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Calculate The Resonance Angle of Surface Plasmon Resonance Gold film Configured with Kretschmann

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ABSTRACT

The current work includes measurements of the resonance angle and reflectance for p-polarization of the electric field by using the Fresnel equation at a given length. Gold's surface plasmon wave can be seen at the metal-to-air boundary. We try to determine the greatest (SPR) angle for a metal thin layer that is most suitable for the surface plasmon excitation while stimulated by a 632.8 nm laser. SPR was performed of a $(50nm)$ single film of gold placed on a glass prism; there are SPR modes in this structure, which match the surface plasmon. We also suggest that the SPR mode associated with the Au surface, which is extremely sensitive to changes in the surrounding environment, particularly (dielectric). A few considerations to be taken into account to attain the SPR, like the incident angle of light rays addressed and analyzed for the purpose of finding the essential value for the plasmon to be emerge; the gold/air resonance angle. Furthermore, we can compare our result with other work, which was performed by using the Finite-Element-Method (FEM), the simulation is done by FDTD (Finite Difference Time Domain) software. SPR was applied in a variety of domains, containing biomedicine science, optics, biomedicine, photo-thermal plasmon, and health.

1. Introduction

Oscillations in charge-density frequency occur in a thin metal film's layer due to the presence of plasmon. Such an oscillation can be induced by p-polarized beam, and resonance phenomenon's (SPR) were noticed by monitoring the intensity of the reflected beam figure (1). The wave vector for both SPW and incident beam are coincided at a given incident angle and there is no reflectance, indicating that the SPR emerges.

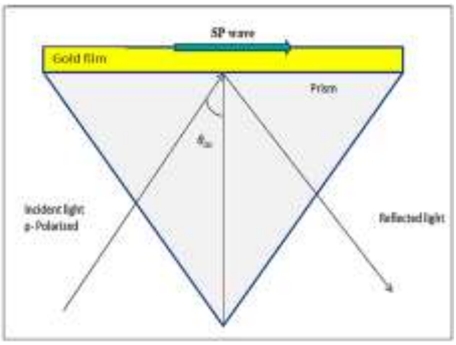

Fig. 1: surface plasmon wave in gold film by using Kretschmann Configuration

SPR seems to be an extremely significant situation, as label-free detection methods have been discovered to be effective and accurate for clinical analysis and molecular reactions [1-3]. The prism coupling strategy is the greatest widely utilized approach for (SP) generation across all SPR techniques. In most situations, gold has greater detection sensitivity in the visible region of the spectrum; hence it's usually used for the plasmonic layer, less oxidized, and has a high resistance to pollutants in the environment. The gold single film SPR sensor on prism developed by us is demonstrated here, Optimum metal lengths, angle of incidence, and dielectric layer all affect SPR sensibility [4-10]. It's found that at a certain angle, the configuration has a superior sensitivity than the others, the angle is known as θ_{spr}. Fresnel's Equations were used to estimate reflection coefficient for p-polarization light and also to determine reflectance for any double interface media which are different in refractive index, as illustrated in Figure 2. The given equation [11]

$$r_p = \frac{n_2 cos\theta_{in} - n_1 cos\theta_t}{n_1 cos\theta_t + n_2 cos\theta_{in}} \quad ...(1)$$

$$n cos\theta_t = n\sqrt{1 - sin^2\theta_t} \quad ....(2)$$

$$R_p = |r_p|^2 \quad ...(3)$$

$$r_p = \frac{\left[n_1\sqrt{1-\left(\frac{n_1}{n_2}cos\theta_{in}\right)^2} - n_2 cos\theta_{in}\right]^2}{\left[n_1\sqrt{1-\left(\frac{n_1}{n_2}cos\theta_{in}\right)^2} + n_2 cos\theta_{in}\right]^2} \quad ... (4)$$

r_p:refelcatance of the light, n_1&n_2:refractive index if first and second medium repectively, θ_{in}:incident angle of light, θ_t:angle of total internal reflectionUsing Equation 3, we may determine reflectance as a function of incidence angle for both medium,they are diferent in permitivty and refractive index the medium is gold to air.

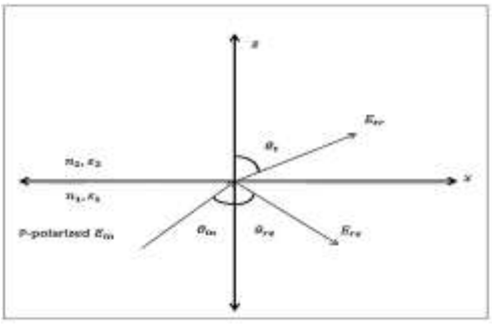

Fig. 2: Fresnel equation for p-polarization electric field with θ_{in}, θ_t *and* θ_{re} in deference dielectric medium

In a total reflection setup, chromatic p-polarized beam imposed on a prism are used to perform and evaluate the work. The prism is coated with gold film (50 nm) that gathers evanescent waves generated by total reflections and releases. The gold/air boundary is used to release the SP wave once the angle is adjusted at a given value which is illustrated in figure (3). The photodiode sensor measures the amount of light that is reflected from the interface. The lowest intensity is reached because there is coupling with (PW) plasmon wave. [12].

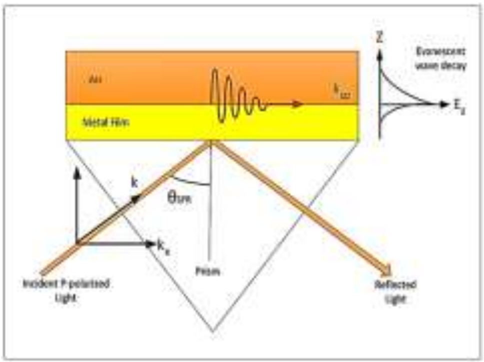

Fig. 3: Evanescence wave in gold/air interface at SPR angle (θ_{spr})

The activation of the SPW is highly influenced by the length and type of conductive layer. This project uses the Kretschmann arrangement to simulate the excitement in determining the most effective waves (SP) for both the supplied metal and light source. To further understand SPW, we investigate how the electric field changes when waves go through a metal thin layer and into the surrounding media (air).[13]

2. Martials and Method

A coherent laser beam source with a wavelength of 0.6328 µm was applied, and the light was directed with a glass lens with a focal length of 10cm. The metal film in the experiments was made of 50nm gold. Prism-made of glass with a refractive index of 1.5151 was utilized as the substrate. The cladding zone is made of air, which has a refractive index of one. The detector can measure the minimum reflection intensity at a particular angle by measuring the reflectance as a function of the incidence angle. The minimum intensity is known as the dark zone, also referred to the SPR angle, is the point where light energy is converted to electron resonance. The metal free electrons' interact with the activator light beam and it's vibrating resonantly with the exact same frequency of beam light shown in figure (4). This was done to obtain incident angle that may stimulate the SPR. The component parallel of the incoming beam's k − vector is equivalent to the parallel component surface Plasmon's k − vector once both the incident angle and angle of resonance are equivalent (also known as the Attenuated Total Reflection angle ((θ_{ATR})). As a consequence, the light from the prism did not reflect back illustrated in figure 4. [13].

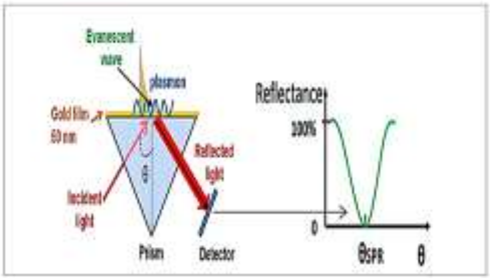

Fig. 4: minimum reflection at θ_{spr} for gold/air interface, the evanescent wave surface plasmon produced

Using Fresnel equation (3) and equation (4), we compute the external, internal, and reflection coefficient r_p of the gold/air interface. Many factors influence the way of determining the proper angle of resonant, such as the metal film's substance, the media's refractive index, beams wavelength of the light source light, and the adjacent zone.[14] Between both the incident beam as well as the glass-metal junction, external and interior angles were evaluated. The equation (5) would be used to control θ_{in}*and* θ_{ext}

$$\theta_{in} = sin^{-1}\left[\frac{sin(\theta_{ext} - A)}{n}\right] + A \quad ...(5)$$

3. Result and discussion

Calculations (estimation) for a metal film (gold film) on a glass in air were performed by using refractive index parameters for different substance such as ($n_{air} = 1$, $n_{gold} = 0.16$ *and* $n_{glass} = 1.515$). The minimal reflectance was discovered at a 44.2° angle of incidence, with a dramatic dip as seen in fig. 5. The lowest point doesn't quite drop to zero.

Table 1: Reflectance of light as a function of incident angle

Incident angle θ_{in}	Reflectance (R)	Incident angle θ_{in}	Reflectance (R)	Incident angle θ_{in}	Reflectance (R)	Incident angle θ_{in}	Reflectance (R)
30.08	0.852	41.08	0.885	43.22	0.121	43.77	0.392
31.41	0.850	41.26	0.909	43.29	0.072	43.94	0.485
32.50	0.851	41.62	0.941	43.41	0.048	44.34	0.636
33.71	0.849	41.92	0.949	43.53	0.082	44.86	0.746
35.16	0.847	42.47	0.925	43.52	0.102	46.42	0.828
36.19	0.845	42.66	0.863	43.58	0.144	48.29	0.851
37.34	0.846	42.86	0.753	43.63	0.181	51.07	0.865
38.79	0.849	43.08	0.578	43.63	0.215	56.09	0.860
39.82	0.852	43.05	0.409	43.68	0.264	59.90	0.867
40.48	0.862	43.07	0.281	43.79	0.321		

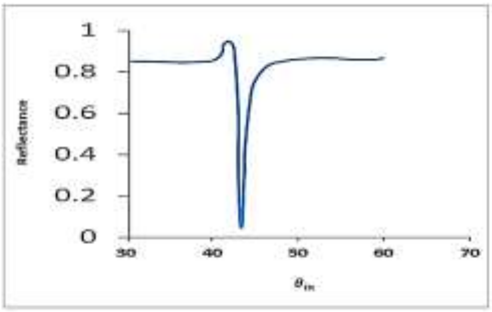

Fig. 5: Reflectance (a.u) as a function of $incident\ angle\ \theta_{in}\ in\ digree$ of gold layer surface in air for p-polarization

As may be seen, reflectance clearly appears at a specific angle and thicknesses. According to theory, as the thickness of a metallic gold film increases by about $100nm$, the SPR will diminish; yet, the same statement holds true for thicknesses less than $10nm$. As a result, improving thickness is key for the SPR method. According to figure (5), the angle of incoming light would be an essential parameter to make the SPR exist. In addition, the relationship among angles of incidence and reflectance, this was clearly visible. When the reflectance drops to zero, the free electrons of metallic gold absorb the beam's energy. The electrons start oscillation (resonance) with the same light's frequency, at this point, the lowest intensity has been recorded (dark region, no reflection), and this is the interaction between the charge of metal and electromagnetic wave. This evanescent wave is naturally fixed to a second medium (dielectric side).Lowest intensity occurs at a given angle (resonance angle), indicating that the light's energy is transferred to charge density variation, the gathering of oscillation electrons is called surface plasmon resonance (SPR) and It is referred to as evanescence depicted in figure (4). The SP wave is launched at the gold/air interface if the angle is fixed at a specific value, this coupling gives an SPW in dimensions (2D), as seen in formula (6). Let us just say the solution would be in the form of: the behavior of the waves and the result is: [12]

$$E = E_O e^{-k_z' Z} \quad e^{i(k_x x - wt)} \quad \ldots(6)$$

$-k_z', k_x$: The wave vector of surface plasmon in z, x-directions, E_O: amplitude of electric filed. The term of $[\ e^{-k_z' Z}]$ referred to damping of SPW (evanescence wave), also the term of $[e^{i(k_x x - wt)}]$ means the SPW propagate in x-direction. In other hand by using Fresnel's Equations (eq 4) we can compute total reflection of gold/air interfaces, which is depicted in table.2 and figure (6) [12].

Table 2: Fresnel's Equations for different refractive index ($n_{air} = 1, n_{gold} = 0.18$) for $632.8nm$

Incident angle θ_{in}	Reflectance (R)	Incident angle θ_{in}	Reflectance (R)
0	0.482	50	0.320
5	0.481	55	0.276
10	0.477	60	0.225
15	0.470	65	0.166
20	0.461	77	0.014
25	0.448	75	0.034
30	0.431	80	9.96E-05
35	0.411	85	0.115
40	0.386	90	1
45	0.356		

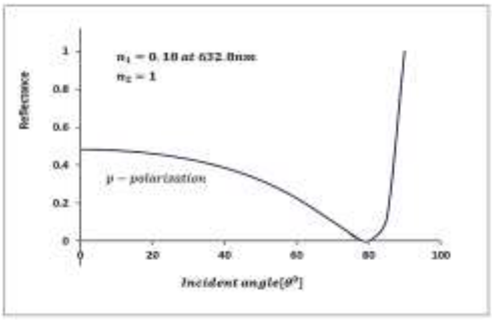

Fig. 6: Fresnel reflection with incident angle of p-polarization for different refractive index

Figure 6 and (eq4) indicates reflectance as a function of incident angle for two different substances (medium), the reflectivity is about 0.5 at (0^0). Approaching 80^0, the reflection approaching to zero after that point the p-state increases reflectivity very rapidly especially at 90^0 because of both medium differences in dielectric Several factors are taken into accounts, such as refractive index, thickness, and length. But there is an additional issue to consider. Adding the influence of metal dimensions on incidence angle and temperature would overcomplicate the problem; we ignore that factors and assume the test is conducted at room temperature [14]. In figure (7) we compare our work with other that is done by FDTD and it gives a slight difference [15]

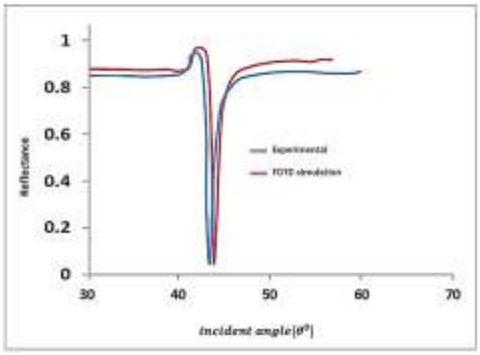

Fig.7: SPR curve of $50nm$ gold film as a function of incident angle incident, comparison between our result and simulation result, they done by Kretschmann Configuration

4. Conclusion

The study found that a 50 nm-thin gold on glass at a specific impact angle produced the best SPR, this is a novel investigation. Alternatively, based on Fresnel equation, the reflectivity of the gold/air interface is affected by the dielectric and angle of incidence. (SPR) the binding analysis method is used to investigate biomolecules. By taking advantage of this technique, it could be utilized for detecting interaction molecular in two different mediums. That's why the SPR has wide range of application chemistry and biology as a biosensor.

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حساب زاوية الرنين لرنين السطح البلازموني في أغشية الذهب الرقيقة باستخدام Kretschmann configuration

يادگار حسين شوان

قسم الفيزياء ، كلية التربية ، جامعة السليمانية ، السليمانية ، العراق

الملخص

يتضمن العمل الحالي قياسات زاوية الرنين والانعكاس لاستقطاب- p للمجال الكهربائي باستخدام معادلة فرينل بطول معين. يمكن رؤية موجة مأكل الطحين السطحية للذهب عند حدود المعدن إلى الهواء. نحاول تحديد أكبر زاوية (SPR) لطبقة رقيقة من المعدن الأكثر ملاءمة لإثارة مأكل الطحين على السطح بينما يتم تحفيزها بواسطة ليزر 632.5 نانومتر. تم إجراء SPR لفيلم واحد من الذهب (50 نانومتر) موضوع على منشور زجاجي؛ هناك أوضاع SPR في هذا الهيكل ، والتي تتطابق مع مأكل الطحين السطحي. نقترح أيضًا أن وضع SPR المرتبط بسطح Au ، وهو حساس للغاية للتغيرات في البيئة المحيطة ، خاصة (عازل الكهربائي). بعض الاعتبارات التي يجب أخذها في الاعتبار لتحقيق SPR ، مثل زاوية سقوط أشعة الضوء التي تمت معالجتها وتحليلها بغرض إيجاد القيمة الأساسية لظهور مأكل الطحين؛ زاوية صدى الذهب / الهواء. علاوة على ذلك، يمكننا مقارنة نتائجنا مع الأعمال الأخرى ، والتي تم إجراؤها باستخدام طريقة العناصر المحدودة (FEM)، ويتم إجراء المحاكاة بواسطة برنامج FDTD (مجال الفروق الزمنية المحدودة). تم تطبيق SPR في مجموعة متنوعة من المجالات ، التي تحتوي على علوم الطب الحيوي، والبصريات ، والطب الحيوي، والطعام الحراري الضوئي، والصحة .