CLAIMS

1. A method for cleaning a semiconductor wafer comprising features of patterned structures, the method comprising:

applying liquid on the semiconductor wafer;

delivering acoustic energy to the liquid at a first frequency and a first power level for a predetermined first time period with an ultra/mega sonic device, wherein bubble implosion does not occur in the first time period; and wherein the first frequency, the first power level and the first time period are determined such that the bubble does not reach an implosion temperature or the bubble size is smaller than a critical dimension of space in patterned structures; and

delivering acoustic energy to the liquid at a second frequency and a second power level for a predetermined second time period with the ultra/mega sonic device, wherein the second power level, the second frequency and the second time period are determined such that the temperatures inside the bubble cools down to a set temperature;

wherein the first and second time periods are alternately applied one after another for a predetermined number of cycles; and

wherein the first and second time periods, the first and second power levels, and the first and second frequencies are determined such that no patterned structures of the semiconductor wafer are damaged as a result of delivering the acoustic energy.

2. The method of claim 1, wherein the first time period is determined by:

alternating between delivering acoustic energy to the liquid at the first frequency and the first power level for a test time period, and delivering acoustic energy to the liquid at the second frequency and the second power level for a sufficiently long time period;

measuring a quantity of damaged patterned structures;

repeating the above steps with a plurality of different test time periods; and

determining the first time period shorter than a time interval, and within the time interval a bubble size is not larger than a critical size of damaging the patterned structures when delivering acoustic energy to the liquid at the first power level.

3. The method of claim 1, wherein the second time period is determined by:

alternating between delivering acoustic energy to the liquid at the first frequency and the first power level for a predetermined time period, and delivering acoustic energy to the liquid at the second frequency and the second power level for a test time period;

measuring a quantity of damaged patterned structures;

repeating the above steps with a plurality of different test time periods; and

determining the second time period longer than a time interval, and within the time interval a bubble size is not larger than a critical size of damaging the patterned structures when delivering acoustic energy to the liquid at the second power level.

4. The method of claim 1, wherein the second power level is lower than the first power level.

5. The method of claim 4, wherein the second power level is zero.

6. The method of claim 1, wherein the second frequency is higher than the first frequency.

7. The method of claim 1, wherein the second frequency in the second time period is in antiphase to the first frequency in the first time period.

8. The method of claim 1, wherein the first frequency is equal to the second frequency, while the first power level is higher than the second power level.

9. The method of claim 1, wherein the first frequency is higher than the second frequency, while the first power level is higher than the second power level.

10. The method of claim 1, wherein the first frequency is lower than the second frequency, while the first power level is equal to the second power level.

11. The method of claim 1, wherein the first frequency is lower than the second frequency, while the first power level is higher than the second power level.

12. The method of claim 1, wherein the first frequency is lower than the second frequency, while the first power lever is lower than the second power level.

13. The method of claim 1, wherein the first power level rises during the first time period.

14. The method of claim 1, wherein the first power level falls during the first time period.

15. The method of claim 1, wherein the first power level both rises and falls during the first time period.

16. The method of claim 1, wherein the first frequency changes from a higher value to a lower value during the first time period.

17. The method of claim 1, wherein the first frequency changes from a lower value to a higher value during the first time period.

18. The method of claim 1, wherein the first frequency changes from a lower value to a higher value and then back to the lower value during the first time period.

19. The method of claim 1, wherein the first frequency changes from a higher value to a lower value and then back to the higher value during the first time period.

20. The method of claim 1, wherein the first frequency is set as f_1 first, f_3 later and f_4 at last during the first time period, where f_4 is smaller than f_3, and f_3 is smaller than f_1.

21. The method of claim 1, wherein the first frequency is set as f_4 first, f_3 later and f_1 at last during the first time period, where f_4 is smaller than f_3, and f_3 is smaller than f_1.

22. The method of claim 1, wherein the first frequency is set as f_1 first, f_4 later and f_3 at last during the first time period, where f_4 is smaller than f_3, and f_3 is smaller than f_1.

23. The method of claim 1, wherein the first frequency is set as f_3 first, f_4 later and f_1 at last during the first time period, where f_4 is smaller than f_3, and f_3 is smaller than f_1.

24. The method of claim 1, wherein the first frequency is set as f_3 first, f_1 later and f_4 at last during the first time period, where f_4 is smaller than f_3, and f_3 is smaller than f_1.

25. The method of claim 1, wherein the first frequency is set as f_4 first, f_1 later and f_3 at last during the first time period, where f_4 is smaller than f_3, and f_3 is smaller than f_1.

26. The method of claim 1, wherein the second frequency is zero and the second power level remains a constant positive value during the second time period.

27. The method of claim 1, wherein the second frequency is zero and the second power level remains a constant negative value during the second time period.

28. The method of claim 1, further comprising rotating the wafer with respect to the ultra/mega sonic device as acoustic energy is delivered.

29. The method of claim 1, wherein the patterned structures are not damaged by expansion of bubbles in the first time period.

30. The method of claim 1, wherein temperatures inside bubbles decrease in the second time period.

31. The method of claim 30, wherein temperatures inside the bubbles decrease to near a temperature of said liquid in the second time period.

32. The method of claim 1, wherein the first time period is shorter than 2,000 times of a cycle period of the first frequency.

33. The method of claim 1, wherein the first time period is shorter than $((T_i - T_0 - \Delta T)/(\Delta T - \delta T) + 1)/f_1$, where T_i is an implosion temperature, T_0 is a temperature of the liquid, ΔT is a temperature increase after one time of compression, δT is a temperature decrease after one time of expansion, and f1 is the first frequency.

34. An apparatus for cleaning a semiconductor wafer comprising features of patterned structures, the apparatus comprising:

a wafer holder configured to hold the semiconductor wafer;

an inlet configured to apply liquid on the semiconductor wafer;

an ultra/mega sonic device configured to deliver acoustic energy to the liquid;

a power supply of the ultra/mega sonic device;

wherein the ultra/mega sonic device is configured to:

deliver acoustic energy to the liquid at a first frequency and a first power level for a predetermined first time period, wherein bubble implosion does not occur in the first time period, and wherein the first frequency, the first power level and the first time period are determined such

that the bubble does not reach an implosion temperature or the bubble size is smaller than a critical dimension of space in patterned structures; and

deliver acoustic energy to the liquid at a second frequency and a second power level for a predetermined second time period, wherein the second power level, the second frequency and the second time period are determined such that the temperatures inside the bubble cools down to a set temperature;

wherein the first and second time periods are alternately applied one after another for a predetermined number of cycles; and

wherein the first and second time periods, the first and second power levels, and the first and second frequencies are determined such that no patterned structures of the semiconductor wafer are damaged as a result of delivering the acoustic energy.

35. The apparatus of claim 34, wherein the wafer holder comprises a rotating chuck.

36. The apparatus of claim 34, wherein the wafer holder comprises a cassette submerged in a cleaning tank.

37. The apparatus of claim 34, wherein the inlet comprises a nozzle.

38. The apparatus of claim 34, wherein the ultra/mega sonic device is connected to the inlet and imparts acoustic energy to the liquid flowing through the inlet.

39. The apparatus of claim 34, wherein the second power level is lower than the first power level.

40. The apparatus of claim 39, wherein the second power level is zero.

41. The apparatus of claim 34, wherein the second frequency is higher than the first frequency.

42. The apparatus of claim 34, wherein the second frequency in the second time period is in antiphase to the first frequency in the first time period.

43. The apparatus of claim 34, wherein the first frequency is equal to the second frequency, while the first power level is higher than the second power level.

44. The apparatus of claim 34, wherein the first frequency is higher than the second frequency, while the first power level is higher than the second power level.

45. The apparatus of claim 34, wherein the first frequency is lower than the second frequency, while the first power level is equal to the second power level.

46. The apparatus of claim 34, wherein the first frequency is lower than the second frequency, while the first power level is higher than the second power level.

47. The apparatus of claim 34, wherein the first frequency is lower than the second frequency, while the first power lever is lower than the second power level.

48. The apparatus of claim 34, wherein the first power level rises during the first time period.

49. The apparatus of claim 34, wherein the first power level falls during the first time period.

50. The apparatus of claim 34, wherein the first power level both rises and falls during the first time period.

51. The apparatus of claim 34, wherein the first frequency changes from a higher value to a lower value during the first time period.

52. The apparatus of claim 34, wherein the first frequency changes from a lower value to a higher value during the first time period.

53. The apparatus of claim 34, wherein the first frequency changes from a lower value to a higher value and then back to the lower value during the first time period.

54. The apparatus of claim 34, wherein the first frequency changes from a higher value to a lower value and then back to the higher value during the first time period.

55. The apparatus of claim 34, wherein the first frequency is set as f_1 first, f_3 later and f_4 at last during the first time period, where f_4 is smaller than f_3, and f_3 is smaller than f_1.

56. The apparatus of claim 34, wherein the first frequency is set as f_4 first, f_3 later and f_1 at last during the first time period, where f_4 is smaller than f_3, and f_3 is smaller than f_1.

57. The apparatus of claim 34, wherein the first frequency is set as f_1 first, f_4 later and f_3 at last during the first time period, where f_4 is smaller than f_3, and f_3 is smaller than f_1.

58. The apparatus of claim 34, wherein the first frequency is set as f_3 first, f_4 later and f_1 at last during the first time period, where f_4 is smaller than f_3, and f_3 is smaller than f_1.

59. The apparatus of claim 34, wherein the first frequency is set as f_3 first, f_1 later and f_4 at last during the first time period, where f_4 is smaller than f_3, and f_3 is smaller than f_1.

60. The apparatus of claim 34, wherein the first frequency is set as f_4 first, f_1 later and f_3 at last during the first time period, where f_4 is smaller than f_3, and f_3 is smaller than f_1.

61. The apparatus of claim 34, wherein the second frequency is zero and the second power level remains a constant positive value during the second time period.

62. The apparatus of claim 34, wherein the second frequency is zero and the second power level remains a constant negative value during the second time period.

63. The apparatus of claim 34, wherein the wafer holder is further configured to rotate the wafer with respect to the ultra/mega sonic device as acoustic energy is delivered.

64. The apparatus of claim 34, wherein the patterned structures are not damaged by expansion of bubbles in the first time period.

65. The apparatus of claim 34, wherein temperatures inside bubbles decrease in the second time period.

66. The apparatus of claim 65, wherein temperatures inside the bubbles decrease to near a temperature of said liquid in the second time period.

67. The apparatus of claim 34, wherein the first time period is shorter than 2,000 times of a cycle period of the first frequency.

68. The apparatus of claim 34, wherein the first time period is shorter than $((T_i - T_0 - \Delta T)/(\Delta T - \delta T) + 1)/f_1$, where T_i is an implosion temperature, T_0 is a temperature of the liquid, ΔT is a temperature increase after one time of compression, δT is a temperature decrease after one time of expansion, and f1 is the first frequency.