CLAIMS

1. A semiconductor substrate processing system, comprising:

a processing chamber;

a substrate support defined to support a substrate in the processing chamber;

a plasma chamber defined separate from the processing chamber, the plasma chamber defined to generate a plasma;

a plurality of fluid transmission pathways fluidly connecting the plasma chamber to the processing chamber, the plurality of fluid transmission pathways defined to supply reactive constituents of the plasma from the plasma chamber to the processing chamber;

an electron beam source defined to generate an electron beam and transmit the electron beam through the processing chamber above and across the substrate support, wherein the electron beam source includes a hollow cathode positioned outside a perimeter of the substrate support and above the substrate support, the hollow cathode having an outlet oriented toward a region of the processing chamber over the substrate support;

a plurality of conductive grids positioned outside a perimeter of the substrate support and above the substrate support, wherein a given one of the plurality of conductive grids is disposed between the outlet of the hollow cathode and the region of the processing chamber over the substrate support to facilitate extraction of electrons from the hollow cathode; and

a heater connected to the plurality of conductive grids to control a temperature of the plurality of conductive grids.

2. A semiconductor substrate processing system as recited in claim 1, wherein the electron beam source is defined to transmit the electron beam along a trajectory substantially parallel to a surface of the substrate support defined to support the substrate.

3. A semiconductor substrate processing system as recited in claim 1, wherein the electron beam source is defined to transmit multiple spatially separated electron beams through the processing chamber above and across the substrate support in a common direction.

4. A semiconductor substrate processing system as recited in claim 1, wherein the electron beam source is defined to transmit multiple spatially separated electron beams through the processing chamber above and across the substrate support in respective multiple directions.

5. A semiconductor substrate processing system as recited in claim 4, wherein the electron beam source is defined to sequentially transmit the multiple spatially separated electron beams.

6. A semiconductor substrate processing system as recited in claim 1, wherein each of the plurality of conductive grids is electrically connected to a power supply so as to have a controlled voltage level applied to each of the plurality of conductive grids in a independently controlled manner.

7. A semiconductor substrate processing system as recited in claim 6, wherein the power supply is defined to supply a positive charge pulse and a negative charge pulse in an alternating manner to the given one of the plurality of conductive grids.

8. A semiconductor substrate processing system as recited in claim 7, wherein another one of the plurality of conductive grids is disposed opposite the substrate support from the outlet of the hollow cathode to provide an electrical sink for the electron beam to be transmitted by the hollow cathode.

9. A semiconductor substrate processing system as recited in claim 1, wherein the hollow cathode includes a first electrode positioned inside the hollow cathode at a location opposite from the outlet of the hollow cathode, the hollow cathode including a second electrode positioned inside the hollow cathode next to the outlet of the hollow cathode so as to circumscribe the outlet of the hollow cathode, the second electrode connected for control independent of the first electrode.

10. A semiconductor substrate processing system as recited in claim 9, further comprising:

a gas supply in fluid communication with an interior region of the hollow cathode, the gas supply defined to supply a process gas to the interior region of the hollow cathode;

a first power supply in electrical communication with the first electrode inside the hollow cathode, the first power supply defined to supply direct current power, radiofrequency power, or a combination of direct current power and radiofrequency power to the first electrode inside the hollow cathode to provide for transformation of the process gas into a plasma within the hollow cathode; and

a second power supply in electrical communication with the second electrode inside the hollow cathode, the second power supply defined to supply direct current power, radiofrequency power, or a combination of direct current power and radiofrequency power to the second electrode inside the hollow cathode to enhance electron extraction from the plasma within the hollow cathode.

11. A method for processing a semiconductor substrate, comprising:

placing a substrate on a substrate support in exposure to a processing region;

generating a plasma in a plasma generation region separate from the processing region;

supplying reactive constituents of the plasma from the plasma generation region to the processing region; and

operating a hollow cathode to inject electrons into the processing region over the substrate, whereby the injected electrons modify an ion density in the processing region to affect processing of the substrate, the hollow cathode positioned outside a perimeter of the substrate support and above the substrate support, the hollow cathode having an outlet oriented toward a region of the processing chamber over the substrate support, operating a heater connected to a conductive grid disposed between the outlet of the hollow cathode and the region of the processing chamber over the substrate to control a temperature of the conductive grid, the conductive grid being one of a plurality of conductive grids positioned outside the perimeter of the substrate support and above the substrate support.

12. A method for processing a semiconductor substrate as recited in claim 11, wherein injecting electrons into the processing region includes transmitting an electron beam along a trajectory substantially parallel to a top surface of the substrate.

13. A method for processing a semiconductor substrate as recited in claim 12, wherein the trajectory of the electron beam extends in a linear manner from a first location outside a periphery of the substrate support and above the substrate support to a second location outside the periphery of the substrate support and above the substrate support.

14. A method for processing a semiconductor substrate as recited in claim 13, further comprising:

applying a positive electrical charge to at least one of the plurality of conductive grids at the second location such that the at least one of the plurality of conductive grids functions as an electrical sink for the electron beam transmitted along the trajectory.

15. A method for processing a semiconductor substrate as recited in claim 11, wherein the electrons are injected into the processing region in a pulsed manner.

16. A method for processing a semiconductor substrate as recited in claim 11, wherein injecting electrons into the processing region includes transmitting multiple spatially separated electron beams through the processing chamber above and across a top surface of the substrate.

17. A method for processing a semiconductor substrate as recited in claim 16, wherein each of the multiple spatially separated electron beams is transmitted in a common direction such that the multiple spatially separated electron beams are transmitted in a substantially parallel manner above and across the top surface of the substrate.

18. A method for processing a semiconductor substrate as recited in claim 16, wherein different ones of the multiple spatially separated electron beams are transmitted at different times such that electrons are injected in a time-averaged substantially uniform manner throughout the processing region in exposure to the substrate.

19. A method for processing a semiconductor substrate as recited in claim 16, wherein the multiple spatially separated electron beams are transmitted in different multiple directions above and across the top surface of the substrate and substantially parallel to the top surface of the substrate.

20. A method for processing a semiconductor substrate as recited in claim 11, wherein different ones of the multiple spatially separated electron beams are transmitted at different times such that electrons are injected in a time-averaged substantially uniform manner throughout the processing region in exposure to the substrate.

CLAIMS

1. A semiconductor substrate processing system, comprising:

a processing chamber;

a substrate support defined to support a substrate in the processing chamber;

a plasma chamber defined separate from the processing chamber, the plasma chamber defined to generate a plasma;

a plurality of fluid transmission pathways fluidly connecting the plasma chamber to the processing chamber, the plurality of fluid transmission pathways defined to supply reactive constituents of the plasma from the plasma chamber to the processing chamber; and

an electron beam source defined to generate an electron beam and transmit the electron beam through the processing chamber above and across the substrate support.

2. A semiconductor substrate processing system as recited in claim 1, wherein the electron beam source is defined to transmit the electron beam along a trajectory substantially parallel to a surface of the substrate support defined to support the substrate.

3. A semiconductor substrate processing system as recited in claim 1, wherein the electron beam source is defined to transmit multiple spatially separated electron beams through the processing chamber above and across the substrate support in a common direction.

4. A semiconductor substrate processing system as recited in claim 1, wherein the electron beam source is defined to transmit multiple spatially separated electron beams through the processing chamber above and across the substrate support in respective multiple directions.

5. A semiconductor substrate processing system as recited in claim 4, wherein the electron beam source is defined to sequentially transmit the multiple spatially separated electron beams.

6. A semiconductor substrate processing system as recited in claim 1, further comprising:

a plurality of conductive grids positioned outside a perimeter of the substrate support and above the substrate support, the plurality of conductive grids electrically connected to a

power supply so as to have a controlled voltage level applied to each of the plurality of conductive grids in a independently controlled manner.

7. A semiconductor substrate processing system as recited in claim 6, wherein the electron beam source is defined as a hollow cathode positioned outside a perimeter of the substrate support and above the substrate support, the hollow cathode having an outlet oriented toward a region of the processing chamber over the substrate support, and

wherein a given one of the plurality of conductive grids is disposed between the outlet of the hollow cathode and the region of the processing chamber over the substrate support to facilitate extraction of electrons from the hollow cathode.

8. A semiconductor substrate processing system as recited in claim 7, wherein another one of the plurality of conductive grids is disposed opposite the substrate support from the outlet of the hollow cathode to provide an electrical sink for the electron beam to be transmitted by the hollow cathode.

9. A semiconductor substrate processing system as recited in claim 7, further comprising:

a heater connected to the plurality of conductive grids to control a temperature of the plurality of conductive grids.

10. A semiconductor substrate processing system as recited in claim 7, further comprising:

a gas supply in fluid communication with an interior region of the hollow cathode, the gas supply defined to supply a process gas to the interior region of the hollow cathode; and

a power supply in electrical communication with one or more power delivery components within the interior region of the hollow cathode, the power supply defined to supply direct current power, radiofrequency power, or a combination of direct current power and radiofrequency power to the one or more power delivery components within the interior region of the hollow cathode to provide for transformation of the process gas into a plasma within the interior region of the hollow cathode.

11. A method for processing a semiconductor substrate, comprising:

placing a substrate on a substrate support in exposure to a processing region;

generating a plasma in a plasma generation region separate from the processing region;

supplying reactive constituents of the plasma from the plasma generation region to the processing region; and

injecting electrons into the processing region over the substrate, whereby the injected electrons modify an ion density in the processing region to affect processing of the substrate.

12. A method for processing a semiconductor substrate as recited in claim 11, wherein injecting electrons into the processing region includes transmitting an electron beam along a trajectory substantially parallel to a top surface of the substrate.

13. A method for processing a semiconductor substrate as recited in claim 12, wherein the trajectory of the electron beam extends in a linear manner from a first location outside a periphery of the substrate support and above the substrate support to a second location outside the periphery of the substrate support and above the substrate support.

14. A method for processing a semiconductor substrate as recited in claim 13, further comprising:

applying a positive electrical charge to a conductive grid at the second location such that the conductive grid functions as an electrical sink for the electron beam transmitted along the trajectory.

15. A method for processing a semiconductor substrate as recited in claim 11, wherein the electrons are injected into the processing region in a pulsed manner.

16. A method for processing a semiconductor substrate as recited in claim 11, wherein injecting electrons into the processing region includes transmitting multiple spatially separated electron beams through the processing chamber above and across a top surface of the substrate.

17. A method for processing a semiconductor substrate as recited in claim 16, wherein each of the multiple spatially separated electron beams is transmitted in a common

direction such that the multiple spatially separated electron beams are transmitted in a substantially parallel manner above and across the top surface of the substrate.

18. A method for processing a semiconductor substrate as recited in claim 16, wherein different ones of the multiple spatially separated electron beams are transmitted at different times such that electrons are injected in a time-averaged substantially uniform manner throughout the processing region in exposure to the substrate.

19. A method for processing a semiconductor substrate as recited in claim 16, wherein the multiple spatially separated electron beams are transmitted in different multiple directions above and across the top surface of the substrate and substantially parallel to the top surface of the substrate.

20. A method for processing a semiconductor substrate as recited in claim 11, wherein different ones of the multiple spatially separated electron beams are transmitted at different times such that electrons are injected in a time-averaged substantially uniform manner throughout the processing region in exposure to the substrate.

21. A semiconductor substrate processing system, comprising:

a processing chamber;

a substrate support defined to support a substrate in the processing chamber;

a plasma chamber defined separate from the processing chamber, the plasma chamber defined to generate a plasma;

a plurality of fluid transmission pathways fluidly connecting the plasma chamber to the processing chamber, the plurality of fluid transmission pathways defined to supply reactive constituents of the plasma from the plasma chamber to the processing chamber;

an electrode disposed within the processing chamber separate from the substrate support; and

a power supply electrically connected to the electrode, the power supply defined to supply electrical power to the electrode so as to liberate electrons from the electrode into the processing chamber.

22. A semiconductor substrate processing system as recited in claim 21, wherein the

electrode is defined as a conductive band disposed outside a perimeter of the substrate support and above the substrate support within the processing chamber.

23. A semiconductor substrate processing system as recited in claim 22, wherein the conductive band is formed as a continuous structure that circumscribes the perimeter of the substrate support.

24. A semiconductor substrate processing system as recited in claim 23, further comprising:

an insulating member formed and disposed around the electrode to electrically isolate the electrode from surrounding structures of the processing chamber.

25. A semiconductor substrate processing system as recited in claim 21, wherein the electrode is defined as a planar conductive segment disposed above and over the substrate support within the processing chamber.

26. A semiconductor substrate processing system as recited in claim 25, further comprising:

a top plate assembly disposed above the substrate support so as to separate the plasma chamber from the processing chamber, wherein the plurality of fluid transmission pathways are defined within the top plate assembly, wherein the planar conductive segment is defined on a bottom surface of the top plate assembly in an orientation facing the substrate support.

27. A semiconductor substrate processing system as recited in claim 26, further comprising:

an insulating member formed and disposed between the planar conductive segment and the top plate assembly to electrically isolate the planar conductive segment from the top plate assembly and surrounding structures of the processing chamber.

28. A semiconductor substrate processing system as recited in claim 21, wherein the power supply is defined to supply direct current power, radiofrequency power, or a combination of direct current power and radiofrequency power to the electrode.

29. A semiconductor substrate processing system as recited in claim 21, wherein the power supply is defined to supply power to the electrode in either a pulsed manner or a continuous manner.

30. A semiconductor substrate processing system as recited in claim 21, wherein the electrode includes both a conductive band disposed outside a perimeter of the substrate support and above the substrate support within the processing chamber, and a planar conductive segment disposed above and over the substrate support within the processing chamber.

31. A method for processing a semiconductor substrate, comprising:

placing a substrate on a substrate support in exposure to a processing region;

generating a plasma in a plasma generation region separate from the processing region;

supplying reactive constituents of the plasma from the plasma generation region to the processing region; and

supplying power to one or more electrodes disposed within the processing region separate from the substrate support, whereby the power supplied to the one or more electrodes injects electrons from the one or more electrodes into the processing region so as to modify an ion density in the processing region to affect processing of the substrate.

32. A method for processing a semiconductor substrate as recited in claim 31, wherein the one or more electrodes includes a conductive band disposed outside a perimeter of the substrate support and above the substrate support in exposure to the processing region.

33. A method for processing a semiconductor substrate as recited in claim 32, wherein the conductive band is formed as a continuous structure that circumscribes the perimeter of the substrate support.

34. A method for processing a semiconductor substrate as recited in claim 31, wherein the one or more electrodes includes a planar conductive segment disposed above and over the substrate support in exposure to the processing region.

35. A method for processing a semiconductor substrate as recited in claim 31,

wherein the one or more electrodes includes both a conductive band disposed outside a perimeter of the substrate support and above the substrate support in exposure to the processing region, and a planar conductive segment disposed above and over the substrate support in exposure to the processing region.

36. A method for processing a semiconductor substrate as recited in claim 31, wherein supplying power to one or more electrodes includes supplying direct current power, radiofrequency power, or a combination of direct current power and radiofrequency power to the one or more electrodes.

37. A method for processing a semiconductor substrate as recited in claim 31, wherein the power is supplied to one or more electrodes in a pulsed manner.

38. A method for processing a semiconductor substrate as recited in claim 31, wherein the power is supplied to one or more electrodes in a continuous manner.

39. A method for processing a semiconductor substrate as recited in claim 31, wherein supplying power to one or more electrodes includes alternating a polarity of electric charge on the one or more electrodes.

40. A method for processing a semiconductor substrate as recited in claim 31, further comprising:

applying a bias voltage across the processing region from the substrate support so as to attract ions that are generated as a result of the injected electrons toward the substrate on the substrate support.

41. A semiconductor substrate processing system, comprising:

a processing chamber;

a substrate support defined to support a substrate in the processing chamber;

a plasma chamber defined separate from the processing chamber, the plasma chamber defined to generate a plasma;

a plurality of fluid transmission pathways fluidly connecting the plasma chamber to the processing chamber, the plurality of fluid transmission pathways defined to supply reactive

constituents of the plasma from the plasma chamber to the processing chamber; and

a plurality of power delivery components defined to deliver power to the plurality of fluid transmission pathways so as to generate supplemental plasma within the plurality of fluid transmission pathways, the plurality of fluid transmission pathways defined to supply reactive constituents of the supplemental plasma to the processing chamber.

42. A semiconductor substrate processing system as recited in claim 41, wherein the plurality of power delivery components includes one or more electrodes disposed in exposure to an interior of each of the plurality of fluid transmission pathways.

43. A semiconductor substrate processing system as recited in claim 41, wherein the plurality of power delivery components includes one or more coils disposed to induce an electric current within an interior of each of the plurality of fluid transmission pathways.

44. A semiconductor substrate processing system as recited in claim 41, wherein the plurality of power delivery components includes one or more lasers disposed to direct laser energy into an interior of each of the plurality of fluid transmission pathways.

45. A semiconductor substrate processing system as recited in claim 41, wherein the plurality of power delivery components include electron beam sources defined to generate electron beams and transmit the electron beams through the plurality of fluid transmission pathways.

46. A semiconductor substrate processing system as recited in claim 41, further comprising:

a power supply in electrical connection with each of the plurality of power delivery components, the power supply defined to supply direct current power, radiofrequency current power, or a combination of direct current power and radiofrequency power to each of the plurality of power delivery components.

47. A semiconductor substrate processing system as recited in claim 41, wherein the plurality of fluid transmission pathways are defined as flow-through hollow cathodes, flow-

through capacitively coupled regions, flow-through inductively coupled regions, flow-through magnetron driven regions, flow-through laser driven regions, or a combination thereof.

48. A semiconductor substrate processing system as recited in claim 41, further comprising:

a process gas supply connected in fluid communication with an interior of each of the plurality of fluid transmission pathways, the process gas supply defined to supply a process gas to the interior of each of the plurality of fluid transmission pathways for generation of the supplemental plasma.

49. A semiconductor substrate processing system as recited in claim 41, further comprising:

an electrode disposed in the plasma chamber to drive charged species from the plasma chamber through plurality of fluid transmission pathways to the processing chamber.

50. A semiconductor substrate processing system as recited in claim 41, further comprising:

an extraction grid disposed within the processing chamber to attract charged species from the fluid transmission pathways into the processing chamber.

51. A method for processing a semiconductor substrate, comprising:

placing a substrate on a substrate support in exposure to a processing region;

generating a plasma in a plasma generation region separate from the processing region;

supplying reactive constituents of the plasma from the plasma generation region through a plurality of fluid transmission pathways into the processing region, whereby the reactive constituents of the plasma affect processing of the substrate;

generating a supplemental plasma in the plurality of fluid transmission pathways; and

supplying reactive constituents of the supplemental plasma from the plurality of fluid transmission pathways into the processing region, whereby the reactive constituents of the supplemental plasma affect processing of the substrate.

52. A method for processing a semiconductor substrate as recited in claim 51, wherein generating the supplemental plasma includes operating the plurality of fluid

transmission pathways as either flow-through hollow cathodes, flow-through capacitively coupled regions, flow-through inductively coupled regions, flow-through magnetron driven regions, flow-through laser driven regions, or a combination thereof.

53. A method for processing a semiconductor substrate as recited in claim 51, wherein supplying reactive constituents of the supplemental plasma from the plurality of fluid transmission pathways into the processing region includes operating an extraction grid disposed within the processing chamber to attract charged species from the plurality of fluid transmission pathways into the processing region.

54. A method for processing a semiconductor substrate as recited in claim 51, wherein supplying reactive constituents of the plasma from the plasma generation region through the plurality of fluid transmission pathways into the processing region includes operating an electrode disposed in the plasma generation region to drive charged species from the plasma generation region through the plurality of fluid transmission pathways into the processing region.

55. A method for processing a semiconductor substrate as recited in claim 51, wherein generating the supplemental plasma in the plurality of fluid transmission pathways includes transmitting direct current power, radiofrequency current power, or a combination of direct current power and radiofrequency power through the plurality of fluid transmission pathways.

56. A method for processing a semiconductor substrate as recited in claim 55, wherein the power is transmitted through the plurality of fluid transmission pathways in a pulsed manner.

57. A method for processing a semiconductor substrate as recited in claim 55, wherein the power is transmitted through the plurality of fluid transmission pathways in a continuous manner.

58. A method for processing a semiconductor substrate as recited in claim 51, wherein generating the supplemental plasma in the plurality of fluid transmission pathways

includes supplying a process gas to the interior of each of the plurality of fluid transmission pathways.

59. A method for processing a semiconductor substrate as recited in claim 51, further comprising:

injecting electrons into the processing region over the substrate, whereby the injected electrons modify an ion density in the processing region to affect processing of the substrate.

60. A method for processing a semiconductor substrate as recited in claim 51, further comprising:

supplying power to one or more electrodes disposed within the processing region separate from the substrate support, whereby the power supplied to the one or more electrodes injects electrons from the one or more electrodes into the processing region so as to modify an ion density in the processing region to affect processing of the substrate.