Faculty of Electrical and Electronic Engineering Technology

OPTIMIZATION OF KRETSCHMANN-SURFACE PLASMON RESONANCE BIOSENSOR BASED ON MULTI-WALLED CARBON NANOTUBE USING TAGUCHI METHOD

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Bachelor of Electronics Engineering Technology (Telecommunications) With Honors

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I hereby declare that I have checked this project report and, in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of **Bachelor of Electronics Engineering Technology (Telecommunications) With Honors**

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DEDICATION

My sincere gratitude goes to my great friends. My completion of this project could not be done without the support of my friends around me and, of course, my family members, who have always encouraged me throughout this journey. The countless times you gave to your children during challenges time will not be forgotten, very grateful to have them all in my life. I also dedicate my project to my dear Supervisor, Mrs. Najmiah Radiah Binti Mohamad. She is always helping me out and never leaves me behind to make this research successful through up and down. I really do appreciate every piece of opportunity that was provided by my committee, their trust, energy, and attention, which helped the project research to be complete. Meanwhile, I always kept reminding myself to Allah SWT was affected in every way possible by this quest.

ABSTRACT

According to the data and challenges, it appears that the ageing population is dealing with diabetes and renal failure issues that affect rising blood sugar, urea, and creatinine levels, which can lead to strokes and heart attacks and frequently result in death. By using the conventional method, glucose monitoring has relied on experiment test such as finger pricks, with indirect approaches using enzymes like glucose oxide and glucose dehydrogenase. In order to overcome these issues, a new approach using Kretschmann - based Surface Plasmon Resonance (K-SPR) sensor is suggested. It is a great platform in biomolecule interactions due to the various options of materials in biosensors. It measured the change in the refractive index of the material being used. In order to optimize this K-SPR biosensor, a few factors must be investigated such as layer materials, thin layer film thicknesses and refractive index of the layer detection. The difference effects of the layer thicknesses on K-SPR are resulting by using WINSPALL software simulator. The research is focused on the impact of varying the thickness of the material layers which are Chromium (Cr), Gold (Au), Multi-Walled Carbon Nanotube (MWCNT) to the sensitivity at three different wavelengths. The four control factors layer thicknesses of this K-SPR sensor were analyzed using MINITAB software and Taguchi's L9 Orthogonal Array (AO) approach. The Kretschmann-based surface plasmon resonance glucose sensor demonstrated improved sensitivity at an optical wavelength of 785 nm in comparison to the near wavelengths of 632.8 nm and 670 nm by 209.80° RIU^{-1}. Therefore, the most effective configuration for the K-SPR sensor has been found to be A3B3C3D1, as a result of optimization using Taguchi Method to achieve the highest sensitivity which is the wavelength at 785 nm, 4 nm of Chromium layer thickness, 60 nm of gold layer thickness and 10 nm of MWCNT layer thickness.

ABSTRAK

Menurut data dan cabaran, populasi yang lebih berumur sedang berhadapan dengan masalah diabetes, kegagalan buah pinggang yang menjejaskan paras gula darah, urea dan kreatinin yang meningkat, sekaligus boleh menyebabkan strok, serangan jantung dan berakhir dengan kematian. Dengan menggunakan kaedah konvensional, pemantauan glukosa bergantung kepada ujian eksperimen seperti tusukan jari atau pendekatan tidak langsung menggunakan enzim seperti glukosa oksida dan glukosa dehidrogenase. Untuk mengatasi isu ini, pendekatan baharu menggunakan penderia Surface Plasmon Resonance (K-SPR) berasaskan Kretschmann dicadangkan. Ia adalah platform yang hebat dalam interaksi biomolekul kerana pelbagai pilihan bahan dalam biosensor. Ia mengukur perubahan dalam indeks biasan bahan yang digunakan. Untuk mengoptimumkan biosensor K-SPR ini, beberapa faktor mesti disiasat seperti bahan lapisan, ketebalan filem lapisan nipis dan indeks biasan pengesanan lapisan. Kesan perbezaan ketebalan lapisan pada K-SPR terhasil dengan menggunakan simulator perisian WINSPALL. Penyelidikan tertumpu kepada kesan mempelbagaikan ketebalan lapisan bahan iaitu cromium (Cr), emas (Au), nanotiub karbon multidinding (MWCNT) kepada sensitiviti pada tiga panjang gelombang yang berbeza. Empat faktor kawalan ketebalan lapisan sensor K-SPR ini dianalisis menggunakan perisian MINITAB dan pendekatan L9 Orthogonal Array (AO) Taguchi. Sensor glukosa resonans plasmon permukaan berasaskan Kretschmann menunjukkan kepekaan yang lebih baik pada panjang gelombang optik 785 nm berbanding dengan panjang gelombang hampir 632.8 nm dan 670 nm sebanyak 209.80° RIU^{-1}. Oleh itu, konfigurasi yang paling berkesan untuk sensor K-SPR telah didapati sebagai A3B3C3D1, hasil pengoptimuman menggunakan kaedah Taguchi untuk mencapai kepekaan tertinggi iaitu pada panjang gelombang 785 nm, 4 nm ketebalan lapisan cromium, 60 nm ketebalan lapisan emas dan 10 nm ketebalan lapisan MWCNT.

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CHAPTER 1

INTRODUCTION

1.1 Background

Surface plasmon resonance (SPR)-based sensors have been frequently used to identify specific medical materials. Numerous techniques and diameters have been used to study the SPR's performance and sensitivity. The SPR's way of assessing the interaction, analyte and ligand without requiring you to invest time and money in costly labelling materials and protocols is one of its key advantages. SPR has been a successful technique for tracking biomolecular interactions in liquids without any need for classification. Due to its high sensitivity approach, it has been used in several application aspects. It uses in industry, including biochemical, medical, clinical experiments, industry research, and visual sensing applications to measure levels.

Many scientists have tested ways to improve the efficiency of the sensors used in SPR applications. The thin layer of metal film at the intersection of two dielectric images with opposite refractive angles and the prism is adversely affected when light is focused onto a metal film through a glass prism and then reflected. When polarized light contacts a metal layer at the intersection of two media with different refractive indices, a phenomenon known as surface plasmon resonance takes place. SPR sensors, which have been used in biosensing for a long time, are used to detect biomolecular interactions. To determine their effectiveness, factors such as the materials used in the thin film, the thickness of the film, and the design of the sensor must be examined.

The aim of this research is to determine the best combinations of thin film thicknesses for glucose detection that will increase the sensitivity of the SPR sensor. One of the ways to identify changes in thickness and wavelength in the refractive index is to detect the sensitivity testing, as proposed an SPR sensor with glucose detection. The Winspall software is used in the experiment to simulate SPR curves for different thicknesses wavelengths and refraction index, RI.

It is important for the researchers to understand the value SPR data can bring to their project work. The accurate angle at which this effect occurs is established before building the surface plasmon resonance biosensor. Because the angle at which the Surface Plasmon mode is formed slightly changes each time a molecule binds to the molecules in the surface coating on the gold film, it is crucially important to measure this angle.

The sensitivity of an SPR biosensor can be determined by how much the wavelength or angle shifts in relation to the change in refractive index on the sensing surface. This sensitivity can be influenced by various factors, depending on the method of excitation used. For prism-coupled SPR biosensors, the sensitivity of the SPR is affected by the type of prism, metal, and wavelength used. The aim of this research is to improve the sensitivity of this type of biosensor. One material that is often studied for its unique properties is MWCNT, as it has been shown to increase the sensitivity of SPR both experimentally and theoretically in previous research.

1.2 Problem Statement

Based on the statistics, from the issues that show, the growing elderly population seems to be facing diabetes and kidney failure problems that affect high blood glucose, urea and creatinine levels and approximately it can cause heart attacks and strokes, this can often result in death. The sensor is now employed in biosensors to measure and the interactions between molecules in surroundings environment. According to that, the variation of refractive index towards the material to be used. To initialize the sensitivity of the glucose in the Kretschmann - based Surface Plasmon Resonance (SPR) sensor in effectiveness.

Previous research using orthogonal techniques may have indicated that there is an interaction between the molecules being studied, but an SPR assay may not show the same interaction.

This could be due to factors such as the denaturing effect of low pH used to immobilize the ligand, or the ligand's protein structure not being able to withstand immobilization or tagging. It is important to consider potential issues related to the sensor surface and immobilization when conducting binding studies using surface-based optical biosensors. To fully understand the observed affinity distributions, it is necessary to use data from a wider range of sensor surfaces and to supplement the information obtained from the sensor surface with data from other techniques that provide information that is perpendicular to the sensor surface. This current study may have limitations in this regard, but it demonstrates the usefulness of the attraction distribution method for studying sensor surface and immobilization properties.

An ideal plasmonic surface sensor has a bioactive area where specific biomolecules recognize analytes, surrounded by an area made of different material. However, it can be challenging to selectively functionalize the supporting sensor surface in the active area. Functionalizing plasmonic surfaces presents more difficulties than functionalizing nanoparticles, which can be fully processed in solution, have a high surface-to-volume ratio, good biocompatibility, and the ability to use appropriate ligands. The composition of the nanostructure is crucial when it comes to surface functionalization. The choice of materials for the individual optical components can affect the sensitivity and overall performance of the sensor. While many materials are commonly used in SPR instrumentation, the material selection is important for achieving the desired performance.

1.3 Research Objective.

a) To simulate the K-SPR curve sensitivity of MWCNT-based material by changing the refractive index using Winspall software.
b) To analyse the performance of water and glucose detection by using K-SPR biosensor at different thicknesses and wavelengths.
c) To optimize the sensor's performance by identifying the optimal combination of design parameters. The L9 method uses a combination of orthogonal arrays.

1.4 Scope of Project.

The K-SPR biosensor detection can define the curve of the glucose detection with polymers layer material due to that, the objective to use in Winspall software to analyze whether it can be an observer to the sensitivity performance and the other few parts need to be observed. To run this simulation, each material's wavelength and thicknesses need to be determined, and there are three different wavelengths: 670 nm,632.8 nm, and 785 nm. While thicknesses will be around 1-50 nm, it precisely depends on the layer material BK7, Cr, Au, and ppy MWCNT.

The material of BK7 is basically from a thin glass to perform the simulation which in the first layer. Thickness BK7 is using in a very thin layer that is narrow to 0 and less than 1 nm. It should be a fixed value around 2 nm. From that, Cr (Chromium) metallic is an additional essential layer to attached in between surfaces as well as to observe the sensitivity, where the Cr thicknesses will be determined during the simulation of this research. Au (Gold) in a third layer provides optical stability and optical qualities since it is the best metal-dielectric for optimum results. At the same time, the fourth material is PPy/MWCNT (Polypyrrole Multiwall Carbon Nanotubes). The Winspall software will be developed to simulate the effectiveness and sensitivity based on the curve of water and glucose K-SPR biosensor observation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Various applications were used to determine the efficiency of detecting some of the difficulties on biomedical sensors. It will discuss the K-SPR sensing principle and SPR-based Biosensor as a flexible method for biological analysis. Its optical properties and Taguchi's L9 Method also include a few processes, as it is necessary to do the previous research and linked to SPR sensors.

2.2 K-SPR Sensor

A biosensor is a device that converts a signal from a biological interaction into a signal that can be understood by the user. In general, biosensors are used to measure the amount of a certain biomolecule, known as an analyte, and to study the interactions of specific biomolecules. A biosensor can be broadly described as a combination of two main components: a bio-recognition element and a sensing element [1]. Figure 2.1 shows the bio-recognition element can be an enzyme, DNA, catalyst, cell, or other biological species. The transducer is the functional part that can rely on one or a combination of electrical, mechanical, acoustic, optical, and piezoelectric principles [2].

It has a significant application in life science, drug development, biological detection, air quality detection, and also other fields. Thorough research studies on the optimization of SPR biosensors by using a few additional new materials and utilizing the structure have been conducted for this purpose. Surface plasmon resonance (SPR) is an effective technique for retrieving information on biomaterials and nanomaterials' optical characteristics. Essentially, the SPR is determined by the material layer's characteristics and environmental factors. One of the main benefits of the SPR is that the light beam will not go through to those dielectric mediums [3]. The main abilities of the SPR are identifying the medium following the metal layer and observing the interaction of the biomolecule layers.

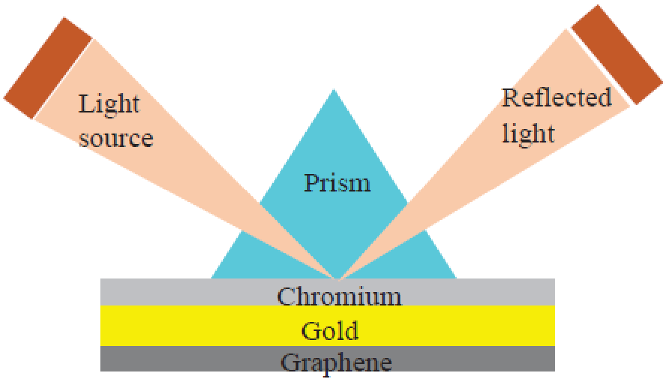

Figure 2.1: Layer of SPR sensor [2].

Nowadays, the Kretschmann – Surface plasmon resonance sensor arrangement, which incorporates a prism, glass slide, and thin metal film, has been ordinarily utilized in various SPR biosensors. The incident light source is created when it is reflected out onto the left side of the sensor by the prism, and a sensor then captures the reflected light. The SPR biosensor is able to change them in terms of the refractive index because the SPR has high sensitivity, and it depends on the surrounding environment as well. The main character of the experiment is the metal used in SPR sensors, and the layer of thicknesses of the metal, thin metal film, can affect sensor performance and can indirectly cause roughness of the metal film surfaces performance in SPR sensors [4].

Wavelength and angular interrogation techniques are the most common SPR interrogation strategies utilized in bio-sensing applications. These interrogation techniques were created and can be used to define and detect the assembly of biological and chemical materials depending on based on what they perform with specific target molecules such as DNA, proteins, antibodies, enzymes, and other molecules. The detection limits of this interrogation approach have been drawn to five orders of magnitude better than the detection limits of previous detection methods. SPR systems are now being developed by various industries, with various throughputs and built-in technology [5]. Sensitivity is the main point for each bio-detecting system [6].

2.3 Metal layer design

Because Au thin layer interacts directly with the sensor properties of the SPR sensor, it is commonly used as the outer properties of the sensing layer because it provides good stability in the chemical environment. As a result, Au thin layer is very popular as the outer properties of the sensing layer because it is suitable for biosensing applications which are preferred to be implemented on that SPR prism. Graphene is being used due to its high optical absorbance, better surface structures, and zero band gap. Meanwhile, the ability of gold to hold into the place is less, so that to lead this problem by adding a graphene layer on gold film to improve the performance of the SPR sensor. However, the geometrical and properties of nanostructures like graphene are difficult. It is designed with four factors materials which are BK7 as glass, Cr (Chromium), Au, a metal layer of gold and graphene. Each material has its own fixed refractive index and extinction coefficient value by determining using refractive index info perpendicular to three thicknesses of optical wavelength, 632.8, 670, and 785 nm. At the same time, the graphene is L x 0.34 nm (L is a count of the graphene layers) [7].

2.4 Sensitivity and thicknesses

The surface sensitivity of responsiveness is a crucial factor that determines the basic measurement of biomolecules detected by surface plasmon resonance biosensors. The ability of the surface to detect can be enhanced by increasing the refractive index contrast between the adsorbate layer and the surrounding environment or by reducing the bandwidth [8].

In view of the below examinations, figure 2.2 shows, we can presume that graphene assumes a significant part in further developing SPR sensing. The figure above shows the variety of responsiveness of sensitivity for the modest metal and graphene layer. The sensitivity rapidly decreases since the number of graphene layers increases.

Graphene has the hybrid structure ITO to improve in terms of sensitivity perpendicularly towards thickness uses. Consists of WS2, MoS2, MoSe2, and ITOWSe2 Metal. They all show the studies of different sensitivity changes towards different Cu thicknesses.

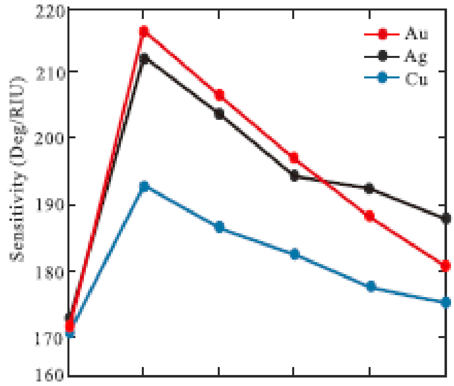

Figure 2.2: Bio-layer 3, 4, 5-layer of graphene [9].

Additionally, ITO graphene can enhance sensitivity, as well as other materials such as WS2, MoS2, and metal. The sensitivity of different amounts of WS2, MoS2, MoSe2, and WSe2 layers on Au is studied. WSe2 has the best results in the Au-ITO of an SPR biosensor. When the value of WSe2 is a monolayer and the thickness of Au and ITO is 55 nm and 2 nm, respectively, the optimal sensitivity is 217.4°/RIU. When the value of WS2 is a monolayer, the thickness of Au is 52 nm, ITO is 2 nm, and the sensitivity recorded 215.4°/RIU. Next, MoSe2 Au's thickness is 53 nm and ITO is 2 nm, the sensitivity recorded is 200.0°/RIU. Lastly, when the number of MoS2 is a monolayer and the thickness of Au is 51 nm and ITO is 3 nm, the sensitivity recorded is 195.2°/RIU [9]. The performance of the SPR sensor is greatly affected by the type of thin metal film used, as well as the different refractive index and thickness of the layers measured in nanometers (nm).

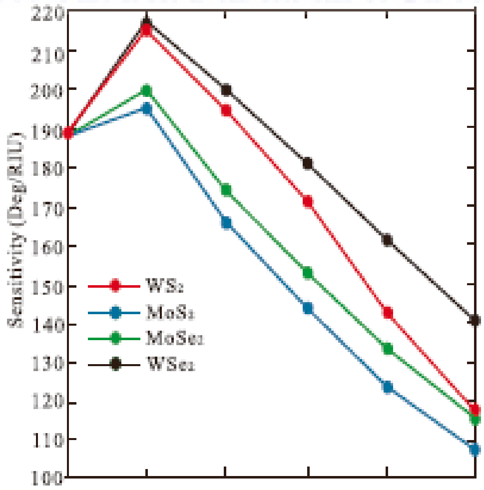

Figure 2.3: Bio-layer 3, 4, 5-layer of graphene Consists of WS_2, MoS_2, $MoSe_2$, and ITOWSe_2 Metal [9].

2.5 Angular resonance

A specific angle is used to direct a p-polarized light beam, which is incident light, into a glass prism in order to increase the wavenumber and create resonance at a certain wavelength. After passing through a prism with a given refractive index, the light is reflected from the thin surface of the metal. The beam lenses allow for a small change in the angle of the incident beam compared to the angle of the light and plasmonic waves. At the intersection of the prism surface and the metal, a spectral wave is created, which can interact with the SP waves that occur at the metal-dielectric interface. An electronic plasmonic wave cannot be excited by s-polarized light, which is perpendicular to the plane of incidence. When a plasmonic wave is formed, the energy associated with it is absorbed in the output beam reflected off the metal [10].

The input monochromatic light source is shown on the left (Figure 2.4), shining onto the prism block at an angle close to pi to the metal surface. The reflected spectrum, which can be seen on a CCD camera, is shown on the right. The decrease in intensity in the reflected light curve is due to the match of input photons with surface plasma waves. The choice of light source and wavelength (polychromatic or monochromatic) is crucial in designing SPR sensors. A monochromatic light source is one that has a single or very narrow range of wavelengths. The choice of wavelength and angle of incidence may be affected by the type of light source used in the SPR experiment [1].

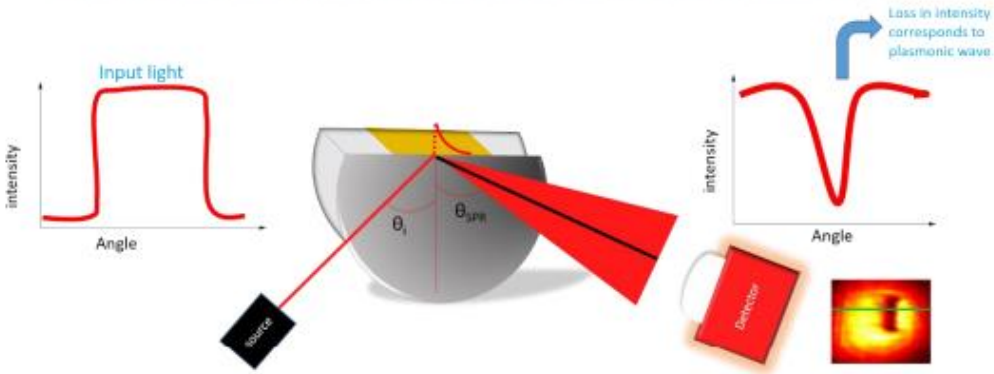

Figure 2.4: Angular interrogation [1].

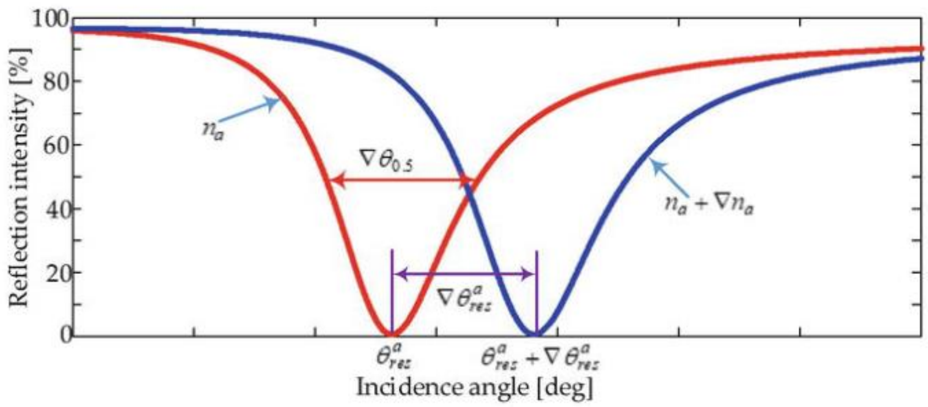

Figure 2.5: Changes in the SPR curve due to changes in the sensing medium RI are represented in this diagram [11].

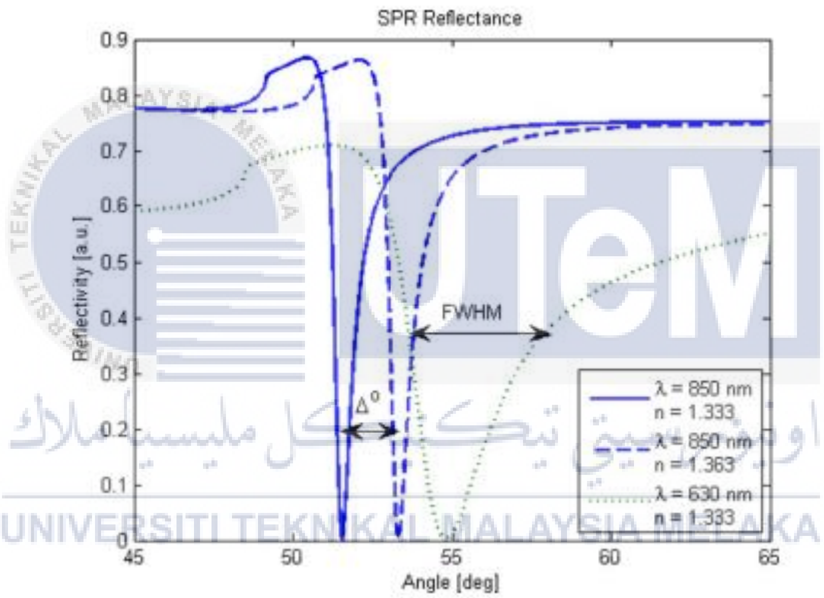

Figure 2.6: SPR curves for wavelengths of 850 nm and 630 nm and FWHM [12].

The absorption band observed is the outcome of the combination of multiple resonance peaks. Each peak corresponds to a specific resonance condition, determined by a specific angle-wavelength combination. The results of the tests indicate that sensor configuration with a photoresist buffer layer performs better in terms of the range of refractive indices that can be recognized and the signal-to-noise ratio (SNR). Therefore, the figure below illustrates the external refractive index of 1.332, and the full width at half maximum (FWHM) of the SPR curve for the two sensor configurations, with and without the buffer layer [13].