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Efficient Ternary Organic Solar Cells Enabled by the Integration of Non-fullerene and Fullerene Acceptors with a Broad Composition Tolerance

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The ternary structure that combines fullerene and non-fullerene acceptors in a photoactive layer has been demonstrated as an effective approach for boosting the power conversion efficiencies (PCEs) of organic solar cells (OSCs). Here we report highly efficient ternary OSCs comprising a wide-bandgap polymer donor (PBT1-C), a narrow-bandgap non-fullerene acceptor (IT-2F), and a typical fullerene derivative (PC₇₁BM). It is found that the addition of PC₇₁BM into the PBT1-C:IT-2F blend not only increases the device efficiency up to 12.2%, but also improves the ambient stability of the OSCs. Detailed investigations indicate that the improvement in photovoltaic performance benefits from synergistic effects of increased photon-harvesting, enhanced charge separation and transport, suppressed trap-assisted recombination and optimized film morphology. Moreover, we notice that such a ternary system exhibits excellent tolerance to the PC₇₁BM component, for which PCEs over 11.2% could be maintained throughout the whole blend ratios, higher than that (11.0%) of PBT1-C:IT-2F binary reference device.

1. Introduction

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Organic solar cells (OSCs) have garnered tremendous attention owing to their great potential in lightweight, mechanically flexible, and roll-to-roll printed devices to harvest solar energy.^[1-5] Bulk-heterojunction (BHJ) OSCs based on a mixture of a polymer donor and a small molecule acceptor have delivered remarkable power conversion efficiencies (PCEs).^[6-14] Further improvement in PCEs is required to meet large-scale commercialization, but restricted by the insufficient spectral coverage of such a BHJ blend film with the solar spectrum.^[15] Ternary OSCs that integrate one more acceptor or donor into a photoactive layer have been established to supplement the optical absorption profiles of binary systems, whilst retaining the simplicity of the fabrication process of single-junction devices.^[16-19] Intriguingly, the additional component also offers the ability to ameliorate the blend morphology, thus facilitating charge transport.^[20-24] Therefore, ternary structure has become an effective and simple approach for enhancing the photovoltaic performance of OSCs, and now the PCEs of ternary devices have exceeded 12% by judiciously selecting material composition.^[25-29]

Over the past few years, extensive research efforts have been devoted to the design and synthesis of non-fullerene acceptors (NFAs) in view of their strong light absorption, easily tunable energy levels and bandgaps compared with the fullerene counterparts.^[30-32] State-of-the-art OSCs based on NFAs can simultaneously realize low voltage loss and high current generation, affording higher PCEs than fullerene-based OSCs. However, NFAs generally suffer from low electron mobilities.^[33,34] In contrast, the typical fullerene derivatives such as [6,6]-phenyl-C₇₁-butyric acid methyl ester (PC₇₁BM) possess unique ball-like fully conjugated structure, which endows them with isotropic electron transport and strong electron-accepting capabilities and excellent electron mobility.^[35] In this regard, the incorporation of a fullerene acceptor as the third component into non-fullerene binary blends may compensate for the deficiencies of NFAs to some extent. Meanwhile, the resulting ternary systems can have the opportunity to benefit from both the strong absorptivity by non-fullerene components and the exceptional charge extraction properties of fullerene molecules. Though there have been a few recent successful studies on ternary systems integrating NFAs and fullerenes,^[36-38] most of them are susceptible to the amount of the third

component, which is unfavorable for practical production. In addition, ternary OSCs with good ambient stability are rarely reported.

In this study, we report a multiple-acceptor ternary system by incorporating PC₇₁BM as the guest acceptor into a host binary blend based on a wide-bandgap donor polymer (PBT1-C)^[39] and a narrow-bandgap NFA (IT-2F).^[40] The PC₇₁BM possesses a perfectly complementary absorption profile with the PBT1-C:IT-2F blend. The introduction of PC₇₁BM into the PBT1-C:IT-2F blend enhanced charge separation and transport, reduced trap-assisted recombination and improved blend morphology. The combined benefits resulted in an enhancement in PCE from 11.0% for PBT1-C:IT-2F based binary device to 12.2% for the optimized ternary device containing 20% PC₇₁BM loading, thanks to the concurrent increase in open-circuit voltage (V_{oc}), short-circuit current (J_{sc}) and fill factor (FF). The stability of PBT1-C:IT-2F:PC₇₁BM based ternary device in ambient conditions is also significantly improved relative to PBT1-C:IT-2F device. Particularly, unlike common ternary systems, the ternary OSC performance is found to be insensitive to the content of PC₇₁BM. A high PCE at 11.23% could be maintained even with PC₇₁BM content equal to the host components,

demonstrating that the PBT1-C:IT-2F blend has excellent compatibility to the PC₇₁BM component.

2. Results and Discussion

2.1. Optoelectronic Characterization

The chemical structures of PBT1-C, IT-2F and PC₇₁BM are presented in **Figure 1a**. We first measured the ultraviolet-visible (UV-vis) absorption spectra of the three pristine materials and all ternary blends with various PC₇₁BM contents. As depicted in Figure 1b, the maximum absorption peaks of PBT1-C and IT-2F are located at 612 nm and 719 nm, respectively, with only limited spectral overlap for them. While the absorption of the secondary acceptor PC₇₁BM concentrates in short wavelength range, it is well complementary to that of PBT1-C and IT-2F. Once these three components are mixed, a broad spectrum covering the entire visible region is realized, thereby favoring high J_{sc} values in relevant ternary devices. Figure 1c shows increasing the PC₇₁BM loading ratio in the PBT1-C:IT-2F host blend gradually enhances the absorption intensity before 530 nm whilst simultaneously reducing the absorption coefficients from 530 to 800 nm.

It is known that the V_{oc} of BHJ solar cells is determined by the energy level difference between the highest occupied molecular orbital (HOMO) of the donors and the lowest unoccupied molecular orbital (LUMO) of the acceptors. In many cases, the existence of a third component leads to a decrease in V_{oc} obtained in the original binary system because of its inappropriate HOMO (or LUMO) energy level alignment.^[41-44] Hence, the cyclic voltammetry measurement was performed to estimate the energy levels of PBDB-T, IT-2F, and PC₇₁BM (Figure S1). From the energy level diagram illustrated in Figure 1d, it can be seen clearly that PC₇₁BM possesses a higher-lying LUMO level than IT-2F (−3.90 eV vs −4.09 eV), which offers a larger energy offset referencing to the HOMO of PBT1-C, implying that PC₇₁BM would not have a negative effect on the V_{oc} of PBT1-C:IT-2F binary devices.

2.2. Photovoltaic Performance

We initially evaluated the photovoltaic performance of binary reference devices based on the PBT1-C:IT-2F and PBT1-C:PC₇₁BM blends using an inverted structure of ITO (indium tin oxide)/zinc oxide (ZnO)/Active layer/molybdenum oxide (MoO₃)/Ag, where ZnO and MoO₃ served as the cathode and anode interlayers, respectively. Coincidentally, both blends

delivered the best performance when spin-casted from their solutions in chloroform with a donor/acceptor weight ratio of 1:1 and 0.5% solvent additive of 1,8-diiodooctane by volume.

The PBT1-C:IT-2F device exhibited a high J_{sc} of 17.28 mA cm⁻², a fill factor (FF) of 72.7%, and a V_{oc} of 0.879 V, resulting in a decent PCE of 11.04%. In contrast, the PBT1-C:PC₇₁BM device yielded a moderate PCE of 8.75% due to the low J_{sc} of 12.28 mA cm⁻², regardless of a higher V_{oc} of 0.914 V and an outstanding FF of 78.0% (see **Figure 2a** and **Table 1**). Then, we fabricated ternary OSCs at the optimal processing conditions of binary systems, wherein the weight ratio of PBDB-T:IT-2F was kept at 1:1 and the proportion of PC₇₁BM relative to the host acceptor IT-2F was carefully optimized. Representative current density-voltage ($J-V$) characteristics under AM 1.5G illumination (100 mW cm⁻²) are shown in Figure 2a and the detailed photovoltaic parameters are summarized in Table 1. The best devices with different PC₇₁BM contents exhibited consistent thickness around 95 nm. It was found that the incorporation of small amounts of PC₇₁BM (< 30%) into PBT1-C:IT-2F blend significantly promoted the value of J_{sc} and FF. The V_{oc} was also improved slightly for all ternary devices, which is consistent with the upshifted LUMO level of PC₇₁BM with respect to IT-2F. At a

1:1:0.2 ratio of PBT1-C:IT-2F:PC₇₁BM, the PCE consequentially reached a maximum of 12.19%, accompanied with a V_{oc} of 0.892 V, a J_{sc} of 18.19 mA cm⁻², and a FF of 75.1%. Notably, the performance of ternary OSCs is insensitive to the content of PC₇₁BM; even when the PC₇₁BM addition is the same as the host acceptor IT-2F, the resulting ternary devices still outperform the PBT1-C:IT-2F binary control devices (see Figure 2c), demonstrating that the PBT1-C:IT-2F system has excellent compatibility to the third component of PC₇₁BM. Herein, we would like to point out that this phenomenon was rarely observed for other reported ternary systems. In addition, we tested the ambient stability of the optimized ternary and PBT1-C:IT-2F binary devices (Figure 2d and **Figure S2**). After 60 days in air conditions (relative humidity, ~35%), the best ternary PBT1-C:IT-2F:PC₇₁BM (1:1:0.2) device retained 96.3% of its PCE (11.74%), whereas PBT1-C:IT-2F performance retained 91.8% (10.13%). Even after 180 days exposed to air, the PCE of the ternary device still gave 76.1% of the initial PCE, higher than that (71.1%) of binary device (**Figure S3**). These results indicate that the use of PC₇₁BM in ternary blends not only enhances photovoltaic performance but also has a synergistic benefit on storage lifetime.

External quantum efficiency (EQE) spectra of ternary devices together with two binary control devices are shown in Figure 2b and the integrated J_{sc} values from EQE spectra are listed in Table 1, which are all in good agreement with these achieved from $J-V$ tests. As expected, the binary PBT1-C:IT-2F device covered a broader photoresponse up to 800 nm than that based on PBT1-C:PC₇₁BM. In comparison to the binary PBT1-C:IT-2F device, the optimized ternary device gave higher EQE values over the whole spectral response range, which accounted for the enhancement in photocurrents. It is notable that the EQE values are raised most obviously in the wavelength region of 500-650 nm where PBT1-C has high absorption.

To elucidate the working mechanism in the ternary system, we carried out steady state photoluminescence (PL) quenching and time-resolved PL (TRPL) analysis on three pristine films and binary PBT1-C:IT-2F, IT-2F:PC₇₁BM as well as ternary PBT1-C:IT-2F:PC₇₁BM (1:1:0.2) blend films. All these examples were excited at 500 nm. The PL spectrum of PC₇₁BM film has an apparent overlap with the absorption spectrum of IT-2F (**Figure S4**), making the energy transfer between PC₇₁BM and IT-2F possible. As shown in **Figure 3**, for

IT-2F:PC₇₁BM blend film, the emission of IT-2F increased greatly while the emission of PC₇₁BM was vanished with a substantially decreased average fluorescence lifetime (τ) from 636 ps to 74.2 ps. Previous reports^[18,45] verified that the energy transfer or charge transfer can shorten the excited-state lifetime, as both of them introduce an additional non-radiative decay path for the excitons in blends. On the other hand, OSCs based on IT-2F:PC₇₁BM (1:0.2) blend delivered a J_{sc} value of 0.09 mA cm⁻², much smaller than that (0.15 mA cm⁻²) of OSCs using IT-2F neat film (see **Figure S5**), indicating that there was no charge transfer between PC₇₁BM and IT-2F. Therefore, we can conclude that only energy transfer from photoexcited PC₇₁BM to IT-2F occurs to facilitate photovoltaic process in ternary devices. In terms of PBT1-C film, it exhibited strong PL emission intensity at ~690 nm with τ of 267 ps. The PL emission of PBT1-C was not completely quenched when mixing with IT-2F, while the introduction of PC₇₁BM into PBT1-C:IT-2F could slightly further quench the PL of PBT1-C and reduce the τ of PBT1-C to 23.6 ps. It indicated that PC₇₁BM could facilitate the dissociation of PBT1-C excitons, thus leading to the enhanced EQE in the PBT1-C absorption region as discussed above.^[46,47] Additionally, the fluorescence intensity of IT-2F

in PBT1-C:IT-2F:PC₇₁BM (1:1:0.2) film decreased relative to that of PBT1-C:PC₇₁BM binary blend, which may be related to the changed aggregate state as discussed in the following section.

2.3. Charge Transport, Generation and Recombination Dynamics

To investigate the influence of PC₇₁BM on charge transport properties, the electron and hole mobilities of ternary blend films for all the compositions were determined using the space charge-limited current (SCLC) method with single-carrier device architectures of ITO/ZnO/Active layer/ZrAcac/Ag and ITO/PEDOT:PSS/Active layer/MoO₃/Ag, respectively.

As shown in Figure 4a, S6 and Table S1, the electron mobility continuously enhanced with increasing PC₇₁BM content, from $2.22 \times 10^{-4} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ for PBT1-C:IT-2F blend to $5.66 \times 10^{-4} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ for PBT1-C:IT-2F:PC₇₁BM (1:1:1) blend. The hole mobility increased to $2.29 \times 10^{-4} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ and $2.12 \times 10^{-4} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$, respectively, after addition of 10% and 20% PC₇₁BM; further increasing the PC₇₁BM content resulted in decreased hole mobility, even lower than that of PBT1-C:IT-2F binary blend. The improved charge mobilities partly explained the

higher FF in ternary devices with low PC₇₁BM content, and also confirmed that the PC₇₁BM indeed improved the charge transport properties of the original PBT1-C:IT-2F binary system.

To characterize the charge generation and dissociation process, we measured the saturation current density (J_{sat}) and charge dissociation probability ($P(E, T)$) of PBT1-C:IT-2F, PBT1-C:IT-2F:PC₇₁BM (1:1:0.2) and PBT1-C:IT-2F:PC₇₁BM (1:1:1) devices. Figure 4b presents the photocurrent density (J_{ph}) versus the effective voltage (V_{eff}) curves for the three devices. $J_{\text{ph}} = J_{\text{L}} - J_{\text{D}}$, where J_{L} and J_{D} are the current density under illumination and in the dark, respectively. $V_{\text{eff}} = V_{\text{o}} - V$, where V_{o} is the voltage at which J_{ph} equals zero and V_{a} is the applied bias voltage.^[48] It can be seen that J_{ph} reached saturation (J_{sat}) when V_{eff} values arrived at ~2V, suggesting that all the excitons inside these three devices were dissociated into free charge carries and collected by the electrodes. The J_{sat} values for the three devices were 17.55 mA cm⁻² (without PC₇₁BM), 18.35 mA cm⁻² (20% PC₇₁BM content) and 17.92 mA cm⁻² (100% PC₇₁BM content), respectively. The improved J_{sat} values in ternary devices confirmed that the third component PC₇₁BM actually assisted the photo-harvesting of PBT1-C:IT-2F blend. Under the short-circuit condition, the calculated $P(E, T)$ values for the three

devices were 96.2%, 97.1% and 97.4%, respectively, which implied that PC₇₁BM promoted charge dissociation in ternary devices, coinciding with the PL analysis.

Furthermore, the dependence of J_{sc} as well as V_{oc} on light intensity (P_{light}) (10-100 mW cm⁻²) was then measured to further clarify the effects of PC₇₁BM content in acceptors on the charge recombination behavior. The relationship between J_{sc} and P_{light} can be expressed by the power-law equation $J_{sc} \propto (P_{light})^a$, where the exponential factor a represents the extent of bimolecular recombination.^[49] Figure 4c depicts the plots of J_{sc} versus $\log P_{light}$, and the extracted a values for the PBT1-C:IT-2F, PBT1-C:IT-2F:PC₇₁BM (1:1:0.2), and PBT1-C:IT-2F:PC₇₁BM (1:1:1) devices are all equal to unity, indicative of a negligible bimolecular recombination occurred in the three solar cells. Clearly, low or high loading of PC₇₁BM would not induce more recombination centers for our ternary system. The measurement of the V_{oc} as a function of P_{light} helps to gain insight into the trap-assisted recombination.^[50] If the bimolecular recombination is the dominate mechanism at open-circuit condition, the slope of the V_{oc} versus the natural logarithm of the P_{light} should be kT/q , where k is the Boltzmann constant, T is temperature in Kelvin and q is the elementary charge. A stronger dependence

of V_{oc} on P_{light} with a slope greater than kT/q is observed when the trap-assisted recombination is involved. In our cases, the PBT1-C:IT-2F device exhibited a slope of $1.48kT/q$ while for PBT1-C:IT-2F:PC₇₁BM (1:1:0.2) and PBT1-C:IT-2F:PC₇₁BM (1:1:1) devices, the slope decreased to $1.25kT/q$ and $1.33kT/q$, respectively (shown in Figure 4d). These results revealed the introduction of PC₇₁BM into the PBT1-C:IT-2F blend suppressed trap-assisted recombination within BHJ blends and thus contributed to improved J_{sc} .

2.4. Film Morphology Characterization

It is well known that favorable blend morphology is crucially important to the photovoltaic performance of BHJ OSCs. Compared with binary references, film morphology of ternary mixtures is much more complicated due to the addition of the third component, wherein intermixing and interactions between the third component and the host may induce unexpected changes in microstructure.^[16] Therefore, we used the tapping-mode atomic force microscopy (AFM) to provide the topography information of the ternary blends. As shown in **Figure 5**, the PBT1-C:IT-2F exhibits fibrous texture arising from PBT1-C crystals, but associated with many small grains that should be attributed to the aggregation of IT-2F.

Once the PC₇₁BM was loaded, the fibrous feature became more visible. Meanwhile, small grains nearly disappeared for all ternary blends. Thus, a better morphology was achieved with fine dispersed polymer fibrils that have previously been found beneficial to exciton dissociation and charge transport.^[39,51-53] In order to determine how the PC₇₁BM impacted the morphology, the AFM height and phase images of neat IT-2F film and IT-2F:PC₇₁BM (1:0.2) blend film were also measured (see **Figure S7**). The crystalline aggregates of IT-2F were disrupted upon the addition of PC₇₁BM with decreased root-mean-square (RMS) roughness from 0.66 nm to 0.50 nm. The results suggested that PC₇₁BM could be compatible and well-mixed with the host acceptor IT-2F despite of their distinctly different molecular configurations. It was interesting that although PBT1-C:PC₇₁BM displayed a higher RMS roughness (2.15 nm) than PBT1-C:IT-2F (1.41 nm), blending PC₇₁BM into PBT1-C:IT-2F up to 100% did not cause any dramatic change in the surface RMS roughness of the host blend. This may elucidate why our ternary system has good tolerance to the content of PC₇₁BM.

Moreover, grazing-incidence wide-angle X-ray scattering (GIWAXS) measurement was carried out to reveal the molecular packing and crystallinity in the neat and blend films. **Figure S8** depicted the two-dimensional (2D) GIWAXS patterns and the corresponding out-of-plane and in-plane line cuts for individual component. Both PBT1-C and IT-2F molecules preferred a face-on orientation with respect to the substrate, as evidenced by a more prominent (010) π - π diffraction signal in the out-of-plane direction located at $1.66 \text{ \AA}^{-1}$ and $1.83 \text{ \AA}^{-1}$, respectively, corresponding to the distances of $3.78 \text{ \AA}$ and $3.43 \text{ \AA}$, respectively. As illustrated in **Figure 6**, the PBT1-C:IT-2F binary blend presented packing motifs of both components and the face-on dominated molecular orientation for PBT1-C and IT-2F could be maintained, which is conducive to vertical charge transport in OSC devices. For the ternary mixtures with low PC₇₁BM concentration, the π - π stacking diffraction peak at $1.83 \text{ \AA}^{-1}$ decreased, indicative of reduced crystallinity of IT-2F, which agrees well with the AFM results. With increasing PC₇₁BM, a typical diffuse reflection for PC₇₁BM at $1.35 \text{ \AA}^{-1}$ was clearly observed, meaning that PC₇₁BM formed its own domain as a new electron-transport network and thereby, the electron mobility was improved.

3. Conclusion

To summary, we have successfully developed a highly efficient ternary OSC with improved ambient stability by introducing PC₇₁BM into the PBT1-C:IT-2F non-fullerene blend, wherein these three materials show well complementary absorptions across the entire visible region. The higher-lying LUMO energy level of PC₇₁BM compared with IT-2F benefits the V_{oc} values in ternary devices. As expected, the addition of PC₇₁BM improved the charge carrier mobility. AFM and GIWAXS characterizations indicated that the active layer morphology in ternary blends was optimized by suppressing the aggregation of IT-2F, leading to a reduced trap-assisted recombination. Consequently, the optimal ternary device delivered an outstanding PCE of 12.2%, which largely outperformed the binary PBT1-C:IT-2F reference device. We noticed that this ternary system exhibited a broad composition tolerance with high PCEs over 11.2% through the whole blend ratios (from 1:1:0 to 1:1:1), mainly due to the good compatibility with PC₇₁BM. The results demonstrate that the integration of non-fullerene and fullerene acceptors in a ternary mixture can further boost the PCE and is a promising strategy towards developing high-performance ternary OSCs.

Supporting Information

Supporting Information is available from the Wiley Online Library or from the author.

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Figure 1. (a) Chemical structures of PBT1-C, PC₇₁BM, and IT-2F. (b) Normalized UV-vis absorption spectra of neat PBT1-C, PC₇₁BM, and IT-2F films. (c) UV-vis absorption spectra of ternary blend films with various PC₇₁BM contents. (d) Energy level diagrams of PBT1-C, PC₇₁BM, and IT-2F.

Figure 2. (a) $J-V$ characteristics and (b) the corresponding EQE spectra for ternary OSCs with different PC_{71}BM contents under simulated AM 1.5G irradiation (100 mW cm^{-2}). (c) PCE for the ternary OSCs as a function of the proportion of PC_{71}BM relative to IT-2F. (d) Ambient stability of the optimal ternary device efficiencies compared with the binary PBT1-C:IT-2F reference device.

Figure 3. (a, b) PL spectra of three pristine films and binary PBT1-C:IT-2F, IT-2F:PC₇₁BM as well as ternary PBT1-C:IT-2F:PC₇₁BM (1:1:0.2) blend films excited at 500 nm. (c) TPPL spectra of PC₇₁BM and IT-2F:PC₇₁BM (1:0.2) films probed at 710 nm. (d) TPPL spectra of PBT1-C, PBT1-C:IT-2F and PBT1-C:IT-2F:PC₇₁BM (1:1:0.2) films probed at 690nm.

Figure 4. (a) Hole and electron mobility of ternary blend films with different PC₇₁BM contents. (b) Photocurrent density (J_{ph}) versus effective voltage (V_{eff}) curves. (c) Dependence of J_{sc} on light intensity and (d) dependence of V_{oc} on light intensity for PBT1-C:IT-2F, PBT1-C:IT-2F:PC₇₁BM (1:1:0.2) and PBT1-C:IT-2F:PC₇₁BM (1:1:1) devices.

Figure 5. Tapping-mode AFM height (a-f) and phase (g-l) images (2×2 μm) for ternary blend films with different PC₇₁BM contents.

Figure 6. (a) 2D GIWAXS patterns and (b) scattering profiles of out-of-plane (solid line) and in-plane (dotted line) for blend films with different PC₇₁BM contents.

Table 1. Summary of photovoltaic parameters for ternary organic solar cells with different PC₇₁BM contents.

PBT1-C:IT-2F:PC ₇₁ BM	V_{oc} [V]	J_{sc} [mA cm ⁻²]	$J_{cal}^{a)}$ [mA cm ⁻²]	FF [%]	PCE ^{b)} [%]
1:1:0	0.879 (0.877 ± 0.004)	17.28 (17.04 ± 0.25)	16.72	72.7 (72.3 ± 1.0)	11.04 (10.81 ± 0.16)
1:1:0.1	0.882 (0.881 ± 0.005)	17.74 (17.58 ± 0.15)	17.24	75.7 (75.8 ± 0.5)	11.84 (11.75 ± 0.10)
1:1:0.2	0.892 (0.888 ± 0.004)	18.19 (18.09 ± 0.14)	17.51	75.1 (74.9 ± 0.7)	12.19 (12.04 ± 0.10)
1:1:0.3	0.893 (0.894 ± 0.004)	18.10 (17.86 ± 0.23)	17.42	74.1 (73.8 ± 1.0)	11.98 (11.78 ± 0.13)
1:1:0.4	0.901 (0.896 ± 0.005)	17.76 (17.71 ± 0.11)	17.25	73.2 (72.7 ± 1.2)	11.71 (11.53 ± 0.19)
1:1:0.6	0.898 (0.898 ± 0.003)	17.69 (17.67 ± 0.13)	17.29	73.5 (72.5 ± 0.7)	11.67 (11.50 ± 0.14)
1:1:1	0.893 (0.893 ± 0.004)	17.64 (17.54 ± 0.10)	17.11	71.3 (70.2 ± 1.4)	11.23 (11.00 ± 0.21)
1:0:1	0.914 (0.909 ± 0.004)	12.28 (12.18 ± 0.11)	11.82	78.0 (77.3 ± 0.6)	8.75 (8.55 ± 0.15)

^{a)}Integrated from EQE spectra; ^{b)}the average PCE values were obtained from eight devices.

Ternary organic solar cells (OSCs) with improved power conversion efficiency (PCE) and ambient stability are developed by combining a non-fullerene acceptor (IT-2F) and a fullerene acceptor (PC₇₁BM). Such a ternary system is found to be insensitive to the content of the third component, and PCEs over 11.2% could be maintained throughout the whole blend ratios, higher than that (11.0%) of the binary reference device.

Ternary organic solar cells, power conversion efficiencies, non-fullerene acceptors, fullerene acceptors, stability

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Efficient Ternary Organic Solar Cells Enabled by the Integration of Non-fullerene and Fullerene Acceptors with a Broad Composition Tolerance

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