

Optical Properties and Sugar Content Determination of Commercial Carbonated Drinks using Surface Plasmon Resonance

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Abstract: In this study, an optical sensor based on Kretschmann SPR technique was used to detect the sugar content in commercial carbonated drinks. Three samples of carbonated drinks labeled as “Coke”, “100 Plus” and “F&N Orange” have been chosen for angle scan SPR measurements. All the measurements were carried out at room temperature using He-Ne laser beam (632.8nm, 5mW) as a light source. The commercially available carbonated samples were diluted by adding distilled water to produce solutions with different sugar content. The results show that the shift of resonance angle ($\Delta\theta_{\text{SPP}}$) increases linearly with the sugar content in which the detection limit and sensor sensitivity could be quantified. Therefore, this technique could be used as optical sensor for detecting sugar content in carbonated soft drinks.

Key words: SPR technique, dielectric constants, detection limit, kinetic behavior

INTRODUCTION

Carbonated soft drinks are popular among many people as a drink that can quench thirst. The thirst quenching effect is due to the presence of gas in the drink. Carbon dioxides are pumped into carbonated drinks to produce the fizz in the drink. One of the main components of carbonated drinks is sucrose. Sucrose that is used in carbonated drinks is made from sugar cane and sugar beets. They are the most important and major ingredients used for sweetening. Sucrose is acidic in nature and the acidity increases when carbon dioxide is pumped into the carbonated drinks. Besides sucrose, fructose is also present in carbonated drinks especially drinks that are derived from fruits. Glucose which is the principal component of starch and corn syrup, which is used in production of carbonated drinks, are also widely used as sweeteners. Each of the carbonated drink has different color and is from the isotonic, cola and fruit juice categories.

Surface plasmon resonance (SPR) spectroscopy is a surface-sensitive technique that has been used to characterize the thickness and/or index of refraction of dielectric medium at noble metal (gold) surface. For the last decade, surface plasmon resonance sensors have been extensively studied^[1]. Phenomenon of surface plasmon resonance can be observed when p-polarized light hits a metal film under total internal reflection conditions^[2]. Surface plasmon resonance technique has emerged as a powerful technique for a variety of chemical and biological sensor applications. The first chemical sensing based on SPR technique was reported by Liedberg *et al.*^[3] where they have demonstrated the exploitation of SPR.

SPR 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. The intensity of the reflected light is reduced at a specific incident angle producing a sharp shadow (called surface plasmon resonance) due to the resonance energy occurs between the incident beam and surface plasmon wave. SPR is regarded as a simple optical technique for surface and interfacial studies^[4] and shows the great potential for investigating biomolecules. SPR has been used to study the refractive index of liquid measurement^[5,6], pesticide detection^[7] and SPR also can be regarded as a significant tool for analyzing saccharides where saccharides solution commonly has a high refractive index^[8]. In this study, we report the surface plasmon resonance technique as an effective optical sensor for detection of sugar content in commercial carbonated drink. Three samples were chosen for the present investigation. They are from carbonated drinks of the isotonic, cola and fruit juice category, respectively.

MATERIALS AND METHODS

The surface plasmon resonance measurement has been carried out by measuring the reflected He-Ne laser beam (632.8 nm, 5 mW) as a function of incident angle. The instrument that we used is schematically shown in Fig. 1.

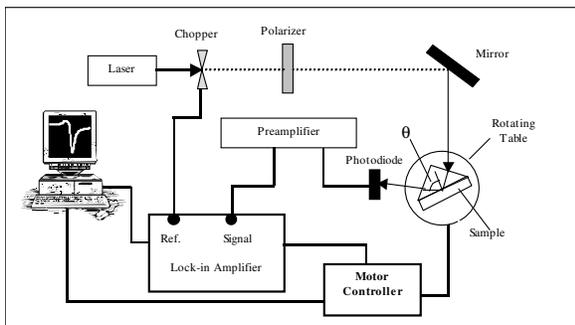


Fig. 1: Experimental setup for angle scan surface plasmon resonance technique

Table 1: The sugar concentration recorded with a refractometer

Diluted Carbonated Soft Drink Solutions (V/V)	Sugar concentration (%) measured by refractometer		
	"100 Plus"	"Coke"	"F&N Orange"
10%	0.6	1.0	1.2
20%	1.2	2.0	2.6
30%	2.0	3.2	4.0
40%	2.6	4.2	5.2
50%	3.2	5.2	6.6
60%	4.0	6.2	7.8
80%	5.2	8.6	10.4
100%	6.6	10.4	13.0

The optical setup consists of a He-Ne laser, an optical stage driven by a stepper motor with a resolution of 0.001° (Newport MM 3000), a light attenuator, a polarizer and an optical chopper (SR 540). The reflected beam was detected by a sensitive photodiode and then processed by the lock-in-amplifier (SR 530). The sugar concentration of "100 Plus" was directly measured using refractometer (Atgo N, 0-32%). This pure soft drink denoted as the 100% "100 Plus". The sample of "100 Plus" was then diluted systematically by adding the right amount of distilled water to produce the final six solutions with concentration of 80%, 60%, 50%, 40%, 20% and 10% of (V/V) ratio. The sugar content of the solutions was again measured by the refractometer. Similar procedure was applied to prepare sample solution of "Coke" and "F&N Orange" soft drinks. Table 1 listed the solution that used in the present work.

RESULTS AND DISCUSSION

In the SPR method, the resonance angle is very sensitive to the refractive index of the medium outside the gold thin film. When the solution of different concentration of reagent was used, the shift of reflectivity was observed. Figure 2 shows the reflectance curves were obtained for selected concentration of "Coke". The resonance angle was observed at 73.413°, 73.795°, 74.112°, 74.620° and 75.188° for the sugar content in "Coke" of 1.0%, 3.2%, 5.2%, 8.2% and 10.4%, respectively. The curve shifts to the right as the concentration increases. This trend was found in all three carbonated drinks.

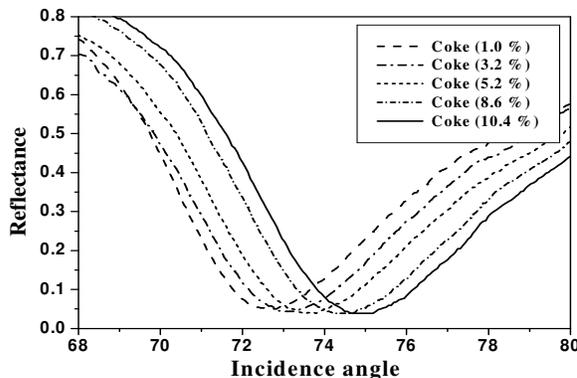


Fig. 2: Reflectance versus incidence angle for selected concentration of Coke

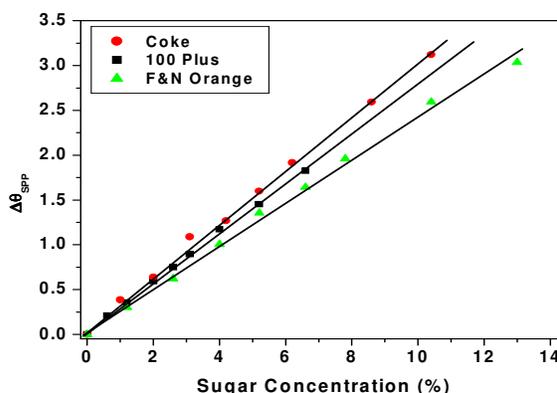


Fig. 3: $\Delta\theta_{SPP}$ observed for different concentration of "100 Plus", "Coke" and "F&N Orange" with reference to distilled water

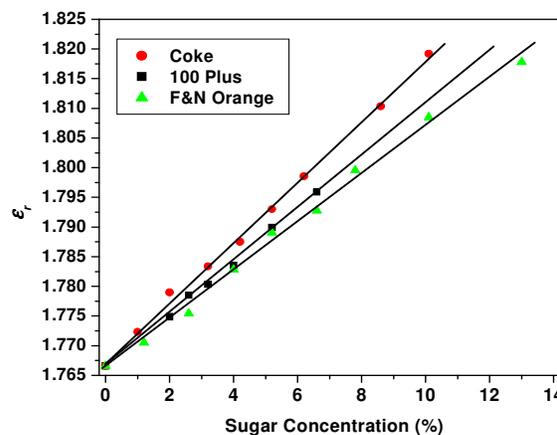


Fig. 4: The real part of dielectric constant, ϵ_r as a function of carbonated soft drinks concentration

The correlation between the sugar concentration in the diluted carbonated soft drinks samples and the shift of the incident angle, $\Delta\theta_{SPP}$ is shown in Fig. 3. The curve shows that the overall shift of resonant angle was highest for "Coke" compared to the other two carbonated drinks. At about 4.0 % sugar concentration,

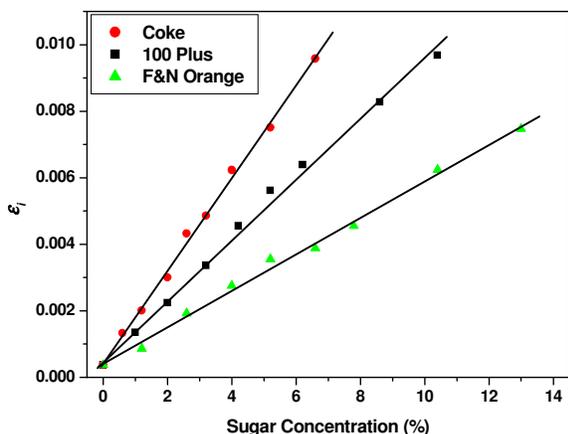


Fig. 5: The imaginary part of dielectric constant, ϵ_i as a function of carbonated soft drinks concentration

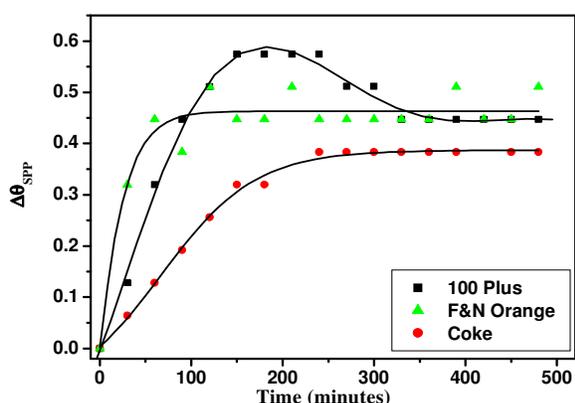


Fig. 6: The shift of resonance angle versus time for carbonated soft drinks

the shift of resonant angles for “Coke”, “100 Plus” and “F&N Orange” were 1.217°, 1.216° and 1.153° respectively. The SPR technique was found to be more sensitive to “Coke” and “100 Plus” than “F&N Orange”. The angle shift, $\Delta\theta_{SPP}$ increases linearly with sample concentration. Since the straight line passes through the origin ($\Delta\theta_{SPP} = 0^\circ$ at zero sugar concentration), it meant that the sensor is only sensitive to the sample solution. The slopes of the straight lines which refer to the sensor sensitivity were determined as 0.295°, 0.275° and 0.239° per (%) sugar concentration for “Coke”, “100 Plus” and “F&N Orange”, respectively.

The detection limits for the present measurements were estimated to be approximately 0.01, 0.03 and 0.05 (%) sugar concentration for “Coke”, “100 Plus” and “F&N Orange”, respectively.

By fitting the experimental data to the Fresnel equation as proposed by previous researchers^[9,10], the value of real and imaginary part of dielectric constants, ϵ_r and ϵ_i of the three carbonated soft drink samples were obtained. Figure 4 and 5 show the value of real and

imaginary part of dielectric constants, ϵ_r and ϵ_i as a function of sugar concentration. We have observed that the experimental values of ϵ_r and ϵ_i for the carbonated drink sample in the present work increase linearly with the increasing of sugar concentration.

The kinetic behaviour of the system was also examined by monitoring the self-assembling process on the metal surface in a real time. Figure 6 shows the variations of the resonance angle for gold/sample interfaces for “100 Plus”, “Coke” and “F&N Orange” obtained at sugar concentration of 1.2 %, 2.0 % and 2.6 %. These particular sugar concentrations were obtained by dilution of 20 ml carbonated drinks per 100 ml of distilled water. The $\Delta\theta_{SPP}$ was recorded by taking the difference between the resonant angles at $t=0$ min to $t=t$ min. It was observed that the shift of incidence angle increase exponentially followed by a slow increasing up to a definite value. These definite values were dependent on the initial concentrations of the solution^[11]. “F&N Orange” responds faster compared to both “100 Plus” and “Coke” before reaching the plateau region. “Coke” requires 240 minutes to reach the plateau region compared to “F&N Orange” that reaches the saturation point at $t = 90$ minutes. The curve for “100 Plus” was observed to increase from $t = 0$ min to $t = 180$ min and start to decrease after $t = 180$ min. At $t = 330$ min, the curve reaches a plateau. This was due to the self-assembling process on the gold surface in real time^[12] of “100 Plus” on the gold surface. The increase in resonance angle with time is mainly due to the increment of the number of molecules adsorbed to the metal surface. Therefore, the binding process changes the refractive index of the medium adjacent to the metal surface^[13]. The differences of those responses may due to the different structure of sugar in carbonated drinks sample.

CONCLUSION

A simple optical sensor based on Kretschmann surface plasmon resonance has been used for determination of sugar concentration in carbonated drink. The sensitivity of the detection was calculated to be 0.295°, 0.275° and 0.239° per (%) sugar concentration for “Coke”, “100 Plus” and F&N Orange, respectively. The detection limit of this sensor was estimated to be 0.01, 0.03 and 0.05 (%) sugar concentration for “Coke”, “100 Plus” and “F&N Orange”, respectively. We observed that the shift of resonance angle ($\Delta\theta_{SPP}$) increases with time greatly due to the increment of the molecule deposited on the gold surface. Since the $\Delta\theta_{SPP}$ increases linearly with the increasing of sugar concentration, this technique is capable to be used as effective optical sensor for detection of sugar content in carbonated soft drink.

ACKNOWLEDGEMENTS

The authors would like to thank the Malaysian Government for financial support through IRPA Research Grant (55155). The laboratory facilities provided by the Department of Physics, UPM are also acknowledged.

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