CLAIMS:

1. A method of preparing a monocrystalline semiconductor donor substrate, the method comprising:

implanting hydrogen ions, helium ions, or a combination of hydrogen ions and helium ions through a front surface of the monocrystalline semiconductor donor substrate to an average depth D_1 as measured from the front surface toward a central plane, wherein the monocrystalline semiconductor donor substrate comprises two major, generally parallel surfaces, one of which is the front surface of the monocrystalline semiconductor donor substrate and the other of which is a back surface of the monocrystalline semiconductor donor substrate, a circumferential edge joining the front and back surfaces of the monocrystalline semiconductor donor substrate, and the central plane between the front and back surfaces of the monocrystalline semiconductor donor substrate; and

irradiating the front surface, the back surface, or both the front and the back surfaces of the monocrystalline semiconductor donor substrate with light at an intensity and duration sufficient to increase a temperature of the monocrystalline semiconductor donor substrate to between about 200°C and about 450°C and thereby form a cleave plane in the monocrystalline semiconductor donor substrate, wherein the monocrystalline semiconductor donor substrate is rotated during irradiation at a rate between about 5 rotations per minute to about 100 rotations per minute.

2. The method of claim 1 wherein the monocrystalline semiconductor donor substrate comprises a semiconductor wafer.

3. The method of claim 2 wherein the semiconductor wafer comprises a material selected from the group consisting of silicon, sapphire, gallium arsenide, gallium nitride, gallium oxide, aluminum gallium nitride, indium phosphide, silicon carbide, silicon germanium, germanium, and combinations thereof.

4. The method of claim 2 wherein the semiconductor wafer comprises a wafer sliced from a single crystal silicon ingot grown by the Czochralski method.

5. The method of claim 1 wherein the front surface of the monocrystalline semiconductor donor substrate comprises an oxidation layer prior to implanting hydrogen ions, helium ions, or a combination of hydrogen ions and helium ions.

6. The method of claim 5 wherein the oxidation layer has a thickness between about 1 nanometer and about 5000 nanometers.

7. The method of claim 1 wherein the light is ultraviolet light, visible light, or a combination of ultraviolet light and visible light.

8. The method of claim 1 wherein the light is ultraviolet light, infrared light, or a combination of infrared light and visible light.

9. The method of claim 1 wherein the light has a wavelength between about 0.3 micrometer and about 3 micrometers.

10. The method of claim 1 wherein the light has a wavelength between about 0.5 micrometer and about 2 micrometers.

11. The method of claim 1 wherein the duration of irradiation is between about 1 millisecond and about 5 minutes.

12. The method of claim 1 wherein the duration of irradiation is between about 30 seconds and about 5 minutes.

13. The method of claim 1 wherein the duration of irradiation is sufficient to increase surface haze on the front surface, the back surface, or both the front and the back surfaces of the monocrystalline semiconductor donor substrate.

14. The method of claim 1 wherein the increasing the temperature of the monocrystalline semiconductor donor substrate is to about 350°C.

15. The method of claim 1 further comprising activating the monocrystalline semiconductor donor substrate having the cleave plane therein via oxygen plasma surface activation.

16. The method of claim 15 further comprising bonding the activated front surface of the monocrystalline semiconductor donor substrate having the cleave plane therein to a surface of a carrier substrate to thereby form a bonded structure comprising the carrier substrate and the monocrystalline semiconductor donor substrate having the cleave plane.

17. The method of claim 16 wherein the carrier substrate is a silicon wafer.

18. The method of claim 17 wherein the silicon wafer comprises a SiO_2 surface layer.

19. The method of claim 17 further comprising annealing the bonded structure.

20. The method of claim 17 wherein the bonded structure is annealed at a temperature between about 150°C and about 500°C.

21. The method of claim 17 further comprising cleaving the bonded structure along the cleave plane to thereby form a multilayer structure comprising the carrier substrate and a monocrystalline semiconductor device layer transferred from the monocrystalline semiconductor donor substrate.

22. The method of claim 16 wherein the carrier substrate is a sapphire wafer.

23. The method of claim 16 wherein the carrier substrate is a quartz wafer.

24. A method of preparing a multilayer structure, the method comprising:

implanting hydrogen ions, helium ions, or a combination of hydrogen ions and helium ions through a front surface of a monocrystalline semiconductor donor substrate to an average depth D_1 as measured from the front surface toward a central plane, wherein the monocrystalline semiconductor donor substrate comprises two major, generally parallel surfaces, one of which is the front surface of the monocrystalline semiconductor donor substrate and the other of which is a back surface of the monocrystalline semiconductor donor substrate, a circumferential edge joining the front and back surfaces of the monocrystalline semiconductor donor substrate, and the central

plane between the front and back surfaces of the monocrystalline semiconductor donor substrate;

irradiating the front surface, the back surface, or both the front and the back surfaces of the monocrystalline semiconductor donor substrate with light at an intensity and duration sufficient to increase a temperature of the monocrystalline semiconductor donor substrate to between about 200°C and about 450°C and thereby form a cleave plane in the monocrystalline semiconductor donor substrate, wherein the duration of irradiation is between about 1 millisecond and about 5 minutes;

activating the monocrystalline semiconductor donor substrate having the cleave plane therein via oxygen plasma surface activation;

bonding the activated front surface of the monocrystalline semiconductor donor substrate having the cleave plane therein to a surface of a carrier substrate to thereby form a bonded structure comprising the carrier substrate and the monocrystalline semiconductor donor substrate having the cleave plane;

annealing the bonded structure; and

cleaving the bonded structure along the cleave plane to thereby form a multilayer structure comprising the carrier substrate and a monocrystalline semiconductor device layer transferred from the monocrystalline semiconductor donor substrate.

25. The method of claim 24 wherein the monocrystalline semiconductor donor substrate comprises a semiconductor wafer.

26. The method of claim 25 wherein the semiconductor wafer comprises a material selected from the group consisting of silicon, sapphire, gallium arsenide, gallium nitride, gallium oxide, aluminum gallium nitride, indium phosphide, silicon carbide, silicon germanium, germanium, and combinations thereof.

27. The method of claim 26 wherein the semiconductor wafer comprises a wafer sliced from a single crystal silicon ingot grown by the Czochralski method.

28. The method of claim 24 wherein the front surface of the monocrystalline semiconductor donor substrate comprises an oxidation layer prior to implanting hydrogen ions, helium ions, or a combination of hydrogen ions and helium ions.

29. The method of claim 28 wherein the oxidation layer has a thickness between about 1 nanometer and about 5000 nanometers.

30. The method of claim 24 wherein the light is ultraviolet light, visible light, or a combination of ultraviolet light and visible light.

31. The method of claim 24 wherein the light is ultraviolet light, infrared light, or a combination of infrared light and visible light.

32. The method of claim 24 wherein the light has a wavelength between about 0.3 micrometer and about 3 micrometers.

33. The method of claim 24 wherein the light has a wavelength between about 0.5 micrometer and about 2 micrometers.

34. The method of claim 24 wherein the duration of irradiation is between about 30 seconds and about 5 minutes.

35. The method of claim 24 wherein the monocrystalline semiconductor donor substrate is rotated during irradiation.

36. The method of claim 35 wherein the monocrystalline semiconductor donor substrate is rotated at a rate between about 5 rotations per minute to about 100 rotations per minute.

37. The method of claim 24 wherein the duration of irradiation is sufficient to increase surface haze on the front surface, the back surface, or both the front and the back surfaces of the monocrystalline semiconductor donor substrate.

38. The method of claim 24 wherein the increasing the temperature of the monocrystalline semiconductor donor substrate is to about 350°C.

39. The method of claim 24 wherein the carrier substrate is a silicon wafer.

40. The method of claim 39 wherein the silicon wafer comprises a SiO_2 surface layer.

41. The method of claim 24 wherein the carrier substrate is a sapphire wafer.

42. The method of claim 24 wherein the carrier substrate is a quartz wafer.

43. The method of claim 24 wherein the bonded structure is annealed at a temperature between about 150°C and about 500°C.