Optimization of Carrier Collection Structure in Graded Organic Solar Cells

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1. Introduction

Organic solar cells (OSCs) have merits of potentiality of large area production, light weight and flexible [1-3]. One of issues for OSC is a lower efficiency. To realize the higher efficiency, bulk heterojunction structure [4-6], material purification [7], multi-step structure [8-10], and synthesis of novel materials for active layer were reported. In a solution processed bulk heterojunction device with poly (3-hexylthiophene) (P3HT) as a donor and methanofullerene [6,6]-phenyl-C61-butyric acid methyl ester (PCBM) as an accepter, precise control of bulk hetero structure and purification of materials and solution are necessary. On the other hand, small molecules with higher purity can be easily obtained by sublimation technique.

In this study, we have examined a graded junction structure into the vacuum processed device with successive composition change of the donor and the accepter materials using small molecules [11-13].

2. Experimental

Graded junction solar cells are fabricated on indium tin oxide (ITO) coated glass substrate. The ITO surface is cleaned with a surfactant, an organic solvent, and a UV ozone treatment. Copper phthalocyanine (CuPc) as a donor material and fullerene (C60) as an accepter material were used in this study. 2,9-dimethyl-4,7-diphenyl-1,10- phenenthroline (BCP) as an exciton blocking layer [14,15] and silver (Ag) as a cathode were used. These organic layers Ag cathode were evaporated under pressure of and 2.0×10^{-6} Torr. Substrate temperature was optimized at 50°C. Graded junction layer of CuPc and C₆₀ was fabricated by varying the deposition rates of both materials. The deposition rates were monitored using two quartz oscillators. Deposition rate was changed between 0 and 1.0 Å/s for both of CuPc and C₆₀. Image of compositional grading are shown in Figs. 1 (a) and (b). This method was identical to combinatorial molecular beam epitaxy [16]. Total thickness of organic layers was fixed at 60 nm. Typical device structure was ITO (200 nm)/ CuPc/ Graded layer/ C₆₀/ BCP (10 nm)/ Ag (100 nm). To improve carrier extraction, thin CuPc and C₆₀ layers were inserted at ITO/graded layer and graded layer/BCP interface, respectively. All measurements were carried out at room temperature in air. Current density vs voltage (J-V) characteristics were measured using a semiconductor parameter analyzer (HP 4155B) in the dark

and under simulated AM1.5, 100 mW/cm² solar simulator (YAMASHITA DENSO YSS-E40). Open-circuit voltage V_{oc} , short-circuit current density J_{sc} , conversion efficiency η , and fill factor FF were evaluated from *J*-*V* characteristics under irradiation. The device area was 2×2 mm².



Fig. 1 (a) Conceptional view of graded organic layer deposition models with dual vapor deposition source, (b) graded layer formation model.

3. Results and Discussion

Figure 2 shows J-V characteristics of devices by varying graded junction, bilayer, codeposition layer and mixed layer structures. Fabricated four types of the device structure were

- (A) ITO/ CuPc (10 nm)/ Graded layer (35 nm)
 - / C₆₀ (15 nm)/ BCP/ Ag,
- (B) ITO/ CuPc (20 nm)/ C₆₀ (40 nm)/ BCP/ Ag,
- (C) ITO/ CuPc+C₆₀ (60 nm)/ BCP/ Ag,
- (D) ITO/ CuPc+ C_{60} (60 nm) (1:1)/ BCP/ Ag.

Higher J_{SC} of 6.11 mA/cm² was obtained in device (A). This result suggested that carrier separation and transport were effectively carried out because of internal electric field.



Fig. 2 *J-V* characteristics with graded layer, bilayer, codepostion layer and mixed layer devices under AM1.5 illumination.



Fig. 3 J-V characteristics with graded layer. Device structure of ITO/ CuPc (10 nm)/ Graded layer/ C_{60} / BCP/ Ag.

Table 1 Device characteristics of graded junction with CuPc thickness of 10 nm

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Graded structure	V_{OC}	J_{SC}	η	FF
(nm)	(V)	(mA/cm^2)	(%)	11
GL (20)/ C ₆₀ (30)	0.49	3.18	0.85	0.55
GL (25)/ C ₆₀ (25)	0.50	5.20	0.95	0.37
GL (30)/ C ₆₀ (20)	0.51	6.05	1.31	0.43
GL (35)/ C ₆₀ (15)	0.51	6.11	1.36	0.44
GL (40)/ C ₆₀ (10)	0.51	6.35	1.26	0.39
GL (45)/ C ₆₀ (5)	0.47	4.25	1.01	0.50

Next, thickness dependence of graded and C_{60} layers were examined. Thickness of CuPc was fixed at 10 nm. Device structures were ITO/ CuPc (10 nm)/ Graded layer (x nm)/ C_{60} (50-x nm)/ BCP/ Ag. Efficiency was maximum at the thickness of graded layer of 35 nm. On the other hand, FF values show opposite tendency. It is assumed that dramatically increment of J_{SC} was due to increment of carrier extraction from donor/acceptor interface nevertheless the decrement of FF and shunt resistances (R_{sh}).

4. Conclusions

We had investigated organic thin-film solar cells with graded heterostructure for active layer. Device characteristics were improved by optimization of the thickness of graded layer. Graded structure is effective for high performance OSCs.

References

- [1] C. W. Tang, Appl. Phys. Lett. 48 (1986) 183.
- [2] D. Wöhrle, D. Meissner, Adv. Mater. 3 (1991) 129.
- [3] M. Hiramoto, H. Fujiwara, M. Yokoyama, Appl. Phys. Lett. 58 (1991) 1062.
- [4] F. Padinger, R. S. Rittberger and N. S. Sariciftci, Adv. Funct. Mater. **13** (2003) 1.
- [5] P. Peumans, S. Uchida, S.R. Forrest, Nature 425 (2003) 158.
- [6] S. Uchida, J. Xue, B.P. Rand, S.R. Forrest, Appl. Phys. Lett. **84** (2004) 4218.
- [7] K. Sakai and M. Hiramoto: Mol. Crystl. Liq. Cryst. 491 (2008) 284.
- [8] A. Yakimov, S.R. Forrest, Appl. Phys. Lett. 80 (2002) 1667.
- [9] P. Sullivan, S. Heutz, S. M. Schultes, and T. S. Jonesa, Appl. Phys. Lett. 84 (2004) 1210.

[10] L. Chen, Y. Tang, X. Fan, C. Zhang, Z. Chu, D. Wang, and D. Zou, Org. Electron. **10** (2009) 724.

- [11] P. Sullivan, S. Heutz, S. M. Schultes, T. S. Jones, Appl. Phys. Lett. **84** (2004) 1210.
- [12] B. Pradhan, A. J. Pal, Synth. Met. 155 (2005) 555.
- [13] L. Chen, Y. Tang, X. Fan, C. Zhang, Z. Chu, D. Wang, D. Zou, Org. Electron. **10** (2009) 724.
- [14] P. Peumans, S.R. Forrest, Appl. Phys. Lett. 79 (2001) 126.

[15] M. Vogel, S. Doka, Ch. Breyer, M.ch. Lux-Steiner, K. fostiropoulos, Appl. Phys. Lett. **89** (2006) 163501-1.

[16] H. Koinuma, T. Koida, T. Ohnishi, D. Komiyama, M. Lippmaa, and M. Kawasaki, Appl. Phys. A 69 (1999) S29.