[0010]

Patent Literature 4 discloses a carbon nanotube sheet having a cylinder diameter of about 1 nm to about 1000 nm, an axial direction length of about 0.1 μm to about 1000 μm, and an L/D of about 100 to about 10000.

CITATION LIST

PATENT LITERATURE

[0011]

Patent Literature 1: PCT Japanese National-Phase Laid-Open Patent Publication No. 2011-530184

Patent Literature 2: WO2014/142125

Patent Literature 3: Japanese Laid-Open Patent Publication No. 2001-48507

Patent Literature 4: Japanese Laid-Open Patent Publication No. 2006-69165

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0012]

Embodiments of the present invention provide a pellicle film, a pellicle frame and a pellicle having a higher EUV transmittance and a higher heat resistance than those described in the above-described prior art documents. Embodiments of the present invention also provide an exposure pattern plate using the same to allow EUV lithography to be performed at a high precision and a method for producing a semiconductor device.

SOLUTION TO PROBLEM

[0013]

According to a first aspect of the present invention, there is provided a pellicle film for exposure, including: a carbon nanotube sheet including bundles each having a plurality of carbon nanotubes, wherein the pellicle film is extendable over an opening of a support frame, a thickness of the pellicle film is 200 nm or less, the bundles each have a diameter of 100 nm or shorter, the bundles are aligned in a planar direction in the carbon nanotube sheet and satisfy the condition that a ratio R_B obtained by dividing a difference between a diffraction intensity in a reciprocal lattice vector being a diffraction intensity peak in a thickness direction of the carbon nanotube sheet derived from a triangular lattice of bundles of the carbon nanotubes in a selected area electron diffraction image of a cross-section of the carbon nanotube sheet and a diffraction intensity at a reciprocal lattice vector serving as a base line and not overlapping the peak in the thickness direction of the carbon nanotube sheet by a difference between a diffraction intensity in a planar direction of the carbon nanotube sheet at the reciprocal lattice vector serving as the base line in the thickness direction and a diffraction intensity in the planar direction of the carbon nanotube sheet at the reciprocal lattice vector being the diffraction intensity peak in the thickness direction is 0.40 or more.

[0014]

With the above-described structure, a pellicle film fulfilling, at the same time, the conditions that the pellicle film has a thickness of 200 nm or less, that the pellicle film includes a carbon nanotube sheet, that the carbon nanotube sheet includes bundles each including a plurality of carbon nanotubes, that the bundles each have a diameter of 100 nm or shorter, and that the bundles are aligned in a planar direction in the carbon nanotube sheet is provided. Such a pellicle film has a high EUV transmittance, has a high durability against EUV, and has a film strength that withstands the pellicle production process and the steps in which the pellicle film is subjected to an atmospheric pressure and also to a vacuum state in

an EUV exposure system.

[0015]

In an embodiment, the carbon nanotubes may each have a diameter of 0.8 nm or longer and 6 nm or shorter.

[0016]

In an embodiment, the carbon nanotube sheet may have a mesh structure of the bundles in the planar direction.

[0017]

In an embodiment, the pellicle film for exposure may further include a protective layer in contact with the carbon nanotube sheet.

[0018]

In an embodiment, the protective layer may contain at least one selected from the group consisting of SiO_x ($x \leq 2$), Si_aN_b (a/b is 0.7 to 1.5), SiON, Y_2O_3, YN, Mo, Ru, Rb, Sr, Y, Zr, Nb, B_4C, SiC and Rh.

[0019]

Disclosed herein is a pellicle film including a carbon nanotube sheet including carbon nanotubes each having a diameter of 0.8 nm or longer and 6 nm or shorter, a length of 10 μm or longer and 10 cm or shorter, and a carbon content of 98% by mass or higher.

[0020]

With the above-described structure, a pellicle film fulfilling, at the same time, the conditions that the carbon nanotubes have a high purity as represented by the carbon content as high as 98% by mass or higher, that the carbon nanotubes each have a diameter of 0.8 nm or longer and 6 nm or shorter, and that the carbon nanotubes each have a length of 10 μm or longer and 10 cm or shorter is provided. Such a pellicle film has a high EUV transmittance, has a high durability against EUV, and has a film strength that withstands the pellicle production process and the steps in which the pellicle film is subjected to an

atmospheric pressure and also to a vacuum state in an EUV exposure system.

[0021]

In an embodiment, the ratio of the length with respect to the diameter of each of the carbon nanotubes (length/diameter) may be 1×10^4 or higher and 1×10^8 or lower.

[0022]

In the case where the diameter of the carbon nanotubes is short, the film strength of the pellicle film is improved but the EUV transmittance is decreased. In order to provide both of a high EUV transmittance and a high film strength, the ratio of the length with respect to the diameter of the nanotube (length/diameter) is important. In the case where the ratio is 1×10^4 or higher and 1×10^8 or lower, both of a high EUV transmittance and a high film strength are provided.

[0023]

In an embodiment, the pellicle film may further include a protective layer in contact with the carbon nanotube sheet. The protective layer may be provided on a surface of the pellicle film closer to the exposure pattern plate or may be provided as an uppermost layer on the pellicle film.

[0024]

In an embodiment, the protective layer may contain at least one selected from the group consisting of SiO_x ($x \leq 2$), Si_aN_b (a/b is 0.7 to 1.5), SiON, Y_2O_3, YN, Mo, Ru, Rb, Sr, Y, Zr, Nb, B_4C, SiC and Rh.

[0025]

In the case where protective layer is provided, the pellicle film is tolerant to both of hydrogen radical (i.e., reduction-tolerant) and oxidation.

[0026]

According to a second aspect of the present invention, there is provided a pellicle including the above-described pellicle and a support frame supporting the pellicle film may be provided.

[0027]

According to a third aspect of the present invention, there is provided a pellicle frame including the above-described pellicle film and a first frame supporting the pellicle film may be provided.

[0028]

According to a fourth aspect of the present invention, there is provided a pellicle including the above-described pellicle frame and a second frame connected with the pellicle frame.

[0029]

According to a fifth aspect of the present invention, there is provided an exposure pattern plate including a pattern plate; and the above pellicle attached to a surface, of the pattern plate, that has a pattern thereon.

[0030]

According to a sixth aspect of the present invention, there is provided an exposure device including the above-described exposure pattern plate may be provided.

[0031]

According to a seventh aspect of the present invention, there is provided an exposure device including a light source releasing exposure light; the above-described 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 to irradiate the pattern plate.

[0032]

In an embodiment, the exposure light may be EUV light.

[0033]

According to an eighth aspect of the present invention, there is provided a method for producing a semiconductor device including the steps of causing

exposure light, released from a light source, to be transmitted through the pellicle film of the exposure pattern plate and to irradiate, and to be reflected by, the pattern plate; and causing the exposure light, reflected by the pattern plate, to be transmitted through the pellicle film and to irradiate a sensitive substrate, so that the exposure light exposes the sensitive substrate while having a shape of a pattern.

[0034]

In an embodiment, the exposure light may be EUV light.

[0035]

Disclosed herein is a method for producing a pellicle that includes incorporating water vapor of 10 ppm or higher and 10000 ppm or lower at a temperature of 600°C or higher and 1000°C or lower in the presence of a metal catalyst to form a carbon nanotube by chemical vapor deposition; putting the resultant carbon nanotube into a sheet to form a carbon nanotube sheet; and connecting the resultant carbon nanotube sheet to a support frame including an opening such that the resultant carbon nanotube sheet covers the opening.

[0036]

Disclosed herein is method for producing a pellicle that includes forming a carbon nanotube sheet from a dispersion containing a carbon nanotube, and connecting the resultant carbon nanotube sheet to a support frame including an opening such that the resultant carbon nanotube sheet covers the opening.

[0037]

In an embodiment, a method for producing a pellicle in which the metal catalyst is located on a substrate for chemical vapor deposition is provided.

[0038]

In an embodiment, a method for producing a pellicle that includes patterning a metal catalyst on a substrate for chemical vapor deposition, and incorporating water vapor of 10 ppm or higher and 10000 ppm or lower at a

temperature of 600°C or higher and 1000°C or lower in the presence of the metal catalyst to form a plurality of single-walled carbon nanotubes by chemical vapor deposition and thus to form a carbon nanotube bulk structure; putting the resultant carbon nanotube bulk structure into a sheet to form a carbon nanotube sheet; and connecting the resultant carbon nanotube sheet to a support frame including an opening such that the resultant carbon nanotube sheet covers the opening. The formation of the plurality of single-walled carbon nanotubes by CVD may be forming the plurality of single-walled carbon nanotubes standing perpendicularly to a surface of the substrate by CVD.

[0039]

In an embodiment, a method for producing a pellicle that includes forming a carbon nanotube sheet of a dispersion containing carbon nanotubes; and connecting the resultant carbon nanotubes to a support frame including an opening such that the resultant carbon nanotubes covers the opening.

ADVANTAGEOUS EFFECTS OF INVENTION

[0040]

Provided are a pellicle film, a pellicle frame and a pellicle having a high EUV transmittance and a high heat resistance. With an exposure pattern plate using the pellicle film, the pellicle frame and or the pellicle, a microscopic pattern (e.g., having a line width of 32 nm or less) is formed by the EUV light or the like. Such an exposure pattern plate and a method for producing a semiconductor device capable of performing patterned exposure in the state where the resolution failure caused by a foreign substance is suppressed are provided.