Claims

1. A method of filling a 3-D structure of a partially manufactured semiconductor substrate with a tungsten-containing material, the 3-D structure comprising sidewalls, a plurality of openings in the sidewalls leading to a plurality of features having a plurality of interior regions fluidically accessible through the openings, the method comprising:

providing a substrate having the 3-D structure to a processing chamber;

depositing a first layer of the tungsten-containing material within the 3-D structure such that the first layer partially fills the plurality of interior regions of the 3-D structure;

etching vertically after depositing the first layer of the tungsten-containing material, the vertical etching comprising removing portions of the first layer from the sidewalls using a first activated etching material without substantially removing portions of the first layer from the plurality of interior regions;

etching horizontally after depositing the first layer of the tungsten-containing material, the horizontal etching comprising removing portions of the first layer from the plurality of interior regions using a second activated etching material; and

depositing a second layer of the tungsten-containing material within the 3-D structure after etching vertically and horizontally such that the second layer fills at least a portion of the interior regions left unfilled by the first layer.

2. The method of claim 1, wherein the first activated etching material comprises an ion species and the second activated etching material comprises a neutral species.

3. The method of claim 2, wherein the second activated etching material is generated from conversion of the first activated etching material within the 3-D structure.

4. The method of claim 3, wherein conversion of the first activated etching material to the second activated etching material comprises the ion species of the first activated etching material accepting one or more electrons and converting to the neutral species of the second activated etching material.

5. The method of claim 4, wherein the ion species is generated within the processing chamber through ionization of one or more of NF_3, CF_4, CHF_3, CH_2F_2, and CH_3F.

6. The method of claim 2, wherein:

the first activated etching material is a plasma comprising an ion species generated within the processing chamber;

the vertical etching comprises applying an electromagnetic field to the ion species so that a portion of the ions are directed towards the bottom of the 3-D structure; and

the second activated etching material is a plasma comprising a free radical species generated remotely from the processing chamber and introduced into the processing chamber.

7. The method of claim 6, wherein:

the ion species comprises fluorine; and

the free radical species comprises fluorine.

8. The method of claim 1, wherein at least a portion of the plurality of features are stacked in substantially vertical alignment with one another.

9. The method of claim 8, wherein the structure has 64 or more vertically stacked features in vertical alignment with one another.

10. The method of claim 1, wherein the partially manufactured semiconductor substrate further comprises an outer layer susceptible to tungsten deposition and upon which the first layer of tungsten-containing material is deposited, and wherein the vertical etching removes the outer layer in at least portions of the sidewalls of the 3-D structure such that substantially no tungsten-containing material is deposited upon these portions during the subsequent deposition of the second layer of tungsten-containing material.

11. The method of claim 10, wherein the outer layer susceptible to tungsten deposition comprises a metal nitride.

12. The method of claim 1, wherein the substrate having the 3-D structure further includes a plurality of polysilicon pillars which partially inhibit the fluidic accessibility of the plurality of interior regions through the plurality of openings.

13. The method of claim 1, further comprising:

providing a polymer precursor to the processing chamber; and

forming a protective layer via polymerization of the polymer precursor over portions of the 3-D structure which attenuates the extent to which these portions are etched in the vertical etching.

14. The method of claim 13, wherein:

the polymer precursor is selected from: CF_4, CHF_3, CH_2F_2, and CH_3F; and

providing the polymer precursor comprises flowing the polymer precursor into the processing chamber at a flow rate between about 30 to 40 sccm.

15. The method of claim 1, further comprising providing the first activated etching material to the processing chamber by flowing one or more of NF_3, CF_4, CHF_3, CH_2F_2, and CH_3F into the processing chamber at a flow rate between about 100 and 700 sccm and ionizing it therein.

16. The method of claim 1, wherein the vertical etching is performed with the processing chamber maintained at:

a temperature between about 10 and 120^o C.; and

a pressure between about 50 and 90 mTorr

while removing portions of the first layer of tungsten-containing material.

17. The method of claim 1, wherein the horizontal etching is performed with the processing chamber maintained at:

a temperature between about 10 and 120^o C.;

and a pressure of less than about 5 mTorr

while removing portions of the first layer of tungsten-containing material.

18. The method of claim 1, wherein:

the first activated etching material is a plasma comprising one or more ion species generated within the processing chamber; and

the plasma is an inductively-coupled plasma generated and maintained by inductively-coupled RF power having a frequency between about 13 and 60 MHz while also generated

and maintained by substrate-biased RF power having a frequency between about 400 kHz and 14 MHz.

19. The method of claim 18, wherein the substrate-biased RF power has a voltage between about 100 and 500 Volts relative to the substrate.

20. The method of claim 19, wherein the substrate-biased RF power is pulsed at a rate of between about 100 Hz and 400 Hz and with a duty cycle between about 10% and 60%.

21. The method of claim 18, wherein the inductively-coupled RF power is between about 500 and 600 Watts.

22. The method of claim 21, wherein the inductively-coupled RF power is generated by generating coils comprising a first generating coil and a second generating coil, the first generating coil supplying inductively-coupled RF power to an outer region of the processing chamber, the second generating coil supplying inductively-coupled RF power to an inner region of the processing chamber, and wherein the total inductively-coupled RF power is split between the first and second generating coils in a ratio between about 0.1 and 1.5.

23. The method of claim 1, wherein the etch-rate corresponding to removal of portions of the first layer of the tungsten-containing material during the horizontal etching is substantially mass-transport limited.

24. The method of claim 1, further comprising:

etching vertically the second layer of tungsten-containing material, the vertical etching comprising removing portions of the second layer from the sidewalls using the first activated etching material without substantially removing portions of the second layer from the plurality of interior regions;

etching horizontally the second layer of tungsten-containing material, the horizontal etching comprising removing portions of the second layer from the plurality of interior regions using the second activated etching material; and

depositing a third layer of the tungsten-containing material within the 3-D structure after horizontally and vertically etching the second layer, such that the third layer fills at least part of the portion of the interior regions left unfilled by the first and second layers.

25. A method of filling a 3-D structure of a partially manufactured semiconductor substrate, the 3-D structure comprising sidewalls, a plurality of openings in the sidewalls leading to a plurality of features having a plurality of interior regions fluidically accessible through the openings, the method comprising:

providing a substrate having the 3-D structure, the 3-D structure already having a first layer of a tungsten-containing material at least partially covering its sidewalls and/or openings in its sidewalls, and partially filling the plurality of interior regions, but with a portion of the plurality of interior regions left unfilled by the first layer;

etching vertically to remove portions of the first layer of the tungsten-containing material from the sidewalls and/or openings in the sidewalls without substantially removing portions of the first layer from the plurality of interior regions;

etching horizontally to remove portions of the first layer of the tungsten-containing material from the plurality of interior regions; and

depositing a second layer of the tungsten-containing material after etching horizontally and vertically.

26. The method of claim 25, wherein the vertical etching utilizes a first activated etching material and the horizontal etching utilizes a second activated etching material generated from conversion of the first activated etching material within the 3-D structure.

27. An apparatus for filling a 3-D structure of a partially manufactured semiconductor substrate with a tungsten-containing material, the 3-D structure comprising sidewalls, a plurality of openings in the sidewalls leading to a plurality of features, the plurality of features having a plurality of interiors fluidically accessible through the plurality of openings, the apparatus comprising:

a processing chamber;

a substrate holder within the processing chamber configured to hold the substrate having the 3-D structure;

one or more gas inlets configured to introduce a tungsten-containing precursor and a reducing agent into the processing chamber;

a power supply configured to generate and maintain an ionized plasma within the processing chamber; and

a controller having instructions in the form of machine readable code for operating the one or more gas inlets and power supply, the controller configured to execute the instructions, the instructions comprising:

instructions for depositing a first layer of the tungsten-containing material within the 3-D structure such that the first layer partially fills the plurality of interior regions of the 3-D structure;

instructions for etching vertically and horizontally after depositing the first layer of the tungsten-containing material, the vertical etching comprising removing portions of the first layer from the sidewalls using a first activated etching material without substantially removing portions of the first layer from the plurality of interior regions, the horizontal etching comprising removing portions of the first layer from the plurality of interior regions using a second activated etching material; and

instructions for depositing a second layer of the tungsten-containing material within the 3-D structure after etching vertically and horizontally such that the second layer fills at least a portion of the interior regions left unfilled by the first layer.