PATTERN FORMING METHOD

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority from Japanese Patent Application No. 2015-177714; filed on September 09, 2015; the entire contents of which are incorporated herein by reference.

FIELD

An embodiment described herein relates generally to a pattern forming method.

BACKGROUND

A block copolymer (BCP) is a copolymer containing multiple types of polymer blocks. Recently, a method of forming a fine pattern which uses directed self-assembly (DSA) of the BCP is noticed. For example, by forming a BCP film in an opening pattern of a resist layer, forming a hole pattern in the BCP film by phase-separating BCP, and transferring the hole pattern on a workpiece layer, a fine pattern smaller than opening pattern can be formed. In this case, the size of the fine pattern is determined by a ratio between polymer blocks or the amount of molecules.

Meanwhile, there are many cases in which a semiconductor device includes one layer having multiple patterns with sizes different from each other. However, if the patterns are formed of BCP, only a pattern with a size which is determined by a material of BCP can be formed. For this reason, if multiple patters with sizes different from each other are formed in one layer, the patterns require lithographies which are separately performed. As a result, the number of processes for manufacturing a semiconductor device increases, and manufacturing cost of a semiconductor device increases.

An example of related art includes JP-A-2011-129874.

DESCRIPTION OF THE DRAWINGS

FIGS. 1A and 1B are sectional views illustrating a pattern forming method according to a first embodiment.

FIGS. 2A and 2B are sectional views illustrating the pattern forming method according to the first embodiment.

FIGS. 3A and 3B are sectional views illustrating the pattern forming method according to the first embodiment.

FIGS. 4A and 4B are sectional views illustrating the pattern forming method according to the first embodiment.

FIGS. 5A and 5B are sectional views illustrating the pattern forming method according to the first embodiment.

FIGS. 6A and 6B are sectional views illustrating the pattern forming method according to the first embodiment.

FIGS. 7A and 7B are sectional views illustrating the pattern forming method according to the first embodiment.

FIG. 8 is a schematic diagram illustrating a molecular structure of BCP according to the first embodiment.

FIGS. 9A and 9B are perspective views illustrating examples of a first pattern in a third opening portion according to the first embodiment.

DETAILED DESCRIPTION

[0005]Embodiments are to provide a pattern forming method which can efficiently form multiple patterns with sizes different from each other.

[0006]According to one embodiment, a pattern forming method includes forming a workpiece layer on a substrate; forming a first film on the workpiece layer; forming a second film on the first film; and forming a first concave portion with a first width and a second concave portion with a second width greater than the first width, in the second film. The method further includes forming a third film in the first and second concave portions; forming a fourth film including a polymer having a first portion and a second portion, on the third film in the first and second concave portions; and forming a first pattern including the first portion and a second pattern including the second portion, in the fourth film by phase-separating the first portion and the second portion. The method further includes removing the first pattern; processing the third film in the first concave portion, using the second pattern as a mask; and processing the first film under the first concave portion, using at least one of the second pattern and the third film as a mask. The method further includes forming a fifth film which covers the first concave portion and does not cover the second concave portion, on the first, second, and third films; processing the third film in the second concave portion and the first film under the second concave portion, using the fifth film as a mask; and processing the workpiece layer, using at least one of the first, second, and third films as a mask.

[0008]Hereinafter, an embodiment will be described with reference to the accompanying drawings.

First Embodiment

[0009]FIGS. 1A to 7B are sectional views illustrating a pattern forming method according to a first embodiment. The pattern forming method according to the present embodiment is used for fabricating, for example, a NAND flash memory.

[0010]First, a base layer 2, a workpiece layer 3, a first mask layer 4, and a resist layer 5 are sequentially formed on a substrate 1 (FIG. 1A). The first mask layer 4 is an example of a first film. The resist layer 5 is an example of a second film.

[0011]As an example, the substrate 1 is a semiconductor substrate of a silicon substrate or the like. FIG. 1A illustrates the X and Y directions which are parallel with a surface of the substrate 1 and are perpendicular to each other, and the Z direction perpendicular to the surface of the substrate 1. In the present specification, the +Z direction denotes the upward direction, and the –Z direction denotes the downward direction. In the present embodiment, the –Z direction may coincide with the gravity direction, and may not coincide with the gravity direction.

[0012]As an example, the base layer 2 and the workpiece layer 3 are various conductive layers, semiconductor layers, insulating layers, or the like. As illustrated in FIG. 1A, the workpiece layer 3 may be formed on the substrate 1 through the base layer 2, and may be formed directly on the substrate 1. In the present embodiment, the workpiece layer 3 is a tetraethyl orthosilicate (TEOS) film, and is formed by using a plasma chemical vapor deposition (CVD) method. In the present embodiment, the thickness of the workpiece layer 3 is 100 nm.

[0013]As an example, the first mask layer 4 is a bottom anti reflective coating (BARC) film, and functions as an anti-reflective film when the resist layer 5 is exposed. In the present embodiment, the first mask layer 4 is an organic film, and is formed by using a spin-coating method. In the present embodiment, the thickness of the first mask layer 4 is 60 nm.

[0014]Subsequently, a first opening portion H1, a second opening portion H2, and a third opening portion H3 are formed in the resist layer 5 by using lithography (FIG. 1B). The lithography is performed by using, for example, an ArF immersion exposure apparatus. The first opening portion H1 is an example of a first concave portion, and the second and third opening portions H2 and H3 are examples of a second concave portion. In addition, the first, second, and third opening portions H1, H2, and H3 are respectively examples of first, second, and third concave portions.

[0015]FIG. 1B illustrates a width W1 of the first opening portion H1 in the X direction, a width W2 of the second opening portion H2 in the X direction, and a width W3 of the third opening portion H3 in the X direction. The width W1 is, for example, 110 nm. The width W2 is, for example, 170 nm, and is set to be longer than the width W1. The width W3 is, for example, 1 mm, and is set to be longer than the width W2. The width W1 is an example of a first width, and the width W2 and the width W3 are examples of a second width. In addition, the widths W1, W2, and W3 are respectively examples of first, second, and third widths.

[0016]The first opening portion H1 according to the present embodiment is a hole pattern in a memory cell unit. Hence, the width W1 denotes a diameter of the first opening portion H1. The second opening portion H2 according to the present embodiment is a hole pattern in a peripheral circuit unit. Hence the width W2 denotes a diameter of the second opening portion H2. The third opening portion H3 according to the present embodiment is a grove pattern for an alignment mark extending in the Y direction. Hence, the width W3 denotes a line width of the third opening portion H3.

[0017]Subsequently, a second mask layer 6 is formed on the entire surface of the substrate 1 (FIG. 2A). As a result, the second mask layer 6 is formed in the first, second, and third opening portions H1, H2, and H3. The second mask layer 6 is an example of a third film.

[0018]The second mask layer 6 according to the present embodiment is an inorganic film such as a silicon oxide film, and is formed by atomic layer deposition (ALD). The thickness of the second mask layer 6 according to the present embodiment is 20 nm. The second mask layer 6 according to the present embodiment is conformally formed on the entire surface of the substrate 1. As a result, the second mask layer 6 is formed on the side surface and the bottom surface of the first, second, and third opening portions H1, H2, and H3.

[0019]Subsequently, a polymer film 7 is formed on the second mask layer 6 in the first, second, and third opening portions H1, H2, and H3 by spin-coating of liquid containing polymer (FIG. 2B). The polymer according to the present embodiment is BCP such as polystyrene-b-polymethylmethacrylate (PS-b-PMMA), and thus, the polymer film 7 according to the present embodiment is a BCP film. The polymer film 7 is an example of a fourth film.

[0020]FIG. 2B illustrates a minimum film thickness T1 of the polymer film 7 in the first opening portion H1, a minimum film thickness T2 of the polymer film 7 in the second opening portion H2, and a minimum film thickness T3 of the polymer film 7 in the third opening portion H3. The minimum film thickness T1 is an example of a first minimum film thickness, and the minimum film thicknesses T2 and T3 are examples of a second minimum film thickness. In addition, the minimum film thicknesses T1, T2, and T3 are respectively examples of the first, second, and third minimum film thicknesses.

[0021]A surface of the polymer film 7 in the first opening portion H1 has a concave shape in general. Hence, the minimum film thickness T1 corresponds to a thickness of the central portion of the polymer film 7 in the first opening portion H1. This is applied to the minimum film thicknesses T2 and T3, in the same manner as above. In the present embodiment, the width W2 is greater than the width W1 and the width W3 is greater than the width W2, and thus, the minimum film thickness T2 is smaller than the minimum film thickness T1, and the minimum film thickness T3 is smaller than the minimum film thickness T2.

[0022]FIG. 8 is a schematic diagram illustrating a molecular structure of BCP according to the first embodiment.

[0023]BCP according to the present embodiment is composed of a PMMA block B1 containing multiple PMMA monomers M1, and a PS block B2 containing multiple PS monomers M2. The PMMA block B1 is an example of a first portion, and an example of a first polymer block. The PS block B2 is an example of a second portion, and an example of a second polymer block.

[0024]In the present embodiment, a ratio between the PMMA block B1 and the PS block B2 or the amount of molecules is set such that a predetermined cylinder phase is formed in the BCP film. Specifically, the ratio or the amount of molecules is set such that a cylinder phase with a diameter of 20 nm is formed in the BCP film of the first opening portion H1 by the PMMA block B1.

[0025]Hereinafter, a pattern forming method according to the present embodiment will be continuously described with reference to FIG. 3A to FIG. 7B.

[0026]Subsequently, annealing of the substrate 1 is performed, and the PMMA block B1 and the PS block B2 are separated by phase separation (FIG. 3A). By doing so, a first pattern 7a containing the PMMA block B1 and a second pattern 7b containing the PS block B2 are formed in the polymer film 7. For example, the above-described annealing is performed for one minute at 250°C in nitrogen (N2) atmosphere. In the present embodiment, a columnar pattern which is called a cylinder phase is formed as the first pattern 7a. At this time, the first opening portion H1 or the like functions as a guide for adjusting a position or a shape of the first pattern 7a.

[0027]In the present embodiment, the phase separation of the polymer film 7 is made in the first opening portion H1, and only one first pattern 7a is formed in the polymer film 7 of the first opening portion H1. The reason is that the width W1 of the first opening portion H1 is set such that phase separation is made in the first opening portion H1 and only one first pattern 7a is formed in the first opening portion H1. The first pattern 7a in the first opening portion H1 is formed in the central portion of the first opening portion H1.

[0028]In addition, in the present embodiment, phase separation of the polymer film 7 is not made in the second opening portion H2, and the first pattern 7a is not formed in the polymer film 7 of the second opening portion H2. The reason is that the width W2 of the second opening portion H2 is shifted from the width W1 of the first opening portion H1 which is a width in which phase separation is made.

[0029]In addition, in the present embodiment, phase separation of the polymer film 7 is made in the third opening portion H3, and multiple first patterns 7a are formed in the polymer film 7 of the third opening portion H3. The reason is that the width W3 of the third opening portion H3 is great, and thus, the PMMA block B1 and the PS block B2 easily and freely move in polymer film 7. The first pattern 7a in the third opening portion H3 is randomly formed in the peripheral portion of the third opening portion H3.

[0030]In the present embodiment, one multiple first patterns 7a may be formed in the second opening portion H2. In addition, in the present embodiment, only one first pattern 7a may be formed in the third opening portion H3, and the first pattern 7a may not be formed in the third opening portion H3.

[0031]FIGS. 9A and 9B are perspective views illustrating examples of the first pattern 7a in the third opening portion H3 according to the first embodiment.

[0032]FIG. 9A illustrates a first example of the first patterns 7a in the third opening portion H3. In the first example, the first patterns 7a extend in parallel in the Z direction.

[0033]FIG. 9B illustrates a second example of the first patterns 7a in the third opening portion H3. In the second example, the first patterns 7a vertically extend the Z direction.

[0034]The first patterns 7a in the first opening portion H1 are formed so as to extend in parallel in the Z direction in the same manner as in the first example.

[0035]Hereinafter, a pattern forming method according to the present embodiment will be continuously described with reference to FIG. 3B to FIG. 7B.

[0036]Subsequently, by developing the polymer film 7, the first pattern 7a is selectively removed, and the second pattern 7b remains (FIG. 3b). By doing so, one opening portion P1 is formed in the polymer film 7 of the first opening portion H1, and multiple opening portions P3 are formed in the polymer film 7 of the third opening portion H3. The opening portion P1 according to the present embodiment is a hole pattern with a diameter of 20 nm. For example, the above-described developing is performed by irradiating the polymer film 7 with vacuum-ultraviolet (VUV) light for cutting the combination of the PMMA block B1, and melting PMMA using isopropyl alcohol (IPA).

[0037]Subsequently, the polymer film 7 in the bottom portion of the opening portions P1 and P3 is removed by using a reactive ion etching (RIE) method (FIG. 4A). By doing so, the second mask layer 6 is exposed in the opening portions P1 and P3. At this time, the thickness of the polymer film 7 of the third opening portion H3 is smaller in the central portion, and thus, the opening portion P3 is also formed in the central portion of the polymer film 7 of the third opening portion H3.

[0038]Subsequently, etching is performed by using the polymer film 7 (second pattern 7b) as a mask, and thereby the second mask layer 6 in the bottom portion of the opening portions P1 and P3 is removed (FIG. 4B). As a result, the opening portions P1 and P3 are transferred to the second mask layer 6, and the first mask layer 4 is exposed in the opening portions P1 and P3.

[0039]Subsequently, etching is performed by using at least one of the polymer film 7 and the second mask layer 6 as a mask, and thereby the first mask layer 4 in the bottom portion of the opening portions P1 and P3 is removed (FIG. 5A). As a result, the opening portions P1 and P3 are transferred to the first mask layer 4, and the workpiece layer 3 is exposed in the opening portions P1 and P3. Since both the first mask layer 4 and the polymer film 7 are organic films, the polymer film 7 is also removed during etching of the first mask layer 4.

[0040]By doing so, the opening portion P1 passes through the second mask layer 6 in the first opening portion H1 and the first mask layer 4 under the first opening portion H1. In the same manner, the multiple opening portions P3 pass through the second mask layer 6 in the first opening portion H1 and the first mask layer 4 under the first opening portion H1. Meanwhile, an opening portion is not formed in the second mask layer 6 in the second opening portion H2 and the first mask layer 4 under the second opening portion H2.

[0041]Subsequently, an organic film 8 is formed by using mixed gas in which methane (CH4) gas is mixed with tetrafluoromethane (CF4) gas (FIG. 5B). The organic film 8 according to the present embodiment is a fluorocarbon film containing carbon and fluorine, and is formed by generating plasma at a low bias using the mixed gas. Furthermore, the organic film 8 may contain hydrogen. The organic film 8 is formed in an etching chamber in which etching of FIG. 4B and FIG. 5A is performed. The organic film 8 is an example of a fifth film.

[0042]The organic film 8 according to the present embodiment is formed on the workpiece layer 3, the first mask layer 4, the resist layer 5, and the second mask layer 6 so as to cover the first opening portion H1, and so as not to cover the second and third opening portions H2 and H3. An arrow A1 denotes a state in which end portions of the organic film 8 come into contact with each other on the first opening portion H1, and an opening end (upper end) of the first opening portion H1 is covered by the organic film 8. Arrows A2 and A3 denote a state in which end portions (upper ends) of the second and third opening portions H2 and H3 are not covered by the organic film 8. The organic film 8 includes a portion 8a which is formed on a surface of the first mask layer 4, the resist layer 5, or the second mask layer 6, and a portion 8b which is formed on a surface of the workpiece layer 3.

[0043]In the present embodiment, the width W1 of the first opening portion H1 is set to be smaller than the width W2 of the second opening portion H2 or the width W3 of the third opening portion H3. For this reason, the first opening portion H1 is covered before the second and third opening portions H2 and H3 are covered. Hence, in the present embodiment, the organic film 8 is continuously deposited until the first opening portion H1 is covered, and deposition of the organic film 8 is completed before the second and third opening portions H2 and H3 are covered.

[0044]The organic film 8 may be formed by using only methane (CH4) gas. In this case, the organic film 8 is formed of a carbon film which contains carbon and does not contain fluorine. Furthermore, the organic film 8 may not contain hydrogen.

[0045]Subsequently, the organic film 8 is isotropically etched by using oxygen (O2) gas (FIG. 6A). As a result, the organic film 8 in the second opening portion H2 is removed, and the second mask layer 6 in the second opening portion H2 is exposed.

[0046]Since the first opening portion H1 is covered, oxygen ions or oxygen radicals hardly reach the organic film 8 in the first opening portion H1. Meanwhile, since the second opening portion H2 is not covered, oxygen ions or oxygen radicals easily reach the organic film 8 in the second opening portion H2. Hence, in a state in which the first opening portion H1 is covered by the organic film 8, it is possible to expose the second mask layer 6 in the second opening portion H2. At this time, the portion 8b of the organic film 8 in the third opening portion H3 may remain or may not remain.

[0047]The second mask layer 6 according to the present embodiment is an inorganic film. For this reason, the second mask layer 6 in the second opening portion H2 functions as an etching stopper when the organic film 8 in the second opening portion H2 is etched. Hence, in the present embodiment, the size of the second opening portion H2 in a horizontal direction can be accurately controlled by the second mask layer 6.

[0048]Subsequently, the second mask layer 6 on the bottom surface of the second opening portion H2 is removed by a RIE method, using the organic film 8 as a mask (FIG. 6B). As a result, the first mask layer 4 is exposed on the bottom surface of the second opening portion H2. At this time, the second mask layer 6 remaining on the bottom surface of the third opening portion H3 is also removed.

[0049]Subsequently, the first mask layer 4 under the second opening portion H2 is removed by a RIE method, using the organic film 8 as a mask (FIG. 7A). As a result, the workpiece layer 3 is exposed under the second opening portion H2. At this time, the first mask layer 4 remaining on the bottom surface of the third opening portion H3 is also removed.

[0050]Since both the first mask layer 4 and the organic film 8 are organic films, the organic film 8 is also etched during etching of the first mask layer 4. Hence, in the etching of FIG. 7A, if the organic film 8 is removed at a certain place on the substrate 1, the resist layer 5 or the second mask layer 6 in a certain place functions as a mask thereafter.

[0051]In FIG. 7A, over-etching is performed until the organic film 8 of the first opening portion H1 or the third opening portion H3 is completely removed. At this time, the second mask layer 6 remains on the bottom surface of the first opening portion H1, and thus, it is possible to prevent the opening portion P1 from being expanded.

[0052]By doing so, the second mask layer 6 in the second opening portion H2 and the first mask layer 4 under the second opening portion H2 are remove, and the workpiece layer 3 is exposed under the second opening portion H2. FIG. 7A illustrates the opening portion P2 which passes through the second mask layer 6 in the second opening portion H2 and the first mask layer 4 under the second opening portion H2. In the same manner, the second mask layer 6 remaining in the third opening portion H3 and the first mask layer 4 remaining under the third opening portion H3 are removed, and the workpiece layer 3 is widely exposed under the third opening portion H3. Meanwhile, the workpiece layer 3 is exposed in advance in the opening portion P1 under the first opening portion H1.

[0053]Subsequently, the workpiece layer 3 is processed by using a RIE method, using at least one of the first mask layer 4, the resist layer 5, and the second mask layer 6 as a mask (FIG. 7B). As a result, first, second, and third opening portions R1, R2, and R3 are respectively formed in the workpiece layers 3 under the first, second, and third opening portions H1, H2, and H3. The second mask layer 6 is removed by the RIE method. Thereafter, the first mask layer 4 and the resist layer 5 are removed by annealing.

[0054]FIG. 7B illustrates a width L1 of the first opening portion R1 in the X direction, the width L2 of the second opening portion R2 in the X direction, and the width L3 of the third opening portion R3 in the X direction. The first opening portion R1 according to the present embodiment is a hole pattern in a memory cell portion, and the width (diameter) L1 is 20 nm. The second opening portion R2 according to the present embodiment is a hole pattern in a periphery circuit portion, and the width (diameter) L2 is 100 nm. The width L2 is greater than the width L1. The third opening portion R3 according to the present embodiment is a groove pattern for an alignment mark extending in the Y direction, and the width (line width) L3 is 1 mm. The width L3 is greater than the width L2.

[0055]Thereafter, a metal material is buried in the first, second, and third opening portions R1, R2, and R3. By doing so, contact plugs are formed in the first and second opening portions R1 and R2, and an alignment mark is formed in the third opening portion R3.

[0056]As described above, in the present embodiment, the first mask layer 4 under the first opening portion H1 is processed by using the polymer film 7 as a mask, and the first mask layer 4 under the second and third opening portions H2 and H3 is processed by using the organic film 8 as a mask. Hence, according to the present embodiment, lithography is simply performed once when the first to third opening portions H1 to H3 are formed (refer to FIG. 1B), and thus, it is possible to form the first to third opening portions R1 to R3 having desired sizes in the workpiece layer 3.

[0057]In the present embodiment, by using the organic film 8 as a mask, it is possible to prevent lithography from being performed twice or more. For example, if the lithography is performed after etching, the substrate 1 needs to be moved from an etching chamber to an exposure machine. Meanwhile, the organic film 8 according to the present embodiment can be formed in an etching chamber, as described with reference to FIG. 5B. Hence, according to the present embodiment, it is possible to simplify fabrication processes of a semiconductor device, compared to a case in which lithography is performed twice or more.

[0058]In the present embodiment, the polymer film 7 is used as a mask, and thus, it is possible to form the first opening portion R1 with the width L1 smaller than the width W1 of the first opening portion H1, and to form fine patterns. According to the present embodiment, it is possible to form the fine patterns by performing the lithography once in common with other patterns.

[0059]As described above, according to the present embodiment, it is possible to efficiently form multiple patterns with sizes different from each other.

[0060]The first and second opening portions R1 and R2 may be concave portions other than contact holes. As an example, the concave portion is a space portion having a line and space (L/S) pattern. In the same manner, the third opening portion R3 may be a concave portion other than a groove for an alignment mark.

[0061]In addition, the polymer of the polymer film 7 may be BCP other than PS-b-PMMA. In addition, the second mask layer 6 may be an inorganic film other than a silicon oxide film. In addition, the resist layer 5 may be replaced with a mask layer other than a resist layer. For example, the resist layer 5 may be replaced with a spin-on-carbon (SOC) film, or a laminating film which includes the SOC film and a silicon oxide film.

[0062]While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

WHAT IS CLAIMED IS:

1. A pattern forming method comprising:

forming a workpiece layer on a substrate;

forming a first film on the workpiece layer;

forming a second film on the first film;

forming a first concave portion with a first width and a second concave portion with a second width greater than the first width, in the second film;

forming a third film in the first and second concave portions;

forming a fourth film including a polymer having a first portion and a second portion, on the third film in the first and second concave portions;

forming a first pattern including the first portion and a second pattern including the second portion, in the fourth film by phase-separating the first portion and the second portion;

removing the first pattern;

processing the third film in the first concave portion, using the second pattern as a mask;

processing the first film under the first concave portion, using at least one of the second pattern and the third film as a mask;

forming a fifth film which covers the first concave portion and does not cover the second concave portion, on the first, second, and third films;

processing the third film in the second concave portion and the first film under the second concave portion, using the fifth film as a mask; and

processing the workpiece layer, using at least one of the first, second, and third films as a mask.

2. The method according to Claim 1, wherein the phase-separating is made in the first concave portion and is not made in the second concave portion.

3. The method according to Claim 1, wherein the phase-separating is made in the first and second concave portions.

4. The method according to any one of Claims 1 to 3, wherein the third film is formed so as to have a first minimum film thickness in the first concave portion, and to have a second minimum film thickness, which is smaller than the first minimum film thickness, in the second concave portion.

5. The method according to any one of Claims 1 to 4, wherein the polymer is a block copolymer which has a first polymer block as the first portion and a second polymer block as the second portion.

6. The method according to any one of Claims 1 to 5, wherein the fifth film contains carbon.

7. A pattern forming method comprising:

forming a workpiece layer on a substrate;

forming a first film on the workpiece layer;

forming a second film on the first film;

forming a first concave portion with a first width, a second concave portion with a second width greater than the first width, and a third concave portion with a third width greater than the second width, in the second film;

forming a third film in the first, second, and third concave portions;

forming a fourth film including a polymer having a first portion and a second portion, on the third film in the first, second, and third concave portions;

forming a first pattern including the first portion and a second pattern including the second portion, in the fourth film by phase-separating the first portion and the second portion;

removing the first pattern;

processing the third film in the first concave portion, using the second pattern as a mask;

processing the first film under the first concave portion, using at least one of the second pattern and the third film as a mask;

forming a fifth film which covers the first concave portion and does not cover the second and third concave portions, on the first, second, and third films;

processing the third film in the second and third concave portions and the first film under the second and third concave portions, using the fifth film as a mask; and

processing the workpiece layer, using at least one of the first, second, and third films as a mask.

8. The method according to Claim 7, wherein the phase-separating is made in the first and third concave portions and is not made in the second concave portion.

9. The method according to Claim 7 or 8, wherein the third film is formed so as to have a first minimum film thickness in the first concave portion, and to have a second minimum film thickness, which is smaller than the first minimum film thickness, in the second concave portion, and to have a third minimum film thickness, which is smaller than the second minimum film thickness, in the third concave portion.

ABSTRACT

According to one embodiment, a pattern forming method includes forming a workpiece layer on a substrate, forming a first film and a second film, and forming first and second concave portions in the second film. The method further includes forming third and fourth films in the first and second concave portions, and forming first and second patterns in the fourth film by phase-separating of the fourth film. The method further includes processing the third film in the first concave portion using the second pattern, and processing the first film thereunder. The method further includes forming a fifth film which covers the first concave portion and does not cover the second concave portion, on the first, second, and third films, processing the third film in the second concave portion and the first film under the second concave portion, using the fifth film, and processing the workpiece layer, using the first, second, or third film.