

CLAIMS:

1. An inductively coupled plasma processing apparatus comprising:

a vacuum chamber;

a vacuum source adapted to exhaust the vacuum chamber;

a substrate support comprising a lower electrode on which a single semiconductor substrate is supported in an interior of the vacuum chamber;

a ceramic showerhead which forms an upper wall of the vacuum chamber wherein the ceramic showerhead includes a gas plenum in fluid communication with a plurality of showerhead gas outlets in a plasma exposed surface thereof for supplying a process gas as a diffusive gas flow to the interior of the vacuum chamber, a central opening in the ceramic showerhead that extends an entire thickness of the ceramic showerhead and the ceramic showerhead including a lower vacuum sealing surface which surrounds the plasma exposed surface and forms a vacuum seal with a vacuum sealing surface of the vacuum chamber;

a central gas injector disposed in the central opening of the ceramic showerhead, wherein the central gas injector includes one or more gas injector outlets, in a surface thereof that is exposed inside the vacuum chamber, for supplying the process gas as a convective gas flow to the interior of the vacuum chamber at least in a direction towards a center of the semiconductor substrate, wherein

the one or more gas injector outlets include a plurality of central gas outlets, wherein the plurality of central gas outlets are arranged to supply the process gas as the convective gas flow directly from the central gas injector into the vacuum chamber without passing through the gas plenum of the ceramic showerhead, and

the one or more gas injector outlets include a plurality of radial gas outlets arranged radially outward of the plurality of central gas outlets, wherein the plurality of radial gas outlets are arranged to supply the process gas as the diffusive gas flow radially outward from the central gas injector into the gas plenum of the ceramic showerhead and through the plurality of showerhead gas outlets;

an RF energy source which inductively couples RF energy through the ceramic showerhead and into the vacuum chamber to energize the process gas into a plasma state to process the semiconductor substrate; and

a control system configured to (i) control supply of the process gas as the convective gas flow through the central gas outlets via a first gas line at a first flow rate and (ii) control supply of, independently of the convective gas flow, the process gas as the diffusive gas flow through the showerhead gas outlets via a second gas line at a second flow rate, wherein the convective gas flow and the diffusive gas flow are supplied simultaneously, and wherein, to control the supply of the convective gas flow and the diffusive gas flow, the control system is further configured to select and control a pressure within the vacuum chamber, the first flow rate, and the second flow rate based on a desired eddy current above the semiconductor substrate, wherein, to achieve the desired eddy current, the control system is configured to independently control the first flow rate and the second flow rate.

2. The plasma processing apparatus of Claim 1, wherein the one or more gas injector outlets include:

an electrically conducting shield on surfaces thereof which minimizes plasma ignition within the one or more gas injector outlets of the central gas injector.

3. The plasma processing apparatus of Claim 1, wherein the central gas injector at least one of:

includes a vacuum sealing surface on an outer portion thereof wherein the vacuum sealing surface is configured to form a vacuum seal with a central vacuum sealing surface of the ceramic showerhead;

is adapted to be slidably fitted in the central opening of the ceramic showerhead with an O-ring between the central gas injector and the ceramic showerhead;

is adapted to fit in the central opening of the ceramic showerhead in a twist and lock arrangement;

injects the process gas as the convective gas flow at a subsonic, sonic, supersonic velocity, or a combination thereof;

is made of a dielectric material; and

is arranged such that a distal end of the central gas injector is disposed below the plasma exposed surface of the ceramic showerhead.

4. The plasma processing apparatus of Claim 1, wherein at least one of:

the ceramic showerhead has a thickness of about 0.4 inch;

the ceramic showerhead has a diameter of at least about 20 inches;

the central opening of the ceramic showerhead has a diameter of about 1 to 1.5 inches;

the showerhead gas outlets have a diameter of about 0.04 inch;

the ceramic showerhead includes at least one blind bore configured to receive a temperature probe;

a wall defining the central opening of the ceramic showerhead includes a circumferential groove disposed therein wherein the groove has a height of about 0.15 inch and a depth of about 0.15 inch;

the gas plenum has a diameter of at least about 10 inches and a height of about 0.06 inch; and

the ceramic showerhead is made of one or more pieces of alumina, silicon nitride, silicon oxide, single crystal silicon, quartz, or silicon carbide.

5. The plasma processing apparatus of Claim 1, wherein the ceramic showerhead is a multizone ceramic showerhead having two or more zones for supplying the process gas as the diffusive gas flow therethrough, and wherein the zones are annular zones or radial zones.

6. The plasma processing apparatus of Claim 1, wherein the central gas injector is a multizone central gas injector having two or more zones for supplying the process gas as the convective gas flow therethrough.

7. The plasma processing apparatus of Claim 1, further comprising

a non-transitory computer machine-readable medium comprising program instructions for control of the plasma processing apparatus.

8. The plasma processing apparatus of Claim 1, wherein the central gas injector includes a showerhead gas supply channel that is connected to the gas plenum in the ceramic showerhead via the plurality of radial gas outlets.