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Review

Recent development of efficient A-D-A type fused-ring electron acceptors for organic solar

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ABSTRACT

The development of acceptor-donor-acceptor (A-D-A) type fused-ring electron acceptors boosted the energy conversion efficiency of organic solar cells. Certified record power conversion efficiencies of single junction organic solar cells have exceeded 14%. In this paper, we briefly reviewed the development of A-D-A type fused-ring electron acceptors which were reported since 2014. The planarity of the central donor moieties, the effects of bulky side-chain and the end-group modification were highlighted.

1. Introduction

With the rapid development of global economy, energy shortage and environmental pollution problems are becoming more and more serious, so the demand for clean energy has become more and more urgent. Solar energy as a kind of green energy attracts more and more attentions (Li et al., 2017a). Organic solar cells (OSCs) have been widely investigated to convert sunlight to electricity for their light weight, low cost, and the capability to fabricate flexible devices (Wang et al., 2016). The typical bulk heterojunction (BHJ) OSCs consist of polymer donor materials and fullerene acceptor materials (Yao et al., 2017a). Because the fullerene acceptors are expensive and hard to modify (Suman et al., 2017), non-fullerene acceptors have caught great attentions in the past several years and great progress has been achieved (Dai et al., 2017; Liu et al., 2018a).

Many strategies have been proposed to design high performance non-fullerene acceptors (NFAs): (1) modifying n-type molecules/blocks, i.e., perylene diimides (Liu et al., 2018b) and naphthalimides derivatives (Lin et al., 2016a), (2) constructing acceptor-donor-acceptor (A-D-A) backbone structures. In some cases, the π bridge is inserted between the donor unit and acceptor unit to fine-tune the properties of these electron acceptors, constructing A-π-D-π-A type NFAs (Wen et al., 2018). But in this review, the π bridge was considered as part of the D moiety as shown in Fig. 1. The A-D-A NFAs can not be comparable to fullerene derivatives until fused-ring electron acceptors (FREAs) appear. So far, FREAs (Lin et al., 2016b) seem to be the most successful ones. The best power conversion efficiencies (PCEs) of binary single heterojunction OSCs have exceeded 14% (Arrechea et al., 2017; Xiao et al., 2017) and tandem OSCs (Wang et al., 2017a) have exceeded 17% (Meng et al., 2018), which demonstrates that the performance of non-fullerene acceptors is even better than that of fullerene derivatives (Li et al., 2017b).

Given the great success and fast progress achieved by FREAs, it is necessary to briefly review the development of FREAs reported since 2014. These FREAs are featuring fused-ring donor moieties, such as indacenodithiophene (IDT), indacenodithieno [3,2-b]thiophene (IDTT) and benzodithiophene (BDT) and so on, and various acceptor moieties are linked to the backbone via olefinic bond (Liu et al., 2016a). These FREAs exhibit strong absorption, tunable lowest unoccupied molecular orbital (LUMO) and highest occupied molecular orbital (HOMO) energy levels, planar structure, and high electron mobility (Dai et al., 2017). This mini review mainly discussed the effects of the planarity of donor unit, the conjugation length of donor unit, side chain engineering and modification of acceptor groups on the optical property, energy levels and photovoltaic performance.

2. The donor unit

2.1. The conjugation length of donor unit

Extending conjugation length in fused-ring ladder acceptors is a useful strategy to simultaneously manipulate the energy levels and absorption. Since Lin and Zhan first designed IEIC in 2014, with an IDT donor-core, IDIC (Lin et al., 2017), INIC (Dai et al., 2017), ITIC (Lin et al., 2015a), ITTIC (Zhang et al., 2017a) and IHIC (Wang et al., 2017b) have been designed with extended conjugation length of the donor units.

Typical fused rings usually have high planarity and suffer from

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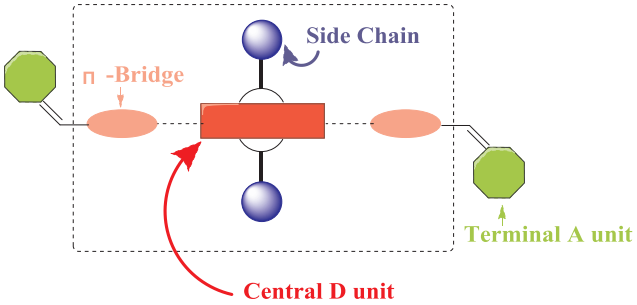
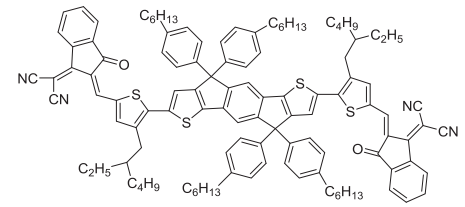


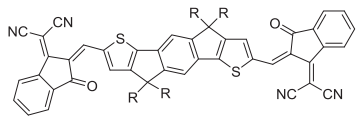
Fig. 1. Chemical structures of A-D-A acceptors.

strong aggregation, leading to the formation of large crystalline domains which will lead to large phase separations, reduced exciton diffusion/separation efficiencies, and finally low PCEs of the PSCs (Huang et al., 2014). Therefore, introducing rigid out-of-plane side chains onto the fused rings is a way to restrict planarity and selfaggregation of the fused ring-based electron acceptors.

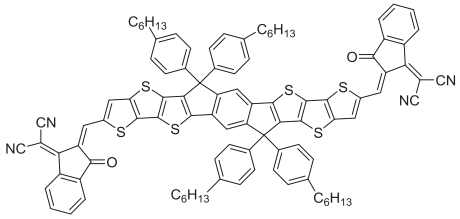
Lin and Zhan first designed IEIC (as shown in Fig. 2), with an IDT as the donor core, a 2-alkyl-thienyl as the π bridge and a 2-(3-oxo-2,3-dihydroinden-1-ylidene)-malononitrile (IC) acceptor as the end group. IEIC exhibited strong absorption in the region of 500–750 nm with an extinction coefficient of $1.1 \times 10^5\ M^{-1}\ cm^{-1}$ at 672 nm, and a relatively high electron mobility of $2.1 \times 10^{-4}\ cm^2\ V^{-1}\ s^{-1}$. HOMO and LUMO levels of IEIC were calculated to be −5.61 eV and −4.04 eV,



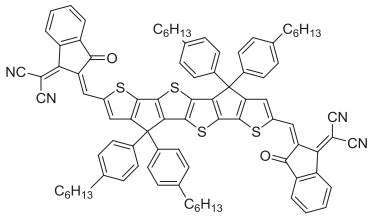
1.1.1 IEIC



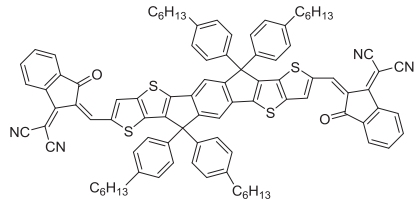
1.1.2 IC-C6IDT-IC R= C_6H_{13}
IDIC1 R=PhC_6H_{13}



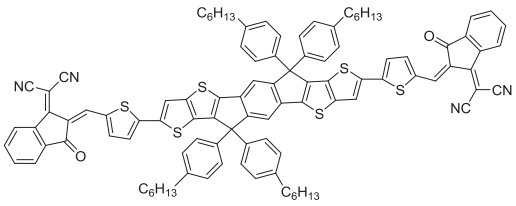
1.1.3 INIC



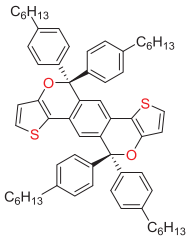
1.1.4 IHIC



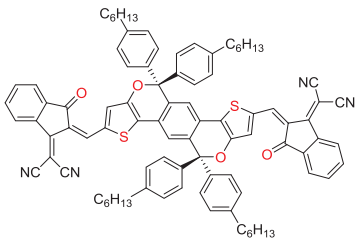
1.1.5 IHIC1



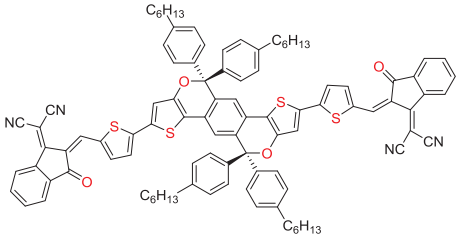
1.1.6 ITTIC



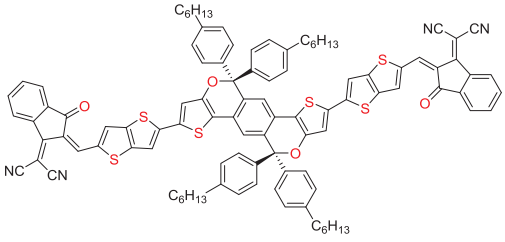
1.1.7 Ph-DTDP



1.1.8 Ph-DTDP-IC/ CO5IC



1.1.9 Ph-DTDP-TIC



1.1.10 Ph-DTDP-TTIC

Fig. 2. Chemical structures of A-D-A acceptors based electron deficient group-flanked IDT/IDTT.