conventional transmissive projection optical system or a mask, thus, a reflection type optical elemental device is applied. Therefore, a reflective mask is also proposed as a mask for the pattern transfer. The reflective mask has a multilayer reflection film that is formed on a substrate and reflects EUV light, and a patterned absorber film that is formed on the multilayer reflection film and absorbs EUV light. Meanwhile, a material (including also a material in which a resist layer is formed) before patterning the absorber film is called a reflective mask blank, and is used as a material for the reflective mask. Generally, a reflective mask blank and a reflective mask for reflecting EUV light are called an EUV mask blank and an EUV mask, respectively.

The EUV mask blank has a basic structure including a low-thermal expansion substrate, a multilayer reflection film that is formed thereon and reflects EUV light, and an absorber film that is formed thereon and absorbs EUV light. As the multilayer reflection film, a multilayer reflection film in which molybdenum (Mo) layers and silicon (Si) layers are alternately laminated to obtain a necessary reflectance for EUV light is usually used. Further, as a protection film for protecting the multilayer reflection film, a ruthenium (Ru) film is formed as the outermost layer of the multilayer reflection film. On the other hand, for the absorber film, a material containing tantalum (Ta) or the like, which has a relatively large extinction coefficient with respect to EUV light, is used (Patent Document 1: JP-A 2002-246299).

Citation List

Patent Document 1: JP-A 2002-246299

Patent Document 2: JP-A 2003-114200

SUMMARY

In process of manufacturing a reflective mask, after forming a pattern by etching process of an absorber film of a reflective mask blank, generally, the pattern is inspected and corrected a defect if the defect is detected. In the case of the reflective mask, a defect so-called a phase defect in which the reflectance has been lowered due to an irregular structure of the multilayer reflection film exists in some cases. However, after forming the pattern of the absorber film, it is very difficult to directly correct this phase defect. Under these circumstances, it is important to detect the phase defect at the stage of the reflective mask blank. For example, JP-A 2003-114200 (Patent Document 2) discloses,

as a method for detecting defects inside a multilayer reflection film using EUV light, a technique using a dark field inspection image.

In the defect inspection, to detect even minute phase defect with good sensitivity, an intensity of scattered light from the portion not including a defect in the formed multilayer reflection film, i.e., background level (BGL), must be reduced. Therefore, whereas it is advantageous that the EUV mask has a higher reflectance with respect to the exposure light (at about 13.5 nm), the background level for the defect detection using the exposure light must be reduced.

The present disclosure has been made to solve the above problems, and an object of the present disclosure is to provide a reflective mask blank including a multilayer reflection film having a high reflectance with respect to EUV light and a controlled low background level, and a method for manufacturing a reflective mask with using the reflective mask blank.

In case of a periodically laminated structure in which molybdenum (Mo) layers and silicon (Si) layers are alternately laminated, a molybdenum layer not containing additive elements such as nitrogen (N), carbon (C), boron (B) and other elements tends to have a high reflectance. However, when the molybdenum layer does not contain the additive elements, the layer having a structure including crystal grains is formed, thus, the background level in the defect inspection with EUV light tends to increase due to the crystal grains.

On the other hand, to reduce the background level in the defect inspection with EUV light, it is effective to form an amorphas structure by adding additive elements such as nitrogen (N), carbon (C), boron (B) and other elements to the molybdenum (Mo) layer. However, when the additive elements are added, the reflectance of the layer tends to be reduced significantly by changes in optical properties (refractive index (n), extinction coefficient (k), and others) due to the influence of additive elements, and by intermixing at the interface between the molybdenum (Mo) layer and the silicon (Si) layer.

With respect to a multilayer reflection film of a reflective mask blank that has a periodically laminated structure in which low-refractive index layers composed of a material containing molybdenum (Mo) and high-refractive index layers are alternately laminated, the inventers found that, when the low-refractive index layer is constituted of a first low-refractive index sublayer containing molybdenum (Mo), and one or more

elements selected from the group consisting of nitrogen (N), carbon (C), hydrogen (H) and boron (B), and a second low-refractive index sublayer containing either of both of molybdenum (Mo) and carbon, and is free of nitrogen (N), hydrogen (H) and boron (B) and having a thickness of not less than 0.1 nm and not more than 0.5 nm, and when either or both of the low-refractive index sublayers that are in contact with the high-refractive index layer are the second low-refractive index sublayer, the reflective mask blank includes a multilayer reflection film having a high reflectance with respect to EUV light and a controlled low background level in inspection of a phase defect by ABI (Actinic Blank Inspection) or the like.

In a first aspect, the present disclosure provides a reflective mask blank which is a material for a reflective mask used in EUV lithography using EUV light as exposure light, including a substrate, a multilayer reflection film that is formed on one main surface of the substrate and reflects the exposure light, a protection film formed in contact with the multilayer reflection film, and an absorber film that is formed on the protection film and absorbs the exposure light, wherein

the multilayer reflection film has a periodically laminated structure in which low-refractive index layers composed of a material containing molybdenum (Mo) and high-refractive index layers are alternately laminated,

the low-refractive index layer consists of one or more of first low-refractive index sublayers, and one or more of second low-refractive index sublayers that have a different composition from a composition of the first low-refractive index sublayer,

the first low-refractive index sublayer contains molybdenum (Mo), and one or more elements selected from the group consisting of nitrogen (N), carbon (C), hydrogen (H) and boron (B),

the second low-refractive index sublayer contains either of both of molybdenum (Mo) and carbon, and is free of nitrogen (N), hydrogen (H) and boron (B),

the second low-refractive index sublayer has a thickness of not less than 0.1 nm and not more than 0.5 nm, and

in the low-refractive index layer, either or both of the low-refractive index sublayers that are in contact with the high-refractive index layer are the second low-refractive index sublayer.

Preferably, the low-refractive index layer includes an amorphous.

Preferably, the second low-refractive index sublayer has a higher compression stress compared with a stress of the first low-refractive index sublayer.

Preferably, the second low-refractive index sublayer is a layer that satisfies the following expression (1):

$$\Delta TIR < 7 \times t \quad (1)$$

wherein ΔTIR nm is an amount of warpage of a SiO_2-TiO_2-based glass substrate that is caused by a stress of the second low-refractive index sublayer when the second low-refractive index sublayer having a thickness of "t" nm is formed on a main surface of the SiO_2-TiO_2-based glass substrate having dimensions of 152 mm-square and 6.35 mm-thick.

Preferably, the high-refractive index layer is composed of a material containing silicon (Si).

Preferably, the high-refractive index layer consists of one or more of first high-refractive index sublayers, and one or more of second high-refractive index sublayers,

the first high-refractive index sublayer contains silicon (Si), and one or more elements selected from the group consisting of nitrogen (N), carbon (C), hydrogen (H) and boron (B),

the first high-refractive index sublayer has a thickness of not less than 0.1 nm and not more than 0.7 nm, and

the second high-refractive index sublayer contains silicon (Si), and is free of nitrogen (N), carbon (C), hydrogen (H) and boron (B).

Preferably, in the high-refractive index layer, a high-refractive index sublayer that is remote from the substrate and in contact with the low-refractive index layer is the first high-refractive index sublayer.

In a second aspect, the present disclosure provides a method for manufacturing a reflective mask blank with using a reflective mask blank according to the first aspect.

The present disclosure can provide a reflective mask blank that includes a multilayer reflection film having a high reflectance with respect to EUV light and a controlled low background level in inspection of a phase defect by ABI (Actinic Blank Inspection) or the like. Further, from the reflective mask blank, the present disclosure can provide a reflective mask in which defects such as phase defects are reduced.