

WHAT IS CLAIMED IS CLAIMS:

1. A method of transferring a silicon layer from a single crystal silicon donor substrate to a handle substrate, the method comprising:

(a) implanting H_2^+ ions, H^+ ions, or a combination of H_2^+ ions and H^+ ions through a silicon dioxide layer in contact with a front surface of the single crystal silicon donor substrate and through the front surface of the single crystal silicon donor substrate, the single crystal silicon donor substrate comprising two major, parallel surfaces one of which is the front surface and one of which is the back surface, a circumferential edge joining the front surface and the back surface, a central plane between the front surface and the back surface, a central axis perpendicular to the front surface, and a bulk region between the front surface and the back surface, wherein the H_2^+ ions are implanted at a dosage between 4.3×10^{15} ions/cm² and 1.1×10^{16} ions/cm² at an implant energy between 10 Kev and 40 Kev and the H^+ ions are implanted at a dosage between 5×10^{15} ions/cm² and 2×10^{16} ions/cm² at an implant energy between 5 Kev and 20 Kev;

(b) implanting He^+ ions through the silicon dioxide layer in contact with the front surface of a single crystal silicon donor substrate and through the front surface of the single crystal silicon donor substrate, wherein the He^+ ions are implanted at a dosage between 6×10^{15} ions/cm² and 8×10^{15} ions/cm² at an implant energy between 5 Kev and 30 Kev;

(c) annealing the ion implanted single crystal silicon donor substrate at a temperature between 200°C and 350°C and for a duration sufficient to form a damage layer in the single crystal silicon donor substrate;

(d) bonding the silicon dioxide layer in contact with the front surface of the single crystal silicon donor substrate to a dielectric layer in contact with the handle substrate to thereby prepare the multilayer substrate;

(e) annealing the multilayer substrate at a temperature between 200°C and 400°C and for a duration sufficient to thermally activate the damage layer; and

(f) cleaving the annealed multilayer substrate at the damage layer in the single crystal silicon donor substrate to thereby transfer the silicon layer having a thickness between ~~about~~ 500 Angstroms and ~~about~~ 2500 Angstroms from the single crystal silicon donor substrate to the handle substrate.

2. The method of claim 1 wherein step (a) occurs before step (b).
3. The method of claim 1 wherein step (b) occurs before step (a).
4. The method of claim 1 wherein steps (a) and (b) occur simultaneously.
5. The method of claim 1 wherein the single crystal donor substrate has a diameter between 150 mm and 450 mm, or ~~about~~ 300 mm.
6. The method of claim 1 wherein the silicon dioxide layer has a thickness between ~~about~~ 100 angstroms and ~~about~~ 1000 angstroms, or between ~~about~~ 100 angstroms and ~~about~~ 700 angstroms, or between ~~about~~ 100 angstroms and ~~about~~ 500 angstroms, or between ~~about~~ 100 angstroms and ~~about~~ 250 angstroms.
7. The method of claim 1 wherein the silicon dioxide layer has a thickness between ~~about~~ 5 angstroms and ~~about~~ 25 angstroms, or between ~~about~~ 10 angstroms and ~~about~~ 15 angstroms.
8. The method of claim 1 wherein step (a) comprises (i) implanting H_2^+ ions at a dosage between ~~about~~ 4.3×10^{15} ions/cm² and ~~about~~ 1.1×10^{16} ions/cm² at an implant energy between ~~about 10 Kev and about 40 Kev, or between about~~ 20 Kev and ~~about~~ 40 Kev, (ii) implanting H^+ ions at a dosage between ~~about~~ 5×10^{15} ions/cm² and ~~about~~ 2×10^{16} ions/cm² at an implant energy between ~~about~~ 5 Kev and ~~about~~ 20 Kev, or (iii) implanting H_2^+ ions at a dosage between ~~about~~ 4.3×10^{15} ions/cm² and ~~about~~ 1.1×10^{16} ions/cm² at an implant energy between ~~about 10 Kev and about 40 Kev, or between about~~ 20 Kev and ~~about~~ 40 Kev and implanting H^+ ions at a dosage between ~~about~~ 5×10^{15} ions/cm² and ~~about~~ 2×10^{16} ions/cm² at an implant energy between ~~about~~ 5 Kev and ~~about~~ 20 Kev.
9. The method of claim 8 wherein a peak density, (D1), of H_2^+ ions, H^+ ions, or a combination of H_2^+ ions and H^+ ions is between ~~about~~ 100 Angstroms and ~~about~~ 3000 Angstroms, or between ~~about~~ 500 Angstroms and ~~about~~ 2500 Angstroms, as measured from the front surface of the single crystal silicon donor substrate and along the central axis.

10. The method of claim 1 wherein step (b) comprises implanting He^+ ions at a dosage between ~~about~~ 6×10^{15} ions/cm² and ~~about~~ 8×10^{15} ions/cm² at an implant energy between ~~about 5 Kev and about 30 Kev, or between about~~ 10 Kev and ~~about~~ 25 Kev.

11. The method of claim 10 wherein a peak density, (D2), of He^+ ions is between ~~about~~ 100 Angstroms and ~~about~~ 4000 Angstroms, or between ~~about~~ 500 Angstroms and ~~about~~ 3000 Angstroms, as measured from the front surface of the single crystal silicon donor substrate and along the central axis.

12. The method of any of claims 8 through 11 wherein the peak density, (D1), of H_2^+ ions, H^+ ions, or a combination of H_2^+ ions and H^+ ions and the peak density, (D2), of He^+ ions are within ~~about~~ 600 angstroms of each other, or within ~~about~~ 500 angstroms of each other, within ~~about~~ 450 angstroms of each other, within ~~about~~ 400 angstroms of each other, within ~~about~~ 300 angstroms of each other, or within ~~about~~ 200 angstroms of each other.

13. The method of any of claims 8 through 12 wherein step (c) comprises annealing the ion implanted single crystal silicon donor substrate at a temperature between ~~about~~ 250°C and ~~about~~ 300°C for a duration between 10 minutes and 60 minutes.

14. The method of any of claims 8 through 13 wherein step (e) comprises annealing the ion implanted single crystal silicon donor substrate at a temperature between ~~about~~ 300°C and ~~about~~ 400°C for a duration between 10 minutes and 60 minutes.

15. The method of any of claims 8 through 14 wherein the silicon layer having the thickness between ~~about~~ 500 Angstroms and ~~about~~ 2500 Angstroms transferred from the single crystal silicon donor substrate to the handle substrate has a thickness variation less than ~~about~~ 10 angstroms.

16. The method of any of claims 1 through 7 wherein step (a) comprises (i) implanting H_2^+ ions at a dosage between ~~about~~ 4.3×10^{15} ions/cm² and ~~about~~ 1.1×10^{16} ions/cm², or between ~~about~~ 6×10^{15} ions/cm² and ~~about~~ 1.1×10^{16} ions/cm², at an implant energy between ~~about~~ 20 Kev and ~~about~~ 40 Kev, (ii) implanting H^+ ions at a dosage

between ~~about~~ 1.1×10^{16} ions/cm² and ~~about~~ 2×10^{16} ions/cm² at an implant energy between ~~about~~ 5 Kev and ~~about~~ 20 Kev, or (iii) implanting H₂⁺ ions at a dosage between ~~about~~ 4.3×10^{15} ions/cm² and ~~about~~ 1.1×10^{16} ions/cm², or between ~~about~~ 6×10^{15} ions/cm² and ~~about~~ 1.1×10^{16} ions/cm², at an implant energy between ~~about~~ 20 Kev and ~~about~~ 40 Kev and implanting H⁺ ions at a dosage between ~~about~~ 1.1×10^{16} ions/cm² and ~~about~~ 2×10^{16} ions/cm² at an implant energy between ~~about~~ 5 Kev and ~~about~~ 20 Kev.

17. The method of claim 16 wherein a peak density, (D1), of H₂⁺ ions, H⁺ ions, or a combination of H₂⁺ ions and H⁺ ions is between ~~about~~ 100 Angstroms and ~~about~~ 3000 Angstroms, or between ~~about~~ 500 Angstroms and ~~about~~ 2500 Angstroms, as measured from the front surface of the single crystal silicon donor substrate and along the central axis.

18. The method of claims 16 or 17 wherein step (b) comprises implanting He⁺ ions at a dosage between ~~about~~ 6×10^{15} ions/cm² and ~~about~~ 8×10^{15} ions/cm² at an implant energy between ~~about~~ 10 Kev and ~~about~~ 30 Kev.

19. The method of claim 18 wherein a peak density, (D2), of He⁺ ions is between ~~about~~ 100 Angstroms and ~~about~~ 4000 Angstroms, or between ~~about~~ 500 Angstroms and ~~about~~ 3000 Angstroms, as measured from the front surface of the single crystal silicon donor substrate and along the central axis.

20. The method of any of claims 16 through 19 wherein the peak density, (D1), of H₂⁺ ions, H⁺ ions, or a combination of H₂⁺ ions and H⁺ ions and the peak density, (D2), of He⁺ ions are within ~~about~~ 600 angstroms of each other, or within ~~about~~ 500 angstroms of each other, within ~~about~~ 450 angstroms of each other, within ~~about~~ 400 angstroms of each other, within ~~about~~ 300 angstroms of each other, or within ~~about~~ 200 angstroms of each other.

21. The method of any of claims 16 through 20 wherein step (c) comprises annealing the ion implanted single crystal silicon donor substrate at a temperature between ~~about~~ 250°C and ~~about~~ 300°C for a duration between 10 minutes and 60 minutes.

22. The method of any of claims 16 through 21 wherein step (e) comprises annealing the ion implanted single crystal silicon donor substrate at a temperature between ~~about~~ 300°C and ~~about~~ 400°C for a duration between 10 minutes and 60 minutes.

23. The method of any of claims 16 through 22 wherein the silicon layer having the thickness between ~~about~~ 500 Angstroms and ~~about~~ 2500 Angstroms transferred from the single crystal silicon donor substrate to the handle substrate has a thickness variation less than ~~about~~ 10 angstroms.

24. The method of any of claims 1 through 7 wherein step (b) comprises implanting He⁺ ions at a dosage between ~~about~~ 6.6x10¹⁵ ions/cm² and ~~about~~ 7x10¹⁵ ions/cm² at an implant energy between ~~about~~ 5 Kev and ~~about~~ 20 Kev.

25. The method of claim 24 wherein a peak density, (D2), of He⁺ ions is between ~~about~~ 100 Angstroms and ~~about~~ 4000 Angstroms, or between ~~about~~ 500 Angstroms and ~~about~~ 3000 Angstroms, as measured from the front surface of the single crystal silicon donor substrate and along the central axis.

26. The method of claims 24 or 25 wherein step (a) comprises (i) implanting H₂⁺ ions at a dosage between ~~about~~ 5.9x10¹⁵ ions/cm² and ~~about~~ 6.7x10¹⁵ ions/cm² at an implant energy between ~~about~~ 10 Kev and ~~about~~ 30 Kev, (ii) implanting H⁺ ions at a dosage between ~~about~~ 6.1x10¹⁵ ions/cm² and ~~about~~ 6.8x10¹⁵ ions/cm² at an implant energy between ~~about~~ 5 Kev and ~~about~~ 20 Kev, or (iii) implanting H₂⁺ ions at a dosage between ~~about~~ 5.9x10¹⁵ ions/cm² and ~~about~~ 6.7x10¹⁵ ions/cm² at an implant energy between ~~about~~ 10 Kev and ~~about~~ 30 Kev and implanting H⁺ ions at a dosage between ~~about~~ 6.1x10¹⁵ ions/cm² and ~~about~~ 6.8x10¹⁵ ions/cm² at an implant energy between ~~about~~ 5 Kev and ~~about~~ 20 Kev.

27. The method of any of claims 24 through 26 wherein a peak density, (D1), of H₂⁺ ions, H⁺ ions, or a combination of H₂⁺ ions and H⁺ ions is between ~~about~~ 100 Angstroms and ~~about~~ 3000 Angstroms, or between ~~about~~ 500 Angstroms and ~~about~~ 2500 Angstroms, as measured from the front surface of the single crystal silicon donor substrate and along the central axis.

28. The method of any of claims 24 through 27 wherein the peak density, (D1), of H_2^+ ions, H^+ ions, or a combination of H_2^+ ions and H^+ ions and the peak density, (D2), of He^+ ions are within ~~about~~ 600 angstroms of each other, or within ~~about~~ 500 angstroms of each other, within ~~about~~ 450 angstroms of each other, within ~~about~~ 400 angstroms of each other, within ~~about~~ 300 angstroms of each other, or within ~~about~~ 200 angstroms of each other.

29. The method any of claims 24 through 28 wherein step (c) comprises annealing the ion implanted single crystal silicon donor substrate at a temperature between ~~about~~ 250°C and ~~about~~ 300°C for a duration between 10 minutes and 60 minutes.

30. The method any of claims 24 through 29 wherein step (e) comprises annealing the ion implanted single crystal silicon donor substrate at a temperature between ~~about~~ 300°C and ~~about~~ 400°C for a duration between 10 minutes and 60 minutes.

31. The method any of claims 24 through 30 wherein the silicon layer having the thickness between ~~about~~ 500 Angstroms and ~~about~~ 2500 Angstroms transferred from the single crystal silicon donor substrate to the handle substrate has a thickness variation less than ~~about~~ 10 angstroms.