

# THE EFFECT OF NANO SURFACE TOPOGRAPHY ON ELECTRICAL PROPERTIES OF ALUMINIUM FILMS DEPOSITED ON PLASTIC SUBSTRATE BY DIFFERENT TECHNIQUE

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## Abstract

Aluminium films have been prepared by two different techniques namely direct current (DC) sputtering and thermal evaporation on polyethylene terephthalate (PET) substrates. Effects of techniques types on the structural and electrical characteristics of the films were studied. The effect of nano surface topography on electrical properties of Aluminium films was studied. Sets of experiments were conducted to optimize the deposition of Aluminium films with appropriate deposition parameters. The deposited films were analyzed with atomic force microscopy and four-point probe technique to determine their structural and electrical characteristics. Film characteristics such as electrical resistivity and surface roughness have been determined.

**Keywords:** Aluminium; polyethylene terephthalate; sputtering; evaporation

## Introduction

Recently, there is a growing interest in the deposition of several thin films materials on polymers using different techniques such as DC sputtering and evaporation methods (Faraj et al., 2010 ; Faraj and Ibrahim, 2012 ; Faraj et al., 2011 ; Guille'n and Herrero, 2005 ; Zhou et al., 2007) . A special attention was given to aluminum thin layers due to numerous of applications. In the development of highly demanding future product applications, for example efficient portable devices with light-weight and flexible display technologies have been needed. The aluminum thin layers have been used extensively in cell phone, remote control units, digital cameras, smart cards, personal digital assistants (PDAs), camcorders and the future "electronic paper" (Suo et al., 1999 ; Yanaka et al., 1999).

The aluminium thin layers have been used as back contact in layer in thin film silicon solar cells (Popovich et al., 2009; Amick et al., 1994). Therefore, it is important to deposit the aluminum thin layers with the desired substrate materials such as polyethylene terephthalate (PET) (Kale et al., 1975; Nasef, 2002). PET, is a thermoplastic polyester resin. PET may exist both as an amorphous (transparent) and as a semi-crystalline material initiated by various techniques (Awaja et al., 2005; Lee, 1990; Jabarin, 1998). As PET is widely used in complex multilayered systems, the nature of

their interface with other metal materials plays a major role in determining the mechanical, electrical and chemical properties of the whole system. However, PET chemical inertness, together with other physical properties, has made it particularly suitable for several applications. PET finds application in a wide array of fields, because it combines low cost with good chemical resistance and good spinnability (Miller, 1966).

Until recently, there is little information concerning the effect of sputtering and evaporation of aluminum thin films on plastic substrates. In this study aluminum thin films have been deposited on PET substrate with DC sputtering and evaporator apparatus. The structural and electrical properties of aluminum thin layers deposited on PET were measured. Film characteristics such as electrical resistivity, sheet resistance and surface roughness have been determined.

## 2. Experimental details

### 2.1. Target preparation

The cleaning of contaminants from the PET substrate is a crucial step and must be performed with great care as it has a direct impact on the performance of the device. A 250 mm-thick PET from Penfibre Film Division was used. The PET substrates were first cleaned by full immersion in Decon 90 for 10 min to remove contamination. After the cleaning process, all of the substrates were rinsed with deionized water (DIW) to

remove the Decon 90 residue. The samples were then dipped in isopropyl alcohol (IPA) and agitated with moderate ultrasonic power for 10 min. The samples were again dipped in DIW and then dried off with nitrogen ( $N_2$ ) gas after the ultrasonic cleaning. An aluminium (Al) film was deposited on the PET plastic substrate using DC sputtering (model: AUTO306). The substrate is placed in a vacuum chamber with the source material (target). The residual gas pressure in the chamber was evacuated to  $8 \times 10^{-3}$  torr by a rotary and diffusion pump arrangement. The chamber was back filled with argon. Gas plasma is struck using a DC power source, causing the gas to become ionized. The ions are accelerated towards the surface of the target, causing atoms of the source material to break off from the target in vapour form and condense on all surfaces including the substrate. The target was pre-sputtered for 10 minutes to remove contaminations, if any, from the surface and then the shutter was displaced to expose the substrates in the sputtering plasma for 30 minutes. The power used was 250 watts. The sputtering was done in room temperature of 298 K. The distance between the target and PET substrate is an approximately 6 cm.

The evaporator system, Edwards Auto 306 utilizes a common diffusion and rotary pump to evacuate the high vacuum chamber that was made of an enclosed bell jar. Wafers were loaded on top of the vacuum chamber while tungsten boat was used to hold the molten aluminum for evaporation. Source of aluminum (99.99% pure) in the form of long rod was cut into small pieces and loaded onto tungsten crucible in the vacuum. Prior the

deposition, the aluminum and tungsten boat were clean in alcohol to remove any contamination and dried with nitrogen gas. The vacuum chamber was evacuated to  $3.0 \times 10^{-5}$  torr before the source was heated. The tungsten boat was heated with 3.0 amperes direct current for 10 seconds to melt the aluminium. The current was increased slowly to 7.0 amperes until all aluminium was evaporated. The PET substrate was removed after waiting for a few minute to cool down the chamber.

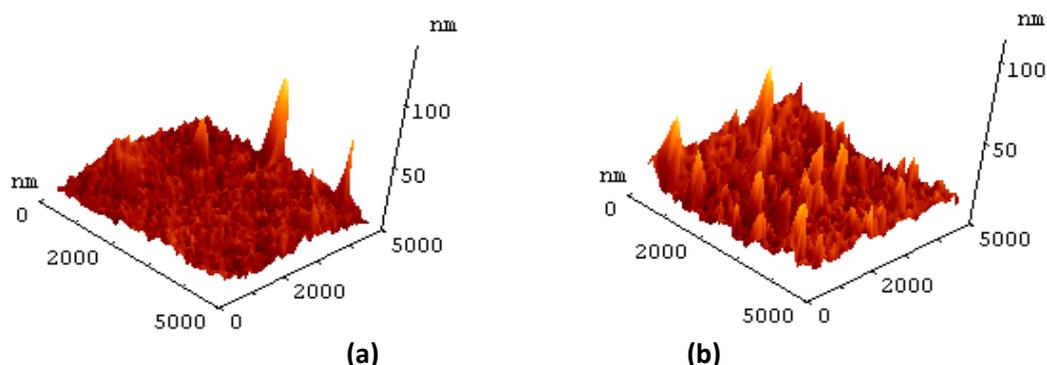
## 2.2. Characterization of the Aluminium Films

The thicknesses of the Al on the PET substrates are of the order of 500 nm, which were measured with an optical reflectometer (Model: Filmetrics F20). The electrical resistivity and sheet resistance of the deposited Al films were measured by four point probe technique (Changmin Tech CMT-SR2000N Resistivity Measurement System). The surface morphology of the Al films were studied by atomic force microscopy (AFM) (Model: ULTRAIObjective model) at the School of Physics, Universiti Sains Malaysia.

## 3. Results and discussions

### 3.1. Structural properties

AFM topographic images were done in non contact mode over  $5 \mu m \times 5 \mu m$  area for both samples. **Fig.1 (a)** and **(b)** shows non contact mode images of PET metalized with Al using DC sputtering and evaporation respectively. Evaporation techniques show many spike compare to DC sputtering. The average grain height for both methods is likely to be the same range 12.51 nm and 12.97 nm respectively.



**Fig. 1:** AFM pictures of Aluminum deposited on PET: **(a)** DC sputtering method, **(b)** evaporation method.

**Table 1:** Statistical data on Aluminum deposited on PET using DC sputtering and evaporation methods.

	DC sputtered Al	Evaporated Al
Max. height different	74.48 nm	57.39 nm
Mean	12.51 nm	12.97 nm
Root mean square	5.66 nm	6.49 nm
Average deviation	3.43 nm	4.69 nm
Skewness	4.28	1.60
Kurtosis	33.33	4.53

The root mean square (RMS) for DC sputtering and evaporation are 5.66 nm and 6.49 nm respectively. This indicates DC sputtering techniques shows better quality compare to evaporation techniques. In the table (1), another parameter that is skewness is a measure of symmetry, or more precisely, the lack of symmetry. The skewness for DC sputtering and evaporation techniques are 4.28 and 1.60 respectively. The DC sputtering techniques, **Fig. 1 (a)** have higher skewness compared to evaporation techniques because the overall distribution have several high peaks on the majority flat surface. However, evaporation techniques, **Fig. 1 (b)** show that the peaks scattered over the substrate tend to be equally distributed.

Kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution. That is, data sets with high kurtosis tend to have a distinct peak near the mean, decline rather rapidly, and have heavy tails. Data sets with low kurtosis tend to have a flat top near the mean rather than a sharp peak. Al deposited by DC sputtering has higher kurtosis value, 33.33 than Al deposited by evaporator, 4.53. **Fig. 1 (a)** shows a very sharp peak out of majority flat area. **Fig. 1 (b)** shows that majority surface area is the same heights indicate low kurtosis value. Obviously, sputtering method shows smoother surface than evaporation technique.

### 3.2. Electrical properties

Electrical resistivity of the Al films deposited on PET substrates using DC sputtering and evaporation techniques were measured by four point probe system. **Table 2** shows the comparison between electrical resistivity using DC sputtering and evaporation techniques. DC sputtering has much lower resistivity around  $2.54 \times 10^{-5} \Omega \cdot \text{cm}$  compared to evaporation method  $3.40 \times 10^{-5} \Omega \cdot \text{cm}$ . It has quite significant difference of  $0.86 \times 10^{-5} \Omega \cdot \text{cm}$ . Sheet resistance for DC sputtered and evaporated Al are 131.68 m $\Omega$ /sq. and 167.30 m $\Omega$ /sq. respectively. The difference between both techniques is 35.62 m $\Omega$ /sq. This indicates DC sputtering has better electrical conductivity. This indicates with increasing the roughness, increase the electrical resistivity of the films prepared by direct current (DC) sputtering and thermal evaporation. In the present work a comparison took place between the electrical resistivity of Al deposited on PET using DC sputtering and Al deposited on PET using evaporation. These results due to low resistivity, suggest that it would be possible to use Al as a back contact layer in thin film silicon solar cells.

**Table 2:** Comparison between electrical resistivity and sheet resistance using DC sputtering and evaporation techniques

	DC sputtered Al	Evaporated Al
Resistivity (average)	$2.54 \times 10^{-5} \Omega \cdot \text{cm}$	$3.40 \times 10^{-5} \Omega \cdot \text{cm}$ average
Sheet resistance (average)	131.68 m $\Omega$ / sq.	167.30m $\Omega$ / sq.

#### 4. Conclusions

It is possible to deposit Al films on PET by means of sputtering and evaporating. The deposition of films with good characteristics does not require the unpractically long "presputtering" periods which had been found necessary in the case of the DC sputtering of Al. Films produced by DC sputtering have characteristics which are comparable to the characteristics of films deposited by evaporation. The resistivity ratio of the best films deposited by DC sputtering is somewhat smaller than that of the best films deposited by evaporation. DC sputtering has much lower resistivity around  $2.54 \times 10^{-5} \Omega \cdot \text{cm}$  compared to evaporation method  $3.40 \times 10^{-5} \Omega \cdot \text{cm}$ . This indicates with increasing the roughness, increase the electrical resistivity of the films prepared by direct current (DC) sputtering and thermal evaporation. The results of electrical properties of Al/ PET substrate can be used as back contact layer in thin film silicon solar cells.

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## تأثير الخشونة السطحية النانوية على الخواص الكهربائية لغشاء الالمنيوم المرسبة على قاعدة بلاستيكية بطرق مختلفة

### الخلاصة

تم تحضير اغشية الالمنيوم بطريقتين الترسيب المختلفة تدعى تقنية التزديد بالتيار المستمر وتقنية التبخير الحراري على قواعد البولي إيثيلين تيرفتالات (PET). تمت دراسة تأثير طريقة الترسيب على الخصائص التركيبية والكهربائية لاغشية المحضرة، وكذلك تأثير الخشونة السطحية النانوية على التوصيلية الكهربائية لغشاء الالمنيوم المرسبة. تم تحديد الخصائص الكهربائية والتركيبية لاغشية المحضرة بالمقاومية الكهربائية و خشونة السطح بواسطة مجهر القوة الذرية (Atomic Force Microscopy) وتقنية تحقيق اربع Four-Point Probe

كارينغري زبره رووي نانوي لهسهر تواناي گهياندي كارهبايي چينه تهنكه كاني ئهلهمنيوم كه به رينگاي جياواز روويوش كراون لهسهر بنچينه يلاستيكي

### پوخته

چينه تهنكه كاني ئهلهمنيوم له رينگاي دوو تهنكي سهره كيهوه ناماده كران بو روويوش كردن لهسهر بنچينه ي پولي ئهسيلين تيريفساليهيت (PET)، ئهوانيش بريتي بوون له رينگاي پرژاندين به تهزووي نه گور و تهنكي ههلماندين به گهري. كارينگري ئهم تهنكيه جياوازان لهسهر بيكهاتهو سيفهته كارهباييه كاني چينه تهنكه كان تاوتوي كرا، بهمهش ليكولينهوه كرا سهبارت به كارينگري زبره رووي نانوي لهسهر تواناي گهياندي كارهبايي چينه تهنكه كاني ئهلهمنيوم. چهند تاقيردنهويههك ئه نجامدرا بو هاوگونجاندين كردن له روويوش كردني چينه كاني ئهلهمنيوم له رينگاي هاو كولهكي شياوي روويوش كردنهوه. شيكردنهوه ي روويي و سيفهته كارهباييه كان بو چينه روويوشكراوه كان ئه نجامدرا له رينگاي تهنكي مايكرؤسكوبي (Atomic Force Microscopy) و تهنكي چوار پنت (Four Point Probe)، له ئه نجامدا بهر بهستي كارهبايي و رووه زبري چينه تهنكه كان ئه ژمار كران.