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Fabrication of Plasmonic Thin Film Via DC Sputtering with Optics Based Assessment for Trasmittance, Absorbance and Resonance

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Abstract

A plasmonic thin film is potentially to be used with the advancement in optical biosensor. It is a label free without a need of fluorescent, chemiluminescent, radioisotope and etc. It is crucial to design a low cost biosensor that is easily fabricated at precise sizes and density. This paper reported a fabrication for copper and gold thin film on a glass substrate with a magnetron sputtering. The objectives are to: 1-Fabricate the thin film, 2- Develop the optics setup, 3-Evaluate the thin films and 4-Exhibit the optical resonance. Seven glass slides were coated with six copper and remaining with gold at different sputtering time. The time was varied from 280 sec to 980 sec while Argon gas and DC power were maintained respectively at 80 sccm and 130 watt. Later, the optics based was employed for assessing the film thicknesses. The thin films fabrication indicates different thicknesses were achieved at various sputtering time. Given y is a thicknesses and x is a sputtering time, respectively the copper and gold thin film were changed quantitatively at y= 28.335e0.0005x and y= 0.25x. Qualitatively, spectral transmittance and absorbance were changed to the thicknesses of the thin films. The plasmonic resonance was achieved with gold thin film at 50 nm thicknesses. The resonance sensitivity was decreases as the thin films thicknesses were increases.

Keywords; *DC sputtering, Optical resonance, Plasmonic, Thin Film, Spectral transmittance, Spectral absorbance*

I. INTRODUCTION

A plasmonic thin film has emerged as optical biosensor, biomedical devices, solar and many other optical applications [1]. Optical properties of plasmonic thin films are evaluated for absorption, refraction, dispersion, reflection, refractive index and resonance [2]. Thin films such as gold (Au), silver (Ag), and copper (Cu) have a maximum optical transmittance in the electromagnetic spectrum. Au and Ag were commonly used as ideal thin films for molecule conjugation. While Cu, Aluminum (Al) and Platinum are a preferred as adhesion low cost thin films. Criteria such as atmospheric inertness, resonance sharpness, chemicals and economical cost will be ideal indicators as an ideal biosensor. The Plasmonic thin film and composite structures of metal semiconductor act as a hot carrier generation, photocatalysis and injection. Noble metals comprise huge absorption section and efficiently enhance and concentrate light. The absorption cause severe light intensity attenuation which is proportional to a refractive index of any dielectric permittivity.

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High conductivity of plasmonic metals is due to the abundance number of collective electrons on the conductor surface. When a plane-polarized light hits a thin metal film under total internal reflection conditions it interacts with the free electron in the metal surface. These are the outer shell and conduction-band electrons. The incident light photons are absorbed and the plasmonic energy is transferred to the electrons. It transforms the photon to plasmonic wave to conserve both momentum and energy as occurs in the conversion process. The plasmonic resonance exists when the momentum of incidence light is equal to the momentum of the electrons density in a metal.

Optics setup is important for evaluating the plasmonic metals properties via transmittance, absorbance and resonance. It provides information of the material constants from the selected metals. It is based on absorption of the plasma energy originated and generated respectively by light and plasmonic thin film. The most interesting effects could be investigated with various thicknesses of the plasmonic thin films. At specific thicknesses, absorption of the plasmonic energy cause anomaly as higher intensity attenuation near UV and visible light. Frequency of light got reflected and transmitted respectively below and above the plasma frequency. Most of metals consists the plasma frequency in the ultraviolet that is reflective in the visible spectrum while Cu, Ag and Au in the visible range.

Most of the thin films are deposited either using Physical Vapor Deposition (PVD) or Chemical Vapor Deposition (CVD) methods [3-5]. A Reactive Magnetron Sputtering (RMS) and Atomic Layer Deposition (ALD) were applied in both methods [6,7]. Impurities and insufficient sputtering in the CVD reflect to the non-quality and nonuniformity to the films formation [8]. This led to RF and DC magnetron sputtering to solve problems due to incorporation of carbon and oxygen atoms and angular distribution [9-11]. Magnetron sputtering via PVD makes thin film deposition possible in mixture compositions. Thin film compositions with 15% Copper and 85% Zirconium had been deposited on the glass substrate using Cu and Zr targets [12, 13]. An optimized Zr-Cu-Ag thin film was deposited and evaluated for antibacterial applications by PVD magnetron sputtering [14].

Various deposition rate of a DC magnetron sputtering was studied to evaluate optical characteristics of Aluminum (Au) thin films [15]. UV-VIS-NIR Spectrophotometer indicates that higher reflection at 96 % spectral reflectance was observed from 250 nm to 2500 nm. However, when applied different sputtering power from 500 W to 2000 W, the hardness of the Aluminum thin film were varied accordingly. A uniformly thin film coating by magnetron sputtering with particle sizes ranging 10 μm to 150 μm was achieved via rotating coating vessel [16]. It rotates the magnetic field to allow ion bombardment to the granular substrate. However, only non-ferromagnetic particles had been coated and the influence of the magnetic field on the trickling behavior needs to be investigated.

The objective of this work is to: 1-fabricate the plasmonic thin film, 2- determine a reliable prediction recipe for various nanometer thicknesses of the Cu/ Au thin film and 3- generate the plasmonic resonance from the plasmonic thin film.

II. METHODOLOGY

This paper describe the phases of the plasmonic thin film fabrication and assessment as depicted in the Figure 1.

Figure 1: Plasmonic Biosensor development phases

PTF's fabrication: A copper and gold target is bombarded by high energy ions from the magnetron

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cathode. The bombardment causes sputtering of target atoms to scattered in the vacuum chamber and deposited onto a glass substrate to form a copper and gold thin film. The sputtering chamber was set according to the parameters in the TABLE I.

Au/ Cu thin film sputtering parameters

Parameters	**Cu**	**Au**
Sputtering Gas	Argon	
Sputtering Time (sec)	280~980	
Argon flow rate (sccm)	80	
Power supply	DC	
Temperature (°C)	24	
Substrate	Glass	
Sputtering Power (W)	130	50
Thin films Thickness (nm)	35~45	70~245
Chamber Pressure (Torr)	50µ	100µ

A 50 nm gold and six copper thin films at different thickness (35 nm to 45 nm) were deposited respectively on the triangular prism and microscope glass slide sized. These parameters were maintained from 280 second to 980 second at 140 second interval for the copper and gold deposition. The surface uniformity and thickness of each thin film were evaluated respectively with F20 metrology module.

PTF's evaluation: A block diagram of optics setup in the Figure 2 was developed on the optical breadboard with high intensity fiber illuminator as a light source. The setup was arranged for evaluating the thin films via transmittance and absorbance measurement. Two condenser lenses were used to collimated the light source to the thin films and focusing lens. The lens assures lossless spectral transmittance through the copper thin films via the CCD spectrometer.

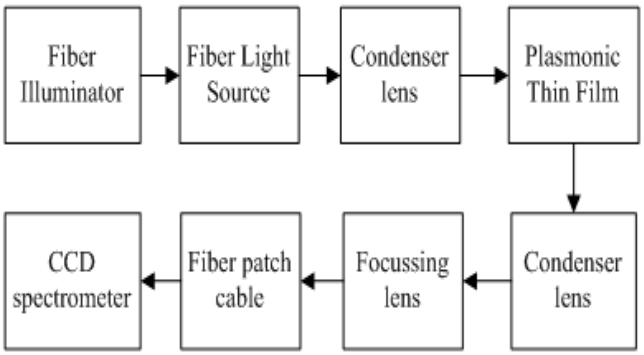

Figure 2: Optics setup block diagram for the spectral transmittance of the copper thin film

III. OPTICS BASED SETUP:

Basic principle

Plasmonic biosensor principle is based on a propagation of light over the metal-dielectric interface. The propagation constant responses to any molecules adjacent to the Plasmonic Thin Film. The PW propagation constant (*β1)* in the Equation 1 is expressed by ω, c, ε_D and ε_M which respectively denoted as the incident light frequency, speed of light in vacuum, dielectric and metal permittivity.

$$\beta_1 = \frac{\omega}{c}\sqrt{\frac{\varepsilon_M \varepsilon_D}{\varepsilon_M + \varepsilon_D}} \quad (1)$$

When ε_0 is a permittivity of free space, the evanescent wave that is travel at parallel direction over the metal surface can be deduced in the Equation 2 as the propagation constant (β_2).

$$\beta_2 = \frac{\omega}{c}\sqrt{\varepsilon_0 \sin\theta} \quad (2)$$

When a Total Internal Reflection (TIR) light source hit the metal surface, the plasmonic energy is generated and absorbs the reflected light intensity. As expressed in the Equation 3, the reduced intensity of the reflected light is not any longer

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belong to the light source. It is now a resonance angle, θ_R that corresponding to a refractive index of any molecules adjacent to the Plasmonic Thin Films.

$$\frac{\omega}{c}\sin\theta_R = \frac{\omega}{c}\sqrt{\frac{\varepsilon_M \varepsilon_D}{\varepsilon_0(\varepsilon_M + \varepsilon_D)}} \quad (3)$$

Finally, the molecules or dielectric refractive index denoted as $\sqrt{\varepsilon_D}$ can be determined by the θ_R when the plasma frequency of the metal is greater than a light source frequency. As expressed in the Equation 4, the photons energy at a plasma frequency excites collective of free electrons in the metal. Note that N is the concentration of free electrons while e and m_e respectively are the electron charge and electron mass.

$$\omega p = \sqrt{\frac{Ne^2}{\varepsilon_0 m_e}} \quad (4)$$

Consequently, the energy penetration from lower to upper layer of the metal occurs and shifting the resonance angle. By observing the resonance angle, it can be concluded the permittivity of the materials.

IV. EXPERIMENTAL SETUP

Referring to the Figure 3, the Plasmonic Thin Film (PTF) coated with gold at thickness of 50 nm was sputtered on a microscope glass slide. The triangular prism had been attached to the PTF with a refractive index matching gel.

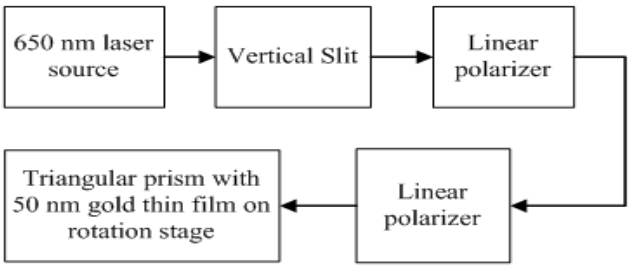

Figure 3: Experimental setup for plasmonic resonance

The prism with refractive index at 1.5 was used to deliver a fraction of the laser power to excite adequate energy into the PTF. A 650 nm laser diode at 7 mW was used for generating the plasmonic wave. The vertical slit removes unwanted diffraction and control the resolution from the laser beam. The excitation of the plasmonic wave was obtained with the linear polarizer that allows the transmission of only one polarization state which in a p-polarization state. The rotation stage was adjusted and fine-tuned to obtain the resonance which is visualized as absorption dip of the reflected beam.

V. RESULTS

Copper and gold thin film were achieved with the magnetron sputtering. In this experiment, a reliable prediction recipe for various nanometer of the copper and gold thin film thicknesses was acquired. Different thicknesses of the copper and gold thin film were achieved at various sputtering time (Tcu) as tabulated in the TABLE II. A quantitative result conclude that the thicknesses of the copper and gold thin film were changed respectively to sputtering time from 280 sec ~ 980 sec as validated from the Filmetrics's thin film measurement.

TABLE II. sputtering Vs thicknesses

No	T(sec)	Cu (nm)	Au (nm)
1	280	35.66	70
2	420	36.07	105
3	560	38.17	140
4	700	40.22	175
5	840	41.95	210
6	980	45.32	245

The relationship of the thin films thicknesses vs sputtering time was interpolated as shown in the Figure 4. The goodness of curve fit for gold (Au) and copper (Cu) thin film respectively indicates linear and exponential interpolation as expressed in Equation 5 and Equation 6.

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$$Y = 0.25x \quad (5)$$

$$Y = 28.335e^{0.0005x} \quad (6)$$

Therefore, given x= 1000 second then y= 46.72 nm thickness. As a result, the generated formula in the Equation 1 could be applied as a recipe for predicting thin film gold/ copper coating at various nanometer thicknesses with the DC magnetron sputtering. The thicknesses measurement of the Au and Cu thin films had shown average thicknesses distributions at uniform coating were achieved

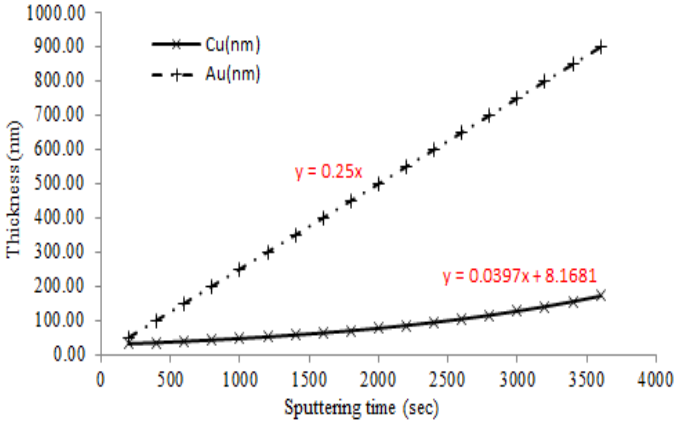

Figure 4: Sputtering time Vs thin films thicknesses (nm)

The respective graph in the Figure 5 and Figure 6 indicates result of a transmittance and absorbance spectral for each of the fabricated copper thin films (Cu1 ~ Cu Cu6) from 35.66 nm to 45.32 nm. However, there were insignificant transmittance intensity between curve Cu5 and curve Cu6. This is because copper thickness greater than 41 nm were begins to dominate in the visible wavelength region.

As a result, a consistent reflectance and insignificant absorbance were observed from Cu4 onwards. Referring to the reflectance spectrum of the Cu thin films, there is a clear result that the copper thin film acts as ideal resonance reflector. Qualitatively, spectral intensities were changed to the thicknesses of the copper thin films. This prove that range of molecules at different wavelength could be detected from the different thickness of Cu thin films.

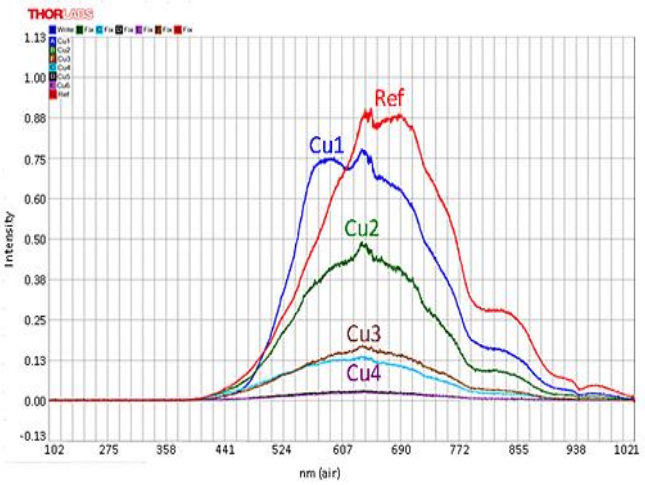

Figure 5: Transmittance assessment of the copper thin films

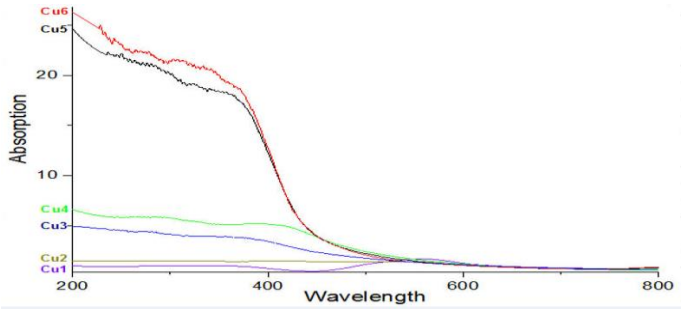

Figure 6: Absorbance assessment of the copper thin

When a 650 nm laser beam strike the 50 nm gold coated of the triangular prism, the beam was deflected towards the plane of interface when it is passing from a higher to lower refractive index. Adjusting the angle of the incidence beam θi, the reflected light change until it reaches a critical angle θc, as shown in the Figure 7. At this point, all the incoming light reflected within the prism at zero refraction rates. This phenomenon is called total internal reflection (TIR). As interpolated, the TIR can be performed when the angles of incidence were greater than critical angle at 34°. The result concluded that when the angles of incidence were increases the refraction rates were gradually decreases.

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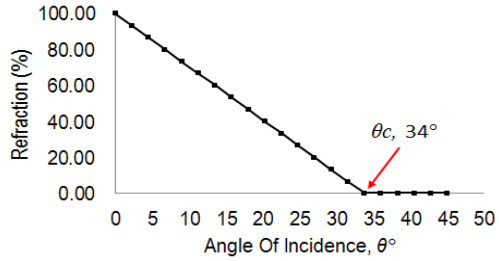

Figure 7: Refraction Vs Angle Of Incidene

As shown in the Figure 8, the absorption or resonant dip was generated from the TIR phenomenon when excitation of the plasmonic energy is above the critical angle. Apparently, the critical angle in this experiment occurs at 34° which is the highest reflectance intensity of 650 nm laser beam. This satisfies the TIR phenomenon with the appearance of the absorbance dip found at 43° due to the excitation of the plasmonic resonance. Therefore, this excitation could be obtained if adequate energy is delivered between the plasmonic thin film and a dielectric molecules boundary. The application of 50 nm gold coated triangular prism works as a light coupler to deliver sufficient energy to generate the plasmonic resonance. Photon to plasmonic conversion requires the conservation of both momentum and energy. The characteristic of momentum is the electric field between the light beam conducting the plasmonic thin film and the molecular properties adjacent to the thin film. As a result, absorbance dip occurs when the momentum of the beam is equal to the momentum of the plasmonic resonance

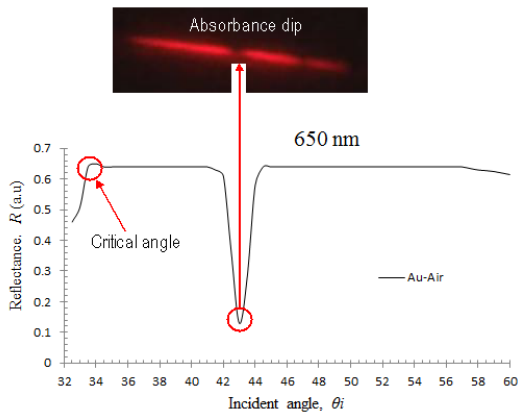

Figure 8: Plasmonic resonance of the 50 nm gold thin film

VI. CONCLUSION

Magnetron sputtering is widely used for the deposition of thin films and surface coatings. It was used at higher scale to produce thin film coatings with outstanding properties. In this paper, preparation of copper thin films has been attempted via variation of the sputtering time from 280 sec to 980 sec at chamber pressure below 5 x 10^{-05} Torr. The argon gas was maintained at 80 sccm while DC power respectively was set to 130 Watt/ 50 Watt for copper/ gold target. It was found that the sputtering time was a very important factor for predicting the thin film thicknesses. Quantitatively, thicknesses of the copper/ gold thin film were changed respectively to sputtering time from 31 nm ~ 171 nm and 50 nm ~ 900 nm within 200 sec ~ 3600 sec. Different intensities wavelength were obtained from six of the Cu thin films. Qualitatively, spectral intensities were changed to the thicknesses of the copper and gold thin films. This prove that range of molecules at different wavelength could be detected from the Cu/ Au thin films. As a result, no extra cost will be incurred to purchase another test kit and label antibodies for molecular detection as experienced in Enzyme-Linked Immunosorbent Assay (ELISA), Polymerase chain reaction (PCR) and Immuno Magnetic Separation (IMS). A high consideration should be met to generate the strong signal of the plasmonic wave. It correlates with the strong absorption of the plasmon and the thicknesses of the gold and copper thin films. The transmittance assessment of the six copper indicates that higher thickness cause insignificant reflectance intensity that lead to the absence of the plasmonic energy. It is because higher thicknesses of the thin film cause higher absorption in the thin film. However, when the thicknesses of the thin film lesser than 30 nm will leads to electron damping oscillations [17]. In this work, the plasmonic wave establishments were depending on the requirement of the prism refractive index, polarization of a laser beam, thin film thicknesses, type of the plasmonic metals and the applied wavelength. Assessment in plasmonic thin

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film provides a useful technique in the biosensor application for molecular characterization based on the molecules permittivity. In the future, the integration of the gold nanoparticles to graphene, carbon nanotube, spectroscopy, fiber optics and nanotechnology will provide outstanding platform to overcome drawbacks and limitations in the biosensors.

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