Cost effective strategy of nano electronic device fabrication by aluminum: Evaporated profiling

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Nanotechnology is the latest promising technology for future that has many potential and actual applications in nanoelectronic devices. However, to gain advantages on nanotechnology is required a sophisticated technology itself. The main problems of nanoelectronic device fabrication are small scale, small area, small volume and low concentration. Manufacturing in nano scale creates issues not only on performance, but also cost for the electronics industry. To overcome this problem, we studied a profiling of metal contact. We present the aluminum (Al) profiling in order to get desired properties as well as effective in cost, since aluminum is widely used in many electronic applications like spintronics, solar cell, thin film transistors, and even for photocatalyst. In this research, the Al was deposited by thermal vacuum evaporator. The structural properties of Al films were characterized using XRD, AFM, and FESEM. The electrical properties were characterized using Four-point probe. The results show increasing the thickness result in decreasing both the resistivity and the strain of the Al films as well as increasing the cost.

Key words: *Nanomaterials; Spintronic; Solar cell; Aluminum; Thin film*

INTRODUCTION

The tendency of miniaturization and downscaled to nano scale is a trend on nowadays nanotechnology and nano electronis devices. The fabrication of nano electronic devices involved many processes such as thin film deposition, etching, annealing, and metallization. The fabrication of nano electronic devices keep improving while the size of the components shrinking as well as increase the difficulties. A metal used to metallization on nano electronic devices requires specific properties in order to achieve a high performance of material-based devices. For example, the quality of the metal contacts on thin film affects contact resistance as the research conducted by [1]. They investigated the effect of metal contacts on ZnO thin film. When platinum (Pt) used as a contact on ZnO thin films it behaves as a rectifying contact, but turns out to be Ohmic in nature when Aluminum (Al) contact is used. Furthermore, [2]. Was also discussed the effects of metal contact on the electrical characteristics in Thin-Film Transistors (TFT). The results show that the metal contacts of a TFT cause two effects: The building up of an in-channel potential that can be in the volts range and the formation of a residual barrier, with a height that depends on the gate bias and measured in the order of some tens of meV. The nature of metals tends to decrease the electrical resistivity when the thickness increase, in reverse the conductivity. Metals with low resistivity like silver (Ag), gold (Au), and Aluminum (Al) are most commonly used as electrode on thin film. Compare to other metals, Al has several advantages such as light weight, good adherence to glass, good reflectance, and good electric conductivity. Furthermore, although aluminum is chemically very active, it does not corrode in moist air just like the iron does. Hence, aluminum is widely used in many fields of microelectronics and nanotechnology such as thin film transistors, flat panel displays, solar cells, and optical mirrors. Moreover, the availability of aluminum in the earth was also abundant, since it the third most abundant element after oxygen and silicon. Al is a metallic compound that has silvery white in color and low melting point of 660 oC [3-7]. There are many methods to deposit metal thin film on substrate, such as sputtering, thermal vacuum evaporation, electron beam-evaporation, Atomic Layer Deposition (ALD), and Chemical Vapour Deposition (CVD). Thermal vacuum evaporation is commonly used to deposit metal films since it has many advantages compared to other methods, such as a high purity of films, less substrate damage, simple and cost-effective. In this work, we present the Al profiling by thermal vacuum evaporation method for metal contact in terms of cost. The characteristics of Al film when deposited on different substrates was also discussed. The obtained results can be used for many applications depend on the objective [8-12].

EXPERIMENTAL METHODS

Thermal vacuum evaporator (Model: Ulvac Kiko VPC-061) was used to deposit Al films on substrates. Before the deposition, firstly the glass substrates were ultrasonically cleaned with acetone and then rinsed with Deionized water (DI water) for 15 minutes to remove contamination. Then, nitrogen gas was used to dry the substrates. High purity of Aluminum metal wire (99.99%) from Kurt J Lesker was used as a target. Al target was then placed inside tungsten boat in vacuum chamber. The deposition condition was conducted in vacuum condition with base pressure approximately ~10-3 Pa. The current supply was turned on and increased gradually from 0 until 35 Ampere, which results in ample heat to melt the Al. Al was vaporized after the temperature achieved ≥ 600oC. The deposition time was run in 2 minutes. There are six samples used in this experiment indexing of S1-S6. Sample 1 or S1 used the smallest mass of target of 12 mg, and S2, S3, until S6 were 14, 18, 26, 42, and 74 mg, respectively. The thicknesses of the films were measured by cross-section method using FESEM. The electrical properties of the films were analyzed using 4 Point Probe (Model: Lucas Labs Pro 4). The SEM imaging of the evaporated Al films was performed with FE-SEM, Model: JEOL JSM-7600F. The structural properties also carried out using X-ray diffraction system (XRD, Model: Panalytical X'Pert3 Powder) with Cu-Kα1 radiation source, λ=1.5406 Å. The crystallographic analysis and peak phase conduct with high score plus software. Surface morphology of the samples was performed using AFM system, Model: XE-100 park series.

RESULTS AND DISCUSSION

High purity of Al wire (99.99%) was deposited on glass substrates by thermal evaporation. The early experiment is to know the correlation between mass and thickness of Al films deposited by thermal evaporation method. The result showed that the thickness of the Al film increases with

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increasing the mass of the Al used as shown in Figure 1. The thickness profiling provides a data how to get certain thickness by a certain amount of Al wire.

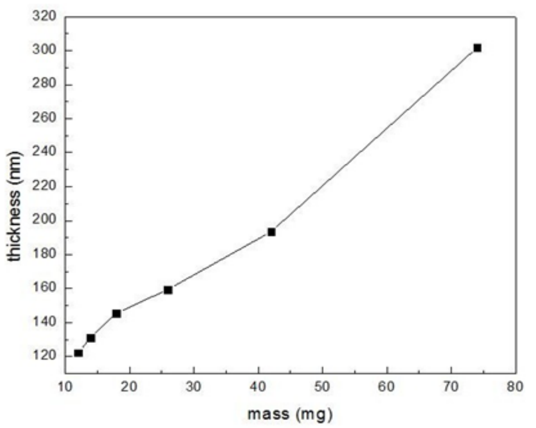

Figure 1) *Thickness of thin Al film deposited on glass, as a function of mass.*

Al is a metal that known has a good electrical conductivity. The resistivity of the Al film confirms decrease with increasing the thickness of the film as shown in Table 1. The resistivity of the Al films obtained from this experiment is close to the electrical resistivity of pure Al of 2.8 x 10-6 Ω.cm, owe to high purity of Al wire used. From the Table 1, it can be seen to obtain a thickness of about 122 nm takes RM 4.9. The costs will continuously increase, as well as the increasing thickness of the metal. Since the usages of metal contact on nanoelectronic device depends on the objectives, the thickness of the metal can be adjusted to achieve the desired results.

TABLE 1
Resistivity data of aluminum thin film with different thickness.

Sample Al	Thickness	Resistivity	Cost	
			MYR	USD
S1	122.28	237.40×10^{-6}	4.92	1.08
S2	131.12	13.25×10^{-6}	5.33	1.17
S3	145.56	12.69×10^{-6}	6.97	1.53
S4	159.58	8.58×10^{-6}	10.25	2.26
S5	193.46	5.42×10^{-6}	16.4	3.61
S6	301.71	4.35×10^{-6}	28.71	6.32

Figure 2 shows the FE-SEM images of Al films. Generally, FE-SEM images of Al films deposited by low vacuum thermal evaporator on glass substrate showed a homogenous structure. Physical vapor deposition method that allows material to attach on substrate physically result in a good imaging of Al structure where the void that separated grain of crystal can clearly observed. However, the thinnest sample shows a hillock-less surface as shown in Figure 2.

Furthermore, it can be seen, increasing the thickness of the films result in increasing the grain size.

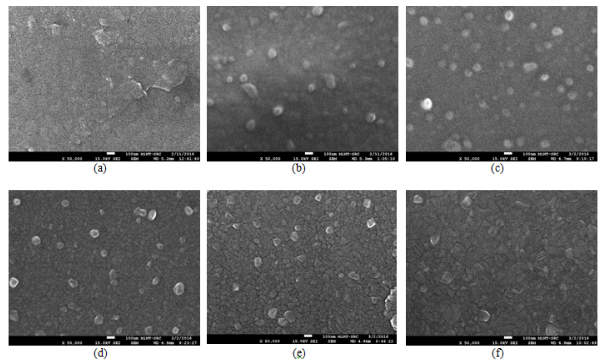

Figure 2) *SEM images of Al films deposited by thermal evaporation of a) Sample 1 ;b) Sample 2; c) Sample; d) Sample 4 ;e) sample 5 ; f) sample 6*

XRD data of Al film with different thickness shows in Figure 3. The intensity of the peak Al (111) increases with increasing the thickness of the Al films. The increasing intensity of the peak XRD is believed due to strain of the films. Sample 1 that only has 122 nm in thickness does not show a peak that attributed as crystal structure. This sample recognized as amorphous structure. This is believed due to the thickness of the film is thin enough, so that when the x-ray beamed to sample, it passes through the sample penetrate to substrate (glass).

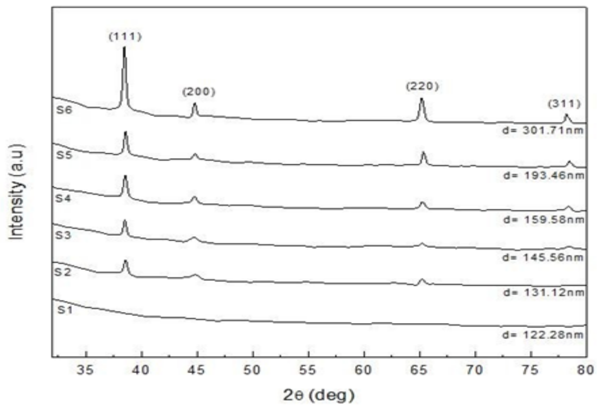

Figure 3) *XRD of thin Al film evaporated on glass with different thickness*

It is also important to know the elastic strength of the film in order to get high quality of nano electonic devices. The strain of the films can be calculated from the XRD data. From the XRD data, d-spacing, Full-Width at Half-Maximum (FWHM), and crystallite size of XRD data measurement, the effects of the strain (ε) can be expressed by the equation (Williamson-Hall method) [13,14].

$$\beta \left(\frac{\cos\theta}{\lambda}\right) = \frac{1}{L} + \varepsilon \frac{(\sin\theta)}{\lambda}$$

Where β is the measured FWHM (radians), θ is the Bragg angle of the peak, λ is the X-ray diffraction wavelength, and L is the crystallite size. Figure 4 shows β cos θ/λ is plotted versus sin θ/λ for Al films deposited on the substrate. The slope of the fitted line indicates the presence of strain in the Al crystal. It can be concluded, increasing thickness of the thin films resulted in decreasing the strain of the films, as shown in Figure 4. This is also supported the data from XRD that shows shifting the peak to lower (Figure 5) angle by increasing the thickness of the film. The shifting is believed due to the strain which resulting from a planar fault and internal stress.

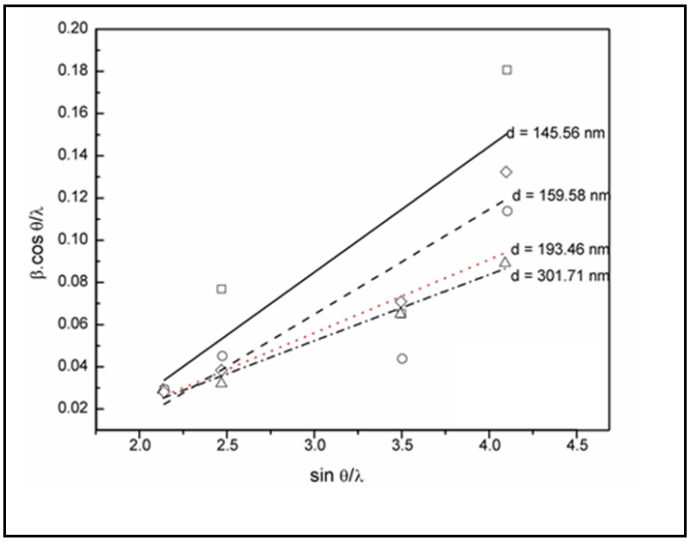

Figure 4) *Plot of strain by Williamson-Hall methods of Al films on glass substrate*

Note: d=145.56 nm, d=159-58 nm, d=193.46 nm, d=301.71 nm.

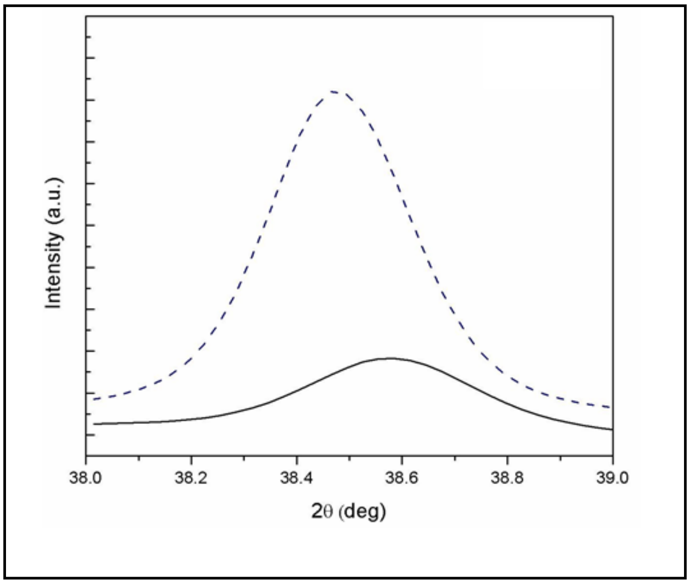

Figure 5) *Peak XRD of Al film shift to lower angle Note: S2, S6*

CONCLUSION

We present a study of profiling aluminum contact deposited by thermal evaporator in order to make cost-effective on nanoelectronic device fabrication. Getting thicker in size, result in the smaller in resistivity, but the higher the cost. As the thickness increase, the resistivity changed and the structural properties like a roughness and crystal size of the film was also changed. However, the thinnest film of Al showed non-uniform surface and less reflectance as well as high resistance.

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