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Sensory Elements and Devices Operational Diagnostic Blood Glucose Using Near Infrared Radiation

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The article describes a method for measuring the concentration of glucose in human blood by non-invasive method using near-infrared optical technology. In medical practice, glucose concentration in the blood in most cases is measured by invasive methods involving the collection of blood from the finger or vein, while non-invasive devices for determining the level of glucose preserve the operational measurement of blood-borne levels. Invasive methods are expensive and painful. Frequent piercing of fingers causes corns on the skin, and also increases the risk of spreading infectious diseases. Thus, the development of a system of non-invasive measurement of glucose in the blood will be useful for patients with diabetes mellitus. Non-invasive way of measuring glucose levels in human blood is based on the use of pain-free optical technology based on near-infrared (NIR) radiation. The proposed system consists of emitters of signals with a wavelength of 940 nm. These optical signals are sent through the earlobe, and the rays passing through it are fixed by a phototransistor located on another part of the device. The concentration of glucose in the blood is determined by analyzing the intensity variation obtained after passing the signal. The results obtained from the developed system show the feasibility of using a non-invasive NIR method for monitoring blood glucose levels. The accuracy of the measurements of the proposed system can be improved by integrating its sensitive and emitting elements based on the SOI of the CMOS structures.

Keywords: blood glucose, diabetes, near-infrared, noninvasive method SOI CMOS-structure.

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Introduction

Diabetes - a type of metabolic disease in which blood glucose (blood sugar) in the body increases significantly or is less than the normal level. Increased blood sugar is due to inadequate production of insulin in the blood cells, or it may be due to inadequate response of body cells to insulin. Diabetes can lead to serious complications, for example, - heart failure and blindness in humans [2]. Therefore, regular monitoring of blood glucose is an urgent problem.

Effective treatment of diabetes patients have to periodically measure the level of glucose in the blood 3-5 times a day, or gain insights throughout the day. Currently, people with diabetes are using an invasive tool for individual measurements - portable glucometers.

Non-invasive glucose monitoring methods reduce glucose-related complications and, therefore, reduce the cost of health care. Noninvasive glucose measurement method as infrared spectroscopy is spreading over the years, but there are still problems with the accuracy of such devices.

In near infrared spectroscopy [3], the cells will produce glucose weakest signals absorption in humans, since glucose is one of the biological components present within the human body. When measuring glucose NIR spectroscopy enables signals to penetrate into the tissue to a depth ranging from 1 to 100 millimeters. The depth of penetration decreases as the value of the wavelength of the signal is increased by [4, 5].

I. The principle of non-invasive measurement of blood glucose

When the light beam interacts with the tissues of the human body, it is weakened by scattering, as well as absorption by tissues. Because of the discrepancy between the refractive index of the extracellular fluid and the cell membrane in tissues, light scattering occurs. The extracellular fluid refractive index depends on the concentration of glucose, whereas the cell membrane index is considered to be relatively constant [6]. The Bouguer-Lambert-Ber (equation 1) law plays an

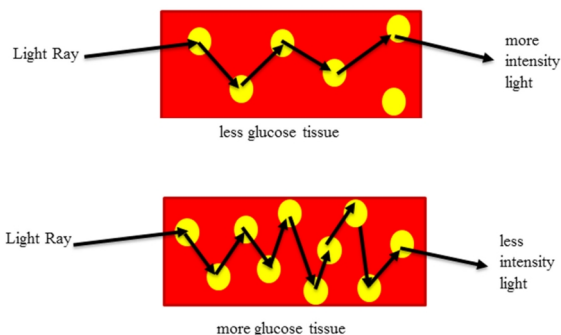


Fig. 1. The model of interaction of near infrared radiation with molecules of glucose.

important role in measuring absorption, which states that the absorption of light through any solution is proportional to the concentration of the solution and the length of the path traversed by the light beam [7].

In Fig. 1 schematically shows the effect of glucose molecules in the light path [3-5]. Fewer glucose results in less scattering, shorter path and hence less absorption, while more tissue glucose leads to greater dispersion of greater length optical path and hence greater tissue uptake.

Due to the higher absorption of high concentrations of glucose is less reflected light intensity compared to tissues with lower glucose and is defined by (1).

$$I = I_0 e^{-kcd} \tag{1}$$

I_0 - where the intensity of light passed, I - the incident light intensity, d - optical path length inside the tissue, c - glucose ratio, which depends on the amount of glucose in the tanning environment. After mathematical transformation of equation 1, we obtain an expression for determining the concentration of glucose:

$$c = \frac{\ln(I) - \ln(I_0)}{-kd} \tag{2}$$

After replacing $\alpha = kd$, where α - factor of a person, which will be individually calculated and programmed, the debugging device of non-invasive measurement of blood glucose. Then equation 2 becomes:

$$c = \frac{\ln(I) - \ln(I_0)}{-\alpha} \tag{3}$$

Thus, based on equations (3), the concentration of glucose in the blood depends on the intensity of the incident radiation and traversed, not including individual rate, which is calculated only once and then used as a constant.

II. Justification of the choice of wavelength emitting LED

The light in the range of 700 nm to 2500 nm enters the region near infrared radiation interacts with tissue with low energy radiation. From 600 nm to 1300 nm is seen as near-infrared window [8], which is also known as therapeutic or optical window. The range of wavelengths where the light has a maximum depth of penetration into the tissue, called "IR window".

Glucose has peaks of light absorption at wavelengths

940 nm, 970 nm, 1197 nm, 1408 nm, 1536 nm, 1688 nm, 1925 nm, 2100 nm, 2261 nm and 2326 nm [1], but at a wavelength of 940 nm weakening optical signals other blood components such as water, platelets, red blood cells and etc. Where is the minimum [6], therefore, at a wavelength of 940 nm can be achieved the desired depth of penetration, and can predict and determine the actual concentration of glucose.

The most optimally non-invasive measurement of blood glucose levels is made using a personal ear clip consisting of two elements: an emitting LED and a phototransistor, radiation peaks and absorption peaks that are compatible with the peak glucose uptake of 940 nm. During the study four pairs of sensitive elements were created, which in turn gave different thresholds of sensitivity. LEDs were the same everywhere - TSAL6100, and the best sensitive characteristics were obtained with a phototransistor - VEMD2000X01. Curves of wavelengths of absorption and radiation are showed in Fig. 2

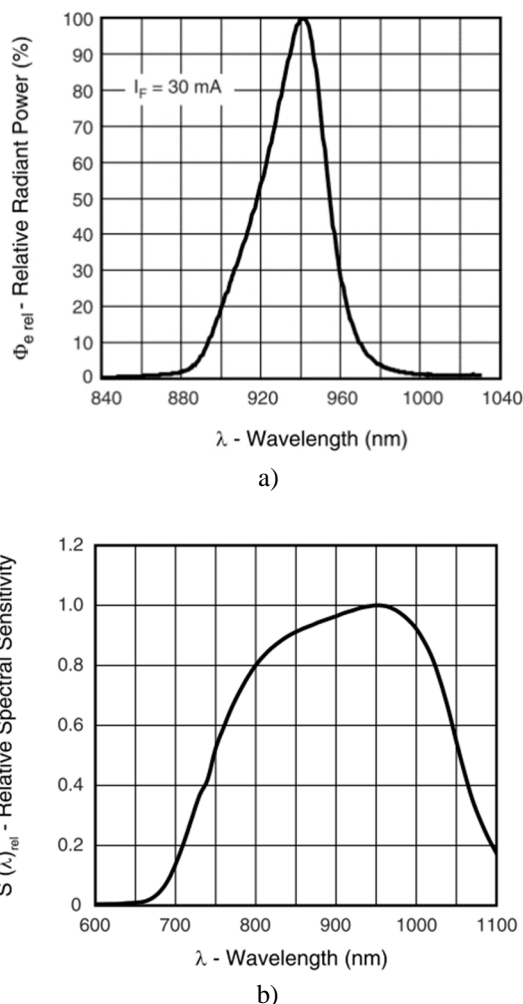


Fig. 2. Spectral radiation power a) and relative spectral sensitivity b) LED and phototransistor, respectively.

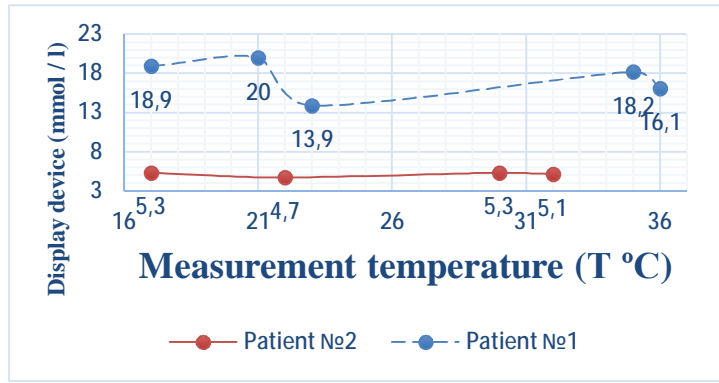


Fig. 3. Temperature of passage of electrochemical reactions.

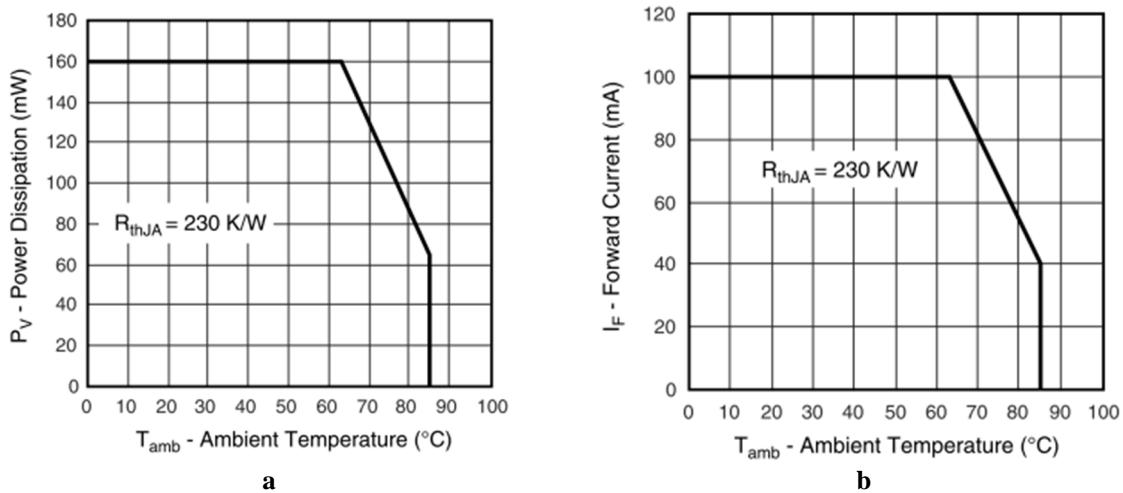


Fig. 4. Temperature Characteristics of the LED.

III. Impact assessment of temperature on the measurement accuracy of blood glucose

Temperature dependence is one of the parameters that significantly affect the measurement accuracy, because one of the requirements for the measurement is the stability display device in a certain temperature range, or the measurement of stable temperature.

Conducting measurement with non-invasive personal ear clipping eliminates measurements at different temperatures, since measurements are made directly on a person's body with a relatively stable temperature that remains constant over a long period of time. Also, when measuring with a personal ear clip, due to heat transfer, the temperature of the device is set the same as the temperature of the ear lobe, and the methods that are advantageous, compared with the invasive. To assess the effect of temperature on the accuracy of measurements using a portable invasive device measuring blood glucose levels in Bionime RightTest GM-110, a series of measurements was carried out at different temperatures. The results of measurements are given in Table 1.

The dependence of the indications of portable invasive devices for measuring blood glucose levels from

Table 1
Dependence of invasive glucose readings on ambient temperature

Patient	Finger	Measurement temperature (T °C)	Display device (mmol / l)
Patient № 1	annulary	23	13,9
		36	16,1
		17	18,9
	middle finger	21	20,0
		35	18,2
Patient № 2	annulary	22	4,7
		32	5,1
		30	5,3
		17	5,3

the instrument temperature, and, accordingly, the temperature of the passage of electrochemical reactions, is shown in Fig.3. As personal ear clip comprises emitting diode and phototransistor at a certain wavelength and its temperature dependence can be equated to the temperature dependence of the elements that make up its membership.

The dependence of these elements on the temperature is shown in Fig 4 and Fig. 5

As can be seen from the temperature dependences of

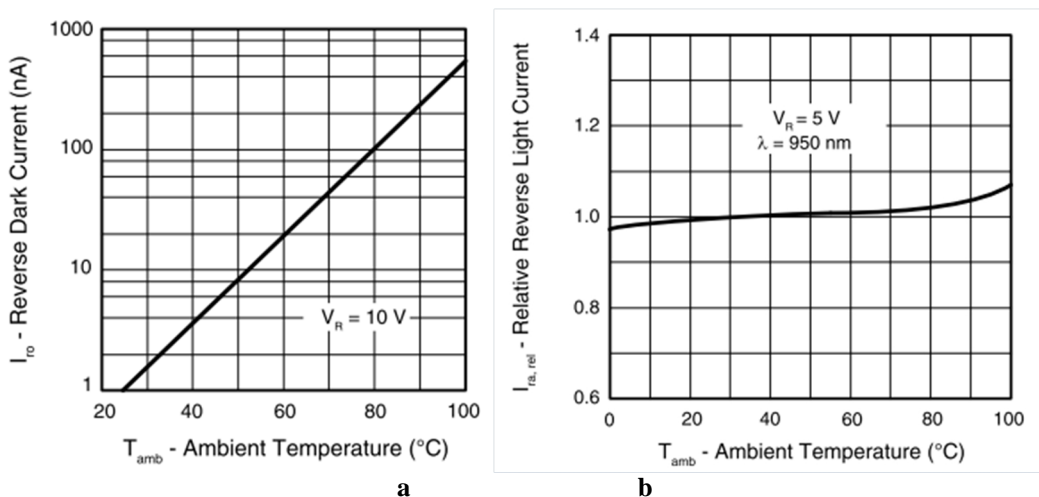


Fig. 5. Temperature characteristics of the phototransistor.

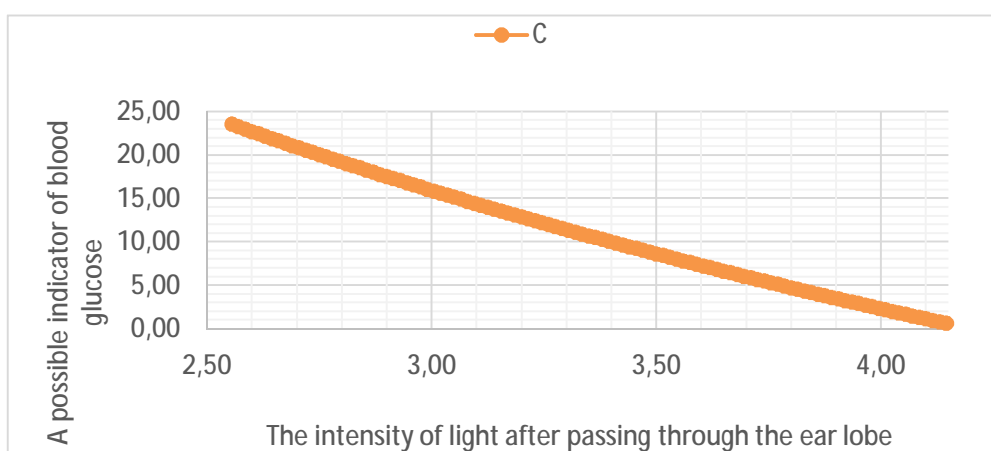


Fig. 6. Dependence of the glucose ratio on the intensity of the light emitted through the ear of the ear.

these elements in the range of operating temperatures (20 – 40 °C), the manufacturer is guaranteed stable operation of these elements.

Conclusions

The features infrared optical method based on non-invasive measurement of blood glucose. Good correlation is observed between the sensor and measurements developed system dimensions. The results also show the feasibility of using non-invasive methods of measuring blood glucose based on NIR. To improve the productivity and accuracy of the system promising is the development of appropriate microsystem-on-chip with integrated performance using SOC CMOS structures. [9]

Based on the analyzed components designed and manufactured an experimental model of a portable device for measuring blood glucose level using noninvasive

optical technique of near infrared radiation. The microcontroller is programmed based on the regression equation (3). This equation is formed so that glucose can be measured non-invasively.

On the basis of the developed our prototype device for non-invasive monitoring of blood glucose and in accordance with the defined dependencies (expression 3) was built graphic dependences for the range and intensity values given individual coefficient ($\alpha = 0.02$) - chosen experimentally (Fig. 6).

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Особливості неінвазивного вимірювання рівня глюкози в крові із застосування ближнього інфрачервоного випромінювання

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В статті описано спосіб вимірювання концентрації рівня глюкози в крові людини неінвазивним методом з використанням оптичної техніки ближнього інфрачервоного випромінювання. У медичній практиці концентрація глюкози в крові у більшості випадків вимірюється інвазивними методами, що передбачають забір крові з пальця чи вени, в той час, як неінвазивні пристрої визначення рівня глюкози дозволяють оперативне вимірювання рівня без забору крові. Інвазивні методи є дорогими та болючими. Часте проколювання пальців викликає мозолі на шкірі, а також збільшує ризик поширення інфекційних захворювань. Таким чином, розробка системи неінвазивного вимірювання глюкози в крові буде корисною для хворих на цукровий діабет. Неінвазивний спосіб вимірювання рівня глюкози в крові людини ґрунтується на використанні безболісної оптичної технології на базі ближнього інфрачервоного (БІЧ) випромінювання. Пропонована система складається з випромінювачів сигналів довжиною хвилі 940 нм. Ці оптичні сигнали надсилаються через мочку вуха, а промені, котрі пройшли її, фіксуються фототранзистором, розташованим на іншій частині приладу. Концентрація глюкози в крові визначається шляхом аналізу варіації інтенсивності отриманого після проходження сигналу. Результати, отримані від розробленої системи, показують доцільність використання неінвазивного методу БІЧ для моніторингу рівня глюкози в крові. Точність вимірювань запропонованої системи може бути покращена шляхом інтегрального виконання її чутливих та випромінюючих елементів на основі КНІ КМОН-структур.

Ключові слова: глюкоза в крові, діабет, ближній інфрачервоний, неінвазивний метод, КНІ КМОН-структури.