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Fabrication and characterization of polysilane thin film solar cells

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1. Introduction

Thin film solar cells using organic semiconductors have been developed as next generation systems. They have advantages of low cost, flexible and light weight product, and photovoltaic and optical properties of the organic solar cells have been studied [1]. However, the power conversion efficiency of the organic cells is lower than inorganic cells. A primary cause of this is low density and mobility of charge carriers. Polysilane has high hole mobility as p-type semiconductor, and has been applied as electrical conductive materials and photovoltaic systems [2].

The purpose of the present work is to fabricate and characterize bulk heterojunction solar cells with polysilane and fullerene (C_{60}). C_{60} is a good electronic acceptor. Light induced carrier separation with charge transfer was investigated by experimental measurements. Electronic structures and energy levels of the molecules were calculated by molecular orbital calculation. Optical absorption of the solar cells was measured by UV-vis spectroscopy. Microstructure analysis was investigated by transmission electron microscopy and atomic force microscopy. Photovoltaic mechanism was discussed on the basis of the experimental results. The purpose of the present work is to fabricate and characterize polysilane/C_{60}-based solar cells. Organic semiconductors have a great advantage to apply environment-friend solar system with low cost and flexibility.

2. Experimental

Three-types polysilanes were used in the present work as follows: poly-methyl-phenyl-silane (PMPS), poly-phenyl-silyne (PPSi), poly-diphenyl-silane (PDPS). Figure 1 shows atomic structures of PMPS, PPSi, PDPS, PEDOT:PSS, PCBM and P3HT to fabricate solar cells. Figures 2 shows structure of polysilane:C_{60} and polysilane:PCBM:P3HT bulk-heterojunction solar cells.

Solar cells were fabricated following procedure. Indium tin oxide (ITO) grass prates (Geomatec, ~10Ω/□) were cleaned by an ultrasonic bath with acetone and methanol, and were dried by nitrogen gas. A thin layer of polyethylendioxythiophen doped with poly (3,4-ethylenedioxythiophene):poly (styrenesulfonate) (PEDOT:PSS, Sigma Aldrich) was spin-coated on the ITO substrates. Then, semiconductor layers were prepared on a PEDOT:PSS layer by spin coating using a mixed solution of (1) C_{60} (Material Technologies Research, 99.98%), (2) C_{60} and P3HT (Sigma Aldrich), (3) PCBM (Frontier Carbon) and P3HT, PMPS (Osaka Gas Chemical Co, Ltd) or PPSi (Osaka Gas Chemical Co, Ltd) or PDPS (Osaka Gas Chemical Co, Ltd) in 1 mL o-dichlorobenzene. Total weight of C_{60}:PMPS, C_{60}:PPSi or C_{60}:PDPS were 10 mg, and weight ratio of C_{60}:PMPS, C_{60}:PPSi or C_{60}:PDPS was 8:2. Aluminium (Al) metal contacts were evaporated as a top electrode. Finally, the devices were annealed at 140°C for 30 min in N_2 atmosphere.

Current density-voltage (J-V) characteristics (Hokuto Denko Corp., HSV-100) of the solar cells were measured both in the dark and under illumination at 100 mW/cm^2 by using an AM 1.5 solar simulator (San-ei Electric, XES-301S) in N_2 atmosphere. The solar cells were illuminated through the side of the ITO substrates, and the illuminated area is 0.16 cm^2. Optical absorption of the solar cells was investigated by means of UV-visible spectroscopy (JASCO, V-670ST).

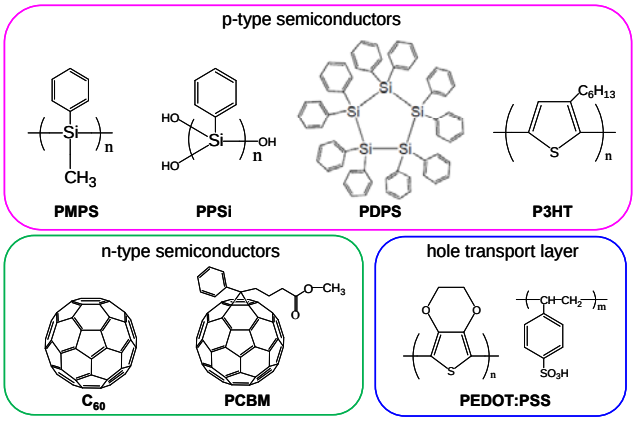

Fig. 1 Atomic structures of polysilanes, P3HT, PCBM and PEDOT:PSS to fabricate solar cells.

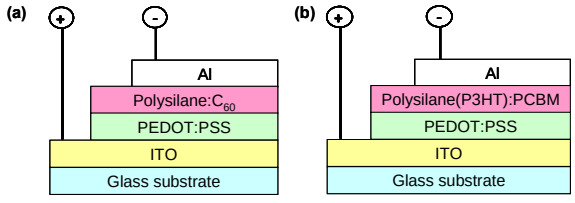

Fig. 2 Structure of (a) polysilane:C_{60} (b) polysilane:PCBM:P3HT bulk-heterojunction solar cells.

3. Results and Discussion

The J-V characteristics of the PMPS(P3HT):PCBM, PPSi(P3HT):PCBM and PDPS(P3HT):PCBM structure under illumination is shown in Fig. 3. Measured parameters of these bulk heterojunction solar cells are summarized in Table 2. A solar cell with PMPS(P3HT):C_{60} structure provided the highest η of 0.31 %, FF of 0.33, J_{SC} of 1.8 mA/cm^2 and V_{OC} of 0.53 V, which is better than those of other devices. It is considered that the efficient charge separation would be increased by interface area of PMPS(P3HT):PCBM sample. In the present study, the PMPS:C_{60} bulk heterojunction solar cell provided η of 0.32 %, FF of 0.31, J_{SC} of 17 mA/cm^2 and V_{OC} of 0.37 V. PMPS has a characteristic of cross-linked and mixed with organic layer with polymer chain [5], which results in the increase of carrier transport. PPSi has a characteristic of compatibility, and uniform spin-coating would be possible. Although PDPS has a high refractive index, spin-coating was not so uniform, which results in the low carrier transport.

PMPS(P3HT):PCBM bulk heterojunction solar cells with a high efficiency has uniform surface structure. It is considered that the efficient charge separation would be increased by interface area of PMPS(P3HT):PCBM sample. The PMPS:C_{60} bulk heterojunction solar cell has not a uniform surface structure, which results in the increase of electrical resistance.

An energy level diagram of polysilane:C_{60} and polysilane(P3HT):PCBM solar cells is summarized as shown in Fig. 4. Previously reported values were used for the energy levels [3]. For the polysilane(P3HT):PCBM solar cells, the combination of P3HT and polysilane would increase the carrier separation, which would results in the increase of efficiency. The incident direction of light is from ITO side. Energy barrier would exist near the semiconductor/metal interface. Electronic charge is transferred by light irradiation from the ITO substrate side. Holes are transported to an ITO substrate and electrons are transported to an Al electrode. A relation between V_{OC} and polymer oxidation potential was reported as $V_{OC}=(1/e)(|E^{Polysilane}HOMO|-|E^{C60}LUMO|)-0.3$ (V), where e is the elementary charge. The value of 0.3 V is an empirical factor, and this is enough for efficient charge separation.

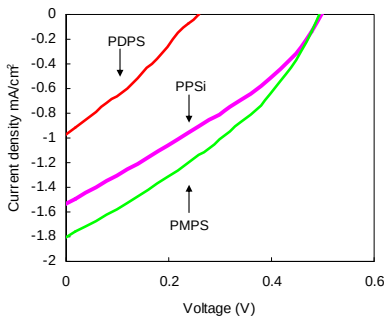

Fig. 3 J-V-characteristics of PMPS(P3HT):PCBM, PPSi(P3HT):PCBM and PDPS(P3HT):PCBM bulk heterojunction solar cells under illumination.

Table 2. Experimental parameters of polysilane:PCBM solar cells.

Sample	V_{OC} (V)	J_{SC} (mA/cm^2)	FF	η (%)
PMPS(P3HT):PCBM	0.53	1.8	0.33	0.31
PPSi(P3HT):PCBM	0.50	1.5	0.32	0.24
PDPS(P3HT):PCBM	0.27	0.9	0.27	0.070

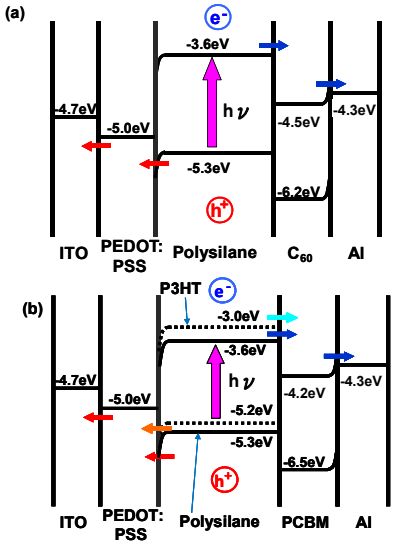

Fig.4 Energy level diagram of (a) ITO/ PEDOT:PSS/ polysilane:C_{60}/ Al (b) ITO/ PEDOT:PSS/ polysilane (P3HT) :PCBM / Al bulk heterojunction solar cells.

4. Conclusions

Polysilane:C_{60}, polysilane(P3HT):C_{60} and polysilane(P3HT):PCBM solar cells were fabricated and characterized. Three types of polisilane were used in the present work. A device based on PMPS(P3HT):C_{60} structure provided the highest η of 0.31 %, FF of 0.33, J_{SC} of 1.8 mA/cm^2 and V_{OC} of 0.53 V, which was better than those of other devices in the present work. It is considered that a device based on polysilane(P3HT):PCBM bulk heterojunction has amorphous structure. A future view is that structure of polysilane and characteristic in the inside of a solar cell are investigated.

References

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