cleaning process is conducted, dry etching using fluorine-based gas is conducted on the transmittance adjusting film 16 with the light shielding pattern 5b as a mask, and a transmittance adjusting film (transmittance adjusting pattern) 16b having a second pattern is formed (see FIG. 8(b)). At this stage, the exposed remaining portion of the phase shift film (phase shift pattern) 15a' that partially includes the first pattern is also removed, and the phase shift film (phase shift pattern) 15a having the first pattern, is formed (see FIG. 8(b)).

[0085]

Next, a resist film is formed by the spin coating method. Thereafter, a pattern which should be formed in the light shielding film 5 is written with an electron beam on the resist film, and predetermined treatments such as developing are further conducted to thereby form a resist film (resist pattern) 9c having a third pattern (see FIG. 8(c)). Thereafter, dry etching using mixed gas of chlorine-based gas and oxygen gas is conducted on the light shielding pattern 5b with the resist pattern 9c as a mask, and a light shielding film (light shielding pattern) 5c having a third pattern is formed (see FIG. 8(c)).

Thereafter, the resist pattern 9c is removed and a cleaning step is conducted. The phase shift mask 200 shown in FIG. 6 can thus be formed.

[0086]

[Manufacture of Semiconductor Device]

In the method of manufacturing a semiconductor device according to the second embodiment, a transfer pattern is transferred to a resist film on a semiconductor substrate by exposure using the phase shift mask 200 of the second embodiment or the phase shift mask 200 manufactured by using the mask blank 20 of the second embodiment. Therefore, when transfer is made on a resist film on a semiconductor device by exposure using the phase shift mask 200 of the second embodiment, a pattern can be formed in the resist film on the semiconductor device with a precision sufficiently satisfying the design specification.

[0087]

[DOCUMENT] CLAIMS

[Claim 1]

A mask blank comprising:

a phase shift film on a transparent substrate; and

a transmittance adjusting film on the phase shift film,

wherein the phase shift film generates a phase difference between an exposure light of an ArF excimer laser transmitted through the phase shift film and the exposure light transmitted through the air for a same distance as a thickness of the phase shift film, and

wherein a refractive index n_U with respect to a wavelength of the exposure light, an extinction coefficient k_U with respect to the wavelength of the exposure light, and a thickness d_U[nm] of the transmittance adjusting film satisfy both relationships according to Equation (1) and Equation (2) given below.

Equation (1) $d_U \leq -17.63 \times n_U^3 + 142.0 \times n_U^2 - 364.9 \times n_U + 315.8$

Equation (2) $d_U \geq -2.805 \times k_U^3 + 19.48 \times k_U^2 - 43.58 \times k_U + 38.11$

[Claim 2]

The mask blank according to claim 1, wherein the refractive index n_U of the transmittance adjusting film is 1.2 or more.

[Claim 3]

The mask blank according to claim 1 or 2, wherein the extinction coefficient k_U of the transmittance adjusting film is 1.5 or more.

[Claim 4]

The mask blank according to any of claims 1 to 3, wherein the phase shift film transmits the exposure light with a transmittance of 12% or more.

[Claim 5]

The mask blank according to any of claims 1 to 4, wherein the extinction coefficient k_U and the thickness d_U[nm] of the transmittance adjusting film satisfy the relationship according to Equation (3) given below.

Equation (3) $d_U \leq 8.646 \times k_U^2 - 38.42 \times k_U + 61.89$

[Claim 6]

The mask blank according to any of claims 1 to 5, wherein

the transmittance adjusting film contains silicon and nitrogen.

[Claim 7]

The mask blank according to any of claims 1 to 6 comprising an intermediate film containing silicon and oxygen between the phase shift film and the transmittance adjusting film.

[Claim 8]

The mask blank according to any of claims 1 to 6, wherein the phase shift film comprises an uppermost layer containing silicon and oxygen on a surface that is opposite to the transparent substrate side.

[Claim 9]

The mask blank according to any of claims 1 to 8 comprising a light shielding film on the transmittance adjusting film.

[Claim 10]

A phase shift mask comprising:

a phase shift film having a first pattern on a transparent substrate; and

a transmittance adjusting film having a second pattern on the phase shift film,

wherein the phase shift film generates a phase difference between an exposure light of an ArF excimer laser transmitted through the phase shift film and the exposure light transmitted through the air for a same distance as a thickness of the phase shift film, and

wherein a refractive index n_U with respect to a wavelength of the exposure light, an extinction coefficient k_U with respect to the wavelength of the exposure light, and a thickness d_U[nm] of the transmittance adjusting film satisfy both relationships according to Equation (1) and Equation (2) given below.

Equation (1) $d_U \leq -17.63 \times n_U^3 + 142.0 \times n_U^2 - 364.9 \times n_U + 315.8$

Equation (2) $d_U \geq -2.805 \times k_U^3 + 19.48 \times k_U^2 - 43.58 \times k_U + 38.11$

[Claim 11]

The phase shift mask according to claim 10, wherein the refractive index n_U of the transmittance adjusting film is 1.2 or more.

[Claim 12]

The phase shift mask according to claim 10 or 11, wherein the extinction coefficient k_U of the transmittance adjusting film is 1.5 or more.

[Claim 13]

The phase shift mask according to any of claims 10 to 12, wherein the phase shift film transmits the exposure light with a transmittance of 12% or more.

[Claim 14]

The phase shift mask according to any of claims 10 to 13, wherein the extinction coefficient k_U and the thickness d_U[nm] of the transmittance adjusting film satisfy the relationship according to Equation (3) given below.

Equation (3) $d_U \leq 8.646 \times k_U^2 - 38.42 \times k_U + 61.89$

[Claim 15]

The phase shift mask according to any of claims 10 to 14, wherein the transmittance adjusting film contains silicon and nitrogen.

[Claim 16]

The phase shift mask according to any of claims 10 to 15 comprising an intermediate film having the second pattern between the phase shift film and the transmittance adjusting film, wherein the intermediate film contains silicon and oxygen.

[Claim 17]

The phase shift mask according to any of claims 10 to 15, wherein the phase shift film comprises an uppermost layer containing silicon and oxygen on a surface that is opposite to the transparent substrate side.

[Claim 18]

The phase shift mask according to any of claims 10 to 17 comprising a light shielding film having a third pattern on the transmittance adjusting film.

[Claim 19]

A method of manufacturing a phase shift mask using the mask blank according to claim 9, comprising the steps of:

forming a first pattern in the light shielding film by dry etching;

forming a first pattern in each of the transmittance adjusting film and the phase shift film by dry etching with a light shielding film having the first pattern as a mask;

forming a second pattern in the light shielding film by dry etching;

forming a second pattern in the transmittance adjusting film by dry etching with a light shielding film having the second pattern as a mask; and

forming a third pattern in the light shielding film by dry etching.

[Claim 20]

A method of manufacturing a semiconductor device comprising the step of transferring a transfer pattern to a resist film on a semiconductor substrate by exposure using the phase shift mask according to claim 18.