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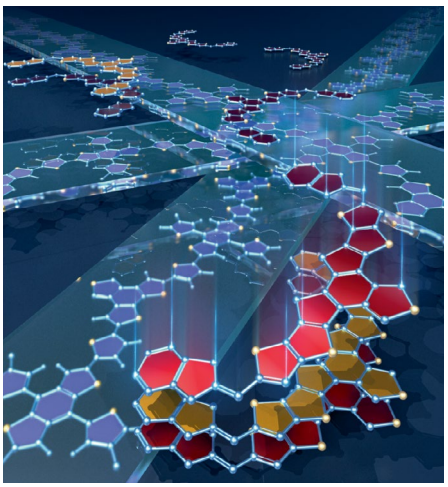
The role of non-fullerene acceptors continues

Non-fullerene acceptors help organic solar cells achieve high performance, transforming organic photovoltaics into a useful technology.

Research on organic photovoltaics (OPVs) dates back to the nineteenth century when researchers observed photoconductivity in certain organic materials. For some time, OPVs remained confined within laboratory walls, as the power conversion efficiency (PCE), a rate to measure how much solar energy is converted to electrical energy, was very low (<0.1%). This fact, along with the poor stability of organic materials in ambient environmental conditions, hindered the further development of OPVs. In 1986, a bilayer heterojunction device that achieved a PCE of approximately 1% was constructed[1]. Although too low to meet industrial requirements, this device showcased the concept of donor–acceptor structures and was the birth of a prototype organic solar cell. Subsequently, propelled by the advent of conducting conjugate polymers and the concept of the bulk heterojunction[2], OPVs gained momentum as a useful technology. Then, the adoption of fullerene-based acceptors improved the PCE to around 10%[3], but inherent material properties prevented OPVs from reaching higher performance. From the early 2010s, non-fullerene acceptors were developed[4], which boosted the PCE, recently surpassing 20%.

In this issue of *Nature Materials*, we present two Articles on single-junction organic solar cells that achieve more than 20% PCE.

In their Article, Yanming Sun and colleagues report molecular engineering of a non-fullerene acceptor to achieve 20.1% PCE in single-junction organic solar cells. They precisely add and tune the alkyl side chains on the thiophene unit of a non-fullerene acceptor, so that the molecule becomes asymmetric with respect to the backbone structure. This strategy improves the crystallization of donor–acceptor blends in the bulk heterojunction region as well as the electroluminescence quantum efficiency. In an accompanying News & Views article, Dieter Neher shares a view that this asymmetric side chain design not only reduces the π–π stacking distance of the blended molecules but also changes the type of electronic coupling towards stronger aggregation. However, the delicate interplay between molecular order and packing, the role of a third component in ternary blends and why symmetric side chains cause the quantum yield to drop are yet to be understood.



In a Q&A, Jenny Nelson shares opinions on recent progress in OPV research. A crucial role of non-fullerene acceptors is that they promote ordered molecular packing, better crystallinity, long exciton lifetimes and good charge carrier mobilities, leading to higher PCE. While several chemical and structural properties can still be improved, it is noted that recent works achieving high PCEs all use the same family of non-fullerene acceptors – the Y6 derivatives along with high-performance polymer donors. Yet, how material properties at the molecular level lead to enhanced device performance remains underexplored.

While a PCE of 20% is attractive for industry, issues such as scalable printing and the fabrication of large-scale films need to be resolved. In their Article, Yaowen Li and colleagues introduce an organic semiconductor regulator to tune the crystalline dynamics of the molecules. When the regulator is added into the donor–acceptor blend, the donor molecules crystallize before the acceptors do, resulting in the formation of a top acceptor/middle bulk heterojunction/bottom donor structure, which is called gradient vertical phase separation (pictured). This strategy not only helps elevate the PCE of the single-junction solar cell to 20.43%, but also enhances the PCE of a 250-nm-thick, 15-cm^2-area module to 18.04%. In an accompanying News & Views article, Francesco Furlan and Nicola Gasparini emphasize that these results move OPVs closer to commercialization. The gradient vertical phase separation combines the dual advantages of a bulk heterojunction to enhance exciton splitting and the layer-by-layer deposition to enhance charge transport, boosting device performance closer to that of inorganic counterparts.

This exciting progress prompts researchers to think about how far OPVs are from industrial applications. In a Q&A, Derya Baran discusses how organic materials can complement silicon in various applications such as low-light indoor conditions, smart home devices and space technologies. Yet, there are challenges on the road to commercialization, for example, scalable production in the presence of oxygen, moisture, light and high-temperature conditions needs to be addressed, and overall cost needs to be reduced.

It is more than 10 years since the first use of non-fullerene acceptors in OPVs. There is little doubt that this will continue to be an exciting field. We must accumulate knowledge to better understand how these molecules help achieve higher performance and stimulate the lab-to-fab progress of OPVs.

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