CLAIMS

1. A system for treating water comprising:

a primary actinic radiation reactor;

a source of a persulfate precursor compound disposed to introduce at least one persulfate precursor compound into the primary actinic radiation reactor;

a total organic carbon (TOC) concentration sensor located upstream of the primary actinic radiation reactor;

a persulfate concentration sensor located downstream of the primary actinic radiation reactor;

a source of a reducing agent disposed to introduce at least one reducing agent downstream from the primary actinic radiation reactor;

a reducing agent concentration sensor located downstream of a point of addition of the at least one reducing agent; and

a controller operatively coupled to receive at least one input signal from at least one of the TOC concentration sensor, the persulfate concentration sensor, and the reducing agent concentration sensor, and generate at least one control signal that regulates one of a rate at which the persulfate precursor compound is introduced into the primary actinic radiation reactor, an intensity of the actinic radiation in the primary actinic radiation reactor, and a rate at which the reducing agent is introduced to the system.

2. The system of claim 1, further comprising a reverse osmosis unit located upstream of the primary actinic radiation reactor.

3. The system of claim 1, further comprising a secondary actinic radiation reactor located downstream of the primary actinic radiation reactor.

4. The system of claim 1, further comprising a particulate filter located downstream of the primary actinic radiation reactor.

5. The system of claim 1, further comprising an ultrafiltration apparatus located downstream of from the primary actinic radiation reactor.

6. The system of claim 1, further comprising at least one unit operation selected from the group consisting of a heat exchanger, a degasifier, a particulate filter, an ion purification apparatus, and an ion-exchange column.

7. The system of claim 6, wherein the ion-exchange column is located upstream of the TOC concentration sensor.

8. The system of claim 1, further comprising a source of water located upstream of the primary actinic radiation reactor comprising one or more unit operations selected from the group consisting of a reverse osmosis filter, an electrodialysis device, an electrodeionization device, a distillation apparatus, an ion-exchange column, and combinations thereof.

9. The system of claim 8, wherein water from the source of water comprises less than about 25 ppb TOC.

10. The system of claim 1, further comprising a TOC concentration sensor located downstream of the primary actinic radiation reactor.

11. The system of claim 1, wherein the reducing agent is sulfur dioxide.

12. A method of treating water comprising:

providing a water to be treated;

measuring a total organic carbon (TOC) value of the water to be treated;

introducing persulfate anions to the water to be treated based in part on at least one input signal of the measured TOC value of the water to be treated;

introducing the water containing persulfate anions to a primary reactor;

exposing the persulfate anions in the water to ultraviolet light in the reactor to produce an irradiated water stream;

adjusting an intensity of the ultraviolet light based in part on at least one of an input signal selected from the group consisting of a TOC value of the water to be treated, a persulfate value of the water downstream of the reactor, and a rate of addition of persulfate anions; and

introducing a reducing agent to the irradiated water.

13. The method of claim 12, further comprising exposing the irradiated water to ultraviolet light in a secondary reactor located downstream of the primary reactor.

14. The method of claim 12, further comprising removing dissolved solids and dissolved gases from the water.

15. The method of claim 12, further comprising treating the water to be treated prior to providing the water to be treated to the reactor vessel.

16. The method of claim 12, further comprising measuring a reducing agent value of the irradiated water.

17. The method of claim 16, further comprising introducing the reducing agent to the irradiated water based on the measured reducing agent value.

18. The method of claim 12, wherein the reducing agent is sulfur dioxide.

19. The method of providing ultrapure water to a semiconductor fabrication unit, comprising:

providing inlet water having a TOC value of less than about 25 ppb;

introducing at least one free radical precursor compound into the water;

converting the at least one free radical precursor compound into at least one free radical scavenging species;

removing at least a portion of any particulates from the water to produce the ultrapure water; and

delivering at least a portion of the ultrapure waer to the semiconductor fabrication unit.

20. The method of claim 19, further comprising regulating a rate of addition of the at least one precursor compound based at least partially on the TOC value of the inlet water.

21. A method for measuring a concentration of a compound in a liquid stream comprising:

measuring a first conductivity of the liquid stream;

irradiating the liquid stream;

measuring a second conductivity of the liquid stream after irradiating; and

calculating the concentration of the compound in the liquid stream based in part on the first conductivity measurement and the second conductivity measurement.

22. The method of claim 21, wherein the compound is persulfate.

23. The method of claim 22, wherein irradiating the liquid stream comprises converting at least a portion of the compound comprising persulfate into sulfate ions.

24. The method of claim 21, wherein the compound is sulfur dioxide.

25. The method of claim 24, wherein irradiating the liquids stream comprises converting at least a portion of the compound comprising sulfur dioxide into sulfate ions.

26. The method of claim 21, further comprising introducing the liquid stream into a first conductivity cell to measure the first conductivity of the liquid stream.

27. The method of claim 26, further comprising introducing the liquid stream into a second conductivity cell to measure the second conductivity of the liquid stream.

28. The method of claim 21, further comprising irradiating the liquid stream in an actinic radiation reactor prior to measuring the first conductivity.

29. The method of claim 28, further comprising introducing a persulfate precursor compound into the liquid stream prior to irradiating the liquid stream in the actinic radiation reactor.

30. An actinic radiation reactor comprising :

a vessel; and

a first array of tubes in the vessel comprising a first set of parallel tubes and a second set of parallel tubes, each tube of the second set of parallel tubes having a respective longitudinal axis that is orthogonal to a respective longitudinal axis of each tube of the first set of parallel tubes, each tube comprising at least one ultraviolet lamp.

31. The actinic radiation reactor of claim 30, further comprising a second array of tubes comprising a third set of parallel tubes and a fourth set of parallel tubes, each tube of the fourth set of parallel tubes having a respective longitudinal axis that is orthogonal to a respective longitudinal axis of the third set of parallel tubes, each tube comprising at least one ultraviolet lamp.

32. The actinic radiation reactor of claim 31, wherein each tube of the fourth set of parallel tubes has a longitudinal axis that is orthogonal to the respective longitudinal axis of one of the second set of parallel tubes and the first set of parallel tubes.

33. The actinic radiation reactor of claim 31, wherein the second array is positioned a predetermined distance from the first array.

34. The actinic radiation reactor of claim 31, wherein each end of each tube is secured to a wall of the vessel.

35. The actinic radiation reactor of claim 31, wherein the tubes of at least one of the first array and the second array extend across an inner volume of the vessel.

36. The actinic radiation reactor of claim 31, wherein one of the first set of parallel tubes and the second set of parallel tubes is positioned a predetermined distance from one of the third set of parallel tubes and the fourth set of parallel tubes.

37. A system for controlling introduction of a reducing agent to a liquid stream comprising:

a persulfate concentration sensor in fluid communication with the liquid stream;

a source of sulfur dioxide disposed to introduce sulfur dioxide to the liquid stream downstream of the persulfate concentration sensor;

a sulfur dioxide concentration sensor in fluid communication with the liquid stream and located downstream of the source of sulfur dioxide; and

a controller configured to generate a control signal that regulates at least one of a rate of addition of and an amount of the sulfur dioxide introduced into the liquid stream based on at least one input signal from one of the persulfate concentration sensor and the sulfur dioxide concentration sensor.

38. The system of claim 37, wherein the persulfate concentration sensor comprises at least one conductivity cell.

39. The system of claim 38, wherein the persulfate concentration sensor comprises a source of ultraviolet light.

40. The system of claim 37, wherein the sulfur dioxide concentration sensor comprises at least one conductivity cell.

41. The system of claim 40, wherein the sulfur dioxide concentration sensor comprises a source of ultraviolet light.

42. The system of claim 37, further comprising an actinic radiation reactor located upstream of the sulfur dioxide concentration sensor.

43. The system of claim 42, further comprising a source of persulfate precursor compound disposed to introduce at least one persulfate precursor compound into the primary actinic radiation reactor.

44. The system of claim 43, further comprising a total organic carbon concentration sensor located upstream of the actinic radiation reactor.

45. The system of claim 44, further comprising a total organic carbon concentration sensor located downstream of the actinic radiation reactor.

46. A method of irradiating a liquid in a vessel comprising:

energizing a first set of ultraviolet lamps in the vessel each of which is disposed to project actinic radiation parallel a first illumination vector; and

energizing a second set of ultraviolet lamps in the vessel each of which is disposed to project actinic radiation parallel a second illumination vector that is substantially perpendicular to the first illumination vector.

47. The method of claim 46, further comprising adjusting an intensity of at least one ultraviolet lamp of the first set of ultraviolet lamps.

48. The method of claim 47, further comprising adjusting an intensity of at least one ultraviolet lamp of the second set of ultraviolet lamps.

49. The method of claim 46, further comprising energizing at least one lamp of the first set of ultraviolet lamps and the second set of ultraviolet lamps based on a measurement of at least one of a total organic carbon (TOC) concentration, a persulfate concentration, and a flowrate of the liquid introduced to the vessel.

50. The method of claim 46, further comprising de-energizing at least one lamp of the first set of ultraviolet lamps and the second set of ultraviolet lamps based on a measurement of at least one of a total organic carbon (TOC) concentration, a persulfate concentration, and a flowrate of the liquid introduced to the vessel.

CLAIMS

1. A system for treating water comprising:

a primary actinic radiation reactor;

a source of a persulfate precursor compound disposed to introduce at least one persulfate precursor compound into the primary actinic radiation reactor;

a total organic carbon (TOC) concentration sensor located upstream of the primary actinic radiation reactor;

a persulfate concentration sensor located downstream of the primary actinic radiation reactor;

a source of a reducing agent disposed to introduce at least one reducing agent downstream from the primary actinic radiation reactor;

a reducing agent concentration sensor located downstream of a point of addition of the at least one reducing agent; and

a controller operatively coupled to receive at least one input signal from at least one of the TOC concentration sensor, the persulfate concentration sensor, and the reducing agent concentration sensor, and generate at least one control signal that regulates one of a rate at which the persulfate precursor compound is introduced into the primary actinic radiation reactor, an intensity of the actinic radiation in the primary actinic radiation reactor, and a rate at which the reducing agent is introduced to the system.

2. The system of claim 1, further comprising a reverse osmosis unit located upstream of the primary actinic radiation reactor.

3. The system of claim 1, further comprising a secondary actinic radiation reactor located downstream of the primary actinic radiation reactor.

4. The system of claim 1, further comprising a particulate filter located downstream of the primary actinic radiation reactor.

5. The system of claim 1, further comprising an ultrafiltration apparatus located downstream of from the primary actinic radiation reactor.

6. The system of claim 1, further comprising at least one unit operation selected from the group consisting of a heat exchanger, a degasifier, a particulate filter, an ion purification apparatus, and an ion-exchange column.

7. The system of claim 6, wherein the ion-exchange column is located upstream of the TOC concentration sensor.

8. The system of claim 1, further comprising a source of water located upstream of the primary actinic radiation reactor comprising one or more unit operations selected from the group consisting of a reverse osmosis filter, an electrodialysis device, an electrodeionization device, a distillation apparatus, an ion-exchange column, and combinations thereof.

9. The system of claim 8, wherein water from the source of water comprises less than about 25 ppb TOC.

10. The system of claim 1, further comprising a TOC concentration sensor located downstream of the primary actinic radiation reactor.

11. The system of claim 1, wherein the reducing agent is sulfur dioxide.

12. A method of treating water comprising:

providing a water to be treated;

measuring a total organic carbon (TOC) value of the water to be treated;

introducing persulfate anions to the water to be treated based in part on at least one input signal of the measured TOC value of the water to be treated;

introducing the water containing persulfate anions to a primary reactor;

exposing the persulfate anions in the water to ultraviolet light in the reactor to produce an irradiated water stream;

adjusting an intensity of the ultraviolet light based in part on at least one of an input signal selected from the group consisting of a TOC value of the water to be treated, a persulfate value of the water downstream of the reactor, and a rate of addition of persulfate anions; and

introducing a reducing agent to the irradiated water.

13. The method of claim 12, further comprising exposing the irradiated water to ultraviolet light in a secondary reactor located downstream of the primary reactor.

14. The method of claim 12, further comprising removing dissolved solids and dissolved gases from the water.

15. The method of claim 12, further comprising treating the water to be treated prior to providing the water to be treated to the reactor vessel.

16. The method of claim 12, further comprising measuring a reducing agent value of the irradiated water.

17. The method of claim 16, further comprising introducing the reducing agent to the irradiated water based on the measured reducing agent value.

18. The method of claim 12, wherein the reducing agent is sulfur dioxide.

19. A system for controlling introduction of a reducing agent to a liquid stream comprising:

a persulfate concentration sensor in fluid communication with the liquid stream;

a source of sulfur dioxide disposed to introduce sulfur dioxide to the liquid stream downstream of the persulfate concentration sensor;

a sulfur dioxide concentration sensor in fluid communication with the liquid stream and located downstream of the source of sulfur dioxide; and

a controller configured to generate a control signal that regulates at least one of a rate of addition of and an amount of the sulfur dioxide introduced into the liquid stream based on at least one input signal from one of the persulfate concentration sensor and the sulfur dioxide concentration sensor.

20. The system of claim 19, wherein the persulfate concentration sensor comprises at least one conductivity cell.

21. The system of claim 20, wherein the persulfate concentration sensor comprises a source of ultraviolet light.

22. The system of claim 19, wherein the sulfur dioxide concentration sensor comprises at least one conductivity cell.

23. The system of claim 22, wherein the sulfur dioxide concentration sensor comprises a source of ultraviolet light.

24. The system of claim 19, further comprising an actinic radiation reactor located upstream of the sulfur dioxide concentration sensor.

25. The system of claim 24, further comprising a source of persulfate precursor compound disposed to introduce at least one persulfate precursor compound into the primary actinic radiation reactor.

26. The system of claim 25, further comprising a total organic carbon concentration sensor located upstream of the actinic radiation reactor.

27. The system of claim 26, further comprising a total organic carbon concentration sensor located downstream of the actinic radiation reactor.