

METHOD OF MANUFACTURING META LENSES AND META LENS STRUCTURE

FIELD OF THE INVENTION

[0001] The present disclosure relates to a method of manufacturing meta lenses and a meta lens structure.

BACKGROUND OF THE INVENTION

[0002] Meta lenses are tiny optical elements that can manipulate electromagnetic waves (light), which is similar to traditional lenses in converging light, however the meta lenses are thinner than a sheet of paper. The technology is exciting to developers across many industries due to their small size, ease and cost efficiency to manufacture at scale, and their potential to revolutionize multiple optical applications.

SUMMARY OF THE INVENTION

[0003] The present disclosure provides a method of manufacturing meta lenses, which includes: depositing an optical material over a substrate; spin coating a nano-imprint resist over the optical material; contacting a mold with the nano-imprint resist, wherein the mold has a plurality of circular cylindrical recesses spaced apart from each other and a protruding portion; curing the nano-imprint resist after the mold is in contact with the nano-imprint resist to form a nano-imprint resist pattern, wherein the nano-imprint resist pattern has a plurality of circular cylindrical thick portions respectively corresponding to the circular cylindrical recesses of the mold and a thin portion corresponding to the protruding portion of the mold; removing the thin portion and remaining the circular cylindrical thick portions; and patterning the optical material according to the remaining circular cylindrical thick portions to form a plurality of circular cylindrical meta lenses.

[0004] In some embodiments of the present disclosure, the method further includes: removing the circular cylindrical thick portions after forming the circular cylindrical meta lenses.

[0005] In some embodiments of the present disclosure, the step of contacting the mold with the nano-imprint resist includes filling the circular cylindrical recesses of the mold with the nano-imprint resist, and the step of filling the circular cylindrical recesses of the mold with the nano-imprint resist includes moving the mold downwardly, heating the nano-imprint resist, or a combination thereof.

[0006] In some embodiments of the present disclosure, the step of curing the nano-imprint resist includes performing an ultraviolet light irradiation treatment.

[0007] In some embodiments of the present disclosure, the step of curing the nano-imprint resist includes performing a cooling treatment, and the nano-imprint resist is made of a thermoplastic material.

[0008] In some embodiments of the present disclosure, the mold has an anti-stick layer applied over the circular cylindrical recesses and the protruding portion of the mold, so that in the step of contacting the mold with the nano-imprint resist, the anti-stick layer is directly in contact with the nano-imprint resist.

[0009] In some embodiments of the present disclosure, the method further includes: forming a chromium-containing layer over the optical material after depositing the optical material over the substrate and before spin coating the nano-imprint resist over the optical material.

[0010] In some embodiments of the present disclosure, the optical material includes amorphous silicon, titanium dioxide or a combination thereof.

[0011] In some embodiments of the present disclosure, the method further includes: forming a back protective layer beneath the substrate after depositing the optical material over the substrate and before spin coating the nano-imprint resist over the optical material, and the substrate is between the optical material and the back protective layer.

[0012] In some embodiments of the present disclosure, the mold is made from a master stamp.

[0013] In some embodiments of the present disclosure, the mold is a disposable polymer stamp.

[0014] The present disclosure also provides a meta lens structure, which includes a plurality of circular cylindrical meta lenses spaced apart from each other, wherein an included angle between a sidewall of one of the circular cylindrical meta lenses and a bottom surface of the one of the circular cylindrical meta lenses is in a range of from 85 degrees to 88 degrees or in a range of from 92 degrees to 95 degrees.

[0015] In some embodiments of the present disclosure, a ratio of a height of the one of the circular cylindrical meta lenses to a maximum diameter of the one of the circular cylindrical meta lenses is in a range of from 1.25 to 3.5.

[0016] In some embodiments of the present disclosure, a height of the one of the circular cylindrical meta lenses is in a range of from 250 nm to 350 nm, and a maximum diameter of the one of the circular cylindrical meta lenses is in a range of from 100 nm to 200 nm.

[0017] In some embodiments of the present disclosure, a minimum distance between adjacent two of the circular cylindrical meta lenses is in a range of from 75 nm to 125 nm.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIGS. 1A, 1B, 1C, 1D, 1E, and 1F are perspective views of various steps of a method of manufacturing meta lenses using a nano-imprint lithography process according to some embodiments of the present disclosure.

[0019] FIGS. 2A, 2B, 2C, and 2D are cross-sectional views of various steps of a nano-imprint lithography process according to some embodiments of the present disclosure.

[0020] FIGS. 3A, 3B, 3C, and 3D are cross-sectional views of various steps of a nano-imprint lithography process according to some embodiments of the present disclosure.

[0021] FIG. 4 is a cross-sectional view of a meta lens structure according to some embodiments of the present disclosure.

[0022] FIG. 5 is a cross-sectional view of a meta lens structure according to some embodiments of the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0023] In order to make the description of the present disclosure more detailed and complete, the following provides an illustrative description for the implementation of the present disclosure and specific embodiments; but this is not the only way to implement or use the specific embodiments of the present disclosure. The embodiments disclosed below can be combined or substituted with each other under beneficial circumstances, and other embodiments can also be added to an embodiment without further description.

[0024] The spatially relative terms in the text, such as “beneath” and “over”, are used to facilitate the description of the relative relationship between one element or feature and another element or feature in the drawings. The true meaning of the spatially relative terms includes other orientations. For example, when the drawing is flipped up and down by 180

degrees, the relationship between the one element and the other element may change from “beneath” to “over.” In addition, the spatially relative descriptions used herein should be interpreted the same.

[0025] Many developers are developing methods for mass production of meta lenses. For example, currently, electron beam lithography technology can be used to manufacture meta lenses, but the process cost is extremely high, which is not conducive to mass production. Therefore, the present disclosure provides a method of manufacturing meta lenses, which has low manufacturing cost and exhibits high yield, and thus can be effectively applied to mass production of meta lenses. Various embodiments of the method of manufacturing meta lenses of the present disclosure will be described in detail below.

[0026] FIGS. 1A, 1B, 1C, 1D, 1E, and 1F are perspective views of various steps of a method of manufacturing meta lenses using a nano-imprint lithography process according to some embodiments of the present disclosure. As shown in FIG. 1A, an optical material 120 is disposed (e.g., deposited) over a substrate 110. In some embodiments, the optical material 120 includes amorphous silicon, titanium dioxide (TiO_2), or a combination thereof, with a reflective index greater than 3.4 and an absorption less than 10^{-3} . In some embodiments, the substrate 110 is a glass substrate, a quartz substrate, or a sapphire substrate. In some embodiments, the optical material 120 is deposited on the substrate 110 by using an inductively coupled plasma chemical vapor deposition (ICP-CVD) process.

[0027] As shown in FIG. 1A and FIG. 1B, a nano-imprint resist 130 is disposed (e.g., spin coated) over the optical material 120. In some embodiments, the nano-imprint resist 130 is coated on the optical material 120 by using a spin coating process. In some embodiments, after the optical material 120 is deposited over the substrate 110 and before the

nano-imprint resist 130 is spin coated over the optical material 120, a back protective layer 115 is formed beneath the substrate 110, and the substrate 110 is between the optical material 120 and the back protective layer 115.

[0028] In some embodiments, after the optical material 120 is deposited over the substrate 110 and before the nano-imprint resist 130 is spin coated over the optical material 120, a chromium-containing layer (not shown) is formed over the optical material 120. The chromium-containing layer can be used to protect the circular cylindrical meta lenses that are subsequently formed (e.g., circular cylindrical meta lenses 122 shown in FIG. 1E).

[0029] As shown in FIG. 1B and FIG. 1C, a mold 140 is brought into contact with the nano-imprint resist 130, in which the mold 140 has a plurality of circular cylindrical recesses and a protruding portion, and the circular cylindrical recesses are spaced apart from each other (not shown in FIG. 1C). In some embodiments, the mold 140 is made from a master stamp (not shown). For example, the master stamp is made of silicon, and thus it is also called as a silicon stamp. In some embodiments, the mold 140 is a disposable polymer stamp. In some embodiments, a polymer material (not shown) is deposited on the master stamp, and then cooling and demolding to obtain the mold 140.

[0030] As shown in FIG. 1C and FIG. 1D, a series of nano-imprint lithography process steps are performed on the nano-imprint resist 130 to form a plurality of circular cylindrical thick portions 132t. The circular cylindrical thick portions 132t are acted as a mask for subsequently patterning the optical material 120 (e.g., using inductively coupled plasma reactive ion etching (ICP-RIE)). Various embodiments of the nano-imprint lithography process steps will be detailed below.

[0031] FIGS. 2A, 2B, 2C, and 2D are cross-sectional views of various steps of a nano-imprint lithography process according to some embodiments of the present disclosure. FIG. 2A is a partial cross-sectional view of FIG. 1C. FIG. 2D is a partial cross-sectional view of FIG. 1D.

[0032] Referring to FIG. 1C and FIG. 2A, the mold 140 has a plurality of circular cylindrical recesses 140r and a protruding portion 140c, and the circular cylindrical recesses 140r are spaced apart from each other. In some embodiments, the step of contacting the mold 140 with the nano-imprint resist 130 includes filling the circular cylindrical recesses 140r of the mold 140 with the nano-imprint resist 130, and the step of filling the circular cylindrical recesses 140r of the mold 140 with the nano-imprint resist 130 includes moving the mold 140 downward, heating the nano-imprint resist 130, or a combination thereof. In some embodiments, as shown in FIG. 2A, the nano-imprint resist 130 is heated to make it into a flow state, and the mold 140 is moved downward to fill the circular cylindrical recesses 140r of the mold 140 with the flowing nano-imprint resist 130. In some embodiments, the mold 140 has an anti-stick layer 141 disposed over the circular cylindrical recesses 140r and the protruding portion 140c of the mold 140. Therefore, in the step of contacting the mold 140 with the nano-imprint resist 130, the anti-stick layer 141 is directly in contact with the nano-imprint resist 130.

[0033] As shown in FIGS. 2A and 2B, after the mold 140 is brought into contact with the nano-imprint resist 130 and the circular cylindrical recesses 140r of the mold 140 are filled with the nano-imprint resist 130, the nano-imprint resist 130 is cured to form a nano-imprint resist pattern 132. As shown in FIG. 2B, the nano-imprint resist pattern 132 has a plurality of circular cylindrical thick portions 132t and a thin portion 132w. The circular cylindrical thick portions 132t correspond to the circular

cylindrical recesses 140r of the mold 140, respectively, and the thin portion 132w corresponds to the protruding portion 140c of the mold 140. In some embodiments, the step of curing the nano-imprint resist 130 includes performing a cooling treatment, and the nano-imprint resist 130 is made of a thermoplastic material.

[0034] As shown in FIGS. 2B and 2C, the mold 140 is moved upward to separate from the nano-imprint resist pattern 132. In some embodiments, since the mold 140 has the anti-stick layer 141, the mold 140 can be easily separated from the nano-imprint resist pattern 132 during the upward movement of the mold 140, so the structure of the nano-imprint resist pattern 132 is not damaged.

[0035] As shown in FIG. 2C and FIG. 2D, the thin portion 132w of the nano-imprint resist pattern 132 is removed, and the circular cylindrical thick portions 132t are remained. The circular cylindrical thick portions 132t are acted as the mask for subsequently patterning the optical material 120. In some embodiments, the thin portion 132w of the nano-imprint resist pattern 132 is removed by using a plasma cleaning process.

[0036] FIGS. 3A, 3B, 3C, and 3D are cross-sectional views of various steps of a nano-imprint lithography process according to some embodiments of the present disclosure. FIG. 3A is a partial cross-sectional view of FIG. 1C. FIG. 3D is a partial cross-sectional view of FIG. 1D.

[0037] As shown in FIG. 1C and FIG. 3A, the mold 140 has a plurality of circular cylindrical recesses 140r and a protruding portion 140c, and the circular cylindrical recesses 140r are spaced apart from each other. In some embodiments, as shown in FIG. 3A, the mold 140 is moved downward to fill the circular cylindrical recesses 140r of the mold 140 with the liquid state nano-imprint resist 130. In some embodiments, the mold 140 has an anti-stick layer 141 disposed over the circular cylindrical

recesses 140r and the protruding portion 140c of the mold 140. Therefore, in the step of contacting the mold 140 with the nano-imprint resist 130, the anti-stick layer 141 is directly in contact with the nano-imprint resist 130.

[0038] As shown in FIGS. 3A and 3B, after the mold 140 is brought into contact with the nano-imprint resist 130 and the circular cylindrical recesses 140r of the mold 140 are filled with the nano-imprint resist 130, the nano-imprint resist 130 is cured to form a nano-imprint resist pattern 132. As shown in FIG. 3B, the nano-imprint resist pattern 132 has a plurality of circular cylindrical thick portions 132t and a thin portion 132w. The circular cylindrical thick portions 132t correspond to the circular cylindrical recesses 140r of the mold 140, respectively, and the thin portions 132w corresponds to the protruding portion 140c of the mold 140. In some embodiments, the step of curing the nano-imprint resist 130 includes performing an ultraviolet light irradiation treatment, and the nano-imprint resist (e.g., a photoresist) 130 is an ultraviolet light curable resin material, and the mold 140 is a transparent mold, which can be made of a transparent polymer material or other suitable transparent material.

[0039] As shown in FIGS. 3B and 3C, the mold 140 is moved upward to separate from the nano-imprint resist pattern 132. In some embodiments, since the mold 140 has the anti-stick layer 141, the mold 140 can be easily separated from the nano-imprint resist pattern 132 during the upward movement of the mold 140, so the structure of the nano-imprint resist pattern 132 is not damaged.

[0040] As shown in FIG. 3C and FIG. 3D, the thin portion 132w of the nano-imprint resist pattern 132 is removed, and the circular cylindrical thick portions 132t are remained. The circular cylindrical thick portions 132t are acted as the mask for subsequently patterning the optical material

120. In some embodiments, the thin portion 132w of the nano-imprint resist pattern 132 is removed by using a plasma cleaning process.

[0041] As shown in FIG. 1D and FIG. 1E, the optical material 120 is patterned according to the remaining circular cylindrical thick portions 132t to form a plurality of circular cylindrical meta lenses 122. In some embodiments, the optical material 120 is patterned by using an etching process, such as an inductively coupled plasma reactive ion etching (ICP-RIE) process.

[0042] As shown in FIGS. 1E and 1F, after the circular cylindrical meta lenses 122 are formed, the circular cylindrical thick portions 132t are removed to expose top surfaces of the circular cylindrical meta lenses 122. In some embodiments, after the circular cylindrical thick portions 132t are removed, the back protective layer 115 is removed. In some embodiments, after the back protective layer 115 is removed, a tape (not shown) is attached on a bottom surface the substrate 110, and then diced, and finally the tape is removed. After singulating the die, the circular cylindrical meta lenses 122 can be tested for function and optical inspection for defects.

[0043] It is worth noting that the method of manufacturing the circular cylindrical meta lenses 122 of the present disclosure is easy to implement, and the process yield is high. In contrast, it is much difficult to produce uniform strip-shaped gratings, and its process yield is much lower.

[0044] The present disclosure also provides a meta lens structure, which includes a plurality of circular cylindrical meta lenses 122 spaced apart from each other, as shown in FIG. 1F. FIG. 4 is a cross-sectional view of a meta lens structure according to some embodiments of the present disclosure. As shown in FIG. 4, an included angle α between a sidewall 122s of one of the circular cylindrical meta lenses 122 and a bottom surface 122b of the one of the circular cylindrical meta lenses 122 is in a range of

from 85 degrees to 88 degrees, such as 86 degrees, 87 degrees, or any value between any two of these values. In some embodiments, the included angle α is greater than or equal to 85 degrees and less than 88 degrees.

[0045] In some embodiments, a ratio of a height H1 of the circular cylindrical meta lens 122 to a maximum diameter W1 thereof is in a range of from 1.25 to 3.5, such as 1.5, 2.0, 2.5, 3.0, or any value between any two of these values.

[0046] In some embodiments, the height H1 of the circular cylindrical meta lens 122 is in a range of from 250 nm to 350 nm, for example, 260 nm, 270 nm, 280 nm, 290 nm, and 300 nm, 310 nm, 320 nm, 330 nm, 340 nm or any value between any two of these values.

[0047] In some embodiments, the maximum diameter W1 of the circular cylindrical meta lens 122 is in a range of from 100 nm and 200 nm, such as 110 nm, 120 nm, 130 nm, 140 nm, and 150 nm, 160 nm, 170 nm, 180 nm, 190 nm or any value between any two of these values.

[0048] In some embodiments, a minimum distance D1 between adjacent two of the circular cylindrical meta lenses 122 is in a range of from 75 nm and 125 nm, such as 80 nm, 85 nm, 90 nm, 95 nm, 100 nm, 105 nm, 110 nm, 115 nm, 120 nm or any value between any two of these values.

[0049] FIG. 5 is a cross-sectional view of a meta lens structure according to some embodiments of the present disclosure. As shown in FIG. 5, an included angle α between a sidewall 122s of one of the circular cylindrical meta lenses 122 and a bottom surface 122b of the one of the circular cylindrical meta lenses 122 is in a range of from 92 degrees to 95 degrees, such as 93 degrees, 94 degrees, or any value between any two of these values. In some embodiments, the included angle α is greater than 92 degrees and less than or equal to 95 degrees.

[0050] In some embodiments, a ratio of a height H2 of the circular cylindrical meta lens 122 to a maximum diameter W2 thereof is in a range of from 1.25 to 3.5, such as 1.5, 2.0, 2.5, 3.0, or any value between any two of these values.

[0051] In some embodiments, the height H2 of the circular cylindrical meta lens 122 is in a range of from 250 nm to 350 nm, such as 260 nm, 270 nm, 280 nm, 290 nm, and 300 nm, 310 nm, 320 nm, 330 nm, 340 nm or any value between any two of these values.

[0052] In some embodiments, the maximum diameter W2 of the circular cylindrical meta lens 122 is in a range of from 100 nm to 200 nm, such as 110 nm, 120 nm, 130 nm, 140 nm, and 150 nm, 160 nm, 170 nm, 180 nm, 190 nm or any value between any two of these values.

[0053] In some embodiments, a minimum distance D2 between adjacent two of the circular cylindrical meta lenses 122 is in a range of from 75 nm to 125 nm, such as 80 nm, 85 nm, 90 nm, 95 nm, 100 nm, 105 nm, 110 nm, 115 nm, 120 nm or any value between any two of these values.

[0054] The above-mentioned embodiments are only illustrative of the principles and effects of the present disclosure, as well as explaining the technical features of the present disclosure, rather than limiting the scope of protection of the present disclosure. Anyone who is familiar with the technology can easily complete changes or equal arrangements without violating the technical principles and spirit of the present disclosure. All of them belong to the scope of the present disclosure.

WHAT IS CLAIMED IS:

1. A method of manufacturing meta lenses, comprising:
depositing an optical material over a substrate;
spin coating a nano-imprint resist over the optical material;
contacting a mold with the nano-imprint resist, wherein the mold has a plurality of circular cylindrical recesses and a protruding portion, and the circular cylindrical recesses are spaced apart from each other;

curing the nano-imprint resist after the mold is in contact with the nano-imprint resist to form a nano-imprint resist pattern, wherein the nano-imprint resist pattern has a plurality of circular cylindrical thick portions and a thin portion, and the circular cylindrical thick portions respectively correspond to the circular cylindrical recesses of the mold, and the thin portion corresponds to the protruding portion of the mold;

removing the thin portion and remaining the circular cylindrical thick portions; and

patterning the optical material according to the remaining circular cylindrical thick portions to form a plurality of circular cylindrical meta lenses.

2. The method of manufacturing the meta lenses of claim 1, further comprising:

removing the circular cylindrical thick portions after forming the circular cylindrical meta lenses.

3. The method of manufacturing the meta lenses of claim 1, wherein the step of contacting the mold with the nano-imprint resist comprises filling the circular cylindrical recesses of the mold with the nano-imprint resist, and the step of filling the circular cylindrical recesses of the mold with the

nano-imprint resist comprises moving the mold downward, heating the nano-imprint resist, or a combination thereof.

4. The method of manufacturing the meta lenses of claim 1, wherein the step of curing the nano-imprint resist comprises performing an ultraviolet light irradiation treatment.

5. The method of manufacturing the meta lenses of claim 1, wherein the step of curing the nano-imprint resist comprises performing a cooling treatment, and the nano-imprint resist is made of a thermoplastic material.

6. The method of manufacturing the meta lenses of claim 1, wherein the mold has an anti-stick layer applied over the circular cylindrical recesses and the protruding portion of the mold, so that in the step of contacting the mold with the nano-imprint resist, the anti-stick layer is directly in contact with the nano-imprint resist.

7. The method of manufacturing the meta lenses of claim 1, further comprising:

forming a chromium-containing layer over the optical material after depositing the optical material over the substrate and before spin coating the nano-imprint resist over the optical material.

8. The method of manufacturing the meta lenses of claim 1, wherein the optical material comprises amorphous silicon, titanium dioxide or a combination thereof.

9. The method of manufacturing the meta lenses of claim 1, further

comprising:

forming a back protective layer beneath the substrate after depositing the optical material over the substrate and before spin coating the nano-imprint resist over the optical material, and the substrate is between the optical material and the back protective layer.

10. The method of manufacturing the meta lenses of claim 1, wherein the mold is made from a master stamp.

11. The method of manufacturing the meta lenses of claim 1, wherein the mold is a disposable polymer stamp.

12. A meta lens structure, comprising:

a plurality of circular cylindrical meta lenses spaced apart from each other, wherein an included angle between a sidewall of one of the circular cylindrical meta lenses and a bottom surface of the one of the circular cylindrical meta lenses is in a range of from 85 degrees to 88 degrees or in a range of from 92 degrees to 95 degrees.

13. The meta lens structure of claim 12, wherein a ratio of a height of the one of the circular cylindrical meta lenses to a maximum diameter of the one of the circular cylindrical meta lenses is in a range of from 1.25 to 3.5.

14. The meta lens structure of claim 12, wherein a height of the one of the circular cylindrical meta lenses is in a range of from 250 nm to 350 nm, and a maximum diameter of the one of the circular cylindrical meta lenses is in a range of from 100 nm to 200 nm.

15. The meta lens structure of claim 12, wherein a minimum distance between adjacent two of the circular cylindrical meta lenses is in a range of from 75 nm to 125 nm.