Reflectance Properties of Silver Thin Film Synthesized via RF Magnetron Sputtering

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Abstract

Nano film materials have now become one of the most interesting areas for research explorations and technological applications due to its unique properties that varied significantly when deposited in different conditions. One of the leading materials with very interesting use in photovoltaic devices, electrochemical applications, optical coatings, and medical applications is silver (Ag). Thus, this study is carried out to investigate the reflectance property of silver nano film. The films are synthesized in a silicon (Si) wafer substrate using radio frequency magnetron sputtering device deposited under 300 °C and 500 °C substrate temperature. The X-ray diffraction (XRD) result revealed the existence of silver crystals in all samples. UV-vis spectrophotometer was used to analyze the optical properties of the silver nano film sample. Correspondingly, the grown silver nano film at 500 °C has a solar reflectance (R_{sol}) of 65.16%, which indicates the sample's remarkable ability to reflect solar energy. Additionally, the sample's reflectance in the ultraviolet (R_{UV}), visible (R_{lum}), and infrared (R_{IR}) spectra are 61.35%, 75.53%, and 49.48 %, respectively. These results indicate that the prepared sample has better reflectance properties compared to the Ag film synthesized 300 °C substrate temperature.

Keywords: colorimeter application, heating chamber, Maillard browning reaction, peanut roaster, roasting chamber

Introduction

The development of new technology has emerge with new material using thin film metals for photovoltaic devices, electrochemical applications, optical coatings, and antimicrobial or medical applications where one of the interesting material for researchers is silver (Bosetti et al., 2002; Haji Abdolvahab & Zamani Meymian, 2018; Mohebbi et al., 2002; Schneid et al., 2015). Silver is one of the nanomaterial that found its favor in the field of biomedicine and other medical applications due to its very bizarre physicochemical feature (Bonilla-Gameros et al., 2020; Chaloupka et al., 2010; De Faria et al., 2014; De Souza E Silva et al., 2013; Duncan, 2011; Marambio-Jones & Hoek, 2010; Pal et al., 2007; Xu et al., 2020). Compared to any other metal materials, silver is found to be very unique since it reveals high in both electrical and thermal conductivity, even its reflectivity (D. R. Smith & Fickett, 1995).

The internal nanocrystal structure and crystal sizes affect the optical properties of the nano film (A. M. Smith & Nie, 2010). Reflectance, absorbance, light emission, and transmittance in nanoscale are dynamic and may vary from properties observed in other scales (Adewuyi & Lau, 2020). The behavior of material in nanoscale is now following the quantum laws instead of classical laws of physics. There are polymers in bulk forms are insulators, but in nanoscale become semiconductors (Mohan Bhagyaraj et al., 2018). This makes the nano structured materials to be more favorable than bulk version of the materials due to its new properties and abilities.

There are several techniques in preparing nano thin films, such as sol-gel, plating, direct current (DC) sputtering, ion plating evaporation and others (Jilani et al., 2017; Suzuki et al., 2002). In this study, we synthesized the silver nano film using RF magnetron sputtering device in a silicon substrate at 300 °C and 500 °C substrate temperature to identify the effect of temperature to the crystal structure and optical reflectance properties on the high value silver nanofilm samples.

Radio frequency magnetron sputtering deposition technique has been used for decades in different industries for thin film deposition onto surfaces. Although, it is not a new technique, but it continually refines and adapt for different future applications (Avrutin et al., 2010). RF magnetron sputtering technique is one of the most advanced technique in nanofilm development due to its charge up effect, reduced arching and can work even in non-conductive target materials (Angus Macleod, 2013). The advantages of silver nanofilm deposited via magnetron sputtering at high temperature compared to other studies include precise and controlled deposition, enhance crystalline quality and crystal preferred orientation, reduced surface roughness, improved adhesion and film density, enhance properties such as optical and electrical conductivity, and deposition rate is increased (Kim et al., 2010; Musil & Vlček, 1999). These advantages making it a promising choice for different applications such as sensing device, electronics, surface engineering, optoelectronics, and even antimicrobial effect (Ivanova et al., 2015; Li et al., 2012). This study aims, to develop a tunable nano material that can be used for future technological applications.

Methods

This study synthesized silver nanofilms on a silicon wafer substrate with crystal orientation of [100] using the Radio Frequency Magnetron Sputtering (ULVAC VTR-151M/SRF (SCOTT-C3)) system. To ensure film quality and eliminate impurities, the chamber is vacuumed using a turbo molecular pump that is already pre-installed in the sputtering system, until reaches a base pressure of $5.0x10^{-4}$ Pa. The temperature of the silicon wafer substrate is set to the desired temperature. Then, the surface of the 99.99% purity silver target is bombarded with ionized argon gas to sputter the silver particles to the silicon substrate which creates a plasma during the process. The deposition time of both high value silver nanofilm samples is 5 minutes. The sputtering conditions of the experiment are summed up in Table 1.

Table 1. *Experimental Parameters*

Parameters	**Silver (Ag) Film**
Base Pressure	$5.0x10^{-4}$ Pa
Substrate temperatures	300 °C and 500 °C
Argon flowrate	20 sccm
Deposition time	5 minutes

The microstructures of the samples are identified using X-ray diffraction (X'pert Pro PANAlytical PW 3040 MPD) with the range (2ϴ values) between 20° and 80°. The X-ray diffraction result will also confirm the presence of silver in the substrate. The optical reflectance was measured using UV-vis-NIR spectrophotometer (Shimadzu UV-3600) in the wavelength between 280 to 1100 nm at room temperature. The reflectance of radiation was calculated in the stellar or solar (sol), near infrared (NIR), visible (vis), and ultraviolet (UV) regions with corresponding wavelength (λ) ranges of 280-1100 nm, 780-1100 nm, 390-780 nm, and 280-390 nm (Barra et al., 2018, 2022; Liu et al., 2015; Moriomoto et al., 2022).

Results and Discussion

The silver nano film was successfully deposited on the silicon substrate as shown in the diffractogram in Fig. 1. The peaks of silver nano film as resulted in the XRD scan are all indexed with ICSD code 96-901-2432. The results show that the film deposited at 500 ˚C has better crystalline structures compared to film deposited at 300 ˚C substrate temperature. Both films have preferred crystalline orientation are along [111] direction.

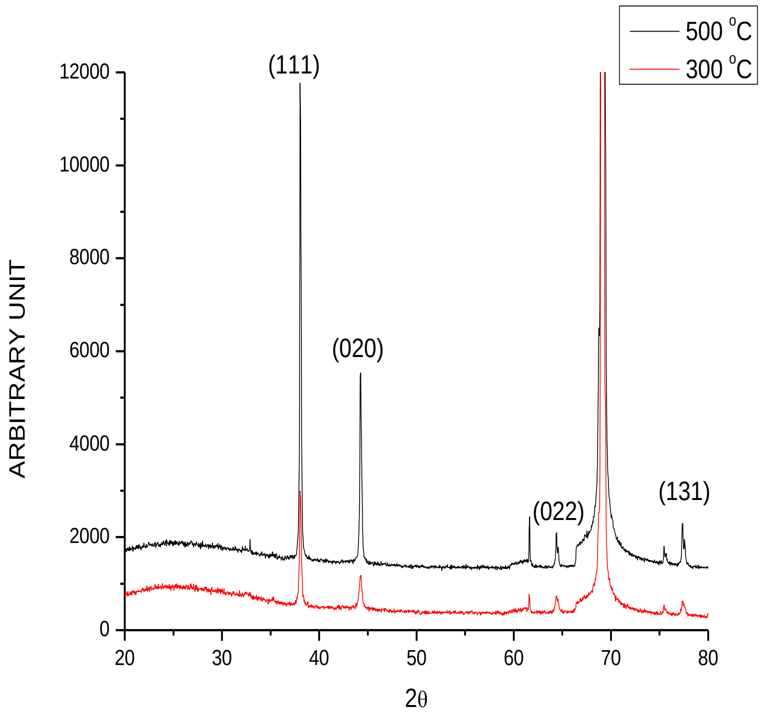

Figure 1. *XRD result of Silver Nanofilm*

The results of the UV-vis-NIR spectrophotometer inspection of the silver nano film samples are displayed in Fig. 2. The results obtained, solar reflectance (R_{sol}), ultraviolet (R_{UV}), near infrared (R_{NIR}), and the reflectance in visible region (R_{vis}) are computed using the equation (Barra et al., 2018, 2022; Dai et al., 2013),

$$R_i = \frac{\int \varphi_i(\lambda) R(\lambda) d\lambda}{\int \varphi_i(\lambda) d\lambda}, \quad (1)$$

where i represents for 'sol', 'UV', 'NIR', 'vis', φ_i is the standard efficiency function of different spectral regions, R is reflectance, λ is for the wavelength, which ranges from 280-1100 nm for R_{sol}, 780-1100 nm for R_{NIR}, 390-780 nm for R_{vis}, and 280-390 nm for R_{UV}.

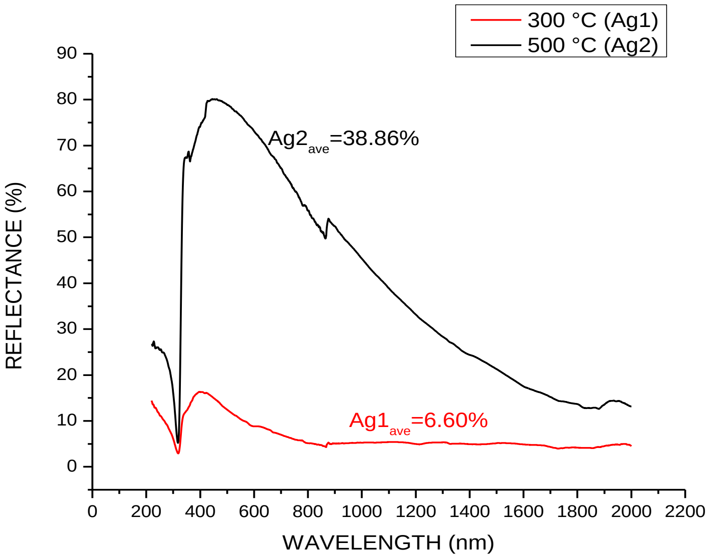

Figure 2. *UV-Vis-NIR Reflectance Spectra of the Silver Nanofilm Samples*

The result in Fig. 2 describes how the reflectance of the silver nanofilm increased as the substrate temperature increases from 300 °C to 500 °C it shows that reflectance properties of the film increased. Furthermore, the calculated values of the optical reflectance in different spectral regions are summarized in Table 2. The results indicated that silver nanofilm deposited at higher substrate temperature has better reflectance compared to the silver film synthesized at lower substrate temperature due to improved crystallinity. The improved film morphology and crystal structures at higher substrate temperature can reduce light absorption and scattering within the film, resulting in higher reflectance. Moreover, silver films with smoother surfaces suggest lesser defects and reduced surface roughness that directly affect the scattering of light.

Table 2. *Optical Reflectance in Different Spectral Regions*

Sample	Spectral Regions			
	R_{sol} (%)	R_{UV} (%)	R_{NIR} (%)	R_{vis} (%)
	(280-1100 nm)	**(280-390 nm)**	**(780-1100 nm)**	**(390-780 nm)**
Ag1	8.88%	12.52%	5.12%	10.31%
Ag2	65.16%	61.35%	49.38%	75.53%

Conclusion

Silver nano film was successfully synthesized using the RF magnetron sputtering method in a silicon wafer substrate. The result in XRD scan shows that the synthesized sample at higher substrate temperature displayed good crystal structure and morphology. Undoubtedly, the results in the optical property investigation show that depositing silver nanofilm at higher substrate temperature significantly can enhance the reflectance behavior of a material. Therefore, this outcome implies that the silver nano film coatings have future technological applications in the physical world.

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