the mask is also repeatedly cleaned even if the mask itself is free of pattern defects, for the reason that if foreign deposits settle on the mask during the photolithography process, a semiconductor substrate which is patterned using that mask eventually bears pattern-transfer failures.

For removing foreign deposits from the halftone phase shift mask blank or mask, chemical cleaning is applied in most cases, using SPM, ozone water or AMP. SPM is a sulfuric acid/hydrogen peroxide mixture which is a cleaning agent having strong oxidizing action. Ozone water is water having ozone dissolved therein and used as a replacement of SPM. AMP is an aqueous ammonia/hydrogen peroxide mixture. When the mask blank or mask having organic foreign deposits on its surface is immersed in the AMP cleaning liquid, the organic foreign deposits are liberated and removed from the surface under the dissolving action of ammonia and the oxidizing action of hydrogen peroxide.

Although the chemical cleaning with such chemical liquid is necessary for removing foreign deposits such as particles and contaminants on the halftone phase shift mask blank or mask, the chemical cleaning can damage the halftone phase shift film on the mask blank or mask. For example, if the surface of a halftone phase shift film is altered by chemical cleaning, the optical properties that the film originally possesses can be changed. In addition, chemical cleaning of the halftone phase shift mask blank or mask is repeatedly carried out. It is thus necessary to minimize any property change (e.g., phase shift change) of the halftone phase shift film during every cleaning step.

Embodiments of the invention seek to provide a halftone phase shift mask blank and halftone phase shift mask having a halftone phase shift film which may be thin enough to be advantageous for pattern formation and 3D effect reduction

while maintaining a necessary phase shift and transmittance for the halftone phase shift function to comply with pattern size miniaturization, and may have chemical resistance against chemical cleaning. Embodiments of the invention also seek to provide a pattern exposure method using the halftone phase shift mask.

Aiming to develop a halftone phase shift film having a reduced thickness and improved chemical resistance while maintaining a necessary phase shift and transmittance for the halftone phase shift function, the inventors made a study on a halftone phase shift film containing a transition metal, typically molybdenum which is commonly used as the halftone phase shift film. However, when a transition metal or oxygen is added to a halftone phase shift film, there arise problems that the refractive index of the film having a predetermined transmittance is reduced in proportion to the amount of transition metal or oxygen added, the film must be thick to gain a necessary phase shift for the phase shift function, and chemical resistance is exacerbated.

Then a study was made on halftone phase shift films having a minimal content of transition metal. It has been found that a single layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and up to 6 at% of oxygen, and having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7, or a multilayer including at least one layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and up to 6 at% of oxygen, and having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7 can form a halftone phase shift film which has a thickness of up to 67 nm, and provides a phase shift of 150 to 200° and a transmittance of 3 to 12% with respect to light of wavelength up to 200 nm.

Additionally the halftone phase shift film has chemical resistance against chemical cleaning. Once the halftone phase shift film is constructed as above, there is obtained a halftone phase shift mask blank which can be advantageously processed into a halftone phase shift film pattern including a main photomask pattern with a width of about 100 to 200 nm, which is necessary in photolithography for forming a pattern with a half pitch of up to 50 nm on a processable substrate such as silicon wafer, using exposure light of wavelength up to 200 nm.

Accordingly, in one aspect, the invention provides a halftone phase shift mask blank comprising a transparent substrate and a halftone phase shift film thereon having a phase shift of 150 to 200° and a transmittance of 3 to 12% with respect to light of wavelength up to 200 nm. The halftone phase shift film is a single layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and oxygen, with an oxygen content being up to 6 at%, the single layer having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7, or a multilayer film including at least one layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and oxygen, with an oxygen content being up to 6 at%, the at least one layer having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7. The halftone phase shift film has a thickness of up to 67 nm, wherein the halftone phase shift film is a single layer composed of a silicon base material consisting of silicon and nitrogen, or a multilayer film including at least one layer

composed of a silicon base material consisting of silicon and nitrogen and at least one layer composed of a silicon base material consisting of silicon, nitrogen and oxygen.

Typically, the mask blank is to be processed into a halftone phase shift mask, the mask being suited in a photolithography method for forming a pattern with a half pitch of up to 50 nm in a processable substrate, comprising the steps of forming a photoresist film on the processable substrate and exposing the photoresist film to light of wavelength up to 200 nm for transferring the pattern to the photoresist film.

In another aspect, the invention provides a halftone phase shift mask comprising a transparent substrate and a pattern of halftone phase shift film thereon having a phase shift of 150 to 200° and a transmittance of 3 to 12% with respect to light of wavelength up to 200 nm. The halftone phase shift film is a single layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and oxygen, with an oxygen content being up to 6 at%, the single layer having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7, or a multilayer film including at least one layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and oxygen, with an oxygen content being up to 6 at%, the at least one layer having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7. The halftone phase shift film has a thickness of up to 67 nm, wherein the halftone phase shift film is a single layer composed of a silicon base material consisting of silicon and nitrogen or a multilayer film including at least one layer composed of a silicon base material consisting of silicon and nitrogen and at least one layer composed of a silicon base material consisting of silicon, nitrogen and oxygen.

Preferred embodiments of said another aspect are the same as above.

Typically, the mask is suited in a photolithography method for forming a pattern with a half pitch of up to 50 nm

in a processable substrate, comprising the steps of forming a photoresist film on the processable substrate and exposing the photoresist film to light of wavelength up to 200 nm for transferring the pattern to the photoresist film.

In connection with photolithography for forming a pattern with a half pitch of up to 50 nm on a processable substrate, in another aspect, the invention provide a method of exposing a photoresist film on the processable substrate to light of wavelength up to 200 nm through a mask for pattern transfer. The mask used herein is a halftone phase shift mask comprising a transparent substrate and a pattern of halftone phase shift film thereon having a phase shift of 150 to 200° and a transmittance of 3 to 12% with respect to light of wavelength up to 200 nm, wherein the halftone phase shift film is a single layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and oxygen, with an oxygen content being up to 6 at%, the single layer having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7, or a multilayer film including at least one layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and oxygen, with an oxygen content being up to 6 at%, the at least one layer having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7, and the halftone phase shift film has a thickness of up to 67 nm, wherein the halftone phase shift film is a single layer composed of a silicon base material consisting of silicon and nitrogen or a multilayer film including at least one layer composed of a silicon base material consisting of silicon and nitrogen and at least one layer composed of a silicon base material consisting of silicon, nitrogen and oxygen.

Preferred embodiments are the same as above.

ADVANTAGEOUS EFFECTS OF INVENTION

The halftone phase shift mask blank or halftone phase shift mask of the invention has a halftone phase shift film which may be thin enough to be advantageous for photomask pattern

formation, may have chemical resistance against chemical cleaning, and may maintain a necessary phase shift for the phase shift function and a necessary transmittance for the halftone function. Using the halftone phase shift mask, lithography exposure complying with the requirements of pattern miniaturization and patterning accuracy becomes possible.

CLAIMS:

1. A halftone phase shift mask blank comprising a transparent substrate and a halftone phase shift film thereon having a phase shift of 150 to 200° and a transmittance of 3 to 12% with respect to light of wavelength up to 200 nm, wherein

said halftone phase shift film is a single layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and oxygen, with an oxygen content being up to 6 at %, the single layer having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7, or a multilayer film including at least one layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and oxygen, with an oxygen content being up to 6 at %, the at least one layer having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7, and said halftone phase shift film has a thickness of up to 67 nm, wherein

said halftone phase shift film is a single layer composed of a silicon base material consisting of silicon and nitrogen, or a multilayer film including at least one layer composed of a silicon base material consisting of silicon and nitrogen and at least one layer composed of a silicon base material consisting of silicon, nitrogen and oxygen.

2. The mask blank of claim 1, which is to be processed into a halftone phase shift mask, the mask being suited in a

photolithography method for forming a pattern with a half pitch of up to 50 nm in a processable substrate, comprising the steps of forming a photoresist film on the processable substrate and exposing the photoresist film to light of wavelength up to 200 nm for transferring the pattern to the photoresist film.

3. A halftone phase shift mask comprising a transparent substrate and a pattern of halftone phase shift film thereon having a phase shift of 150 to 200° and a transmittance of 3 to 12% with respect to light of wavelength up to 200 nm, wherein

said halftone phase shift film is a single layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and oxygen, with an oxygen content being up to 6 at %, the single layer having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7, or a multilayer film including at least one layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and oxygen, with an oxygen content being up to 6 at %, the at least one layer having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7, and said halftone phase shift film has a thickness of up to 67 nm, wherein

said halftone phase shift film is a single layer composed of a silicon base material consisting of silicon and nitrogen, or a multilayer film including at least one layer composed of a silicon base material consisting of silicon and nitrogen and at least one layer composed of a

silicon base material consisting of silicon, nitrogen and oxygen.

4. The mask of claim 3, suited in a photolithography method for forming a pattern with a half pitch of up to 50 nm in a processable substrate, comprising the steps of forming a photoresist film on the processable substrate and exposing the photoresist film to light of wavelength up to 200 nm for transferring the pattern to the photoresist film.

5. A method of exposing a photoresist film on a processable substrate to light of wavelength up to 200 nm through a mask for pattern transfer, the method being a photolithography for forming a pattern with a half pitch of up to 50 nm on the processable substrate, wherein

said mask is a halftone phase shift mask comprising a transparent substrate and a pattern of halftone phase shift film thereon having a phase shift of 150 to 200° and a transmittance of 3 to 12% with respect to light of wavelength up to 200 nm,

said halftone phase shift film is a single layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and oxygen, with an oxygen content being up to 6 at %, the single layer having a refractive index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7, or a multilayer film including at least one layer composed of a silicon base material consisting of silicon and nitrogen or a silicon base material consisting of silicon, nitrogen and oxygen, with an oxygen content being up to 6 at %, the at least one layer having a refractive

index n of at least 2.4 and an extinction coefficient k of 0.4 to 0.7, and said halftone phase shift film has a thickness of up to 67 nm, wherein

said halftone phase shift film is a single layer composed of a silicon base material consisting of silicon and nitrogen, or a multilayer film including at least one layer composed of a silicon base material consisting of silicon and nitrogen and at least one layer composed of a silicon base material consisting of silicon, nitrogen and oxygen.