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Research paper

Silver Metallization Characterization and Resistivity Performance Potential toward Chemical Sensor Application

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Abstract

Performance of limiting resistive and capacitive signal delays increases gradually depends on the complexity degree of multilayer metallization. Electrodes sensor for electrical applications requires low surface roughness and low resistivity metal layers. Amongst conductive metal series, silver (Ag) has the lowest resistivity. On the other hand, compared to aluminum and copper, this metal also has higher oxidation resistance. This study aims to characterize Ag thin film on the glass substrate and the resistivity performance by using a physical deposition technique for chemical sensor application. A series of Ag thin film with different thickness were prepared from thermal vacuum evaporator at 3.45 x 10-5 Pa with applied current at 28 Ampere in 21 minutes. Four-point resistivity probing instrument was used for resistivity testing of the thin films with different thickness. The prepared Ag thin film shows a low average roughness at 1.89 nm. A smooth and homogeneous of Ag thin film is an advantage to provide a sensitive surface for element recognition in the development of chemical sensor and an adsorbate can be justified whereas it schematically assembled with the arrangement onto smooth and perfectly flat thin film surface. Ag thin film has shown a crystallite size with respect to 50.84 nm. The low rough surfaces have fewer nucleation sites, therefore fewer grains (crystallites) will appear. The optimum thickness was determined at 107 nm and the resistivity of Ag thin film was an average at 1.988 x10-8 Ohm m.

Keywords: *a Thermal evaporator; resistivity; roughness; silver; thin film.*

1. Introduction

Silver metallization and its potential as a favorable candidate for implementation as a future interconnect material for integrated circuit technology. Basically, Ag has a malleable metallic element, ductile and lustrous white with the atomic weight of 107.87 u. The melting point of Ag is 961 °C which is much higher that Al (600 °C) [1]. Ag has reflected optical properties and also has a reduction of their antimicrobial activity [2]. Ag has much application in various fields including, electronic, sensor, optical [3], surface-enhanced Raman scattering [4], medicine [5] and environmental [6].

Amongst conductive metal series, silver (Ag) has the lowest bulk electrical resistivity at 1.57 μΩ cm at room temperature compared to other interconnection pure metal such as copper (Cu) at 1.7 μΩ cm and aluminum (Al) at 2.7 μΩ cm [7],[8]. The lower resistivity can reduce the RC delays and high power consumption. Ag also expected has higher electromigration (0.95 eV at 225-285°C) resistance compared to Al [9]. Ag has lower resistance than that of Al, based on these reasons Ag is considered to be one of potential metallization schemes for future integrated circuits (IC's). The thermal stability of metallization and barrier layers become more critical for device reliability as feature sizes in multilevel metallization continue to shrink. Besides having low dielectric constant, the materials must have a good adhesion to silicon and to interconnect materials and thermal stability. But in anyhow, Ag thin film agglomeration has been observed on many substrates at high temperatures and considered as a drawback of silver metallization. The ability to deposit thin films of various materials is important for the fabrication of modern microelectronic devices and for enabling a variety of investigations of fundamental physical principles. The texture and the microstructure of thin metal films are closely related to the property of reliability and the structural of the thin film. Typically, the thin film layer structures, less than a micron in thickness, tailored to achieve the desired functional properties and with the better performance of interconnection in electrical properties.

Most techniques that fabricate Ag thin films are usually based on vacuum including evaporation, sputtering, and molecular beam epitaxy. Electrochemical deposition as an alternative for Ag deposition technique is important because of its affordability and flexibility. However, the mechanism of electrodeposition is complicated, because it is a non-equilibrium growth process and involves a large number of variables that influence the process including cation diffusion, pH and concentration of electrolyte and substrate type. The physical vapor deposition technique by using vacuum thermal evaporator instrument has a simplicity in experimental setup and cost-effective.

The objective of vacuum evaporation is to controllably of transfer atoms from a heated target. Basically, the thermal evaporation was operated with the target is heated directly or indirectly with the suitable pressure, power, and current until the point is reached where it efficiently sublimes or evaporates.

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In the present work, Ag thin films with various thicknesses from 10 to 230 nm have been prepared by physical vacuum deposition on unheated glass substrates. The structure, morphology and electrical properties of the films have been analyzed as a function of the layer thickness.

2. Methodology

The glass substrate was cleaned in a "piranha" solution, which is a mixture of 30% H_2O_2 and concentrated H_2SO_4 (1:3, v/v) for 5 min at room temperature. Then, the glass substrate was rinsed copiously with deionized water and it will be ultra-sonicated thrice in deionized water to completely remove traces of sulfuric acid and ion. Afterward, the glass substrate was ultra-sonicated once in ethanol solution to remove undesirable particles, and dried under a stream of nitrogen gas as mentioned by [10], [11],
The experiment on the fabrication of Ag thin film was carried out to investigate the optimization of thickness in resistivity. This experiment will be carried out by using a thermal evaporator model of Ulvac Kiko VPC-061 (Figure 1) with the glass substrate 1 x 1 cm (Figure 2).

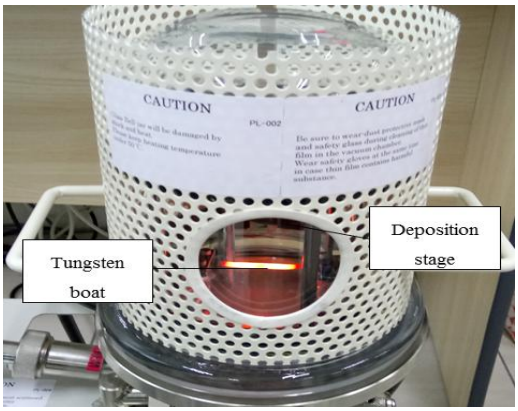

Fig.1: Thermal evaporator

Ag wire (99.999 % purity) was weighed using analytical balance and will be placed at the tungsten boat at thermal evaporator instrument. Then, the clean glass substrate was transferred immediately at thermal evaporator deposition stage. The current of deposition will be operated constantly at 3.45 x 10-5 Pa with applied current at 28 Ampere in 21 minutes. The resistivity of different thickness at Ag thin film will be tested by using *Four Point Resistivity Probing* (model S-3024) instrument. The thickness of Ag thin film will be measured by using a surface profiler. The roughness of Ag was characterized by using Atomic-force microscopy (AFM) and the surface morphology of thin film was observed by using field emission scanning electron microscope (FESEM, JEOL7670) and the crystallinity of thin film was tested by using X-ray Diffraction (XRD).

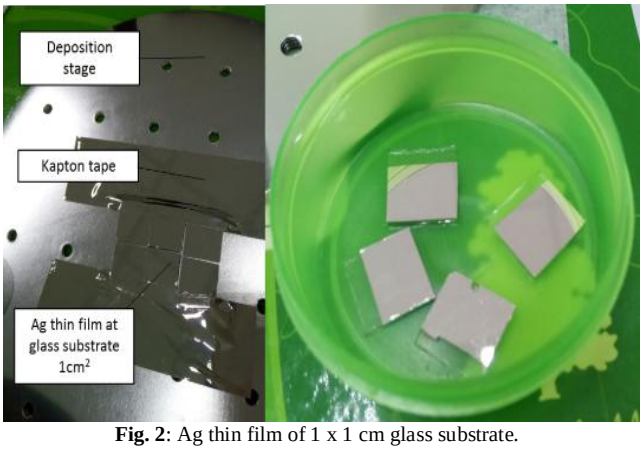

Fig. 2: Ag thin film of 1 x 1 cm glass substrate.

3. Result

The morphology of Ag thin film on substrate glass was presented with the magnification at 50 000x by using FESEM image (Figure 3). In another word, this thin film was successfully deposited with 40.5 mg at 5 mm length of 99.999% pure silver wire by using a physical deposition technique. The Ag thin film was prepared by the physical technique of thermal vacuum evaporator at a high and excellent pressure which is 3.45 x 10^{-5} Pa. The thickness of the Ag thin film was determined by surface profiler at 107 nm.

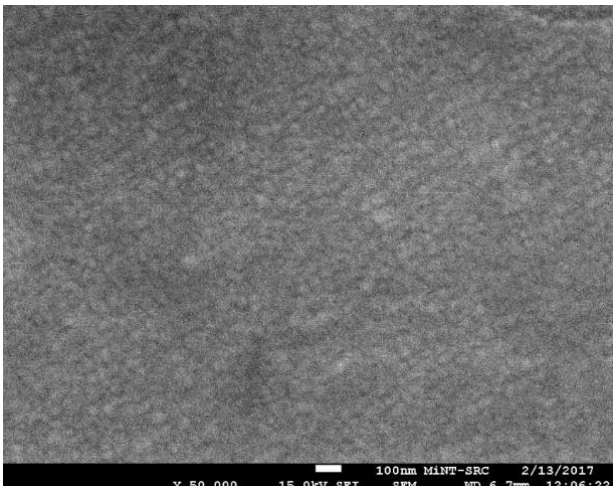

Fig. 3: Scanning electron microscopy micrographs of the image of the Ag thin film at 105 nm

Additionally, Figure 4 shows the topography of Ag thin film by using AFM measurement image of Ag thin film on glass substrate. Indeed, the slow deposition of Ag thin film fabrication with a duration of 21 minutes was applied rather than rapid deposition with respect to current at 28 Ampere and the potential at 1.3 v. As a result, the slow deposition that is applied to the fabrication of Ag thin film shows a low roughness at 1.89 nm average roughness. Correspondingly, a smooth and homogeneous of Ag thin film is an advantage for Ag-SAM fabrication as the recognition element and the topography plays an important role towards a substrate which is a similar order or bigger than the size of the molecule adsorbate in the fabrication of integrated molecular assemblies as highlight by [12],[13].

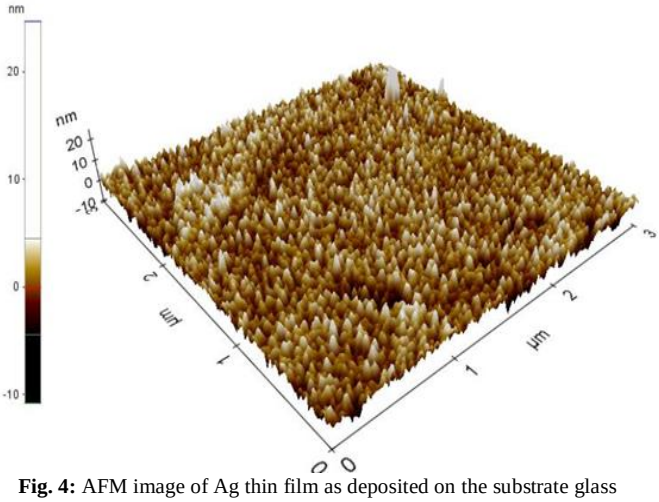

Fig. 4: AFM image of Ag thin film as deposited on the substrate glass

Meanwhile, the crystallinity from XRD instruments result of Ag thin film has shown a good crystallite size with respect to 50.84 nm. Important to realize, that the crystallinity of the substrate sur-

face becomes the essential role in determining the compactness, often quantitatively estimated by the pinholes distribution.
As revealed by the graph of mass Ag with thickness and resistivity in Figure 5, the thickness of Ag thin film was gradually increased with the increased of Ag mass. As a conductive element, Ag has good resistivity with an average of 1.988 x10^{-8} Ohm.m. The optimum of thickness Ag thin film was obtained with the interception of thickness and resistivity line which is 105 nm with 40 mg of Ag mass.

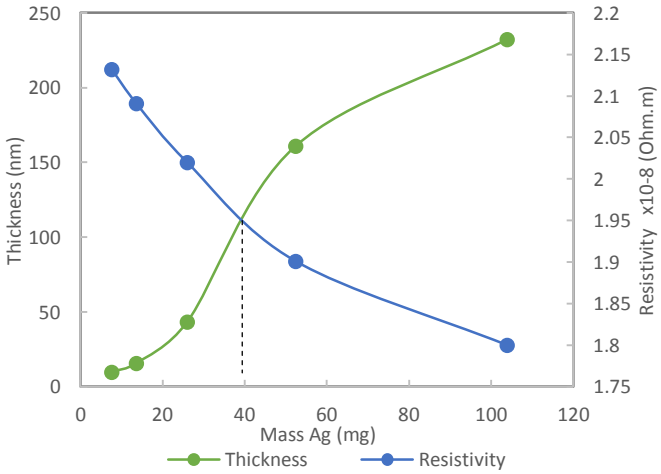

Fig. 5: Mass Ag with thickness and resistivity

The linear increase of resistivity is a result of electron scattering by lattice vibration. The resistivity of thinner films is lower than that of thicker films. The electrical resistivity changes dependence of the thickness of Ag on the glass substrate structure. The change in the morphology of Ag thin films also influence variations of the electrical resistivity which is an increase in resistivity due to increased surface scattering of conduction electrons [1].

4. Conclusion

From this study, it can be concluded that resistivity of silver thin films was studied using an in situ four-point probe technique. It was observed that film thickness plays an important role in the resistivity, which increased as the film thickness increased. Supersmooth metal films are particularly desirable for various electronic devices. The adhesion quality of deposited films onto substrates is directly dependent on the cleanliness of the substrate surface.

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