the multi-layer reflective film, and the EUV light reflecting the pattern formed at the absorber at the reticle surface is transmitted from the reticle surface through the pellicle and thus is output.

[0202]

The light output from the reticle surface of the photomask is directed toward the substrate having a resist layer formed thereon, and thus the pattern is exposed to the resist layer. As a result, unconventionally microscopic processing is realized.

REFERENCE SIGNS LIST

[0203]

100: pellicle; 101; pellicle film; 105: substrate; 111: first frame; 113: second frame; 113A: first surface; 113B: second surface; 115: thick portion; 117: