CLAIMS

WHAT IS CLAIMED:

1. A method, comprising:

exposing surface areas of a transistor of a semiconductor device to a plasma-free ammonia (NH_3) and nitrogen (N_2) containing atmosphere so as to prepare said surface areas for deposition of a first strain-inducing material layer;

forming said first strain-inducing material layer on said surface areas by using a first plasma assisted deposition process, said first strain-inducing material layer inducing a compressive strain in a channel region of said transistor and having a first internal stress level; and

forming a second strain-inducing material layer on said first strain-inducing material layer by using a second plasma assisted deposition process, said first plasma assisted deposition process differing from said second plasma assisted deposition process by at least one process parameter setting, said second strain-inducing material layer inducing a compressive strain in said channel region and having a second internal stress level that is higher than said first internal stress level.

2. The method of claim 1, further comprising maintaining a temperature of said semiconductor device in a range between 300-550°C when exposing said surface areas of said transistor to said plasma-free ammonia and nitrogen containing atmosphere.

3. The method of claim 1, wherein exposing surface areas of a transistor of a semiconductor device to a plasma-free ammonia and nitrogen containing atmosphere

comprises controlling a pressure of said atmosphere so as to be within a range from 1.8-3.0 Torr.

4. The method of claim 1, wherein exposing surface areas of a transistor of a semiconductor device to a plasma-free ammonia and nitrogen containing atmosphere comprises adjusting a flow rate ratio of ammonia to nitrogen so as to be within a range from 2/35 to 1.0.

5. The method of claim 4, further comprising supplying argon to said plasma-free ammonia and nitrogen containing atmosphere and controlling a flow rate ratio of said argon to said nitrogen so as to be within a range from 10/35 to 3.5.

6. The method of claim 1, wherein said surface areas are exposed to said plasma-free ammonia and nitrogen containing atmosphere for a time interval of at least 20 seconds.

7. The method of claim 1,wherein forming said first strain-inducing material layer by using said first plasma assisted deposition process comprises establishing a first plasma atmosphere by using high frequency (HF) power of a first HF power level and low frequency (LF) power of a first LF power level with a ratio of HF power level to LF power level in the range from 1.5 to 2.5.

8. The method of claim 7, wherein forming said second strain-inducing material layer by using said second plasma assisted deposition process comprises establishing a second plasma atmosphere by using high frequency power of a second HF power level that is

higher than said first HF power level and by using low frequency power of a second LF power level that is lower than said first LF power level.

9. The method of claim 1, wherein a thickness of said first strain-inducing material layer is less than a thickness of said second strain-inducing material layer.

10. The method of claim 9, wherein said thickness of said first strain-inducing material layer is 15 nm or less.

11. The method of claim 1, wherein said first and second strain-inducing material layers comprise silicon and nitrogen.

12. A method of forming a compressive bi-layer above a transistor, said method comprising:

removing oxygen-containing contaminants from a surface area above said transistor by establishing a chemically reactive atmosphere without supplying ionizing power to said chemically reactive atmosphere;

forming a first strain-inducing material layer on said surface area by establishing a first plasma atmosphere, said first strain-inducing material layer having a first internal stress level and a first thickness; and

forming a second strain-inducing material layer on said first strain-inducing material layer by establishing a second plasma atmosphere, said second plasma atmosphere differing from said first plasma atmosphere with respect to at least one process parameter, said second strain-inducing material layer having a second internal stress level and a second thickness, said second internal stress

level being higher than said fist internal stress level, said second thickness being greater than said first thickness.

13. The method of claim 12, wherein establishing said chemically reactive atmosphere comprises supplying ammonia gas (NH_3) and nitrogen gas (N_2) into a process environment used to contain said chemically reactive atmosphere.

14. The method of claim 13, wherein establishing said chemically reactive atmosphere comprises controlling a pressure so as to be in a range from 1.8-3.0 Torr.

15. The method of claim 12, wherein forming said second strain-inducing material layer comprises controlling said second internal stress level so as to be at 3.0 GPa or higher.

16. The method of claim 15, wherein forming said first strain-inducing material layer comprises controlling said first internal stress level so as to be in a range from 2.2-2.5 GPa.

17. The method of claim 15, wherein establishing said second plasma atmosphere comprises controlling a pressure so as to be in a range from 1.8-3.0 Torr.

18. The method of claim 17, wherein establishing said second plasma atmosphere comprises supplying ammonia and silane (SiH_4) as precursor gases and supplying argon and hydrogen as carrier and dilution gases, and wherein a ratio of flow rates of precursor gases to flow rates of carrier and dilution gases is in the range from 1/140 to 1/20.

19. The method of claim 12, further comprising performing three or more transition steps after forming said first strain-inducing material layer and prior to forming said second strain-inducing material layer, wherein a plasma atmosphere is maintained in each of said three or more transition steps.

20. A semiconductor device, comprising:

a first strain-inducing material layer formed above a P-channel transistor, said first strain-inducing material layer having a first thickness and a first internal stress level of 2.2-2.5 GPa so as to induce a compressive strain in a channel region of said transistor; and

a second strain-inducing material layer formed on said first strain-inducing material layer above said transistor, said second strain-inducing material layer having a second thickness and a second internal stress level of 3.0 GPa and higher, said first thickness being less than said second thickness.

CLAIMS

1. A method, comprising:

exposing surface areas of a transistor of a semiconductor device to a plasma-free ammonia (NH_3) and nitrogen (N_2) containing atmosphere so as to prepare said surface areas for deposition of a first strain-inducing material layer;

forming said first strain-inducing material layer on said surface areas using a first plasma assisted deposition process said first strain-inducing material layer inducing a compressive strain in a channel region of said transistor and having a first internal stress level;

wherein the first plasma assisted deposition process comprises:

(a) providing an initial process atmosphere comprising an initial flow rate of carrier gas of zero or higher at a low frequency power of from 30-150 W for a deposition time of about 15 seconds, and,

(b) performing:

(i) a first transition step comprising supplying a high frequency power of from about 60-160 W, the ratio of high frequency power to low frequency power being in the range of 1.5-2.5, and

(ii) a second transition step comprising increasing the flow rate of carrier gas while maintaining said high frequency power for a time of 72-110 seconds; and

forming a second strain-inducing material layer on said first strain-inducing material layer by using a second plasma assisted deposition process, said first plasma assisted deposition process differing from said second plasma assisted deposition process by at least one process parameter setting, said second strain-inducing material layer inducing a compressive strain in said channel region and having a second internal stress level that is higher than said first internal stress level.

2. The method of claim 1, further comprising maintaining a temperature of said semiconductor device in a range between 300-550℃. when exposing said surface areas of said transistor to said plasma-free ammonia and nitrogen containing atmosphere.

3. The method of claim 1, wherein exposing surface areas of a transistor of a semiconductor device to a plasma-free ammonia and nitrogen containing atmosphere

comprises controlling a pressure of said atmosphere so as to be within a range from 1.8-3.0 Torr.

4. The method of claim 1, wherein exposing surface areas of a transistor of a semiconductor device to a plasma-free ammonia and nitrogen containing atmosphere comprises adjusting a flow rate ratio of ammonia to nitrogen so as to be within a range from 2/35 to 1.0.

5. The method of claim 4, further comprising supplying argon to said plasma-free ammonia and nitrogen containing atmosphere and controlling a flow rate ratio of said argon to said nitrogen so as to be within a range from 10/35 to 3.5.

6. The method of claim 1, wherein said surface areas are exposed to said plasma-free ammonia and nitrogen containing atmosphere for a time interval of at least 20 seconds.

7. The method of claim 1, wherein a thickness of said first strain-inducing material layer is less than a thickness of said second strain-inducing material layer.

8. The method of claim 7, wherein said thickness of said first strain-inducing material layer is 15 nm or less.

9. The method of claim 1, wherein said first and second strain-inducing material layers comprise silicon and nitrogen.

10. The method of claim 1, wherein the carrier gas is argon.

11. A method of forming a compressive bi-layer above a transistor, said method comprising:

removing oxygen-containing contaminants from a surface area above said transistor by establishing a chemically reactive atmosphere without supplying ionizing power to said chemically reactive atmosphere;

forming a first strain-inducing material layer on said surface area by establishing a first plasma atmosphere, said first strain-inducing material layer having a first internal stress level and a first thickness; wherein the first plasma assisted deposition process comprises:

(a) providing an initial process atmosphere comprising an initial flow rate of carrier gas of zero or higher at a low frequency power of from 30-150 W for a deposition time of about 15 seconds, and,

(b) performing:

(i) a first transition step comprising supplying a high frequency power of from about 60-160 W, the ratio of high frequency power to low frequency power being in the range of 1.5-2.5, and

(ii) a second transition step comprising increasing the flow rate of carrier gas while maintaining said high frequency power for a time of 72-110 seconds; and

forming a second strain-inducing material layer on said first strain-inducing material layer by establishing a second plasma atmosphere, said second plasma atmosphere differing from said first plasma atmosphere with respect to at least one process parameter, said second strain-inducing material layer having a second internal stress level and a second thickness, said second internal stress level being higher than said first internal stress level, said second thickness being greater than said first thickness.

12. The method of claim 11, wherein establishing said chemically reactive atmosphere comprises supplying ammonia gas (NH_3) and nitrogen gas (N_2) into a process environment used to contain said chemically reactive atmosphere.

13. The method of claim 12, wherein establishing said chemically reactive atmosphere comprises controlling a pressure so as to be in a range from 1.8-3.0 Torr.

14. The method of claim 11, wherein forming said second strain-inducing material layer comprises controlling said second internal stress level so as to be at 3.0 GPa or higher.

15. The method of claim 14, wherein forming said first strain-inducing material layer comprises controlling said first internal stress level so as to be in a range from 2.2-2.5GPa.

16. The method of claim 14, wherein establishing said second plasma atmosphere comprises controlling a pressure so as to be in a range from 1.8-3.0 Torr.

17. The method of claim 16, wherein establishing said second plasma atmosphere comprises supplying ammonia and silane (SiH_4) as precursor gases and supplying argon and

hydrogen as carrier and dilution gases, and wherein a ratio of flow rates of precursor gases to flow rates of carrier and dilution gases is in the range from 1/140 to 1/20.

18. The method of claim 11, further comprising performing three or more transition steps after forming said first strain-inducing material layer and prior to forming said second strain-inducing material layer, wherein a plasma atmosphere is maintained in each of said three or more transition steps.

19. The method of claim 11, wherein the carrier gas is argon.

20. A semiconductor device processed with a method in accordance with any one of the preceding claims.