RESEARCH HIGHLIGHTS

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Star polymer donors

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Organic solar cells (OSCs) as a promising photovoltaic technology have attracted great attention due to its unique advantages, such as solution processing, low cost, lightweight and excellent mechanical flexibility[1–5]. Conventional OSCs always employ fullerene derivatives, e.g. $PC_{61}BM$, $PC_{71}BM$ and $IC_{70}BA$, as electron acceptors. Fullerene derivatives present weak absorption in the visible region, while polymer donors show excellent light-harvesting ability in the visible and even near-infrared (NIR) regions. Many medium- or low-bandgap polymer donors have been developed for complementary absorption, and the power conversion efficiencies (PCEs) for fullerene-based OSCs reach ~12%[6, 7].

In 2015, a nonfullerene acceptor (NFA) ITIC was reported by Zhan *et al.*, bringing OSC to a new era. Many efficient NFAs have been developed, and the PCEs of solar cells have soared to ~19%[1, 2]. NFAs always exhibit much low optical bandgap with strong absorption in 600–900 nm, so the development of wide-bandgap (WBG) polymer donors with good light-harvesting ability in 400–700 nm is desirable[8–12]. The pairing of WBG polymer donors and low-bandgap (LBG) NFAs presents reduced voltage loss (V_{loss}), and the highest occupied molecular orbital (HOMO) offset between donor and acceptor can be very small, even close to zero[2, 3].

BDTT is one of the best building blocks in constructing D-A conjugated polymers[13]. The two-dimensional conjugated structure and weak electron-donating ability endow its copolymers with good hole mobilities and low HOMO energy levels. In 2015, Hou *et al.* reported PM6 (PBDB-TF), and its fullerene solar cells gave a 9.2% PCE (Fig. 1). PM6 offered over 18% PCE when blending with Y-series NFAs[13]. PM6 works very well with most NFAs, and has become one of the best commercial polymer donors. In addition, the chlorinated derivative PM7 (PBDB-TCl) achieved over 17% PCE in PM7:Y6 cells[14]. What's more, some donor or acceptor units as the third component were introduced into PM6. Efficient terpolymer donors were obtained by using random D-A copolymerization to tune the energy levels and absorption. Li *et al.* introduced an electron-withdrawing unit 2,5-bis(4-(2-ethylhexyl)thiophen-2-yl)pyrazine into PM6 backbone to get a D-A_1-D-A_2 type terpolymer PMZ-10. PMZ-10:Y6 solar cells gave a PCE of 18.23%[15].

In 2020, Ding *et al.* reported a milestone WBG polymer donor D18 based on DTBT unit with large molecular plane and strong electron-withdrawing capability[1, 16]. D18:Y6 cells offered a PCE of 18.22%, with an open-circuit voltage (V_{oc}) of 0.859 V, a short-circuit current density (J_{sc}) of 27.70 mA/cm^2 and a FF of 76.6%, which was the first report on single-junction OSCs with over 18% efficiency[1]. Then, the chlorinated analogue D18-Cl was reported. D18-Cl:N3 cells and D18-Cl:N3:$PC_{61}BM$ cells delivered PCEs of 18.13% and 18.69%, respectively[17, 18]. Later, D18-B and D18-Cl-B were also developed *via* side-chain engineering. D18-B:N3:$PC_{61}BM$ and D18-Cl-B:N3:$PC_{61}BM$ cells offered PCEs of 18.53% and 18.74%, respectively[19]. D18 derivatives have been developed and present good performance[20, 21].

Hou *et al.* reported two dithieno[3,2-*f*:2′,3′-*h*]quinoxaline (DTQx)-based polymer donors PBQx-TF and PBQx-TCl with fluorinated or chlorinated BDTT as the donor units[22, 23]. 19.0% and 18.0% PCEs were achieved for PBQx-TF:F-BTA3:eC9-2Cl and PBQx-TCl:BTA3:BTP-eC9 cells, respectively. Very recently, Hou *et al.* developed a WBG polymer donor PB2F containing fluorinated BDTT and 1,3,4-thiadiazole units with a very deep HOMO level of –5.64 eV. PB2F:PM6:BTP-eC9 cells gave a PCE of 18.6%[24].

The polymer donors mentioned above are based on BDTT donor unit, and they need complex syntheses. Li *et al.* reported a low-cost polymer donor PTQ10 with thiophene and 6,7-difluoro-2-(2-hexyldecyloxy)quinoxaline units, which was synthesized from commercial materials *via* a two-step synthesis (yield 87.4%). PTQ10:BTP-FTh:IDIC cells demonstrated a PCE of 19.05%[2].

Currently, most efficient polymer donors are synthesized through multi-step reactions, exhibiting high cost. Cheap and high-performance polymer donors well matching those LBG NFAs are needed[25–30]. We are expecting single-junction OSCs with >20% PCE.

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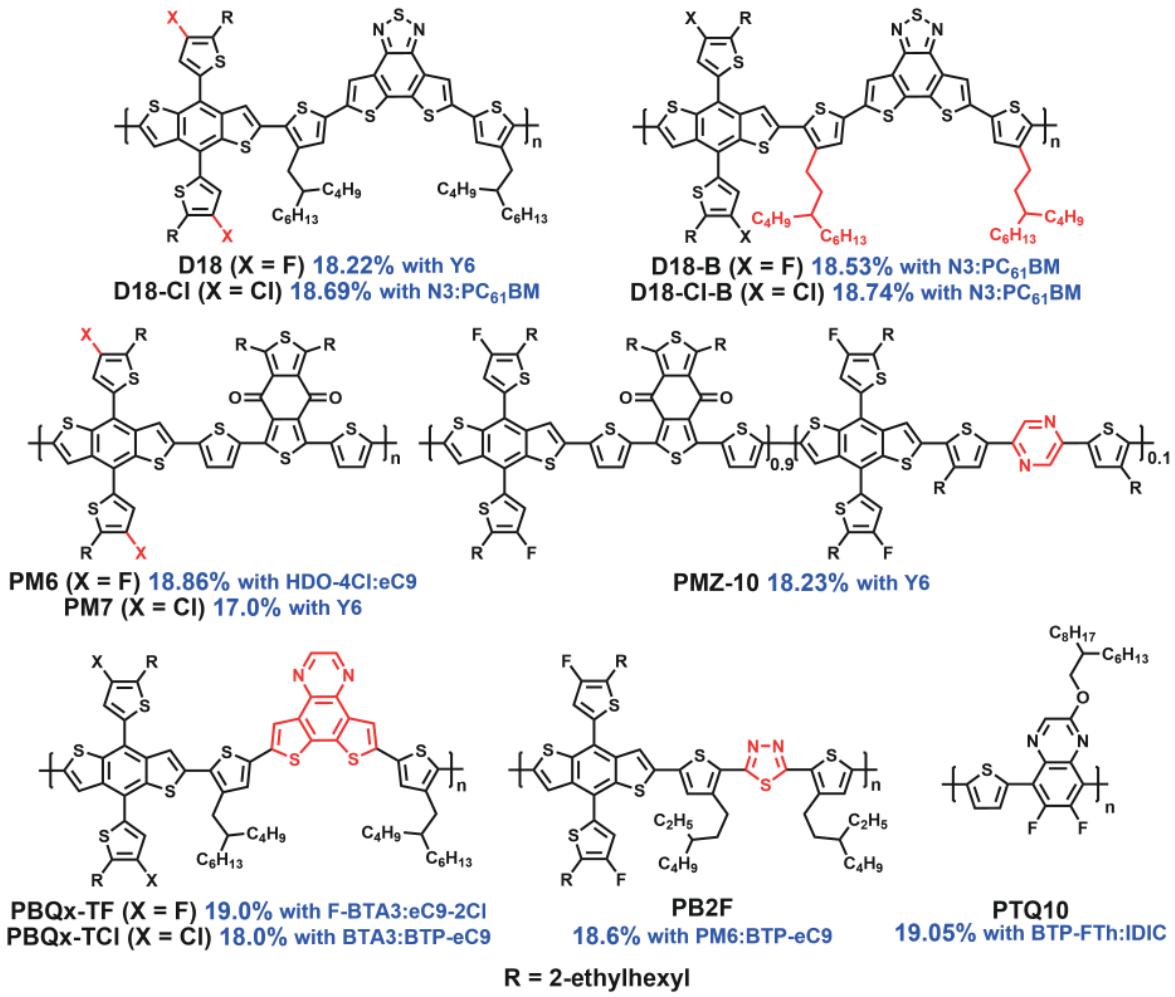

Fig. 1. (Color online) The chemical structures for representative polymer donors and the PCEs.

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