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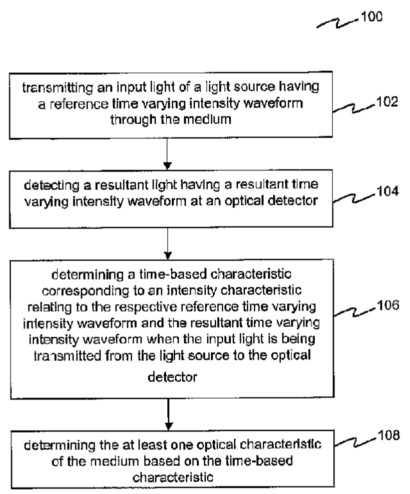

Figure 1

(57) Abstract: In an embodiment, a method of detecting at least one optical characteristic of a medium may be provided. The method may include transmitting an input light of a light source having a reference time varying intensity waveform through the medium; detecting a resultant light having a resultant time varying intensity waveform at an optical detector; determining a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform when the input light is being transmitted from the light source to the optical detector; and determining the at least one optical characteristic of the medium based on the time-based characteristic. A method of detecting presence of a medium between a light source and an optical detector may also be provided.

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A DETECTION METHOD

Technical Field

[0001] Embodiments relate to a method of detecting at least one optical characteristic of a medium and a method of detecting presence of a medium between a light source and an optical detector.

Background

[0002] Measurement of low optical losses of an absorbing medium has been performed by measuring the ring-down time, or decay time, of a light pulse. Such measurement methods may require high intensity of light source, high sensitivity or response of a detector and complex instruments which may render the measurement device to be expensive and bulky.

[0003] Therefore, there is a need for an alternative method to measure optical losses of a medium which may be relatively simple and require less expensive and bulky measurement devices.

Summary

[0004] In various embodiments, a method of detecting at least one optical characteristic of a medium may be provided. The method may include transmitting an input light of a light source having a reference time varying intensity waveform through the medium, detecting a resultant light having a resultant time varying intensity waveform at an optical detector, determining a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform when the input light may be transmitted from the light source to the optical detector and determining the at least one optical characteristic of the medium based on the time-based characteristic.

[0005] In various embodiments, a method of detecting presence of a medium between a light source and an optical detector may also be provided. The method may include transmitting an input light of the light source having a reference time varying intensity waveform, detecting a resultant light having a resultant time varying intensity waveform at the optical detector, determining a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform when the input light is being transmitted from the light source to the optical detector and determining the presence of the medium based on the time-based characteristic.

Brief Description of the Drawings

[0006] In the drawings, like reference characters generally refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of various embodiments. In the following description, various embodiments of the invention are described with reference to the following drawings, in which:

FIG. 1 shows a flowchart illustrating a method of detecting at least one optical characteristic of a medium according to an embodiment;

FIG. 2 shows a flowchart illustrating a method of detecting presence of a medium between a light source and an optical detector according to an embodiment;

FIG. 3 shows a device setup for a detection method according to an embodiment;

FIG. 4A shows a reference time varying intensity waveform of sinusoidally decreased intensity with time of an input light of a light source according to an embodiment;

FIG. 4B shows a resultant time varying intensity waveform of a resultant light as detected at an optical detector according to an embodiment;

FIG. 4C shows both the reference time varying intensity waveform of sinusoidally decreased intensity with time of the input light of the light source and the resultant time varying intensity waveform of the resultant light as detected at the optical detector on a single intensity versus time plot according to an embodiment;

FIG. 5A shows a reference time varying intensity waveform of monotonically increased intensity with time of an input light of a light source according to an embodiment;

FIG. 5B shows a resultant time varying intensity waveform of a resultant light as detected at an optical detector according to an embodiment;

FIG. 5C shows both the reference time varying intensity waveform of monotonically increased intensity with time of the input light of the light source and the resultant time varying intensity waveform of the resultant light as detected at the optical detector on a single intensity versus time plot according to an embodiment;

FIG. 6A shows a reference time varying intensity waveform of monotonically decreased intensity with time of an input light of a light source according to an embodiment;

FIG. 6B shows a resultant time varying intensity waveform of a resultant light as detected at an optical detector according to an embodiment;

FIG. 6C shows both the reference time varying intensity waveform of monotonically decreased intensity with time of the input light of the light source and the resultant time varying intensity waveform of the resultant light as detected at the optical detector on a single intensity versus time plot according to an embodiment;

FIG. 7A shows both the reference time varying intensity waveform of monotonically decreased intensity with time of the input light of the light source and the resultant time varying intensity waveform of the resultant light as detected at the optical detector on a single intensity versus time plot according to an embodiment;

FIG. 7B shows a zoom-in view of a triangle portion of the intensity versus time plot in FIG. 7A according to an embodiment; and

FIG. 8A shows a reference time varying intensity waveform of periodically decreased or increased intensity with time of an input light of a light source according to an embodiment;

FIG. 8B shows a further reference time varying intensity waveform of periodically decreased or increased intensity with time of an input light of a light source according to an embodiment;

FIG. 8C shows a yet further reference time varying intensity waveform of periodically decreased or increased intensity with time of an input light of a light source according to an embodiment; and

FIG. 8D shows an even yet further reference time varying intensity waveform of periodically decreased or increased intensity with time of an input light of a light source according to an embodiment.

Description

[0007] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be utilized and structural, logical, and electrical changes may be made without departing from the scope of the invention. The various embodiments are not necessarily mutually exclusive, as some embodiments can be combined with one or more other embodiments to form new embodiments.

[0008] The word "exemplary" is used herein to mean "serving as an example, instance, or illustration". Any embodiment or design described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments or designs.

[0009] In various embodiments, a detection method may be provided, which may provide a relatively simple and accurate method to detect optical losses by converting the absorption of light into time difference.

[0010] In various embodiments, a method of detecting at least one optical characteristic of a medium may be provided. The method may include transmitting an input light of a light source having a reference time varying intensity waveform through the medium, detecting a resultant light having a resultant time varying intensity waveform at an optical detector, determining a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform when the input light may be transmitted from the light source to the optical detector and determining the at least one optical characteristic of the medium based on the time-based characteristic.

[0011] In various embodiments, a method of detecting presence of a medium between a light source and an optical detector may also be provided. The method may include transmitting an input light of the light source having a reference time varying intensity waveform, detecting a resultant light having a resultant time varying intensity waveform at the optical detector, determining a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform when the input light is being transmitted from the light source to the optical detector and determining the presence of the medium based on the time-based characteristic.

[0012] An embodiment may provide a method of detecting at least one optical characteristic of a medium. The method may include transmitting an input light of a light source having a reference time varying intensity waveform through the medium, detecting a resultant light having a resultant time varying intensity waveform at an optical detector, determining a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform when the input light may be transmitted from the light source to the optical detector and determining the at least one optical characteristic of the medium based on the time-based characteristic.

[0013] In an embodiment, the time-based characteristic may include a time difference or an area difference. The area difference may be a difference between the area under the respective reference time varying intensity waveform and the resultant time varying intensity waveform.

[0014] In an embodiment, the intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform may include an intensity difference between the reference time varying intensity waveform and the resultant time varying intensity waveform.

[0015] In an embodiment, determining the time-based characteristic may include determining the time-based characteristic at which a predetermined intensity may be received at the optical detector.

[0016] In an embodiment, the predetermined intensity may include a value less than a peak resultant intensity of the resultant time varying intensity waveform.

[0017] In an embodiment, determining the time-based characteristic further may include determining a reference time characteristics of the input light, determining a resultant time characteristics of the resultant light and determining a difference between the reference time characteristic and the resultant time characteristic.

[0018] In an embodiment, the reference time varying intensity waveform may be selected from a group of waveform consisting of a waveform of monotonically decreased intensity with time, a waveform of monotonically increased intensity with time, a waveform of periodically decreased intensity with time, a waveform of periodically increased intensity with time, a waveform of sinusoidally decreased intensity with time, a waveform of sinusoidally increased intensity with time. Other suitable waveforms may be included.

[0019] In an embodiment, the method may further include driving the light source using a power supply circuit.

[0020] In an embodiment, the method may further include transmitting the resultant light detected at the optical detector to an amplifying circuit to achieve an amplified resultant light. The amplifying circuit may be an amplifier.

[0021] In an embodiment, the method may further include displaying the amplified resultant light on a display. The display may be a power meter.

[0022] In an embodiment, transmitting the input light of the light source may further include transmitting the input light of the light source along a waveguiding medium.

[0023] In an embodiment, the waveguiding medium may include a medium selected from a group consisting of a lens, an optical fiber, an optical waveguide, a photonic crystal, a flow cell and a cuvette.

[0024] In an embodiment, the waveguiding medium may include a material selected from a group consisting of polymer, glass, quartz and silicon.

[0025] In an embodiment, the light source may be selected from a group consisting of a light-emitting diode, an organic light-emitting diode and a laser source.

[0026] In an embodiment, the input light may include a wavelength range from about 200 nm to about 2000 nm. Other suitable wavelength ranges may also be included.

[0027] In an embodiment, the optical detector may be selected from a group consisting of a photodiode and an optical photodetector.

[0028] In an embodiment, the medium may be selected from a group consisting of a light reducing material and a light enhancing material. The light reducing material may include a light absorption material, a scattering material, a reflection material, for example. The light enhancing material may include a fluorescence material, a phosphorescence material, a photoluminance material, for example.

[0029] In an embodiment, the medium may be selected from a group consisting of a liquid, a solid and a gas.

[0030] In an embodiment, the at least one optical characteristic of the medium may include absorbance, scattering, reflection, refraction, transmittance, fluorescence and phosphorescence for example.

[0031] In an embodiment, each of the reference time varying intensity waveform and the resultant time varying intensity waveform may include a first portion of constant intensity over a first time interval and a second portion of varying intensity over a second time interval.

[0032] In an embodiment, the difference between the reference time characteristic and the resultant time characteristic may change according to the second time interval. The difference between the reference time characteristic and the resultant time characteristic may increase if the second time interval increases.

[0033] An embodiment may provide a method of detecting presence of a medium between a light source and an optical detector. The method may include transmitting an input light of the light source having a reference time varying intensity waveform, detecting a resultant light having a resultant time varying intensity waveform at the optical detector, determining a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform when the input light is being transmitted from the light source to the optical detector and determining the presence of the medium based on the time-based characteristic.

[0034] In an embodiment, the time-based characteristic may include a time difference or an area difference.

[0035] In an embodiment, the intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform may include an intensity difference between the reference time varying intensity waveform and the resultant time varying intensity waveform.

[0036] In an embodiment, determining the time-based characteristic may include determining the time-based characteristic at which a predetermined intensity may be received at the optical detector.

[0037] In an embodiment, the predetermined intensity may include a value less than a peak resultant intensity of the resultant time varying intensity waveform if the medium may include a light reducing material. In an embodiment, the predetermined intensity may include a value less than a peak reference intensity of the reference time varying intensity waveform if the medium may include a light enhancing material. In an embodiment, the predetermined intensity may include a value less than the lesser of the respective values of the peak resultant intensity or the peak reference intensity.

[0038] In an embodiment, determining the time-based characteristic may further include determining a reference time characteristics of the input light, determining a resultant time characteristics of the resultant light and determining a difference between the reference time characteristic and the resultant time characteristic.

[0039] In an embodiment, the reference time varying intensity waveform may be selected from a group of waveform consisting of a waveform of monotonically decreased intensity with time, a waveform of monotonically increased intensity with time, a waveform of periodically decreased intensity with time, a waveform of periodically increased intensity with time, a waveform of sinusoidally decreased intensity with time, a waveform of sinusoidally increased intensity with time.

[0040] In an embodiment, the method may further include driving the light source using a power supply circuit.

[0041] In an embodiment, the method may further include transmitting the resultant light detected at the optical detector to an amplifying circuit to achieve an amplified resultant light.

[0042] In an embodiment, the method may further include displaying the amplified resultant light on a display.

[0043] In an embodiment, transmitting the input light of the light source may further include transmitting the input light of the light source along a waveguiding medium.

[0044] In an embodiment, the waveguiding medium may include a medium selected from a group consisting of a lens, an optical fiber, an optical waveguide, a photonic crystal, a flow cell and a cuvette.

[0045] In an embodiment, the waveguiding medium may include a material selected from a group consisting of polymer, glass, quartz and silicon.

[0046] In an embodiment, the light source may be selected from a group consisting of a light-emitting diode, an organic light-emitting diode and a laser source.

[0047] In an embodiment, the input light may include a wavelength range from about 200 nm to about 2000 nm.

[0048] In an embodiment, the optical detector may be selected from a group consisting of a photodiode and an optical photodetector.

[0049] In an embodiment, the medium may be selected from a group consisting of a light reducing material and a light enhancing material. The medium may include other materials that may increase or decrease the intensity of light. For example, scattering materials or reflection materials may decrease the intensity of light.

[0050] In an embodiment, the medium may be selected from a group consisting of a liquid, a solid and a gas.

[0051] In an embodiment, each of the reference time varying intensity waveform and the resultant time varying intensity waveform may include a first portion of constant intensity over a first time interval and a second portion of varying intensity over a second time interval.

[0052] In an embodiment, the difference between the reference time characteristic and the resultant time characteristic may change according to the second time interval. The difference between the reference time characteristic and the resultant time characteristic may increase if the second time interval increases.

[0053] In an embodiment, a method for measuring one or more optical properties, such as absorbance of a test medium such as a gas, a liquid or solid material may be provided. The method may include a light source such as a LED, a laser and an OLED, and a light detector such as a complementary metal-oxide semiconductor photo-diode (CMOS-PD), silicon photo-diode (Si-PD) and optical photodetector (OPD). A method may be provided such that that the light intensity difference caused by absorbance of the the test medium may be converted to time difference of a certain light intensity that photodetector may detect. An improvement of detection limit may be achieved by changing the intensity of the light source generally in accordance with various embodiments.

[0054] In an embodiment, when the intensity of light source may increase or decrease generally depending on time, the intensity that the photo-diode (PD) detects may also increase or decrease generally depending on time. If there may be a test medium between the light source and the PD, the test medium may absorb some light and then the intensity that the PD detects may also decrease.

[0055] In an embodiment, light signal from a light source may be generated with a waveform of gradually changed intensity by time. Light from the light source may then be coupled into a transparent waveguiding medium. Further, light may propagate through a medium and may interact with the medium. Light may be subsequently detected by a photo-detector. An optical signal detected by the photo-detector may be amplified. The detected optical signal may increased or reduced to an offset intensity value I at a particular time point of ts and the detected reference optical signal may reach the offset intensity value I at a particular time point tr. The time difference between tr and ts may be measured as a sensing parameter which may referred to various contents of the medium. The relation between the measured time difference and one or more optical properties of a medium may be calibrated in order to perform the qualitative and quantitative measurement.

[0056] In an embodiment, a simple sensing system to convert an optical signal into a time difference may be provided.

[0057] FIG. 1 shows a flowchart 100 illustrating a method of detecting at least one optical characteristic of a medium according to an embodiment.

[0058] At 102, an input light of a light source having a reference time varying intensity waveform may be transmitted through the medium.

[0059] At 104, a resultant light having a resultant time varying intensity waveform may be detected at an optical detector.

[0060] At 106, a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform may be determined when the input light may be transmitted from the light source to the optical detector.

[0061] At 108, the at least one optical characteristic of the medium may be determined based on the time-based characteristic.

[0062] FIG. 2 shows a flowchart 200 illustrating a method of detecting presence of a medium between a light source and an optical detector according to an embodiment.

[0063] At 202, an input light of the light source having a reference time varying intensity waveform may be transmitted.

[0064] At 204, a resultant light having a resultant time varying intensity waveform may be detected at the optical detector.

[0065] At 206, a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform may be determined when the input light may be transmitted from the light source to the optical detector

[0066] At 208, the presence of the medium may be determined based on the time-based characteristic.

[0067] FIG. 3 shows a device setup 300 for a detection method according to an embodiment. The device setup 300 may include a power supply circuit 302, a light source 304, a medium holder 306 for accommodating a medium of interest 308, a waveguiding medium 310, an optical detector 312, an amplifying circuit 314 and a display 316.

[0068] The power supply circuit 302 may be a power source configured to provide an applied voltage or current 318 to drive the light source 304. The light source 304 may include a light-emitting diode (LED), an organic light-emitting diode (OLED) and a laser source. The light source 304 may provide an input light 320 having a wavelength range from about 200 nm to about 2000 nm. The medium holder 306 may be any suitable holder configured to accommodate the medium of interest 308 between the light source 304 and the optical detector 312. The medium of interest 308 may be selected from a group consisting of a light reducing material and a light enhancing material. The light reducing material may include a light absorption material, a scattering material, a reflection material, for example. The light enhancing material may include a fluorescence material, a phosphorescence material, a photoluminance material, for example. The medium of interest 308 may also be selected from a group consisting of a liquid, a solid and a gas. The optical detector 312 may be selected from a group consisting of a photodiode (PD) and an optical photodetector (OPD). The optical detector 312 may be configured to detect a resultant light 322 after the input light 320 may be transmitted across the medium of interest 308. The waveguiding medium 310 may include a medium selected from a group consisting of a lens, an optical fiber, an optical waveguide, a photonic crystal, a flow cell and a cuvette. The waveguiding medium 310 may include a material selected from a group consisting of polymer, glass, quartz and silicon. The waveguiding medium 310 may be configured to guide the input light 320 from the light source 304 through the medium of interest 308 and then to further guide the resultant light 322 transmitted through the medium of interest 308 to the optical detector 312. The amplifying circuit 314 may include an amplifier. A detected resultant light 324 detected by the optical detector 312 may be transmitted to the amplifying circuit 314 to achieve an amplified resultant light 326. The display 316 may include a power meter. The amplified resultant light 326 may be displayed on the display 316.

[0069] For the detection method, the input light 320 of the light source 304 may be transmitted or propagated through the medium of interest 308 to form the resultant light 322 to be detected by the optical detector 312. The input light 320 may include a reference time varying intensity waveform (not shown) and the resultant light 322 may include a resultant time varying intensity waveform (not shown) of a reduced or increased intensity compared to the input light 320. The transmission of the input light 320 through the medium of interest 308 may reduce or enhance the intensity of the input light 320 depending on whether the medium of interest 308 include a light reducing material or a light enhancing material.

[0070] FIG. 4A shows a reference time varying intensity waveform 400 of sinusoidally decreased intensity with time of an input light 320 of a light source 304 according to an embodiment; FIG. 4B shows a resultant time varying intensity waveform 402 of a resultant light 322 as detected at an optical detector 312 according to an embodiment; FIG. 4C shows both the reference time varying intensity waveform 400 of sinusoidally decreased intensity with time of the input light 320 of the light source 304 and the resultant time varying intensity waveform 402 of the resultant light 322 as detected at the optical detector 312 on a single intensity versus time plot according to an embodiment. The medium of interest 308 may include a light reducing material in FIG. 4A, FIG. 4B and FIG. 4C.

[0071] FIG. 4A shows a reference time varying intensity waveform 400 of sinusoidally decreased intensity with time of an input light 320 of a light source 304 according to an embodiment. The peak reference intensity of the reference time varying intensity waveform 400 may be represented by Ir. The value of the peak reference intensity (Ir) and the gradient of the slope of the reference time varying intensity waveform 400 may change depending on the type of light source 304, the type of optical detector 312 (or photo diode) and the type of the material of the waveguiding medium 310 (but may not be influenced by the change in the medium of interest 308 (or absorbing test material)). The value of the peak reference intensity (Ir) and the gradient of the slope of the reference time varying intensity waveform 400 may change depending on the material of the waveguiding medium 310 because the material of the waveguiding medium 310 may also absorb some light. And the absorbance of the material of the waveguiding medium 310 may change depending on the type of material which may be employed. The reference time varying intensity waveform 400 may be obtained by allowing the input light 320 to be detected by the optical detector 312 without the presence of a medium 308 or with the presence of a reference medium 308.

[0072] FIG. 4B shows a resultant time varying intensity waveform 402 of a resultant light 322 as detected at an optical detector 312 according to an embodiment. The peak resultant intensity of the resultant time varying intensity waveform 402 may be represented by Is. As the medium of interest 308 may include a light reducing material, the peak resultant intensity (Is) of the resultant time varying intensity waveform 402 may be of a reduced intensity as compared to the peak reference intensity (Ir) of the reference time varying intensity waveform 400 as some of the input light 320 may be absorbed by the medium of interest 308.

[0073] FIG. 4C shows both the reference time varying intensity waveform 400 of sinusoidally decreased intensity with time of the input light 320 of the light source 304 and the resultant time varying intensity waveform 402 of the resultant light 322 as detected at the optical detector 312 on a single intensity versus time plot according to an embodiment.

[0074] At a predetermined intensity (I), a reference time characteristic (tr) of the input light 320 may be determined from the reference time varying intensity waveform 400 and a resultant time characteristic (ts) of the resultant light 322 may be determined from the resultant time varying intensity waveform 402.

[0075] When the medium of interest 308 may include a light reducing material and the reference time varying intensity waveform 400 may be a waveform of sinusoidally decreased intensity, the peak reference intensity (Ir) of the reference time varying intensity waveform 400 may be higher than the peak resultant intensity (Is) of the resultant time varying intensity waveform 402 and the reference time characteristic (tr) may be longer than the resultant time characteristic (ts) at the predetermined intensity (I). The intensity difference (Ir - Is) between the peak reference intensity and the peak resultant intensity may be related to the time difference (tr – ts) between the reference time characteristic and the resultant time characteristic as shown in the following equation (1) :

$$Ir - Is = \sum_{k=1}^{n} a_k (t_r - t_s)^k \qquad \text{- Equation (1)}$$

a_k : real number

[0076] The relationship between the intensity difference and the time difference may also depend on the predetermined intensity (I), the inherent property of respective photo-detector and light source and the voltage applied to the light source. Therefore, the detection method may allow the conversion of the intensity difference caused by absorbance of the medium of interest 308 to the time difference of a certain light intensity (i.e. predetermined intensity) that the optical detector 312 may detect.

[0077] FIG. 5A shows a reference time varying intensity waveform 500 of monotonically increased intensity with time of an input light 320 of a light source 304 according to an embodiment; FIG. 5B shows a resultant time varying intensity waveform 502 of a resultant light 322 as detected at an optical detector 312 according to an embodiment; FIG. 5C shows both the reference time varying intensity waveform 500 of monotonically increased intensity with time of the input light 320 of the light source 304 and the resultant time varying intensity waveform 502 of the resultant light 322 as detected at the optical detector 312 on a single intensity versus time plot according to an embodiment.

[0078] FIG. 5A, FIG. 5B and FIG. 5C may be similar to FIG. 4A, FIG. 4B and FIG. 4C except that the medium of interest 308 may be a light enhancing material in FIG. 5A, FIG. 5B and FIG. 5C instead of a light reducing material in FIG. 4A, FIG. 4B and FIG. 4C. Further the reference time varying intensity waveform 500 and the resultant time varying intensity waveform 502 may be a waveform of monotonically increased intensity with time as shown in FIG. 5A, FIG. 5B and FIG. 5C instead of a waveform of sinusoidally decreased intensity with time as shown in FIG. 4A, FIG. 4B and FIG. 4C.

[0079] FIG. 5A shows a reference time varying intensity waveform 500 of monotonically increased intensity with time of an input light 320 of a light source 304 according to an embodiment. The peak reference intensity of the reference time varying intensity waveform 500 may be represented by Ir. The value of the peak reference intensity (Ir) and the gradient of the slope of the reference time varying intensity waveform 500 may change depending on the type of light source 304, the type of optical detector 312 (or photo diode) and the type of the material of the waveguiding medium 310 (but may not be influenced by the change in the medium of interest 308 (or absorbing test material)).

[0080] FIG. 5B shows a resultant time varying intensity waveform 502 of a resultant light 322 as detected at an optical detector 312 according to an embodiment. The peak resultant intensity of the resultant time varying intensity waveform 502 may be represented by Is. As the medium of interest 308 may include a light enhancing material, the peak resultant intensity (Is) of the resultant time varying intensity waveform 502 may be of an increased intensity as compared to the peak reference intensity (Ir) of the reference time varying intensity waveform 500 as some of the input light 320 may be enhanced, for example by the photoluminance or fluorescent of the medium of interest 308.

[0081] FIG. 5C shows both the reference time varying intensity waveform 500 of monotonically increased intensity with time of the input light 320 of the light source 304 and the resultant time varying intensity waveform 502 of the resultant light 322 as detected at the optical detector 312 on a single intensity versus time plot according to an embodiment.

[0082] At a predetermined intensity (I), a reference time characteristic (tr) of the input light 320 may be determined from the reference time varying intensity waveform 500 and a resultant time characteristic (ts) of the resultant light 322 may be determined from the resultant time varying intensity waveform 502.

[0083] When the medium of interest 308 may include a light enhancing material and the reference time varying intensity waveform 500 may be a waveform of monotonically increased intensity, the peak reference intensity (Ir) of the reference time varying intensity waveform 500 may be lower than the peak resultant intensity (Is) of the resultant time varying intensity waveform 502 and the reference time characteristic (tr) may be longer than the resultant time characteristic (ts) at the predetermined intensity (I).

[0084] FIG. 6A shows a reference time varying intensity waveform 600 of monotonically decreased intensity with time of an input light 320 of a light source 304 according to an embodiment; FIG. 6B shows a resultant time varying intensity waveform 602 of a resultant light 322 as detected at an optical detector 312 according to an embodiment; FIG. 6C shows both the reference time varying intensity waveform 600 of monotonically decreased intensity with time of the input light 320 of the light source 304 and the resultant time varying intensity waveform 602 of the resultant light 322 as detected at the optical detector 312 on a single intensity versus time plot according to an embodiment. The medium of interest 308 may include a light reducing material in FIG. 6A, FIG. 6B and FIG. 6C.

[0085] FIG. 6A, FIG. 6B and FIG. 6C may be similar to FIG. 4A, FIG. 4B and FIG. 4C except that the reference time varying intensity waveform 600 and the resultant time varying intensity waveform 602 may be a waveform of monotonically decreased intensity with time as shown in FIG. 6A, FIG. 6B and FIG. 6C instead of a waveform of sinusoidally decreased intensity with time as shown in FIG. 4A, FIG. 4B and FIG. 4C.

[0086] FIG. 6A shows a reference time varying intensity waveform 600 of monotonically decreased intensity with time of an input light 320 of a light source 304 according to an embodiment. The peak reference intensity of the reference time varying intensity waveform 600 may be represented by Ir. The value of the peak reference intensity (Ir) and the gradient of the slope of the reference time varying intensity waveform 600 may change depending on the type of light source 304, the type of optical detector 312 (or photo diode) and the type of the material of the waveguiding medium 310 (but may not be influenced by the change in the medium of interest 308 (or absorbing test material)).

[0087] FIG. 6B shows a resultant time varying intensity waveform 602 of a resultant light 322 as detected at an optical detector 312 according to an embodiment. The peak resultant intensity of the resultant time varying intensity waveform 602 may be represented by Is. As the medium of interest 308 may include a light reducing material, the peak resultant intensity (Is) of the resultant time varying intensity waveform 602 may be of a reduced intensity as compared to the peak reference intensity (Ir) of the reference time varying intensity waveform 600 as some of the input light 320 may be absorbed by the medium of interest 308.

[0088] FIG. 6C shows both the reference time varying intensity waveform 600 of monotonically decreased intensity with time of the input light 320 of the light source 304 and the resultant time varying intensity waveform 602 of the resultant light 322 as detected at the optical detector 312 on a single intensity versus time plot according to an embodiment.

[0089] At a predetermined intensity (I), a reference time characteristic (tr) of the input light 320 may be determined from the reference time varying intensity waveform 600 and a resultant time characteristic (ts) of the resultant light 322 may be determined from the resultant time varying intensity waveform 602.

[0090] When the medium of interest 308 may include a light reducing material and the reference time varying intensity waveform 600 may be a waveform of monotonically decreased intensity, the peak reference intensity (Ir) of the reference time varying intensity waveform 600 may be higher than the peak resultant intensity (Is) of the resultant time varying intensity waveform 602 and the reference time characteristic (tr) may be longer than the resultant time characteristic (ts) at the predetermined intensity (I).

[0091] Whether the value of the peak reference intensity (Ir) may be lower or higher than the peak resultant intensity (Is) may depend on whether the medium of interest 308 may include a light reducing material or a light enhancing material.

[0092] Whether the value of the reference time characteristic (tr) may be longer or shorter than the resultant time characteristic (ts) at the predetermined intensity (I) may depend on whether the medium of interest 308 may include a light reducing material or a light enhancing material and on whether the reference time varying intensity waveform may include a waveform of a decreased intensity or an increased intensity with time.

[0093] In other words, for a light reducing material, whether the value of the reference time characteristic (tr) may be longer or shorter than the resultant time characteristic (ts) may depend on whether the reference time varying intensity waveform is a waveform of a decreased intensity or an increased intensity. As an example, if the reference time varying intensity waveform may be a waveform of monotonically decreased intensity with time, tr may be longer than ts. If the reference time varying intensity waveform may be a waveform of monotonically increased intensity with time, tr may be shorter than ts.

[0094] For a light enhancing material, whether the value of the reference time characteristic (tr) may be longer or shorter than the resultant time characteristic (ts) may depend on whether the reference time varying intensity waveform may be a waveform of an increased intensity or a decreased intensity with time. As an example, if the reference time varying intensity waveform may be a waveform of monotonically decreased intensity with time, tr may be shorter than ts. If the reference time varying intensity waveform may be a waveform of monotonically increased intensity with time, tr may be longer than ts.

[0095] FIG. 7A shows both the reference time varying intensity waveform 600 of monotonically decreased intensity with time of the input light 320 of the light source 304 and the resultant time varying intensity waveform 602 of the resultant light 322 as detected at the optical detector 312 on a single intensity versus time plot according to an embodiment; FIG. 7B shows a zoom-in view of a triangle portion 700 of the intensity versus time plot in FIG. 7A according to an embodiment.

[0096] FIG. 7A may be similar to FIG. 6C and shows both the reference time varying intensity waveform 600 of monotonically decreased intensity of the input light 320 of the light source 304 and the resultant time varying intensity waveform 602 of the resultant light 322 as detected at the optical detector 312 on a single intensity versus time plot.

[0097] Further, FIG. 7A and FIG. 7B shows a rectangle portion 702 and a triangle portion 700. In the rectangle portion 702, the peak reference intensity (Ir) of the reference time varying intensity waveform 600 and the peak resultant intensity (Is) of the resultant time varying intensity waveform 602 may be of a respective constant value over a first time interval 704. And in the triangle portion 700, the respective intensity of the reference time varying intensity waveform 600 and the resultant time varying intensity waveform 602 may vary with time over a second time interval 706. The first time interval 704 and the second time interval 706 may be adjusted accordingly by a user. The second time interval 706 may be adjusted so as to provide a higher time difference (tr –ts) at a predetermined intensity (I) or detecting point. The second time interval 706 may include or may not include a relationship with the first time interval 704. The second time interval 706 may be longer, equal or shorter than the first time interval 704. The time difference (tr-ts) may be related to the second time interval, and may not be related to the first time interval 704. The first time interval 704 may or may not be existent or may include a zero value.

[0098] FIG. 7B shows a zoom-in view of a triangle portion 700 of the intensity versus time plot in FIG. 7A according to an embodiment. In that triangle portion 700, the time difference (tr-ts) may be obtained at the detecting point. The detecting point may be at the predetermined intensity I and may include any suitable value lesser than the peak resultant intensity (Is). All the numerical values shown below are just examples and may be amended accordingly.

[0099] In the triangle portion 700, the time difference may be calculated as such if the second time interval may be 1s :

$$1s \times 0.01\% \times \frac{1}{100} \times \frac{0.9}{0.9999} = 9.0 \times 10^{-5} s$$ - Equation (2)

[00100] The time difference may be made larger or increased by changing the second time interval 706. The detection method may enable an user to detect relatively small absorption difference by detecting the time difference.

[00101] The effect of adjusting the second time interval 706 may be as shown in Table 1 below :

Absorbance	Second Time Interval	Time difference at detecting point
0.01%	1s	90μs
0.01%	2s	180μs
0.001%	2s	18μs

Table 1

[00102] FIG. 8A shows a reference time varying intensity waveform 800 of periodically decreased or increased intensity with time of an input light 320 of a light source 304 according to an embodiment; FIG. 8B shows a further reference time varying intensity 802 waveform of periodically decreased or increased intensity with time of an input light 320 of a light source 304 according to an embodiment; FIG. 8C shows a yet

further reference time varying intensity waveform 804 of periodically decreased or increased intensity with time of an input light 320 of a light source 304 according to an embodiment; FIG. 8D shows an even yet further reference time varying intensity waveform 806 of periodically decreased or increased intensity with time of an input light 320 of a light source 304 according to an embodiment.

[00103] FIG. 8A, FIG. 8B, FIG. 8C and FIG. 8D may differ from each other in that the value of the peak reference intensity may be different and the gradient of the slope may be different. The first time interval 704 may not exist or may not be shown in FIG. 8A and FIG. 8B while the first time interval 704 may be as shown in FIG. 8C and FIG. 8D.

[00104] While the invention has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims. The scope of the invention is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced.

Claims

What is claimed is:

1. A method of detecting at least one optical characteristic of a medium, the method comprising:

transmitting an input light of a light source having a reference time varying intensity waveform through the medium;

detecting a resultant light having a resultant time varying intensity waveform at an optical detector;

determining a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform when the input light is being transmitted from the light source to the optical detector; and

determining the at least one optical characteristic of the medium based on the time-based characteristic.

2. The method of claim 1,

wherein the time-based characteristic comprises a time difference or an area difference.

3. The method of claim 1 or 2,

wherein the intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform comprises an intensity difference between the reference time varying intensity waveform and the resultant time varying intensity waveform.

4. The method of any one of claims 1 to 3,

wherein determining the time-based characteristic comprises determining the time-based characteristic at which a predetermined intensity is received at the optical detector.

5. The method of claim 4,

wherein the predetermined intensity comprises a value less than a peak resultant intensity of the resultant time varying intensity waveform.

6. The method of any one of claims 1 to 5,

wherein determining the time-based characteristic further comprises

determining a reference time characteristics of the input light;
determining a resultant time characteristics of the resultant light; and
determining a difference between the reference time characteristic and the resultant time characteristic.

7. The method of any one of claims 1 to 6,

wherein the reference time varying intensity waveform is selected from a group of waveform consisting of a waveform of monotonically decreased intensity with time, a waveform of monotonically increased intensity with time, a waveform of periodically decreased intensity with time, a waveform of periodically increased intensity with time, a waveform of sinusoidally decreased intensity with time, a waveform of sinusoidally increased intensity with time.

8. The method of any one of claims 1 to 7, further comprising

driving the light source using a power supply circuit.

9. The method of any one of claims 1 to 8, further comprising

transmitting the resultant light detected at the optical detector to an amplifying circuit to achieve an amplified resultant light.

10. The method of claim 9, further comprising

displaying the amplified resultant light on a display.

11. The method of any one of claims 1 to 10,

wherein transmitting the input light of the light source further comprises transmitting the input light of the light source along a waveguiding medium.

12. The method of claim 11,

wherein the waveguiding medium comprises a medium selected from a group consisting of a lens, an optical fiber, an optical waveguide, a photonic crystal, a flow cell and a cuvette.

13. The method of claim 11 or 12,

wherein the waveguiding medium comprises a material selected from a group consisting of polymer, glass, quartz and silicon.

14. The method of any one of claims 1 to 13,

wherein the light source is selected from a group consisting of a light-emitting diode, an organic light-emitting diode and a laser source.

15. The method of any one of claims 1 to 14,

wherein the input light comprises a wavelength range from 200 nm to 2000 nm.

16. The method of any one of claims 1 to 15,

wherein the optical detector is selected from a group consisting of a photodiode and an optical photodetector.

17. The method of any one of claims 1 to 16,

wherein the medium is selected from a group consisting of a light reducing material and a light enhancing material.

18. The method of any one of claims 1 to 17,

wherein the medium is selected from a group consisting of a liquid, a solid and a gas.

19. The method of any one of claims 1 to 18,

wherein the at least one optical characteristic of the medium comprises absorbance, scattering, reflection, refraction, transmittance, fluorescence and phosphorescence

20. The method of any one of claims 6 to 19,

wherein each of the reference time varying intensity waveform and the resultant time varying intensity waveform comprises a first portion of constant intensity over a first time interval and a second portion of varying intensity over a second time interval.

21. The method of claim 20,

wherein the difference between the reference time characteristic and the resultant time characteristic changes according to the second time interval.

22. A method of detecting presence of a medium between a light source and an optical detector, the method comprising:

transmitting an input light of the light source having a reference time varying intensity waveform;

detecting a resultant light having a resultant time varying intensity waveform at the optical detector;

determining a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform when the input light is being transmitted from the light source to the optical detector; and

determining the presence of the medium based on the time-based characteristic.

23. The method of claim 22,

wherein the time-based characteristic comprises a time difference or an area difference.

24. The method of claim 22 or 23,

wherein the intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform comprises an intensity difference between the reference time varying intensity waveform and the resultant time varying intensity waveform.

25. The method of any one of claims 22 to 24,

wherein determining the time-based characteristic comprises determining the time-based characteristic at which a predetermined intensity is received at the optical detector.

26. The method of claim 25,

wherein the predetermined intensity comprises a value less than a peak resultant intensity of the resultant time varying intensity waveform.

27. The method of any one of claims 22 to 26,

wherein determining the time-based characteristic further comprises

determining a reference time characteristics of the input light;
determining a resultant time characteristics of the resultant light; and
determining a difference between the reference time characteristic and the resultant time characteristic.

28. The method of any one of claims 22 to 27,

wherein the reference time varying intensity waveform is selected from a group of waveform consisting of a waveform of monotonically decreased intensity with time, a waveform of monotonically increased intensity with time, a waveform of periodically decreased intensity with time, a waveform of periodically increased intensity with time, a waveform of sinusoidally decreased intensity with time, a waveform of sinusoidally increased intensity with time.

29. The method of any one of claims 22 to 28, further comprising

driving the light source using a power supply circuit.

30. The method of any one of claims 22 to 29, further comprising

transmitting the resultant light detected at the optical detector to an amplifying circuit to achieve an amplified resultant light.

31. The method of claim 30, further comprising

displaying the amplified resultant light on a display.

32. The method of any one of claims 22 to 31,

wherein transmitting the input light of the light source further comprises transmitting the input light of the light source along a waveguiding medium.

33. The method of claim 32,

wherein the waveguiding medium comprises a medium selected from a group consisting of a lens, an optical fiber, an optical waveguide, a photonic crystal, a flow cell and a cuvette.

34. The method of claim 32 or 33,

wherein the waveguiding medium comprises a material selected from a group consisting of polymer, glass, quartz and silicon.

35. The method of any one of claims 22 to 34,

wherein the light source is selected from a group consisting of a light-emitting diode, an organic light-emitting diode and a laser source.

36. The method of any one of claims 22 to 35,

wherein the input light comprises a wavelength range from 200 nm to 2000 nm.

37. The method of any one of claims 22 to 36,

wherein the optical detector is selected from a group consisting of a photodiode and an optical photodetector.

38. The method of any one of claims 22 to 37,

wherein the medium is selected from a group consisting of a light reducing material and a light enhancing material.

39. The method of any one of claims 22 to 38,

wherein the medium is selected from a group consisting of a liquid, a solid and a gas.

40. The method of any one of claims 27 to 39,

wherein each of the reference time varying intensity waveform and the resultant time varying intensity waveform comprises a first portion of constant intensity over a first time interval and a second portion of varying intensity over a second time interval.

41. The method of claim 40,

wherein the difference between the reference time characteristic and the resultant time characteristic changes according to the second time interval.

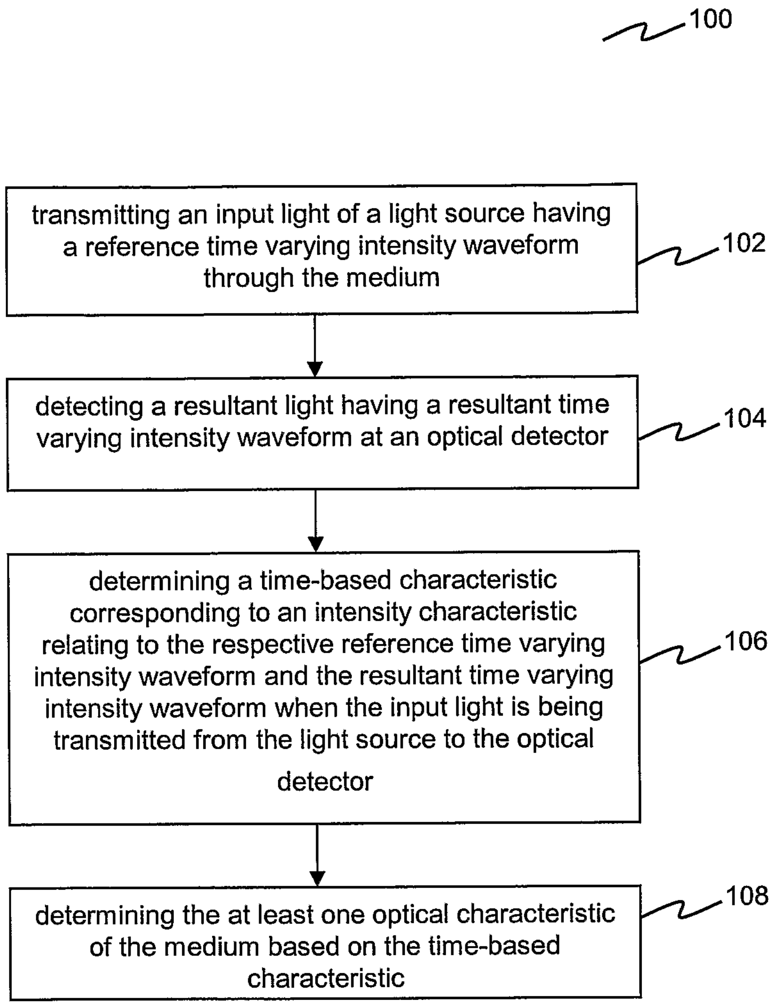
100
transmitting an input light of a light source having a reference time varying intensity waveform through the medium
102
detecting a resultant light having a resultant time varying intensity waveform at an optical detector
104
determining a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform when the input light is being transmitted from the light source to the optical detector
106
determining the at least one optical characteristic of the medium based on the time-based characteristic
108

Figure 1

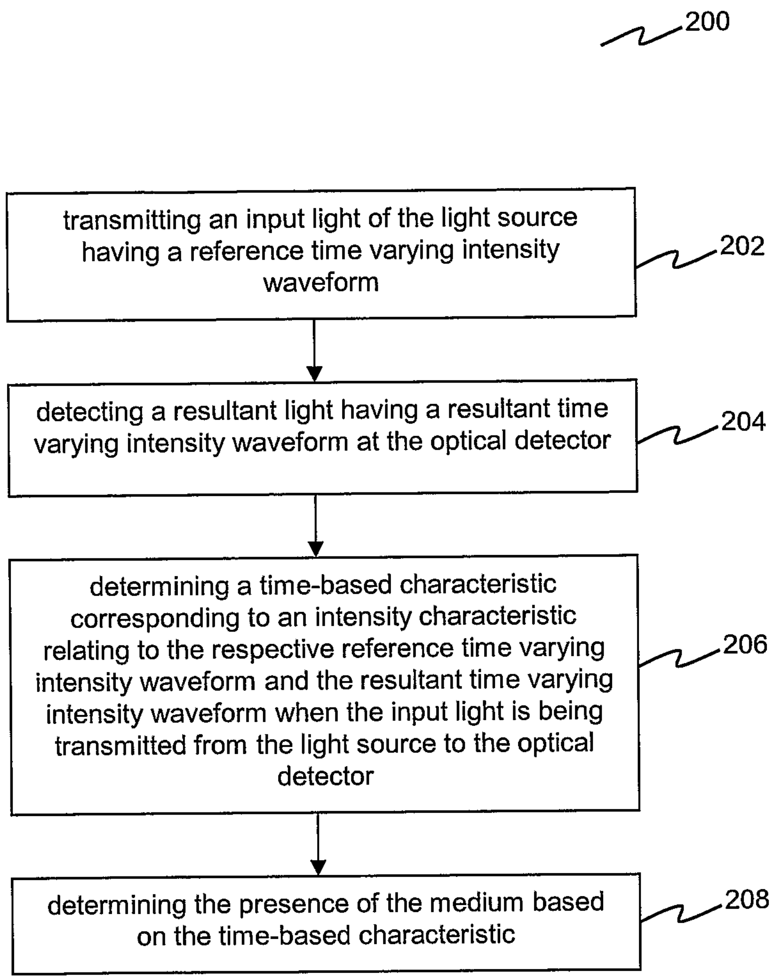
200
transmitting an input light of the light source having a reference time varying intensity waveform
202
detecting a resultant light having a resultant time varying intensity waveform at the optical detector
204
determining a time-based characteristic corresponding to an intensity characteristic relating to the respective reference time varying intensity waveform and the resultant time varying intensity waveform when the input light is being transmitted from the light source to the optical detector
206
determining the presence of the medium based on the time-based characteristic
208

Figure 2

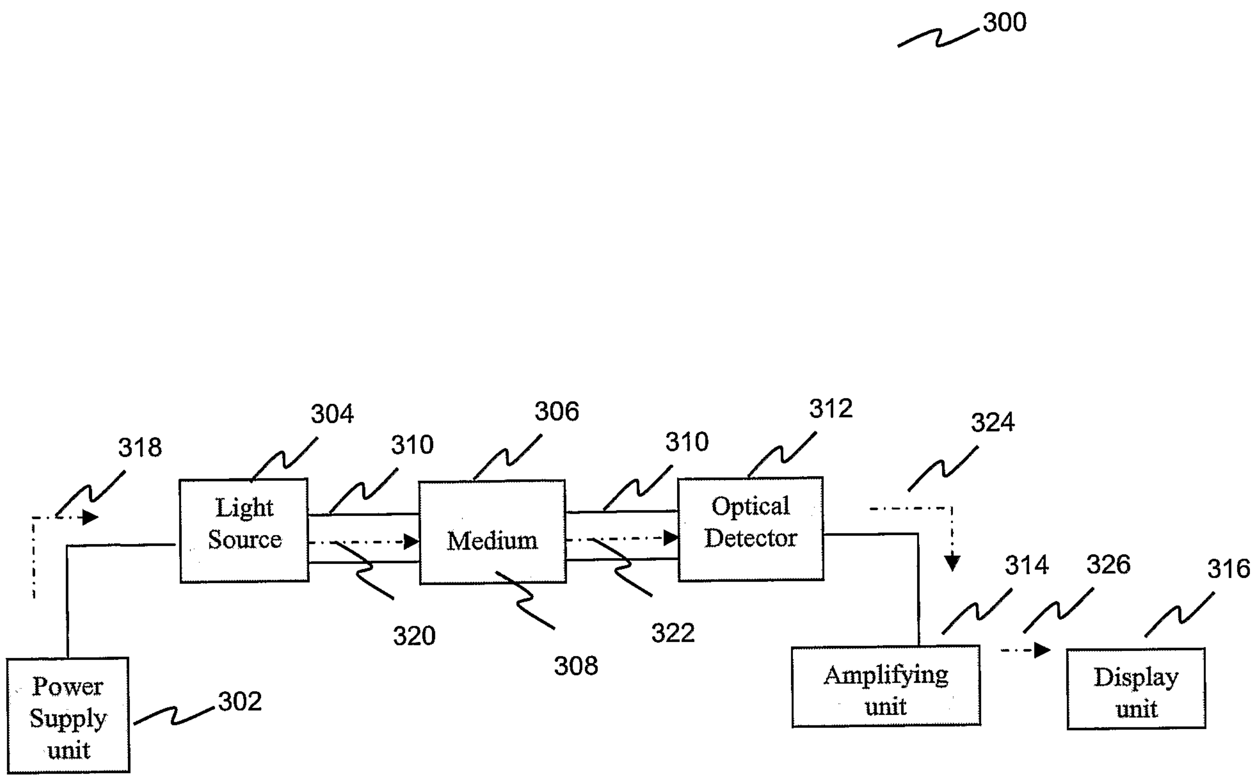
300
304
306
312
324
318
310
310
Light Source
Medium
Optical Detector
320
322
308
314
326
316
Power Supply unit
302
Amplifying unit
Display unit

Figure 3

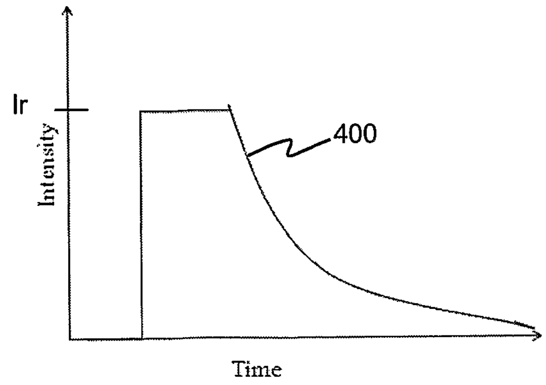

Figure 4A

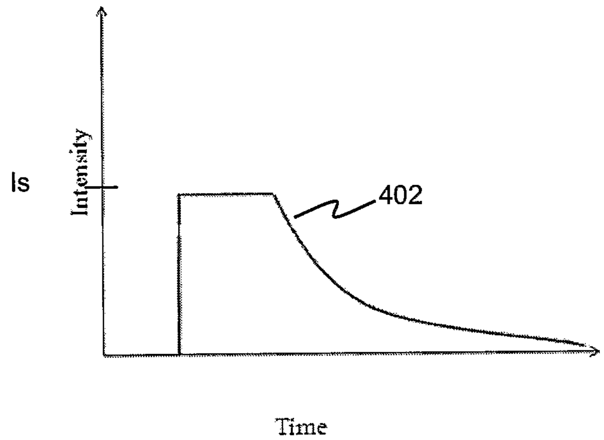

Figure 4B

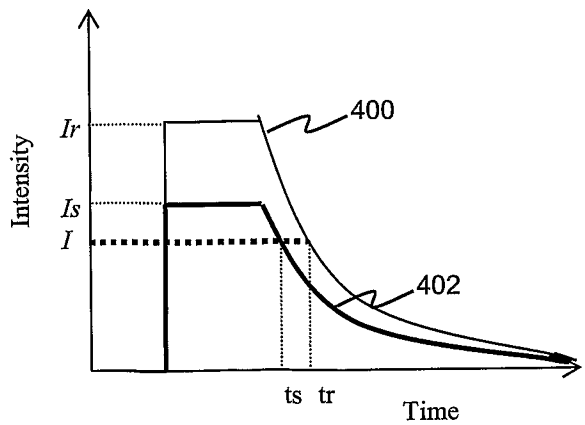

Figure 4C

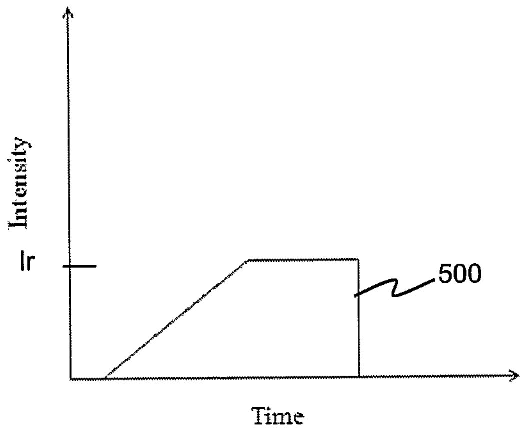

Figure 5A

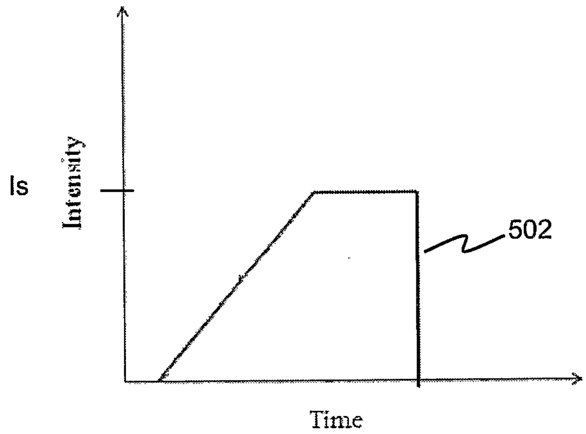

Figure 5B

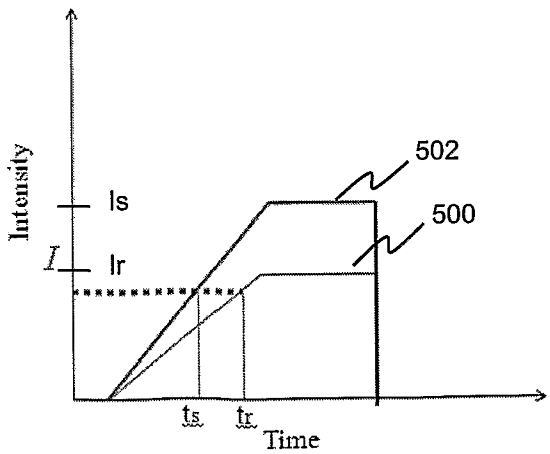

Figure 5C

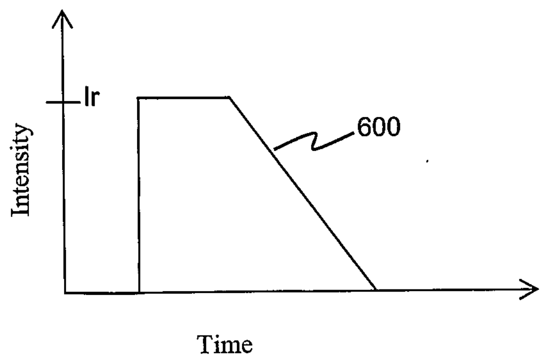

Figure 6A

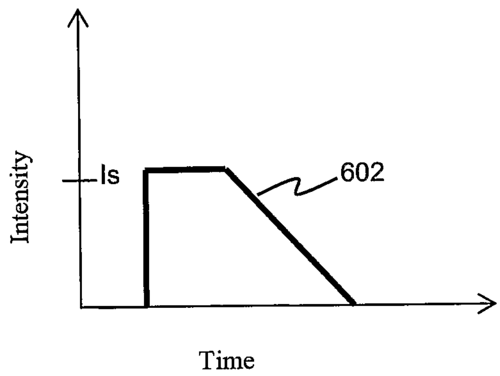

Figure 6B

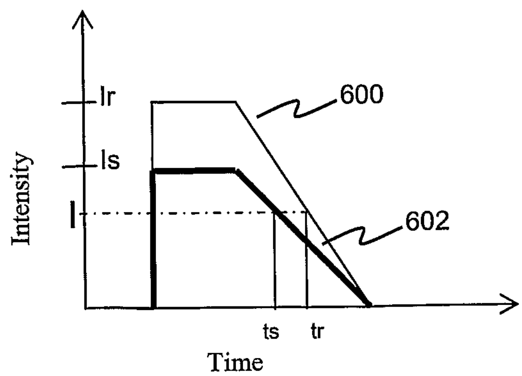

Figure 6C

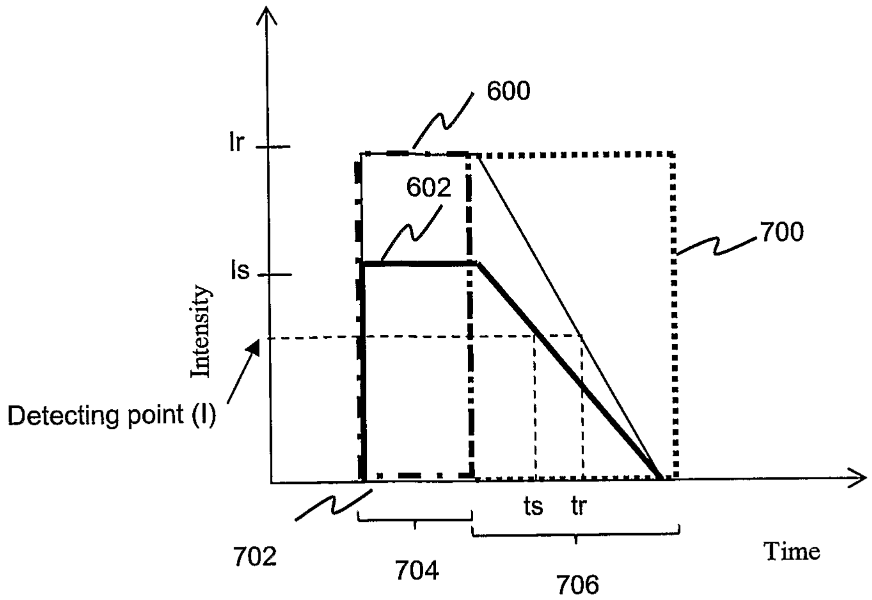

Figure 7A

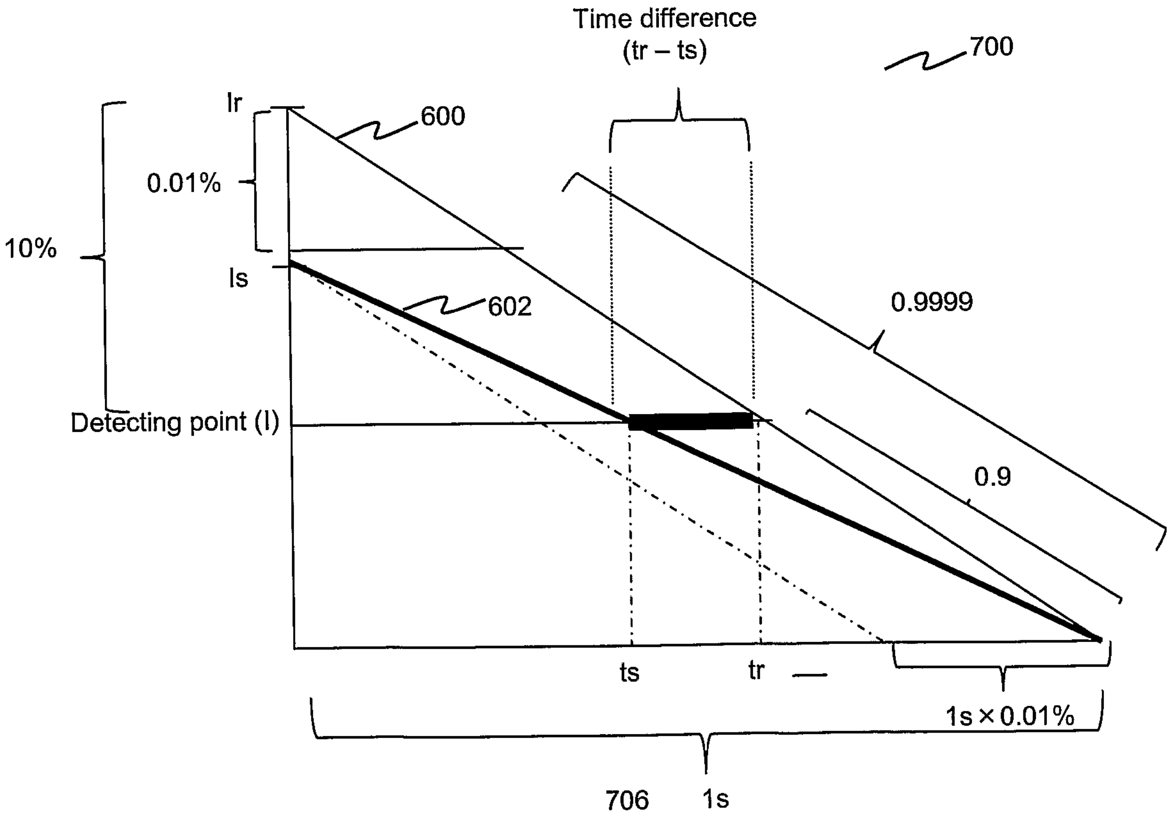

Figure 7B

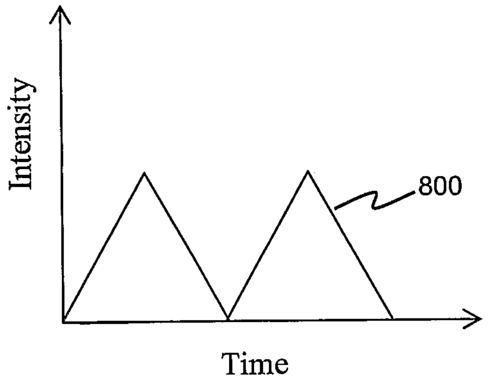

Figure 8A

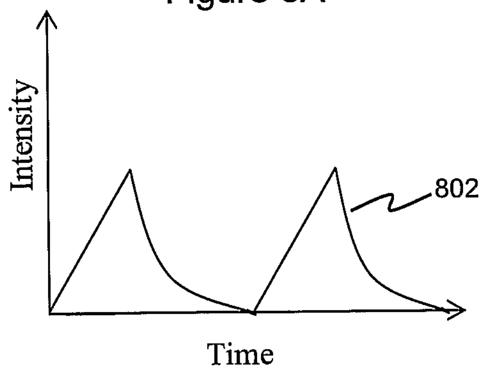

Figure 8B

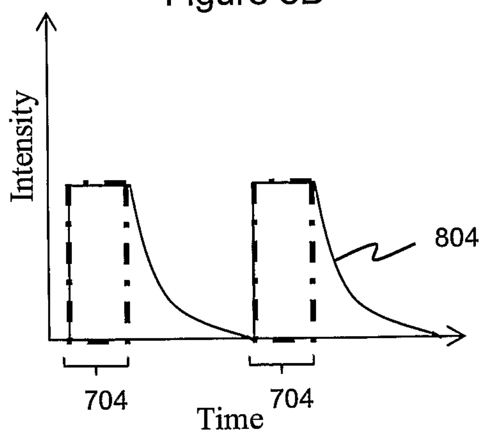

Figure 8C

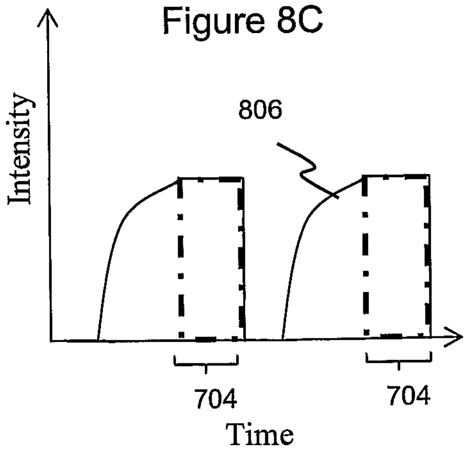

Figure 8D

INTERNATIONAL SEARCH REPORT

International application No
PCT/SG2009/000336

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N21/64 G01N21/49 G01N21/59
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, COMPENDEX, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 230 602 A (HAMAMATSU PHOTONICS KK [JP]) 24 October 1990 (1990-10-24) abstract figure 1 claim 1 -----	1-41
X	US 4 101 221 A (SCHUNCK GUNTER ET AL) 18 July 1978 (1978-07-18) abstract; claim 1 -----	1-41
X	EP 1 291 643 A1 (HAMAMATSU PHOTONICS KK [JP]) 12 March 2003 (2003-03-12) abstract figure 8 claims 1-3 -----	1-41

-/--

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 June 2010	15/06/2010

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Rasmusson, Marcus

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/SG2009/000336

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 760 477 A2 (HAMAMATSU PHOTONICS KK [JP]) 5 March 1997 (1997-03-05) claim 12 -----	1-41
X	US 5 173 749 A (TELL ROBERT [SE] ET AL) 22 December 1992 (1992-12-22) abstract column 2, line 61 - column 3, line 25 -----	1-41

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No
PCT/SG2009/000336

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			DE	68924163	T2	02-05-1996
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			EP	0423223	A1	24-04-1991
			JP	3505782	T	12-12-1991
			JP	3108420	B2	13-11-2000
			NO	910008	A	07-02-1991
			WO	9000732	A1	25-01-1990