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(54) **Title**: METHOD AND SYSTEM FOR NON-INVASIVE BLOOD GLUCOSE DETECTION UTILIZING SPECTRAL DATA OF ONE OR MORE COMPONENTS OTHER THAN GLUCOSE

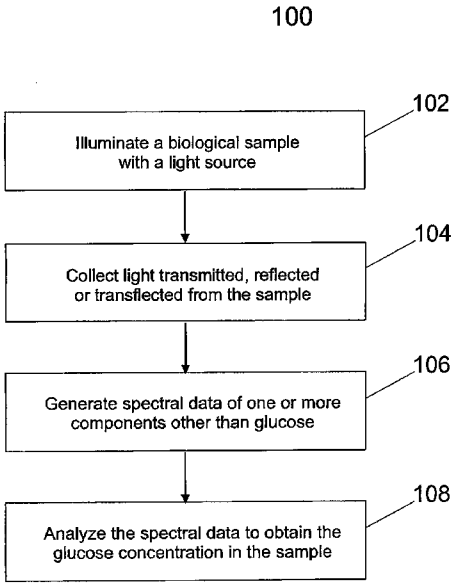

FIG.1

(57) **Abstract**: A method and system for detecting glucose in a biological sample is disclosed. This includes illuminating a biological sample with a light source, collecting transmitted, transflected or reflected light from the sample with a detector, generating spectral data of one or more components in the sample other than glucose in a spectral data analysis device, and analyzing the spectral data of the one or more components, sufficient to provide a glucose measurement from the spectral data of the one or more components other than glucose with the spectral data analysis device.

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METHOD AND SYSTEM FOR NON-INVASIVE BLOOD GLUCOSE DETECTION UTILIZING SPECTRAL DATA OF ONE OR MORE COMPONENTS OTHER THAN GLUCOSE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This patent application claims priority to U.S. Provisional Patent Application Serial Number 61/039,170 filed March 25, 2008, the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] Diabetes is a chronic disease that, when not controlled, over time leads to serious damage to many of the body's systems, including the nerves, blood vessels, eyes, kidneys and heart. The National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK) estimates that 23.6 million people or 7.8 percent of the population in the United States have diabetes in 2007. Globally, the World Health Organization (WHO) estimates that more than 180 million people have diabetes, a number they expect to increase to 366 million by 2030, with 30.3 million in the United States. According to the WHO, an estimated 1.1 million people died from diabetes in 2005. They project that diabetes deaths will increase by more than 50% between 2006 and 2015 overall and by more than 80% in upper-middle income countries.

[0003] The economic burden from diabetes for individuals and society as a whole is substantial. According to the American Diabetes Association, the total annual economic cost of diabetes was estimated to be $174 billion in the United States in 2007. This is an increase of $42 billion since 2002. This 32% increase means the dollar amount has risen over $8 billion more each year.

[0004] A vital element of diabetes management is the self-monitoring of blood glucose (SMBG) concentration by diabetics in the home environment. By testing blood glucose levels often, diabetics can better manage medication, diet and exercise to maintain control and prevent the long-term negative health outcomes. In fact, the Diabetes Control and Complications Trial (DCCT), which followed 1,441 diabetics for several years, showed that those following an intensive-control program with multiple blood sugar tests each day as compared with the standard-treatment group had only one-fourth as many people develop diabetic eye disease, one-half as many develop kidney disease, one-third as many develop nerve disease, and far fewer people who already had early forms of these three complications got worse.

[0005] However, current monitoring techniques discourage regular use due to the inconvenient and painful nature of drawing blood through the skin prior to analysis, which causes many diabetics to not be as diligent as they should be for good blood glucose control. As a result, non-invasive measurement of glucose concentration is a desirable and beneficial development for the management of diabetes. A non-invasive monitor will make testing multiple times each day pain-free and more palatable for children with diabetes. According to a study published in 2005 (J. Wagner, C. Malchoff, and G. Abbott, Diabetes Technology & Therapeutics, 7(4) 2005, 612 – 619), people with diabetes would perform SMBG more frequently and have improved quality of life with a non-invasive blood glucose monitoring device.

[0006] Currently, there remains a concentrated effort in academia and industry to develop reliable, affordable non-invasive blood glucose monitors. One technique of non-invasive blood chemicals detection involves collecting and analyzing light spectra data. Extracting information about blood characteristics such as glucose concentration from spectral or other data obtained from spectroscopy is a complex problem due to the presence of components (e.g., skin, fat, muscle, bone, interstitial fluid) other than blood in the area that is being sensed. Such other components can influence these signals in such a way as to alter the reading. In particular, the resulting signal may be much larger in magnitude than the portion of the signal that corresponds to blood and therefore limits the ability to accurately extract blood characteristics information.

[0007] The prevailing view is to correlate the change in optical absorption at certain wavelengths with blood glucose concentration, while ignoring the fact that similar changes in optical absorption could also be caused by other factors, such as physical exercise, medication, emotion, or a change in body chemistry, such as endocrine levels, etc. As such, good correlations obtained in well controlled laboratory conditions do not translate into successful, reliable market devices.

[0008] The present invention is directed to overcoming one or more of the problems set forth above.

SUMMARY OF INVENTION

[0009] Embodiments of the present invention relate to a method for detecting glucose in a biological sample. The method includes illuminating a biological sample with a light source, collecting transmitted, transflected or reflected light from the sample, generating spectral data of one or more components in the sample other than glucose and analyzing the spectral data

of the one or more components sufficient to provide a glucose concentration measurement from the spectral data of the one or more components other than glucose.

[0010] These are merely some of the innumerable aspects of the present invention and should not be deemed an all-inclusive listing of the innumerable aspects associated with the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] For a better understanding of the present invention, reference may be made to accompanying drawings, in which:

[0012] FIG. 1 illustrates a block flow diagram of a method for detecting glucose in a biological sample, according to some embodiments;

[0013] FIGS. 2A and 2B illustrate plots of a pulse wave corresponding to light absorption of arterial blood in a human finger, according to some embodiments;

[0014] FIG. 3 illustrates a graphical view of a water absorbance spectrum, according to some embodiments;

[0015] FIG. 4 illustrates a graphical view of an absorbance spectrum of a 1250 mg/dL glucose solution, according to some embodiments;

[0016] FIG. 5 illustrates a graphical view of an absorbance spectrum of a 2500 mg/dL glucose solution, according to some embodiments;

[0017] FIG. 6 illustrates a graphical view of differential water spectrum, according to some embodiments; and

[0018] FIG. 7 illustrates a system for detecting glucose in a biological sample, according to some embodiments.

DETAILED DESCRIPTION OF THE INVENTION

[0019] In the following detailed description, numerous exemplary specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those skilled in the art that the present invention may be practiced without these specific details, or with various modifications of the details. In other instances, well known methods, procedures, and components have not been described in detail so as not to obscure the present invention.

[0020] Embodiments of the invention relate to a method for non-invasive blood glucose detection. Glucose has extremely weak optical absorption in the visible (Vis) and near infrared (NIR) regions from about 400 nm to about 2500 nm. It is very difficult to accurately

determine the concentration of glucose in a biological sample by determining the portion of optical absorption generated by glucose in the biological sample, because the portion of optical absorption by other components is typically several orders of magnitude larger than that directly by glucose in the two wavelength regions. But, glucose can induce changes in the optical absorption of other components in the sample, such as hemoglobin or water. These changes in optical absorption of components other than glucose can be used to indirectly determine the concentration of glucose in a biological sample.

[0021] Referring to FIG. 1, a block flow diagram of a method for detecting glucose in a biological sample is shown, according to some embodiments and is generally indicated by numeral 100. In the description of the flowcharts, the functional explanation marked with numerals in angle brackets <nnn>, will refer to the flowchart blocks bearing that numeral. A biological sample may be illuminated with a light source <102>. Transmitted, transflected or reflected light may then be collected from the sample <104>. Spectral data of one or more components in the sample other than glucose may be generated <106>. The spectral data of the one or more components may be analyzed, sufficient to provide a glucose concentration measurement from the spectral data of the one or more components other than glucose <108>.

[0022] Illuminating <102> may refer to exposing the biological sample to a light source in the visible (Vis), near infrared (NIR) or mid-infrared spectral regions. The wavelength range for illumination <102> may occur between about 400 nm and about 10,000 nm, for example. The illuminating <102> may occur between about 400 nm and about 2500 nm or about 400 nm and about 1000 nm, for example. The light source may be lasers, light emitting diodes (LED), incandescent lamps, halogen lamps or a combination thereof, for example. The light source may be a plurality of lasers. Prior to or after illumination of the sample <102>, a reference sample may be illuminated for calibration.

[0023] The biological sample may be any portion of the human body that contains glucose or has the potential to contain glucose. The biological sample may be a human finger, toe, ear lobe, tongue or arm, for example.

[0024] After illumination <102>, transmitted, transflected or reflected light may then be collected from the sample <104>. The light may be collected by one or more detectors or light-sensing devices. An array of photodiodes may be utilized, for example.

[0025] Spectral data of one or more components in the sample other than glucose may be generated <106>. The detector may generate a corresponding current signal that is proportional to the power of the light received by the detector. The current signal generated

by the detector can be converted to another form of signal, such as an analog voltage signal or a digital signal. Such signals may be converted to spectral or absorbance data using known processors and algorithms.

[0026] The spectral data of the one or more components may be analyzed <108>, sufficient to provide a glucose concentration measurement from the spectral data of the one or more components other than glucose.

[0027] Spectroscopic data generation <106> and analysis <108> may be carried out using a pulsatile or a stationary methodology.

[0028] A pulsatile data generation and analysis methodology has been described in presently owned U.S. Patent Application Serial No. 12/245,298, filed October 3, 2008, which is incoporated herein by reference and U.S. Patent Application Serial No. 12/209,807, filed September 12, 2008, which is incoporated herein by reference. When light is transmitted through a biological sample, such as a human finger, the light is absorbed and scattered by various components of the finger including muscle, bone, fat and blood. It has been observed, however, that light absorption by a human finger exhibits a small cyclic pattern that corresponds to a heartbeat.

[0029] FIG. 2A depicts a plot 202 of a pulse wave that corresponds to the light absorption of arterial blood in the capillary due to the heartbeat of the user. Although the magnitude of the cyclic pattern is small in comparison to the total photocurrent generated by the detector, considerable information can be extracted from the cyclic pattern of the plot 202. For example, assuming that the person's heart rate is sixty beats per minute, the time between the start of any pulse beat and the end of that pulse beat is one second. During this one-second period, the plot will have a maximum or peak 204 reading and minimum or valley 206 reading. The peak 204 reading of the plot corresponds to when there is a minimum amount of blood in the capillaries, and the valley 206 reading corresponds to when there is a maximum amount of blood in the capillaries. By using optical information provided by the peak and valley of the cyclic plot, the major constituents that are in the body that are not in the capillaries, such as fat, muscle (i.e., protein) and interstitial fluid, are excluded. These major constituents that are not in the capillaries are excluded because they are not likely to change during the one-second interval. In other words, the light that is impeded by the blood can be detected based on the peaks and valleys of the plot 202. FIG. 2A illustrates the cyclic pattern on a magnified scale. FIG. 2B depicts a more accurate reflection of the cyclic pattern in terms of signal amplitude.

[0030] In a stationary data acquisition and analysis methodology, the light absorption is

averaged over a period of time to remove the fluctuation in light absorption due to the heart beat. The glucose concentration can be extracted from the averaged light absorption at different wavelengths over the same period of data acquisition time.

[0031] Referring again to FIG. 1, analyzing <108> may also include mathematically comparing the changes in absorbance of the one or more components to changes in glucose concentration. Analyzing <108> may include eliminating spectral data of the one or more components for changes in absorbance not related to interactions with glucose.

[0032] Because glucose in the biological sample has such a weak optical signal in the Vis and NIR spectral range, the methods of the present invention do not attempt to analyze the glucose signal. Glucose does physically or chemically interact with one or more components in the blood and induce changes in the optical signal of these components as a function of glucose concentration. By analyzing the changes in the one or more components, the concentration of glucose in the sample may be determined.

EXAMPLE

[0033] FIG. 3 shows the NIR spectrum of water between 850 nm to 1100 nm. A strong positive peak is seen between about 920 nm and 1070 nm. The spectrum was taken with a Perkin-Elmer™ Lambda-14™ Double Beam UV-Vis-NIR (190 nm to 1100 nm) spectrometer. The scanning speed was 30 nm/min, the spectrum resolution was 4 nm, and one data point was collected per nm. The reference was the air and the sample was HPLC grade water in a quartz cuvette with 1 cm light path. The baseline absorbance of the spectrum, about 0.05, is due to reflections from two air/quartz interfaces and two water/quartz interfaces.

[0034] FIG. 4 shows the absorbance spectrum of a 1250 mg/dL solution of alfa-D(+)-glucose in HPLC grade water, and FIG. 5 shows the absorbance spectrum a 2500 mg/dL solution of alfa-D(+)-glucose in HPLC grade water. The two spectra were taken under the same condition as the water spectrum in FIG. 3, except that the quartz cuvette containing HPLC grade water was used as the reference. To minimize the effect of temperature on water absorption, the two glucose solutions and HPLC grade water were equilibrated in the sample chamber of the spectrometer for four hours before the measurements.

[0035] Both FIG. 4 and FIG. 5 show a large negative peak at about 960 nm, about -0.0018 for the 1250 mg/dL glucose solution and about -0.0030 for the 2500 mg/dL glucose solution. This negative peak is not caused by the optical absorption of glucose in this region. Instead, it is a result of change in water absorption due to the presence of glucose. This is supported by

the simulated differential water spectrum in FIG. 6. The simulated differential water spectrum was obtained by manually red shifting 1 nm of all data points in the water spectrum of FIG. 3, then subtracting the original water spectrum from the red shifted spectrum. FIG. 6 shows a negative peak centered at 960 nm with a very similar peak shape as those of FIG. 4 and FIG. 5.

[0036] FIG. 7 shows an exemplary system for conducting an embodiment of the present invention that is generally indicated by numeral 700. The system of FIG. 7 comprises a light source 701, biological sample 703, detector 705, and spectral data analysis device 707. A light source 701 may be lasers, light emitting diodes (LED), incandescent lamps, halogen lamps or a combination thereof, for example. The light source may be a plurality of lasers. A biological sample 703 may be a human finger, toe, ear lobe, tongue or arm. A detector 705 may be any of a wide variety of light detectors with an illustrative, but nonlimiting, example being an array of photodiodes. Spectral data analysis device 707 may be any device capable of analyzing spectral data as described herein. An illustrative, but nonlimiting, example of a spectral data analysis device 707 may include an SR760™ from Stanford Research Systems, which is a single-channel 100 kHz FFT spectrum analyzers with a dynamic range of 90 dB and a real-time bandwidth of 100 kHz.

[0037] Thus, there has been shown and described several embodiments of a novel invention. As is evident from the foregoing description, certain aspects of the present invention are not limited by the particular details of the examples illustrated herein, and it is therefore contemplated that other modifications and applications, or equivalents thereof, will occur to those skilled in the art. The terms "have," "having," "includes" and "including" and similar terms as used in the foregoing specification are used in the sense of "optional" or "may include" and not as "required." Many changes, modifications, variations and other uses and applications of the present construction will, however, become apparent to those skilled in the art after considering the specification and the accompanying drawings. All such changes, modifications, variations and other uses and applications which do not depart from the spirit and scope of the invention are deemed to be covered by the invention which is limited only by the claims that follow.

CLAIMS

1. A method for detecting glucose in a biological sample, comprising:

illuminating a biological sample with a light source;

collecting transmitted, transflected or reflected light from the sample with a detector;

generating spectral data of one or more components in the sample other than glucose in a spectral data analysis device; and

analyzing the spectral data of the one or more components, sufficient to provide a glucose measurement from the spectral data of the one or more components other than glucose with the spectral data analysis device.

2. The method of claim 1, further comprising before or after illuminating, calibrating a light source to a reference sample.

3. The method of claim 1, wherein the light source comprises lasers, light emitting diodes, halogen lamps, incandescent lamps or a combination thereof.

4. The method of claim 1, wherein illuminating comprises exposing the biological sample to a light source in at least one of the near infrared, mid-infrared and visible light regions.

5. The method of claim 1, wherein illuminating comprises exposing the biological sample to a light source in the range of about 400 nm to about 2500 nm.

6. The method of claim 1, wherein collecting comprises collecting transmitted, transflected or reflected light with one or more detectors.

7. The method of claim 1, wherein analyzing spectral data comprises performing a pulsation analysis on the spectral data.

8. The method of claim 1, wherein analyzing spectral data comprises performing a stationary analysis on the spectral data.

9. The method of claim 1, wherein analyzing comprises mathematically comparing the changes in absorbance of the one or more components to changes in glucose concentration.

10. The method of claim 1, wherein analyzing comprises eliminating spectral data of the one or more components for changes in absorbance not related to interactions with glucose.

11. The method of claim 1, wherein the biological sample comprises a portion of at least one of a human finger, toe, ear lobe, tongue and arm.

12. A system for detecting glucose in a biological sample, comprising:

a biological sample comprising a plurality of components, the components comprising glucose and at least one component other than glucose;

a light source configured to illuminate the biological sample;

a detector configured to collect transmitted, transflected or reflected light from the sample; and

a spectral data analysis device configured to (1) generate spectral data of one or more components in the sample other than glucose, and (2) analyze the spectral data, sufficient to provide a glucose measurement from the spectral data of the one or more components other than glucose.

13. The system of claim 12, wherein the light source comprises lasers, light emitting diodes, halogen lamps, incandescent lamps or a combination thereof.

14. The system of claim 12, wherein the light source is configured to emit light in at least one of the near infrared, mid-infrared and visible light regions.

15. The system of claim 12, wherein the light source is configured to emit light having a wavelength in the range of about 400 nm to about 2500 nm.

16. The system of claim 12, wherein the detector is configured to collect transmitted, transflected or reflected light.

17. The system of claim 12, wherein the spectral data analysis device is configured to perform a pulsation analysis on the spectral data.

18. The system of claim 12, wherein the spectral data analysis device is configured to perform a stationary analysis on the spectral data.

19. The system of claim 12, wherein the spectral data analysis device is configured to mathematically compare the changes in absorbance of the one or more components to changes in glucose concentration.

20. The system of claim 12, wherein the spectral data analysis device is configured to eliminate portions of the spectral data that are attributable to changes in absorbance not related to interactions with glucose.

21. The system of claim 12, wherein the biological sample comprises a portion of at least one of a human finger, toe, ear lobe, tongue and arm.

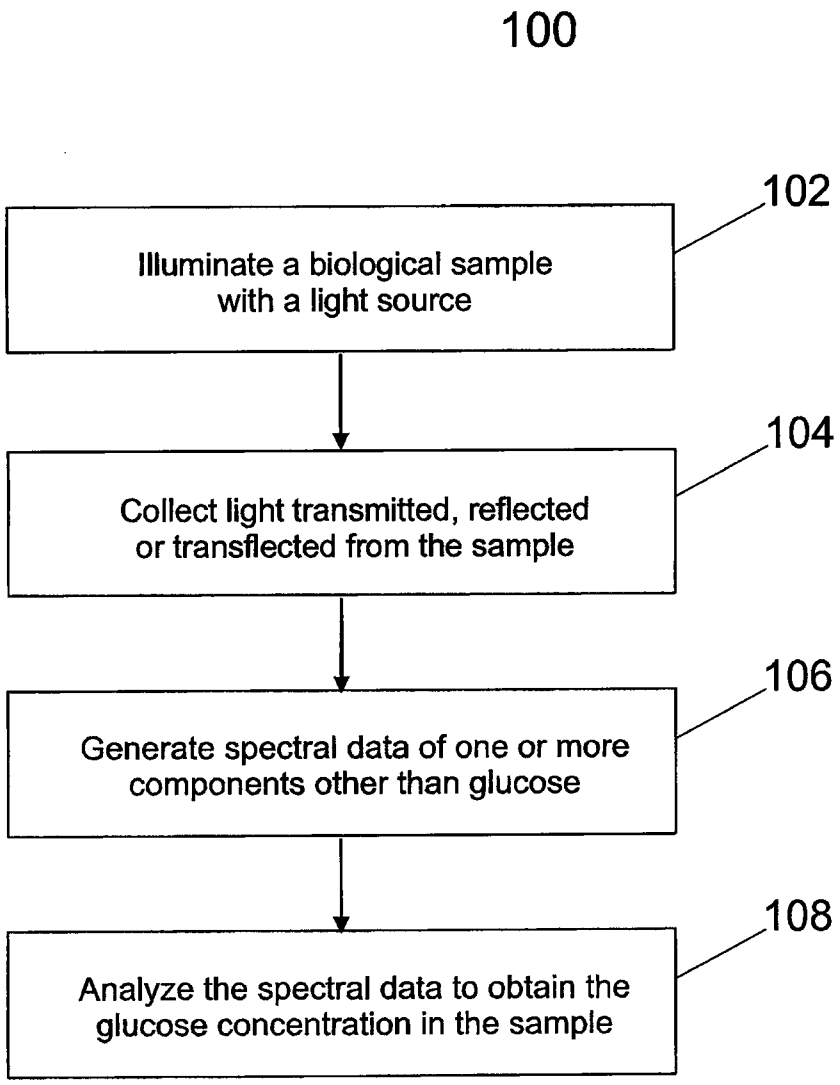

100
102
Illuminate a biological sample with a light source
104
Collect light transmitted, reflected or transflected from the sample
106
Generate spectral data of one or more components other than glucose
108
Analyze the spectral data to obtain the glucose concentration in the sample

FIG.1

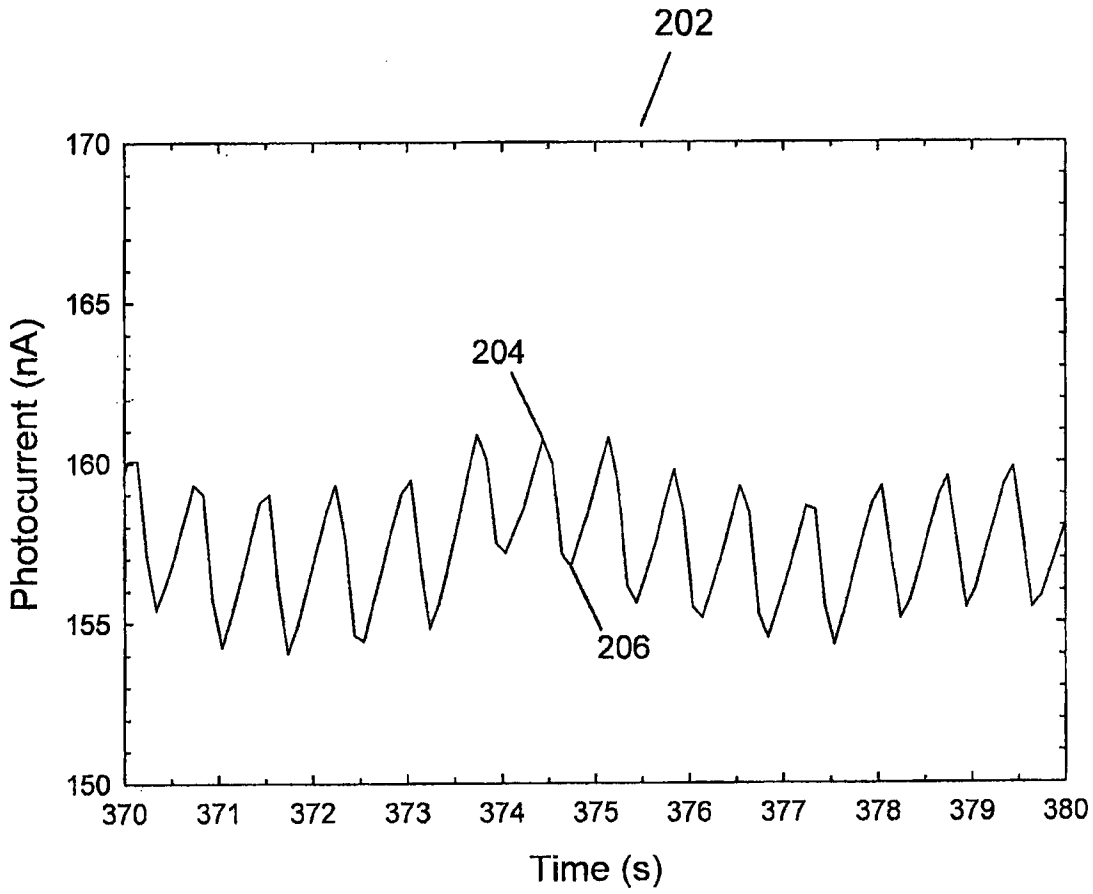
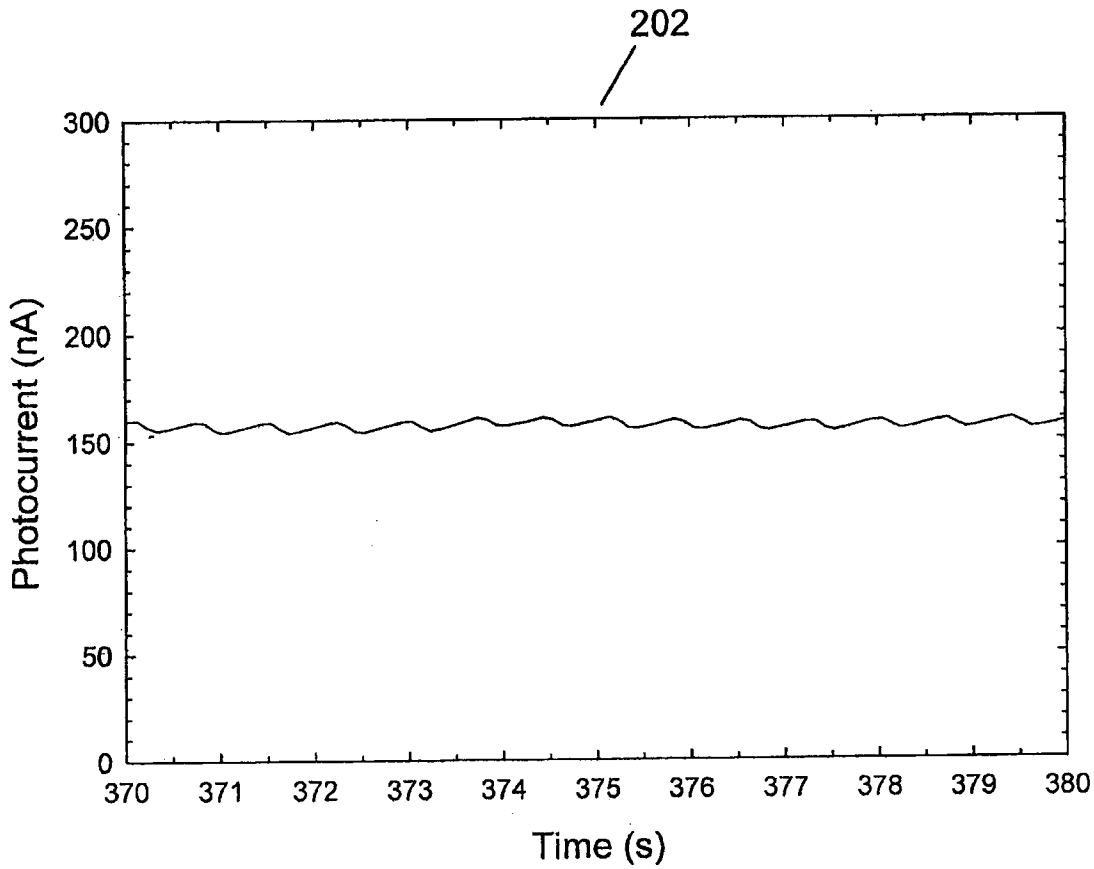

202
204
206
Photocurrent (nA)
170
165
160
155
150
370
371
372
373
374
375
376
377
378
379
380
Time (s)

FIG. 2A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300
250
200
150
100
50
0
Photocurrent (nA)
370
371
372
373
374
375
376
377
378
379
380
Time (s)

FIG. 2B

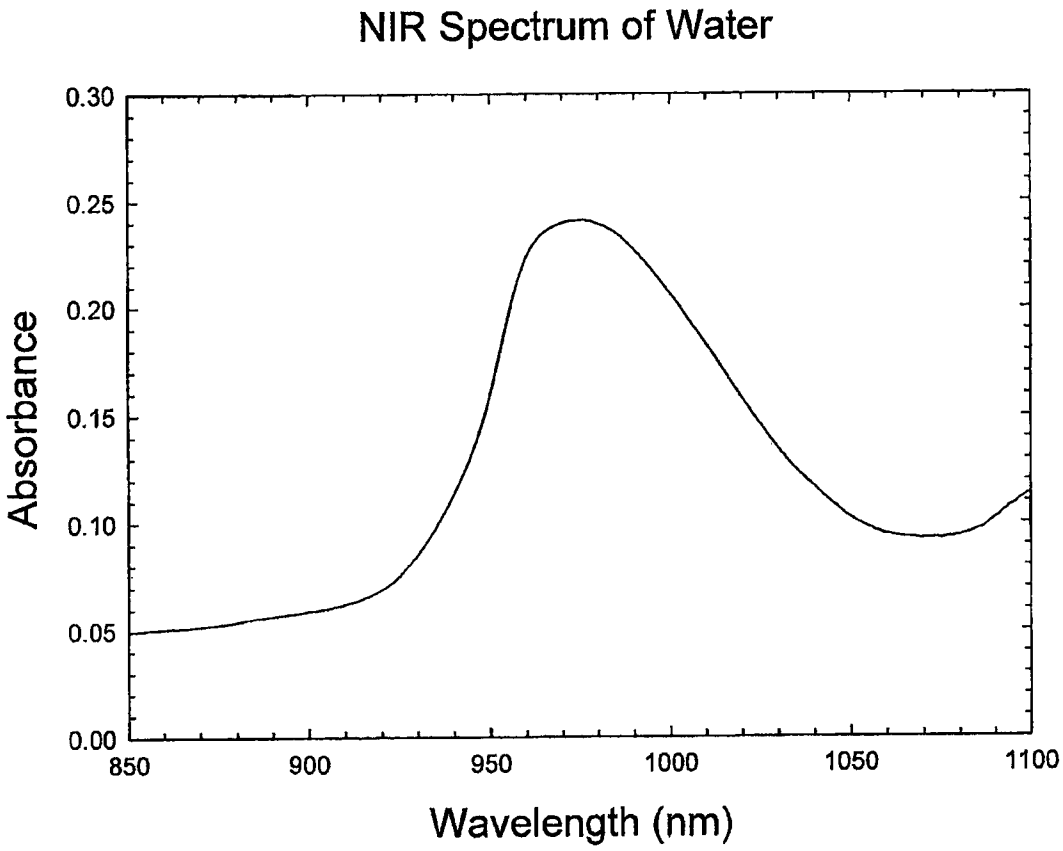
NIR Spectrum of Water
Absorbance
0.30
0.25
0.20
0.15
0.10
0.05
0.00
850
900
950
1000
1050
1100
Wavelength (nm)

FIG. 3

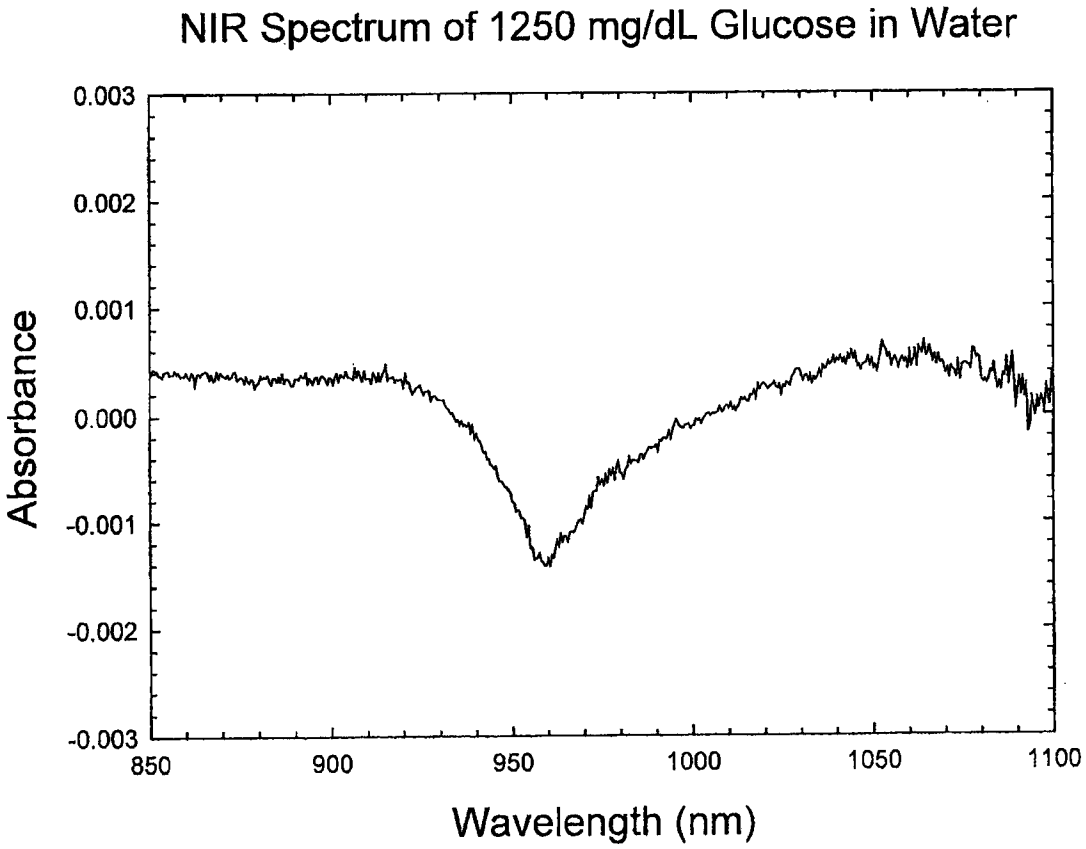
NIR Spectrum of 1250 mg/dL Glucose in Water
Absorbance
0.003
0.002
0.001
0.000
-0.001
-0.002
-0.003
850
900
950
1000
1050
1100
Wavelength (nm)

FIG. 4

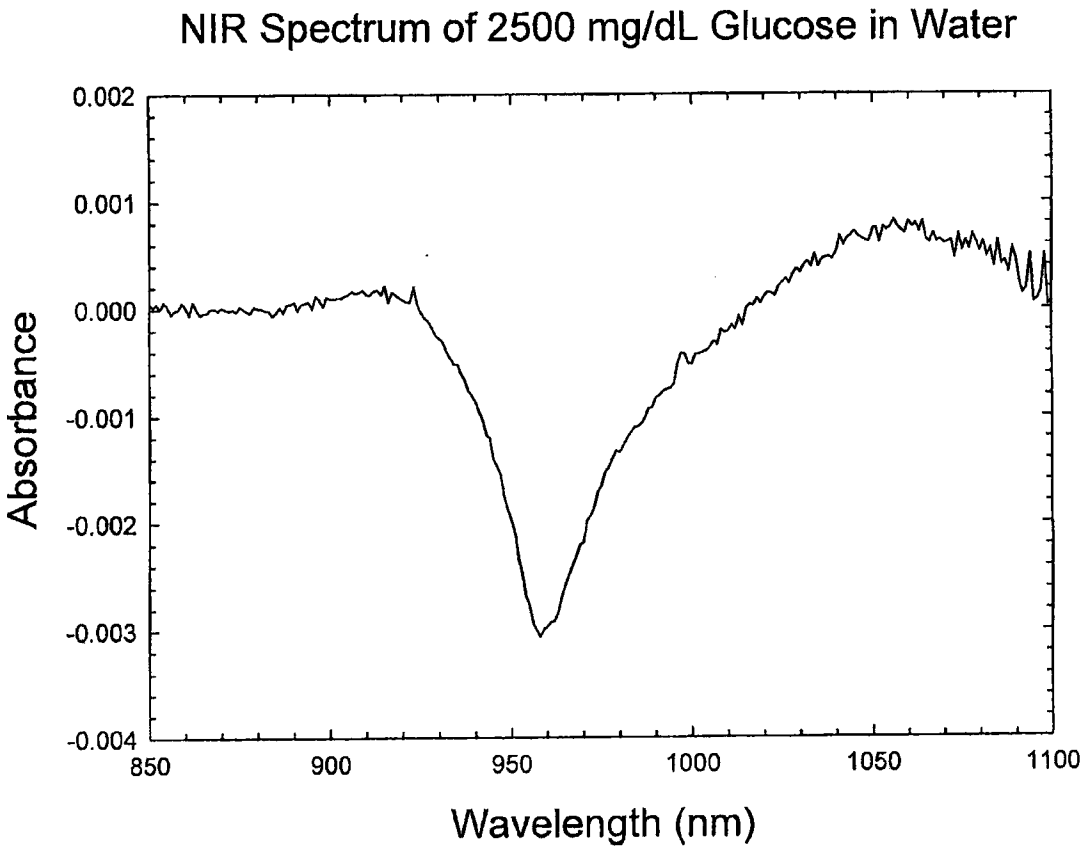
NIR Spectrum of 2500 mg/dL Glucose in Water
Absorbance
0.002
0.001
0.000
-0.001
-0.002
-0.003
-0.004
850
900
950
1000
1050
1100
Wavelength (nm)

FIG. 5

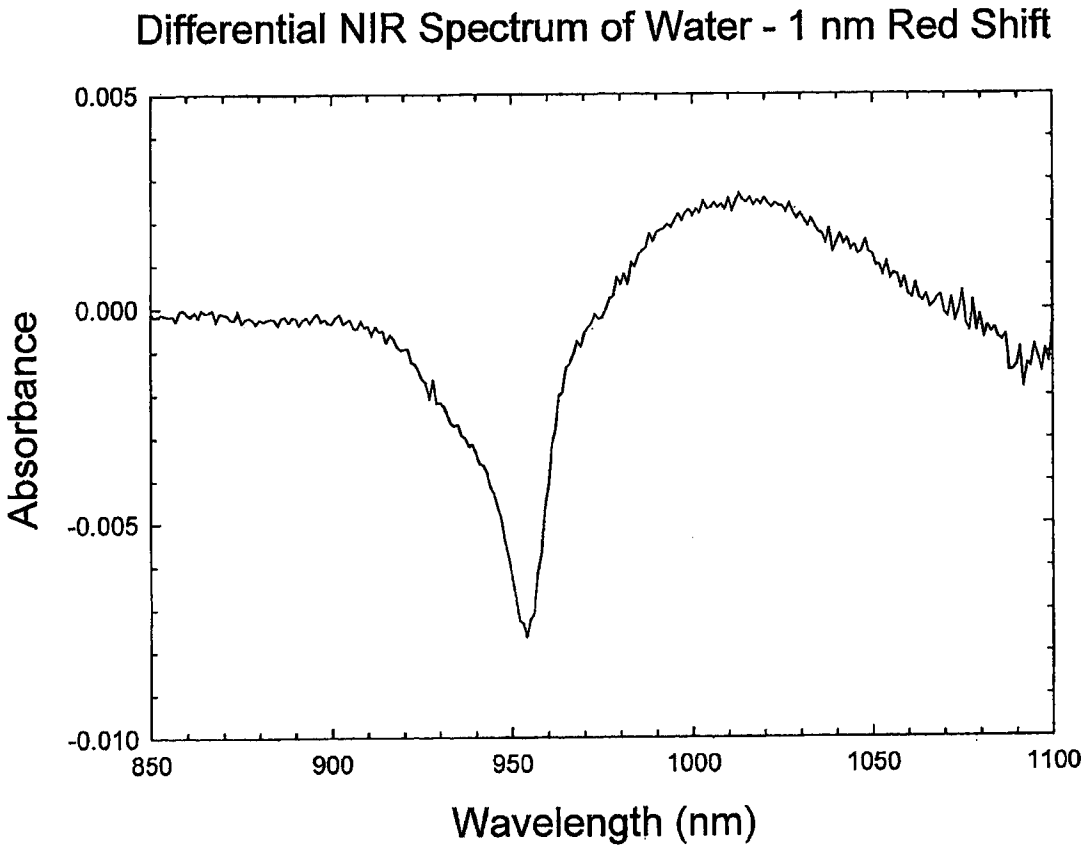
Differential NIR Spectrum of Water - 1 nm Red Shift
0.005
0.000
-0.005
-0.010
Absorbance
850
900
950
1000
1050
1100
Wavelength (nm)

FIG. 6

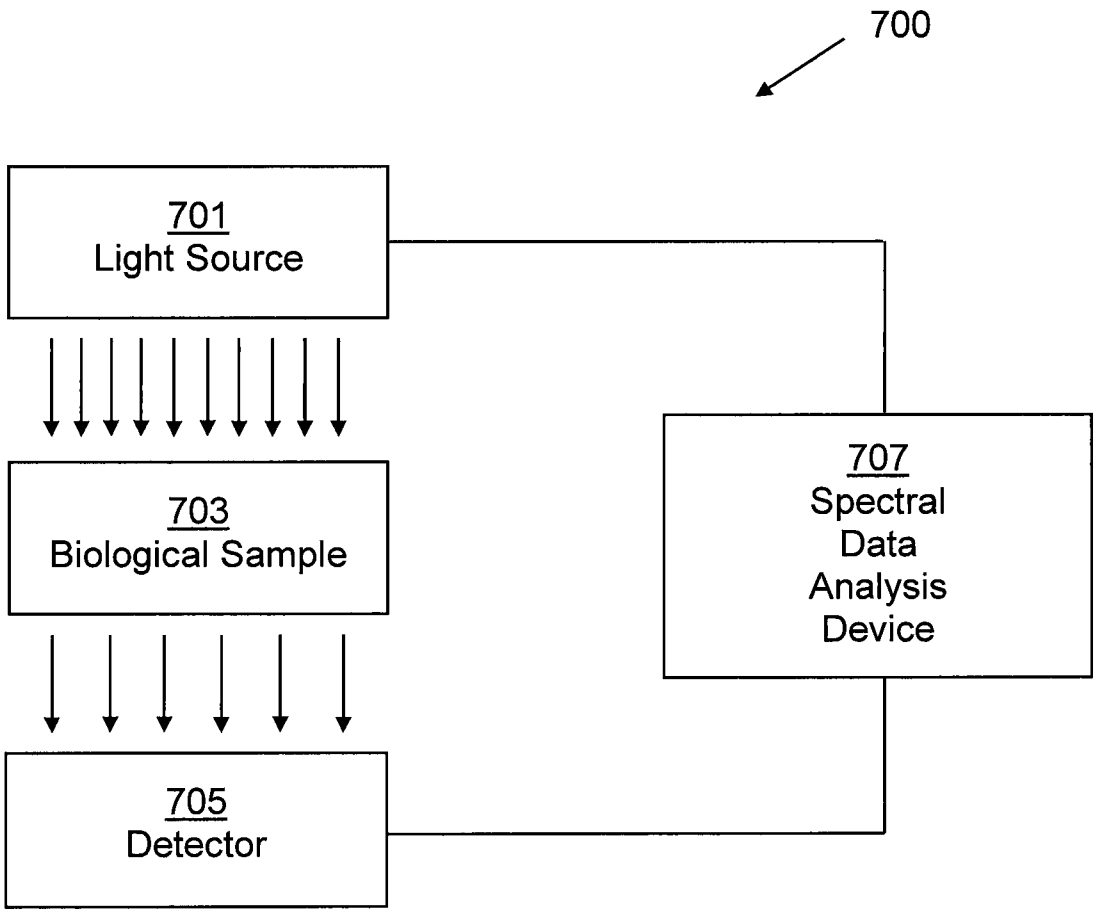
700
701
Light Source
703
Biological Sample
705
Detector
707
Spectral
Data
Analysis
Device

FIG. 7