Properties of polyimide substrate for applications in flexible solar cells

M. Z. PAKHURUDDIN*, K. IBRAHIM, A. ABDUL AZIZ
Nano-Optoelectronics Research and Technology Laboratory, School of Physics, Universiti Sains Malaysia, Minden 11800 Penang, Malaysia

In this paper, the structural, surface morphology, thermal and optical properties of the Kapton polyimide (PI) 300HN plastic substrate (75 µm thickness) from Dupont Corporation have been investigated by various techniques for applications in flexible solar cells. High resolution X-ray diffraction (HR-XRD) measurement showed 4 diffraction peaks from the PI substrate at 22.08°, 25.88°, 44.56° and 64.87° (2θ angle). Atomic force microscope (AFM) depicted that the substrate has a fairly smooth morphology with surface roughness root-mean-square (RMS) of 22.52 nm. Thermogravimetric analysis (TGA) illustrated high thermal stability of the substrate as evident by the high decomposition temperature of around 600°C. Differential scanning calorimetric (DSC) measurement confirmed that the PI material has a glass transition temperature (T_g) of approximately 311°C and has no melting peak (observed within temperature range of 30 - 500°C) which conforms to the intrinsic property of standard Kapton PI 300HN. Optical transmittance demonstrated that the PI substrate has a fairly low transmittance (below 70%) in visible region and around 75 - 80% in infra-red (IR) region. The applications of the substrate in flexible solar cells were subsequently discussed.

(Received September 13, 2012; accepted June 12, 2013)

Keywords: X-ray diffraction, Thermogravimetric analysis, Differential scanning calorimetric, Atomic force microscope, Transmittance

1. Introduction

PI is an excellent polymeric material. It has attracted interests of many parties in photovoltaic (PV) research and development activities due to its flexibility, light-weight, low-cost (therefore potentially low-cost devices can be fabricated on top of PI), high temperature resistance (typically up to 400°C processing temperature), low coefficient of thermal expansion (CTE), low moisture uptake and high moisture release characteristics, excellent electrical properties and also increased voltage endurance [1]. Due to its superior properties, PI has found its applications as substrates in flexible thin film solar cells, flexible printed circuits and high density interconnects [2,3]. This paper aims to investigate properties of PI substrate that are crucial for applications in flexible solar cells (i.e. thin film cells). HR-XRD measurement is vital to reveal crystallinity of the substrate. AFM is used to show surface morphology of the substrate so that necessary light trapping techniques can be adopted in the solar cells to improve their photocurrents and conversion efficiencies. TGA and DSC characterisations are essential to reveal maximum temperature limit and thermal stability (i.e. thermal properties) of the substrate during solar cells processing steps. Optical transmittance measurement is critical during selecting device configuration. High transmittance substrate is used in superstrate-configuration while low transmittance substrate is used in substrate-configuration [4].

2. Experimental

In this experiment, Kapton 300HN PI plastic (75 µm thickness), with 2×2 cm^2 in dimension, from DuPont Corporation was used as the substrate.

For structural properties, the substrate was characterised on HR-XRD (for crystalline and phase information) and AFM (for surface morphology) systems. For the HR-XRD, the measurement was carried out on PANalytical X'Pert PRO MRD PW3040 (with Cu-Kα_1 radiation source, wavelength of 1.5406 Å). The diffraction patterns were collected in between 20° to 80° (2θ angle) and compared to ICDD library [5]. Surface morphology of the substrate was verified on ULTRA Objective AFM measurement system. The spot size of the measurement was set to 30 × 30 µm.

For TGA measurement, 10 mg of PI substrate was placed inside TGA 7 Perkin Elmer within N_2 environment at 30°C. The temperature of the environment was then raised to 900°C at a heating rate of 20°C/min while the weight loss profile of the substrate being recorded. The weight loss profile was then extracted and analysed. For DSC measurement, 5.3 mg of PI substrate was placed inside Pyris 1 Perkin Elmer within N_2 environment at 30°C. The substrate was heated (first heating) to 500°C at a heating rate of 20 °C/min and then held at that temperature for 1 min. Then, the substrate was cooled down to 30°C at a rate of 100°C/min and held at that temperature for 5 min, followed by a second heating from 30°C to 500°C again at the same heating rate (20°C/min). The heat flow profile was then extracted and analysed.

Optical transmittance of the substrate was measured by Hitachi U-2000 UV-Vis spectrophotometer system within spectral range of 200 – 1100 nm.

3. Results and discussion

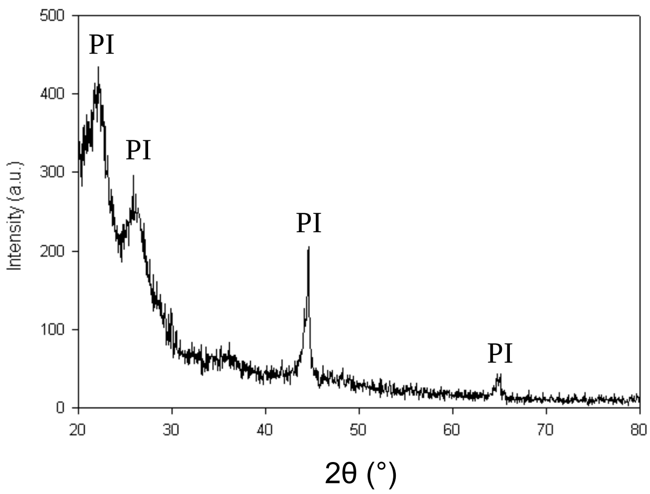

Fig. 1. XRD pattern of PI substrate.

Fig. 1 shows the HR-XRD pattern of the PI substrate measured within the spectral range of 20 - 80° (2θ angle). The output pattern was compared to International Centre for Diffraction Data (ICDD) library [5]. From the figure, it can be observed that there are 4 peaks attributed to the PI substrate; at 22.08°, 25.88°, 44.56° and 64.87° (2θ angle). This result is very important because it will be used as a baseline or reference when analysing structural properties of layers fabricated on this substrate at a later stage of the solar cells fabrication.

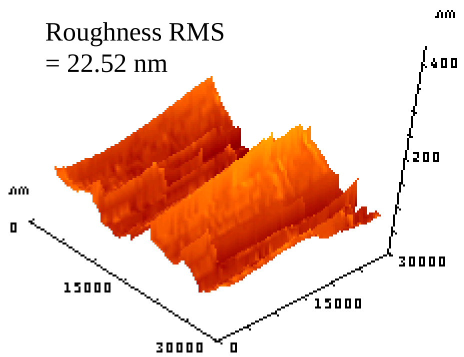

Fig. 2. AFM image of PI substrate (30 x 30 µm spot size).

Fig. 2 illustrates the AFM image of the PI substrate. The result shows that the substrate has a smooth morphology with surface roughness RMS of 22.52 nm. To pursue with fabrication of flexible thin film solar cells on the PI substrate, the PI surface can be textured to introduce surface roughness RMS of 40 – 150 nm to enhance light trapping within the solar cells [6].

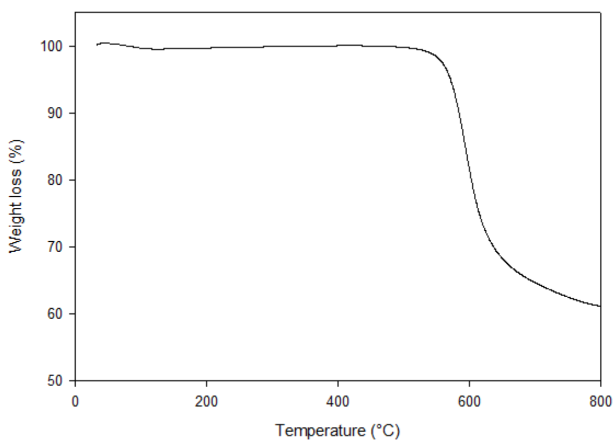

Fig. 3. TGA plot of PI substrate.

Fig. 3 depicts the TGA plot of the PI substrate heated from 30°C to 900°C with heating rate of 20°C/min in N_2 ambient. From the plot, it can be seen that the weight loss (%) of the substrate is only below 0.5% from 30°C until almost 500°C. Beyond 500°C, the substrate starts to decompose gradually and the weight begins to suffer a more significant loss as the temperature increases further. Maximum rate of weight loss is recorded at approximately 600°C where a steep gradient is observed. As the temperature reaches nearly 900°C, the total weight loss is about 40%, given by difference of original weight at 30°C and final weight at 900°C. Based on the above result, it can be concluded that the PI substrate possesses a high thermal stability that is highly desired in thin film crystallisation and defects annealing steps in the flexible solar cells fabrication [7].

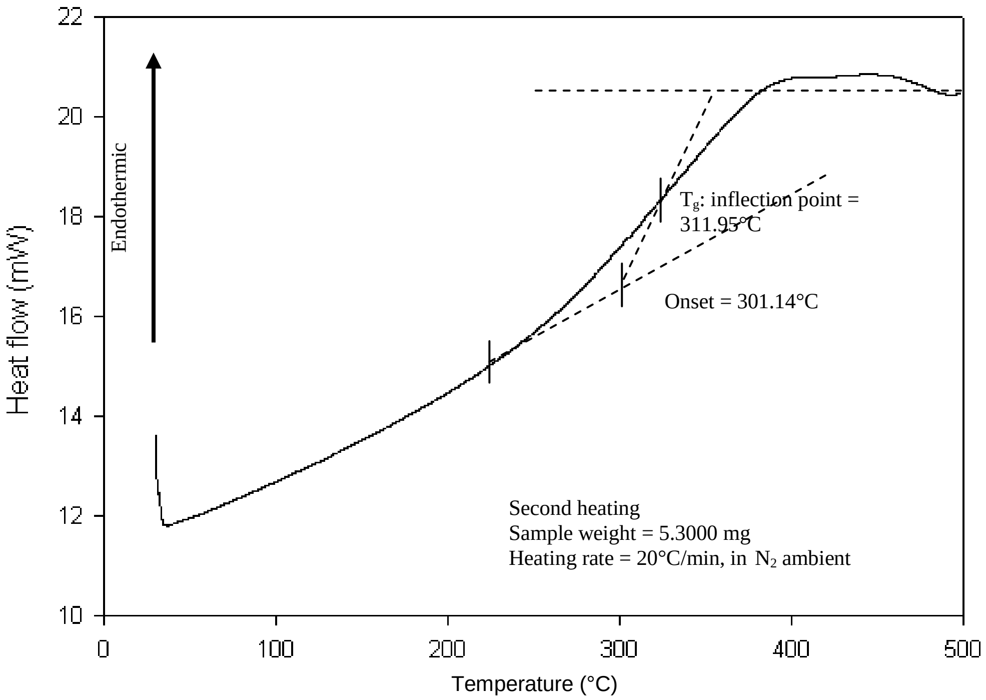

Fig. 4. DSC plot of PI substrate.

Fig. 4 plots the second DSC heating curve of the PI substrate heated from 30°C to 500°C in N_2 ambient (heating rate = 20°C/min). The upwards arrow indicates endothermic reaction (i.e. direction of transition that absorbs energy in the form of heat flow). From the figure, glass transition temperature (T_g) of approximately 311°C is evident (as shown by the inflection point). This transition is indicated by an increase in heat capacity due to increased molecular motions in the PI substrate [8]. No melting peak is observed within this temperature range (30 – 500°C) which conforms to the intrinsic property of standard Kapton polyimide 300HN that possesses no melting point [9].

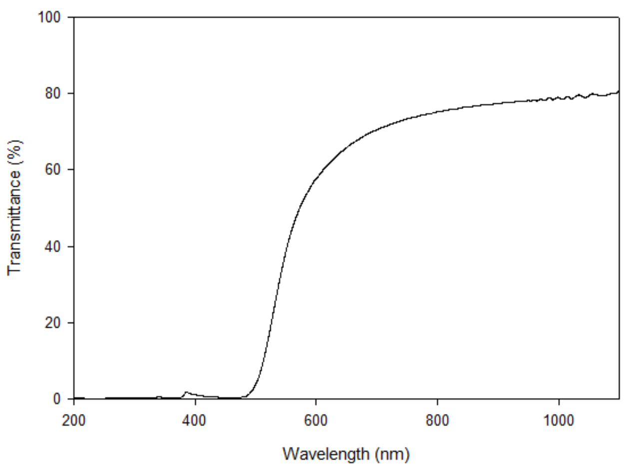

Fig. 5. Optical transmittance of PI substrate.

In Fig. 5, the optical transmittance of the PI substrate (75 µm thickness) is plotted within spectral range of 200 - 1100 nm. As can be seen from the figure, the PI substrate shows a fairly low overall optical transmittance. The transmittance only starts to increase after 500 nm and approaches 80% in the IR region. Due to the low transmittance values of PI in both visible and IR regions, it is evident that the substrate under investigation cannot be used in superstrate-configuration in flexible thin film solar cells because the low transmittance properties will reduce some fractions of the incident sunlight from reaching the p-n junction for photocurrent generation process hence making the efficiency of the cells lower than expected [10]. Therefore, the substrate under investigation needs to be used in substrate-configuration where it will only serve as the device carrier located at the bottom of the cells, thus relaxes the optical transmittance requirement.

4. Conclusions

In this paper, the structural, surface morphology, thermal and optical properties of the Kapton polyimide (PI) 300HN plastic substrate (75 µm thickness) from Dupont Corporation have been investigated by various techniques for applications in flexible solar cells. HR-XRD showed 4 diffraction peaks from the PI substrate. AFM depicted that the substrate has a smooth morphology with surface roughness RMS of 22.52 nm. TGA illustrated high thermal stability of the substrate which is highly desired in thin film crystallisation and defects annealing steps in the flexible solar cells fabrication. DSC measurement confirmed that the PI material has a T_g of approximately 311°C and has no melting peak. Optical transmittance demonstrated that the substrate has a low transmittance (below 70%) in visible region and around 75 - 80% in infra-red (IR) region, limiting its use only in substrate-configuration.

Acknowledgements

The support of Universiti Sains Malaysia, financial assistance from Incentive Grant 1001/PFIZIK/821061 and contribution of Kapton 300HN PI substrate (75 µm thickness) from DuPont Corporation (Malaysia and Singapore) are gratefully acknowledged.

References

[1] F. Kessler, D. Rudmann, Solar Energy **77**, 685 (2004).
[2] A. Pecora, L. Maiolo, M. Cuscunà, D. Simeone, A. Minotti, L. Mariucci, G. Fortunato, Solid-State Electronics **52**, 348 (2008).
[3] A. N. Tiwari, A. Romeo, D. Baetzner, H. Zogg, Progress in Photovoltaics: Research and Applications **9**, 211 (2001).
[4] T. Brammer, W. Reetz, N. Senoussaoui, O. Vetterl, O. Kluth, B. Rech, H. Stiebig, H. Wagner, Solar Energy Materials and Solar Cells **74**, 469 (2002).
[5] ICDD. International Centre for Diffraction Data (ICDD). 2011 [cited 2012 9 September]; Available from: http://www.icdd.com/.
[6] F. Llopis, I. Tobias, Solar Energy Materials and Solar Cells **87**, 481 (2005).
[7] Y. Tao, S. Varlamov, G. Jin, M. Wolf, R. Egan, Thin Solid Films **520**, 543 (2011).
[8] H. Gleskova, S. Wagner, Electron Device Letters **20**, 473 (1999).
[9] C. Guillen, J. Herrero, Thin Solid Films **431 –432**, 403 (2003).
[10] J. Nelson, The Physics of Solar Cells, Imperial College Press (2003).

*Corresponding author: zamirlitho@gmail.com