US Patent & Trademark Office
Patent Public Search | Text View

United States Patent Application Publication	20250264347
Kind Code	A1
Publication Date	August 21, 2025
Inventor(s)	OGAWA; Jun-Ichi

MEASUREMENT DEVICE AND MEASUREMENT METHOD

Abstract

There is provided a measurement device including a flow channel which includes a main inlet and a main outlet; a pump which supplies a fluid containing a radical precursor to the main inlet of the flow channel; a radical generation unit which generates a radical from the radical precursor in a radical generation region in the flow channel; and a measurement unit which measures a measurement value depending on a concentration of the radical at at least one measurement position which exists toward the main outlet relative to the radical generation region in the flow channel. In the measurement device described above, the radical generation unit may generate the radical by applying at least one of a voltage, heat, light, or an electron beam to the fluid containing the radical precursor.

Inventors: **OGAWA; Jun-Ichi (Tokyo, JP)**

Applicant: **Yokogawa Electric Corporation** (Tokyo, JP)

Family ID: **1000008239569**

Appl. No.: **18/936767**

Filed: **November 04, 2024**

Foreign Application Priority Data

JP	2024-022622	Feb. 19, 2024

Publication Classification

Int. Cl.: **G01F1/661** (20220101)

U.S. Cl.:

CPC **G01F1/661** (20130101);

Background/Summary

[0001] The contents of the following patent application(s) are incorporated herein by reference: NO. 2024-022622 filed in JP on Feb. 19, 2024

BACKGROUND

1. Technical Field

[0002] The present invention relates to a measurement device and a measurement method.

2. Related Art

[0003] Patent Document 1 describes "a device which irradiates a sample photo-excited by being irradiated by pulse light with probe light, and observes a transient absorption spectrum or its change by detecting a change in intensity of the probe light with a streak camera" in claim **1**.

[0004] Patent Document 2 describes, in paragraph 0010, "the present invention is a device which measures a transient absorption of a substance, including an excitation light source which emits excitation light for exciting the substance; a probe light source which emits probe light as steady light to a sample including the substance being excited by the excitation light; a spectroscopic means which performs spectroscopy for transmitted probe light transmitted through the sample and outputs it as output light; and a light detection means which detects the output light, wherein the light detection means includes an avalanche photodiode, or APD".

[0005] Patent Document 3 describes, in paragraph 0007, "an optical measurement device according to several embodiments includes a first irradiation unit which irradiates one first irradiation region on a movement path of a moving sample with excitation light, a second irradiation unit which irradiates a second irradiation region positioned on the movement path toward a movement direction of the sample relative to the one first irradiation region with probe light, a detection unit which detects the probe light irradiated to the sample by the second irradiation unit, and a control unit, which calculates, based on detected intensity of the probe light transmitted through the sample at each of a plurality of moments different from each other during a course of a transient response of an optical parameter of the sample resulting from being excited by the excitation light and detected at a different timing by the detection unit, the optical parameter at the plurality of moments, and calculates a physical property parameter of the sample based on the calculated optical parameter."

[0006] Patent Document 4 describes, in paragraph 0015, "FIG. 1 shows an embodiment of a gas sampling detection system useful for detecting the concentration of radicals within a gas stream. As shown, the gas sampling detection system 10 includes at least one plasma generator and/or radical gas generator 12 in fluid communication with at least one processing chamber 16 via at least one gas passage 14." and describes, in paragraph 0019, "As shown in FIG. 1, at least one sampling module 32 may be in fluid communication with the radical gas generator 12 via at least one sampling conduit 30."

PRIOR ART DOCUMENTS

Patent Documents

[0007] Patent Document 1: Japanese Examined Patent Publication No. H6-17866

[0008] Patent Document 2: Japanese Patent Application Publication No. 2007-212145

[0009] Patent Document 3: Japanese Patent No. 7298746

[0010] Patent Document 4: Japanese Translation Publication of a PCT Rout Patent Application No. 2021-517638

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** illustrates a configuration of a measurement device **10** according to the present embodiment.

[0012] FIG. **2** is a cross-sectional view of a first example of a flow channel **101**.

[0013] FIG. **3** illustrates an operational flow in the measurement device **10** according to the present embodiment.

[0014] FIG. **4** is a cross-sectional view of a second example of the flow channel **101**.

[0015] FIG. **5** is a perspective view of a third example of the flow channel **101**.

[0016] FIG. **6** is a cross-sectional view of a fourth example of the flow channel **101**.

[0017] FIG. **7** is a perspective view of a fifth example of the flow channel **101**.

[0018] FIG. **8** is a cross-sectional view of a sixth example of the flow channel **101**.

[0019] FIG. **9** illustrates an example of a computer **2200** in which a plurality of aspects of the present invention may be embodied entirely or partially.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0020] Although the present invention will be hereinafter described through an embodiment of the invention, the following embodiment is not intended to limit the invention according to the claims. In addition, not all combinations of features described in the embodiment are essential to a solution of the invention.

[0021] FIG. **1** illustrates a configuration of a measurement device **10** according to the present embodiment. The measurement device **10** is a device which generates a radical from a radical precursor and measures a concentration of a generated radical. Here, the radical precursor is a substance which may be turned into the radical by one or more stages of reactions. The measurement device **10** includes a distribution cell **100**, a pump **120**, a radical generation unit **132**, a measurement unit **140**, a measurement control unit **150**, a calculation unit **160**, a storage unit **170**, and an output unit **180**.

[0022] The distribution cell **100** is a cell in which a fluid containing the radical precursor and the radical flows. In the present embodiment, the distribution cell **100** has a plate-like structure. The distribution cell **100** may be formed by a light-transmitting material. The distribution cell **100** has a flow channel **101**.

[0023] The flow channel **101** is a channel in which the fluid containing the radical precursor and the radical flows. The flow channel **101** may have a certain cross-sectional area. The flow channel **101** may have a polygonal or circular cross-section. The flow channel **101** may have a rectangular or square cross-section. The flow channel **101** includes a main inlet **102**, a main outlet **104**, a radical generation region **106**, and one or more measurement positions.

[0024] The main inlet **102** is an inlet for supplying a fluid containing the radical precursor to the flow channel **101**. The main outlet **104** is an outlet for discharging the measured fluid out of the flow channel **101**. The main outlet **104** may be connected to a flow channel for discharge. Alternatively, the main outlet **104** may be connected to the main inlet **102**. That is, the fluid may be supplied to the main inlet **102** repeatedly after exiting from the main outlet **104**. In this case, the measurement device **10** can repeatedly measure the radical discharged from the main outlet **104**. As used herein, for the sake of convenience, “a main path” is defined as a path in the flow channel **101** for introducing the fluid containing the radical precursor, performing a measurement of the radical, and discharging the measured fluid, and “the main inlet **102**” and “the main outlet **104**” are defined as an inlet and outlet relating to the main path, for the sake of convenience of description. Accordingly, the terms “main inlet” and “main outlet” are not intended to limit a magnitude relationship between a cross-sectional area of a flow channel of “the main inlet” and “the main outlet” and that of “an auxiliary inlet” and “an auxiliary outlet” described below, a magnitude relationship between a merging/diverting angle of a merging/diverting section of “the main inlet” and “the main outlet” and that of “the auxiliary inlet” and “the auxiliary outlet”, or the like.

[0025] The radical generation region **106** is a region in the flow channel **101** for generating the radical from the radical precursor. The radical generation region **106** exists between the main inlet **102** and the main outlet **104** in the flow channel **101**.
[0026] A measurement position is a position in the flow channel **101** at which a measurement value depending on a radical concentration is measured. The measurement position exists toward the main outlet **104** relative to the radical generation region **106** in the flow channel **101**. In addition to this, the measurement position may exist toward the main inlet **102** relative to the radical generation region **106** for a baseline measurement.
[0027] The pump **120** is connected to the main inlet **102**. The pump **120** supplies the main inlet **102** in the flow channel **101** with the fluid containing the radical precursor. The pump **120** may be a syringe pump or a diaphragm pump which has a relatively low pulsation. The pump **120** may be provided with a damper located between the pump **120** and the main inlet **102**, which reduces a pulsation of the pump **120**.
[0028] The radical generation unit **132** generates the radical from the radical precursor in the radical generation region **106** in the flow channel **101**. The radical generation unit **132** may generate the radical by applying at least one of a voltage, heat, light, or an electron beam to the fluid containing the radical precursor. In the present embodiment, the radical generation unit **132** generates the radical by applying the voltage to the radical generation region **106** in the flow channel **101**.
[0029] Alternatively, the radical generation unit **132** may generate the radical by applying the heat to the fluid containing the radical precursor, using at least one of a microheater, an electrically-heated wire, an induction heater, microwave heating, or a laser. The radical generation unit **132** may generate the radical by supplying an oxidizing agent to the fluid containing the radical precursor.
[0030] When the radical generation unit **132** applies the voltage, the measurement device **10** includes a current/voltage supply unit **134**. The current/voltage supply unit **134** is connected to the radical generation unit **132**. The current/voltage supply unit **134** supplies at least one of a current or a voltage to the radical generation unit **132** to control the voltage applied to the fluid containing the radical precursor by the radical generation unit **132**. The current/voltage supply unit **134** may be at least one of a potentiostat or a galvanostat.
[0031] The measurement unit **140** measures the measurement value depending on the concentration of the radical at the one or more measurement positions. Here, the one or more measurement positions may be set regularly or irregularly along a flow direction of the fluid in the flow channel **101**. When a plurality of measurement positions exist, the measurement unit **140** measures the measurement value for each elapsed time from generation of the radical which corresponds to each of the plurality of measurement positions. The measurement unit **140** may measure the measurement value including inspection-light intensity. The measurement unit **140** includes an inspection-light irradiation unit **142**, a luminous flux adjustment unit **144**, and one or more detectors **146**.
[0032] The inspection-light irradiation unit **142** includes any light source such as a semiconductor laser. The inspection-light irradiation unit **142** irradiates the fluid at the one or more measurement positions with inspection light. The inspection-light irradiation unit **142** radiates the inspection light which includes light at a wavelength absorbed by the radical to be measured. The inspection-light irradiation unit **142** may radiate the inspection light which includes light with one or more wavelengths. When the inspection-light irradiation unit **142** radiates the inspection light including a plurality of wavelengths, the measurement device **10** may measure a plurality of substances simultaneously.
[0033] The luminous flux adjustment unit **144** is arranged on an optical path of the inspection light. The luminous flux adjustment unit **144** is arranged between the measurement position and the inspection-light irradiation unit **142**. The luminous flux adjustment unit **144** adjusts a diameter of

the inspection light such that the inspection light is radiated onto the measurement position. When the flow channel **101** includes a plurality of measurement positions, the luminous flux adjustment unit **144** may adjust the diameter of the inspection light such that all of the plurality of measurement positions are irradiated uniformly.

[0034] A detector **146** is arranged on the optical path of the inspection light. The detector **146** is arranged on an opposite side of the inspection-light irradiation unit **142** relative to the measurement position. When a plurality of detectors **146** exist, the plurality of detectors **146** may be arranged in a row along the flow direction of the fluid in the flow channel **101**. The detector **146** detects the inspection light transmitted through the fluid at at least one measurement position in the flow channel **101**. The detector **146** measures light intensity of the detected inspection light, or the inspection-light intensity. Since the inspection light includes light at a wavelength absorbed by the radical, the inspection-light intensity decreases when the radical concentration in the fluid is high, and the inspection-light intensity increases when the radical concentration in the fluid decreases.

[0035] The measurement control unit **150** is connected to the pump **120**, the current/voltage supply unit **134**, and the calculation unit **160**. The measurement control unit **150** controls an operation of the pump **120** and the current/voltage supply unit **134**.

[0036] The calculation unit **160** is connected to the detector **146** and the storage unit **170**. The calculation unit **160** calculates a lifetime of the radical, using the measurement value for each elapsed time from the generation of the radical. The calculation unit **160** receives a measurement value at a corresponding measurement position from the detector **146**. The calculation unit **160** may receive the inspection-light intensity at the corresponding measurement position from the detector **146**. The calculation unit **160** receives information on a flow rate in the flow channel **101** from the measurement control unit **150**. The calculation unit **160** writes measurement data to the storage unit **170**, which includes at least one of the measurement value received from the detector **146**, the information on the flow rate received from the measurement control unit **150**, or information obtained by processing these kinds of information by the measurement control unit **150**.

[0037] The storage unit **170** stores the measurement data. The storage unit **170** may be an electronic storage medium, a magnetic storage medium, an optical storage medium, an electromagnetic storage medium, or a semiconductor storage medium.

[0038] The output unit **180** is connected to the calculation unit **160**. The output unit **180** outputs the lifetime of the radical calculated by the calculation unit **160**. At least one of the measurement control unit **150**, the calculation unit **160**, the storage unit **170**, or the output unit **180** may be a computer such as a personal computer, or PC, a tablet computer, a smartphone, a workstation, a server computer, or a general-purpose computer, and may be a computer system in which a plurality of computers are connected. Such computer system is also a computer in a broad sense. In addition, at least one of the measurement control unit **150**, the calculation unit **160**, the storage unit **170**, or the output unit **180** may be implemented by one or more virtual computer environments which are executable in the computer. Alternatively, at least one of the measurement control unit **150**, the calculation unit **160**, the storage unit **170**, or the output unit **180** may be a special-purpose computer designed for a measurement of the radical concentration, or may be special-purpose hardware realized by a dedicated circuit.

[0039] FIG. **2** is a cross-sectional view of a first example of the flow channel **101**. In the example of the present illustration, the radical generation unit **132** including a pair of a first electrode **200** and a second electrode **202** is arranged in the radical generation region **106** in the flow channel **101**. The first electrode **200** is arranged on an inner wall surface of the flow channel **101**, and the second electrode **202** is arranged on the inner wall surface of the flow channel **101** opposite to the first electrode **200**. The pair of the first electrode **200** and the second electrode **202** is connected to the current/voltage supply unit **134**, and supplied with at least one of the current or the voltage from the current/voltage supply unit **134**. The first electrode **200** and the second electrode **202** have different polarities, with one functioning as an anode and another as a cathode. The radical generation unit **132** may accelerate the radical precursor by applying the voltage to the radical precursor, and generate the radical by colliding each radical precursor with one another to cause ionization.

[0040] FIG. **3** illustrates the operational flow in the measurement device **10** according to the present embodiment. In S**302**, or a step **302**, the measurement control unit **150** turns on the pump **120** to cause the pump **120** to start an operation. In this way, the pump **120** continuously supplies the fluid containing the radical precursor to the flow channel **101**. The pump **120** may supply the fluid containing the radical precursor at a predetermined ratio, to the flow channel **101**.

[0041] In S**304**, the inspection-light irradiation unit **142** irradiates the one or more measurement positions in the flow channel **101** with the inspection light. The measurement control unit **150** controls the current/voltage supply unit **134** not to supply the current and the voltage to the radical generation unit **132**. In this case, since the voltage is not applied to the radical generation region **106**, the fluid at each of the measurement positions does not contain the radical. In S**306**, each of the one or more detectors **146** detects the intensity of the inspection light passing through the fluid at each of the one or more measurement positions. The calculation unit **160** writes the inspection-light intensity detected by each of the one or more detectors **146** to the storage unit **170** as a baseline.

[0042] In S**308**, the measurement control unit **150** applies the voltage to the fluid in the radical generation region **106** by instructing the current/voltage supply unit **134** to supply the current or the voltage to the radical generation unit **132**. In this way, the radical generation unit **132** generates the radical from the radical precursor contained in the fluid.

[0043] In S**310**, the inspection-light irradiation unit **142** irradiates the flow channel **101** with the inspection light. Each of the one or more detectors **146** detects the intensity of the inspection light passing through the fluid at each of the corresponding measurement positions. The calculation unit **160** receives the intensity of the inspection light detected by each detector **146**, from each of the one or more detectors **146**.

[0044] The calculation unit **160** acquires positional information of each of the measurement positions, the inspection-light intensity at each of the measurement positions, and the flow rate of the fluid in the flow channel **101**. Here, the calculation unit **160** may store the positional information of each of the measurement positions in advance, or may read the positional information of each of the measurement positions from the storage unit **170**. The positional information may be information on a distance from an end of the radical generation region **106** on a side of the main outlet **104** to each of the measurement positions.

[0045] The calculation unit **160** receives the information on the flow rate of the fluid from the measurement control unit **150**. The flow rate may represent a volume of the fluid flowing per unit time.

[0046] Based on the distance from the radical generation region **106** to each of the measurement positions and the flow rate, the calculation unit **160** calculates an elapsed time for the fluid to travel from the radical generation region **106** to each of the measurement positions, namely an elapsed time from the generation to the measurement of the radical. For example, when the flow rate represents the volume of the fluid flowing per unit time, the calculation unit **160** may calculate the elapsed time by computing (a cross-sectional area of the flow channel **101**)×(the distance from the radical generation region **106** to the measurement position)/(the flow rate of the fluid). The calculation unit **160** stores the measurement data including the inspection-light intensity, the flow rate of the fluid, and the elapsed time at each of the one or more measurement positions in the storage unit **170**.

[0047] In S**312**, the measurement control unit **150** determines whether the measurement has been completed for an entire flow rate for which the inspection-light intensity is to be measured. When the measurement control unit **150** determines that the measurement has not been completed for the entire flow rate, namely No in S**312**, the measurement device **10** advances the process to S**314**. In

S**314**, the measurement control unit **150** controls the pump **120**. The pump **120** changes a flow velocity of the fluid in the flow channel **101** such that the flow velocity of the fluid becomes a value corresponding to the flow rate to be measured next.

[0048] In S**310** after returning from S**314**, the inspection-light irradiation unit **142** irradiates the flow channel **101** through which the fluid with the changed flow rate is flowing, with the inspection light. Each of the one or more detectors **146** detects the intensity of the inspection light passing through the fluid at each of the corresponding measurement positions. The calculation unit **160** receives the intensity of the inspection light detected by each detector **146**, from each of the one or more detectors **146**. The calculation unit **160** receives information on the changed flow rate of the fluid from the measurement control unit **150**, and calculates the elapsed time at each of the one or more measurement positions. The calculation unit **160** stores the measurement data including the inspection-light intensity, the flow rate of the fluid, and the elapsed time at each of the one or more measurement positions in the storage unit **170**.

[0049] When the measurement control unit **150** determines that the measurement has been completed for the entire flow rate, namely Yes in S**312**, the measurement device **10** advances the process to S**316**. In this case, it means that the measurement unit **140** has measured the measurement value for each elapsed time from the generation of the radical which corresponds to each of a plurality of flow velocities different from each other. In S**316**, the calculation unit **160** calculates an optical density from the inspection-light intensity stored in the storage unit **170**. The calculation unit **160** acquires a two-dimensional plot of the calculated optical density versus the elapsed time.

[0050] In S**318**, the calculation unit **160** calculates the lifetime of the radical based on the two-dimensional plot obtained in S**316**. The calculation unit **160** may calculate a time constant which represents the lifetime of the radical, by fitting an optimal function which approximates the two-dimensional plot obtained in S**316** to the two-dimensional plot. The optimal function may be an exponential function. When the exponential function is fitted to the two-dimensional plot, the time constant may be calculated based on the obtained exponential function. For example, when the exponential function expressed by $x=x_0\exp(-t/\tau)$ for time t, where x_0 is any constant, is obtained by fitting, the time constant of the radical is τ. Alternatively, the calculation unit **160** may calculate a half-life of the radical as the lifetime of the radical. In S**320**, the output unit **180** outputs the lifetime of the radical calculated by the calculation unit **160**.

[0051] According to the measurement device **10** described above, since the lifetime of the radical is calculated based on the inspection-light intensity for each of the elapsed times different from each other, it is possible to measure the lifetime of the radical with an extended lifetime in a short time. In addition, since the above-described measurement device **10** has a simple system configuration, it is possible to perform an experiment with high reproducibility. Furthermore, according to the measurement device **10** described above, since the flow rate of the fluid can be changed, even when only one measurement position and one corresponding detector **146** are provided, it is possible to measure the radical after a different elapsed time by changing the flow rate. In this case, the measurement device **10** has a less expensive configuration, since it includes only one detector **146**.

[0052] FIG. **4** is a cross-sectional view of a second example of the flow channel **101**. In the example of the present illustration, a plurality of pairs of the first electrodes **200** and the second electrodes **202** are arranged in the radical generation region **106** in the flow channel **101** along the flow direction of the fluid in the flow channel **101**. The first electrode **200** and the second electrode **202** in each pair may take a similar arrangement and configuration to the first electrode **200** and the second electrode **202** in FIG. **2**. The first electrode **200** and the second electrode **202** are each connected to the current/voltage supply unit **134**, and each pair is supplied with at least one of the current or the voltage by the current/voltage supply unit **134**. The measurement device **10** including the flow channel **101** of the present illustration may control the generated amount of the radical by changing a number of the pairs of the first electrode **200** and the second electrode **202** to which at least one of the current or the voltage is supplied by the current/voltage supply unit **134**.

[0053] FIG. **5** is a perspective view of a third example of the flow channel **101**. In the example of the present illustration, the measurement device **10** further includes an excitation light irradiation unit **500**, and includes one or more detectors **510** instead of the one or more detectors **146**. The excitation light irradiation unit **500** irradiates the fluid with excitation light between the radical generation region **106** in which the first electrode **200** and the second electrode **202** are arranged and the one or more measurement positions in the flow channel **101**. The excitation light irradiation unit **500** may radiate an ultraviolet ray as the excitation light. The substance irradiated with the excitation light, namely a measured substance, becomes an excited state, and emits light in a course of returning to a ground state. The measured substance may be the radical contained in the fluid, or may be a substance other than the radical which interacts with the radical contained in the fluid.

[0054] A detector **510** is connected to the calculation unit **160**. The detector **510** detects the light emitted from the measured substance. The detector **510** may be provided in a location away from the optical path of the excitation light, so as not to detect the excitation light. Alternatively, the detector **510** may be provided with a filter located between the detector **510** and the measurement positions in the flow channel **101** and may separate the excitation light from emitted light, so as not to detect the excitation light. In this case, the detector **510** may be provided on the optical path of the excitation light. When a plurality of detectors **510** exist, the plurality of detectors **510** may be arranged in a row along the flow direction of the fluid in the flow channel **101**. In the example of the present illustration, the detector **510** detects the light emitted perpendicularly to the optical path of the excitation light.

[0055] The calculation unit **160** receives emitted light intensity detected by each detector **510**, from each of the one or more detectors **510**. The calculation unit **160** receives positional information of each measurement position from the storage unit **170**. The positional information of each measurement position may be information on a distance from a position in the flow channel **101** which is irradiated with the excitation light by the excitation light irradiation unit **500** and each measurement position. The calculation unit **160** calculates the elapsed time based on information on the positional information of each measurement position and the flow rate of the fluid. The calculation unit **160** may calculate the elapsed time with a method similar to S**310** in FIG. **3**. The measurement control unit **150** may perform a process similar to S**312** in FIG. **3**. The calculation unit **160** acquires a two-dimensional plot of the emitted light intensity versus the elapsed time. The calculation unit **160** calculates the lifetime of the excited state of the measured substance based on the two-dimensional plot of the emitted light intensity versus the elapsed time. The calculation unit **160** may calculate the lifetime of the excited state of the measured substance with a method similar to S**318** in FIG. **3**. According to the measurement device **10** including the flow channel **101** described above, it is possible to measure the lifetime of the excited state of the measured substance based on a change in the light emitted by the measured substance.

[0056] FIG. **6** is a cross-sectional view of a fourth example of the flow channel **101**. In the example of the present illustration, the flow channel **101** has a bent shape. In addition, the measurement device **10** includes a microheater **600** instead of the radical generation unit **132** and the current/voltage supply unit **134** in FIG. **1**. The microheater **600** is connected to and controlled by the measurement control unit **150**. The microheater **600** generates the radical by applying the heat to the fluid containing the radical precursor in the radical generation region **106** in the flow channel **101**. A pressure loss due to a collision of the fluid with the wall surface of the flow channel **101** may be suppressed by making an angle θ between an inflow direction and an outflow direction of the fluid in a bent section in the flow channel **101** closer to 180°.

[0057] FIG. **7** is a perspective view of a fifth example of the flow channel **101**. In the example of the present illustration, the flow channel **101** is formed in a Y-shape and includes the main inlet **102** and a first auxiliary inlet **700**. The radical generation unit **132** generates the radical from the radical precursor by supplying the oxidizing agent to the first auxiliary inlet **700**. The radical generation

unit **132** may supply the oxidizing agent to the first auxiliary inlet **700** and cause the oxidizing agent to merge with the fluid containing the radical precursor supplied from the main inlet **102** in the radical generation region **106** to oxidize the radical precursor. The radical generation unit **132** may supply hydrogen peroxide or hydrogen peroxide bromide as the oxidizing agent.
[0058] FIG. **8** is a cross-sectional view of a sixth example of the flow channel **101**. In the example of the present illustration, the flow channel **101** includes a second auxiliary inlet **800** between the radical generation region **106** and the one or more measurement positions. The second auxiliary inlet **800** may introduce another fluid which reacts with the radical in the fluid to the flow channel **101**. The second auxiliary inlet **800** may introduce a fluid including a substance which reacts with the radical in the fluid, as the another fluid which reacts with the radical in the fluid, to the flow channel **101**.
[0059] The measurement device **10** including the flow channel **101** in the present illustration acquires a two-dimensional plot of the optical density versus the elapsed time with a method shown in S**310** to S**316** in FIG. **3**. Here, the positional information of each measurement position may be information on a distance from a connected position between the flow channel **101** and the second auxiliary inlet **800** to each measurement position. According to the measurement device **10** including the flow channel **101** described above, since the radical generated in the radical generation region **106** may be reacted with the another fluid introduced from the second auxiliary inlet **800** to measure the concentration of the radical for each elapsed time from a start of a reaction, it is possible to analyze the reaction using the radical.
[0060] Various embodiments of the present invention may be described with reference to a flowchart and a block diagram whose block may represent (1) a stage of a process in which an operation is executed or (2) a section of a device responsible for executing the operation. A particular stage and section may be implemented by a dedicated circuit, a programmable circuit supplied together with a computer-readable instruction stored on a computer-readable medium, and/or a processor supplied together with the computer-readable instruction stored on the computer-readable medium. The dedicated circuit may include a digital and/or analog hardware circuit and may include an integrated circuit, or IC, and/or a discrete circuit. The programmable circuit may include a reconfigurable hardware circuit including logical AND, logical OR, logical XOR, logical NAND, logical NOR, and another logical operation, a memory element or the like such as a flip-flop, a register, a field programmable gate array, or FPGA, a programmable logic array, or PLA, or the like.
[0061] The computer-readable medium may include any tangible device that may store an instruction to be executed by an appropriate device, and as a result, the computer-readable medium including an instruction stored thereon will include a product including the instruction that may be executed to create means for executing the operation specified in the flowchart or the block diagram. Examples of the computer-readable medium may include an electronic storage medium, a magnetic storage medium, an optical storage medium, an electromagnetic storage medium, a semiconductor storage medium, or the like. More specific examples of the computer-readable medium may include a floppy (registered trademark) disk, a diskette, a hard disk, a random access memory, or RAM, a read-only memory, or ROM, an erasable programmable read-only memory, or EPROM or flash memory, an electrically erasable programmable read-only memory, or EEPROM, a static random access memory, or SRAM, a compact disc read-only memory, or CD-ROM, a digital versatile disk, or DVD, a Blu-ray (registered trademark) disk, a memory stick, an integrated circuit card, or the like.
[0062] The computer-readable instruction may include an assembler instruction, an instruction-set-architecture, or ISA instruction, a machine instruction, a machine-dependent instruction, a microcode, a firmware instruction, state-setting data, or either a source code or an object code described in any combination of one or more programming languages, including an object-oriented programming language such as Smalltalk (registered trademark), JAVA (registered trademark),

C++, or the like, and a conventional procedural programming language such as a “C” programming language or a similar programming language.

[0063] The computer-readable instruction may be provided for a processor or programmable circuit of a programmable data processing device, such as a general-purpose computer, special purpose computer, or another computer, locally or via a local area network, or LAN, a wide area network, or WAN, such as the Internet, or the like to execute the computer-readable instruction to create means for executing the operation specified in the flowchart or the block diagram. Examples of the processor include a computer processor, a processing unit, a microprocessor, a digital signal processor, a controller, a microcontroller, or the like.

[0064] FIG. **9** illustrates an example of a computer **2200** in which a plurality of aspects of the present invention may be embodied entirely or partially. A program installed in the computer **2200** may cause the computer **2200** to function as an operation associated with a device according to the embodiment of the present invention or as one or more sections of the device, or may cause the operation or the one or more sections to be executed, and/or may cause the computer **2200** to execute a process according to the embodiment of the present invention or a stage of the process. Such a program may be executed by a CPU **2212** to cause the computer **2200** to execute a particular operation associated with some or all of the blocks in the flowchart and the block diagram described herein.

[0065] The computer **2200** according to the present embodiment includes the CPU **2212**, a RAM **2214**, a graphics controller **2216**, and a display device **2218**, which are interconnected by a host controller **2210**. The computer **2200** also includes an input/output unit such as a communication interface **2222**, a hard disk drive **2224**, a DVD-ROM drive **2226**, and an IC card drive, which is connected to the host controller **2210** via an input/output controller **2220**. The computer also includes a legacy input/output unit such as an ROM **2230** and a keyboard **2242**, which is connected to the input/output controller **2220** via an input/output chip **2240**.

[0066] The CPU **2212** operates according to a program stored in the ROM **2230** and the RAM **2214**, thereby controlling each unit. The graphics controller **2216** acquires image data generated by the CPU **2212** in a frame buffer or the like provided in the RAM **2214** or in itself and causes the image data to be displayed on the display device **2218**.

[0067] The communication interface **2222** communicates with another electronic device via a network. The hard disk drive **2224** stores a program and data used by the CPU **2212** in the computer **2200**. The DVD-ROM drive **2226** reads a program or data from a DVD-ROM **2201** and provides the program or the data to the hard disk drive **2224** via the RAM **2214**. The IC card drive reads a program and data from the IC card, and/or writes the program and the data to the IC card.

[0068] The ROM **2230** stores therein a boot program or the like executed by the computer **2200** at a time of activation, and/or a program which depends on a hardware of the computer **2200**. The input/output chip **2240** may also connect various input/output units to the input/output controller **2220** via a parallel port, a serial port, a keyboard port, a mouse port, or the like.

[0069] A program is provided by a computer-readable medium such as the DVD-ROM **2201** or the IC card. The program is read from the computer-readable medium, installed in the hard disk drive **2224**, the RAM **2214**, or the ROM **2230** which is also an example of the computer-readable medium, and executed by the CPU **2212**. The information processing described in these kinds of the program is read by the computer **2200**, and provides cooperation between the program and the various types of hardware resources described above. A device or method may be configured by realizing an operation or processing of information according to use of the computer **2200**.

[0070] For example, when communication is executed between the computer **2200** and an external device, the CPU **2212** may execute a communication program loaded in the RAM **2214** and instruct the communication interface **2222** to perform communication processing based on processing described in the communication program. Under control of the CPU **2212**, the communication interface **2222** reads transmission data stored in a transmission buffer processing region provided in a recording medium such as the RAM **2214**, the hard disk drive **2224**, the DVD-ROM **2201**, or the IC card, transmits the read transmission data to the network, or writes reception data received from the network in a reception buffer processing region or the like provided on the recording medium.

[0071] In addition, the CPU **2212** may cause the RAM **2214** to read all or a necessary part of a file or database stored in an external recording medium such as the hard disk drive **2224**, the DVD-ROM drive **2226**, or DVD-ROM **2201**, the IC card, or the like, and execute various types of processing on data on the RAM **2214**. Then, the CPU **2212** writes the processed data back in the external recording medium.

[0072] Various types of information such as various types of a program, data, a table, and a database may be stored in the recording medium and subjected to information processing. The CPU **2212** may execute, on the data read from the RAM **2214**, various types of processing including various types of an operation, information processing, conditional judgment, conditional branching, unconditional branching, information retrieval/replacement, or the like described throughout the present disclosure and specified by an instruction sequence of the program, and writes a result back to the RAM **2214**. In addition, the CPU **2212** may retrieve information in a file, a database, or the like in the recording medium. For example, when a plurality of entries, each having an attribute value of a first attribute associated with an attribute value of a second attribute, is stored in the recording medium, the CPU **2212** may retrieve, out of the plurality of entries, an entry with the attribute value of the first attribute specified which matches a condition, read the attribute value of the second attribute stored in the entry, thereby acquiring the attribute value of the second attribute associated with the first attribute meeting a predetermined condition.

[0073] The program or software module described above may be stored in a computer-readable medium on or near the computer **2200**. In addition, the recording medium such as a hard disk or a RAM provided in a server system connected to a dedicated communication network or the Internet may be used as a computer-readable medium, thereby providing a program to the computer **2200** via the network.

[0074] While the present invention has been described hereinabove by using the embodiment, a technical scope of the present invention is not limited to a scope of the above-described embodiment. It is apparent to persons skilled in the art that various alterations or improvements may be made to the embodiment described above. It is apparent from description of the claims that the embodiment to which such alterations or improvements are made may also be included in the technical scope of the present invention.

[0075] It should be noted that each process of the operations, procedures, steps, stages, and the like performed by the device, system, program, and method shown in the claims, specification, and drawings may be executed in any order as long as the order is not particularly explicitly indicated by “prior to”, “before”, or the like and as long as an output from a previous process is not used in a later process. Even when the operational flow in the claims, specification, and drawings is described using phrases such as “first”, “next”, or the like for the sake of convenience, it does not necessarily mean that the process must be performed in this order.

EXPLANATION OF REFERENCES

[0076] **10**: measurement device; [0077] **100**: distribution cell; [0078] **101**: flow channel; [0079] **102**: main inlet; [0080] **104**: main outlet; [0081] **106**: radical generation region; [0082] **120**: pump; [0083] **132**: radical generation unit [0084] **134**: current/voltage supply unit; [0085] **140**: measurement unit; [0086] **142**: inspection-light irradiation unit [0087] **144**: luminous flux adjustment unit [0088] **146**: detector; [0089] **150**: measurement control unit; [0090] **160**: calculation unit; [0091] **170**: storage unit; [0092] **180**: output unit; [0093] **200**: first electrode; [0094] **202**: second electrode; [0095] **500**: excitation light irradiation unit; [0096] **510**: detector; [0097] **600**: microheater; [0098] **700**: first auxiliary inlet; [0099] **800**: second auxiliary inlet; [0100] **2200**: computer; [0101] **2201**: DVD-ROM; [0102] **2210**: host controller; [0103] **2212**: CPU;

[0104] **2214**: RAM; [0105] **2216**: graphics controller; [0106] **2218**: display device; [0107] **2220**: input/output controller; [0108] **2222**: communication interface; [0109] **2224**: hard disk drive; [0110] **2226**: DVD-ROM drive; [0111] **2230**: ROM; [0112] **2240**: input/output chip; [0113] **2242**: keyboard.

Claims

1. A measurement device comprising: a flow channel which comprises a main inlet and a main outlet; a pump which supplies a fluid containing a radical precursor to the main inlet of the flow channel; a radical generation unit which generates a radical from the radical precursor in a radical generation region in the flow channel; and a measurement unit which measures a measurement value depending on a concentration of the radical at at least one measurement position which exists toward the main outlet relative to the radical generation region in the flow channel.
2. The measurement device according to claim 1, wherein the radical generation unit generates the radical by applying at least one of a voltage, heat, light, or an electron beam to the fluid containing the radical precursor.
3. The measurement device according to claim 1, wherein the flow channel comprises a first auxiliary inlet, and the radical generation unit generates the radical from the radical precursor by supplying an oxidizing agent to the first auxiliary inlet.
4. The measurement device according to claim 1, wherein the flow channel comprises a second auxiliary inlet which is connected to the flow channel between the radical generation region and the at least one measurement position and introduces another fluid which reacts with the radical in the fluid to the flow channel.
5. The measurement device according to claim 1, wherein the measurement unit comprises an inspection-light irradiation unit which irradiates the fluid with inspection light at the at least one measurement position, and a detector which detects the inspection light transmitted through the fluid at the at least one measurement position in the flow channel.
6. The measurement device according to claim 1, wherein the at least one measurement position comprises a plurality of measurement positions, and the measurement unit measures the measurement value for each elapsed time from generation of the radical which corresponds to each of the plurality of measurement positions.
7. The measurement device according to claim 1, wherein the pump changes a flow velocity of the fluid in the flow channel, the flow velocity comprises a plurality of flow velocities, and the measurement unit measures the measurement value for each elapsed time from generation of the radical which corresponds to each of the plurality of flow velocities different from each other.
8. The measurement device according to claim 6, further comprising a calculation unit which calculates a lifetime of the radical, using the measurement value for each elapsed time from the generation of the radical.
9. The measurement device according to claim 1, comprising an excitation light irradiation unit which irradiates the fluid with excitation light between the radical generation region and the at least one measurement position in the flow channel.
10. A measurement method comprising: supplying a fluid containing a radical precursor to a main inlet in a flow channel which comprises the main inlet and a main outlet; generating a radical from the radical precursor in a radical generation region in the flow channel; and measuring a measurement value depending on a concentration of the radical in at least one measurement position which exists toward the main outlet relative to the radical generation region in the flow channel.