need to be alleviated.

[0009]

As a result of studies, the present inventors have found that when an adhesive for a pellicle not for EUV exposure is used, outgassing may occur.

[0010]

In order to solve the above-described problems, embodiments of the present invention provide a pellicle for EUV exposure that uses an adhesive but causes little outgassing, an exposure pattern plate, an exposure device, and a method for manufacturing a semiconductor device.

SOLUTION TO PROBLEM

[0011]

In order to solve the above-described problems, a first aspect according to the present invention provides a pellicle. The pellicle includes a pellicle film; a support frame supporting the pellicle film; and a first adhesive layer provided at an end of the support frame, the end being opposite to an end on which the pellicle film is extended. The pellicle further includes an inorganic layer on a side surface of the first adhesive layer, the side surface extending in a direction crossing a surface of the pellicle film, and the pellicle film being extended on the side surface. The inorganic layer has a mass absorption coefficient (μ_m) in the range of 5×10^3 cm^2/g to 2×10^5 cm^2/g.

[0012]

In an embodiment according to the present invention, the support frame may include a first frame connected with the pellicle film and a second frame connected with the first frame.

[0013]

In an embodiment according to the present invention, the first frame and

the second frame may be connected with each other by a second adhesive layer, and the pellicle may further include a second inorganic layer on either one of side surfaces of the second adhesive layer, the side surfaces extending in the direction crossing the surface of the pellicle film.

[0014]

In an embodiment according to the present invention, the inorganic layer, in the case of having a thickness of 400 nm, may have a transmittance of 10% or lower to EUV (Extreme Ultraviolet) light having a wavelength of 13.5 nm.

[0015]

In an embodiment according to the present invention, the inorganic layer may have a thickness of 50 nm or greater.

[0016]

In an embodiment according to the present invention, the inorganic layer may be a metal layer.

[0017]

In an embodiment according to the present invention, the metal layer may be formed of one metal material selected from the group consisting of aluminum, titanium, chromium, iron, nickel, copper, ruthenium, tantalum and gold; an alloy containing two or more elements selected from the group; or an oxide containing one element or two or more elements selected from the group.

[0018]

In an embodiment according to the present invention, the pellicle may further include a protective layer on an end surface of the first adhesive layer, the end surface being opposite to an end surface on which the pellicle film is formed.

[0019]

In a second aspect according to the present invention, an exposure pattern plate including a pattern plate; and the above pellicle attached to a surface of the pattern

plate, the surface having a pattern formed therein, may be provided.

[0020]

In an embodiment according to the present invention, an exposure device including the exposure pattern plate may be provided.

[0021]

In a third aspect according to the present invention, an exposure device may be provided. The exposure device includes a light source releasing exposure light; the above exposure pattern plate; and an optical system guiding the exposure light released from the light source to the exposure pattern plate. The exposure pattern plate is located such that the exposure light released from the light source is transmitted through the pellicle film and is directed toward the pattern plate.

[0022]

In an embodiment according to the present invention, the exposure light may be EUV light.

[0023]

In a fourth aspect according to the present invention, a method for manufacturing a semiconductor device is provided. The method includes causing exposure light, released from a light source, to be transmitted through the pellicle film of the above exposure pattern plate and to be directed toward, and reflected by, the pattern plate; and causing the exposure light, reflected by the pattern plate, to be transmitted through the pellicle film and to be directed toward a sensitive substrate, so that the sensitive substrate is exposed to the exposure light so as to have a shape of a pattern. The exposure light may be EUV light.

ADVANTAGEOUS EFFECTS OF INVENTION

[0024]

[0030]

In this specification, a step of removing a part of the substrate while leaving the pellicle film will be referred to as "back-etching". In this specification, a step of etching the substrate from a rear surface thereof (surface of the substrate that is opposite to the surface having the pellicle film formed thereon) is shown as an example of back-etching.

[0031]

In this specification, a "first adhesive layer" refers to an "adhesive layer that sets a pellicle to a mask". The "adhesive layer that sets a pellicle to a mask" refers to an adhesive provided at an end of the support frame of the pellicle that is opposite to an end on which the pellicle film is extended. The adhesive layer is used to connect the mask and the pellicle to each other.

[0032]

The first adhesive layer of the pellicle has two side surfaces and an end surface, which are respectively a first side surface, a second side surface and a first end surface. In this specification, a "surface" is not limited to a flat surface, but encompasses a curved surface. Each of the first side surface, the second side surface and the first end surface is not limited to a flat surface but may be a curved surface.

[0033]

In this specification, the first side surface of the first adhesive layer is a side surface of the first adhesive layer which extends in a direction crossing a surface of the pellicle film and on which the pellicle film is extended.

[0034]

In this specification, the second side surface of the first adhesive layer is a side surface of the first adhesive layer which extends in the direction crossing the surface of the pellicle film and is opposite to the side surface on which the pellicle is extended.

[0035]

In this specification, the first end surface of the first adhesive layer is a surface of the first adhesive layer that is generally parallel to the surface of the pellicle film and is opposite to a surface on which the pellicle film is formed.

[0036]

In this specification, a "second adhesive layer" refers to a layer connecting the first frame and the second frame to each other.

[0037]

In this specification, an "adhesive" used for the adhesive layer encompasses a pressure-sensitive adhesive as well as an adhesive.

[0038]

[Problems of the conventional art found in relation with the present invention]

As a method for connecting a pellicle for EUV exposure to a mask, use of the following method is being discussed: the pellicle is secured to the mask (mechanically) by a press spring attached to the pellicle and a pin called a "stud" that is set to the mask, via a catch provided commonly to the mask and the pellicle. However, with this method, it may be required to alleviate the troublesome process that may be needed during the attachment or the detachment of the pellicle. In addition, it may be required to suppress dust, which is generated by vibration or the like during the attachment or the detachment, from adhering to a surface of the mask as a foreign substance. In the case where a gap is provided for ventilation between the mask and the pellicle frame, it may be required to suppress a foreign substance, entering through the gap, from adhering to the surface of the mask. In the meantime, as a method for closing the gap with an adhesive to eliminate a route by which the foreign substance enters the inside of the pellicle, it has conventionally been considered to use an adhesive for the pellicle that is used in the case where an ArF laser is

(FIG. 5A shows an example in which the side surface 141 and the side surface 143 are respectively coated with the inorganic layer 115 and the inorganic layer 117). The side surface 141 and the side surface 143 may be coated together with the second frame 107 by the inorganic layer 111 (FIG. 4B). The side surfaces of the first adhesive layer 109 and the side surfaces of the second adhesive layer 105 may be coated together with the second frame 107 by the inorganic layer 111 and the inorganic layer 113 (FIG. 5B). The second adhesive layer 105 bonds the first frame 104 connected with the pellicle film 101 and the second frame 107 (formed of aluminum or the like) to each other. It is more preferred that a side of the second adhesive layer 105 surrounded by the mask and the pellicle 100 and/or an external side of the adhesive layer 105 is coated with an inorganic layer. It is preferred that the inorganic layer 111 and the inorganic layer 113 are provided on the second frame 107 in order to prevent the EUV light from hitting the second adhesive layer 105.

[0050]

The second adhesive layer 105 may be made thinner than the first adhesive layer 109, and the second adhesive layer 105 is at a height away from the mask and may be shadowed by the second frame 107. Therefore, the second adhesive layer 105 is not hit by the EUV light scattering on the surface of the mask, and thus does not need to be coated. Namely, it is not needed to provide an inorganic layer on the second adhesive layer 105.

[0051]

[Material of the inorganic layer]

It is preferred that the inorganic layer fulfills the conditions of being tolerant to EUV light and having a transmittance of 10% or lower to EUV light. In the case of fulfilling these conditions, the inorganic layer does not cause much outgassing. It is more preferred that the inorganic layer is tolerant to hydrogen radical. It is preferred that the inorganic layer has a thickness of about 50 nm to

about 1 μm.

[0052]

The "transmittance of 10% or lower to EUV light" indicates that a predetermined inorganic layer having a thickness of 400 nm transmits 10% or lower of EUV light having a wavelength of 13.5 nm directed thereto.

[0053]

The inorganic layer may be formed of a material having a low transmittance to EUV light (metal material, ceramic material, or the like). At the time of setting a pellicle to a mask, a force is applied to the adhesive layer in a direction of setting; and in an exposure device, a force is applied to the adhesive layer in a direction crossing the direction of setting (i.e., shear stress is applied). For these reasons, it is preferred that the inorganic layer is formed of a metal material in order to allow the inorganic layer to follow the shape of the adhesive layer.

[0054]

Examples of method for coating the adhesive layer with the inorganic layer include vapor deposition, sputtering and the like, but the method is not limited to any one of these. Any method is usable as long as the inorganic layer is formed on a surface of the adhesive layer.

[0055]

It is preferred that a metal material usable for the inorganic layer has a mass absorption coefficient (μ_m) in the range of 5×10^3 cm^2/g to 2×10^5 cm^2/g. A technological significance of such numerical values will be described below.

[0056]

It is preferred that a metal material usable for the inorganic layer is one selected from the group consisting of Al (aluminum), Ti (titanium), V (vanadium), Cr (chromium), Mn (manganese), Fe (iron), Co (cobalt), Ni (nickel), Cu (copper), Zn (zinc), Ga (gallium), Ge (germanium), Rb (rubidium), Sr (strontium), Y

(yttrium), Zr (zirconium), Nb (niobium), Mo (molybdenum), Ru (ruthenium), Rh (rhodium), Pd (palladium), Ag (silver), Hf (hafnium), Ta (tantalum) W (tungsten), Pt (platinum), and Au (gold). The inorganic layer may be formed of an alloy containing two or more elements selected from the above group or an oxide containing two or more elements selected from the above group.

[0057]

Among the above-listed metal materials, it is more preferred that the metal material usable for the inorganic layer is one selected from the group consisting of Al (aluminum), Ti (titanium), Cr (chromium), Fe (iron), Ni (nickel), Cu (copper), Ru (ruthenium), Ta (tantalum), and Au (gold).

[0058]

The inorganic layer may be formed of an alloy containing two or more elements selected from the group consisting of Al (aluminum), Ti (titanium), Cr (chromium), Fe (iron), Ni (nickel), Cu (copper), Ru (ruthenium), Ta (tantalum), and Au (gold), or an oxide containing two or more elements selected from the above group.

[0059]

The mass absorption coefficient mentioned above will be described. First, light transmittance T of the inorganic layer may be calculated as follows based on the thickness d of the inorganic layer, the density ρ of the inorganic layer, and the absorption coefficient μ of the inorganic layer.

[0060]

As a premise, the transmittance T is defined by the following expression (1).

[Expression 1]

$$T \equiv \frac{I}{I_0} \cdots (1)$$

[0061]

Therefore, the mass absorption coefficient μ_m does not depend on the binding state of atoms of a compound contained in the inorganic layer. For this reason, the mass absorption coefficient μ_m of the compound contained in the inorganic layer is found by the following expression (5) based on the mass absorption coefficient μ_{mi} of each of elements (1, 2, ···, i) contained in the inorganic layer and the mass fraction W_i of each of the elements.

$$\mu_m = \mu_{m1}W_1 \times \mu_{m2}W_2 + \cdots \mu_{mi}W_i \quad \ldots (5)$$

[0067]

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

[0068]

For the mass absorption coefficient μ_{mi} of each element in expression (5) above and the atomic scattering factor f_2 of each element, 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 version of these numerical figures are on http://www.cxro.lbl.gov/optical_constants/.)

[0069]

If the absorption coefficient μ of the inorganic layer (or the mass absorption coefficient μ_m and the density ρ of the inorganic layer) and the thickness d of the inorganic layer are specified, the transmittance of the inorganic layer to light having a wavelength of 13.5 nm may be calculated based on expressions (1) and (2) above. The transmittance may be calculated in the website of the Center for X-Ray Optics of Lawrence Berkeley National Laboratory regarding the optical constant.

[0070]

The absorption constant μ of each of the above-listed metal materials usable for the inorganic layer is as follows: Al (aluminum) = 0.027 nm^{-1}, Cr (chromium) = 0.036 nm^{-1}, Ni (nickel) = 0.068 nm^{-1}, Ru (ruthenium) = 0.017 nm^{-1}, and Ta (tantalum) = 0.038 nm^{-1}. The mass absorption coefficient μ_m is as follows: Al (aluminum) = 1.0×10^5 cm^2/g, Cr (chromium) = 5.0×10^4 cm^2/g, Ni (nickel) = 7.6×10^4 cm^2/g, Ru (ruthenium) = 1.3×10^4 cm^2/g, and Ta (tantalum) = 2.3×10^4 cm^2/g. These metal materials all have a mass absorption coefficient (μ_m) in the range of 5×10^3 to 2×10^5 cm^2/g.

[0071]

[Adhesive]

As described above, the "adhesive" in this specification refers to an adhesive in a broad sense, and the concept of the "adhesive" encompasses a pressure-sensitive adhesive. Examples of the "adhesive" include acrylic resin adhesive, epoxy resin adhesive, polyimide resin adhesive, silicone resin adhesive, inorganic adhesive, two-sided tape, silicone resin pressure-sensitive adhesive, acrylic resin-based pressure-sensitive adhesive, polyolefin-based pressure-sensitive adhesive, and the like. Any type of adhesive is usable with no specific limitation.

[0072]

An intermediate layer may be provided between the adhesive layer and the inorganic layer in order to, for example, prevent generation of cracks in the inorganic layer. The inorganic layer is stacked on the intermediate layer, and therefore, there is no specific limitation on the properties of the intermediate layer regarding the transmittance to EUV light or outgassing. The intermediate layer may be formed of, for example, parylene, polyimide, a ceramic material, a metal material or the like. The intermediate layer may be formed by a method such as vapor deposition, sputtering, CVD or the like.

[0073]

with no adhesive applied thereto. The area of the nickel-coated surface irradiated with the EUV light was not specifically discolored or deformed.

[0081]

Comparative test example 2

A sample substantially the same as that in the example described above was created except that the adhesive was not coated with nickel, and was irradiated with EUV light (comparative test example 2). After the irradiation with the EUV light, the pressure inside the chamber was raised by 24 μPa as compared with before the irradiation. This value of pressure rise was higher by one or more digits than the value of pressure rise in the case where the EUV light was directed with no sample being inserted and than the value of pressure rise in the case where the EUV light was directed toward a silicon wafer with no adhesive applied thereto. It is considered that this pressure rise was derived from a decomposition product of the adhesive generated by the irradiation with the EUV light. The area of the surface of the adhesive irradiated with the EUV light was discolored to black, and a recessed portion was observed in the area. As a result of comparing test example 2 and comparative test example 2, the tolerance of the adhesive to irradiation with EUV light was found to be improved because the adhesive was not deteriorated (discolored) by the irradiation with the EUV light and outgassing was not caused.

[0082]

<Evaluation on adhesion of contaminants>

Test example 3

FIG. 7 is a schematic cross-sectional view of a test device 400 used for an evaluation on adhesion of contaminants in test example 3. A water-containing styrene-based hotmelt adhesive 420 was applied, with a thickness of about 100 μm and a width of 1.5 to 2.0 mm, to one surface of an aluminum frame 410 having an outer size of 151 mm × 118.5 mm, an inner size of 147 mm × 114.5 mm

in contact with at least a part of the first end surface 136 of the first adhesive layer 109 in addition to the second side surface 131. Specifically, the inorganic layer 113 is in contact with a region 136D, of the first end surface 136, adjacent to the second side surface 131. A region 136E of the first end surface 136, that is located between the region 136C and the region 136D and is adjacent to the region 136C and the region 136D is in contact with the surface of the mask 200 beneath the first adhesive layer 109. The thickness of each the inorganic layer 111 and the inorganic layer 113, namely, the length of each of the inorganic layer 111 and the inorganic layer 113 in the direction perpendicular to the film surface of the pellicle film 101 is shorter at a position closer to the region 136E than at a position farther from the region 136E. The support frame 103 may further include the second frame. A form in the case where the second frame is included is as described above. In FIG. 10, "101" represents the pellicle frame.

[0099]

FIG. 11 is a view of the pellicle 100 shown in FIG. 10 as seen from below. FIG. 11 omits the support frame 103 and the pellicle film 101. The inorganic layer 111 and the inorganic layer 113 are each formed in a rectangular (encompassing "square") frame shape. The first adhesive layer 109 is held between the outer circumference of the inorganic layer 111 and an inner circumference of the inorganic layer 113, and is formed in a rectangular (encompassing "square") frame shape along the entirety of the outer circumference of the inorganic layer 111 and the inner circumference of the inorganic layer 113. With such a structure, the area T inner to the inorganic layer 111 is a closed space closed by the mask 200, the inorganic layer 111 (first adhesive layer 109), the support frame 103, and the pellicle film 101. In the example shown in FIG. 10 and FIG. 11, the method for forming the inorganic layer 111 may be, for example, a method of coating the first adhesive layer 109 with an inorganic material by, for example, magnetron