Enhanced SPR response using Au/GO thin films via Kretschmann coupling by controlling the incident light intensities

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Monolayer Au and hybrid Au/GO thin films with thicknesses of 50 nm and 52 nm sequentially, were deposited onto the glass substrate. The effect of laser intensities towards SPP excitation via Kretschmann coupling technique was investigated by varying laser intensities between 30 nW to 80 nW. Maximum SPR represented by the smallest value of R_{min} =0.0838 a.u was obtained as 80 nW of laser intensity had incident onto the hybrid films. The deployment of 52 nm Au/GO resulted excellent SPR properties indicated by the greatest Q-factor=0.7668 a.u with percentage difference about 22.24 % in comparison with 50 nm monolayer Au thin film. The utilization of high intensity light demonstrated significant increment of Q-factor value, in which the SPR response was successfully amplified due to the maximum number of photons pumped by the laser.

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1. Introduction

Recently, surface plasmon resonance (SPR) sensor receives more attention because of its outstanding features such as high sensitivity, simple construction and non-invasive detection capability [1,2]. This sensor has been used in many applications such as for detection of heavy metal ions [3], water quality monitoring [4], urea detection [5] and in healthcare area [6]. SPR is an optical method that measure the refractive index of detected medium as light is absorbed by the metal resulting the excitation of surface plasmon polaritons (SPP). Surface plasmon excited by a light wave propagates along the metal film and its evanescent field probes the sample which in contact with the metal film.

The SPR phenomenon are created by matching the wavevectors of incident light in the plane of surface, k_x with the SPP wave vector, k_{spp} in metal thin film layer. The derivations of related equations had been discussed elsewhere [7]. To achieve this condition, prism coupling techniques namely Kretschmann and Otto configurations have been introduced. Kretschmann coupling is most favourable due to its simple structure, easy monitoring and low cost [8]. The strength of evanescent field can be controlled by manipulating the light's incident angle, controlling metal's thicknesses and utilizing multilayers thin films [9].

Numerous types of noble metal thin film such as silver (Ag), gold (Au) and copper (Cu) have been proved able to generate SPR signal [10-11]. Among them, Au exhibits the best performance in producing strong and stable SPR [12]. Note that, Ag and Cu are easily oxidized in which lead to the SPR decay as they expose to the environment [13,14]. Maximum SPR can be achieved by setting the thickness of metal around 50 nm [15]. If the film is too thick, the SPR cannot be generated due to the energy absorbance by the metal itself. Meanwhile, an electron damping oscillations will be occurred if the film is too thick [16]. Recently, Au has been used to induce strong SPR response by combine it with graphene oxide (GO) which act as active layer to enhance SPR signal [17]. GO sheets which is the oxidized counterpart of graphene usually has abundant functional groups that are advantageous for biosensor applications [18]. It is suitable to be utilized as dielectric layer in SPR sensing because of its large surface area for adsorption efficiency and suitable to be deployed as metal's protection layer from environment disruption [19]. Considering its impressive feature such as high conductivity and great durability, GO layer is usually deposited on top of Au layer producing hybrid thin films [20, 21].

The amplification of SPR can be achieved by control noble metal's thicknesses using various types of techniques such as electron beam and sputtering [22, 23]. Nonetheless, those techniques require combination of high end and expensive equipment. This study proposed less complicated technique to enhance SPR generation using Au/GO thin films via Krestchmann coupling by controlling laser intensities. The output of this study demonstrates the notable combination between hybrid

Au/GO thin films with 52 nm of specific thickness and maximum light intensity at 80 nW to amplify the SPP excitations up to 22.24%.

2. Materials and methods

A 50 nm thickness of Au thin film (99.99 % purity) was deposited onto the glass substrate with dimension of 10 mm × 10 mm via electron beam process at a pressure of 2.7×10^{-5} Pa in the evaporation chamber with a deposition rate of 0.7 Å/sec, an emission voltage at 5.2 kV and a current at 57 mA. Prior the e-beam process, the glass substrates were ultrasonically cleaned using acetone in an ultrasonic bath and rinsed with distilled water before dried in oven for about 30 minutes at 60 °C. A monolayer of GO was coated on top of the Au thin film via spin coating technique at the deposition rate of 4000 rpm for 60 seconds, producing Au/GO hybrid thin films. Next, the Au/GO thin films were dried at 50 °C in a vacuum oven for 30 minutes to ensure that the GO layer was perfectly attached on top of Au thin film layer. Atomic force microscope (AFM) was used to measure the thickness and the roughness of Au thin film. The morphology of Au/GO was characterized by using field emission scanning electron microscopy (FESEM). Energy dispersive X-ray (EDX) analysis was performed to confirm the elemental composition of Au/GO thin films.

Fig. 1 illustrates the Kretschmann-based SPR experiment setup consists of p-polarized He-Ne laser with wavelength 633 nm, polarizer, mirror, triangular prism (n=1.51) placed on a lab jack, pinhole and silicon photodetector. The Au/GO (total thickness of 52 nm) coated glass slide was coupled on the hypotenuse side of the triangular prism by using index matching gel via Kretschmann configuration. P-polarized laser with intensities between P_1=30 nW and P_6=80 nW were incident onto the hypotenuse side of the coated prism with an increment of 10 nW for each reading. Note that the p-polarized light is a compulsory requirement to excite SPP as there are no solutions exist for the s-polarization light.

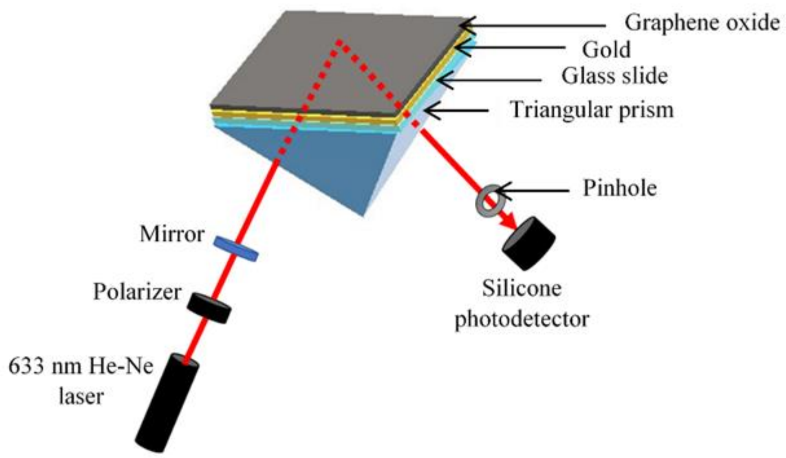

Fig. 1. Au/GO coated SPR experimental setup using Kretschmann configuration (color online)

An angular interrogation technique was performed to excite SPP by modulating the incident angle from angle 20° to 60° with the increment of 2° per reading. The reading of reflected power was recorded using an optical power meter as the reflected laser from the prism had been detected by silicon photodetector. The value of reflectance, R was calculated by using Eq. (1):

$$R(a.u) = \frac{P_{reflected}(\mu W)}{P_{incident}(\mu W)} \tag{1}$$

where $P_{reflected}$ is the reading of reflected power and $P_{incident}$ is the reading of incident power from power meter. A pinhole with diameter of 3 mm was placed in front of photodetector to ensure the stabilization of the reflected power reading. The properties of SPR signal were studied by analysing the Q-factor values. Note that the Q-factor represents the strength of SPR signal. It represents the amount of light which is successfully converted into SPR. The greater the Q-factor value, the stronger the signal. Finally, the experimental results were compared with the WINSPALL 3.02 simulation data for the validation purpose. Table 1 lists the materials' refractive indices values to generate SPR which was used in our simulation work [15].

Table 1

Medium	Refractive index	
	n (real)	*k (imaginary)*
Glass prism	1.51	0
Au	0.1759	3.4104
GO	3	1.1491
Air	1	0

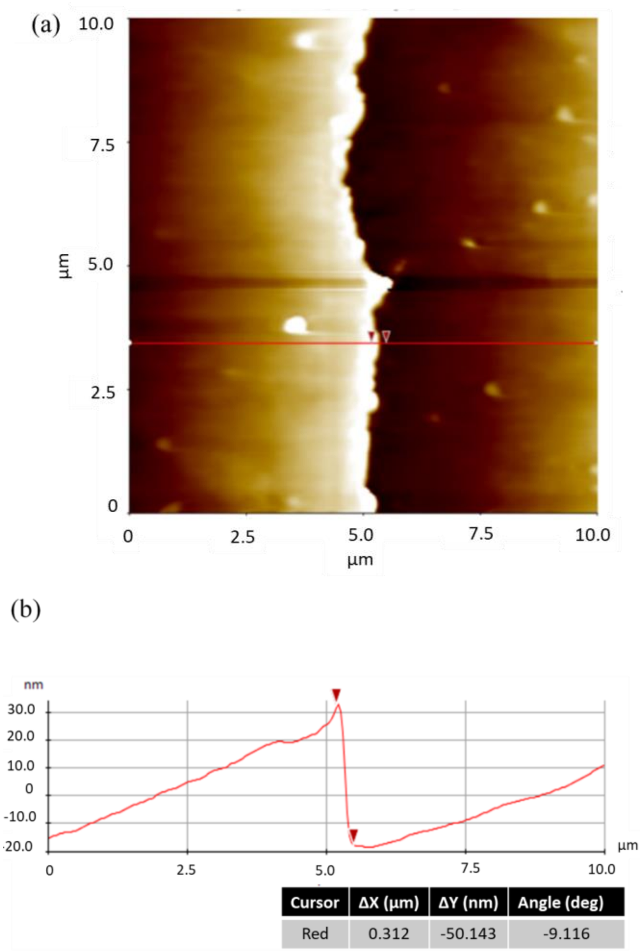

Fig. 2. (a) AFM image of 50 nm Au thin film (b) Height profile value of 50 nm Au thin film (color online)

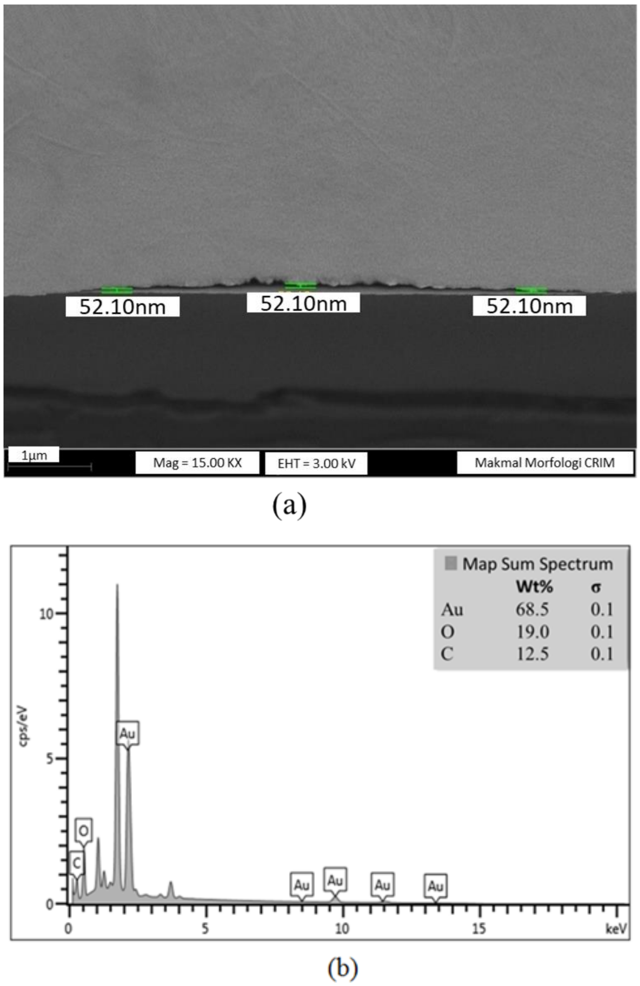

Fig. 3. Cross section FESEM image of 52 nm Au/GO thin films (b) EDX spectrum of Au/GO thin films

3. Results and discussions

Fig. 2 shows the AFM image and its height profile of Au monolayer thin film with thickness about 50.14 nm ≈ 50 nm. The cross-section of 52 nm hybrid Au/GO thin films which was captured by FESEM is depicted in Fig. 3(a). It confirmed the thickness of GO was around 2 nm. Based on EDX analysis as shown in Fig. 3(b), Au was the highest composition in the Au/GO sample by considering that 96.15 % of the total thicknesses were contributed from this metal.

Fig. 4(a) and 4(b) display the SPR response for 50 nm Au thin film and 52 nm Au/GO thin films respectively; as the intensities of laser were varied from P_1=30 nW until P_6 = 80 nW. The occurrence of SPR was discovered at incident angle of 46° for all six levels of laser intensities. Table 2 summarizes the values of R_{min} for Au and Au/GO, and ΔR_{min} as the laser intensities increased. Apparently, the deployment of maximum laser intensity indicated the strongest SPR response.

The enhancement of laser intensity levels leads to the increment of Q-factor values as shown in Fig. 5. The maximum Q-factor values for both 50 nm single Au thin film and 52 nm hybrid Au/GO thin films were obtained as 0.6273 a.u and 0.7668 a.u respectively. The obvious increment of Q-factor due to the SPR amplification was resulted with the presence of GO layer on top of Au thin film. This situation happens due to the maximum number of photons which had been pumped by high intensity laser; before they strike onto the large surface area of Au/GO thin films. Hence, large number of photons were converted into SPP resulting the enhancement of SPR response. It is expected that if the laser intensity exceeds 80 nW, the strength of SPR signal will be maximized considering the increment number of photons excitations.

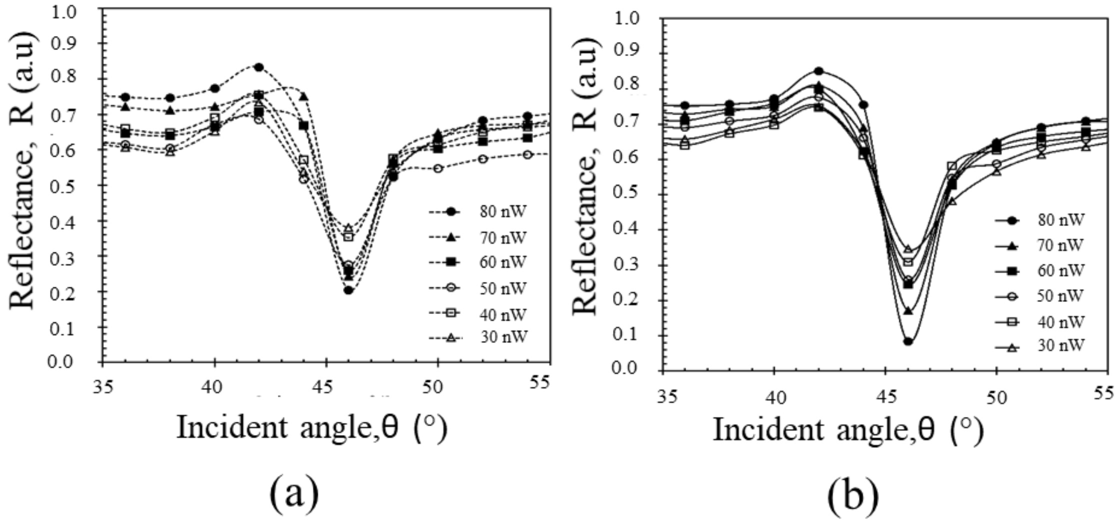

Fig. 4. Various SPR curve depths with the increment of laser intensities (a) 50 nm Au thin film (b) 52 nm Au/GO thin films

Table 2

Laser intensity, P (nW)		$R_{min\ (Au)}$,(a.u)	$R_{min\ (Au/GO)}$, (a.u)	ΔR_{min} (a.u)
P_1	30	0.3813	0.3468	0.0345
P_2	40	0.3535	0.3091	0.0444
P_3	50	0.2752	0.2603	0.0149
P_4	60	0.2607	0.2462	0.0145
P_5	70	0.2430	0.1713	0.0717
P_6	80	0.2050	0.0838	0.1212

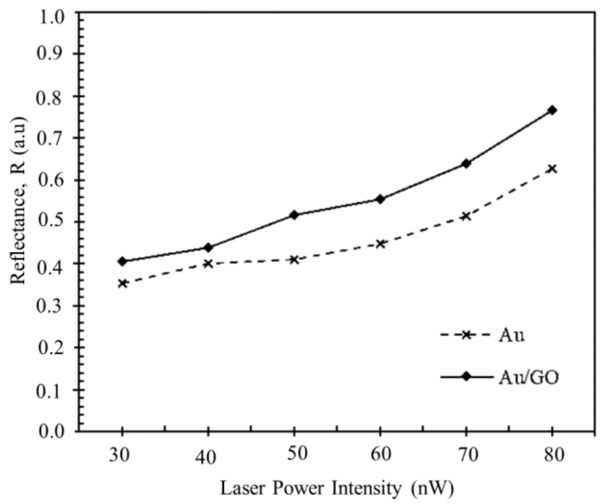

Fig. 5. Relationship between Q-factor and laser power intensity for 50 nm Au and 52 nm Au/GO

Fig. 6 portrays the comparison of SPR signals obtained theoretically (via simulation) and experimentally between 50 nm Au and 52 nm hybrid Au/GO using 80 nW He-Ne laser source. Note that, the SPR peaks for both configurations were formed at the incident angle of 44° and 46° respectively. It is noteworthy to highlight that few environmental factors were ignored during the simulation such as ambient temperature, air turbulence and humidity, in which lead to the minor disagreement between experimental and simulation results about 4.54%. Greater Q-factor value of Au/GO in comparison with Au monolayer indicated the notable property of Au/GO thin films as suitable candidate to provide stronger SPR. This situation exhibits the significant role of GO in maximizing the SPP excitations because of its large surface area in which acts as active layer for directly supports surface plasmon at visible range. Besides, GO also can be utilized as protective layer to prolong the lifetime of the Au thin film. In contrast, our proposed enhanced Au/GO SPR device using 80 n nW laser intensity (He-Ne laser) exhibits better SPP excitations than the SPR based white light source device [20]. Evidently, by control light intensity, the deployment of very thin layer of GO (t=2 nm) is sufficient enough to amplify the SPR signal about 76.68 %. Without manipulating light intensity, the combination of Au/GO with thicknesses of 50 nm and 16.2 nm respectively only able to achieve up to 20 % of maximum SPP excitations [20]. Our proposed SPR device manifests its comprehensive fascinating package which are low cost, less complicated and simple technique to generate strong SPR signal.

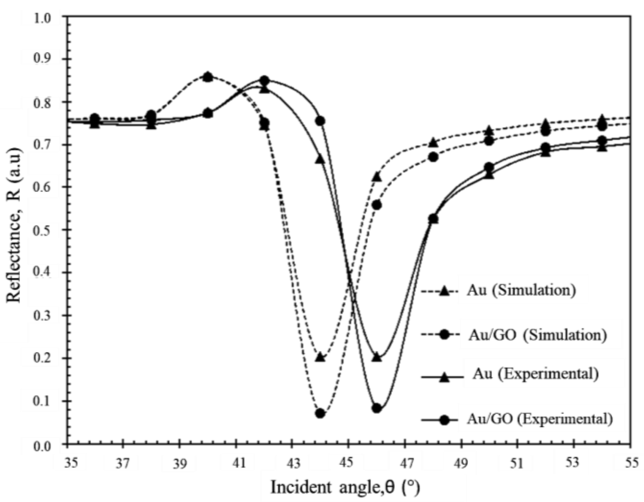

Fig. 6. Simulation and experimental SPR curves for Au and Au/GO thin films

4. Conclusions

This study demonstrates the remarkable role of light intensity to pump maximum number of photons in enhancing the SPR response. Maximum SPP excitations can be achieved as high intensity laser (P=80 nW) was incident onto the 52 nm Au/GO hybrid thin films using Kretschmann coupling configuration. The introduction of GO additional layer in SPR device witnessed an increase of 22.24% of the SPP excitations in comparison with Au monolayer. By control light intensity, the generation of SPR signal is successfully enhanced up to 56.68% compares to the previous work. For future investigation, an introduction of Au nanoparticles on top of Au/GO is believed will enhance the evanescent waves generation due to their unique and tunable optical properties.

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