**International Journal of Scientific Research and Management (IJSRM)**
**||Volume||11||Issue||06||Pages||25-28||2023||**
**Website: www.ijsrm.in ISSN (e): 2321-3418**
**DOI: 10.18535/ijsrm/v11i06.p01**

# The effect of fatty acid's dielectric constant in the generation of surface plasmons using numerical attenuated total reflection (ATR)

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**Abstract**
The surface plasmons were collective excitation of free charges which can be generated at the interface between metal and dielectrics. The active material was metal which provided free charges while dielectrics was passive material which maintained the electric fields at the interface. One of the most effective method to generate surface plasmons was attenuated total reflection (ATR). The basic concept of this method was total internal reflection. Hence, it required a high index prism, such as thallium halogenide. The ATR method can be done numerically by deriving ATR reflectivity. In the process of derivation, we should consider the reflectivity at the all involved interfaces. Then, the ATR reflectivity can be obtained by scanning frequency at the certain interval near the surface plasmon frequency. In this report, we study the surface plasmon which was generated at the interface between gold and fatty acid. We analysed the effect of fatty acid's dielectric constant to the ATR spectroscopy. We found that the decrease of the fatty acid's permittivity increase the surface plasmon resonance (SPR frequency and decrease the reflectivity at this resonance frequency.

**Keyword:** fatty acid, plasmon polaritons, attenuated total reflection

## Introduction

Surface plasmons (SP) could be generated at the interface between dielectric and metal. In this configuration, plasmons were provided by metal as an active medium. At the interface, the electric fields were maintained by dielectrics. Surface plasmons had studied many decades ago (Wood, 1968; Garnet, 1904; Mie, 1908). Surface plasmon studies had many attentions because of its various applications as: biosensors (Kabashin et al., 2010), data storage (O'Connor et al., 2009), wave-guides (Nagpal et al., 2009) and also solar cells (Ferry et al., 2008).

Many methods had performed to study surface plasmons resonance, especially in the generation of surface plasmon polaritons. Zayats (Zayats et al., 2003) used grating method, while Zhang (Zhang et al., 2012) utilized diffraction of the roughness surface to obtain surface plasmons. One of the most well know method to excite surface plasmons is attenuated total reflection (ATR). This method was popularized by Otto (Otto, 1968) and Kretchmann (Kretchmann et al., 1968). The total internal reflection at the base of high index prism is utilized to generate evanescent wave which propagated across the metal film to excite surface plasmon at the interface between metal and dielectric. Using this method, the existence of surface plasmon excitation was shown by a sharp decrease in ATR spectroscopy. The ATR had successfully used in the studies of surface plasmons excitation in various materials, such as: dielectrics (Borstel et al., 1974 ;Torii et al., 2000), magnetics (Jensen et al., 1995; Jensen et al.,1997) and also magnetoelectric multiferroics (Gunawan et al, 2011; Gunawan et al., 2017; Gunawan et al., 2021).

The ATR can also be performed numerically by calculating the ATR reflection. In the derivation of the ATR reflectivity, we had to consider all the interfaces in the ATR system. The reflectivity at the involved interfaces will affect the value of ATR reflection. The ATR reflectivity had the same value with the initial wave when excitation had not happen. In this condition the value of ATR reflectivity was one. The excitation of the surface plasmons at the interface between metal and dielectrics decreased the ATR reflection, then the value of ATR reflectivity will be below one.

In this present paper, we studied the excitation of surface plasmons in the fatty acid. We predict that the permittivity values of fatty acid affected of the excitation of surface plasmons. In this numerical studied, we used parameters appropriate for gold to represents metal and thallium halogenide as high index prism.

**The method and formulation**

The geometry of this study was given in Figure 1. A high index prism with half ball shape set with the base located at $z = 0$. The metal was placed above the base of the prism at $0 \leq z \leq d$. We assumed that the thickness of the metal film is lower than the skin depth, so that the evanescence wave could reach the interface between metal and fatty acid. In the top of metal, we set the fatty acid. In this work, all the interfaces were placed at $x - y$ plane.

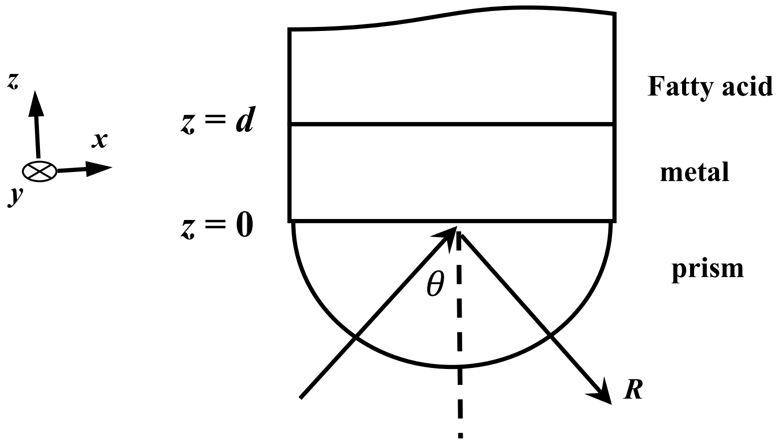


**Figure 1.** Geometry of the ATR The incoming waves propagated into a high index prism. Total internal reflection at the base of prism at $z = 0$ generating evanescence waves. Then, this evanesce waves travelled to the interface between metal-fatty acid to excite surface phonon. This interaction decreased the ATR reflection *R*.

The numerical ATR spectroscopy can be obtained by scanning frequency in a certain interval which resulted the ATR reflection using formulation

$$R = \left|\frac{[\varepsilon_g k_x(1+r) - i\varepsilon_p \beta_g(1-r)]}{[\varepsilon_g k_x(1+r) + i\varepsilon_p \beta_g(1-r)]}\right| \qquad (1)$$

where $\varepsilon_p$ and $\varepsilon_g$ represent permittivity of prism and gold, while $\beta_g$ was attenuation constant of gold. Here, the reflectance at the interface be1tween gold and fatty acid was given as

$$r = \frac{\varepsilon_f \beta_g - \varepsilon_g \beta_f}{\varepsilon_f \beta_g + \varepsilon_g \beta_f} \qquad (2)$$

where $\varepsilon_f$ and $\beta_f$ were permittivity and attenuation constant of fatty acid. The attenuation constants were obtained by calculating

$$\beta = \left[k_x^2 - \varepsilon_i \frac{\omega^2}{c^2}\right]^{1/2} \qquad (3)$$

where index *i* represented metal or fatty acid.dielectric constant for metal. The calculated ATR spectroscopy was obtained by scanning frequency at the certain interval, especially near resonant frequency.

**Results and Discussion**

In this paper, we was using metal's permittivity which was formulated as $\varepsilon_g = \left(1 - \frac{\omega_g^2}{\omega^2}\right)$, where $\omega_p = 2.94 \times 10^5 \text{ cm}^{-1}$ represented plasma frequency appropriated for gold. We also used permittivity for prism $\varepsilon_p = 32$ which was suitable for thallium halogenide (KRS-5). Since the values of dielectric constant of the fatty acids depended on their biological sources, we varied the values of fatty acid's permittivity at around 2. The value of the dielectric constant of the fatty acid was varied at: 2.2; 2.4; 2.6 and 2.8.

The result of the numerical ATR which was formulated in equation 1 for SPR generated at the interface between gold and fatty acid was given in figure 2. The color of the curves represented ATR spectroscopy for a certain value of fatty acid's dielectric constant $\varepsilon_f$. Magenta and black curves were obtained with $\varepsilon_f = 2.2$

and 2.4. The red curve was get with dielectric constant was 2.6. The blue curvature was acquired using fatty acid with permittivity was 2.8. The curvatures showed the dips around the frequency $0.4 \times 10^5$ to $0.6 \times 10^5$ $cm^{-1}$ depend on the values of fatty acid's permittivity. The existence of these dips predicted the possibility to excite surface plasmon which then generating surface plasmon polaritons at the interface between metal and fatty acid.

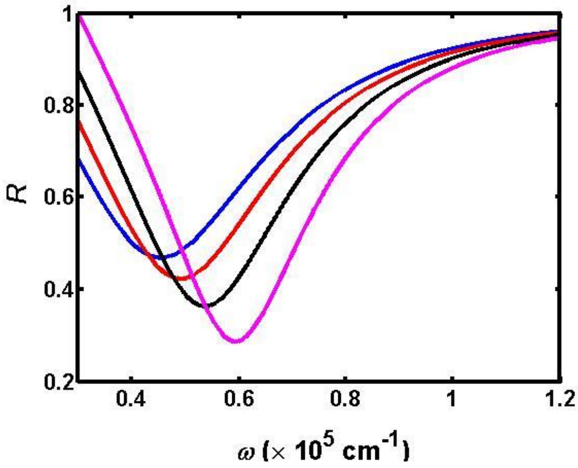


**Figure 2.** The calculated ATR spectroscopy of surface plasmon generated at the interface of gold-fatty acid. Here, we vary the value of fatty acid's permittivity. Magenta for $\varepsilon_f = 2.2$; black for $\varepsilon_f = 2.4$; red for $\varepsilon_f = 2.6$ and blue for $\varepsilon_f = 2.8$. It can be noticed that each curve had similar trend, with the dips around $\omega = 0.5 \times 10^5$ $cm^{-1}$.

The results in figure 2 also showed that the trend of the curvatures similar to the shape of calculated ATR spectroscopy from the previous studies (Jensen, 1997; Gunawan, 2021). These SPR was significantly affected by metal since it had the role as active material to provide the free charges. Hence, the SPR frequency only shifted in a little value when we vary the values of fatty acid's permittivity.

Figure 2 also showed tendency that the SPR frequency was increased while the value of fatty acid's permittivity was decreased. In our opinion, the role of dielectrics were maintain the displacement fields ($\vec{D}$ fields) at the surface. Hence, when the permittivity was reduced, it will increase the electric fields. In turn, this will also increase the electrostatic energy of the surface plasmon. Then, it required higher frequency to excite surface plasmon. It was also noticed in figure 2 that the ATR reflectivity at the dips decreased as the permitivitty of the dielectric was reduced. This meant that the probability to excite plasmons increased as the dielectric constant's decreased. In our opinion, surface plasmon which was generated using fatty acid with $\varepsilon_f = 2.2$ had resonance frequency that most suitable to the frequency of evanescence waves.

## Conclusion

The permittivity of fatty acid significantly affected the excitation of surface plasmon. The decline of dielectric permittivity will increase the SPR frequency and decrease the reflectivity at those frequency. It meant that surface plasmons could be generated effectively using low value of the dielectric permittivity.


## Acknowledgment

We highly acknowledge Physics Department, Faculty of Sciences and Mathematics, Diponegoro University for the support of this work


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