Proceedings of the 4th ITB Graduate School Conference
Innovation and Discovery for Sustainability
July 6, 2023

A Surface Plasmon Resonance (SPR) Simulation Based on Kretschmann Configuration for Glucose Detection

Fadli Hastito[1,*], Ni Luh Wulan Septiani[2,4], Chandra Wulandari[2], Gilang Gumilar[2] Endang Juliastuti[3] & Brian Yuliarto[2,5]

[1]Master Program of Instrumentation and Control, Faculty of Industrial Technology, Institut Teknologi Bandung, Jalan Ganesa 10, Bandung 40132, Indonesia
[2]Advanced Functional Material Research Group, Faculty of Industrial Technology, Institut Teknologi Bandung, Jalan Ganesa 10, Bandung 40132, Indonesia
[3]Instrumentation and Control Research Group, Faculty of Industrial Technology, Institut Teknologi Bandung, Jalan Ganesa 10, Bandung 40132, Indonesia
[4]Research Center for Advanced Materials, Research, and Innovation Agency (BRIN), Kawasan PUSPIPTEK, Serpong, South Tangerang 15314, Banten, Indonesia
[5]BRIN and ITB Collaborative Research Center for Biosensors and Biodevices, Jl. Ganesha 10, Bandung, West Java, 40132 Indonesia.
[*]Email: fadlyhastito114@gmail.com

Abstract. Numerous studies have been conducted on the detection of glucose as the prevalence of diabetes grows in both industrialized and developing countries. a poor way of living those results in a persistent buildup of blood sugar levels over the acceptable limit. Therefore, to detect glucose concentrations, high sensitivity, label-free, and high-resolution sensors are required. A biosensor is a device or device that utilizes the molecules of living things to detect chemical materials with output in the form of electrical, thermal, or optical signals. Biosensors that are now widely developed are optical biosensors. This is because optical biosensors can make real-time measurements, have high sensitivity, simpler analysis, and lower costs. One of the basic technologies in optical biosensors is the observation of the Surface Plasmon Resonance (SPR) phenomenon. SPR is an optical phenomenon where there is a resonance between light waves and free electrons (plasma) that oscillate and travel along the metal surface layer. In this study, biosensor Surface Plasmon Resonance (SPR) simulations were carried out and the effects of varying the glucose concentration on the sensor response were examined. The modeling outcomes showed that the decline in reflectance varied with glucose concentration. In the simulation analysis, the curve obtained shows that there is a shift in the angle towards the positive x-axis. This shows that with every increase in the concentration of glucose solution there is a shift in the angle and an increase in the refractive index. A range of glucose readings that might indicate diabetic symptoms were used in the study with sensitivity was 147.84 ^{0}/RIU. Herefore, this sensor type may be used to detect glucose in the concentration range for diabetic patients.

Keywords: *surface plasmon resonance; biosensing; FDTD; glucose; and the Kretschmann configuration.*

1 Introduction

A growing area of study is glucose sensors, notably in the field of medical technology. The disadvantages of finger-stick blood testing, which is now the most used method for measuring blood sugar levels, have drawn increased attention to the development of non-invasive glucose sensors [1,2]. Label-free and real-time attributes are crucial for improving sensor performance and reducing battery consumption [3]. Over the past 10 years, the relevance of research into Surface Plasmon Resonance (SPR)-based sensors with these characteristics has increased.

The SPR-based sensor is an optical sensor that uses the surface plasmon wave (SPW) phenomena. SPW are p-polarized electromagnetic waves that cross the metal-dielectric contact [4]. It may be activated by a certain resonance condition that is affected by the angle, wavelength, and strength of the input optical light [5]. There is detecting activity when the background dielectric constant or the analytes' refractive indices on the topmost metal surface vary [6]. As SPR-based sensors are used for various biochemical detection, the metals used in the arrangement must have high mechanical and chemical stability, as well as good conductivity and transparency [7]. Because of their characteristics, noble metals like Au and Ag were chosen for this [8]. One of the precious metals mentioned above that is appropriate for usage in SPR is gold. Compared to silver, gold is more oxidation-resistant [9].

Gold thin film-based SPR-based sensors were used in previous work because to their excellent performance [10]. The angle of SPR is proportional to the thickness of the gold layer on the prism, which is known to alter the angle's magnitude, according to a recent study by Miyazaki et al. on the first analysis of the SPR phenomenon employing gold (au). This illustrates how the SPR angle changes depending on the metal's thickness. When the SPR phenomenon happens may be determined using the angle shift of SPR. Variations in the optical characteristics of the light-transmitting layers cause the angle shift observed in SPR [11].

In today's research, simulation is an important and helpful phase to achieve the best findings before manufacturing and testing. Finite Difference Time Domain (FDTD) solutions in any study field, particularly the optical one, include a variety of geometric shapes made of various materials, such as dielectric, magnetic, frequency-dependent, nonlinear, and anisotropic materials, such as wide-angle broadband [12], tunable terahertz add-drop filter [13], and photonic crystal fiber[14]. The difficult Maxwell's equation is frequently the subject of FDTD's theoretical studies [10]. The FDTD approach may be used to determine the spatial and temporal properties in a single run [15–17]. Lumerical, XFDTD, and

SEMCAD are just a few of the commercial products that have been created using the FDTD approach [18].

Several sugar level indications are employed in the fasting blood sugar (FBS) test, which is used to detect diabetes. Blood sugar levels below 100 mg/dL are regarded as normal; if they exceed that mark, pre-diabetes sets in. Diabetes is indicated by a blood sugar level of 200 mg/dL or above[19]. Each adjustment has been evaluated using FDTD simulation. Sensitivity is used to evaluate the performance of the sensor with Au thin films, the most widely used material in SPR-based sensors for glucose detection [8, 10].

2 Simulation design

In this research, FDTD is used to look at the surface plasmon resonance phenomenon in the Kretschman configuration. The laser with a wavelength of 785 nm was chosen because it has a refractivity index of 90.8% [20]. Figure 1(a) shows the simulation design that will be used based on the Kretchmann configuration on the XY axis, where the sensor chip can be seen in Figure 1(b). The front and back power monitor components are represented by yellow lines, while the sweep component of the optical source is represented by blue and purple arrows.

The thin-film layers and the substrate layer make up the sensor chip. As the prism/substrate layer for the biometallic thin film deposition, a BK7 glass substrate with a thickness of 795 nm and a refrective index of 1.5210 was used. The sensing surface is the single metal gold (Au) thin film which is located aboved the substrate and serves as the sensing surface (nAg = 0.1836, kAg = 4.5871; 1(b)). When the y component of the source wave vector and the vector of the SPR mode coincide in the bimetallic metal layers, the SPR phenomenon occurs. Utilizing mathematical examination, the boundaries of the plane-wave source is coordinated to the metal layers in aclear way over a scope of accurrence points to get the reververation point to energize the SPR mode, went in 58^0 to 78^0 in glucose. The back-power monitor that is situated behind the source to measure the structure's reflection will be able to identify this mode [21].

A short time later, the ideal plan was recreated in different groupings of glucose as the foundation analyte, which is 108, 144, 180, 216 mg/dL. Each fixatio gives an alternate refractive list determined utilizing direct fitting to detailed exploratory information [22], in the light of the direct connection among n and $\lambda(n = a + b\lambda)$A single metal sensor chip made of nano-laminated gold (Au) with a thickness of 50 nm was used to ceck the SPR phenomenon in glucose solution.

$$S = \frac{\Delta\theta_{\mathrm{SPR}}}{\Delta_n} = \frac{\theta_{\mathrm{SPR(glu)}} - \theta_{\mathrm{SPR(water)}}}{\theta_{n\mathrm{(glu)}} - \theta_{n\mathrm{(water)}}} \quad (2.1)$$

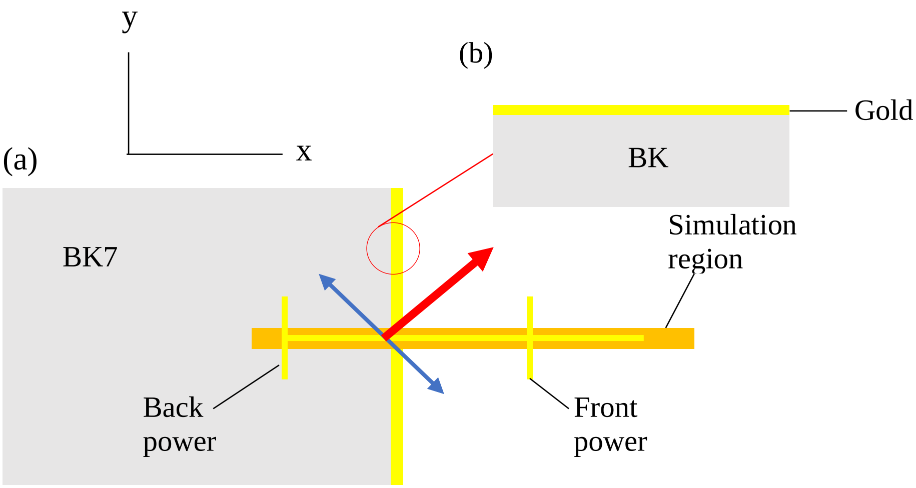

Figure 1 (a) Simulation display in Lumerical FDTD; sensor chip configuration

3 Results and Discussion

Surface plasmon excitation events happen when Magnetic Transverse (TM) k passes over a nanofilm of metal with a refractive index that is lower than the refractive index of an analyte (nP> nD) at a certain angle [23]. The Kretschmann arrangement has this as its foundation. The resonance conditions in the Kretschmann setup may be described based on the presumption that the Prism-Metal-Layer sensor layer polarizes the laser beam. The reflectance is therefore calculated using the three-layer Fresnel equation [24, 25].

$$R = \left|\frac{r_{pm} + r_{ms} exp(2ik_{mz}d)}{1 + r_{pm} r_{ms} exp(2ik_{mz}d)}\right|^2 \quad (3.1)$$

$$R = 1 - \frac{4\eta}{(1+\eta)^2} \tag{3.2}$$

$$\eta \cong \frac{\epsilon_m''}{4|\epsilon'_m| sin\theta}\left(1 + \frac{2{\varepsilon'_m}^2}{{n_s}^3 \epsilon_m''} k_s\right)$$

$$exp[\frac{4\pi d}{\lambda}\sqrt{|\epsilon_m'|}(1 + \frac{{n_s}^2}{2|\epsilon_m'|})] \tag{3.3}$$

The simulation of sensors was done using the FDTD method. Gold-plated thin-film SPR was used to determine the sensitivity of glucose sensors, figure 3 at a wavelength of 785 nm displays the results of an FDTD research using water as the analytic medium or a glucose concentration of 0 mg/L. A resonance event takes place at an angle of 70.72^0. Indicators include a noticeable decrease in curve reflectance or weakened total reflection (ATR) [26]. Plasmon oscillations on the metal surface that happen at the same frequency as the electromagnetic waves of the laser cause ATR. The occurrence may be described by Equation (1). The resonance angle at 0 mg/L of glucose was used as a reference point for computing the resonance angle shift.

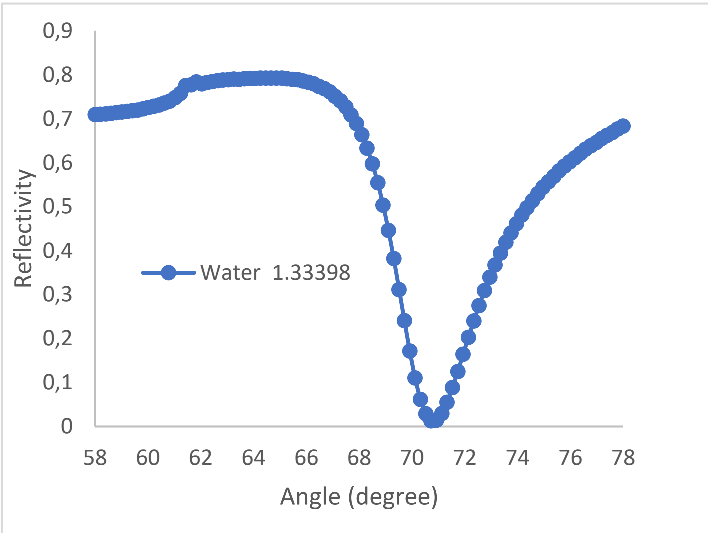

Figure 2 Curve for the resonance angle at 0 mg/dL of glucose.

The sensor's performance against variations in analyte concentration is impacted, as shown by Fig. 3, by fluctuations in the concentration of glucose. The simulation results for glucose at concentrations of 108, 144, 180, and 216 mg/dL at a wavelength of 785 nm showed that ATR angles varied. ATR glucose angles at high concentrations were greater than those at low concentrations. This is due to the refractive index being changed by the glucose content near the thin gold coating. Eq. (3.2) states that when the concentration of glucose grows, the refractive index close to the gold layer increases. This is based on research by Prabowo et al [21] that looks at how objects' angles are affected by the refractive index.

Figure 3 displays the various glucose concentrations that affect the resonance angle. With an increase in glucose concentration, the resonance angle also increases. In comparison to low glucose concentration, high glucose concentration showed a larger increased resonance angle. The sensor shows the robustness and capacity of nano-laminated gold sheets to detect a range of glucose concentrations rapidly and continuously. Using a method like Fig. 4, data may be plotted to assess the sensor's sensitivity.

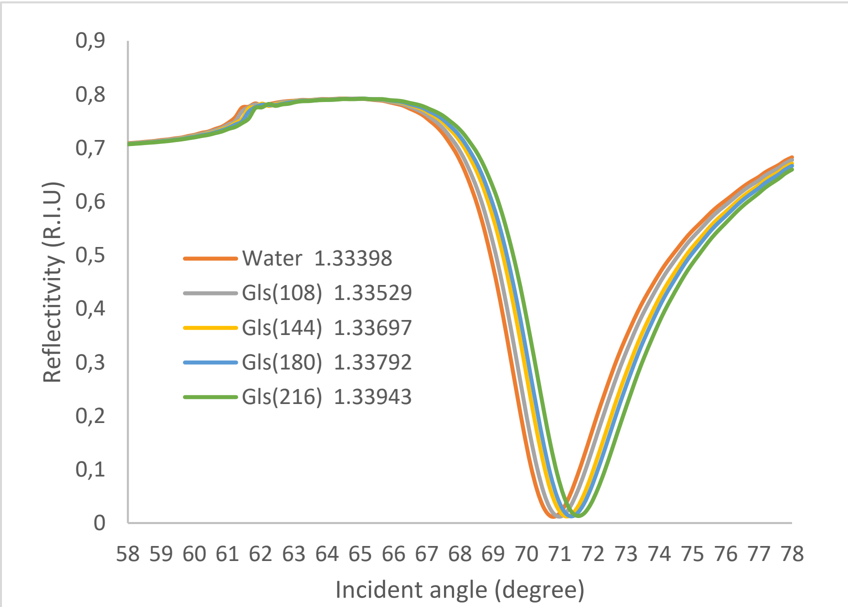

Figure 3 Results simulation of glucose at concentrations of 0, 108, 144, 180, and 216 mg/dL at 785 nm.

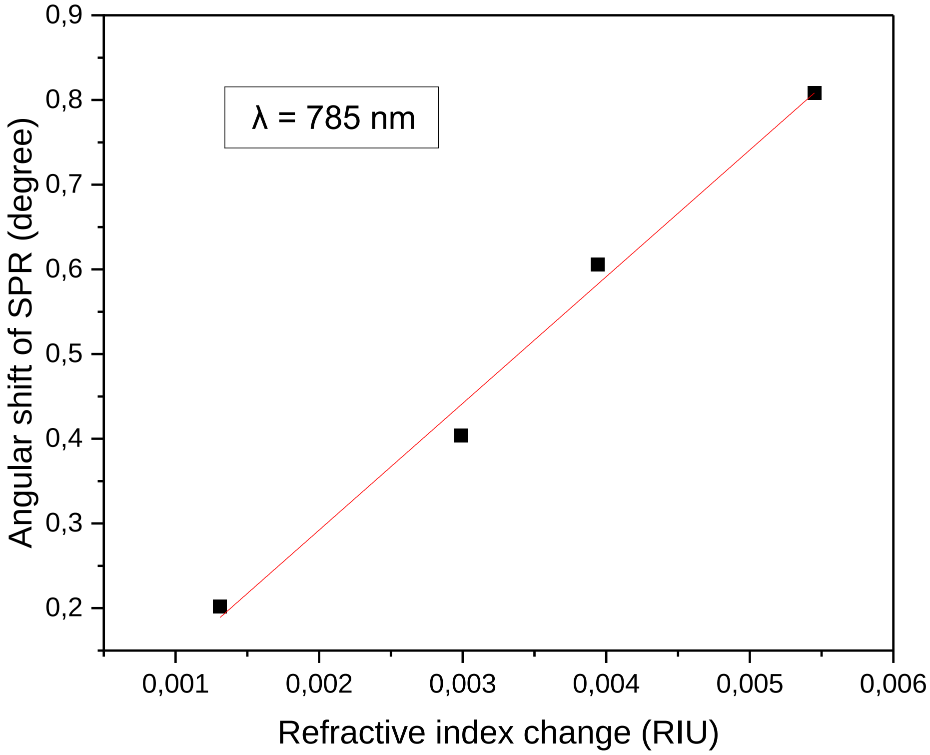

Figure 4 Change in SPR angle to change in refractive index of glucose solution.

Variations in the resonance angle shift at different concentrations showed a linear increase. Consequently, the sensitivity value of 147.84 ^{0}/RIU may be calculated by computing the gradient of the curve. The amount of glucose in the sample and variations in the resonance angle have an impact on the sensor's sensitivity. An important element in the detection of glucose is the shift in resonance angle. This is because as movement rises, so does the sensor's sensitivity. High sensitivity may be able to distinguish between minute concentration changes and significant shifts, as shown by Menon et al [10]. Fluctuations in concentration may be seen as a result. The sensor may thus be used to assess the glucose levels in people with diabetes, as indicated in Table 1.

Table 1 Minimum reflectance (R_{min}), maximum reflectance (R_{max}), and SPR angle(°) values of SPR-based sensor testing for glucose solution detection at 785 nm wavelengths.

Concentration (mg/dL)	n (RIU)	$\boldsymbol{\theta}_{\text{SPR}}(°)$	Δ_n	$\Delta\theta_{\text{SPR}}$	Sensitivity (°/RIU)	Category
108	1.33529	70.9293	0,00131	0,2020	154.19	Normal
144	1.33697	71.1313	0,00299	0,4040	135.11	Prediabetes
180	1.33792	71.3333	0,00394	0,6060	153.80	Prediabetes
216	1.33943	71.5354	0,00545	0,8081	148.27	Diabetes
Average					147.84	

4 Conclusions

Surface plasmon resonance sensor simulation has been completed to detect glucose solution based on the Kretschmann configuration. The curve obtained shows that there is a shift in the angle towards the positive x-axis. this shows that every increase in the concentration of glucose solution there is a shift in the angle and an increase in the refractive index. A range of glucose readings that might indicate diabetic symptoms were used in the study with sensitivity was 147.84 °/RIU.

References

[1] Makaram, Prashanth, Dawn Owens, & Juan Aceros. Trends in nanomaterial-based non-invasive diabetes sensing technologies. *Diagnostics*, **4**(2), pp.27-46, 2014.

[2] Daghestani, Hikmat N., and Billy W. Day. "Theory and applications of surface plasmon resonance, resonant mirror, resonant waveguide grating, and dual polarization interferometry biosensors." *Sensors* 10.11 (2010): 9630-9646.

[3] Pitarke, J. M., et al. "Theory of surface plasmons and surface-plasmon polaritons." *Reports on progress in physics* 70.1 (2006): 1.

[4] C. M. Miyazaki, F. M. Shimizu, M. Ferreira, "Surface plasmon resonance (SPR) for sensors and biosensors. In Nanocharacterization Techniques", William Andrew Publishing 183-200 (2017).

[5] Kurihara, Kazuyoshi, and Koji Suzuki. "Theoretical understanding of an absorption-based surface plasmon resonance sensor based on Kretchmann's theory." *Analytical chemistry* 74.3 (2002): 696-701.

[6] Matarèse, Bruno FE, et al. "Use of SU8 as a stable and biocompatible adhesion layer for gold bioelectrodes." *Scientific reports* 8.1 (2018): 5560.

[7] Purwidyantri, Agnes, et al. "Plasmonic nanomaterial structuring for SERS enhancement." *RSC advances* 9.9 (2019): 4982-4992

[8] Ordal, Mark A., et al. "Optical properties of the metals al, co, cu, au, fe, pb, ni, pd, pt, ag, ti, and w in the infrared and far infrared." *Applied optics* 22.7 (1983): 1099-1119.

[9] Anggraita, Pramudita. "Penelitian Bahan Nano (Nanomaterial) di Badan Tenaga Nuklir Nasional." *Jurnal Sains Materi Indonesia* (2019): 6-8.

[10] Menon, P. Susthitha, et al. "Refractive index and sensing of glucose molarities determined using Au-Cr K-SPR at 670/785 nm wavelength." *Sains Malaysiana* 48.6 (2019): 1259-1265.

[11] Miyazaki, Celina Massumi, et al. "Surface plasmon resonance biosensor for enzymatic detection of small analytes." *Nanotechnology* 28.14 (2017): 145501.

[12] Zhang, Kun, et al. "Concentration modulated photoluminescence and optical switching performance of graphene-oxide quantum dots." *Journal of Luminescence* 209 (2019): 116-120.

[13] Yee, Kane. "Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media." *IEEE Transactions on antennas and propagation* 14.3 (1966): 302-307.

[14] Mei, G. S., et al. "Robust Design of Bimetallic ZnO Nanofilm SPR Sensor using Taguchi Method." *2020 4th IEEE Electron Devices Technology & Manufacturing Conference (EDTM)*. IEEE, 2020.

[15] Jamil, Nur Akmar, et al. "CVD-grown Graphene-on-Au characterization and sensing using Kretschmann-based SPR." *2020 4th IEEE Electron Devices Technology & Manufacturing Conference (EDTM)*. IEEE, 2020.

[16] Said, Fairus Atida, et al. "Investigation of graphene-on-metal substrates for SPR-based sensor using finite-difference time domain." *Iet Nanobiotechnology* 11.8 (2017): 981-986.

[17] Mulyanti, B., et al. "Bimetallic Ag/Au thin films in Kretschmann-based surface plasmon resonance sensor for glucose detection." *e Optoelectronics and Advanced Materials—Rapid Communications* 14 (2020): 487-493.

[18] Kim, Seon Hoon, et al. "The effect of Au/Ag bimetallic thin-films on surface plasmon resonance properties comparing with those of Au and Ag single thin-films." *Journal of Nanoscience and Nanotechnology* 18.3 (2018): 1777-1781.

[19] Harvard Medical School “Controlling blood sugar in diabetes: How low should you go?” Harvard Health Publishing (2011).

[20] P. S. Menon, A. A. Jamil, G. S. Mei, A. R. M Zain, D. Hewak, C-C. Huang, M. A. Mohamed, B. Y.

[21] A. Belay, Journal of Lasers, Optics & Photonics 5(2), (2018).

[22] Prabowo, Briliant Adhi, Agnes Purwidyantri, and Kou-Chen Liu. "Surface plasmon resonance optical sensor: A review on light source technology." *Biosensors* 8.3 (2018): 80.
[23] Uddin, Syed Mohammad Ashab, Sayeed Shafayet Chowdhury, and Ehsan Kabir. "Numerical analysis of a highly sensitive surface plasmon resonance sensor for sars-cov-2 detection." *Plasmonics* 16.6 (2021): 2025-2037.
[24] Kurihara, Kazuyoshi, and Koji Suzuki. "Theoretical understanding of an absorption-based surface plasmon resonance sensor based on Kretchmann's theory." *Analytical chemistry* 74.3 (2002): 696-701.
[25] Srivastava, S. K., and I. Abdulhalim. "Spectral interrogation based SPR sensor for blood glucose detection with improved sensitivity and stability." *J. Biosens. Bioelectron* 6.2 (2015): 1.