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THE NUMERICAL STUDY OF SURFACE PLASMON POLARITON AT THE SINGLE INTERFACE BETWEEN METAL AND VEGETABLE OILS DIELECTRICS

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Abstract: We report the numerical studies of the properties of surface plasmon polaritons which are generated at the single interface between metal and dielectric. In this numerical work, we used parameters representing natural dielectrics. Using Maxwell equations and also the continuity of the fields at the interface between metal and dielectrics, the dispersion relation of the surface plasmon polaritons were derived. The dispersion relations were solved by taking parameters for metal appropriate for gold. For natural dielectric, we used parameters which are correspond to castor oil, coconut oil and sun flower oil with the range of dielectric constants were from tens to sixties. The results showed that the lower part of dispersion curves of surface plasmon polaritons approach SPP frequencies. We found that the highest surface plasmon frequency was resulted by using crude palm oil (CPO) as liquid dielectric. The usage of sunflower oil as dielectric lead to the lowest surface plasmon polaritons frequency.
Keywords: dispersion relation, single interface, surface plasmon, polaritons, vegetable oil dielectrics

I. INTRODUCTION

The electromagnetic waves which propagate at the interface between metal and dielectric materials are called surface plasmon polaritons. Here, the metallic material act as active medium while the dielectrics work as passive medium. The term surface plasmon polariton was firstly proposed by Cunningham [1].The SPP phenomena were noticed for the first time in the observation of reflection in metallic with grating surface [2].There were many studies regarding surface plasmons and surface plasmons polaritons. Dispersion relation for surface plasmon had discussed in 1960's [3-4]. The surface plasmon polaritons was generated optically using attenuated total reflection method (ATR) [5-6]. The determination of surface plasmon in gold and silver had also performed by Kreibig [7]. The developments of surface plasmon and surface plasmon polaritons studies were nicely reviewed in detail in Refs.[8-10]. In recent years, the study of surface plasmon polaritons is regarded to the scale of nanometre since they have high potential applications, such as sensor [11-12], solar cell [13] and data storage [14]. In generating surface plasmon polaritons, it is required two types of materials. The first material is metallic materials which provide free charges which in turn guarantee the existence of surface plasmon. The second material is dielectric which is required to support the normal component of the electric fields to create the surface charges. The surface waves are generated on the boundary between conductor and dielectrics. Hence, the surface waves are also affected by the properties of dielectrics, especially to their permittivity. In the previous studies [10], the frequency of surface plasmon polariton is affected significantly by the permittivity of dielectrics. The frequency is low when the dielectric's permittivity is high, and vice versa. The dielectrics which are usually used in generating surface plasmon polaritons is in the form of solid. The other from of dielectric materials is liquid dielectrics. The liquid dielectrics were studied recently since it has potential application for the insulation in the transformer [15-16]. In recent decade, the natural dielectric such as palm oil, sun flower oil and other natural oils have a great attention due to their potential applications [16-17].These natural oils have also advantages regarding to the impact to the environment. It is environment-friendly since the mineral oils are renewable and biodegradable.

However, the studies about bio-oils are mainly focused on the application as transformer insulation. In this paper, we interest to explore the possibility of using bio-oils as dielectrics in generating surface plasmon polaritons.

II. RESEARCH METHOD

Consider two semi-infinite media with the interface is located at $x-y$ plane in $z=0$. The space at $z>0$ is filled up with dielectrics while conductor material fills the space at $z<0$. In this study, we focus on the transverse magnetic (TM) modes where the magnetic component (*H* fields) of electromagnetic waves is perpendicular to the plane of reflection. In our directed to the $\hat{y}$ direction. In our configuration, $\vec{H}$ field is in the $\hat{y}$ direction. The solution of surface modes is in the form

$$\vec{H}=\begin{cases}\hat{y}H_d e^{(-\beta_d z)}e^{i(k_x x-\omega t)}, & z<0\\ \hat{y}H_m e^{(\beta_m z)}e^{i(k_x x-\omega t)}, & z>0\end{cases} \qquad (1)$$

where H_d and H_m are amplitudes of magnetic component in dielectric and metal. The variables β_d and β_m represent the attenuation constants for dielectric and conductor. These constants can be derived by solving the Maxwell equations which results in the form

$$\beta_{d,m}=\left(k_x^2-\varepsilon_{d,m}\frac{\omega^2}{c^2}\right)^{1/2}. \qquad (2)$$

Here, dielectric permittivity $\varepsilon_d\approx\varepsilon_\infty$ since transverse resonance frequency is almost similar to longitudinal resonance frequency, $\omega_T\approx\omega_L$. The susceptibility of metal in free electron model is determined as [10]

$$\varepsilon_m=1-\frac{\omega_p^2}{\omega^2} \qquad (3)$$

where ω_p represents the plasma frequency of the metal.

The dispersion relation for surface modes is determined using continuity of the fields at the interface $(z=0)$. The continuity of the normal $\vec{H}$ field result in the equation

$$H_d=H_m. \qquad (4)$$

This result is similar to the continuity of normal $\vec{D}$ field. Since $\vec{B}$ field does not have any normal component, then there is no continuity of normal $\vec{B}$ field. The continuity of tangential $\vec{E}$ component led to the equation

$$\frac{\beta_d}{\varepsilon_d}H_d=-\frac{\beta_m}{\varepsilon_m}H_m. \qquad (5)$$

Using Eq.(4) and (5), we obtained the dispersion relation for single surface as [9-10]

$$k_x=\frac{\omega}{c}\left(\frac{\varepsilon_d\varepsilon_m}{\varepsilon_d+\varepsilon_m}\right)^{1/2}. \qquad (6)$$

III. RESULTS AND DISCUSSION

In numerical calculation, we used plasma frequency $\omega_p=5.8$ eV, appropriate for gold. The dielectric constant was taken as $\varepsilon_d=2.1$ for crude palm oil [17], $\varepsilon_d=14.78$ for castor oil, $\varepsilon_d=36.40$ for coconut oil and $\varepsilon_d=63.4$ for sunflower oil [15]. The result for dispersion relation for surface plasmon polariton at the interface between gold and CPO is presented in figure 1.

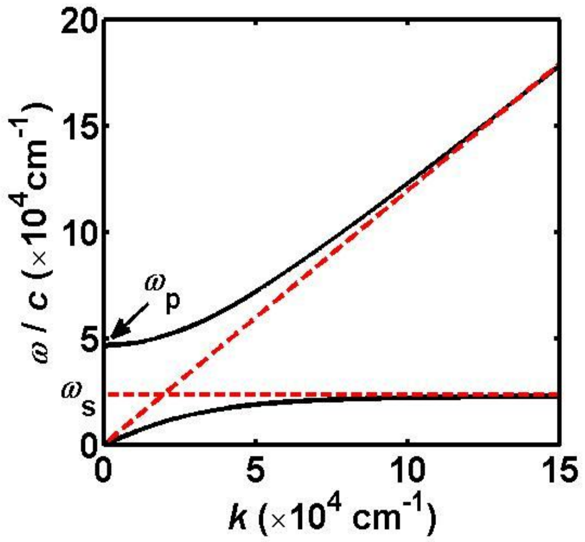

Figure 1. The Dispersion relation of the Eq.(6). There two branches. The upper branch which starts from ω_p above represents the dispersion of light in metal. The lower branch which starts from zero to ω_s is surface plasmon polaritons.

We obtain numerically, that the dispersion relation of surface modes at the interface of gold and crude palm oil (CPO) consist of two parts as it is illustrated in Fig.1. The upper part starts from the plasma frequency ω_p and the curve approach $\omega = ck\left(1 + \varepsilon_d^{-3/2}\right)$ as frequency is increased. This upper part represents the dispersion of light in conductor [8]. The lower part which illustrates surface plasmon polaritons starts from a dispersion curve of light in CPO at zero and then approach surface frequency ω_s as vector of propagation k is increased. This result of dispersion relation curve has the similar trend of the dispersion relation which is discussed previously for solid dielectrics [8]. It means that the liquid form of dielectrics is possible to use in generating surface plasmon polaritons. However, since the permittivity of liquid form is very sensitive to pressure and temperature, further studies are required to explain those parameters to the surface modes. The surface plasmon polaritons cannot exist in the frequency range between ω_s to plasma frequency ω_p, since the value of attenuation constant is imaginary. Next, we want to study the dispersion relations for other vegetable oils. We variate the liquid dielectrics with castor oil, coconut oil and sunflower oil. The dielectric constant is ranging from 14 to 64. We found that the upper part of dispersion relations which are generated at the interface between gold and those vegetable oils are basically similar for the various vegetable oils. The very little difference appears near plasma frequency, however the overall differences for the upper part of the dispersion relations do not significant.

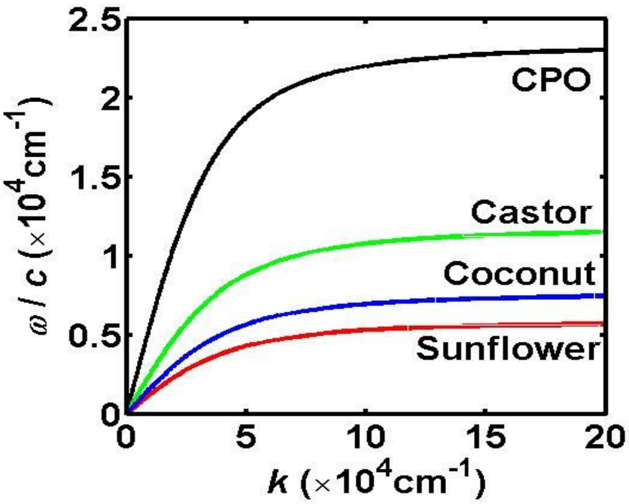

Figure 2. The lower part of dispersion relations of the surface plasmon which are generated at the interfaces between gold and various vegetable oils. The red curve is obtained using sunflower oils, the blue line is resulted from coconut oils. The green and black curvatures are acquired from castor oil and CPO.

In figure 2, the curves of dispersion relation of surface plasmon polaritons which is generated at the interface between gold as a conductor and various vegetable oils as a dielectric are presented. It is shown that using sunflower oils as dielectric leads to the dispersion relation with the lowest surface plasmons frequency ($\omega_s = 0.58 \times 10^4$ cm^{-1}). The curve with the highest frequency ($\omega_s = 2.34 \times 10^4$ cm^{-1}) is obtained when we used crude palm oil (CPO) as dielectric. The complete values of frequency from the lowest to highest are: sunflower ($\omega_s = 0.58 \times 10^4$ cm^{-1}), Coconut oil ($\omega_s = 0.76 \times 10^4$ cm^{-1}), castor oil ($\omega_s = 1{,}18 \times 10^4$ cm^{-1}) and CPO ($\omega_s = 2.34 \times 10^4$ cm^{-1}). If we compare the frequency with the permittivity, it shows that vegetable oil with the low permittivity such as CPO ($\varepsilon_d = 2.1$) has high frequency ($\omega_s = 2.34 \times 10^4$cm^{-1}). On the other hand, organic oil with high permittivity such as sunflower oil ($\varepsilon_d = 63.4$) leads to low frequency ($\omega_s = 0.58 \times 10^4$cm^{-1}). We argue that materials with low dielectric constant (permittivity) requires high energy (in the form of high electric field) to polarise the charges. Since high energy is equivalent with high frequency, then it is clear that surface plasmon polaritons which is generated using low value permittivity of dielectrics lead to the high value of frequency ω_s.

IV. CONCLUSIONS

In this study, we showed that it is possible to generate surface plasmon polariton numerically by using vegetable oils. We found that the usage of crude palm oil leads to the highest frequency of surface plasmon polaritons (ω_s) while using sunflower oil results in the lowest frequency of ω_s.

REFERENCES

1. S. L. Cunningham, A.A Maradudin and R. F. Wallis, "Effect of a charge layer on the surface-plasmon-polariton dispersion curve", Phys. Rev. B., vol. 10, pp 3342, 1974. https://doi.org/10.1103/physrevb.10.3342
2. R. W. Wood, "On a Remarkable Case of Uneven Distribution of Light in a Diffraction Grating Spectrum.", Phil. Mag. 4, pp.396, 1902.
3. H. Kanazawa, "On the plasma oscillations in metal foils", Prog. Theor. Phys. 26, pp. 861, 1961. https://doi.org/10.1143/ptp.26.851

4. R. H. Ritchie, "On Surface Plasma Oscillations in Metal Foils", Prog. Theor. Phys. 29, pp. 607, 1963. https://doi.org/10.1143/ptp.29.607
5. A. Otto, "Excitation of nonradiative surface plasma waves in silver by the method of frustrated total reflection", Z. Phys. 216, pp 398, 1968. https://doi.org/10.1007/bf01391532
6. E. Kretschmann and H. Raether, "Radiative Decay of Non-Radiative Surface Plasmons Excited by Light", Z. Naturforsch. 23 a, pp. 2135, 1968. https://doi.org/10.1515/zna-1968-1247
7. U. Kreibig and P. Zacharias, "Surface plasma resonances in small spherical silver and gold particles.", Z Phys. 231, pp. 128, 1970. https://doi.org/10.1007/bf01392504
8. K. Welford, "Surface plasmon polaritons and their uses.", Optical and Quantum Electronics., 23, pp. 1, 1991. https://doi.org/10.1007/bf00619516
9. J. M. Pitarke, V. M. Silkin, E. V. Chulkov and P. M. Echenique, "Theory of surface plasmons and surface plasmon polaritons." Rep. Prog. Phys. 70, pp. 1-87, 2007. https://doi.org/10.1088/0034-4885/70/1/r01
10. J. Zhang, L. Zhang and W. Xu, "Surface plasmon polaritons: physics and applications.", J. Phys. D: Appl. Phys. 45, pp. 113001, 2012. https://doi.org/10.1088/0022-3727/45/11/113001
11. A. V. Kabashin, P. Evans, S. Pastkovsky, W. Hendren, G. A. Wurtz, R. Atkinson, R. Pollard, V. A. Podolskiy and A. V. Zayats, "Plasmonic nanorod metamaterials for biosensing.", Nature Mater 8, pp. 867, 2009. https://doi.org/10.1038/nmat2546
12. F. Goettmann, A. Moores, C. Boissiere, P. Le Floch and P. Sanchez, "A selective chemical sensor based on the plasmonic response of phosphinine-stabilized gold nanoparticles hosted on periodically organized mesoporous silica thin layers", Small 1, 636, 2005. https://doi.org/10.1002/smll.200500037
13. M. D. Brown, T. Suteewong, R. S. S. Kumar, V. D'Innocenzo, A. Petrozza, M. M. Lee, U. Weisner and H. J. Snaith, "Plasmonic Dye-Sensitized Solar Cells Using Core−Shell Metal−InsulatorvNanoparticles", Nano Lett. 11, pp.438, 2011. https://doi.org/10.1021/nl1031106
14. D. O'Connor and A. V. Zayats, "The third plasmonic revolution", Nature Nanotechnol., 5, pp. 482, 2010.
15. T. Sankarappa and M. Prashantkumar, "Dielectric Properties and AC conductivity in some Refined and Unrefined Edible Oils", IJARPS 1, pp. 1-7, 2014.
16. M. H. A. Hamid, M. T. Ishak, N. S. Suhaimi, J. Adnan, N. I. Hahim, M. Ariffin, N. I. A. Katim, Rahisham and A. Rahman., "Electrical properties of palm oil and rice bran oil under AC stress for transformer application", Alexandria Engineering Journal, in press, 2022. https://doi.org/10.1016/j.aej.2022.02.049
17. M. H. Roslan, N. A. Mohamad, T. Y. Von, H. M. Sadeh and C. Gomes, "Latest Development of Palm Oil as a Sustainable Transformer Fluid: A Green Alternative to Mineral Oils.", Biointerface Research in Applied Chemistry 11, pp. 13715, 2021. https://doi.org/10.33263/briac115.1371513728