Non-Patent Document 1: Thomas Faure et al., "Characterization of binary and attenuated phase shift mask blanks for 32 nm mask fabrication," Proc. of SPIE, vol. 7122, pp 712209-1 to 712209-12

SUMMARY

In yet another aspect, the present disclosure provides a method of manufacturing the halftone phase shift-type photomask blank comprising a transparent substrate, and a halftone phase shift film formed in contact with the substrate, the halftone phase shift film consisting of a plurality of layers consisting of silicon, nitrogen and oxygen, wherein the plurality of layers consisting of silicon, nitrogen and oxygen has an oxygen content of up to 39 at%, the halftone phase shift film has a thickness of at least 71 nm, a phase shift of at least 150° and up to 200° and a transmittance of at least 20%, with respect to at least one exposure light having a wavelength of up to 200 nm, and a film surface having a surface roughness RMS of up to 0.8 nm, and an in-plane variation of transmittance calculated from the maximum transmittance T_{max} and the minimum transmittance T_{min} within a mask pattern forming area by the following expression: $(T_{max}-T_{min})/(T_{max}+T_{min})\times 100$ is up to 2%,wherein the method comprises the step of forming the halftone phase shift film by sputtering, wherein in the step, of the plurality of layers consisting of silicon, nitrogen and oxygen is formed by sputtering with disposing at least one silicon target in a chamber and feeding argon gas, nitrogen gas and
oxygen gas into the chamber, wherein a flow rate of the nitrogen gas is set in accordance with a hysteresis curve that is obtained when the flow rate of nitrogen gas fed into the chamber is swept by increasing the flow rate, and then decreasing the flow rate, the hysteresis curve being drawn by the flow rate and a sputtering voltage or a sputtering current measured on one target upon the sweeping, and wherein the sputtering for forming said layer composed of silicon, nitrogen and oxygen is performed under a sputtering condition of transition mode in which a flow rate of nitrogen gas is within a range between more than the lowest flow rate and less than the highest flow rate of the hysteresis.

DISCLOSURE OF INVENTION

A transmittance of a halftone phase shift film was commonly a transmittance of up to 20%, typically about 6%, however, recent studies are also directed to higher transmittance. The film having a high transmittance has also a high attenuation effect of light due to interference, making an advantage for fine patterning in some cases. Besides, the halftone phase shift film is mostly formed by reactive sputtering. It is effective to add oxygen to the film to form a film having a transmittance of at least 20%. Particularly, it is necessary to add oxygen to the film to form a film having a transmittance of at least 25%.

When a film composed of silicon, nitrogen and oxygen is formed by sputtering, and, as reactive gases, oxygen gas is used with nitrogen gas, a large amount of reactive gases must be fed to increase transmittance while forming the film. In addition, when heat treatment is performed after forming the halftone phase shift film, it is necessary to be set a high temperature for the heat treatment in some cases. For these reasons, when the film composed of silicon, nitrogen and oxygen is formed by sputtering, in-plane variation of transmittance tends to be large.

The invention was made in order to solve the aforementioned problems, and an object of the invention is to provide a halftone phase shift-type photomask blank and a halftone phase shift-type photomask having a halftone phase shift film that has a good uniformity in film quality, particularly, high in-plane uniformity of transmittance. Further, an object of the invention is to provide a manufacturing method of such a halftone phase shift-type photomask blank.

The inventors have found that one of the factors relating to in-plane variation of transmittance of the film composed of silicon, nitrogen and oxygen is the surface roughness of the film. In other words, under a condition where the surface of the halftone phase shift film is contacted with oxygen gas, for example, under a condition where the halftone phase shift film is handled under air atmosphere, or under a condition where the halftone phase shift film is heat-treated under oxygen-containing atmosphere, a film having

CLAIMS:

1. A method of manufacturing a halftone phase shift-type photomask blank comprising a transparent substrate, and a halftone phase shift film formed in contact with the substrate, the halftone phase shift film consisting of a plurality of layers consisting of silicon, nitrogen and oxygen, wherein

the plurality of layers consisting of silicon, nitrogen and oxygen has an oxygen content of up to 39 at%,

the halftone phase shift film has a thickness of at least 71 nm, a phase shift of at least 150° and up to 200° and a transmittance of at least 20%, with respect to at least one exposure light having a wavelength of up to 200 nm, and a film surface having a surface roughness RMS of up to 0.8 nm, and

an in-plane variation of transmittance calculated from the maximum transmittance T_{max} and the minimum transmittance T_{min} within a mask pattern forming area by the following expression:

$$(T_{max}-T_{min})/(T_{max}+T_{min})\times 100$$

is up to 2%, wherein

the method comprises the step of forming the halftone phase shift film by sputtering, wherein

in the step, the plurality of layers consisting of silicon, nitrogen and oxygen is formed by sputtering under a chamber pressure of at least 0.05 Pa and less than 0.15 Pa with disposing at least one silicon target in a chamber and feeding argon gas, nitrogen gas and oxygen gas into the chamber, wherein

a flow rate of the nitrogen gas is set in accordance with a hysteresis curve that is obtained when the flow rate of nitrogen gas fed into the chamber is swept by increasing the flow rate, and then decreasing the flow rate, the hysteresis curve being drawn by the flow rate and a sputtering voltage or a sputtering current measured on one target upon the sweeping, wherein

the sputtering for forming each of the plurality of layers consisting of silicon, nitrogen and oxygen is performed under a sputtering condition of transition mode in which

a flow rate of nitrogen gas is within a range between more than the lowest flow rate and less than the highest flow rate of the hysteresis.

2. The method of claim 1 wherein the method comprises the step of heat treating the halftone phase shift film at a temperature of at least 200 °C and up to 500 °C for at least 5 minutes after the halftone phase shift film has been formed.

3. The method of claim 1 or 2, wherein the plurality of layers consisting of silicon, nitrogen and oxygen has a total content of nitrogen and oxygen of at least 50 at%.