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Double Lock-in Amplifier Faraday Rotation Glucometer

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Abstract

We previously proposed a new approach to optical glucose sensing using Faraday rotation in glucose solutions which we called the MORE effect "magnetic optical rotatory effect". Here we introduce an improved light detection method using a double lock-in amplifier technique [1,2]. We present experimental data to confirm the concept of using a double lock-in amplifier technique to improve SNR by separating a small, narrow band signal from interfering noise. Preliminary results show excellent SNR with input laser intensity at 300 Micro Watts, suggesting that safety standards for short duration laser exposure in the eye can be met.

Introduction

Gillham [3,4] introduced the first precision optical polarimeter using the Faraday effect in 1957. Cote, Northrop, and Fox [5,6] proposed a true phase optical glucose sensor to monitor glucose concentration. Jang and Fox [7,8] demonstrated that a closed loop polarimeter using a single Faraday rotator in 1997 and also introduced a concept using double lock-in technique to optical glucose sensing [2]. Fox and Censor [9] described reflections in different mediums and their effect on the conventional optical rotation effect.

The studies proposed here to confirm the double lock-in technique concept by measuring actual data from the optical glucose sensor shown in Fig.1. Since the lock-in amplifier acts as a detector and narrow band filter combined, this approach has potential advantages in eliminating uncorrelated noise to improve SNR when the frequency and phase of the desired signal are known.

Methods

The Magnetic Optical Rotatory Effect [MORE] was introduced indicating that when MORE is set up in a glucose solution there is a rotation of the polarization vector of the incident light that is proportional to the path length, magnetic field strength, and the concentration of glucose in the MORE cell. The rotation following reflection from a dielectric interface at near normal incidence is enhanced (rather than cancelled as is the case in conventional optical activity). The reason is that the direction of rotation is dependent on the **B** vector representing the magnetic field and this **B** vector remains the same following reflection from the mirror unlike **k** vector (wave propagation vector) that reverses following reflection[1].

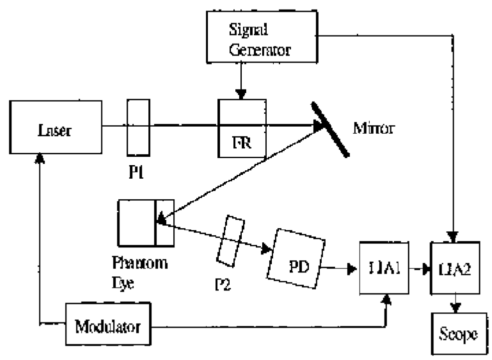

Fig.1. Schematic block diagram of an optical glucose sensor using the double lock-in concept and measuring Vdc output from the 2nd lock-in amplifier with a phantom eye as a calibration of the open loop system.: P1 & P2 are polarizers; FR is a Faraday rotator; PD is the photo-diode; LIA is lock-in amplifier.

The main components of an optical glucose sensor are shown in Fig.2. A diode laser (approx. 0.8 mW effective output after first polarizer, λ=630-680 nm) modulated by a signal generator at about 2 kHz and polarizer are used to provide linearly polarized light. The light was then passed through a Faraday rotator driven by a signal generator at about 120 Hz also used as an input reference signal to 2nd lock-in amplifier. The magnitude of rotation due to the signal generator was linearly proportional to Vrms of the input from the generator.

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The lock-in amplifier provided an output signal which was a dc voltage proportional to the amplitude of the 2 kHz present in the detected signal from the photo-diode. This dc output voltage with 120 Hz ac component due to the Faraday rotator was then applied as an input signal to 2nd lock-in amplifier. The 1st and 2nd lock-in amplifiers provided phase and frequency locked detection of the 2 kHz and 120 Hz components, which themselves were proportional to the net rotation between the two polarizers disposed at 45° to each other. The experimental data were taken by reading the dc output voltage through the oscilloscope shown in Fig.1 while changing the input signal to the Faraday thus changing the input polarization angle at the frequency input to the rotator.

Results

The optical glucose sensor illustrated in Fig.1 was calibrated by taking output from 2nd lock-in while varying the angle of P2. The results are shown in Fig.2. The results shown in Fig.3 indicate that the dc output voltage from the 2nd lock-in amplifier was linearly proportional to the input signal to the Faraday rotator. According to the data in Fig.3, even if intensity of laser light was reduced up to 0.3mW, the dc output voltage from the 2nd lock-in amplifier was still linearly proportional to the input with good SNR. The output slopes for 0.8mW and 0.3mW were 82.94 and 20.64 (mV/Vrms) respectively.

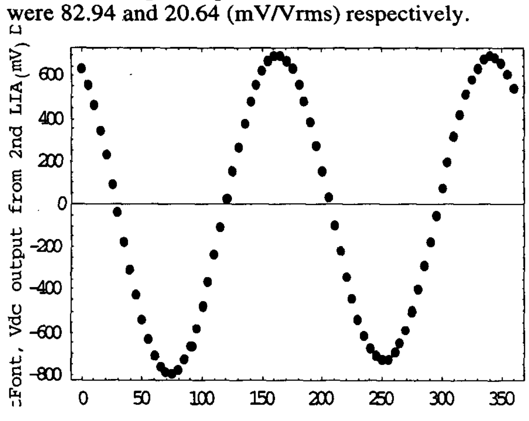

Fig.2. Vdc(mV) output from 2nd lock-in amplifier corresponding on the rotation of the 2nd polarizer shown in Fig.1.

Discussion

We have presented the experimental results in the optical glucose sensor using a double lock-in amplifier technique. The data confirmed our basic concept that the dual lock in approach would improve SNR. Our future work will be directed toward the experimental demonstration on using animal eyes with the system shown in Fig.1 by replacing the phantom eye with an *Ex Vivo* goat's eye. Preliminary results indicate that the lock-in amplifier approach can detect polarization rotation following reflection from the lens/aqueous interface in the goat eye.

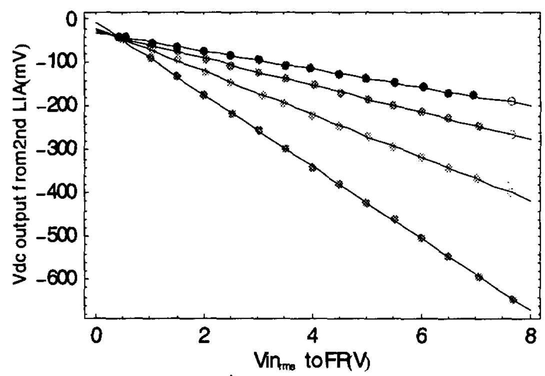

Fig.3. Vdc output from 2nd lock-in amplifier depends on Vac input of the Faraday rotator and intensity of the laser light. Several different intensities (0.3mW, 0.45mW, 0.57mW, and 0.8mW from the top) of laser light have been applied in this study due to the safety concern for the future application with human eye.

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