

removal of irradiated regions of the radiation-sensitive material (as in the case of positive photoresist), or non-irradiated regions (as in the case of negative resist) using a developing solvent. This mask layer can comprise multiple sub-layers.

[5] Conventional lithographic techniques for exposing a pattern of radiation or light onto a substrate have various challenges that limit a size of features exposed, and limit pitch or spacing between exposed features. One conventional technique to mitigate exposure limitations is that of using a double patterning approach to allow the patterning of smaller features at a smaller pitch than what is currently possible with conventional lithographic techniques.

SUMMARY

[5a] According to a first aspect of the present invention, there is provided a method of patterning a substrate, the method comprising:

- forming mandrels on a target layer of a substrate, the mandrels being comprised of a first material, the target layer being comprised of a third material;

- forming sidewall spacers on sidewalls of the mandrels by depositing a conformal film on the substrate and removing portions of the conformal film above top surfaces of the mandrels while leaving the conformal film below top surfaces of the mandrels such that the sidewall spacers are formed on vertical sidewalls of the mandrels and such that the conformal film covers the target layer between adjacent sidewall spacers, the conformal film being comprised of a second material;

- forming a first etch mask on the substrate, the first etch mask defining openings that uncover regions of both the first material and the second material

- executing a first etch process that selectively etches uncovered portions of the second material until the conformal film covering the target layer between adjacent sidewall spacers is removed while the sidewall spacers remain on the substrate; and

- forming a second etch mask on the substrate, the second etch mask defining openings that uncover regions of both the first material and the second material; and

- executing a second etch process that selectively etches uncovered portions of the first material until uncovered mandrels are removed.

[5b] According to a second aspect of the present invention, there is provided a method of patterning a substrate, the method comprising:

- forming mandrels on a target layer of a substrate using a first etch mask, the mandrels being comprised of a first material, the target layer being comprised of a third material, wherein a film of the first material covers the target layer between the mandrels such that a top surface of the mandrels is greater in height as compared to a top surface of the film of the first material;

- forming sidewall spacers on sidewalls of the mandrels, the sidewall spacers being comprised of a second material, the sidewall spacers defining open spaces between each other that leave the film of the first material uncovered;

- depositing a fill material on the substrate that at least partially fills the open spaces defined between the sidewall spacers, the fill material being comprised of a fourth material, wherein the first material, the third material and the fourth material are all chemically different from each other;

- forming a second etch mask on the substrate, the second etch mask defining openings that uncover portions of the top layer of the mandrels;

- after forming the second etch mask, executing a first etch process that etches, using the second etch mask, the uncovered portions of the fill material and that etches uncovered portions of the top layer of the mandrels;

- after executing the first etch process, forming a third etch mask on the substrate, the third etch mask defining openings that uncover regions of both the first material and the second material; and

- executing a second etch process, using the third etch mask, that selectively etches uncovered portions of the first material until uncovered mandrels are removed.

[5c] According to a third aspect of the present invention, there is provided a method of patterning a substrate, the method comprising:

- forming a tri-layer stack on a target layer, the tri-layer stack including a bottom layer, an intermediate layer, and an upper layer, each layer being deposited as a horizontal and homogeneous layer, the upper layer being comprised of a first material, the intermediate layer being comprised of a fifth material, the bottom layer being comprised of a sixth material, the target layer being comprised of a third material;

forming mandrels comprised of the first material by using a first etch mask and executing a first etch process that etches a mandrel pattern into the upper layer until uncovering the intermediate layer, the intermediate layer having a different etch resistivity as compared to the upper layer such that the intermediate layer provides an etch stop layer for the first etch process;

forming sidewall spacers on sidewalls of the mandrels, the sidewall spacers being comprised of a second material, the sidewall spacers defining open spaces between each other that leave the bottom layer uncovered;

forming a second etch mask on the substrate, the second etch mask defining openings that uncover regions of both the first material and the second material;

executing a second etch process, using the second etch mask, that selectively etches uncovered portions of the sixth material until the bottom layer covering the target layer between adjacent sidewall spacers is removed while the sidewall spacers remain on the substrate;

after executing the second etch process, forming a third etch mask on the substrate, the third etch mask defining openings that uncover regions of both the first material and the second material; and

executing a third etch process, using the third etch mask, that selectively etches uncovered portions of the mandrels until uncovering the intermediate layer.

[6] Semiconductor technologies are continually progressing to smaller feature sizes including feature sizes of 14 nanometers, 7 nm, 5 nm, and below. This continual reduction in sizes of features from which various elements are fabricated places ever-greater demands on techniques used to form the features. The concept of “pitch” can be used to describe the sizing of these features. Pitch is the distance between the two identical points in two adjacent repetitive features. Half-pitch then is half the distance between identical features of an array.

[7] Pitch reduction techniques, often somewhat erroneously yet routinely termed “pitch multiplication” as exemplified by “pitch doubling” etc., can extend the capabilities of photolithography beyond feature size limitations (optical resolution limitations). That is, conventional multiplication of pitch (more accurately pitch reduction or multiplication of pitch density) by a certain factor involves reducing a

target pitch by a specified factor. Double patterning techniques used with 193 nm immersion lithography are conventionally considered as one of the most promising techniques to pattern 22nm nodes and smaller. Noteworthy is that self-aligned spacer double patterning (SADP) has already been established as a pitch density doubling process and has been adapted in high volume manufacturing of NAND flash memory devices. Moreover, ultra-fine resolution can be obtained to repeat the SADP step twice as pitch quadrupling.

[8] Although there exist several patterning techniques to increase pattern density or pitch density, conventional patterning techniques suffer from poor resolution or rough surfaces of etched features. Thus, conventional techniques

CLAIMS

1. A method of patterning a substrate, the method comprising:

forming mandrels on a target layer of a substrate, the mandrels being comprised of a first material, the target layer being comprised of a third material;

forming sidewall spacers on sidewalls of the mandrels by depositing a conformal film on the substrate and removing portions of the conformal film above top surfaces of the mandrels while leaving the conformal film below top surfaces of the mandrels such that the sidewall spacers are formed on vertical sidewalls of the mandrels and such that the conformal film covers the target layer between adjacent sidewall spacers, the conformal film being comprised of a second material;

forming a first etch mask on the substrate, the first etch mask defining openings that uncover regions of both the first material and the second material

executing a first etch process that selectively etches uncovered portions of the second material until the conformal film covering the target layer between adjacent sidewall spacers is removed while the sidewall spacers remain on the substrate; and

forming a second etch mask on the substrate, the second etch mask defining openings that uncover regions of both the first material and the second material; and

executing a second etch process that selectively etches uncovered portions of the first material until uncovered mandrels are removed.

2. The method of claim 1, wherein forming the sidewall spacers includes depositing a second filler material on the substrate, the second filler material filling trenches defined by the conformal film; and

executing a chemical-mechanical polishing step that removes conformal film material and second filler material above top surfaces of the mandrels.

3. The method of claim 2 further comprising removing the second filler material from the trenches defined by the conformal film.

4. The method of claim 1, wherein forming the sidewall spacers includes depositing a second filler material on the substrate, the second filler material filling trenches defined by the conformal film;

executing a third etching process that etches the second filler material until uncovering top surfaces of the conformal film;

executing a fourth etching process that etches the conformal film until uncovering top surfaces of the mandrels.

5. The method of claim 4, further comprising removing the second filler material from the substrate.

6. The method of claim 1, further comprising:

removing the first etch mask subsequent to executed the first etch process and prior to forming the second etch mask; and

removing the second etch mask subsequent to executing the second etch process, remaining portions of the mandrels, the sidewall spacers, and the conformal film covers the target layer between adjacent sidewall spacers, together forming a combined relief pattern.

7. The method of claim 6, further comprising executing a fifth etch process that uses the combined relief pattern as an etch mask and transfers a corresponding pattern into the target layer.

8. The method of claim 1, wherein forming the first etch mask includes depositing a first filler material on the substrate that planarizes the substrate, wherein the first etch mask is formed on the first filler material, the first filler material comprised of a fourth material, wherein during the first etch process, the first material and the second material and the third material and the fourth material exhibit different etch resistivities relative to each other such that the mandrel formed of the first material is not etched, a height of the spacer sidewall formed of the second material is reduced, an exposed portion of the target layer formed of the third material is not etched, and uncovered portions of the first filler material formed of the fourth material are removed.

9. The method of claim 1, wherein forming the second etch mask includes depositing a second filler material on the substrate that planarizes the substrate, wherein the second etch mask is formed on the second filler material, the second filler material comprised of a fourth material, wherein during the second etch process, the first material and the second material and the third material and the fourth material exhibit different etch resistivities relative to each other such that the mandrel formed of the first material is removed, the spacer sidewall formed of the second material is not etched, an exposed portion of the target layer formed of the third material is not etched, and uncovered portions of the second filler material formed of the fourth material are not removed.

10. A method of patterning a substrate, the method comprising:

forming mandrels on a target layer of a substrate using a first etch mask, the mandrels being comprised of a first material, the target layer being comprised of a third material, wherein a film of the first material covers the target layer between the mandrels such that a top surface of the mandrels is greater in height as compared to a top surface of the film of the first material;

forming sidewall spacers on sidewalls of the mandrels, the sidewall spacers being comprised of a second material, the sidewall spacers defining open spaces between each other that leave the film of the first material uncovered;

depositing a fill material on the substrate that at least partially fills the open spaces defined between the sidewall spacers, the fill material being comprised of a fourth material, wherein the first material, the third material and the fourth material are all chemically different from each other;

forming a second etch mask on the substrate, the second etch mask defining openings that uncover portions of the top layer of the mandrels;

after forming the second etch mask, executing a first etch process that etches, using the second etch mask, the uncovered portions of the fill material and that etches uncovered portions of the top layer of the mandrels;

after executing the first etch process, forming a third etch mask on the substrate, the third etch mask defining openings that uncover regions of both the first material and the second material; and

executing a second etch process, using the third etch mask, that selectively etches uncovered portions of the first material until uncovered mandrels are removed.

11. A method of patterning a substrate, the method comprising:

forming a tri-layer stack on a target layer, the tri-layer stack including a bottom layer, an intermediate layer, and an upper layer, each layer being deposited as a horizontal and homogeneous layer, the upper layer being comprised of a first material, the intermediate layer being comprised of a fifth material, the bottom layer being comprised of a sixth material, the target layer being comprised of a third material;

forming mandrels comprised of the first material by using a first etch mask and executing a first etch process that etches a mandrel pattern into the upper layer until uncovering the intermediate layer, the intermediate layer having a different etch resistivity as compared to the upper layer such that the intermediate layer provides an etch stop layer for the first etch process;

forming sidewall spacers on sidewalls of the mandrels, the sidewall spacers being comprised of a second material, the sidewall spacers defining open spaces between each other that leave the bottom layer uncovered;

forming a second etch mask on the substrate, the second etch mask defining openings that uncover regions of both the first material and the second material;

executing a second etch process, using the second etch mask, that selectively etches uncovered portions of the sixth material until the bottom layer covering the target layer between adjacent sidewall spacers is removed while the sidewall spacers remain on the substrate;

after executing the second etch process, forming a third etch mask on the substrate, the third etch mask defining openings that uncover regions of both the first material and the second material; and

executing a third etch process, using the third etch mask, that selectively etches uncovered portions of the mandrels until uncovering the intermediate layer.

12. The method of claim 11,

wherein executing the third etch process further includes, after the uncovered portions of the mandrels are selectively etched, then etching uncovered portions of the intermediate layer, and then etching uncovered portions of the bottom layer until uncovering the target layer, wherein during the third etch process, the first material and the second material exhibit different etch resistivities.

13. The method of claim 11, wherein during the second etch process, the first material and the sixth material exhibit a same etch resistivity.

14. The method of claim 11, wherein during the third etch process, the fifth material and the second material exhibit a same etch resistivity.

15. The method of claim 11, wherein the etch stop layer and the sidewall spacers are comprised of a same material.