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Doumon, Nutifafa Y.; Koster, L. Jan Anton

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Effects of the Reduction and/or Fluorination of the TT-Units in BDT-TT Polymers on the Photostability of Polymer:Fullerene Solar Cells

Nutifafa Y. Doumon* and L. Jan Anton Koster*

Polymer solar cells have a promising future for applications in our day to day usage of energy in small appliances and portable devices. However, their performance in terms of efficiency is limited by a number of factors, among which is their low open circuit voltage (V_{oc}). It is, therefore, understandable that much effort is channeled by the scientific community in improving the V_{oc} . One way to achieve this goal is the development of novel materials, for example, polymers, through chemical structure modification. Typical examples are addition (chlorination, fluorination, or sulfonylation) and/or reduction (from alkyl-ester to ketone substituents) mechanisms. This paper reports on the study of the effect of these structural changes for V_{oc} enhancement on the performance of the polymers in polymer:fullerene solar cells. In particular, it looks at seven polymers of the polybenzodithiophene-thienothiophene family, identifying the structural changes in the thienothiophene units or their moieties as a function of V_{oc} behavior in relation to their UV-stability. The findings reveal that the fluorination of the TT-units or having alkyl-ester groups as substituents on the TT-units is bad for photostability. However, when these alkyl-ester groups are reduced into ketone substituents, the photostability behavior improves.

1. Introduction

Polymer solar cell (PSC) technology has received a boost in recent years, in advancing its performance in terms of efficiency, with the development of the uniquely novel designed benzodithiophene (BDT) polymers.^[1–3] As BDT polymers proved to be a step in the good direction, the synthetic chemistry community, through materials chemical structure engineering, has gone a step further, fusing thienothiophene (TT) units together with the BDT structure, thus, developing the benzodithiophene-thieno-

thiophene (BDT-TT) polymers^[4] which apparently should advance the technology even further.

In retrospect, the 1D BDT alkoxy-substituted polybenzodithiophene-thienothiophene (PBDT-TT) polymers were first synthesized and soon followed by the design of their 2D counterparts, the BDT alkylthienyl-substituted PBDT-TT polymers.^[4,5] Within the structure of the PBDT-TT polymers, the TT-units are either fluorinated or chlorinated and/or mostly substituted with either an alkyl-ester or a ketone or a sulfonyl group as side chains.^[1,6–14] These developments in the synthetic chemistry community have created a surge in the organic photovoltaic (OPV) research community^[6,7,9–12,15–17] in order to realize the potentials of these new materials. The changes in structure consist of addition reactions such as the fluorination,^[6,9,10,12,13,18] chlorination,^[19,20] or sulfonylation^[11] of the TT-unit, and of reduction reaction on the TT-substituents, that is the removal of one oxygen atom and

thus, moving from alkylester.^[21,22] to ketone-substituent group on the TT-unit. These changes mainly target improvement in device performance, specifically the open circuit voltage (V_{oc}), thus, the power conversion efficiency (PCE).^[9–14,16,18,22,23] Soon after, single junction bulk heterojunction polymer:fullerene solar cells (PFSCs) reach PCE beyond 10%.^[24–28] This achievement is mainly enabled by changes in the polymer substituents, the processing techniques, and the device architecture.^[28] The change in substituents is a simple transition from the 1D PBDT-TT polymers to the 2D ones. An example is the case of PTB7 and PTB7-Th. The only difference between these two polymers, of the same family, is the replacement of the alkoxy side chains on the BDT unit by alkylthienyl side chains.^[16,29] Indeed, so far the predicted potentials are reached with a new quest to push the efficiency even further by the advent of the non-fullerene acceptors with the current PCE beyond 17%.^[30] Meanwhile, while the focal point in performance is on PCE of the devices, the stability issues of these polymers are not fully paid attention to, and thus, creating a gap in the foreseen potentials of the PSC technology for this kind of polymers. Stability and longevity are fundamental to the performance of the cells and the advancement of the field. Photostability of these

N. Y. Doumon, Prof. L. J. A. Koster
Photophysics and OptoElectronics
Zernike Institute for Advanced Materials
University of Groningen
Nijenborgh 4, NL-9747 AG, Groningen, The Netherlands
E-mail: n.y.doumon@rug.nl; l.j.a.koster@rug.nl

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polymers is one key concern which is not yet sufficiently investigated. Previous studies showed that thermal stability is slightly improved by the introduction of the 2D polymers.^[31] The changes in the TT units admittedly improved the performance of the device in terms of efficiency but the literature remains silent on their effects on photostability. For example, Yang et al.^[32] showed in a study that fluorination improves the V_{oc} of the device and the dielectric constant of the films but there is no comment on film or device stability.

This paper addresses this obvious gap in the literature and thus, investigates the photostability performance of the PBDDTT-TT polymers. In particular, the specific objective of this work is to assess the effect of the substituents of the TT moieties on the UV-degradation of their solar cells. For us to undertake this study in a systematic but comprehensive way, six polymers of the PBDDTT-TT family are selected and are classified into two groups of three each: 1D polymers, alkoxy substituted-BDT, and 2D polymers, alkylthienyl substituted-BDT. These polymers, with similar optical band gap as depicted in Figure S1A and B, Supporting Information, are studied in their respective groups to arrive

separately at a final conclusion. In each group, as shown in Figure 1A–F, from polymer 1 (PBDDTTT-E and PBDDTTT-ET) to polymer 2 (PBDDTTT-C and PBDDTTT-CT), the difference is the reduction of an alkyl-ester-substituent on the TT-unit to a ketone-substituent, that is the removal of an oxygen atom, and from polymer 1 to polymer 3 (PTB7 and PTB7-Th), the difference is an addition reaction, the fluorination of the TT-unit. To underline the effect of fluorination on the UV-stability, a seventh polymer, a 1D polymer is introduced into the study as depicted in Figure 1G. This polymer is different from polymer 2 only in the fluorination of the TT-unit. Note, moving from polymer 1 to polymer 2 or to polymer 3 means improvement in V_{oc} . The transition from polymer 1 to polymer 4 means an extra increase in V_{oc} . The aim in the study of the photostability of the solar cells is to identify, how these subtle changes in the chemical structure of the polymers affect the UV-degradation in their PFSCs. To arrive at this end, conventional solar cells, single-carrier devices, and films on glass are fabricated based on these polymers and exposed continuously at open circuit condition to a simulator lamp of the AM1.5G spectrum at room temperature in an inert

Figure 1. Chemical structure of the employed polymers. A) PBDDTTT-E, B) PBDDTTT-C, C) PTB7, D) PBDDTTT-ET, E) PBDDTTT-CT, F) PTB7-Th, and G) PBDDTTT-CF. 1D (2D): 1 or 2-dimensional; E_g : optical band gap; PDI: polydispersity index.

atmosphere. They are subsequently characterized to determine their photodegradation in PCE, charge transport and absorbance. We find that in the solar cells the ketone-TT unit polymers are the most photostable, followed by the alkyl-ester-TT unit polymers and finally by the fluorinated-TT unit polymers.

2. Results and Discussions

Conventional PFSCs are fabricated from the blend of the polymers (with a similar band gap, molecular weight (see Table 1), and a polydispersity index of 2) with fullerene derivative [70]PCBM. The current–voltage (J – V) characteristics are measured under continuous illumination at open circuit with an AM1.5G simulated light source, in an inert environment with H_2O and O_2 levels below 0.1 ppm. Table 1 shows the J – V characteristics of the best performing (amidst roughly 190 solar cells altogether) devices of each of the seven types of cells together with their average efficiencies. The J – V parameters as well as the J – V curves in Figures 2A and 3A show a notable increasing trend in V_{oc} from the alkyl ester group to ketone-group TT-substituents and also with the fluorination of the TT-units while no clear trend is observed in fill factor (FF). The increase is also observed in short circuit current (J_{sc}). This trend, in turn, explains the differences observed in the PCEs of the devices. For the 1D PFSCs, the reduction of the alkyl-ester-TT-substituent polymer, PBDTTT-E, to the ketone-TT-substituent polymer, PBDTTT-C, improves the V_{oc} from 0.69 to 0.73 V. The fluorination of the TT-unit of PBDTTT-E into PTB7 yields an improvement in V_{oc} from 0.69 to 0.77 V. Likewise, the fluorination of the TT-unit of PBDTTT-C into PBDTTT-CF improves the V_{oc} from 0.73 to 0.78 V. These increase in V_{oc} effects coupled with those of J_{sc} lead respectively to increment in PCE, from 3.8 to 5.0%, then to 5.2%, and from 5.0 to 5.6%. In a similar way, for the 2D polymer, the reduction leads to an increase in V_{oc} from 0.72 V to 0.84 V and the fluorination yields an increase in V_{oc} from 0.72 to 0.81 V, translating partly into an increase in PCEs respectively from 4.8 to 5.8%, and then to 9.4%. Details of device counts with the efficiency spread of the 1D and 2D PFSCs are displayed in Figure S1C–E, Supporting Information. Note, the solar cells are not processed with additive, such as diiodooctane (DIO) in order to avoid the degradation effects^[33,34]

from the additive. Nonetheless, in general, the reported PCEs are close enough to the literature values,^[6,35,36] especially for devices without DIO. Atomic force microscopy images of the six as-cast/fresh blend films show very little differences in their root-mean-square roughnesses between 0.5 to 1.0 nm.

It is interesting how these subtle changes in polymer chemical structure could lead to these staggering improvements in the performance of their solar cells as far as efficiency is concerned. However, the question is “how do these changes affect the performance of the devices in terms of stability?”. To this end, the relationship between these changes in structure and the photostability of their solar cells is studied in an inert atmosphere at room temperature by active cooling. The findings lead to the general observation that, the reduction of the alkyl-ester-substituents on the TT-unit into a ketone-substituents improved the UV-stability of the solar cell while the fluorination leads to a rapid decline in UV-stability as shown in Figures 2 and 3. These figures show the comparative PCE decays for the best performing devices while Figure S3, Supporting Information displays the comparative average trend in PCE decays, for all seven PFSCs. The trends are similar in both 1D and 2D PFSCs, however, it is more pronounced in the 2D PFSCs, certainly due to the effect of the alkylthienyl substituent on the BDT, which were previously shown^[33,37] through 1H NMR of the monomers to make them much less stable.

For example, in Figure 2B and 3B, when one transits from an alkyl-ester-substituted-TT-unit PFSC to a ketone-substituted-TT-unit PFSC, improvements in the UV-stability are recorded. For the best performing devices, an improvement in PCE decay from 8.5 to 0.6% was obtained for 1D PFSCs. On the average, this is from 13.4% PCE decay to 5.4% decay. A similar enhancement is achieved for 2D PFSCs from 10.2% decay to 5.0% decay with average from 12.6% PCE decay to 6.3% decay. In Figures 2C,E, and 3C, the fluorination of the alkyl-ester- or ketone-substituted-TT-units shows deteriorations in the UV-stability of the cells. For the best performing devices, there are accelerations in PCE decay for 1D PFSCs, from 8.5% PCE decay to 11.3% and then from 0.6% PCE decay to 12.7%. On the average, these are from 13.4% PCE decay to 16.5% decay and from 5.4% PCE decay to 25.1% decay. A similar increase in PCE decay is observed for 2D PFSCs from 10.2 to 15.3% with average from 12.6% PCE decay to 25.3% decay. This decline in the UV-stability evidently becomes wider

Table 1. Device parameters of solar cells under study with the polymers blended with [70]PCBM.

Class of PBDTTT polymer	Polymer	M_n [kDA]	TT-unit structural Changes	L [nm]	J_{sc} [A m ⁻²]	V_{oc} [V]	FF [%]	PCE [PCE _{avg}] [%]
1D polymer (alkoxy-BDT)	PBDTTT-E ^{a)}	≈24	Alkylester	90	99.7 (93.3 ± 6.6)	0.689 (0.682 ± 0.005)	55.1 (54.7 ± 1.3)	3.8 (3.5 ± 0.3)
	PBDTTT-C ^{b)}	≈23	Ketone	105	129.9 (121.1 ± 6.9)	0.731 (0.742 ± 0.008)	52.7 (48.0 ± 3.6)	5.0 (4.2 ± 0.5)
	PTB7 ^{c)}	≈23	Alkylester-Fluorinated	100	115.2 (101.6 ± 9.4)	0.773 (0.773 ± 0.018)	58.4 (55.4 ± 2.3)	5.2 (4.2 ± 0.4)
	PBDTTT-CF ^{d)}	≈22	Ketone-Fluorinated	100	123.0 (124.3 ± 2.9)	0.782 (0.776 ± 0.007)	56.0 (52.6 ± 3.4)	5.6 (4.4 ± 1.0)
2D polymer (alkylthienyl-BDT)	PBDTTT-ET ^{d)}	≈23	Alkylester	100	116.5 (114.7 ± 6.4)	0.721 (0.717 ± 0.012)	57.3 (55.7 ± 2.0)	4.8 (4.4 ± 0.4)
	PBDTTT-CT ^{e)}	≈22	Ketone	110	126.0 (123.1 ± 4.1)	0.839 (0.830 ± 0.010)	54.9 (54.9 ± 1.7)	5.8 (5.5 ± 0.3)
	PTB7-Th ^{f)}	≈22	Alkylester-Fluorinated	90	172.8 (156.8 ± 6.5)	0.806 (0.802 ± 0.005)	67.4 (65.9 ± 3.7)	9.4 (8.2 ± 0.6)

The average values for the cells are obtained for the indicated number of devices per polymer processed from oDCB.

^{a)}22 devices; ^{b)}32 devices; ^{c)}37 devices; ^{d)}27 devices; ^{e)}25 devices; ^{f)}32 devices; ^{g)}17 devices; M_n (molecular weight), L (Thickness), avg (average).

Figure 2. Performance of 1D polymer:fullerene solar cells. A) J - V curves; Evolution under continuous illumination of PCEs normalized to their initial values of B) Ketone-substituent-TT PBDTTT-C:[70]PCBM and alkylester-substituent-TT PBDTTT-E:[70]PCBM cells, C) alkylester-substituent-TT PBDTTT-E:[70]PCBM and alkylester-substituent-fluorinated-TT PTB7:[70]PCBM, D) Ketone-substituent-TT PBDTTT-C:[70]PCBM and alkylester-substituent-fluorinated-TT PTB7:[70]PCBM, and E) Ketone-substituent-fluorinated-TT PBDTTT-C:[70]PCBM and ketone-substituent-fluorinated-TT PBDTTT-CF:[70]PCBM.

when one moves from a ketone-substituted-TT-unit PFSCs to an alkylester-fluorinated-TT-unit PFSCs. Figures 2D and 3D depict the changes. For the 1D PFSCs an increase in PCE degradation from 0.6 to 11.3%. On the average, this is from 5.4% PCE decay to 16.5% decay. While the 2D PFSCs recorded an accelerated PCE degradation from 5.0% to 15.3% with average from 6.3% PCE decay to 25.3% decay.

From previous studies^[37] and as shown in Figure S2, Supporting Information, there are neither changes in blend film morphologies upon exposure nor changes in blend film absorbance before and after UV-exposure, so these changes can emphatically be attributed to these subtle changes in the TT-units of the PBDT-TT polymers. A quick look at the decay of the other J - V parameters of the best performing devices in Figure S4, Supporting Information, reveals that in all considered polymers, loss in J_{sc} is largely the main factor contributing to the PCE decay except for the fluorinated-TT-units polymer PBDTTT-CF (1D) and PTB7-Th (2D) cells which also record losses in FF.

To further grasp the reason behind these observations, charge transport studies are performed on the pristine and blend films by the fabrication of single-carrier devices and their subsequent J - V characterization. As reported earlier, and as depicted in Figure S5, Supporting Information, [70]PCBM shows no difference in electron current/mobility before and after exposure

to UV. In general, there is a decrease in the hole current of the pristine polymer upon UV-exposure of the hole only devices. This observed trend is as follows: reduction implied a reduction in the observed hole current loss moving from an alkylester-TT polymer to a ketone-TT polymer while fluorination means an increase in the observed current loss moving from an alkylester-TT polymer to an alkylester-fluorinated-TT polymer. These losses can be better observed in Figure 4A-C for the 2D polymers and Figure S6A-C, Supporting Information, for the 1D polymers. The hole currents of the blend hole only devices remain unchanged upon UV-exposure while being limited by the hole current of the exposed pristine films. There is a slight loss in hole currents when compared to the hole currents of pristine polymer devices. The main effect behind the observed degradation can be explained by the changes in electron currents of the blends in Figures 4G-I and S5G-I, Supporting Information. In general, there are losses in electron currents of the blend film devices upon UV-exposure. Interestingly, with the reduction of the alkylester-TT polymer to a ketone-TT polymer, there is a decrease in the electron current loss (comparing Figure 4H-G and Figure S6H-S6G) explaining why the ketone-based devices perform better in terms of stability. However, fluorination, moving from an alkylester-TT polymer to an alkylester-fluorinated-TT polymer, shows an increase in the observed

Figure 3. Performance of 2D polymer:fullerene solar cells. A) J - V curves; Evolution under continuous illumination of PCEs normalized to their initial values of B) Ketone-substituent-TT PBDTTT-CT:[70]PCBM and alkylester-substituent-TT PBDTTT-ET:[70]PCBM cells, C) alkylester-substituent-TT PBDTTT-ET:[70]PCBM and alkylester-substituent-fluorinated-TT PTB7-Th:[70]PCBM, D) Ketone-substituent-TT and PBDTTT-CT:[70]PCBM and alkylester-substituent-fluorinated-TT PTB7-Th:[70]PCBM.

electron current loss, possibly explaining why the corresponding fluorinated PFSCs are the least photostable compared to other devices in their family. This trend is even more apparent in the 2D polymer devices, reinforcing why in general they also record bigger losses in PCE over time compared to the 1D counterparts. In brief, these findings point to the fact that, in our case, reduction improves photostability while fluorination deteriorates photostability.

Finally, V_{oc} light intensity dependence measurements reveal that both reduction and fluorination decrease the ideality factor (n) as shown in Table 2 and thus, the number of initial traps present in their corresponding polymer solar cells. The slope of the plot of V_{oc} against light intensity, $n \frac{KT}{q}$, tells about the type of recombination mechanisms present in a solar cell. If $1 < n < 2$ then trap-assisted recombination is dominant, while $n = 1$ means bimolecular recombination is dominant.^[38,39] Fewer traps will also lead to higher open-circuit voltages as it reduces trap-assisted recombination. This confirms why they perform better in efficiency compared to the alkylester-TT based solar cells. For example, reduction decreases n from 1.66 to 1.00, in the case of 1D polymers as shown in Figure S7A, Supporting Information, while it decreased it from 1.43 to 1.12 in the case of 2D ones. Fluorination reduces n from 1.66 to 1.39 when one transits from PBDTTT-E to PTB7, as shown in Figure S7B, Supporting Information, and from 1.43 to 1.2 while going from PBDTTT-ET to PTB7-Th in Figure 5B. Upon continuous exposure to light for 1 h and 2 h, as shown in Figure 5A and B, n increases for the alkylester-TT and the fluorinated-TT polymers, especially for PBDTTT-ET from 1.43 to 1.54, and then to

1.58, for PTB7 from 1.39 to 1.48, and then to 1.52 and for PTB7-Th from 1.20 to 1.31, and then to 1.33. However, n remains fairly constant for the ketone-TT polymers, that is for PBDTTT-C from 1.00 to 1.04 and for PBDTTT-CT from 1.12 to 1.12, and then to 1.04. This implies that the presence of the fluorine atom and that of the alkylester groups (or the alkoxy group or the extra oxygen within the alkylester moiety) on the TT-units upon cleavage under the effect of illumination are possible sources of extra traps in the solar cells. Thus, leading to their faster degradation compared to the other solar cells of the same family. The alkoxy groups are known to be easily cleavable^[33,37,40] in films and solutions under continuous exposure to light, heat, oxygen or the combination of any of the above. This supports the notion that the increase in trap density is the reason behind the observed trends in degradation.

3. Conclusion

The main goal of the study is to find the relationship between the structural changes in the TT-moieties of the PBDT-TT polymers and the photostability of their PFSCs. The reduction of the alkylester-groups on the TT-unit into ketone-substituents makes a significant difference in the UV-stability of the solar cells in the considered cases, that is, an improvement in terms of percentage efficiency decay over the period of exposure. In contrast, the addition reaction, in this case, the fluorination of the TT-units results in the opposite effect, greatly worsening the UV-stability of the solar cells in all three considered cases. In general, in

Figure 4. Current–Voltage characteristics of unexposed (black, dark yellow, and blue) and exposed (1 h – red) of 2D polymers devices. Pristine polymer hole only (HO) devices A–C) PBDTTT-CT, PBDTTT-ET, and PTB7-Th; blend HO devices D–F) PBDTTT-CT:[70]PCBM, PBDTTT-ET:[70]PCBM and PTB7-Th:[70]PCBM; and blend electron only (EO) devices G–I) PBDTTT-CT:[70]PCBM, PBDTTT-ET:[70]PCBM and PTB7-Th:[70]PCBM.

terms of photostability of the solar cells, ketone-TT unit polymers are the best performers (PBDTTT-C and PBDTTT-CT), followed by the alkylester-TT units ones (PBDTTT-E and PBDTTT-ET) and then in last position the fluorinated-TT unit polymers (PTB7, PBDTTT-CF, and PTB7-Th). These findings, first of the kind, add to the limited understanding in the literature on the effect that the structural changes in polymers for V_{oc} enhancement in solar cells have on their stability and in this particular case photostability. These results, even though important additions to

the knowledge of the scientific community, are only limited to the PBDT-TT polymers and may not be generalized to all polymers. It would be interesting to see if this is the case for all fluorinated, chlorinated, sulfonated, or alkylester polymers.

4. Experimental Section

Device & Film Fabrication: All polymers were purchased from Solarmer Energy Inc., while [70]PCBM was obtained from Solenne BV. The polymers

Table 2. Ideality factor (n), at different (continuous) illumination time, of polymers blended with [70]PCBM solar cells processed from oDCB.

Class of PBDTTT polymer	Polymer	TT-unit structural changes	n , Fresh	n , 1 h	n , 2 h
1D polymer (alkoxy-BDT)	PBDTTT-E	Alkylester	1.66	1.66	1.66
	PBDTTT-C	Ketone	1.00	1.04	1.04
	PTB7	Alkylester-Fluorinated	1.39	1.48	1.52
	PBDTTT-CF	Ketone-Fluorinated	1.04	1.00	1.00
2D polymer (alkylthienyl-BDT)	PBDTTT-ET	Alkylester	1.43	1.58	1.54
	PBDTTT-CT	Ketone	1.12	1.12	1.04
	PTB7-Th	Alkylester-Fluorinated	1.20	1.31	1.33

Figure 5. Ideality factor (n) for 2D polymer:fullerene solar cells under continuous illumination over time A) PBDTTT-CT against PBDTTT-ET and B) PTB7-Th against PBDTTT-ET.

were processed in anhydrous 1,2-dichlorobenzene (oDCB), acquired from Sigma-Aldrich Co. LLB. For single carrier devices and solar cells, pristine polymers (20 or 25 mg) and polymers with [70]PCBM in a ratio of 1:1.5 with a total weight of 25 mg were respectively dissolved in 1 ml anhydrous oDCB. The solutions were mostly stirred overnight by the aid of magnetic stirrers on a hot plate, kept at 60 °C. Glass and pre-patterned ITO glass substrates were cleaned with soap-water, then rinsed in deionized water, followed by acetone and isopropanol washing in an ultrasonic bath for at least 10 min in each solvent. They are then removed, spin dried, and annealed in an oven at 140 °C for at least 10 min and then treated in UV-Ozone for 20 min. Films, or conventional solar cells, or single carrier devices were fabricated through spin coating with the dissolved materials. For solar cells, first, a 50 nm PEDOT:PSS (VP Al4083, H.C. Starck) layer was spin coated in ambient conditions on the pre-patterned ITO glass substrate and dried in an oven at 140 °C for 10 min. Atop the PEDOT:PSS layer, the blend solutions were spin coated at 800 rpm for 5 s and spin dried for 120 s in a glovebox in an inert atmosphere. The films were usually left in vacuum overnight and the devices were ultimately finished by thermal evaporation at $<10^{-7}$ mbar of LiF (1 nm) and Al (100 nm). The final device structure is ITO/PEDOT:PSS/Blend/LiF/Al. For single carrier devices, the bottom contacts, either Al (20 nm) for electron-only devices or Cr (1 nm)/Au (20 nm) for hole only devices were first thermally evaporated at $<10^{-7}$ mbar on glass substrates kept overnight in vacuum. Then, the respective solutions were spin coated at 600 rpm for 5 seconds and spin dried for 120 seconds atop the substrates and finished with thermal evaporation of the cathodes, with electron-only devices having the following structure Al (20 nm)/ Blend/LiF/Al and hole only devices having the following structure Cr (1 nm)/Au (20 nm)/PEDOT:PSS/Pristine polymer or Blend/Pd (15 nm)/Au (80 nm). The thickness of the active layers of the single carrier devices is between 100 and 120 nm. Finally, films of pristine polymers, of [70]PCBM and of blends were fabricated by spin-coating on glass substrates for UV-Vis absorption measurements.

Characterization

J–V Characteristics and UV-Vis Absorption: J–V characteristics of the solar cells and the single carrier devices were taken as previously described.^[37]

The absorption measurements were performed on the films in the wavelength range of 300–900 nm with a UV-3600 Shimadzu UV-Vis-NIR spectrometer against a glass substrate as a reference.

Supporting Information

Supporting Information is available from the Wiley Online Library or from N. Y. Doumon.

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Keywords

alkylester/ketone substituents, fluorination, photodegradation, photostability, polymer solar cells, thienothiophene

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