mask, a film containing molybdenum and silicon is mostly used (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 exposure light is KrF excimer laser, the phase shift film consists of a single layer or a plurality of layers, the single layer or each of the plurality of layers has a refractive index n of at least 2.5 and an extinction coefficient k of 0.4 to 1, with respect to the exposure light, and the phase shift film has a phase shift of 170 to 190° and a transmittance of 4 to 8%, with respect to the exposure light, and a thickness of up to 85 nm.

In another 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 exposure light is KrF excimer laser, the phase shift film consists of a single layer or a plurality of layers, at least part of the single layer or at least part of the plurality of layers has a content ratio N/(Si+N) within a range of 0.43 to 0.53, the ratio N/(Si+N) representing nitrogen content (at%) to the sum of silicon and nitrogen contents (at%), and the phase shift film has a phase shift of 170 to 190° with respect to the exposure light.

In yet another aspect, there is provided a method of manufacturing the phase shift mask blank as described herein, comprising the step of forming the phase shift film by reactive sputtering using a silicon-containing target and nitrogen gas, wherein in the forming step, a flow rate of the nitrogen gas is set to a value of -20% to +20% of the flow rate imparting the highest refractive index n, with respect to the exposure light, of the phase shift film, and maintained constant or varied continuously or stepwise, the flow rate

imparting the highest refractive index n being obtained from varying the flow rate from low rate to high rate.

In a further aspect, there is provided a phase shift mask manufactured by using the phase shift mask blank as described herein.

DISCLOSURE OF INVENTION

In case that exposure light is KrF excimer laser (wavelength of 248 nm), a phase shift film having a transmittance of 6%, a phase shift of approx. 180° and a thickness of approx. 100 nm is generally used in a phase shift mask employed a film containing molybdenum and silicon. 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 KrF excimer laser is used as exposure light with silicon nitride, it is necessary to adjust the content ratio of nitrogen and silicon in accordance with its wavelength for forming a film satisfying a predetermined phase shift and a predetermined transmittance with KrF excimer laser. Further, in consideration of inclination of the pattern during processing into the phase shift mask, and a cross-sectional shape of the pattern, a thinner film having a uniform composition is desired. When exposure light is ArF excimer laser, silicon nitride containing more nitrogen has a higher refractive index n and a smaller extinction coefficient k. Thus, a phase shift film having a nitrogen content as high as possible has been proposed.

The present invention has been made to solve the above problems, and an object of the present invention is to provide a phase shift mask blank and a phase shift mask, including a thin phase shift film, and satisfying a requirement for pattern miniaturization, which is advantageous in terms of patterning and reduction of three-dimensional effect, and with satisfying necessary phase shift and transmittance for the phase shift film even when