09.30.2020

BERKELEY PUBLICATION AND RESEARCH INTERNATIONAL

Journal of Med., Biological and Pharm. Sci. Vol. 13 No. 3

SURFACE PLASMON POLARITON TECHNIQUE IN DETERMINATION OF SUCROSE IN CARBONATED DRINKS

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ABSTRACT

In this research, an optical sensor based on Kretschmann Surface Plasmon Polarton technique known as Charge couple device (CCD) with a sensitivity of 0.03 was used to detect the sucrose content in a carbonated drink. The drink samples with assumed different sucrose concentration have been chosen for angle scan SPR measurements using transfer matrix method of MATLAB programming language. All the simulation were assumed at room temperature as from the input data of sucrose refractive index was collected from the international scale of refractive index at 20⁰C. The samples with different sucrose content as reflected by their various refractive index. The results show that the shift of resonance angle ($\Delta\theta_{SPP}$) increases linearly with the sugar content. Therefore, this technique could be used as optical sensor for detecting sucrose content in carbonated.

Introduction:

Surface Plasmon Polariton (SPP) has emerged as the powerful optical detection technique for the study of free molecular interaction in real time, within a variety of devices applications, such as life science, electrochemistry, optoelectronics, chemical vapour detection, food, environmental safety etc. in this project SPPs will be used to measure the accuracy and concentration of sugar content in a liquid. Due to its simplicity nearly every commercially SPP instrument uses the detection scheme called the Kreschmann configuration. In the set-up the light from the light source passes through the dielectric – metal medium and reflect off all the back side of the surface and into the detector

Key: Surface Plasmon Resonance, Carbonated drink, Sucrose, MatLab, Transfer Matrix Method.

at a certain incidence angle known as Resonant angle (Chen et. al., 2007). Light is absorbed by the electrons in the metal film of the surface, causing them to resonant. These resonating electrons are also known as surface plasmon. Surface plasmon are sensitive to the surrounding environment, and the result is the intensity lost in the reflective beam, which appears as a dark band and can be seen in a plot of intensity against dip angle as a dip in SPP curve, the shape and location of the SPR depth can then be used to convey information about the surface. SPP technology is commonly utilized for the study of molecular binding interaction between free molecules and solution, which they are linked to. As the molecular binding event takes place the angular position of the dark-band shifts, and the shift in reflectivity curve can also be observed. This is the direct method of detection which avoids the drawback of labels. Another powerful aspect of SPP technology is its ability to observe the time dependent binding interaction between molecules by monitoring their changes in SPP response over time, researchers can study the kinetic of a molecule binding event (Bendickson et.al., 1996).

SPP spectroscopy is a surface-detective method that has been utilised to characterize the thickness and/or index of refraction of dielectric medium at noble metal gold (Au) surface. Previously, SPP detection techniques have been extensively studied (Homola, 1999). SPRs, are infrared or visible frequency electromagnetic waves, which go along a metal-dielectric or metal-air interface. The expression "SPP" clarifies that the wave includes both charge movement in the metal ("surface plasmon") and electromagnetic waves noticeable all around or dielectric ("polariton") (Zayat et al, 2003). Application of SPPs enables subwavelength optics in microscopy and lithography beyond the diffraction limit. SPR enables the first advanced micro-mechanical measurement of a fundamental property of light; we can deduce momentum of a photon through di-electric medium. Other applications of SPR are, light generation, bio-photonic and photonic data storage (Pujol *et. al., 2007*). This proposed research will deal with the photonic application of SPPs, the photonic is the science of light (photon) amplification, switching, signal processing, modulation, transmission, detection, generation, and sensing though covering all light's technical applications over the whole spectrum, most photonic applications are in the scope of visible and near-infrared light. The term photonics developed as an extensively of the first practical semiconductor light emitters was designed in first quarter of 1960s and optical fibers developed in the 1970s. In this project the method of SPRs will be used to measure the concentration of sugar in a liquid, this will lead to its application in the medical field (Bozhevolnyi et. al., 1996)

Methodology

The method which will be conducted by simulation, involve using a Broad band light source. Sample include liquid of different sugar concentration. The Surface plasmon polariton deals with metal-dielectric interface, so will need a silver surface as the metal and sugar concentration as the dielectric. The light source will be directed towards the interface and different refractive index will be observed. The material needed for this research includes; Mat-lab programming software for data analysis, laser, metal film (silver coated), glass prism, CCD and liquid with different percentage of sugar concentration.

The main barriers if there are any are getting the silver coated metal and may be financial implication. The project does not involve human ethics, animal ethics and travel or fieldwork are not required. There is no need major concern about laboratory safety regulations and handling of laser safety guides, as the only the method of simulation will be involved using the matrix transfer platform of the MATLAB programming language.

In this method Surface plasmon waves (SPWs) is generated at the interface between the conductive metal film (Ag) and the insulating molecular layer (sugar concentration) by striking the metal sensor with a particular type of light from a Laser light source. During the generation of SPWs, light is also reflected off of the metal surface i.e the metal film (Ag). Past a specific incident angle as shown, and only in the presence of the highly refractive glass prism, all the energy from the incident light wave will be transferred to the reflected light wave which is known as the total internal reflection. Furthermore, at a very specific angle past the point of total internal reflection called the SPR angle, a majority of the incident light energy that would have typically been transferred to the reflected light wave will instead interact with the generated SPWs, resulting in a phenomenon called resonance. At resonance, a minimum in reflected light intensity will be observed, and the SPR angle can thus be determined by measuring the intensity of the reflected light through a photo detector where in this research we using the Pin type photodetector, and plotting it as a function of incidence angle as clearly illustrated in Figure 8. Finally the sugar concentration will served as the sensing material.

Testing

The developed simulation will not be of much use if it does not satisfy the object it was designed for. Much of that will be achieved if the system is tested properly to ensure that it complies with the requirements that were specified at the beginning of the software life cycle. The developed software was tested and retested to meet the simulation needs that it was designed for.

Do note in the code that input were not asked for, but were rather hard coded into the program code, reason being that given the number of parameters that were required, it would have taken a longer time testing if these parameters were to be input every time a test was done.

Since the system was not compiled, but run in the same development environment, changeable parameters were easily changed in the program code to see how they affect the final results, the throughput and the normalized throughput in this instance.

Code Implementation

The proper software programming language was considered (MATLAB) in the execution of the project, and in that light a strategy was decided upon for the successful using the Transfer Matrix method of the program that will do the simulation of various among of sugar concentration, in liquid using surface plasmon polariton was considered.

Optical Thickness

In this simulation we going to try different values to obtain the right thickness (optical thickness) of the thin film the values to be tried ranges from 20^{-9} $metres\ to$ 90^{-9} metres, but shown in the figure below is that of 40 nm, 50 nm and 60 nm, where using the Ag coating material as the thin film. Line 52 in appendix 2 is the value for the optical thickness as in Eqn 3.1 below.

h1m=50e-9; 3.1 % the optical thickness of the Ag thin film

At the optical thickness we will notice the reflection will be zero, conclusively after several trials, it was found out that the thin film of the silver value should be 50 nm for the optical thickness. This was run several time before obtaining our desire optical thickness, which is 50 nm, as shown from the figures below.

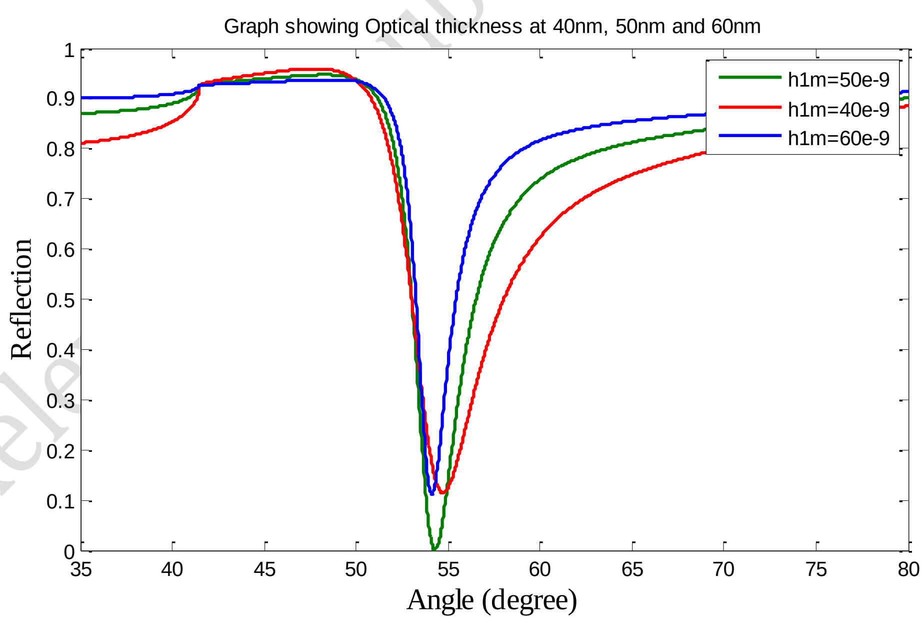

Fig 3.5. The graph of reflection against angle, showing different values of optical thickness.

From figure 9 above after testing the various values of optical thickness, it was observed that at exactly 50 nm (green line), the reflection is at exactly zero. This gives us the desire value of OP. The optical thickness of a light-absorbing medium is its geometrical thickness times its intensity attenuation coefficient. For example, an optical thickness of 1 implies that the transmitted power is reduced to 1/e (≈ 37%) of its original value. Therefore for maximum power transmission we try to make our OP to be zero, which was achieved in case of this design. As noticed the green line in the figure touches vertical, which means the reflection ias at zero. The red, blue lines have a values 40nm and 60nm respectively and they do not fit in to our design. It can be seen that the resonance wavelength rises with the increasing thickness of metal layer. As the thickness of metal layer is greater than 80 nm, the resonance wavelength changes little, and the resonance dip becomes flat, as shown in figure 10 below

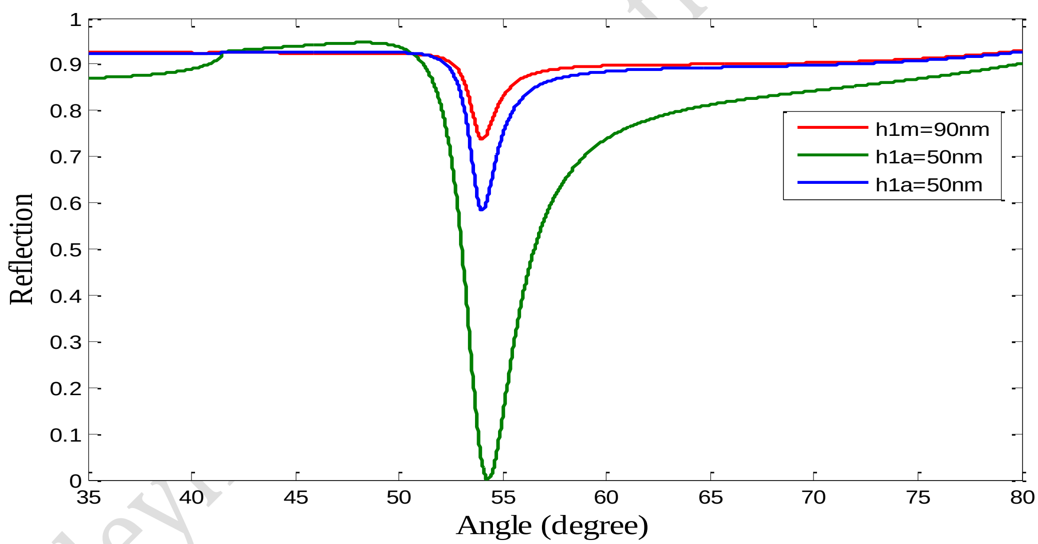

Fig 3.6. Graph of reflection against angle showing the effect in increasing the Optical thickness

Thickness of the Sensing Layer

Figure 10 below is the plot of reflection against angle showing how to choose the preferred thickness of the sensing material. This was achieved by adjusting the value of formula describing the sensor thickness. As in Appendix B line 62, as shown in equation 3.2 below.

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h1a=90e-9; 3.2 % thickness of sensing layer

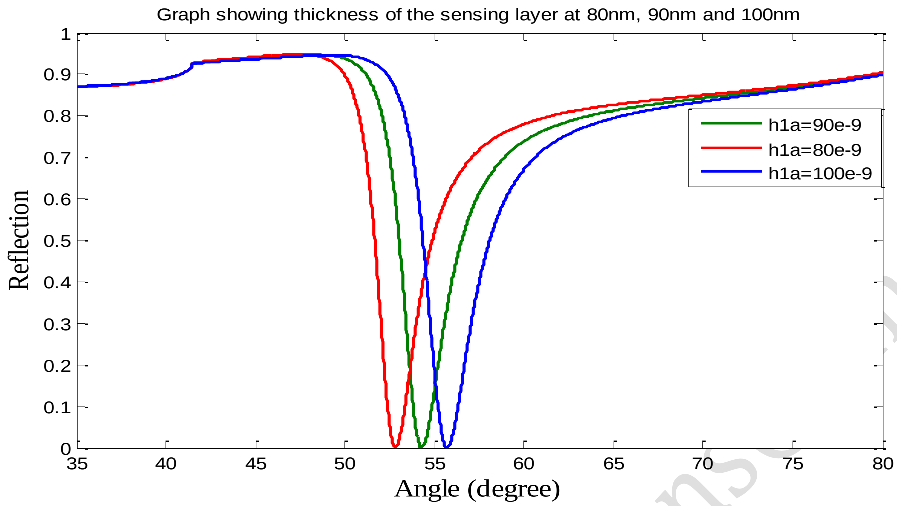


Fig 3.7. The graph of reflection against angle, showing different values of optical thickness.

The green line has value of sensing thickness of 90nm which is the desired thickness because it corresponds to the value of refractive index. Blue and red lines have the values of 80nm and 100nm it was displayed to show the different irritation that was conducted before arriving at our desired value. As the thickness of sensing layer exceeds a certain value, about 200 nm, the resonance wavelength is insensitive to the sample RI, since the sensing layer shields the effect of sample dielectric function.

Result

The aim of this research is to measure the concentration of sugar content in a liquid using SPR method. This was achieved from the simulation results using transform matrix method of MATLAB programing as shown in appendix B. The input parameter is the reflective index (n) was obtained from appendix B, which is deduced in line 13, as shown in equation 4.2, the equation is the permittivity of the sensing material. Sensing material used in this case was the liquid with different sugar concentration. Where the permittivity is given by

$\mathcal{E} = n^2$

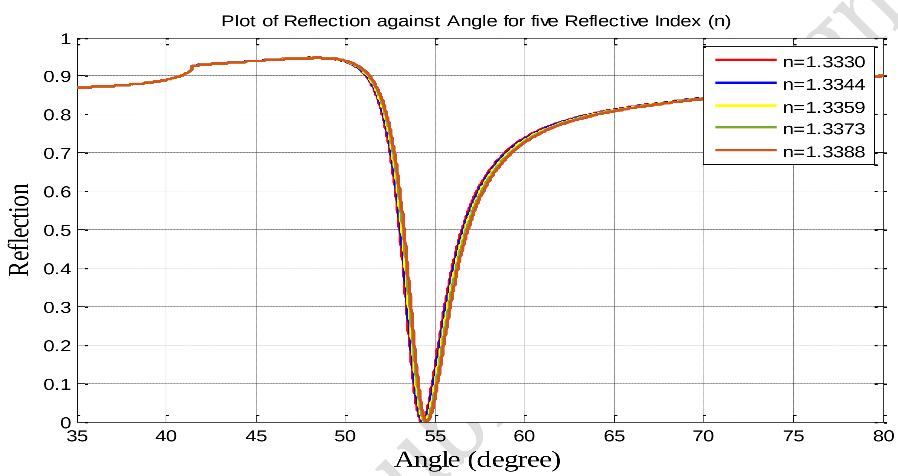
Where $\mathcal{E}$ = permittivity

$n = refractive\ index$

This is also given in appendix B in line 13, as shown in Eqn 4.2 below
Epsa0=1.3330^2; % permittivity of sensing material

Simulated Results

The values of refractive index n was obtained in appendix A, the value ranges from $n =$ 1.3330,1.3340, 1.3359, 1.3373 … … … … … … … … … .1.4980, 1.5009, 1.5033. A total of 86 values of where simulated and results are displayed from the figures shown below.



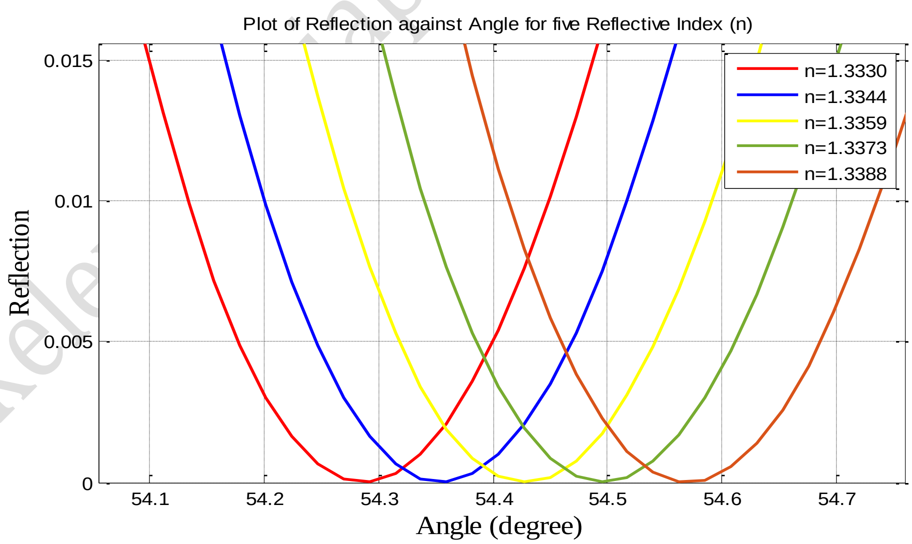


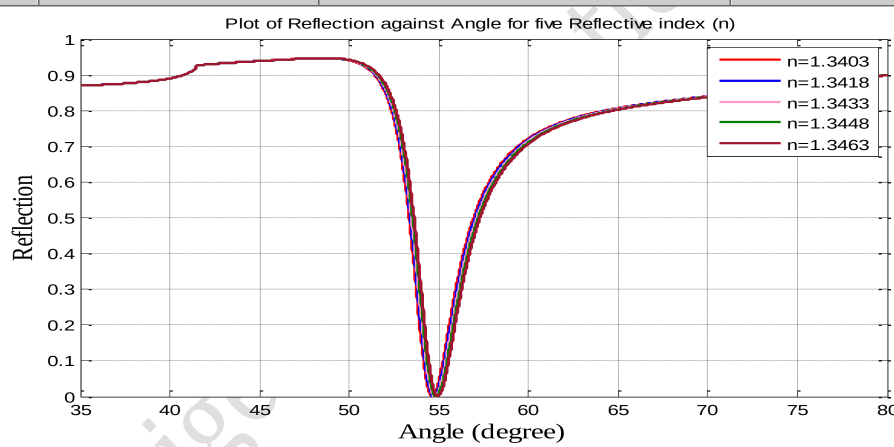
Fig 3.1. The plot of Reflection against incidence angle with refractive index from n= 1.3330 to 1.3388

ISSN: 1211-4401

Figure show the result of different permittivity of liquid, with n ranges from 1.3330 to 1.3388 ie five values of n. The value 1.3330 is the refarctive index of pure water at 20°C, therefore it can be observed at this point sugar concentration is zero. A noticed of the change of angles where observed which is our output, which where tabulated in table 2 below.

Table 3.1: The relationship between incidence angle and Concentration of n from 1.3330 to 13388

S/N	Reflective Index	Incidence Angle (degree)	Concentration (%)
1	1.3330	54.292	0
2	1.3344	54.360	1
3	1.3359	54.427	2
4	1.3373	54.495	3
5	1.3388	54.562	4



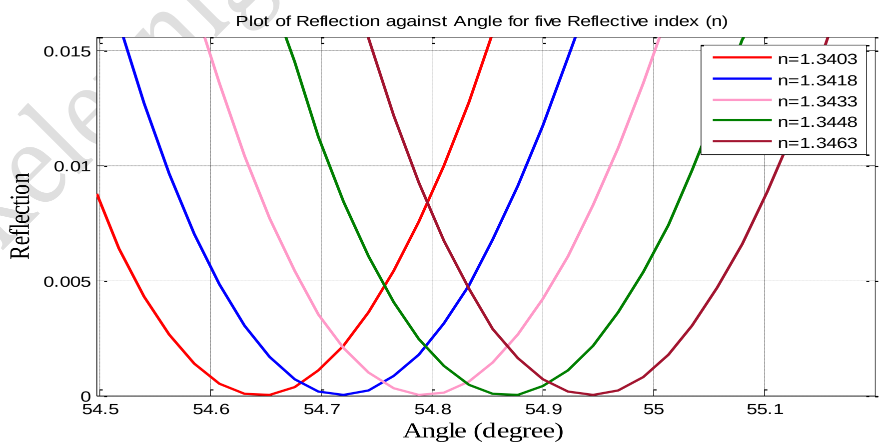


Fig 3.2. The plot of Reflection against incidence angle with refractive index from n= 1.3403 to 1.3463

Figure show the result of different permittivity of liquid, with n ranges from 1.3403 to 1.3463 ie five values of n. A noticed of the change of angles where observed which isour output, which was tabulated in table 3.2 below.

Table 3.2:The relationship between incidence angle and Concentration of n from 1.3403 to 13463

S/N	Reflective Index	Incidence Angle (degree)	Concentration (%)
1	1.3403	54.652	5
2	1.3418	54.720	6
3	1.3433	54.787	7
4	1.3448	54.877	8
5	1.3463	54.945	9

Measured Resonance Angles

The aim of this project is to notice the shift of angle, the shift in the angle can be monitor using a detector. Charge couple device (CCD) detector will be used in this case. Another method of measuring the concentration if by motoring the shift in wavelength (λ), but this method is very expensive because its uses spectrometer instead of CCD, the cost of spectrometer is higher than CCD. Table 18 is the complete tabulated simulated results showing relationship of three parameters, that is refractive index (Input parameter), incidence angle and the sugar concentration. Their comparison were plotted in figure 28 and 29 below.

Table 3.1: The complete table of the simulated results

S/N	Reflective Index	Resonance Angle (degree)	Concentration (%)	Shift in Angle □□□SPR
1	1.3330	54.292	0	-
2	1.3344	54.360	1	0.068
3	1.3359	54.427	2	0.067

4	1.3373	54.495	3	0.068
5	1.3388	54.562	4	0.067
6	1.3403	54.652	5	0.090
7	1.3418	54.720	6	0.068
8	1.3433	54.787	7	0.067
9	1.3448	54.877	8	0.090
10	1.3463	54.945	9	0.068
11	1.3478	55.013	10	0.068
12	1.3494	55.103	11	0.090
13	1.3509	55.170	12	0.067
14	1.3525	55.260	13	0.090
15	1.3541	55.350	14	0.090
16	1.3557	55.418	15	0.068
17	1.3573	55.508	16	0.090
18	1.3589	55.598	17	0.090
19	1.3605	55.665	18	0.067
20	1.3622	55.755	19	0.090

Conclusions

The study was set out to explore the concept of using simulation to measure sugar concentration in a liquid using Surface Plasmon Polariton (SPP). SPP is an optical process in which light satisfying a resonance condition excites a charge-density wave propagating along the interface between a metal and dielectric material by monochromatic and p-polarized light beam

This work set out to measure the concentration of sucrose in carbonated drink using the surface Plasmon Polariton method.

*From the results we see that:

- We can record the resonance angle from the values of refractive index (input parameter).
- We can observed that the refractive index of a liquid is directly proportional to resonance angle.

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- It was confirmed that the resonance angle is proportional to the sugar concentration
- The higher the number of errors, the lower the achieved throughput.

Based on the above, for optimum result the optical thickness and thickness of the sensing material most be put into consideration. The perfect optical thickness for this model was simulated to be 50nm and the sensing material thickness is 90 nm.*

There is far little literature available so as to enable a comparison of the results arrived at here "apple for apple", but however, the little that are available agree wholly with what is presented here. Variations with other results, if any, may be due to assumptions made, network topologies, and maybe network parameters set by each researcher as discussed by Lévesque et al, in 1994 .

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