

WHAT IS CLAIMED IS:

1. A plasma processing apparatus comprising:
 - a chamber;
 - a substrate support having an electrode and configured to support a substrate in the chamber;
 - a power source system electrically connected to the electrode and configured to apply a bias voltage to the electrode to draw ions from a plasma in the chamber into the substrate on the substrate support; and
 - a controller,wherein the power source system is configured to periodically output a first pulse to the electrode at a frequency of 100 kHz or more and 1 MHz or less in a first period and periodically output a second pulse to the electrode at a frequency of 100 kHz or more and 1 MHz or less in a second period after the first period, as the bias voltage, each of the first pulse and the second pulse is a pulse of a negative voltage, a voltage level of the first pulse is different from a voltage level of the second pulse, and the controller is configured to control the power source system to output a single pulse of a positive voltage to the electrode before start of the first period within a subsequent cycle of two cycles, each of which includes the first period and the second period.
2. The plasma processing apparatus according to claim 1, wherein an absolute value of the voltage level of the first pulse is

smaller than an absolute value of the voltage level of the second pulse.

3. The plasma processing apparatus according to claim 1,
wherein an absolute value of the voltage level of the first pulse is larger
5 than an absolute value of the voltage level of the second pulse.

4. The plasma processing apparatus according to claim 3,
wherein the power source system is configured to periodically output
the first pulse to the electrode in the first period to etch a silicon oxide
10 film of a multilayer film in the first period and periodically output the
second pulse to the electrode in the second period to etch a silicon
nitride film of the multilayer film in the second period.

5. The plasma processing apparatus according to claim 1,
15 wherein an absolute value of a voltage level of one of the first pulse and
the second pulse is 6 kV or more.

6. The plasma processing apparatus according to claim 1,
wherein the power source system is further configured to output a single
20 pulse of a positive voltage immediately before outputting the second
pulse first in the second period.

7. The plasma processing apparatus according to claim 1,
further comprising a radio frequency power source electrically
25 connected to the substrate support and configured to supply a radio
frequency power to generate a plasma in the chamber.

8. The plasma processing apparatus according to claim 1, wherein the power source system comprises:

5 a first direct current power source including a positive terminal connected to a ground, the first direct current power source being a variable direct current power source;

a first circuit configured to generate the first pulse and the second pulse from a negative voltage output from a negative terminal of the first direct current power source;

10 a second direct current power source including a negative terminal connected to a ground; and

a second circuit configured to generate a single pulse from a positive voltage output from a positive terminal of the second direct current power source, wherein

15 the first circuit includes:

one or more first switching transistors connected in series between the positive terminal of the first direct current power source and a first node;

20 one or more second switching transistors connected in series between the negative terminal of the first direct current power source and the first node;

a first diode having a cathode connected to the positive terminal of the first direct current power source and an anode connected to a second node which is connected to the first node and the electrode of the substrate support; and

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a second diode having a cathode connected to the

second node and an anode connected to the negative terminal of the first direct current power source, and

the second circuit includes:

5 one or more third switching transistors connected in series between the positive terminal of the second direct current power source and a third node;

one or more fourth switching transistors connected in series between the negative terminal of the second direct current power source and the third node;

10 a third diode having a cathode connected to the positive terminal of the second direct current power source and an anode connected to a fourth node which is connected to the third node and the electrode of the substrate support; and

15 a fourth diode having a cathode connected to the fourth node and an anode connected to the negative terminal of the second direct current power source.

9. The plasma processing apparatus according to claim 1, wherein the power source system comprises:

20 a first direct current power source including a positive terminal connected to a ground;

a first circuit configured to generate the first pulse from a negative voltage output from a negative terminal of the first direct current power source;

25 a second direct current power source including a negative terminal connected to a ground;

a second circuit configured to generate a single pulse from a positive voltage output from a positive terminal of the second direct current power source;

5 a third direct current power source including a positive terminal connected to a ground; and

a third circuit configured to generate the second pulse from a negative voltage output from a negative terminal of the third direct current power source, wherein

the first circuit includes:

10 one or more first switching transistors connected in series between the positive terminal of the first direct current power source and a first node;

one or more second switching transistors connected in series between the negative terminal of the first direct current power source and the first node;

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a first diode having a cathode connected to the positive terminal of the first direct current power source and an anode connected to a second node which is connected to the first node;

a second diode having a cathode connected to the second node and an anode connected to the negative terminal of the first direct current power source; and

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an additional switching transistor connected between the second node and a common node, the common node being connected to the electrode of the substrate support,

25 the second circuit includes:

one or more third switching transistors connected in

series between the positive terminal of the second direct current power source and a third node;

5 one or more fourth switching transistors connected in series between the negative terminal of the second direct current power source and the third node;

a third diode having a cathode connected to the positive terminal of the second direct current power source and an anode connected to a fourth node which is connected to the third node and the electrode of the substrate support; and

10 a fourth diode having a cathode connected to the fourth node and an anode connected to the negative terminal of the second direct current power source, and

the third circuit includes:

15 one or more fifth switching transistors connected in series between the positive terminal of the third direct current power source and a fifth node;

one or more sixth switching transistors connected in series between the negative terminal of the third direct current power source and the fifth node;

20 a fifth diode having a cathode connected to the positive terminal of the third direct current power source and an anode connected to a sixth node which is connected to the fifth node;

a sixth diode having a cathode connected to the sixth node and an anode connected to the negative terminal of the third direct current power source; and

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an additional switching transistor connected between the sixth

node and the common node.

10. A plasma processing apparatus comprising:

a chamber;

5 a substrate support having an electrode and configured to support a substrate in the chamber;

a power source system electrically connected to the electrode and configured to apply a bias voltage to the electrode to draw ions from a plasma in the chamber into the substrate on the substrate support;

10 and

a controller,

wherein the power source system is configured to periodically output a first pulse to the electrode at a frequency of 100 kHz or more and 1 MHz or less in a first period and periodically output a second pulse to the electrode at a frequency of 100 kHz or more and 1 MHz or less in a second period after the first period, as the bias voltage,

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each of the first pulse and the second pulse is a pulse of a negative voltage,

a voltage level of the first pulse is different from a voltage level of the second pulse, and

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the controller is configured to control the power source system to alternately output the first pulse and a pulse of a positive voltage to the electrode in the first period and alternately output the second pulse and a pulse of a positive voltage to the electrode in the second period.

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11. A plasma processing method comprising:

preparing a substrate on a substrate support provided in a chamber of a plasma processing apparatus, wherein the substrate support includes an electrode;

5 periodically outputting a first pulse from a power source system to the electrode at a frequency of 100 kHz or more and 1 MHz or less in a first period as a bias voltage to draw ions from plasma in the chamber into the substrate; and

10 periodically outputting a second pulse as the bias voltage from the power source system to the electrode at a frequency of 100 kHz or more and 1 MHz or less in a second period,

wherein each of the first pulse and the second pulse is a pulse of a negative voltage,

a voltage level of the first pulse is different from a voltage level of the second pulse, and

15 the plasma processing method further comprises outputting a single pulse of a positive voltage to the electrode before start of the first period within a subsequent cycle of two cycles, each of which includes the first period and the second period.