Comparison of Different Encapsulating Adhesives to Enhance the Efficiencies and Lifetimes of Polymeric Solar Cells

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Comparison of Different Encapsulating Adhesives to Enhance the Efficiencies and Lifetimes of Polymeric Solar Cells

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Polymeric solar cells (PSCs) with a derivative of C_{60} [[6,6]-phenyl C_{61}-butyric acid methyl ester (PCBM)], and 3-hexylthiophene (P3HT) as active layers have been fabricated. The PSC devices were also packaged with glass and novel UV glues to improve their lifetimes and power conversion efficiencies (PCEs). After encapsulation with UV glue I, II, and III, the PCEs of PSCs reached 4, 4.82, and 6%, respectively, and their half-lifetimes increased to 16–18, 26–28, and 90 h, respectively, while the PCEs and half-lifetimes of PSCs without encapsulation were 3.76% and 2.5 h, respectively.

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1. Introduction

Because sunlight is a clean, environmentally-friendly, and inexhaustible energy source, the conversion of sunlight into electrical energy has recently become an attractive issue. Silicon-based solar cells have been discovered to possess excellent power conversion efficiencies (PCEs) for the conversion of sunlight into electrical energy; however, their cost is very high, since purified silicon is expensive and the manufacturing procedure is complicated. Therefore, polymeric solar cells (PSCs) are alternative candidates for photoelectric conversion owing to their low cost and high processability. Nonetheless, the lifetimes of PSCs are a crucial factor for their commercialization because oxygen and moisture in the atmosphere corrode the metal electrodes and organic materials of devices, markedly decreasing their lifetimes. In addition, most research has focused on the improvement of the PCEs for PSCs, while fewer studies on the extension of lifetimes have been reported.

Poly(3-hexylthiophene) (P3HT) possesses good film and excellent semiconductor characteristics, such as high carrier mobility, and can be applied to a flexible plastic substrate to fabricate electrooptical devices. It can also be applied to multilayer structures according to the device requirements.[1)] In 1995, Yu *et al.* used 1-methoxy-4-(2-ethyl-hexyloxy)-benzene (MEH-PPV) mixed with [6,6]-phenyl C_{61}-butyric acid methyl ester (PCBM) to form a bulk heterojunction structure and obtained a PCE of 1.5%.[2)] In 2001, Shaheen *et al.* used poly{[2-methoxy-5-(3′,7′-dimethyloctyloxy)]-1,4-phenylenevinylene} (MDMO-PPV) mixed with PCBM employing LiF/Al as the cathode in a PSC.[3)] They increased the PCE to 2.1%. In 2005, Li *et al.*[4)] used the self-organization effect in the active layer and a "slow growth" treatment to reduce the resistance of components connected in series. The carrier mobility of holes was increased and the PCE was raised to 4.37%.[4)] In 2005, the PCEs of PSCs in 2005 reached 5%, primarily through the use of materials such as P3HT/PCBM to produce the p–n junction structure.[5)] Since these types of solar cells exhibit the advantages of low cost, light weight, deflection, and large-area processability,[6)] they merit further research. In 2007, Jin *et al.* integrated the optimal processing conditions and added glycerol to the buffer layer to increase the short-circuit current density, resulting in a PCE of 4.64%.[7)] In this study, we have fabricated PSCs with P3HT/PCBM as an active layer and compared their PCEs and half-lifetimes for the packaging process of components with three different types of encapsulating adhesives prepared using by ultraviolet (UV) illumination.

2. Experimental Methods

2.1 Materials

All monomers (Fig. 1), photoinitiators (Fig. 2), solvents, and fillers (silica: 30–100 nm) used in the experiments were purchased from Aldrich and used without further purification.

2.2 Preparation of encapsulating adhesives

2.2.1 Preparation of UV glue I

Benzyl methacrylate (BZMA) (117 g), methyl methacrylate (MAA) (86 g), 2-hydroxyethyl methacrylate (2-HEMA) (130 g), silica (18 g), and 1-hydroxycyclohexyl benzophenone (I-184) (4 g) were mechanically stirred and irradiated using a UV lamp (Entela UVP: 100 W) for 20 min (Fig. 3). The data for the weight-average molecular weight (M_w) and viscosity of UV glue I are tabulated in Table I.

2.2.2 Preparation of UV glues II and III

UV glues II and III were prepared by a synthetic procedure similar to that of UV glue I as shown in Fig. 4. The weight ratio of I-184 to 2-benzyl-2-*N*,*N*-dimethylamino-1-(4-morpholinophenyl)-1-butanone (I-369) was 1 : 2. The duration of UV illumination for UV glues II and III was 5 and 20 min, respectively. Their viscosities and molecular weight data are listed in Table I.

2.3 Fabrication of PSCs

The thickness and resistance of the indium tin oxide (ITO) glass substrate were 280 nm and 5 Ω/□, respectively. Using photolithography, we determined the anode graphics. The glass substrate was cleaned with neutral detergent and then supersonically cleaned with acetone, methanol, and deionized (DI) water. Nitrogen was then used for air drying, after which we continued to oven-dry the substrate for 10 min. After cleaning in an oxygen RF plasma cleaner at 30 W and

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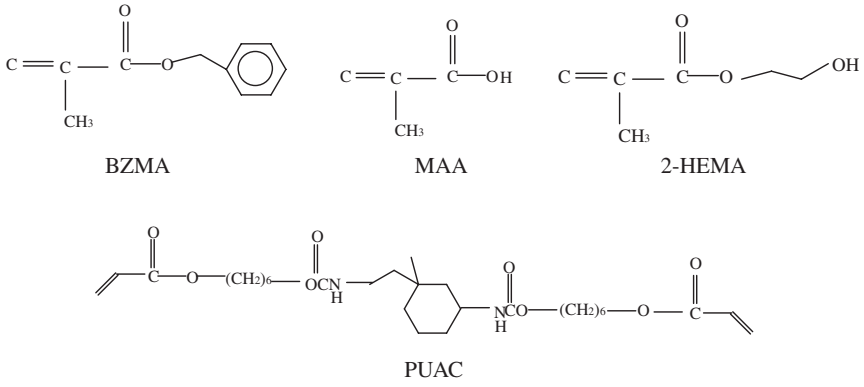

Fig. 1. Monomers for encapsulating adhesives.

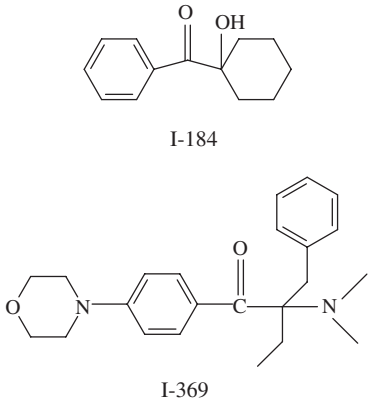

Fig. 2. Photoinitiators for encapsulating adhesives.

with an oxygen flow at 10 sccm, the substrate was then removed and spin-coated with a glycerol doped poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (G-PEDOT:PSS) film, whose thickness was 30 nm, to repair the surface and support the transfer of holes to the electrode. The sample was then placed in a N_2 glove box, and the active layer material [P3HT : PCBM = 1 : 1 (w/w)] was dissolved in *o*-dichlorobenzene (1.7 wt %). The solvent was then placed on a hot plate and stirred for more than 24 h at 40 °C and 150 rpm. The polymer solution was further spin-coated on the G-PEDOT:PSS layer and then placed in a petri dish. Because of the self-organization effect, a "slow growth" process occurred. We used a petri dish 12.9 cm in diameter and 4.5 cm high. After the component was coated, it was placed in the vapor-saturated container. Since the active layer was still in the liquid state, its solid film had not yet formed owing to the self-organization effects of the P3HT and PCBM. We waited until the active layer, whose thickness was 50 nm, was dry before removing it, and then thermally annealed it with a hot plate at 110 °C for 10 min. We then produced the LiF (10 nm)/Al cathode (80 nm) component by metal vapor deposition. After finishing the component, the packaging process was carried out in a glove box with encapsulating adhesives (i.e., UV glues I, II, and III), whose physical properties are listed in Table I. As shown in Fig. 5, UV glue I was applied using an adhesive injecting machine, and glass was placed on top to block the absorption of moisture and oxygen from the air. Finally, UV curing was performed with 3 s of UV illumination. UV glues II and III were applied directly to the components, as shown in Fig. 6, with 10 s of UV illumination. The thicknesses of UV glues I, II, and III were 100 μm.

Table I. Physical properties of encapsulating adhesives.

UV glue	Filler (5 wt %)	Viscosity (cps)	M_w	Adhesive strength (kgf/cm^2)	Gas penetration ($g\,m^{-2}\,d^{-1}$)
I	Silica	6,500	226,100	0.32	0.59
II	Silica	150	62,100	0.86	0.46
III	Silica	8,300	285,000	1.47	0.32

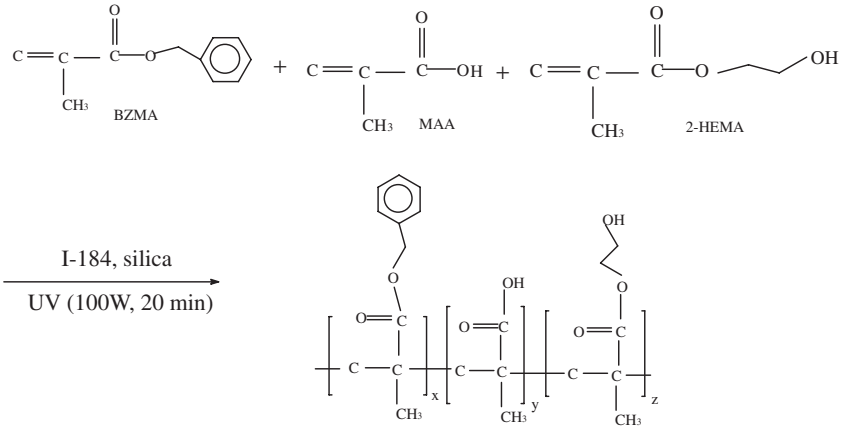

Fig. 3. Synthesis of UV glue I.

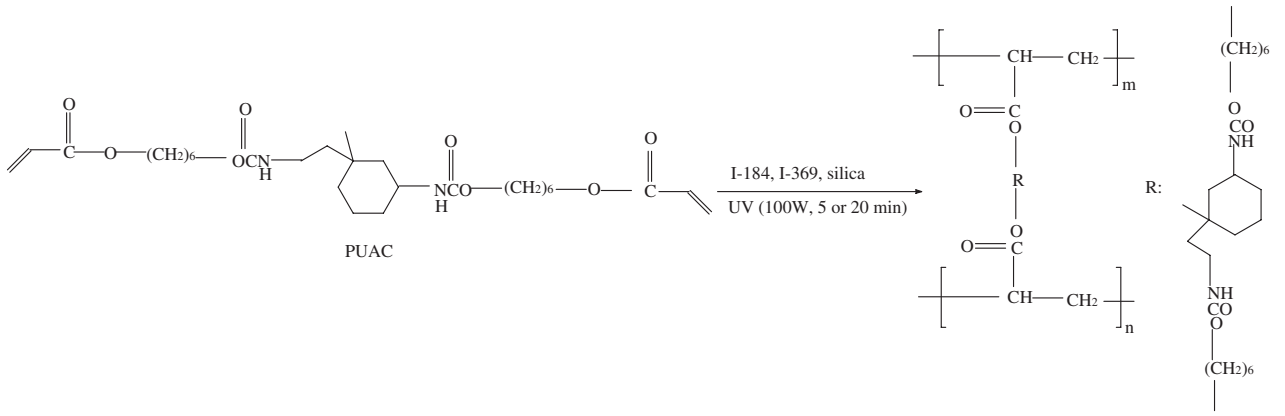

Fig. 4. Synthesis of UV glue II and III.

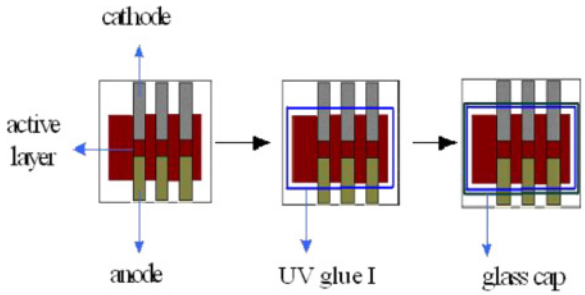

Fig. 5. (Color online) Packaging diagram of PSCs with glass and UV glue I encapsulation.

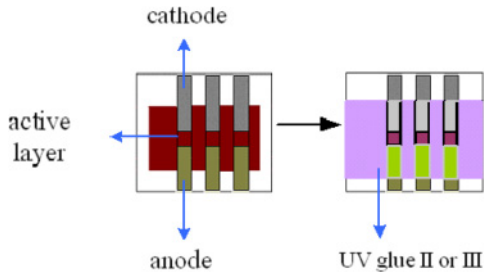

Fig. 6. (Color online) PSCs packaged directly with UV glue II or III on the surface.

2.4 Instruments

Molecular weight and viscosity were measured using a Waters Alliance GPC V2000 and a Viscolite 700, respectively. In addition, we also examined the adhesive strength and gas penetration using a microcomputer universal testing machine (Hung Ta ASTM D1002) and an Illinois-8501, respectively. The UV lamps used for synthesis and curing of UV glues I, II, and III were both Entela UVP at 100 W and 2,450 W, respectively. Furthermore, an AM G1.5 (100 mW/cm^2) was used to simulate sunlight, and a Keithley 2400 power meter was used to measure the current–voltage (J–V) characteristics of the PSCs. The film thickness was recorded using a surface profiler (Tencor P-10).

3. Results and Discussion

As shown in Fig. 7 and Table II, PSCs without encapsulation initially exhibited the photoelectric conversion capability, and the PCE reached 3.76%. When the operating time increased, however, the photoelectric conversion properties

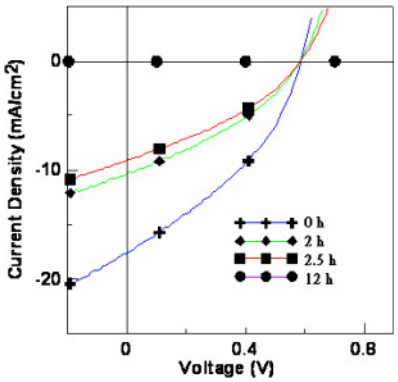

Fig. 7. (Color online) J–V characteristics curves of PSCs without packaging.

gradually decreased since moisture and oxygen from the air intruded into the device, resulting in the erosion of organic materials and the metal electrode. After operation for 2.5 h, the PCE remained at half of its original value. Eventually, the PCE dropped to approximately zero when the operating time was 12 h.

To extend the lifetimes of PSCs, we have utilized diverse encapsulating adhesives and packaging methods for the encapsulation of the devices. With the UV glue I package, as shown in the Fig. 8 and Tables I and II, the initial PCE and half-lifetimes increased to 4% and 16–17 h, respectively. UV glue I, whose gas penetration is 0.59 g m^{-2} d^{-1}, may obstruct the invasion of oxygen and moisture from the air into the device and effectively prolong the lifetimes of PSCs. Moreover, similar results can also be observed in the case of UV glue II and III, as shown in Figs. 9 and 10 and Tables I and II. PSCs with the encapsulation of UV glues II and III exhibit initial PCEs of 4.82 and 6%, respectively, and half-lifetimes of 26–28 and 90 h, respectively. The experimental results reveal that PCE differences occurred and strongly depend on the adhesive strength and gas penetration of the encapsulating adhesives when PSCs are packaged with UV glue I, II, or III. Among all the devices, the decay of PCE for PSCs with the encapsulation of UV glue III is the lowest, as shown in Fig. 11, since UV glue III has the highest adhesive strength and the lowest gas penetration.

4. Conclusions

The applications of PSCs are limited owing to their

Table II. Parameters and photoelectric conversion properties of fabricated devices.

G-PEDOT (6% glyerol)	Active layer (P3HT : PCBM = 1 : 1, 1.7 wt %)			Cathode	Encapsulation	PCE (%)
Spin speed/ time (rpm/s)	Spin speed (rpm)	Drying method	Annealing	LiF/Al (nm)	Manner	Fresh device
2500/30	1st-400 2nd-600	Slow dry	110 °C/10 m	10/80	without encapsulation	3.76
					UV glue I	4
					UV glue II	4.82
					UV glue II	6

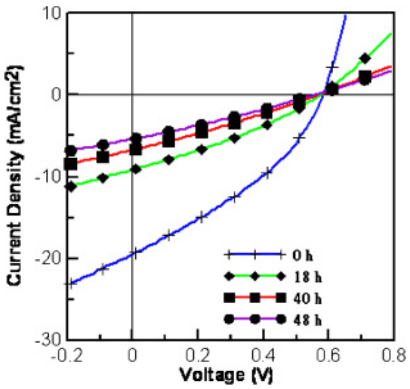

Fig. 8. (Color online) *J*–*V* characteristics curves of PSCs with the UV glue I package.

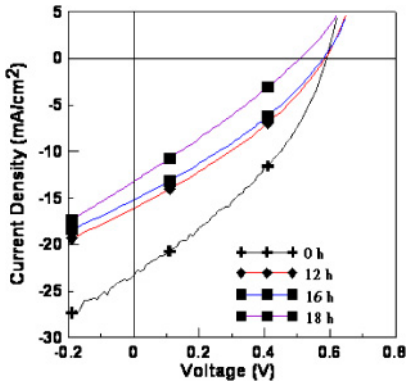

Fig. 9. (Color online) *J*–*V* characteristics curves of PSCs with the UV glue II package.

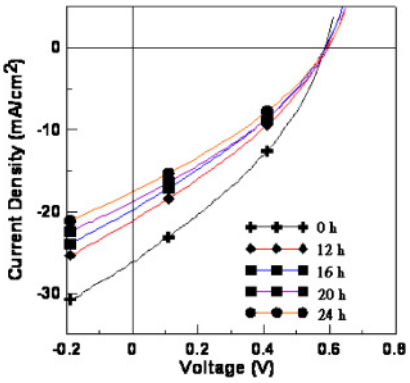

Fig. 10. (Color online) *J*–*V* characteristics curves of PSCs with the UV glue III package.

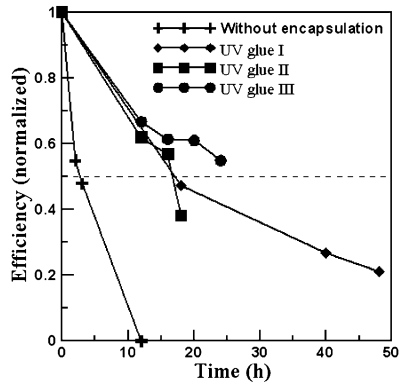

Fig. 11. Comparison chart for decrease in PSC lifetimes.

low efficiencies and short lifetimes. These issues can be improved by packaging. For components without encapsulation, their PCEs and half-lifetimes are about 3.76% and 2.5 h, respectively. However, their efficiencies and lifetimes can be enhanced when the devices are packaged with appropriate encapsulating adhesives. We have found that UV glue III exhibits the best gas blocking capability among the materials used, and the PCEs as well as the half-lifetimes of PSCs with encapsulation have been increased to 6% and 90 h, respectively.

Acknowledgement

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