

CLAIMS

1. A method of processing a semiconductor device structure, comprising:
5 generating a plasma of a gas;
cooling an electrostatic chuck on which a semiconductor device structure is
positioned to a temperature of about -30°C or less, the semiconductor device
structure comprising tiers of alternating materials including at least one
dielectric material;
10 applying a low frequency radio frequency having a non-sinusoidal waveform to the
electrostatic chuck; and
with the plasma and while cooling the electrostatic chuck, forming a high aspect
ratio opening in the semiconductor device structure.
- 15 2. The method of claim 1, wherein generating a plasma of a gas comprises
generating a plasma of a gas comprising a hydrogen-based gas and a fluorine-based gas,
the hydrogen-based gas comprising between about 10 percent by volume (vol%) and 90
vol% of the gas;
- 20 3. The method of claim 1, wherein generating a plasma of a gas comprises
generating a plasma of a gas comprising about 50 vol% hydrogen-based gas.
4. The method of claim 1, wherein generating a plasma of a gas comprises
generating a plasma of a gas comprising difluoromethane (CH₂F₂), hydrogen (H₂), and
25 nitrogen trifluoride (NF₃).
5. The method of claim 1, wherein generating a plasma of a gas comprises
generating a plasma of a gas comprising methane (CH₄), hydrogen (H₂), and nitrogen
trifluoride (NF₃).
- 30 6. The method of claim 1, wherein generating a plasma of a gas comprises
generating a plasma of a gas comprising hydrogen (H₂) and carbon tetrafluoride (CF₄).

7. The method of claim 1, wherein generating a plasma of a gas comprises generating a plasma of a gas comprising carbonyl sulfide (COS), hydrogen bromide (HBr), methane (CH₄), ~~octafluorocyclobutane~~ octafluorocyclobutane (C₄F₈), fluoromethane (CH₃F), hydrogen (H₂), nitrogen trifluoride (NF₃), and trifluoriodomethane (CF₃I).
8. The method of claim 1, wherein cooling an electrostatic chuck comprises cooling the electrostatic chuck to a temperature of about -60°C or less.
9. The method of claim 1, wherein the semiconductor device structure comprises alternating tiers of the at least one dielectric material and another dielectric material.
10. The method of claim 1, wherein the semiconductor device structure comprises alternating tiers of the at least one dielectric material and a conductive material.
11. The method of claim 1, wherein the at least one dielectric material comprises a silicon oxide.
12. The method of claim 1, wherein applying a low frequency radio frequency comprises combining a plurality of sinusoidal waveforms to generate the low frequency radio frequency having the non-sinusoidal waveform.
13. The method of claim 12, wherein combining a plurality of sinusoidal waveforms to generate the low frequency radio frequency comprises combining a fundamental frequency and at least two harmonic frequencies of the fundamental frequency.
14. The method of claim 12, wherein combining a plurality of sinusoidal waveforms to generate the low frequency radio frequency comprises combining at least a fundamental frequency, a third harmonic frequency of the fundamental frequency, and a fifth harmonic frequency of the fundamental frequency.

15. The method of claim 1, wherein applying a low frequency radio frequency to the electrostatic chuck comprises applying a radio frequency having a frequency between about 100 Hz and about 3.2 MHz or less.

5 16. A system for processing a semiconductor device structure, comprising:
a chamber;
an electrode in the chamber;
at least one DC power source operably coupled to the electrode;
an electrostatic chuck located in the chamber below the electrode and configured to
10 receive a semiconductor device structure thereon;
a coolant system operably coupled to the electrostatic chuck and configured to
reduce the electrostatic chuck to a temperature of about -30°C or less; and
at least one low frequency radio frequency (RF) power source coupled to the
electrostatic chuck, the low frequency RF power source configured to
15 generate a frequency of between about 100 Hz and about 3.2 MHz
exhibiting a non-sinusoidal waveform comprising a combination of a
plurality of sinusoidal waveforms.

17. The system of claim 16, wherein the at least one low frequency RF power
20 source is configured to generate a frequency having a non-sinusoidal waveform by
combining a fundamental frequency with at least two harmonic frequencies of the
fundamental frequency.

18. The system of claim 17, wherein the at least two harmonic frequencies of
25 the fundamental frequency comprise a third harmonic frequency and a fifth harmonic
frequency of the fundamental frequency.

19. The system of claim 16, wherein the at least one low frequency RF power
source is configured to generate a non-sinusoidal waveform having one of a square
30 waveform shape and a flat-bottom waveform shape.

20. The system of claim 16, wherein one of the electrode and the electrostatic
chuck is operably coupled to a high frequency RF power source configured to generate a
frequency of about 13 MHz to about 60 MHz.

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cooling an electrostatic chuck on which a semiconductor device structure is
positioned to a temperature of about -30°C or less, the semiconductor device
structure comprising tiers of alternating materials including at least one
dielectric material;
10 applying a low frequency radio frequency having a non-sinusoidal waveform to the
electrostatic chuck; and
with the plasma and while cooling the electrostatic chuck, forming a high aspect
ratio opening in the semiconductor device structure.
- 15 2. The method of claim 1, wherein generating a plasma of a gas comprises
generating a plasma of a gas comprising a hydrogen-based gas and a fluorine-based gas,
the hydrogen-based gas comprising between about 10 percent by volume (vol%) and 90
vol% of the gas.
- 20 3. The method of claim 1, wherein generating a plasma of a gas comprises
generating a plasma of a gas comprising about 50 vol% hydrogen-based gas.
4. The method of claim 1, wherein generating a plasma of a gas comprises
generating a plasma of a gas comprising difluoromethane (CH₂F₂), hydrogen (H₂), and
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6. The method of claim 1, wherein generating a plasma of a gas comprises
generating a plasma of a gas comprising hydrogen (H₂) and carbon tetrafluoride (CF₄).

7. The method of claim 1, wherein generating a plasma of a gas comprises generating a plasma of a gas comprising carbonyl sulfide (COS), hydrogen bromide (HBr), methane (CH₄), octafluorocyclobutane (C₄F₈), fluoromethane (CH₃F), hydrogen (H₂), nitrogen trifluoride (NF₃), and trifluoroiodomethane (CF₃I).

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8. The method of claim 1, wherein cooling an electrostatic chuck comprises cooling the electrostatic chuck to a temperature of about -60°C or less.

9. The method of claim 1, wherein the semiconductor device structure
10 comprises alternating tiers of the at least one dielectric material and another dielectric material.

10. The method of claim 1, wherein the semiconductor device structure
comprises alternating tiers of the at least one dielectric material and a conductive material.

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11. The method of claim 1, wherein the at least one dielectric material
comprises a silicon oxide.

12. The method of claim 1, wherein applying a low frequency radio frequency
20 comprises combining a plurality of sinusoidal waveforms to generate the low frequency radio frequency having the non-sinusoidal waveform.

13. The method of claim 12, wherein combining a plurality of sinusoidal
waveforms to generate the low frequency radio frequency comprises combining a
25 fundamental frequency and at least two harmonic frequencies of the fundamental frequency.

14. The method of claim 12, wherein combining a plurality of sinusoidal
waveforms to generate the low frequency radio frequency comprises combining at least a
30 fundamental frequency, a third harmonic frequency of the fundamental frequency, and a fifth harmonic frequency of the fundamental frequency.

15. The method of claim 1, wherein applying a low frequency radio frequency to the electrostatic chuck comprises applying a radio frequency having a frequency between about 100 Hz and about 3.2 MHz or less.

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a chamber;
an electrode in the chamber;
at least one DC power source operably coupled to the electrode;
an electrostatic chuck located in the chamber below the electrode and configured to
10 receive a semiconductor device structure thereon;
a coolant system operably coupled to the electrostatic chuck and configured to
reduce the electrostatic chuck to a temperature of about -30°C or less; and
at least one low frequency radio frequency (RF) power source coupled to the
electrostatic chuck, the low frequency RF power source configured to
15 generate a frequency of between about 100 Hz and about 3.2 MHz
exhibiting a non-sinusoidal waveform comprising a combination of a
plurality of sinusoidal waveforms.

17. The system of claim 16, wherein the at least one low frequency RF power
20 source is configured to generate a frequency having a non-sinusoidal waveform by
combining a fundamental frequency with at least two harmonic frequencies of the
fundamental frequency.

18. The system of claim 17, wherein the at least two harmonic frequencies of
25 the fundamental frequency comprise a third harmonic frequency and a fifth harmonic
frequency of the fundamental frequency.

19. The system of claim 16, wherein the at least one low frequency RF power
source is configured to generate a non-sinusoidal waveform having one of a square
30 waveform shape and a flat-bottom waveform shape.

20. The system of claim 16, wherein one of the electrode and the electrostatic
chuck is operably coupled to a high frequency RF power source configured to generate a
frequency of about 13 MHz to about 60 MHz.