**[0007]** In some embodiments, if the one or more frontside layers are not compensated by the first backside layer, the substrate has a first bow or a second bow of about 300 μm or more. In some embodiments, the first non-uniform thickness profile is a curved bar that is thicker toward a center of the substrate than edges of the substrate. In some embodiments, the curved bar has a longitudinal axis that is substantially parallel to the y-direction. In some embodiments, the curved bar has a generally parabolic shape that varies in thickness in a z-direction perpendicular to the x- and y-directions, away from the backside of the substrate as a function of the x-direction. In some embodiments, the second non-uniform thickness profile is a curved channel that is thicker toward edges of the substrate than a center of the substrate. In some embodiments, the curved channel has a parabolic shape that varies in thickness in a z-direction, away from the backside of the substrate as a function of the x-direction. In some embodiments, the first type of internal stress is a tensile stress. In some embodiments, the first type of internal stress is a compressive stress. In some embodiments, further including a third backside layer on the backside of the substrate, wherein the third backside layer has a uniform shape and either the first or the second type of internal stress. In some embodiments, the type of internal stress and a magnitude of the internal stress of the third backside layer is based upon bowing of the substrate after forming the first backside layer and the second backside layer. In some embodiments, further including additional complementary film stacks. In some embodiments, the complementary film stack and the additional complementary film stacks together alternate between the first backside layer and the second backside layer. In some embodiments, a total thickness of all complementary film stacks is at least about 2μm. In some embodiments, a thickness of each complementary film stack is less than about 1 μm. In some embodiments, a change in total wafer bow compensation of all of the complementary film stacks after annealing is less than about 20%. In some embodiments, further including a third backside layer on the backside of the substrate deposited after all of the complementary film stacks, wherein the third backside layer increases a flatness of the backside of the substrate.

**[0008]** In another aspect of the embodiments herein, an apparatus is provided, the apparatus including: a process chamber; and a controller including memory and processors configured for: receiving a substrate having a frontside and a backside, wherein the substrate has a first bow in an x-direction of the substrate and a second bow in a y-direction of the substrate; performing one or more cycles of: (a) forming a first backside layer on the backside of the substrate, wherein the first backside layer compensates the first bow more than it compensates the second bow or compensates

shaped wafer may have backside layers deposited thereon that change the shape to a bowl or dome shaped wafer. The difference between x-bow and y-bow is reduced, but the wafer is still bowed. A uniform thickness profile cap layer may compensate for such a wafer bow by having a uniform tensile internal stress or compressive internal stress. As the x-bow and y-bow have been substantially equalized by the complementary profile films, the uniform thickness profile film may thus compensate the remaining wafer bow.

**[0060]** Figure 3G presents an illustration of a filler layer 344. During deposition of a curved bar profile film 308, a curved bar profile film may have a "center drop," where the thickness of the film has two maxima offset from a center position of the film at or near radius zero (i.e., at or near the wafer center), and at radius zero the thickness of the film is less than the maxima. This difference in thickness may be insubstantial for small thicknesses of complementary profile films, e.g., less than about 1μm. However, for larger thicknesses of the complementary profile films or an alternating stack of complementary profile films having a large overall thickness, e.g., greater than about 2 μm or greater than about 2.5 μm, the center drop may become noticeable and affect the flatness of the film. Thus, a filler layer 344 may be deposited to fill the gap formed in the curved bar profile film. In some embodiment, a filler layer 344 may be deposited to fill the gap formed in the curved channel profile film, for example, where the alternating stack film 340 is formed similarly to that of Figure 3D. Filler layer 344 may be deposited using similar techniques as curved bar profile 344 with a sharper taper in thickness as a function of radius.

**[0061]** An alternating stack of films may have various advantages over a single stack. As noted above, an alternating stack of films has a higher cracking margin. This may result from the compressive stress film applying a compressive stress on the tensile stress films, reducing the internal tensile stress at the exterior edge of the tensile stress film and thus reducing the risk of cracking.

**[0062]** An alternating stack of films may also have improved thermal stability. Backside layers such as silicon nitride may have a stress shift under thermal annealing conditions, e.g., during fabrication processes performed at about 600°C or higher. A stress shift is the change in internal stress of a film, typically after annealing, which is generally undesirable as it may reduce the effectiveness of films to compensate wafer bow or increases the risk of cracking. This stress shift may result from unreacted species in the film, such as hydrogen and nitrogen, which may be

**[00112]** Further shown is that a top surface of the ShoPed 606 will include a hole pattern 606a that is distributed throughout the surface to provide even distribution and output of gases during operation. In one embodiment, the hole pattern 606a is distributed in a plurality of concentric rings that start at the center of the top surface of the ShoPed 606 and extend to an outer periphery of the ShoPed 606. At least one hole pattern 606a is provided at an edge hole region 607 of the hole pattern, and orifices defined in the edge hole region 607 are preferably angled to provide gases non-perpendicular to the surface of the ShoPed 606.

**[00113]** In one example, the angle or tilt at which the orifices in the edge hole region 607 is defined to tilt or angle away from the center of the ShoPed 606. In one embodiment, the angle is approximately 45° from horizontal. In other embodiments, the angle can vary between 20° from horizontal to about 80° from horizontal. In one embodiment, by providing the angled orifices in the edge hole region 607, additional distribution of process gases can be provided during backside deposition of the wafer 602. In one embodiment, the remainder orifices 606d of the hole pattern 606a are oriented substantially perpendicular to the surface of the ShoPed 606 and directed toward the underside of the wafer 602.

**[00114]** Figure 7B illustrates that when the wafer 602 is held by the carrier ring 654, the wafer 602 edge will sit on an edge region closer to the carrier ring inner radius 654a of the carrier ring 654. The surface of the showerhead 636 facing the top surface of the wafer 602, when positioned using spacers 644, may be substantially close to prevent deposition during a mode where deposition is being carried out to the backside of the wafer 602.

**[00115]** By way of example, the distance between the top of the wafer 602 and the surface of the showerhead 636 is preferably between about 2 mm to about.5 mm, and in some embodiments about 1 mm to about .5 mm, depending on the wafer bow. That is, if the wafer is bowed substantially, the separation will be about .5 mm or larger. If the wafer is not yet bowed substantially, the separation can be less than about .5 mm. In one embodiment, it is preferable that the separation be minimized to prevent deposition on the top side of the substrate when the backside of the substrate is being deposited with a layer of material. In some embodiments, the showerhead 636 is configured to supply an inert gas flow over the top side of the wafer 602 during when the backside of the substrate is being deposited and deposition gases are being supplied by the ShoPed 606.

## CLAIMS

1. A method of reducing bow in a substrate, the method comprising:

receiving a substrate having a frontside and a backside, wherein the substrate has a first bow in an x-direction of the substrate and a second bow in a y-direction of the substrate;

performing one or more cycles of:

(a) forming a first backside layer on the backside of the substrate, wherein the first backside layer compensates the first bow more than it compensates the second bow or compensates the second bow more than it compensates the first bow, and wherein the first backside layer has a first type of internal stress and a first non-uniform thickness profile;

(b) forming a second backside layer on the backside of the substrate, wherein the second backside layer compensates either of the first bow or the second bow that was less compensated by the first backside layer, wherein the second backside layer has a second type of internal stress, which is opposite the first type of internal stress, and a second non-uniform thickness profile; and

wherein the first non-uniform thickness profile and the second non-uniform thickness profile complement each other, such that when the first backside layer and second backside layers are formed, they provide a complementary film stack having a substantially flat surface on the backside of the substrate.

2. The method of claim 1, wherein the substrate is a semiconductor wafer having partially fabricated integrated circuits on the front side.

3. The method of claim 1, wherein the first non-uniform thickness profile is a curved bar that is thicker toward a center of the substrate than edges of the substrate.

4. The method of claim 3, wherein the curved bar has a longitudinal axis that is substantially parallel to the y-direction.

5. The method of claim 3, wherein the curved bar has a generally parabolic shape that varies in thickness in a z-direction perpendicular to the x- and y-directions, away from the backside of the substrate as a function of the x-direction.

6. The method of claim 1, wherein the second non-uniform thickness profile is a curved channel that is thicker toward edges of the substrate than a center of the substrate.

7. The method of claim 6, wherein the curved channel has a parabolic shape that varies in thickness in a z-direction, away from the backside of the substrate as a function of the x-direction.

8. The method of claim 1, further comprising forming a third backside layer on the backside of the substrate, wherein the third backside layer has a uniform shape and either the first or the second type of internal stress.

9. The method of claim 1, wherein the one or more cycles are two or more cycles.

10. The method of claim 1, wherein first backside layer and the second backside layer exhibit a change in wafer bow compensation after annealing less than about 20%.

11. The method of claim 1, further comprising performing a plasma treatment after forming the first backside layer, performing a plasma treatment after forming the second backside layer, or both, wherein the plasma treatment improves adhesion of backside layers.

12. A substrate comprising:

one or more frontside layers on a frontside of the substrate, wherein the substrate has a first bow in an x-direction of the substrate and a second bow in a y-direction of the substrate;

a first backside layer on a backside of the substrate, wherein the first backside layer compensates the first bow more than it compensates the second bow or compensates the second bow more than it compensates the first bow, and wherein the first backside layer has a first type of internal stress and a first non-uniform thickness profile;

a second backside layer on the backside of the substrate, wherein the second backside layer compensates either of the first bow or the second bow that was less compensated by the first backside layer, wherein the second backside layer has a second type of internal stress, which is opposite the first type of internal stress, and a second non-uniform thickness profile; and wherein the first non-uniform thickness profile and the second non-uniform thickness profile complement each other, such that when the first backside layer and second backside layers are formed, they provide a complementary film stack having a substantially flat surface on the backside of the substrate.

13. The substrate of claim 12, wherein the first non-uniform thickness profile is a curved bar that is thicker toward a center of the substrate than edges of the substrate.

14. The substrate of claim 12, further comprising additional complementary film stacks.

15. An apparatus for semiconductor processing, the apparatus comprising:

a process chamber; and

a controller comprising memory and processors configured for:

receiving a substrate having a frontside and a backside, wherein the substrate has a first bow in an x-direction of the substrate and a second bow in a y-direction of the substrate;

performing one or more cycles of:

(a) forming a first backside layer on the backside of the substrate, wherein the first backside layer compensates the first bow more than it compensates the second bow or compensates the second bow more than it compensates the first bow, and wherein the first backside layer has a first type of internal stress and a first non-uniform thickness profile;

(b) forming a second backside layer on the backside of the substrate, wherein the second backside layer compensates either of the first bow or the second bow that was less compensated by the first backside layer, wherein the second backside layer has a second type of internal stress, which is opposite the first type of internal stress, and a second non-uniform thickness profile; and

wherein the first non-uniform thickness profile and the second non-uniform thickness profile complement each other, such that when the first backside layer and second backside layers are formed, they provide a complementary film stack having a substantially flat surface on the backside of the substrate.