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Investigation of the Structural Properties of Thermally Evaporated Aluminium Thin Films on Different Polymer Substrates.

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Abstract: This paper studies the properties of thermally evaporated 1 μm of aluminium (Al) thin films on polyimide (PI) and polyethylene terephthalate (PET) substrates at room temperature with thermal evaporation in a vacuum of about 3 x 10^{-5} Torr for use as window materials for solar cells. Effects of substrate types on the structural and electrical characteristics of the films were studied. Sets of experiments were conducted to optimize the deposition of Al films with appropriate deposition parameters. The deposited films were analyzed with atomic force microscopy (AFM), energy dispersive X-ray (EDX), X-ray diffraction (XRD). Energy dispersive X-ray (EDX) spectra shows presence of Al contacts on both PI and PET substrates. X-ray diffraction (XRD) results illustrate proper formation of Al (111) plane at 38.4^{o} with full width at half maximum (FWHM) of 0.1968° on both samples. Atomic force microscope (AFM) images reveal that both samples possess smooth surfaces with surface roughness root mean square (RMS) below 10 nm.

Keywords: polyimide; polyethylene terephthalate; polymers; thin film; thermal evaporation; solar-cells.

1.Introduction

Aluminium (Al) is the most abundant metal in the earth's crust and is the third most abundant element after oxygen (O_2) and silicon (Si). It is silvery white in colour, shows high electrical and thermal conductivity and has a melting point of 660^{o}C. Al has been widely used for various applications. Al films evaporated on substrates are the most commonly used surface coatings for aspheric mirrors since Al is a good light reflector in the visible region and an excellent reflector in the mid and far infra-red (IR) regions [1]. Besides, Al is widely used in the microelectronics technology as ohmic contacts, schottky barrier contacts, gate electrodes and also as interconnects [2].

Al also finds its application in the fabrication of thin film transistors (TFTs), photodetectors, solar cells and many other devices [3]. In the fabrication of solar cells, Al is heavily used as back contacts due to its ease of deposition, low sheet resistance and its capability to introduce back surface field effects (BSF) that could minimize carrier recombination rates at the rear side of the device [4]. Nowadays, Al is being introduced as back contacts in thin film solar cells too [5]. In this device, the high reflectance property of the Al contacts is exploited to serve as a light-trapping solution where low energy photons (after passing through the absorber layer for the first time without being absorbed) will be obliquely reflected back into the absorber layer. This increases the optical path length of the light (photons) in the device thereby increasing absorption efficiency, photocurrent generation, and quantum efficiency of the thin film solar cells particularly in the long wavelength region [6].

Deposition of Al contacts can be carried out by several physical vapor deposition (PVD) methods such as thermal evaporation, electron beam (e-beam) evaporation and also sputtering [7]. Since Al has a fairly low melting point (660^{o}C), thermal evaporation appears to be good enough for its deposition. In addition, thermal evaporation is the simplest and the most cost-effective compared to the other techniques which makes it a more appealing option.

Even though extensive research has been carried out on the evaporation of Al as contacts in bulk and thin film solar cells, most of the research activities employ either wafers or glass materials as substrates [8]. Studies of Al back contacts on polymeric materials like polyimide (PI) and polyethylene terephthalate (PET) plastics substrates are still in their infancy phase. Both PI and PET are excellent polymeric materials. They have attracted interests of many

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parties in photovoltaic (PV) and other related fields due to their reasonable temperature resistance, flexibility, light-weight, low-cost properties [9].

This paper studies the properties of Al contacts on PI and PET substrates via thermal evaporation technique for applications in thin film solar cells. Following the deposition, structural, surface morphology of the thin films on both substrates are investigated and compared. Their applicability in thin film solar cells is subsequently discussed.

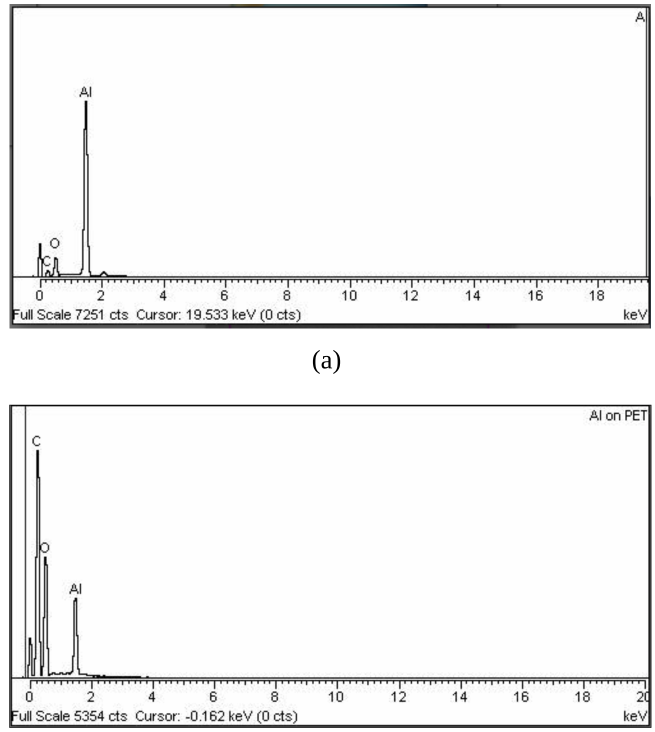
2. Experimental Methods

In this experiment, PI (75 µm thickness) and PET (250 µm thickness), 2 x 2 cm^2 in dimension, from DuPont Corporation (Malaysia and Singapore) and Penfibre Sdn. Bhd. (Malaysia) respectively are used as substrates for Al contacts deposition. Before deposition, both substrates are firstly cleaned by using Decon90 chemical for 10 minutes and then rinsed with deionised water (DI water) to remove contamination. For thermal evaporation process, Al pellets with purity 99.9% are prepared. The evaporation of Al contacts is carried out on Edwards AUTO 306 system. Before the evaporation, both substrates are mounted onto substrate holder, located 8 cm from the Al pellets (placed in tungsten boat). Vacuum chamber is then evacuated by using roughing and diffusion pumps until 3.4 x 10^{-5} Torr base pressure is reached.

Current supply is then turned on and increased gradually until ~100 Ampere to start the evaporation process and produce ~1 µm Al contacts. During the evaporation process, both substrates are held at room temperature (300 K).

Structural properties of the evaporated Al contacts are characterised by energy dispersive X-ray (EDX, Model: JSM-6460 LV) system and X-ray diffraction system (XRD, Model: Panalytical X'Pert PRO MRD PW3040, with Cu-Kα_1 radiation source, λ = 1.5406 Å). Surface morphology of the samples is inspected by atomic force microscope (AFM, Model: Ultra Objective). The thickness and surface reflectance of the samples are measured on optical reflectometer (Model: Filmetrics F20).

3. Results and Discussion



(a)

(b)

Fig.1 EDX spectra of Al contacts on (a) PI and (b) PET substrates.

Thicknesses of both samples are measured to be ~1 µm by reflectometer. Fig. 1 shows the EDX spectra of the Al contacts on both PI and PET substrates. From the spectra, it can be seen that the peak at 1.4866 keV belongs to Al atom, confirming the existence of the Al layer. The other peaks at 0.2774 keV and 0.5249 keV belong to carbon (C) and oxygen (O) atoms that constitute both the PI and PET substrates [10].

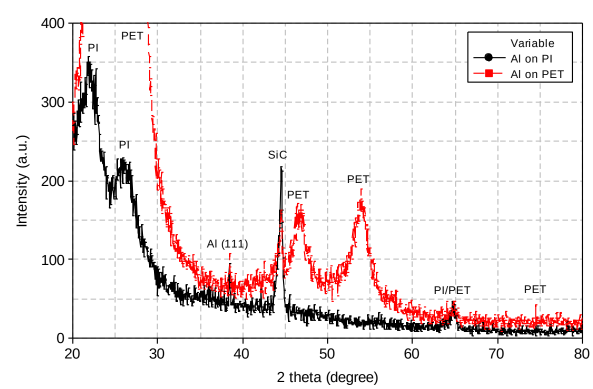
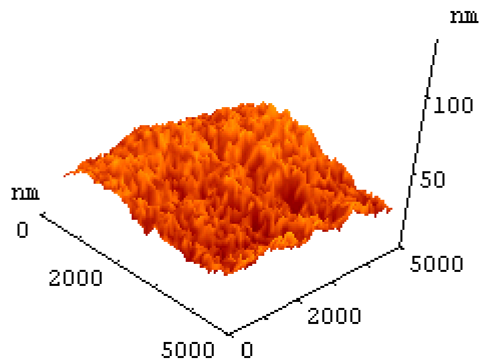
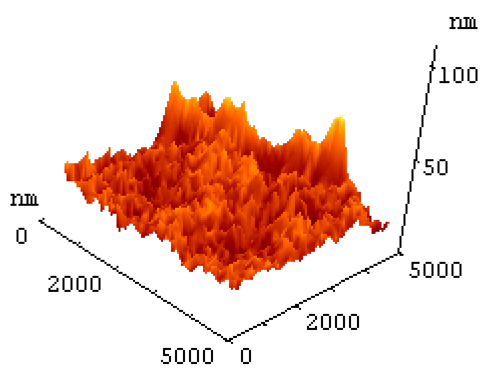


Fig.2 XRD patterns of Al contacts on PI and PET substrates.

Fig.2 illustrates the XRD patterns of the Al contacts on PI and PET substrates. The output patterns are compared to International Centre for Diffraction Data (ICDD) library [11] as the reference database. From the figure, both samples show that the evaporated Al is crystalline in nature with (111)-oriented grains at 38.4°. The full width at half maximum (FWHM) of both peaks are 0.1968°, corresponding to 45.60 nm crystallite size as calculated by Scherrer's formula [12]. The other peaks in the figure belong to the substrates while a high peak at 44.4° from both diffraction patterns belong to silicon carbide (SiC) stage used to place the samples for XRD measurement [13].



(a)



(b)

Fig.3 AFM images (spot size 5 x 5 µm^2) of Al contacts on (a) PI (RMS roughness = 9.38 nm) (b) PET (RMS roughness = 8.28 nm).

Fig. 3 reveals the AFM images of the Al contacts on PI and PET substrates with spot size of spot size 5 x 5 µm2. From the figure, it can be observed that both samples possess fairly smooth surfaces with surface roughness RMS below 10 nm. This is believed to be due to the highly directional line-of-sight deposition nature of thermal evaporation technique which normally results in samples with smooth (planar) rather than textured surfaces [14].

4. Conclusion

In this paper, properties of thermally evaporated 1 µm Al contacts on PI and PET substrates for applications in thin film solar cells are investigated. EDX spectra shows presence of Al contacts on both PI and PET substrates at 1.4866 keV. XRD results illustrate proper formation of Al (111) plane at 38.4° with FWHM of 0.1968° on both samples. AFM images reveal that both samples have fairly smooth surfaces with surface roughness RMS below 10 nm. This result of both samples can be used as back contact layer in thin film silicon solar cells.

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