film composed of molybdenum silicon oxide or molybdenum silicon oxynitride is known (JP-A H07-140635 (Patent Document 1)).

Citation List

Patent Document 1: JP-A H07-140635
Patent Document 2: JP-A 2007-33469
Patent Document 3: JP-A 2007-233179
Patent Document 4: JP-A-2007-241065

## SUMMARY

In one aspect, there is provided a phase shift mask blank comprising a substrate, and a phase shift film thereon, the phase shift film composed of a material containing silicon and nitrogen and free of a transition metal, wherein the phase shift film has a phase shift of 170 to 190° and a transmittance of 4 to 8%, with respect to exposure light of KrF excimer laser, and a thickness of 85 to 90 nm, the phase shift film comprises at least one compositionally graded layer having a composition continuously varying in a thickness direction, and a refractive index n and an extinction coefficient k, with respect to the exposure light, varying in the thickness direction, and the compositionally graded layer has a difference between a maximum refractive index n(H) and a minimum refractive index n(L) of up to 0.40, and a difference between a maximum extinction coefficient k(H) and a minimum extinction coefficient k(L) of up to 1.5.

In another aspect, there is provided a phase shift mask having a patterned phase shift film manufactured by using the phase shift mask blank described herein.

## DISCLOSURE OF INVENTION

As a phase shift film for exposure light of KrF excimer laser (wavelength of 248 nm) generally used, a phase shift film composed of a material containing molybdenum and silicon, and has a phase shift of 180° and a transmittance of approximately 6%. In this case, the phase shift film has a thickness of approximately 100 nm. Recently, for a phase shift film used with ArF excimer laser (wavelength of 193 nm) as exposure light, a phase shift film of silicon nitride has been used for the purposes of minimizing film thickness and enhancing washing resistance and light resistance. Although not much as exposure light of ArF excimer laser, also when KrF excimer laser is used as the exposure light, the phase

shift film having high washing resistance and high light resistance and being hard to generate haze is needed.

When a phase shift film used with KrF excimer laser as exposure light is made of silicon nitride, if the phase shift film is formed to a single layer having single composition (uniform composition in thickness direction) having a refractive index n and an extinction coefficient k corresponding to a phase shift of 170 to 190° and a transmittance of 4 to 8%, the film is formed under a film-forming condition of unstable region (so-called transition mode region) is employed in reactive sputtering, thus, the film has a problem that in-plane uniformity of optical characteristics becomes worse.

Meanwhile, to obtain a film having high in-plain uniformity of optical characteristics, it is conceivable that a phase shift film composed of silicon nitride is constructed to a multilayer consisting of layers having single composition (uniform composition in thickness direction) and formed by a reactive sputtering under a film-forming condition of stable region (so-called metal mode or reaction mode). However, a refractive index n of a film formable under this region is lower than a refractive index n of

CLAIMS:

1. A phase shift mask blank comprising a substrate, and a phase shift film thereon, the phase shift film composed of a material containing silicon and nitrogen and free of a transition metal, wherein

the phase shift film has a phase shift of 170 to 190° and a transmittance of 4 to 8%, with respect to exposure light of KrF excimer laser, and a thickness of 85 to 90 nm,

the phase shift film comprises at least one compositionally graded layer having a composition continuously varying in a thickness direction, and a refractive index n and an extinction coefficient k, with respect to the exposure light, varying in the thickness direction, and

the compositionally graded layer has a difference between a maximum refractive index n(H) and a minimum refractive index n(L) of up to 0.40, and a difference between a maximum extinction coefficient k(H) and a minimum extinction coefficient k(L) of up to 1.5.

2. The phase shift mask blank of claim 1, wherein the compositionally graded layer has a minimum refractive index n(L) of at least 2.3 and a maximum extinction coefficient k(H) of up to 2, the compositionally graded layer comprises a zone satisfying a refractive index n of at least 2.55 and an extinction coefficient k of up to 1.0, and said zone has a thickness of 5 to 30 nm.

3. The phase shift mask blank of claim 1 or 2, wherein the compositionally graded layer has a zone continuously varying a content ratio N/(Si+N) within a range of 0.2 to 0.57 in a thickness direction, the ratio N/(Si+N) representing nitrogen content (at%) to the sum of silicon and nitrogen contents (at%).

4. The phase shift mask blank of any one of claims 1 to 3, wherein the compositionally graded layer has a difference between a maximum silicon content (at%) and a minimum silicon content (at%) of up to 30.

5. The phase shift mask blank of any one of claims 1 to 4, wherein

in the phase shift film, a ratio of a deference between a maximum phase shift and a minimum phase shift to an average phase shift in plane of up to 3 %, and a ratio of a deference between a maximum transmittance and a minimum transmittance to an average transmittance in plane of up to 5%, and

the phase shift film has a thickness of up to 90 nm.

6. The phase shift mask blank of any one of claims 1 to 5, wherein the material containing silicon and nitrogen and free of a transition metal is a material consisting of silicon and nitrogen.

7. The phase shift mask blank of any one of claims 1 to 6, further comprising a second layer consisting of a single layer or multiple layers on the phase shift film, the second layer being composed of a chromium-containing material.

8. A phase shift mask having a patterned phase shift film manufactured by using the phase shift mask blank of any one of claims 1 to 7.