CLAIMS

1. A sensor comprising:

an antenna configured to receive a partial discharge signal; and

a vertical-cavity surface-emitting laser coupled to the antenna, wherein the vertical-cavity surface-emitting laser is configured to convert the received partial discharge signal into an optical signal,

wherein the antenna comprises a pair of antennas coupled in series to each other, each of the pair of antennas comprising a pair of elements arranged as mirror images of each other about a central axis of the pair of elements, each element of the pair of elements comprising a continuous rectangular serpentine line, and

wherein each of the pair of antennas is dimensioned differently from the other of the pair of antennas to receive a partial discharge signal of a frequency different from a partial discharge signal to be received by the other of the pair of antennas.

2. The sensor as claimed in claim 1, wherein the vertical-cavity surface-emitting laser is integrated in the antenna.

3. The sensor as claimed in claim 1, wherein the vertical-cavity surface-emitting laser is coupled to the antenna via an electrical interconnection.

4. The sensor as claimed in claim 3, wherein the electrical interconnection is an RF cable.

5. The sensor as claimed in claim 4, wherein the vertical-cavity surface-emitting laser comprises an SMA connector or a BNC connector coupled to an anode and a cathode of the vertical-cavity surface-emitting laser for coupling to the RF cable.

6. The sensor as claimed in any one of claims 1 to 5, further comprising a biasing circuit coupled to the vertical-cavity surface-emitting laser.

7. The sensor as claimed in any one of claims 1 to 6, further comprising an amplifying circuit coupled to the vertical-cavity surface-emitting laser.

8. The sensor as claimed in any one of claims 1 to 7, further comprising an optical waveguide coupled to the vertical-cavity surface-emitting laser, the optical waveguide configured to transmit the optical signal.

9. The sensor as claimed in claim 8, wherein the optical waveguide is an optical fiber.

~~10. The sensor as claimed in any one of claims 1 to 9, wherein the antenna comprises a pair of antennas coupled in series.~~

~~11~~10. The sensor as claimed in any one of claims 1 to ~~10~~9, wherein the optical signal has a different frequency from that of the partial discharge signal.

~~12~~11. The sensor as claimed in any one of claims 1 to ~~11~~10, wherein the antenna is operable in a frequency range of between about 100 kHz to about 1 GHz.

~~13~~12. The sensor as claimed in any one of claims 1 to ~~12~~11, further comprising a second antenna coupled to the vertical-cavity surface-emitting laser.

~~14~~13. A system for detecting a partial discharge signal, the system comprising:

at least one sensor as claimed in any one of claims 1 to ~~13~~12; and

at least one detector coupled to the at least one sensor, wherein the at least one detector is configured to detect the optical signal from the at least one sensor and convert the optical signal into an electrical signal.

~~15~~14. The system as claimed in claim ~~14~~13, further comprising a data acquisition circuit configured to convert the electrical signal from the at least one sensor into a digital signal.

~~16~~15. The system as claimed in claim ~~15~~14, further comprising a processing device configured to process the digital signal.

~~17~~16. The system as claimed in any one of claims ~~14~~13 to ~~16~~15, wherein the at least one sensor comprises a plurality of sensors, and wherein each of the plurality of sensors is configured to receive a respective partial discharge signal and convert the respective received partial discharge signal into a respective optical signal.

~~18~~17. The system as claimed in claim ~~17~~16, wherein the at least one detector comprises a plurality of detectors, and wherein each of the plurality of detectors is configured to detect the respective optical signal and convert the respective optical signal into a respective electrical signal.

~~19~~18. The system as claimed in claim ~~18~~17, further comprising an optical cable comprising a plurality of optical fibers, wherein a respective optical fiber of the plurality of optical fibers is configured to couple a respective detector of the plurality of detectors and a respective sensor of the plurality of sensors.

~~20~~19. The system as claimed in any one of claims ~~17~~16 to ~~19~~18, further comprising an optical switch coupled to the plurality of sensors.

~~21~~20. The system as claimed in any one of claims ~~17~~16 to ~~20~~19, wherein a respective wavelength of the respective optical signal is different.

~~22~~21. The system as claimed in claim ~~21~~20, further comprising:

at least one coupler configured to combine the respective optical signal; and

a demultiplexer configured to receive and demultiplex the combined optical signal.

~~23~~22. The system as claimed in claim ~~22~~21, wherein the at least one coupler is a 1×2 coupler configured to combine two respective optical signals into the combined signal.

~~24~~23. The system as claimed in claim ~~23~~22, wherein the 1×2 coupler has a coupling ratio selected from a group consisting of 10/90, 20/80, 30/70, 40/60 and 50/50.

~~25~~24. The system as claimed in claim ~~23~~22 or ~~24~~23, wherein the at least one coupler comprises a plurality of couplers, wherein the number of the plurality of couplers is one less than the number of the plurality of sensors.

~~26~~25. The system as claimed in any one of claims ~~22~~–21 to ~~25~~24, wherein the at least one coupler is coupled to the demultiplexer via an optical fiber.

~~27~~26. The system as claimed in claim ~~21~~20, further comprising:

a multiplexer configured to multiplex the respective optical signal; and

a demultiplexer configured to receive and demultiplex the multiplexed optical signal.

~~28~~27. The system as claimed in claim ~~27~~26, wherein the multiplexer is coupled to the demultiplexer via an optical fiber.

~~29~~28. A method of manufacturing a sensor, the method comprising:

providing an antenna configured to receive a partial discharge signal; and

coupling a vertical-cavity surface-emitting laser to the antenna, wherein the vertical-cavity surface-emitting laser is configured to convert the received partial discharge signal into an optical signal,

wherein providing the antenna comprises providing a pair of antennas coupled in series to each other, each of the pair of antennas comprising a pair of elements arranged as mirror images of each other about a central axis of the pair of elements, each element of the pair of elements comprising a continuous rectangular serpentine line, and

wherein each of the pair of antennas is dimensioned differently from the other of the pair of antennas to receive a partial discharge signal of a frequency different from a partial discharge signal to be received by the other of the pair of antennas.

~~30~~29. The method as claimed in claim ~~29~~28, wherein coupling the vertical-cavity surface-emitting laser to the antenna comprises integrating the vertical-cavity surface-emitting laser in the antenna.

~~31~~30. The method as claimed in claim ~~29~~28, wherein coupling the vertical-cavity surface-emitting laser to the antenna comprises coupling via an electrical interconnection.

~~32~~31. The method as claimed in claim ~~31~~30, wherein the electrical interconnection is an RF cable.

~~33~~32. The method as claimed in claim ~~32~~31, further comprising coupling the RF cable to the vertical-cavity surface-emitting laser via an SMA connector or a BNC connector connected to an anode and a cathode of the vertical-cavity surface-emitting laser.

~~34~~33. The method as claimed in any one of claims ~~29~~28 to ~~33~~32, further comprising coupling a biasing circuit to the vertical-cavity surface-emitting laser.

~~35~~34. The method as claimed in any one of claims ~~29~~28 to ~~34~~33, further comprising coupling an amplifying circuit to the vertical-cavity surface-emitting laser.

~~36~~35. The method as claimed in any one of claims ~~29~~28 to ~~35~~34, further comprising coupling an optical waveguide to the vertical-cavity surface-emitting laser, the optical waveguide configured to transmit the optical signal.

~~37~~36. The method as claimed in claim ~~36~~35, wherein the optical waveguide is an optical fiber.

~~38. The method as claimed in any one of claims 29 to 37, wherein providing the antenna comprises providing a pair of antennas coupled in series.~~

3937. The method as claimed in any one of claims ~~29~~ 28 to ~~38~~36, wherein the optical signal has a different frequency from that of the partial discharge signal.

4038. The method as claimed in any one of claims ~~29~~ 28 to ~~39~~37, wherein the antenna is operable in a frequency range of between about 100 kHz to about 1 GHz.

4139. The method as claimed in any one of claims ~~29~~ 28 to ~~40~~38, further comprising coupling a second antenna to the vertical-cavity surface-emitting laser.

4240. A method of forming a system for detecting a partial discharge signal, the method comprising:

manufacturing at least one sensor using the method as claimed in any one of claims ~~29~~ 28 to ~~41~~39; and

coupling at least one detector to the at least one sensor, wherein the at least one detector is configured to detect the optical signal from the at least one sensor and convert the optical signal into an electrical signal.

4341. The method as claimed in claim ~~42~~40, further comprising providing a data acquisition circuit configured to convert the electrical signal from the at least one sensor into a digital signal.

4442. The method as claimed in claim ~~42~~40, further comprising providing a processing device configured to process the digital signal.

4543. The method as claimed in any one of claims ~~42~~ 40 to ~~44~~42, wherein manufacturing the at least one sensor comprises forming a plurality of sensors, and wherein each of the plurality of sensors is configured to receive a respective partial

discharge signal and convert the respective received partial discharge signal into a respective optical signal.

~~46~~44. The method as claimed in claim ~~45~~43, wherein coupling the at least one detector comprises coupling a plurality of detectors, and wherein each of the plurality of detectors is configured to detect the respective optical signal and convert the respective optical signal into a respective electrical signal.

~~47~~45. The method as claimed in claim ~~46~~44, further comprising providing an optical cable comprising a plurality of optical fibers, and coupling a respective optical fiber of the plurality of optical fibers to a respective detector of the plurality of detectors and a respective sensor of the plurality of sensors.

~~48~~46. The method as claimed in any one of claims ~~45~~43 to ~~47~~45, further comprising coupling an optical switch to the plurality of sensors.

~~49~~47. The method as claimed in any one of claims ~~45~~43 to ~~48~~46, wherein a respective wavelength of the respective optical signal is different.

~~50~~48. The method as claimed in claim ~~49~~47, further comprising:

providing at least one coupler configured to combine the respective optical signal; and

providing a demultiplexer configured to receive and demultiplex the combined optical signal.

~~51~~49. The method as claimed in claim ~~50~~48, wherein the at least one coupler is a 1×2 coupler configured to combine two respective optical signals into the combined signal.

~~52~~50. The method as claimed in claim ~~51~~49, wherein the 1×2 coupler has a coupling ratio selected from a group consisting of 10/90, 20/80, 30/70, 40/60 and 50/50.

~~53~~51. The method as claimed in claim ~~51~~ 49 or ~~52~~50, wherein providing the at least one coupler comprises providing a plurality of couplers, wherein the number of the plurality of couplers is one less than the number of the plurality of sensors.

~~54~~52. The method as claimed in any one of claims ~~50~~ 48 to ~~53~~51, further comprising coupling the at least one coupler to the demultiplexer via an optical fiber.

~~55~~53. The method as claimed in claim ~~49~~47, further comprising:

providing a multiplexer configured to multiplex the respective optical signal; and

providing a demultiplexer configured to receive and demultiplex the multiplexed optical signal.

~~56~~54. The method as claimed in claim ~~55~~53, further comprising coupling the multiplexer to the demultiplexer via an optical fiber.

~~57~~55. A method of detecting a partial discharge signal, the method comprising:

receiving a partial discharge signal by an antenna; and

converting the received partial discharge signal into an optical signal by a vertical-cavity surface-emitting laser coupled to the antenna.

wherein the antenna comprises a pair of antennas coupled in series to each other, each of the pair of antennas comprising a pair of elements arranged as mirror images of each other about a central axis of the pair of elements, each element of the pair of elements comprising a continuous rectangular serpentine line,

wherein each of the pair of antennas is dimensioned differently from the other of the pair of antennas, and

wherein receiving a partial discharge signal comprises receiving, by one of the pair of antennas, a partial discharge signal of a frequency different from a partial discharge signal to be received by the other of the pair of antennas.

~~58~~56. The method as claimed in claim ~~57~~55, further comprising converting the optical signal into an electrical signal.

~~59~~57. The method as claimed in claim ~~58~~56, further comprising converting the electrical signal into a digital signal.

~~60~~58. The method as claimed in claim ~~59~~57, further comprising processing the digital signal.

CLAIMS

1. A sensor comprising:

an antenna configured to receive a partial discharge signal; and

a vertical-cavity surface-emitting laser coupled to the antenna, wherein the vertical-cavity surface-emitting laser is configured to convert the received partial discharge signal into an optical signal,

wherein the antenna comprises a pair of antennas coupled in series to each other, each of the pair of antennas comprising a pair of elements arranged as mirror images of each other about a central axis of the pair of elements, each element of the pair of elements comprising a continuous rectangular serpentine line, and

wherein each of the pair of antennas is dimensioned differently from the other of the pair of antennas to receive a partial discharge signal of a frequency different from a partial discharge signal to be received by the other of the pair of antennas.

2. The sensor as claimed in claim 1, wherein the vertical-cavity surface-emitting laser is integrated in the antenna.

3. The sensor as claimed in claim 1, wherein the vertical-cavity surface-emitting laser is coupled to the antenna via an electrical interconnection.

4. The sensor as claimed in claim 3, wherein the electrical interconnection is an RF cable.

5. The sensor as claimed in claim 4, wherein the vertical-cavity surface-emitting laser comprises an SMA connector or a BNC connector coupled to an anode and a cathode of the vertical-cavity surface-emitting laser for coupling to the RF cable.

6. The sensor as claimed in any one of claims 1 to 5, further comprising a biasing circuit coupled to the vertical-cavity surface-emitting laser.

7. The sensor as claimed in any one of claims 1 to 6, further comprising an amplifying circuit coupled to the vertical-cavity surface-emitting laser.

8. The sensor as claimed in any one of claims 1 to 7, further comprising an optical waveguide coupled to the vertical-cavity surface-emitting laser, the optical waveguide configured to transmit the optical signal.

9. The sensor as claimed in claim 8, wherein the optical waveguide is an optical fiber.

10. The sensor as claimed in any one of claims 1 to 9, wherein the optical signal has a different frequency from that of the partial discharge signal.

11. The sensor as claimed in any one of claims 1 to 10, wherein the antenna is operable in a frequency range of between about 100 kHz to about 1 GHz.

12. The sensor as claimed in any one of claims 1 to 11, further comprising a second antenna coupled to the vertical-cavity surface-emitting laser.

13. A system for detecting a partial discharge signal, the system comprising:

at least one sensor as claimed in any one of claims 1 to 12; and

at least one detector coupled to the at least one sensor, wherein the at least one detector is configured to detect the optical signal from the at least one sensor and convert the optical signal into an electrical signal.

14. The system as claimed in claim 13, further comprising a data acquisition circuit configured to convert the electrical signal from the at least one sensor into a digital signal.

15. The system as claimed in claim 14, further comprising a processing device configured to process the digital signal.

16. The system as claimed in any one of claims 13 to 15, wherein the at least one sensor comprises a plurality of sensors, and wherein each of the plurality of sensors is configured to receive a respective partial discharge signal and convert the respective received partial discharge signal into a respective optical signal.

17. The system as claimed in claim 16, wherein the at least one detector comprises a plurality of detectors, and wherein each of the plurality of detectors is configured to detect the respective optical signal and convert the respective optical signal into a respective electrical signal.

18. The system as claimed in claim 17, further comprising an optical cable comprising a plurality of optical fibers, wherein a respective optical fiber of the plurality of optical fibers is configured to couple a respective detector of the plurality of detectors and a respective sensor of the plurality of sensors.

19. The system as claimed in any one of claims 16 to 18, further comprising an optical switch coupled to the plurality of sensors.

20. The system as claimed in any one of claims 16 to 19, wherein a respective wavelength of the respective optical signal is different.

21. The system as claimed in claim 20, further comprising:

at least one coupler configured to combine the respective optical signal; and

a demultiplexer configured to receive and demultiplex the combined optical signal.

22. The system as claimed in claim 21, wherein the at least one coupler is a 1×2 coupler configured to combine two respective optical signals into the combined signal.

23. The system as claimed in claim 22, wherein the 1×2 coupler has a coupling ratio selected from a group consisting of 10/90, 20/80, 30/70, 40/60 and 50/50.

24. The system as claimed in claim 22 or 23, wherein the at least one coupler comprises a plurality of couplers, wherein the number of the plurality of couplers is one less than the number of the plurality of sensors.

25. The system as claimed in any one of claims 21 to 24, wherein the at least one coupler is coupled to the demultiplexer via an optical fiber.

26. The system as claimed in claim 20, further comprising:

a multiplexer configured to multiplex the respective optical signal; and

a demultiplexer configured to receive and demultiplex the multiplexed optical signal.

27. The system as claimed in claim 26, wherein the multiplexer is coupled to the demultiplexer via an optical fiber.

28. A method of manufacturing a sensor, the method comprising:

providing an antenna configured to receive a partial discharge signal; and

coupling a vertical-cavity surface-emitting laser to the antenna, wherein the vertical-cavity surface-emitting laser is configured to convert the received partial discharge signal into an optical signal,

wherein providing the antenna comprises providing a pair of antennas coupled in series to each other, each of the pair of antennas comprising a pair of elements arranged as mirror images of each other about a central axis of the pair of elements, each element of the pair of elements comprising a continuous rectangular serpentine line, and

wherein each of the pair of antennas is dimensioned differently from the other of the pair of antennas to receive a partial discharge signal of a frequency different from a partial discharge signal to be received by the other of the pair of antennas.

29. The method as claimed in claim 28, wherein coupling the vertical-cavity surface-emitting laser to the antenna comprises integrating the vertical-cavity surface-emitting laser in the antenna.

30. The method as claimed in claim 28, wherein coupling the vertical-cavity surface-emitting laser to the antenna comprises coupling via an electrical interconnection.

31. The method as claimed in claim 30, wherein the electrical interconnection is an RF cable.

32. The method as claimed in claim 31, further comprising coupling the RF cable to the vertical-cavity surface-emitting laser via an SMA connector or a BNC connector connected to an anode and a cathode of the vertical-cavity surface-emitting laser.

33. The method as claimed in any one of claims 28 to 32, further comprising coupling a biasing circuit to the vertical-cavity surface-emitting laser.

34. The method as claimed in any one of claims 28 to 33, further comprising coupling an amplifying circuit to the vertical-cavity surface-emitting laser.

35. The method as claimed in any one of claims 28 to 34, further comprising coupling an optical waveguide to the vertical-cavity surface-emitting laser, the optical waveguide configured to transmit the optical signal.

36. The method as claimed in claim 35, wherein the optical waveguide is an optical fiber.

37. The method as claimed in any one of claims 28 to 36, wherein the optical signal has a different frequency from that of the partial discharge signal.

38. The method as claimed in any one of claims 28 to 37, wherein the antenna is operable in a frequency range of between about 100 kHz to about 1 GHz.

39. The method as claimed in any one of claims 28 to 38, further comprising coupling a second antenna to the vertical-cavity surface-emitting laser.

40. A method of forming a system for detecting a partial discharge signal, the method comprising:

manufacturing at least one sensor using the method as claimed in any one of claims 28 to 39; and

coupling at least one detector to the at least one sensor, wherein the at least one detector is configured to detect the optical signal from the at least one sensor and convert the optical signal into an electrical signal.

41. The method as claimed in claim 40, further comprising providing a data acquisition circuit configured to convert the electrical signal from the at least one sensor into a digital signal.

42. The method as claimed in claim 40, further comprising providing a processing device configured to process the digital signal.

43. The method as claimed in any one of claims 40 to 42, wherein manufacturing the at least one sensor comprises forming a plurality of sensors, and wherein each of the plurality of sensors is configured to receive a respective partial discharge signal and convert the respective received partial discharge signal into a respective optical signal.

44. The method as claimed in claim 43, wherein coupling the at least one detector comprises coupling a plurality of detectors, and wherein each of the plurality of detectors is configured to detect the respective optical signal and convert the respective optical signal into a respective electrical signal.

45. The method as claimed in claim 44, further comprising providing an optical cable comprising a plurality of optical fibers, and coupling a respective optical fiber of the plurality of optical fibers to a respective detector of the plurality of detectors and a respective sensor of the plurality of sensors.

46. The method as claimed in any one of claims 43 to 45, further comprising coupling an optical switch to the plurality of sensors.

47. The method as claimed in any one of claims 43 to 46, wherein a respective wavelength of the respective optical signal is different.

48. The method as claimed in claim 47, further comprising:

providing at least one coupler configured to combine the respective optical signal; and

providing a demultiplexer configured to receive and demultiplex the combined optical signal.

49. The method as claimed in claim 48, wherein the at least one coupler is a 1×2 coupler configured to combine two respective optical signals into the combined signal.

50. The method as claimed in claim 49, wherein the 1×2 coupler has a coupling ratio selected from a group consisting of 10/90, 20/80, 30/70, 40/60 and 50/50.

51. The method as claimed in claim 49 or 50, wherein providing the at least one coupler comprises providing a plurality of couplers, wherein the number of the plurality of couplers is one less than the number of the plurality of sensors.

52. The method as claimed in any one of claims 48 to 51, further comprising coupling the at least one coupler to the demultiplexer via an optical fiber.

53. The method as claimed in claim 47, further comprising:

providing a multiplexer configured to multiplex the respective optical signal; and

providing a demultiplexer configured to receive and demultiplex the multiplexed optical signal.

54. The method as claimed in claim 53, further comprising coupling the multiplexer to the demultiplexer via an optical fiber.

55. A method of detecting a partial discharge signal, the method comprising:

receiving a partial discharge signal by an antenna; and

converting the received partial discharge signal into an optical signal by a vertical-cavity surface-emitting laser coupled to the antenna.

wherein the antenna comprises a pair of antennas coupled in series to each other, each of the pair of antennas comprising a pair of elements arranged as mirror images of each other about a central axis of the pair of elements, each element of the pair of elements comprising a continuous rectangular serpentine line,

wherein each of the pair of antennas is dimensioned differently from the other of the pair of antennas, and

wherein receiving a partial discharge signal comprises receiving, by one of the pair of antennas, a partial discharge signal of a frequency different from a partial discharge signal to be received by the other of the pair of antennas.

56. The method as claimed in claim 55, further comprising converting the optical signal into an electrical signal.

57. The method as claimed in claim 56, further comprising converting the electrical signal into a digital signal.

58. The method as claimed in claim 57, further comprising processing the digital signal.