Glucose sensor based on ellipsometry and circular dichroism in achiral plasmonic structure

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Abstract:

Various efforts have been made to detect minimum value of glucose in any medium like water or body buffer solutions with high-sensitivity, accurate, and low-cost sensors in order to enhance life style. Therefore, the present study was done to investigate reliability of two-dimensional plasmonic structure by circular dichroism (CD) and ellipsometry tools in different concentrations of glucose. Our results confirmed a dependency of the CD signal on glucose concentrations and also a very good sensitivity based on the phase difference between each polarization in ellipsometry parameters with the help of an achiral plasmonic structure.

Keywords: Achiral plasmonic structure; Circular dichroism; Glucose; ellipsometry method.

I. Introduction

Diabetes mellitus is a chronic metabolic disorder that, according to a statistical report by International Diabetes Federation, affects about 400 million people worldwide per year. In the United States, an estimated cost of 245 billion dollars puts a huge burden on the country [1]. The increasing prevalence of this chronic disease among children and adolescents is regarded as a serious threat to the future security of communities. Among the many causes known for diabetes, its most important symptom is a high blood glucose. Therefore, by controlling the blood glucose levels, all the long-term related complications such as developing cardiovascular disease, chronic renal failure, and diabetic retinopathy can consequently be controlled. Up to now, various devices have been proposed for the control of the blood glucose levels. Accordingly, most of these blood glucose measuring (BGM) devices use bio-electrochemical designs based on glucose oxidase (GOx) or immobilized glucose dehydrogenase (GDH) on the surface of a disposable electrode [2]. Moreover, these monitoring schemes are nontoxic and with high selectivity. However, these methods are invasive, so in order to use them, blood must be taken from diabetic persons. However, to solve this problem, saliva and interstitial fluids are used to determine the patients' glucose level, because it has been proved that there is a direct relationship between their glucose level and glucose in the blood [3]. Recently, many studies have been performed on optical methods as non-invasive and high-accuracy methods, instead of electrochemical methods, in order to detect the amount of glucose in interstitial fluids. In addition, some minimally invasive or noninvasive techniques were studied for the blood glucose monitoring, including infrared (IR) spectroscopy [4], terahertz time domain spectroscopy [5], Raman spectroscopy [6], and surface plasmon resonance (SPR). However, the results should still be correlated with the direct blood glucose measurements, and the

sensitivity and reliability are also limited by spectral signal-to-noise ratio (SNR) level and skin thickness.

Among the optical methods, an optical sensor based on the SPR is very popularly used to determine very low concentrations of any disease with high sensitivity based on the changes in metal refractive index as well as dielectric adjacent environment and also to detect the amount of glucose in the human body. For example, a plasmonic cuvette that is dye chemistry coupled to plasmonic interferometry for glucose sensing [7]; use of gold nanoparticles along with the stimulation of available plasmon polaritons in which high-molecular-weight dextran coated nanoparticles are aggregated with concanavalin A (Con A), which results in a significant shift as well as broadening of the gold plasmon absorption [8]; and a SPR system used for the measurement of glucose in aqueous solution [9].

In the above-mentioned studies, the manufacturing process due to the modification of the surface of the sensor chip or the labeling of nanoparticles, is very complex. As well, some of them have low accuracy for detecting glucose in interstitial fluids. However, it is obvious that the phase sensitivity of SPR systems is much higher than their intensity sensitivity. In this regard, in our earlier works, we established and approved that enhancing SNR can help in detecting very low concentrations diseases at early stage by phase sensitive methods in tissue [10,11], texture or in membrane activity [12]. Correspondingly, this phase sensitive method, named as Plasmonic ellipsometry, is an optical technique that measures the amplitude and phase changes of linear polarizations in reflecting light radiated from the surface of a sensor chip. In general, this technique can be applied to characterize material properties, including composition, roughness, thickness (depth), crystalline nature, doping concentration, electrical conductivity, etc. [13].

In spite of phase differences, circular dichroism (CD), as the difference between right and left circular polarizations' transmission, is widely used for biophotonic applications [14] such as the investigation of circular dichroism-active interactions between Fipronil and Neuronal cells in a study by Xiuxiu Wang et al. [15]. However, the problem of low SNR still remains a major obstacle to the CD sensing. Up to now, various methods have been proposed for SNR amplification, including the use of chiral near-field, which being chiral means that, this plasmonic near-field is not compatible with the mirror image of itself and creates a nanostructure with extrinsic chirality. Mohammadi et al. in their study theoretically investigated the amplification of the CD signal by both chiral plasmonic and dielectric nanostructures [16]. By the use of helical plasmonic nanostructures as prototypical Chiral near-field Sources, Martin Schäferling et al. created electromagnetic fields with intrinsic chirality, which then enhanced their interaction with chiral molecules [17]. As well, Maria C. di Gregorio et al. studied the interaction between silver and glutathione nanocubes, in order to investigate the amplification of chiroptical effects on plasmon-molecule interactions [18]. In another study, using LSPR from gold chiral nanohooks, Gunnar Klös et al. designed a CD sensor with the enhanced refractive index sensitivity due to the reduction of substrate noise [19].

Therefore, in the present research, we proposed ellipsometry and CD methods based on the phase changes of the polarization of both reflective and transmission beams relative to the incident beam as a high accuracy, online measurement, low-cost, and label free sensor, in order to measure low concentrations of glucose.

II. Material and methods

In this study, we applied soft nano lithography to fabricate an achiral periodic sample using polydimethylsiloxane (PDMS) substrate and 2D charge coupled device (CCD), as the main

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stamp [20]. This PDMS perforated substrate is covered by a 35 nm thick gold layer using the thermal vapor deposition method to produce two dimensional plasmonic sample. The patterned PDMS, that serves as a 2D grating with periodicity of 3.11 μm, as estimated from scanning electron microscopy (SEM)–is shown in Fig. 1(a). In order to investigate the detection of glucose in the phosphate buffered saline (PBS) biological solution in the transmission measurement setup, we designed the fluidic channel (Fig. 1(b)). Moreover, we designed a transparent flow cell with two inlet channels with the same size: one of them for the equal entry of different concentrations of glucose in the PBS solution and the other one for washing the sensor cell after each measurement of glucose with di-ionized (DI) water using laser incisions on a transparent plexiglass sheet of 2 mm thickness. In addition, the generated sensor chip glued to the surrounding cube, which was embedded inside the flow cell, so that its gold-coated surface was adjacent to the material passing through the flow cell.

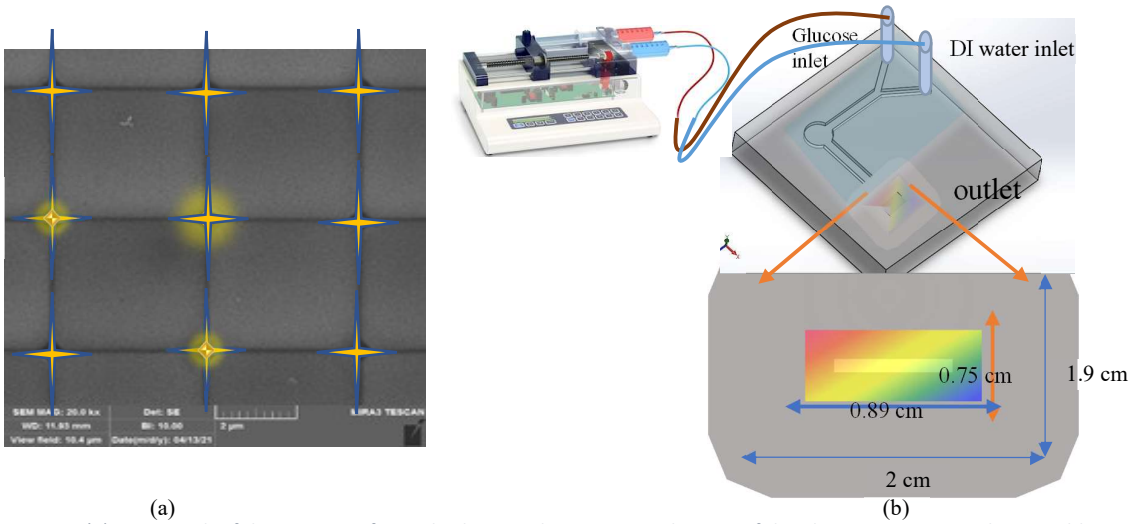

Figure 1: (a) SEM graph of the PDMS perforated substrate that serves as the part of the plasmonic sensor. Schematic blue lines demonstrate the areas where the coupled gold nanowires will be formed after the gold deposition. Yellow color cross sections demonstrate the areas of the plasmon resonances. (b) Scheme of the test system, that contains the inlet and a syringe pump, main channel with a plasmonic sensor at the end.

Thereafter, in order to demonstrate the capability of the sensor chip in accurately detecting different concentrations of glucose, we firstly prepared the PBS biological solvent.

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Subsequently, 7 PBS pills were purchased from Pharmed Biomaterials Company and then dissolved them in 7 Erlenmeyer flasks, each one containing 100 ml of DI water. Afterwards, we placed each Erlenmeyer flask in an ultrasonic chamber for 10 minutes to dissolve the PBS pills uniformly.

At this stage, in order to prepare six different concentrations of glucose in the PBS solvent, 10 mg, 20 mg, 30 mg, 50 mg, 75 mg, and 100 mg of glucose powder were poured into the produced PBS solvents and then placed in the ultrasonic chamber again for 10 minutes to be solved completely and uniformly. The generated sample was then flushed to flow cell through a syringe pump, which were placed adjacent to a 2D sensor chip. Additionally, the reflection and transmission measurements' processes were performed in two separate setups under light irradiation using linear (S, P) and circular polarizations (LCP, RCP), respectively. After measuring each glucose concentration, the flow cell medium was flushed through its second inlet channel by a syringe pump, in order to prevent the previous glucose concentration from remaining on the chip's surface.

Since the wave vector of surface plasmon polaritons has a non-zero imaginary part, in linear polarized light reflection from the plasmonic sample, according to the Airy formula for sequential systems, the phase difference and intensity between the reflected beams with s, p polarization are created which are described by Δ and Ψ parameters, respectively. Therefore, any change in the properties of the metal and its adjacent dielectric environment in the plasmon sample causes Δ and Ψ changes. [13,21].

In addition, plasmonic structures have been used to increase the intensity of the circular dichroism signal and also to enhance the chirality of adjacent chiral molecules or structures due to the presence of near-fields obtained from the plasmonic chiral localized dipoles. Correspondingly, this interpretation was generally expressed by the following relationship

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regarding the transition matrix approach of multilayer structures of substrates, metal nanoparticles, and chiral molecules by utilizing the Poynting vector relationship of passing fields as follows [16]:

$$A \propto \alpha_e U_e + \alpha_m U_b - \beta C \,, \tag{1}$$

where A indicates the transmission light through the structure, U_e and U_b describe the density of electrical and magnetic energy and α_e and α_m are equivalent to the imaginary part of the polarizability of electric and magnetic dipoles, respectively. Additionally, β is an intrinsic parameter of the structure, known as the polarizability of the electric-magnetic dipole, which describes its chirality. The optical chirality parameter C shows the result of inductive chirality in electromagnetic field, which can be calculated as follows:

$$C = -\frac{\varepsilon_0 \omega}{2} Im(\boldsymbol{E}^* \cdot \boldsymbol{B}) \,, \tag{2}$$

where E and B are the complex electric and magnetic fields, respectively. Notably, parameter *C* which depends on the circular polarizations of the incident light, describes the ability of the incident electromagnetic light in being coupled with the chiral structure [17, 22]. However, the difference between our approach and the one mentioned earlier was that our two-dimensional plasmonic structure was completely achiral and the β parameter was non-zero due to either external or extrinsic chirality resulted from both the stimulation and interference of surface plasmon polaritons.

So, as mentioned earlier, both ellipsometry and circular dichroism signal methods were done based on the polarized light phase changes. The first one, ellipsometry, as the Δ and Ψ parameters based on the phase difference and aspect ratio of the reflectance of S and P polarized light, respectively, and the second one, circular dichroism, based on the absorption difference of circularly polarized light. The presence of external chirality is the result of anisotropy created

 doi:10.20944/preprints202112.0297.v1

by the surface plasmon polaritons interferences obtained by the left and right circular polarizations of the incident light.

III. Result and Discussion

When an overlap occurs between the localize surface plasmon polaritons resonances (LSPRs) resulted from the nanowires of each unit cell of square lattice (350 *100 nm) with lattice diffraction order in a 2D lattice structure, a phenomenon of surface lattice resonance (SLR) occurs [23]. These plasmonic SLRs arising from LSPRs of individual metal nanowires are shown as stars in Fig. 1 with diffractive orders presented in a periodic array.

Figure 2 shows the results of the measurements of the incident radiation at a 48-degree angle to the surface of the sensor chip for the concentrations of 10, 20, and 30 mg/dl. The Δ parameter was usually checked at the peak closest to the SLR wavelength at about 677 nm. In this regard, Δ values for different glucose concentrations are shown in Fig. 2b. Accordingly, this diagram shows that the Δ parameter values for the three concentrations of 10, 20, and 30 mg/dl were 13.2, 19.7, and 20.1, respectively. Additionally, the sensitivity parameter resulted from the ratio of changes in the delta parameter to changes of glucose concentration, was estimated as S = 0.34 for this measurement, indicating the high sensitivity of this method to the changes in glucose concentration. Fig. 2c shows the Ψ intensity parameter in the reflection of s, and p as the polarized wave from the chip's surface. It was indicated that the Ψ parameter changes with increasing glucose concentration and a small red-shift can also be observed in it. Accordingly, for the concentrations of 10, 20, and 30mg/dl, these appeared at the wavelengths of 707.4, 708.2, and 708.7nm, respectively.

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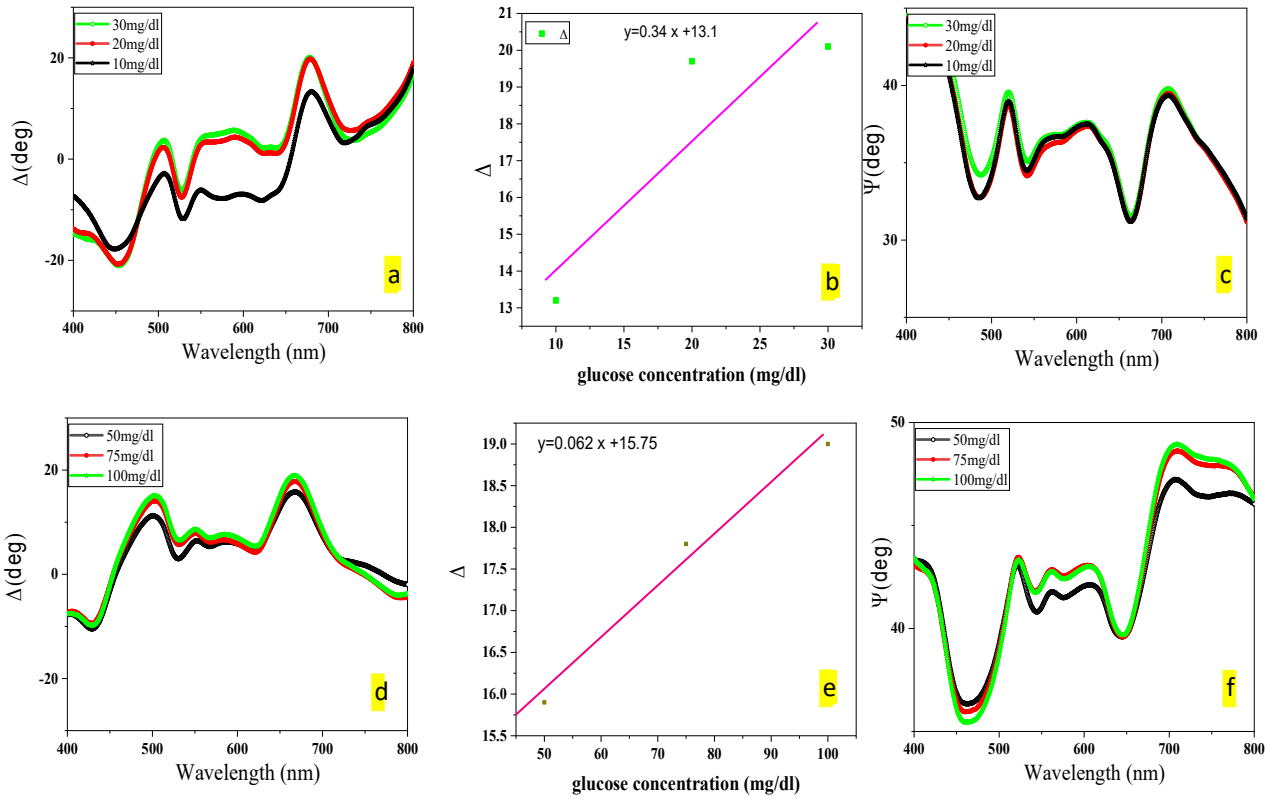

Figure 2: (a) Δ spectrum, (b) Δ parameter sensitivity diagram to glucose (c) Ψ spectrum for concentration of 10, 20, 30mg/dl of glucose and (d) Δ spectrum (e) Δ parameter sensitivity diagram to glucose (f) Ψ spectrum for concentration of 50, 75, 100mg/dl of glucose.

The measurements were repeated for three larger concentrations of 50, 75, and 100 mg/dl using ellipsometry method as shown in Figs.2 (d to f). It can be seen in Fig. 2d that at the nearest peak to the SLR wavelength (668nm), the Δ has considerably increased along with concentration increasing, so that for the concentrations of 50, 75, and 100mg/dl, Δ levels were 15.9, 17.8, and 19, respectively. Accordingly, Δ values for different concentrations are shown in Fig. 2e. In addition, the sensitivity parameter of this measurement was then calculated by the slope of this diagram, the value of which was S = 0.06. The diagram of the changes in the Ψ parameter is plotted in Fig. 2f, which shows a red-shift for increasing glucose concentrations, similar to the measurements of the previous three concentrations.

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Here, after measuring plasmonic ellipsometry, to detect the baseline values of glucose in the saliva and interstitial fluid simulator environment of the human body, we use another detection method, namely the circular dichroism signal sensing method in 2D achiral plasmonic structure as shown in Fig. 3. To do this, it is necessary to record the transmission spectrum of the circular polarized incident light at a normal angle to the surface of the sensor chip in the

adjacent of the dielectric medium. Fig. 3 shows the left-handed incident light spectrum of the plasmonic sample adjacent of glucose in concentrations of 50, 75, and 100 mg / dL.

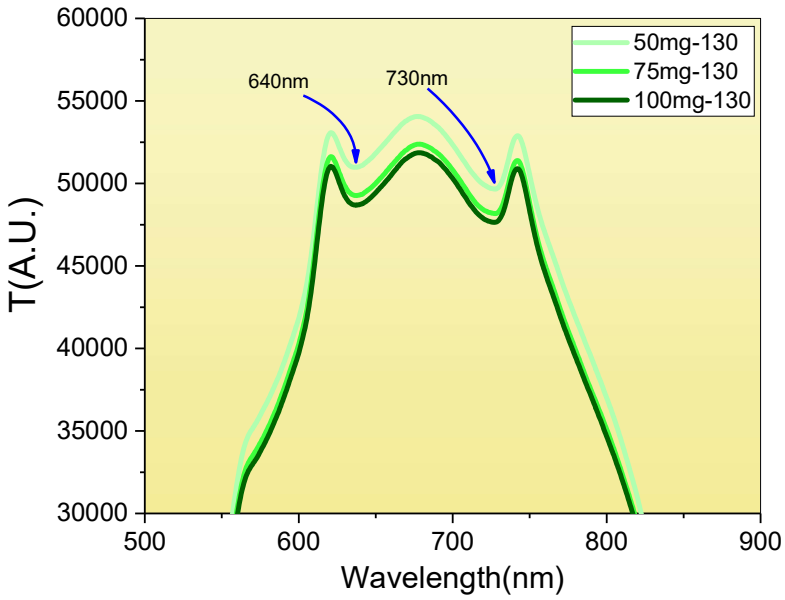

Figure 3: Left-handed circular polarization transmission spectrum of an Achiral sample adjacent to glucose.

In the experimental measurement of the transmission spectrum of the achiral plasmonic sample in the adjacent of the glucose solution, these dipole and quadrupole absorption valleys can be seen, which confirms the stimulation of LSPRs and Propagating Surface Plasmons (PSPs) that form at the unit cell boundaries of a lattice of structure. These valleys do not directly describe only LSPRs and PSPs, but more generally describe the SLR phenomenon that was discussed earlier. Before conducting the experimental measurements, we firstly simulated a sensor chip

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with a square array achiral structure using the FDTD module of Lumerical software. As shown in Fig. 4, the results of the electric field distribution for normal radiation showed that due to the interference of SLRs from the nanowires of each lattice point and the fact that in each angle, some parts of the structural points projection create an asymmetry in the structure as well as external chirality.

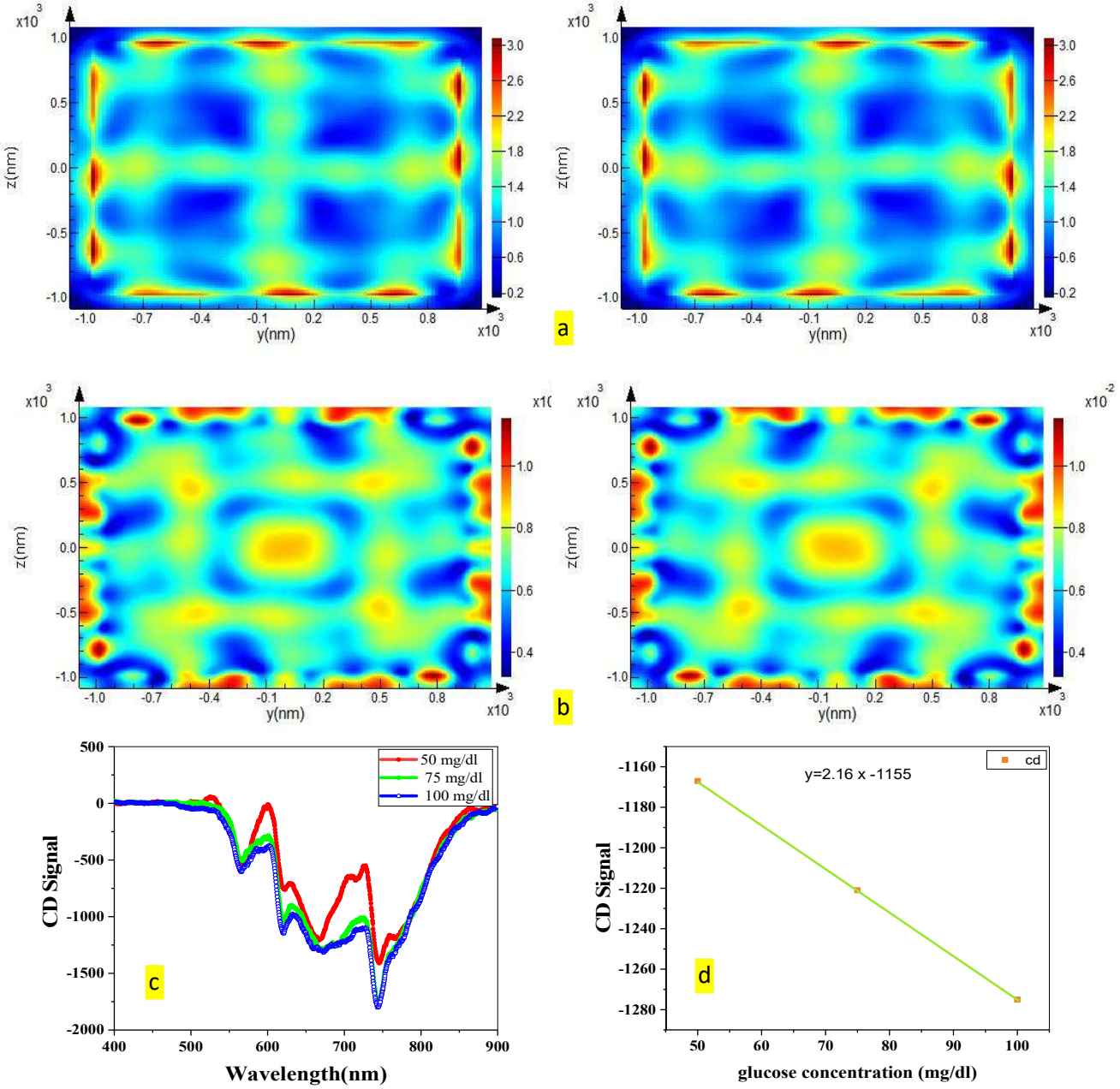

Figure 4: magnetic and Electric field distributions of the sample for right and left circular polarizations for (a) LCP-T-E and RCP-T-E and (b) LCP-T-H and RCP-T-H for normal incidence, (c) CD signal for three difference concentration of glucose. (d) sensitivity graph of the 2D achiral plasmonic sensor.

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As can be seen, the CD signal was generated at both the plasmon resonance wavelengths of 645 and 735 nm, which are close to the extraordinary transmittance (EOT) of the plasmonic nanostructure, confirming that the CD signal is mainly resulted from the intrinsic chirality of the SLRs.

After the simulation and fabrication of the sensor, glucose was detected in three concentrations of 50, 75, and 100mg/dl, which were previously dissolved in the PBS biological solution. Of note, the results of the experimental measurement of the CD signal for a glucose concentration are shown in Figure 4(c), which shows that the values of the CD signal at 647 nm, which is similar to the SLR wavelength, were near the starting point of the EOT wavelength range 680 nm. CD signal values were measured at 647 nm for glucose at concentrations of 50, 75 and 100 mg / dl equal to -1167, -1221 and -1275, respectively. Furthermore, the results show that the CD signal is significantly amplified by increasing glucose concentration, which was found to be due to changes in SLRs in the presence of different concentrations of glucose, thereby changing their interference conditions at the sample level. Additionally, with concentration increasing, a significant red-shift was observed in the CD signal, and this result again proves that only SLRs are the causes of amplifying the CD signal. According to the diagram shown in Fig. 4d, presenting the CD signal for different concentrations of glucose in the SLR wavelength, the sensitivity parameter as equal to the slope of the graph, i.e. the ratio of changes in the CD signal to changes in glucose concentration, was obtained as S = 2.16 $\frac{A.U}{mg/dl}$.

In this study, we used two sensing methods with high sensitivity which are compared with other optical methods in Table I, both of which were based on the changes of surface plasmon polaritons phase caused by the changes in glucose concentration. The ellipsometry method was used to measure the phase changes of SPPs directly and to assure us that this phase change has occurred. But circular dichroism was applied to measure the transmission intensity of the two

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circular polarizations resulted from the external chirality that was created by the same phase changes of SPPs.

Table 1: sensitivity in Glucose detection by optical methods

Method	*Sensitivity*
Dye chemistry coupled to plasmonic interferometry [24]	$1.7 \times 10^5 \ \frac{\%\ relative\ intensity\ chenge}{Glucose\ Con\ (M)}$
SPR system [25]	$S = 0.05 \frac{nm}{mg/dl}$
SPR with borate polymer binding [26]	$S \equiv \frac{\Delta RU}{GLucose\ Con} = 1.33 \frac{\Delta RU}{mg/dl}$
Localized SPR-Based U-Shaped Fiber Optic [27]	$S = 0.005 \frac{A.U}{mg/dl}$
SPR based fiber optic glucose biosensor [28]	$S = 0.036 \frac{nm}{mg/dl}$
Circular Dichroism signal (Our work)	$S = 2.16 \frac{A.U}{mg/dl}$

IV. Conclusion:

In sum, the achiral plasmonic structure was used in this study as a sensitive and low-cost sensor to detect glucose by transmitted and reflected beams. Our results showed that changes in glucose concentrations caused changes in the refractive index of the surrounding medium of the 2D plasmonic substrate. Resonant frequency of SLR in the main sample was altered by this refractive index change and both methods as CD and ellipsometry based on the extrinsic chirality and phase difference were successfully implemented.

Acknowledgements

This work was financially supported by the Russian Foundation of Basic Research projects N 18-29-02120 and 18-29-20113.

References:

[1] Centers for Disease Control and Prevention, Estimates of Diabetes and Its Burden in the United States, Atlanta, GA: CDC; (2014).

[2] Joseph Wang, Electrochemical glucose biosensors, Chem Rev, 25, 108-814, (2008).

[3] Arati S. Panchbhai, Correlation of Salivary Glucose Level with Blood Glucose Level in Diabetes Mellitus, J Oral Maxillofac Res, vol. 3, No 3, e3, p.1, (2012).

[4] Rong Liu,Wenliang Chen, Xiaoyu Gu, Ruikang Kwang, and Kexin Xu Chance correlation in non-invasive glucose measurement using near-infrared spectroscopy, J. Phys. D: Appl. Phys, 38, 2675-2681, (2005).

[5] O. P. Cherkasova; M. M. Nazarov; A. P. Shkurinov, Application of terahertz time-domain spectroscopy for blood glucose monitoring, International Conference Laser Optics (LO), St. Petersburg, Russia, (2016).

[6] Olga Lyandres, M.S, Jonathan M. Yuen, M.S, Nilam C. Shah, M.S, Richard P. VanDuyne, Ph.D, Joseph T. Walsh Jr, Ph.D and Matthew R. Glucksberg, Ph.D, Progress Toward an In Vivo Surface-Enhanced Raman Spectroscopy Glucose Sensor, DIABETES TECHNOLOGY & THERAPEUTICS, 10, Number 4, (2008).

[7] Vince S. Siu, Jing Feng, Patrick W. Flanigan, G. Tayhas R. Palmore and Domenico Pacifici, A “plasmonic cuvette”: dye chemistry coupled to plasmonic interferometry for glucose sensing, Nanophotonics, 3(3),125-140, (2014).

[8] Kadir Aslan, Joseph R. Lakowicz, and Chris D. Geddes, Nanogold-plasmon-resonance-based glucose sensing, Analytical Biochemistry, 330, 145-155, (2004).

[9] W.W. Lam, L.H. Chu, C.L. Wong, Y.T. Zhang, A surface plasmon resonance system for the measurement of glucose in aqueous solution, Sensors and Actuators B, 105, 138-143, (2005).

[10] F Sohrabi, D Etezadi, R Perin, Y Jahani, E Mohammadi, SM Hamidi, Phase-sensitive optical neural recording of cerebellum tissue on a flexible interface, Journal of Applied Physics, 127 (11), 113101, (2020).

[11] Sajede Saeidifard, Foozieh Sohrabi, Mohammad Hossein Ghazimoradi, S. M. Hamidi, Shirin Farivar, and Mohammad Ali Ansari, Two-Dimensional Plasmonic Biosensing Platform: Cellular Activity Detection under Laser Stimulation, Journal of applied physics, 126 (10), 104701, (2019).

[12] F Sohrabi, Y Jahani, JV Sanchez-Mut, E Mohammadi, Z Barzegar, X Li, S. M. Hamidi, Membrane activity detection in cultured cells using phase-sensitive plasmonics, Optics Express, 28 (24), 36643-36655, (2020).

[13] F Sohrabi, SM Hamidi, Optical detection of brain activity using plasmonic ellipsometry technique, Sensors and Actuators B: Chemical, 251, 153-163, (2017).

[14] E. Hendry, T. Carpy, J. Johnston, M. Popland, R. Mikhaylovskiy, A. J. Lapthorn, S. M. Kelly, L. D. Barron, N. Gadegaard and M. Kadodwala, Ultrasensitive detection and characterisation of biomolecules using superchiral fields, Nat Nanotechnol, 5, 783−787, (2010).

[15] Xiuxiu Wang, Liguang Xu, Changlong Hao, Chuanlai Xu, and Hua Kuang, Circular Dichroism-Active Interactions between Fipronil and Neuronal Cells, Environ. Sci. Technol. Lett, 5, 500−507, (2018).

[16] E. Mohammadi, K. L. Tsakmakidis, A. N. Askarpour, P. Dehkhoda, A. Tavakoli and H. Altug, Nanophotonic Platforms for Enhanced Chiral Sensing, ACS Photonics, 5, 2669−2675, (2018).

[17] Martin Schäferling, Xinghui Yin, Nader Engheta, and Harald Giessen, Helical Plasmonic Nanostructures as Prototypical Chiral Near-Field Sources, ACS Photonics, 1, 530−537, (2014).

[18] Maria C. di Gregorio, Assaf Ben Moshe, Einat Tirosh, Luciano Galantini, and Gil Markovich, Chiroptical Study of Plasmon−Molecule Interaction: The Case of Interaction of Glutathione with Silver Nanocubes, J. Phys. Chem. C, 119, 17111−17116, (2015).

[19] Gunnar Klös, Matteo Miola, and Duncan S. Sutherland, Increased Refractive Index Sensitivity by Circular Dichroism Sensing through Reduced Substrate Effect, J. Phys. Chem. C, 123, 7347−7355, (2019).

[20] N. Asgari and S. M. Hamidi, Exciton-plasmon coupling in two-dimensional plexitonic nano grating, Opt. Mater, 81, 45–54, (2018).

[21] Maria Losurdo, Kurt Hingerl, Ellipsometry at the Nanoscale, (Springer, Berlin), p. 730, (2013).

[22] Vassilios Yannopapas, Circular dichroism in planar nonchiral plasmonic metamaterials, Optics Letter, 34, No. 5, (2009).

[23] H. Mbarak, R. Taheri Ghahrizjani, S. M. Hamidi, E. Mohajerani & Y. Zaatar, Reversible and tunable photochemical switch based on plasmonic structure, Scientific Reports, 10:5110, (2020).

[24] Vince S. Siu, Jing Feng, Patrick W. Flanigan, G. Tayhas R. Palmore and Domenico Pacifici, A “plasmonic cuvette”: dye chemistry coupled to plasmonic interferometry for glucose sensing, Nanophotonics, 3(3),125-140, (2014).

[25] W.W. Lam, L.H. Chu, C.L. Wong, Y.T. Zhang, A surface plasmon resonance system for the measurement of glucose in aqueous solution, Sensors and Actuators B, 105, 138–143, (2005).

[26] Dachao Li, Di Yang, Jia Yang, Yuan Lin, Yingjuan Sun, Haixia Yu, Kexin Xu, Glucose affinity measurement by surface plasmon resonance withborate polymer binding, Sensors and Actuators A, 222, 58–66, (2015).

[27] Sachin K. Srivastava, Vikas Arora, Sameer Sapra, Banshi D. Gupta, Localized Surface Plasmon Resonance-Based Fiber Optic U-Shaped Biosensor for the Detection of Blood Glucose, Plasmonics, 7, 261–268, (2012).

[28] Sachin K. Srivastava, Roli Verma, Banshi D. Gupta, Surface plasmon resonance based fiber optic glucose biosensor, Proc. of SPIE, Vol. 8351 83511Z-2, (2012).