CLAIMS

1. A plasma processing apparatus comprising:

a chamber;

a substrate support having a lower electrode and an electrostatic chuck provided on the lower electrode, and configured to support a substrate which is placed thereon in the chamber;

a radio frequency power source configured to generate radio frequency power which is supplied to generate plasma from a gas in the chamber, the radio frequency power having a first frequency;

a bias power source electrically connected to the lower electrode and configured to periodically apply a pulsed negative direct-current voltage to the lower electrode at a cycle that is defined by a second frequency lower than the first frequency; and

a controller configured to control the radio frequency power source,

wherein the controller controls the radio frequency power source to supply the radio frequency power in a first partial period in the cycle and set a power level of the radio frequency power in a second partial period in the cycle to a power level reduced from a power level of the radio frequency power in the first partial period.

2. The plasma processing apparatus according to claim 1, wherein the first partial period is a period in which the pulsed negative direct-current voltage is applied to the lower electrode, and

the second partial period is a period in which the pulsed negative direct-current voltage is not applied to the lower electrode.

3. The plasma processing apparatus according to claim 2, wherein the bias power source is configured to apply a positive direct-current voltage to the lower electrode within the second partial period and immediately before the first partial period.

4. The plasma processing apparatus according to claim 1, wherein the first partial period is a period in which the pulsed negative direct-current voltage is not applied to the lower electrode, and

the second partial period is a period in which the pulsed negative direct-current voltage is applied to the lower electrode.

5. The plasma processing apparatus according to claim 4, wherein the bias power source is configured to apply a positive direct-current voltage to the lower electrode within the first partial period and immediately before the second partial period.

6. The plasma processing apparatus according to claim 1, further comprising a

voltage sensor configured to directly or indirectly measure a potential of the substrate placed on the substrate support,

wherein the controller is configured to determine a period in which the potential of the substrate measured by the voltage sensor is higher or lower than an average value of the potential of the substrate in the cycle, as the first partial period.

7. The plasma processing apparatus according to any one of claims 1 to 6, wherein the controller controls the radio frequency power source to stop supply of the radio frequency power in the second partial period.

8. The plasma processing apparatus according to any one of claims 1 to 7, wherein the controller controls the radio frequency power source to periodically supply a pulse of the radio frequency power in the first partial period.

9. The plasma processing apparatus according to claim 8, wherein a frequency for defining a cycle at which the pulse of the radio frequency power is supplied in the first partial period is equal to or more than twice the second frequency and equal to or less than 0.5 times the first frequency.

10. The plasma processing apparatus according to any one of claims 1 to 9, wherein the first frequency is not less than 27 MHz and not more than 100 MHz.

11. The plasma processing apparatus according to any one of claims 1 to 10, wherein the bias power source is configured to change a voltage level of the pulsed negative direct-current voltage within a period in which the pulsed negative direct-current voltage is applied to the lower electrode.

12. A plasma processing method using a plasma processing apparatus,

the plasma processing apparatus including

a chamber,

a substrate support having a lower electrode and an electrostatic chuck provided on the lower electrode, and configured to support a substrate which is placed thereon in the chamber,

a radio frequency power source configured to generate radio frequency power which is supplied to generate a plasma from a gas in the chamber, the radio frequency power having a first frequency, and

a bias power source electrically connected to the lower electrode,

the plasma processing method being executed to perform plasma processing on a substrate in a state where the substrate is placed on the electrostatic chuck, and comprising:

periodically applying a pulsed negative direct-current voltage from the bias power source to the lower electrode at a cycle that is defined by a second

frequency lower than the first frequency;

supplying the radio frequency power from the radio frequency power source in a first partial period in the cycle; and

setting a power level of the radio frequency power in a second partial period in the cycle to a power level reduced from a power level of the radio frequency power in the first partial period.

13. The plasma processing method according to claim 12, wherein the first partial period is a period in which the pulsed negative direct-current voltage is applied to the lower electrode, and

the second partial period is a period in which the pulsed negative direct-current voltage is not applied to the lower electrode.

14. The plasma processing method according to claim 13, wherein the bias power source is configured to apply a positive direct-current voltage to the lower electrode within the second partial period and immediately before the first partial period.

15. The plasma processing method according to claim 12, wherein the first partial period is a period in which the pulsed negative direct-current voltage is not applied to the lower electrode, and

the second partial period is a period in which the pulsed negative direct-current voltage is applied to the lower electrode.

16. The plasma processing method according to claim 15, wherein the bias power source is configured to apply a positive direct-current voltage to the lower electrode within the first partial period and immediately before the second partial period.

17. The plasma processing method according to claim 12, wherein the plasma processing apparatus further comprises a voltage sensor configured to directly or indirectly measure a potential of the substrate placed on the substrate support, and

the plasma processing method further comprises determining a period in which the potential of the substrate measured by the voltage sensor is higher or lower than an average value of the potential of the substrate in the cycle, as the first partial period.

18. The plasma processing method according to any one of claims 12 to 17, wherein supply of the radio frequency power is stopped in the second partial period.

19. The plasma processing method according to any one of claims 12 to 18,

wherein a pulse of the radio frequency power is periodically supplied from the radio frequency power source in the first partial period.

20. The plasma processing method according to claim 19, wherein a frequency for defining a cycle at which the pulse of the radio frequency power is supplied in the first partial period is equal to or more than twice the second frequency and equal to or less than 0.5 times the first frequency.

21. The plasma processing method according to any one of claims 12 to 20, further comprising:

periodically applying the pulsed negative direct-current voltage from the bias power source to the lower electrode at the cycle that is defined by the second frequency, in a state where supply of the radio frequency power from the radio frequency power source is stopped, in a period in which plasma is present in the chamber and which has a time length longer than a time length of the cycle that is defined by the second frequency.

22. The plasma processing method according to any one of claims 12 to 21, further comprising:

supplying the radio frequency power from the radio frequency power source in a state where application of the pulsed negative direct-current voltage from the bias power source to the lower electrode is stopped, in a period having a time length longer than a time length of the cycle that is defined by the second frequency.

23. The plasma processing method according to any one of claims 12 to 22, wherein the first frequency is not less than 27 MHz and not more than 100 MHz.

24. The plasma processing method according to any one of claims 12 to 23, wherein a voltage level of the pulsed negative direct-current voltage is changed within a period in which the pulsed negative direct-current voltage is applied to the lower electrode.