OPTICAL FILTER

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to Chinese Patent Application, with the Application No. 201910487270.2 and the title "Optical Filter", filed before the China National Intellectual Property Administration (CNIPA) on June 5, 2019, the disclosure of which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to the field of optical elements, and more particularly, to a near infrared optical filter.

BACKGROUND

[0003] The near-infrared narrow-band optical filter can be applied to a face recognition system, a gesture recognition system, a laser radar, a smart appliance, and the like. When the above-mentioned systems or devices operate, the near-infrared narrow-band optical filter often receives light incident at an oblique angle.

[0004] The near-infrared narrow-band optical filter generally includes a substrate, and both sides of the substrate are coated with a multilayer film to form a set of films. The near-infrared narrow-band optical filter has a passband corresponding to light. A majority of light corresponding to the passband can pass through the near-infrared narrow-band optical filter, and a majority of light corresponding to a non-passband is cut off. There is a need in the art for an optical filter having excellent optical filter properties to improve imaging quality.

SUMMARY

[0005] To address or partially address the above-mentioned drawbacks of the prior art, examples of the present disclosure propose an optical filter and a method for manufacturing the optical filter. Examples of the present disclosure also provide an optical system.

[0006] Examples of the present disclosure provide an optical filter including a substrate and a first set of films disposed on a first surface of the substrate, wherein the first set of films includes a high refractive index film layer, a low refractive index film layer, and a matching film layer. A material of the matching film layer includes a nitrogen-doped silicon germanium mixture having a chemical formula $Si_xGe_{1-x}N_y$, where $0 \leq x \leq 1$, and $0 < y \leq 0.1$. In a wavelength range of 780nm to 3000nm, a refractive index of the high refractive index film layer is greater than a refractive index of the low refractive index film layer, and a refractive index of the matching film layer is not equal to a refractive index of its adjacent film layer.

[0007] In one embodiment, the optical filter has a passband within a wavelength range of

780nm to 1200nm, and when an incident angle of light changes from 0° to 30°, a drift amount of a center wavelength of the passband is not greater than 16nm.

[0008] In one embodiment, the passband of the optical filter has a center wavelength corresponding to a *p* light and a center wavelength corresponding to a *s* light, and when the incident angle of light is 30°, a drift between the center wavelength corresponding to the *p* light and the center wavelength corresponding to the *s* light is not greater than 5 nm.

[0009] In one embodiment, an average transmittance of the passband of the optical filter is not less than 93%.

[0010] In one embodiment, the refractive index of the high refractive index film layer is greater than 3, the refractive index of the low refractive index film layer is less than 3, and the refractive index of the matching film layer is between 1.7 and 4.5, in a wavelength range of 780nm to 1200nm.

[0011] In one embodiment, the nitrogen-doped silicon germanium mixture may further be doped with hydrogen and have a chemical formula $Si_xGe_{1-x}N_y:H_z$, where $0 \leq x \leq 1$, $0 < y \leq 1$, and $z \leq 1$, at least a part of which is an amorphous hydrogenated nitrogen-doped silicon germanium mixture α-$Si_xGe_{1-x}N_y:H_z$.

[0012] In one embodiment, the nitrogen-doped silicon germanium mixture further includes an auxiliary component including one or more of oxygen, boron, or phosphorus, and a ratio of a number of each atom in the auxiliary component to a number of silicon atoms is less than 10%.

[0013] In one embodiment, a material of the high refractive index film layer includes $Si_wGe_{1-w}:H_v$, where $0 \leq w \leq 1$, and $0 \leq v \leq 1$.

[0014] In one embodiment, a material of the low refractive index film layer includes a mixture of one or more of SiO_2, Si_3N_4, Ta_2O_5, Nb_2O_5, TiO_2, Al_2O_3, SiCN, or SiC.

[0015] In one embodiment, the substrate further includes a second surface facing away from the first surface. The optical filter further includes a second set of films disposed on the second surface of the substrate. The second set of films is a set of longwave pass films or a set of wideband pass films, and the first set of films is a set of narrowband pass films. A passband of the second set of films covers a passband of the first set of films.

[0016] In one embodiment, a sum of a thickness of the first set of films and a thickness of the second set of films is less than 12μm.

[0017] In one embodiment, the second set of films is the set of longwave pass films. In a wavelength range of 350nm to 1200nm, the set of narrowband pass films has a passband, the set of longwave pass films has a passband and a cut-off band, and the passband of the set of

longwave pass films covers the passband of the set of narrowband pass films. A blocking of the cut-off band of the set of longwave pass films is not lower than a blocking of a corresponding band of the set of narrowband pass films.

[0018] In one embodiment, the second set of films is the set of wideband pass films. In a wavelength range of 780nm to 1200nm, the set of narrowband pass films has a passband, the set of wideband pass films has a passband, and the passband of the set of wideband pass films covers the passband of the set of narrowband pass films. In a wavelength range less than 780nm, an average blocking of the set of wideband pass films is not lower than an average blocking of the set of narrowband pass films.

In one embodiment, along a direction away from the substrate, the first set of films has a structure in one of the following forms: $(L_3\text{-}L_1\text{-}L_3\text{-}L_2)^s\text{-}L_3\text{-}L_1$; $(L_1\text{-}L_3)^2\text{-}(L_2\text{-}L_3\text{-}L_1\text{-}L_3)^s\text{-}L_1\text{-}L_3$; $(L_1\text{-}L_3)^s\text{–}(L_2\text{-}(L_1\text{-}L_3)^p\text{-}L_1\text{-}L_2)^q\text{-}(L_1\text{-}L_3)^r\ L_1$; $(L_3\text{-}L_1)^s\text{–}(L_2\text{-}(L_1\text{-}L_3)^p\text{-}L_1\text{-}L_2)^q\text{-}(L_3\text{-}L_1)^r\ L_3\text{-}L_1\text{-}(L_2\text{-}(L_1\text{-}L_3)^t\text{-}L_1\text{-}L_2)^n$; or $(L_3\text{-}L_1)^s\text{–}(L_3\text{-}L_1)^r\ L_3\text{-}(L_2\text{-}(L_1\text{-}L_3)^p\text{-}L_1\text{-}L_2)^q\ \text{-}(L_3\text{-}L_1)^r\ L_3\text{-}\ (L_2\text{-}(L_1\text{-}L_3)^t\text{-}L_1\text{-}L_2)^n\text{-}(L_3\text{-}L_1)^r$. In the structural of the first set of films, L_1 represents the high refractive index film layer, L_3 represents the low refractive index film layer, L_2 represents the matching film layer, p, q, r, and s represent a number of repetitions of a structure in parentheses, wherein p, q, r, and s are integers greater than or equal to 0.

[0019] According to a second aspect, an example of the present disclosure provides an optical system which may include an infrared image sensor and the aforementioned optical filter. The optical filter is arranged on a photosensitive side of the infrared image sensor.

[0020] Examples of the present disclosure provide an optical filter. A first set of films of the optical filter includes a high refractive index film layer, a matching film layer, and a low refractive index film layer. A material of the matching film layer is a nitrogen-doped silicon germanium mixture to be suitable for matching the high refractive index film layer or the low refractive index film layer. Specifically, by doping nitrogen atoms in a silicon-germanium mixture, the bonding manner of germanium element (or silicon element) to other elements is changed, and the mole number of the nitrogen element is less than 10% of the sum of the mole number of the silicon element and the mole number of the germanium element. Different nitrogen doping content has different effects on the refractive index of the material. For details, see the graph attached for the relationship between refractive index and nitrogen doping. Depending on different product or customer requirements on optical specifications, the amount of nitrogen doping is adjusted to produce a suitable medium refractive index material for the material of the F-P structure or the material of the matching film layer. By matching the matching film layer with other film layers, the optical filter provided in the present disclosure

index of the high refractive index film layer is 4.5, the refractive index of the low refractive index film layer is 2.8, and the plurality of matching film layers each has a different refractive index, for example, the refractive indexes are 3, 3.5, and 4, respectively. By controlling the refractive index of the matching film layer, the refractive index of the high refractive index film layer, and the refractive index of the low-refractive-index film layer, the state in which light passes through each film layer is controlled, for example, the difference in optical characteristics of the state in which *p* light and *s* light pass through is small, so that specific optical characteristics of the first set of films 52 are realized.

[0044] In an exemplary embodiment, the refractive index of the matching film layer is smaller than the refractive index of the high refractive index film layer, and the refractive index of the matching film layer is greater than the refractive index of the low refractive index film layer.

[0045] In an exemplary embodiment, the nitrogen-doped silicon germanium mixture is a hydrogenated nitrogen-doped silicon germanium mixture, and the hydrogenated nitrogen-doped silicon germanium mixture has the chemical formula $Si_xGe_{1-x}N_y:H_z$, where $0 \leq x \leq 1$, $0 < y \leq 0.1$, and $z \leq 1$. Exemplarily, in $Si_xGe_{1-x}N_y:H_z$, $0 \leq x \leq 0.5$, $0 < y < 0.1$, and $z \leq 1$. For example, the chemical formula of the hydrogenated nitrogen-doped silicon germanium-based material is $Si_{0.5}Ge_{0.5}N_{0.05}:H_{0.5}$.

[0046] In an exemplary embodiment, the chemical formula of the hydrogenated nitrogen-doped silicon germanium-based material is $Si_xGe_{1-x}N_y:H_z$, where $0 \leq x \leq 0.3$, $0 < y < 0.1$, and $0.8 < z \leq 1$. Exemplarily, the chemical formula of the hydrogenated nitrogen-doped silicon germanium-based material is $Si_{0.1}Ge_{0.9}N_{0.02}:H_{0.7}$. Exemplarily, the chemical formula of the hydrogenated nitrogen-doped silicon germanium-based material is $SiN_{0.1}:H$, i.e., a hydrogenated nitrogen-doped silicon-based material.

[0047] In an exemplary embodiment, at least a part of the hydrogenated nitrogen-doped silicon germanium mixture is an amorphous hydrogenated nitrogen-doped silicon germanium mixture: α-$Si_xGe_{1-x}N_y:H_z$.

[0048] In an exemplary embodiment, the nitrogen-doped silicon germanium mixture further includes an auxiliary component including one or more of nitrogen, boron, or phosphorus, wherein the ratio of a number of each atom in the auxiliary component to a number of silicon atoms is less than 0.1.

[0049] Referring to FIG. 2a and 2b, the conditional expression $a < 0.1b$ is satisfied. It is possible to use a relatively small amount of nitrogen elements and auxiliary components, and change in a relatively narrow range to achieve a relatively large range of refractive index adjustment. The physicochemical properties of the corresponding matching film layers are stable and can have

blocking of the set of narrowband pass films. By controlling the blocking of the set of wideband pass films, the blocking of the optical filter 5 can be improved better, and the transmittance of the light in the corresponding band is reduced, so that the noise signal in the image formed by the light passing through the optical filter 5 is weak.

[0057] In an exemplary embodiment, along a direction away from the substrate, the structure of the first set of films is one of the following structures: $(L_3\text{-}L_1\text{-}L_3\text{-}L_2)^s\text{-}L_3\text{-}L_1$; $(L_1\text{-}L_3)^2\text{-}(L_2\text{-}L_3\text{-}L_1\text{-}L_3)^s\text{-}L_1\text{-}L_3$; $(L_1\text{-}L_3)^s\text{–}(L_2\text{-}(L_1\text{-}L_3)^p\text{-}L_1\text{-}L_2)^q\text{-}(L_1\text{-}L_3)^r\ L_1$; $(L_3\text{-}L_1)^s\text{–}(L_2\text{-}(L_1\text{-}L_3)^p\text{-}L_1\text{-}L_2)^q\text{-}(L_3\text{-}L_1)^r\ L_3\text{-}L_1\text{-}(L_2\text{-}(L_1\text{-}L_3)^t\text{-}L_1\text{-}L_2)^n$; and $(L_3\text{-}L_1)^s\text{–}(L_3\text{-}L_1)^r\ L_3\text{-}(L_2\text{-}(L_1\text{-}L_3)^p\text{-}L_1\text{-}L_2)^q\ \text{-}(L_3\text{-}L_1)^r\ L_3\text{-}\ (L_2\text{-}(L_1\text{-}L_3)^t\text{-}L_1\text{-}L_2)^n\text{-}(L_3\text{-}L_1)^r$. In the structure of the first set of films, L_1 represents a high refractive index film layer, L_3 represents a low refractive index film layer, L_2 represents a matching film layer, and p, q, r, and s represent the number of repetitions of the structure in parentheses, wherein p, q, r, and s are integers greater than or equal to 0.

[0058] Three examples provided herein are described in detail below in connection with FIGS. 3 to 5.

Example 1

[0059] The optical filter 5 of the present example includes a substrate 51. A first set of films 52 formed by sputtering coating is disposed on a first surface of the substrate 51. The first set of films 52 may include a set of narrowband pass films provided in Table 1, wherein the 1st layer is a layer closest to the substrate 51. A second set of films 53 formed by sputtering coating is disposed on a second surface of the substrate 51. The second set of films 53 may include a set of longwave pass films provided in Table 2, wherein the 1st layer is a layer closest to the substrate 51. Referring to FIG. 3, when the incident angle of the light changes from 0° to 30°, the drift amount of the center wavelength of the passband of the optical filter 5 is not greater than 12nm.

[0060] Table 1 of the present disclosure provides a set of narrowband pass films. The materials of the layers in the same column in Table 1 are the same. In Table 1, reference numerals 1-22 denotes the order in which each layer of the first set of films 52 is stacked in a direction away from the substrate 51. For example, "1" denotes the 1st layer, which is the layer closest to the substrate 51 as described above.

Table 1: Layer structure of a set of narrowband pass films (unit of thickness: nm)

Material	SiO_2	α-Si:H	SiO_2	α-SiN_y:H_z
Layer	1	2	3	4
Thickness	20.65	255.43	294.11	174.64

WHAT IS CLAIMED IS:

1. A optical filter, characterized in that, the optical filter comprises a substrate and a first set of films disposed on a first surface of the substrate, wherein the first set of films comprises a high refractive index film layer, a low refractive index film layer, and a matching film layer;

a material of the matching film layer comprises a nitrogen-doped silicon germanium mixture having a chemical formula $Si_xGe_{1-x}N_y$, where $0 \leq x \leq 1$, and $0 < y \leq 0.1$, in a wavelength range from 780nm to 3000nm, a refractive index of the high refractive index film layer is greater than a refractive index of the low refractive index film layer, and a refractive index of the matching film layer is not equal to a refractive index of its adjacent film layer.

2. The optical filter according to claim 1, characterized in that, the optical filter has a passband within a wavelength range of 780nm to 1200nm, and a drift amount of a center wavelength of the passband is not greater than 16nm when an incident angle of light changes from 0° to 30°.

3. The optical filter according to claim 2, characterized in that, the passband of the optical filter has a center wavelength corresponding to a *p* light and a center wavelength corresponding to a *s* light, and when the incident angle of light is 30°, a drift between the center wavelength corresponding to the *p* light and the center wavelength corresponding to the *s* light is not greater than 5 nm.

4. The optical filter according to claim 2, characterized in that, an average transmittance of the passband of the optical filter is not less than 93%.

5. The optical filter according to claim 1, characterized in that, the refractive index of the high refractive index film layer is greater than 3, the refractive index of the low refractive index film layer is less than 3, and the refractive index of the matching film layer is between 1.7 and 4.5 in a wavelength range from 780nm to 1200nm.

6. The optical filter according to claim 1, characterized in that, the nitrogen-doped silicon germanium mixture is further doped with hydrogen and have a chemical formula $Si_xGe_{1-x}N_y:H_z$, where $0 \leq x \leq 1$, $0 < y \leq 1$, and $z \leq 1$, at least a part of which is an amorphous hydrogenated nitrogen-doped silicon germanium mixture $\alpha\text{-}Si_xGe_{1-x}N_y:H_z$.

7. The optical filter according to claim 1, characterized in that, the nitrogen-doped silicon germanium mixture further comprises an auxiliary component, wherein the auxiliary component comprises one or more of oxygen, boron, or phosphorus, and a ratio of a number of each atom in the auxiliary component to a number of silicon atoms is less than 10%.

8. The optical filter according to claim 1, characterized in that, a material of the high refractive index film layer comprises $Si_wGe_{1-w}:H_v$, where $0 \leq w \leq 1$, and $0 \leq v \leq 1$.

9. The optical filter according to claim 1, characterized in that, a material of the low refractive index film layer comprises a mixture of one or more of SiO_2, Si_3N_4, Ta_2O_5, Nb_2O_5, TiO_2, Al_2O_3, SiCN, or SiC.

10. The optical filter according to claim 4, characterized in that, the substrate further comprises a second surface facing away from the first surface, wherein the optical filter further comprises a second set of films disposed on the second surface of the substrate;

the second set of films is a set of longwave pass films or a set of wideband pass films, and the first set of films is a set of narrowband pass films, wherein a passband of the second set of films covers a passband of the first set of films.

11. The optical filter according to claim 10, characterized in that, a sum of a thickness of the first set of films and a thickness of the second set of films is less than 12μm.

12. The optical filter according to claim 10, characterized in that, the second set of films is the set of longwave pass films, wherein in a wavelength range of 350nm to 1200nm, the set of narrowband pass films has a passband, the set of longwave pass films has a passband and a cut-off band, and the passband of the set of longwave pass films covers the passband of the set of narrowband pass films; and

a blocking of the cut-off band of the set of longwave pass films is not lower than a blocking of a corresponding band of the set of narrowband pass films.

13. The optical filter according to claim 10, characterized in that, the second set of films is the set of wideband pass films, wherein in a wavelength range of 780nm to 1200nm, the set of narrowband pass films has a passband, the set of wideband pass films has a passband, and the

passband of the set of wideband pass films covers the passband of the set of narrowband pass films; and

in a wavelength range less than 780nm, an average blocking of the set of wideband pass films is not lower than an average blocking of the set of narrowband pass films.

14. The optical filter according to claim 11, characterized in that, along a direction away from the substrate, the first set of films has a structure in one of the following forms:

$(L_3\text{-}L_1\text{-}L_3\text{-}L_2)^s\text{-}L_3\text{-}L_1$;

$(L_1\text{-}L_3)^2\text{-}(L_2\text{-}L_3\text{-}L_1\text{-}L_3)^s\text{-}L_1\text{-}L_3$;

$(L_1\text{-}L_3)^s\text{–}(L_2\text{-}(L_1\text{-}L_3)^p\text{-}L_1\text{-}L_2)^q\text{-}(L_1\text{-}L_3)^r\ L_1$;

$(L_3\text{-}L_1)^s\text{–}(L_2\text{-}(L_1\text{-}L_3)^p\text{-}L_1\text{-}L_2)^q\text{-}(L_3\text{-}L_1)^r\ L_3\text{-}L_1\text{-}(L_2\text{-}(L_1\text{-}L_3)^t\text{-}L_1\text{-}L_2)^n$; or

$(L_3\text{-}L_1)^s\text{–}(L_3\text{-}L_1)^r\ L_3\text{-}(L_2\text{-}(L_1\text{-}L_3)^p\text{-}L_1\text{-}L_2)^q\ \text{-}(L_3\text{-}L_1)^r\ L_3\text{-}\ (L_2\text{-}(L_1\text{-}L_3)^t\text{-}L_1\text{-}L_2)^n\text{-}(L_3\text{-}L_1)^r$,

in the structural of the first set of films, L_1 represents the high refractive index film layer, L_3 represents the low refractive index film layer, L_2 represents the matching film layer, p, q, r, and s represent a number of repetitions of a structure in parentheses, wherein p, q, r, and s are integers greater than or equal to 0.