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# Thiophene based Donor-Acceptor Copolymers for Photovoltaic Applications: A Review

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## Abstract

*The modern urbanization and advanced lifestyle are always at a greater danger of consuming energy. Unfortunately, there are significant problems with conventional fossil fuel energy sources, including a lack of storage, high costs, and hazardous contamination. Instead, solar energy is an affordable, sustainable, and sustainable choice for the coming energy requirement on the global market. Among photovoltaic technologies, organic photovoltaics (OPVs) show a low-cost, adaptable, environmentally friendly, and simple-to-process method of converting solar energy into electricity. However, due to their limited lifespan and the energy-intensive deposition of the top metal electrode, OPVs with a standard device configuration are still a long way from being industrialized. To enhance the stability, cost issues and easy fabrication process, an inverted device architecture is widely preferred model. Polymers doped with metals leads to improved charge transport, plasmonic effects, stability enhancement, optical properties, and functionality by exploiting the unique properties of metals. Ongoing research in this area aims to further optimize metal-doped polymer solar cells for commercial applications in renewable energy. This review summarizes and illustrates recent developments in device architectures, operating principles, functionalities, and advancements at each component layer, as well as how these developments relate to the effectiveness of OPVs. Author tries to accentuate the various research practices and methods opted by scholars to stimulate the efficiency of organic solar cell which will provide a broad idea for chemist to develop new synthetic monomers and strategies to enhance the photovoltaic applications.*

**Keywords:** *Donor-Acceptor Low Bandgap Polymers, Conducting Polymers, Organic Solar Cell*

## 1.0 Introduction

80% of electricity in India is supplied by fossil fuels which may last for another 100 to 200 years[1]. To meet the growing energy demands of India, harnessing solar energy is one of the important ways to meet the energy requirements as it is readily available and inexhaustible. In India out of 365 days in a year, 300 days are sunny. Hence photovoltaic becomes a promising technology. Polymeric solar cells are low cost, very flexible to design, light weighted, and proved to be capable of generating clean and renewable energy. They can be easily fabricated in large sizes also. The first-generation Silicon based Photovoltaic (PV) cells were very expensive as to fabricate the defect free crystalline silicon cost is too high. To overcome this high cost, second generation inorganic semiconductors like

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cadmium, telluride, Copper, Indium, Galanium, Selenide (CIGS) thin film were developed. Second generation inorganic semiconductors are less expensive than the first generation. Later on, third generation material was developed by researchers in which they explored the solar cells based on organic materials. Main advantage of this third-generation material is its lowest cost production and easy fabrication over first- and second-generation materials[2]. Further, metals are commonly used in OPVs as electrodes to collect and transport the generated charge carriers. Typically, metals such as aluminum, gold, or silver are employed as the cathode or anode in OPV devices, depending on their work function and compatibility with the active materials[3].

## 1.1 Background (Development of Polymer Solar Cell)

In 1954, PV technologies had attained great interest after the discovery of crystalline silicon with a 25% power conversion efficiency and module efficiency for the performance of PV products is 10%. But to manufacture crystalline silicon of 99.999% purity involves high temperature and it is expensive therefore researchers started to look for an alternative of polycrystalline silicon[4-6].

The second generation is based on thin film photovoltaic technique in which inorganic semiconductor materials were found to provide better absorption than compared to first generation crystalline silicon. In the second generation the semiconducting material used were amorphous silicon and CIGS. These materials can be processed on large area substrate but like first generation they are also costly due to the usage of rare elements[7].

The concept of organic sell emerged due to the conducting nature of semiconducting materials like polymers. Several polymers were synthesized by different methodology, and it was observed that efficiency of a Polymer Solar Cell (PSC) was 2.5% during the year 2001 to 18% in 2020[8]. This drastic increase suggests that PSC can replace traditional inorganic solar cells in the coming days. Their flexibility over inorganic solar cells and low cost in manufacturing at large scale were the major advantages of organic solar cells[9,10].

In 2017, Lee and Jung[11] designed high performance PSC's. Absorption level upto 620nm indicates that polymer may have bandgap of 2.0eV which may give efficiency around 25%. Extension of absorption level upto 1100nm may have a band gap ~1.1 eV[1] with an increased Power Conversion Efficiency (PCE) to 77%[12]. So it is very necessary to synthesize copolymers with narrow bandgap which increases PCE of Polymer solar cells[13]. In order to achieve high PCE, the proper selection of D-A combination is essential which controls the optical energy gap of semiconducting polymers. He *et al.*[14] in 2015 designed and synthesized donor- acceptor small molecule. One atom substitution makes remarkable changes on optoelectronic and photovoltaic performance of PSC's. Author concluded that parameters like absorption band width, architecture, lower optical density with charge carrier mobility, structure and morphology of photo active layer are the other factors which contribute to the performance of PSCs [15].

Zhang and Wang[16] in 2012 attained High PCE around 10% in semiconducting polymers by thiophene derivatives because sulfur is less electronegative compared to nitrogen and oxygen. Substituting electron withdrawing unit on acceptor and electron donating atom on donor is an effective way to get high PCE [17]. Substitution on D and A also play an important role in elevated PCE. Hence, to achieve high performance PSCs, selection of D-A type copolymer is very important[18].

## 1.2 Efficiency of Polymer Solar Cell

In 2001, Shaheen *et al.*[19] synthesiszed efficient organic plastic solar cells of PCE 2.5% (Figure 1) and concluded

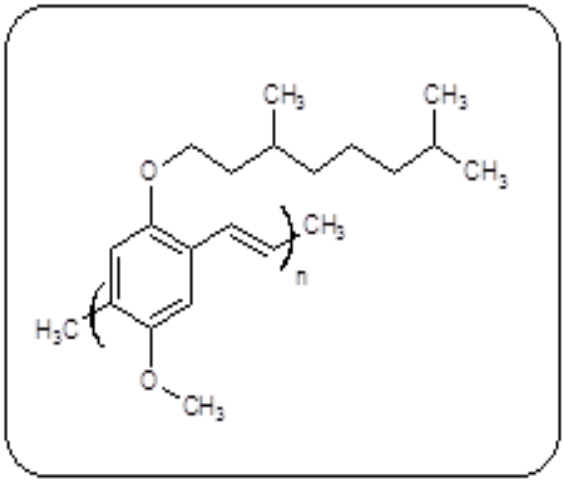



**Figure 1.** Structure of plastic solar cell exhibiting PCE~2.5%.

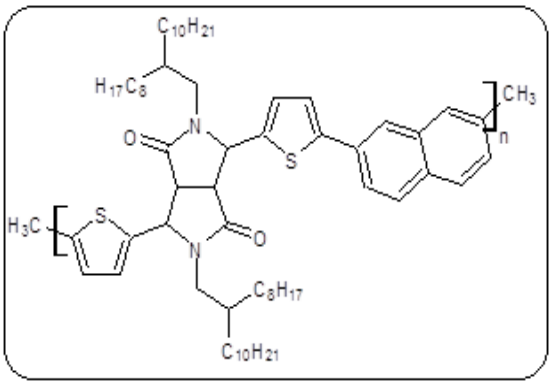


**Figure 2.** Structure of low bandgap polymer exhibiting PCE~4.7%.

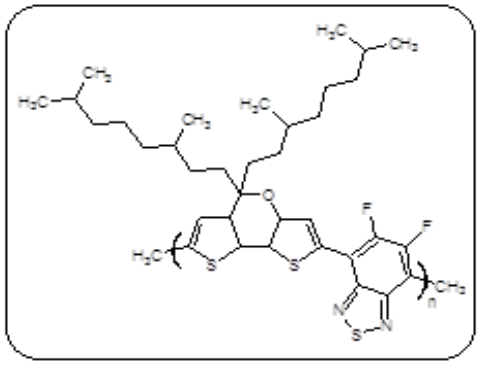


**Figure 3.** Structure of polymer exhibiting high PCE 10.6%.

that conversion of absorbed photons into electrons was around 100% at 425-575nm. They fabricated the device with two different solvents like chlorobenzene and toluene. It was observed that short circuit value for chlorobenzene-based device was two times higher than compared to toluene. Not only solvent other structural modifications like donor acceptor combination and parameters like polymer:fullerene composition and thermal annealing influences the performance of polymer solar cells. Al-Ibrahim *et al.* in 2005 synthesised poly(3-hexylthiophene):fullerene(P3HT:PCBM) and found that PCE of solar cell can be increased from 1.5 to 3.4% by thermal annealing. Composite film formation and degree of polymerization helped to improve the performance of polymer solar cell[20].

Several polymers were prepared by changing the solvents to increase the efficiency over few years. But no one was able to do radical increase in PCE. In 2009 Chen, K.F *et al.* designed and synthesized organic solar cell. Chen *et al.*[21] in 2009 synthesized and characterized 1,3-cyclohexadiene with π-bridge thiophene as dye sensitized based solar cells. The efficiency of cell was reported 4.4%.

Later Sonar *et al.*[22] in 2011 synthesized low bandgap polymer (Figure 2) via Suzuki coupling of dikettopyrrolopyrrole (DPP) with naphthalene boronic ester with PCE 4.7%. Composed cell showed high hole mobility due to strong intermolecular interactions and π-π stacking between naphthalene and DPP blocks. They concluded that D-A combination influences the relative positions of the energy levels, enhancing the π energy by incorporating suitable aromatic compounds such as thiophene, quinoidal, aniline or pyrrole like structures to lower the optical bandgap of polymers.

Improvement in PCE was observed in a series of polymers with electron rich unit and electron withdrawing units and same was reported in 2014 by Yau *et al.*[23]. The reported polymers were synthesized by Stille coupling of 4,4-bis(2-ethylhexyl)-4 H-germolo[3,2- b:4,5- b′] dithiophene ( DTG) as donor unit with 3 different electron withdrawing units like 2-octyl-2 *H* -benzo[ *d* ][1,2,3] triazole(BTz), 5,6-difluorobenzo[*c*][1,2,5]thiadiazole (DFBT) and [1,2,5] thiadiazolo[3,4- *c*]pyridine (PT). synthesized DTG-PT polymer exhibited PCE of 5.2% which proves that low bandgap polymers enhanced the PCE of the polymers. Dou, L *et al.*[24] in 2012 synthesiszed Benzothiadazole(BT) and DPP based polymers by Stille coupling. Result exhibited that the synthesized polymers showed PCE around 6%, low bandgap (1.4-1.5eV), deeper HOMO (Highest Occupied Molecular Orbital) levels and good charge transport properties which enhanced the open circuit voltage ($V_{oc}$) and short circuit current ($J_{sc}$) values in PSC devices.

Further improvement in PCE to around 9.21% was observed for semi crystalline photovoltaic polymers which were synthesized by Nguyen, T.L *et al.*[25] in 2014. Polymer synthesized by Stille cross coupling of benzothiazadole (BT) and dialkoxyphenylene. It exhibited low bandgap, and long term thermal stability. The author explained that it is due their planar polymeric backbone structure which was formed due to the noncovalent intra and interchain hydrogen bonds. Dipole interactions lead to highly ordered film morphologies, low lying

HOMO level, balanced mobilities of the electron and hole[26].

Jingbi You *et al.* in 2014 found that introduction of electronegative atom like fluoro on acceptor unit is an effective way to increase the PCE. In their tandem solar cell by using fluoro unit (Figure 3) PCE was improved upto 10.6%. They discussed that compared to single layer, multilayer solar cell (Tandem cell) is an effective way to increase the PCE, introduction of two electron withdrawing units on acceptor lowers the HOMO level and insertion of alkoxy group on donor unit lowers the bandgap[27].

Low bandgap and deep HOMO level were the main criteria for polymer solar cell to get high efficiency. Such structural modifications may lead to high PCE for polymer solar cell and can be incorporated for new electron donor and electron acceptor units in future[28,29].

## 2.0 Donor-Acceptor Conjugated Organic Polymers

Conjugated organic polymeric backbone mainly consists of electron-donating and electron-withdrawing units in alternate position[30]. Excellence performance was observed for conjugated small molecules[31]. For the development of conjugated polymer for solar cell device mainly there are three phases[32]. In first phase, researchers used chlorinated solvents to tune the active layer morphologies, resulting low HOMO energy level values, high open circuit voltage. But adverse effect of wide bandgap enhanced the short circuit current density of synthesized polymer[33]. This limitation can be overcome in second phase by increasing π-stacking and crystallinity of the polymers which yielded high hole mobility, low bandgap with high short circuit current density. Active layer morphology of the designed polymer can be optimized by thermal or solvent annealing[34]. In phase three, to get high PCE, and to increase the parameters like fill factor, $V_{oc}$, and $J_{sc}$ various structural modifications has been done[35]. Structural modifications like donor acceptor combination and proper tuning of energy levels enhances the efficiency of organic solar cells.

Many scholars focused on to improve the PCE by various combinations of D and A Donor (D) and acceptor (A) copolymers with good power conversion efficiency

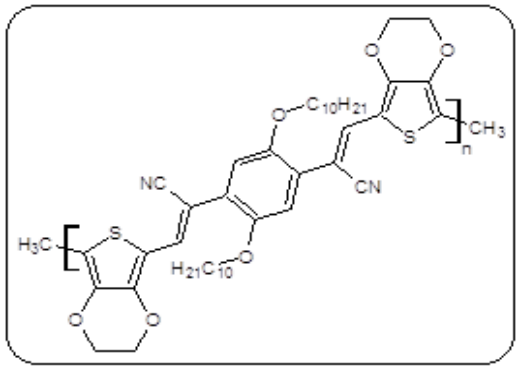



**Figure 4.** Structure of low bnadgap polymer synthesized by chemical oxidation of monomer.

(where normally PCE > 5%). For this they tried different combinations like strong donor-strong acceptor, strong donor – medium acceptor and medium donor strong acceptor for solar cell applications[36].

The most effective combination, out of several possible combinations, is Medium Donor - Strong Acceptor. Combination of Weak Donor-Weak Acceptor[37], Medium Donor-Weak Acceptor[38] and Weak Donor-Medium Acceptor[39] generally results in large band gap due to poor orbital mixing between D-A[40]. This results in poor power conversion efficiency (PCE<5%). Globally new electron acceptor and donor molecules are explored from different research groups to increase the charge transport performance beyond the current level[41].

Many research groups are working on conjugated polymers for Photovoltaic cells. Conjugated polymers based on bis(1-cyano-2-thienylvinylene) phenylene were prepared with thiophene derivatives as donor and cyanovinylene linker as acceptor by Colladet, K *et al.*[42]

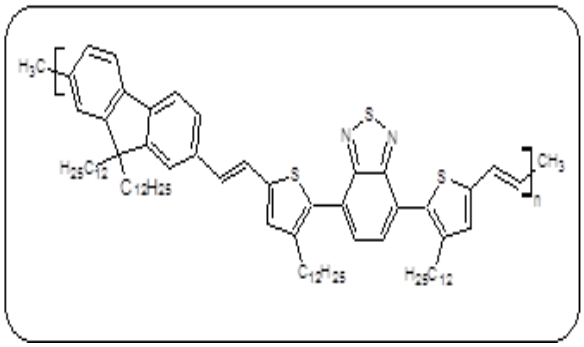



**Figure 5.** Vinylene linked polymer exhibiting PCE 1.42%.

in 2007 (Figure 4). bis(1-cyano-2-thienylvinylene) phenylene base structured conjugated polymer prepared by chemical oxidation of thiophene based monomers, exhibited low bandgap (1.6-2.0eV). Fine-tuning of electronic and solubility properties by changing thiophene unit in the donor segment and aryl unit with cyanogroup as a strong electron withdrawing group[43].

Donor-acceptor combination of vinylene linked fluorene and cyclopentadithiophene with benzothiadiazole copolymers were synthesized by Ko *et al.*[44] In 2010 (Figure 5) by Suzuki coupling followed by stille coupling in which fluorine coupled benzothiadazole polymer exhibited power conversion efficiency up to 1.42% due to its high hole mobility.

Low bandgap polymers to improve the PCE of polymer solar cells were synthesiszed using stille cross coupling of benzothiadazole with fuorene and cyclopentadithiophene by Lee *et al.*[45] in 2012 with π- conjugated system which increased photon absorption by extending the spectral sensitivity. Synthesized polymers showed low bandgap (1.6eV). D-A based series of copolymers in combination with thienyl substituted benzo[1,2-b:4,5-b′]dithiophene (BDTT) as donor and electron-deficient pyrrolo[3,4-c] pyrrole-1,4-dione(DPP) were synthesized by Kang *et al.*[46] in 2016 were synthesized by Suzuki and stille condensation with different compositions and covered

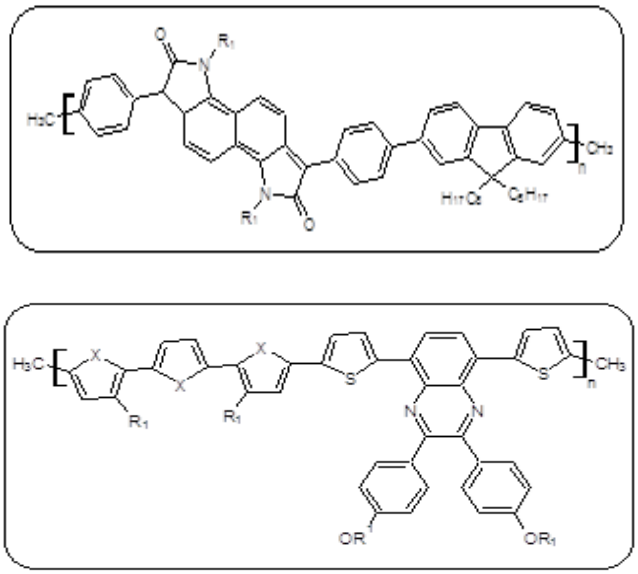


**Figure 6.** Structure of low bandgap polymers with different acceptor units.

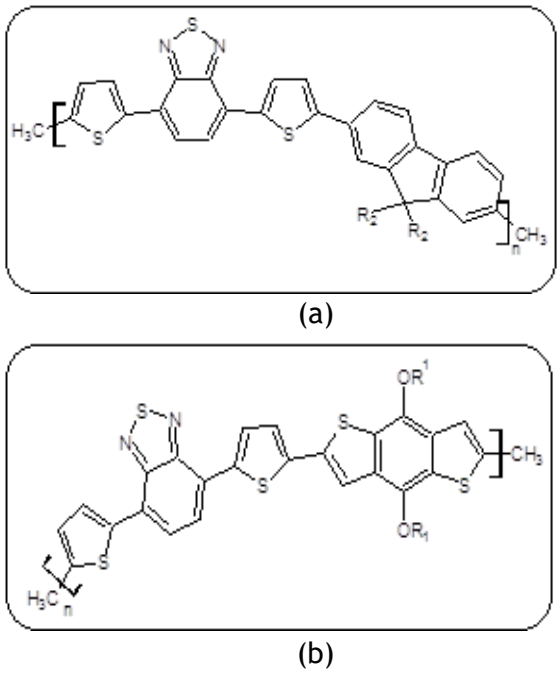



**Figure 7.** **(a)** Stuctrure of polymers with π-bridge between donor and acceptor units. (**b)** Stuctrure of polymers with π-bridge between donor and acceptor units.

light absorption over a broad range (400-900) nm, PCE of 5.63% and properties were optimized by proper controlling over D-A combination which increased the photovoltaic performances.1,6-naphthodipyrrolodinone based donor acceptor copolymers were prepared by Zhang[47] in 2015 by Suzuki followed by stille coupling and exhibited broad UV/Vis absorption(400-850nm) with bandgap(1.27-1.47eV). The additional benzene rings of 1,6-naphthodipyrrolodinone enlarge the π-conjugated system and also lead to bathochromic shift of UV/Vis absorption (Figure 6).

By insertion of π-bridge between electron donor and acceptor units, Kim *et al.*[48], successfully improved the PCE to 10%. They synthesized series of polymers (Figure 7 (a, b)). All the synthesized polymers exhibited low bandgap. This results from an increase in-conjugation length and polymer backbones. Concept of π-bridge enhanced the light harvesting property of polymer[49] and also showed HOMO and LUMO energy levels that are appropriate for solar applications. Author concluded that D-A based polymers exhibited 10% higher power conversion efficiency with π-bridge due to enhanced light harvesting ability and excellence nanoscale architecture.

A new technique, i.e., donor-acceptor-acceptor(D-A-A) was developed by Dang *et al.*[50] to improve the PCE of polymer solar cell. They synthesized two polymers PBDT-DTQ and PIDT-DTQ terpolymers using benzodithiophene (BDT) and indacenodithiophene (IDT) in D-A-A fashion. Polymers exhibited broader absorption covering from 300 to 800 nm with low band gap better than alternate A-D type polymers. Author concluded that comparative to PBDT-DTQ, PIDT-DTQ polymer exhibited deeper HOMO energy level, higher charge carrier mobility and PCE 6.41% whereas PCE of PBDT-DTQ was 3.84%.

Jiang *et al.*[51] in 2016 worked and reported on isoindigo [7,6-g]isoindigo ([3E,8E]-3,8-bis(2-oxoindo-lin-3-ylidene)-6,8-dihydroindolo [7,6-g] indole-7(1H,3H)-dione, DIID) as Acceptor -unit and thiophene derivatives as Donor units by Stille polycondensation. The synthesized molecules showed broader absorption spectra (covering 400–950 nm) with a band gap of 1.3 ev, which is good compared to isoindigo-based molecules (Figure 8).

Jeong[52] and his group in 2016 showed that combination of 6-(2-thienyl) -4H-thieno[3,2-b] indole as donating unit and 2,2-dimethyl-2H-benzimidazole as withdrawing unit in polymer (Figure 9). The insertion of alkyl chain for synthesized molecule exhibited good solubility, broad absorption spectra in UV-Vis range, low band gap of 1.57 ev, high hole mobility that led to high $J_{sc}$ value. Further solubility of polymers can be increased by insertion of

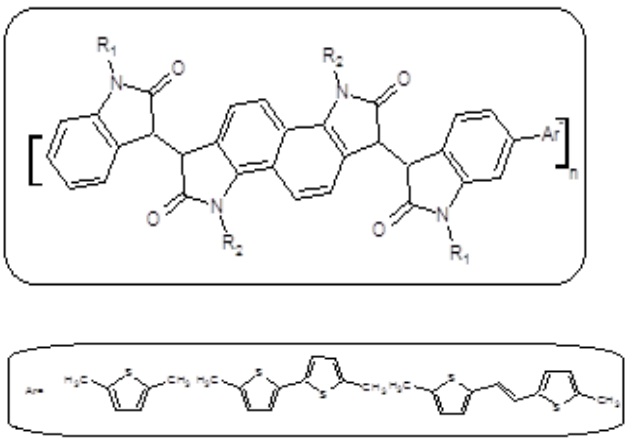


**Figure 8.** Stucture of isoindigo based polymers.

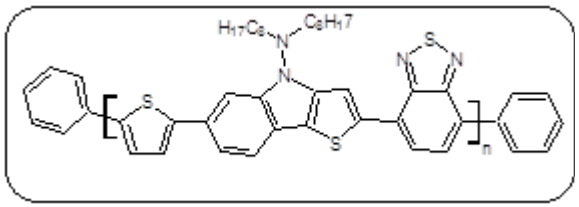


**Figure 9.** Structure of polymer exhibiting bandgap 1.57eV.

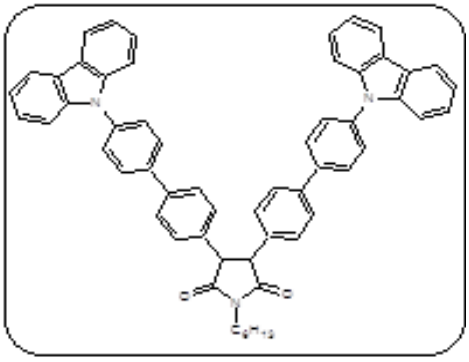


**Figure 10.** Structure of polymer with (D-π-A-π-D) structure.

long alkyl chain plays an important role to increase the solubility of the polymer.

Wang and research group[53] synthesized fluorinated polymer PDTPT-2TF. Synthesiszed polymer showed enhanced intermolecular interaction, increase in absorption coefficient, down shift towards longer wave length when compared to a polymer PDTPT-2T which is without fluorine. The author also concluded that developed polymer PDTPT-2TF exhibited low lying HOMO and LUMO energy levels. Reported PCE of PDTPT-2TF polymer was 8.01% whereas for PDTPT-2T polymer it was only 2.65%.

Sharma and his research group[54] working on highly fluorescent material 3,4-bis(40-(9H-carbazol-9-yl)-[1,10-biphenyl]-4-yl)-1-hexyl-1H-pyrrole-2,5-dione (Cbz-MI) based on donor- π -acceptor- π -donor (D-π-A-π-D) backbone (Figure 10). They analysed several donor and acceptor molecules such as carbazole as donor, phenyl as p-conjugated spacer and maleimide as an acceptor. Synthesized molecules were examined for their photophysical properties. They displayed high photoluminescence quantum yield of 0.84 in solution and in doped matrix 0.72.

Li and co-workers[55] worked on Diketopyrrolopyrrole (DPP) molecule to attain high PCE 9% in single layer and 11% in multilayer. For this purpose, DPP was coupled with different donating groups mainly with substituents of thiophene as well as by variable alkyl chain. Their research work was focussed to increase external quantum efficiency (EQE). Li, W group considered three parameters: increase in dielectric constant of polymer, removal of impurities in the polymer and control over molecular weight and polydispersity. Chen and his group[56] synthesized DPP coupled oligothiophene-Fullerene triads are reported to have good solubility in most common organic solvents. Polymers showed broad absorption in the UV-visible range 250-800nm. In results they notified that the chain length of alkyl linker has prominent effect on electronic properties and device characteristics. [6,6]-phenyl-$C6_1$-butyric acid methyl ester (PCBM) plays an important role in enhancing the PCE of polymers by its contribution in light harvesting and charge transport. So, blending new polymer with PCBM is a good method to improve the PCE[57].

PCE of 14.6% was achieved by Yao *et al.*[58] in 2019 for synthesis of polymer containing PTO2 as donor and norfullerene acceptor in a single junction solar cell. PTO2:IT-4F based device showed high charge generation efficiency compared to PTO2:$PC_{71}BM$. Introduction of fluorine contribute in the separation of excitons and down shifted molecular energy levels. Same was reported by Cui and his research group[59]. They synthesized a polymer by using PBDB-TF as donor and BTP-4F as acceptor by replacement with BTP-4Cl. Developed polymer gave 16.5% PCE and increases the open circuit voltage. Sun *et al.*[60] in 2019 modified thiophene by introducing fluorine and ester group on β- position which down-shifted the HOMO and lead to high PCE i.e. 16.4%.

Yu *et al.*[61] in 2019 used solid additives, electron withdrawing groups, non-fullerene acceptors to improve the π-π interaction and to enhance the PCE. Volatility is a key factor for designing solid additives to improve the efficiency because incomplete volatilization with residue lead to negative effect on morphology resulting in poor efficiency. By casting a film on a heated substrate, which improves light absorption at long wavelengths and exciton dissociation, molecular order control or molecular organization time can also improve PCE of polymers[62].

In 2019, Guo and his group[63] synthesized polymer based on boron dipyrromethene as donor and naphthalene diimide as acceptor. They introduced methyl substitution on α-position of donor unit. Author and his co-workers found that effect of methyl group has its remarkable effect on the optoelectronic properties of polymers. Methyl substituted polymers exhibited high PCE compared to non-substituted methyl polymer. Not only methyl group, but methoxy group also has a major role in increasing optoelectronic properties of polymer. β-substituted homopolymer and copolymers of DPP showed reduction in bandgap and red shift towards near-infrared region[64].

Designing and synthesis of acceptor is a complicated task. Mikie and Osaka[65] in 2019 synthesized an ester functionalised polymer with Naphthobispyrazine as an acceptor which reported 6% of PCE and polymer showed 1.5eV narrow optical bandgap. This was achieved along with introduction of side chain to attain high solubility of the material[66]. Thermal annealing of materials leads to efficient charge generation from donors by making the longer exciton diffusion length and produce electric current hence PCE of solar cells increased[67].

Yoon and his group[68] in 2016 synthesized bis lactum unit 3,7-dithiophen-2-yl-1,5-dialkyl-1,5-naphthyridine-2,6- dione (NTDT) as acceptor coupled with benzo [1,2- b:4,5-b′]dithiophene (BDT) as donor. The synthesized polymer showed 8.16% PCE and high short circuit current 18.51mA $cm^{-2}$ among BDT based polymers.

Low bandgap can be attained by various parameters: Incorporating different aromatic linkers in the polymer backbone, energy levels can be finetuned[69]. Inserting π-bridge also an efficient method and its selection of π-bridge is a crucial task as it playing a major role in determining the optical absorption, hole mobility, molecular levels of PSC's[70]. Role of interface layer in OSC is complex and can be varied to improve the performance[71]. Replacing fullerene by non-fullerene derivative is a powerful alternative technique to achieve high PCE[72,73].

In 2016, Gautam[74] and his group synthesized 1,8-naphthalimide based small molecule in D-A-A pattern coupled with tetracyanobutadiene and dicyanoquino-dimethane. Both polymers showed 4.94% and 6.11% PCE. These results are helpful for designing non-fullerene-based acceptor for OSC's. Same year porphyrin

based small molecules were synthesized in A-D-A pattern showed considerable PCE of 7.70% in a conventional device. It was due to their strong intermolecular π-π stacking and high charge transfer mobility[75]. Fullerene crystallisation using relatively pure fullerene is a driving force to separate photogenerated electrons and holes[76]. *N*-alkyl 2-pyridone dithiophene (PDT) unit blended with $PC_{71}BM$ showed 5.33% PCE and is a promising candidate in PSC devices. Due to their wide bandgap 2.0eV, the synthesized polymers were thermally stable upto 450°C and has strong correalation between π-π stacking[77]. For narrow bandgap many parameters are responsible in which orientation of the polymer is also a crucial factor[78].

Yang and his group worked[79] on non-fullerene derivatives by cross linking donors to increase the efficiency and durability of organic solar cells. Conjugated polymers can be designed by considering three factors like conjugated backbone, side chain and substituents. By these parameters, efficiency of PSCs can be improved[80]. Compared to (x-DAD) n, (x-DADAD) n polymer showed good solubility and low bandgap. Alexander V and group synthesized copolymers of benzothiadiazole and carbabole with thiophene as a π-linker. (x-DADAD) n polymer showed good charge transport properties, increased energy levels and reduction in bandgap due to bithiophene unit which has its strong effect on neighbouring benzodithiazole moiety[81]. The existence of thieno(3,4-b) thiophene increases the absorption towards longer wavelength and is a promising donor. This can be coupled with new acceptors for attaining high efficiency in PSC's[82].

Compared to toxic halogenated solvents, halogen free solvents were eco-friendly[83]. By proper solvent selection and material design strategy, it is easy to attain high efficiency up to 4-5%. Hole and electron transporting materials are blended and their mixing behavior plays a major role in influencing the functioning of PSC's[84]. Extensive solubility has been obtained by attaching the four side chains on same side of pentacyclic dithienosilolothiophene. A new polymer synthesized by Bob C Schroeder and his team. The molecule showed low bandgap and failed to give high PCE[85]. Use of fullerene derivatives in PSC may lead to difficulty in modulation of energy levels and this can be overcome by non-fullerene molecules as acceptors in PSC's[86].

Non–fullerene material as acceptors were the materials to get high open circuit voltage in organic solar cells. Different donors were blended with non-fullerene like fluorinated thiophene fused benzotriazole to get high $V_{oc}$[87].

## 3.0 Recent/Current Research Focus

Wang and his group[88] in 2020 suggest that for fabrication of ternary solar cells, dye molecules can be used as a third component to compensate many negative aspects of solar cells such charge transfer, exciton dissociation, and photon harvesting. Two novel low bandgap thiazolothiazole based copolymers were synthesized which showed 60-70% of initial efficiency in outdoor test. The polymers look promising and useful to improve the efficiency by various other methods[89]. Another limitation of organic PSC is low conductivity of PEDOT: PSS due to its acidic nature. For increasing the efficiency, a new effective strategy has been adapted by Sai Jiang and his team. They replaced the methyl group in the π-bridge by chlorine and noted that the planarity and rigidity of π-conjugated backbone was improved[90]. Water rinsing of PEDOT: PSS films in a conventional device before fabrication will increase the efficiency. This simple method by Li and team[91] showed the increase in the efficiency from 15.98% to 16.75%[92]. The charge transport mobility was also enhanced by introduction of S…Cl as noncovalent conventional lock[93]. A new energetic molecule indandione as a donor was synthesized by using benzoyl chloride and malonyl chloride. The molecule was polymerized by D-π-A pattern and its photophysical, electronic properties were studied. The polymer exhibited bandgap 1.98eV. Here π-bridge enhanced the molecular packing and charge transport[94,95]. Nowadays synthesis of non-fullerene derivatives has become a trend to improve the efficiency. These non-fullerene derivatives were blended with donor and one acceptor in the pattern of A1-A2-D-A2-A1. The polymer showed high Voc and good planarity[96].

Interconnecting layer in tandem solar cell possesses good characteristics as it enhances the PCE of solar cells. Fullerene/non fullerene mixed acceptor in implemented as it enhanced the charge transport, separation and the morphology of active layer[97].

Nazim and his team[98] used an active layer of 1,8-diiodooctane as an additive to isatin core moiety which exhibited a promising PCE 4.10%. Use of additive also tuned the optoelectronic properties. It also improved the morphology of active layer. PCE of 13.2% was achieved by introducing poly(9,9-bis(3'-(N,N-dimethyl)-N-ethylammoniumpropyl-2,7-fluorene)-alt-2,7-(9,9-dioctylfluorene))dibromide(PFN-Br). This improved the interfacial contact in between the active layer and ZnO as electron transport layer[99,100]. Addition of third component in ternary OSC can broaden the absorption spectrum and fine tune the bend morphology. The ternary OSC with fullerene and nonfullerene blended with donor reported a PCE of 8.11%. Addition of third component promotes the charge transport properties One more strategy to improve the photovoltaic performance was to use the fused ring central core and end capping group engineering[101].

Printing technique in ambient temperature to fabricate the PSC's is an alternative technique to spin coating for achieving high performance in OSC's[102]. In inverted OSC's, ZnO will be used as electron extraction layer. Replacement of this ZnO by polyethylenimine has increased the photo stability of active layer[103]. Annealing effect was studied for PffBT4T-2OD: $PC_{71}BM$ based organic solar cell up to 140°C. It was found that most efficient exciton dissociation and charge transfer takes place for device annealed at 80°C. Annealed devices will reduce the energetic disorder in comparison with fresh devices[104,105]. Yuriy N Luponosov *et al.,* reported acridine based D-A molecule appearing likestar shape obtained by fused derivative of triphenylamine. They synthesized the molecule with π- linker as terthiophene and PCE of 6.14% was attained. The molecule exhibits good solubility and excellent crystallinity and can be a promising candidate for organic photovoltaics[106,107].

## 4.0 Conclusion

Semiconducting conjugated polymers showed remarkable progress in achieving high efficiency of PSC's. The D-A combination of organic solar cell has their control over morphology of polymer blends to get excellent optoelectronic properties. The bandgap can be lowered by extending the π-conjugation of conjugated polymers by the introduction of aromatic hydrocarbon, heterocyclic compounds in chain backbone the side chain. This gives chain planarity and improvement in crystallinity which enhances the charge carrier mobility. Without affecting the other parameters like bandgap, charge carrier mobility, etc. lowering of HOMO level can be done by introducing electron withdrawing substituents such as halogen atom such as fluorine, sulfonyl, imine or carbonitrile functionalities. Though there is lot of scope for organic conducting polymers in the application of photovoltaic cell, silicon based inorganic photovoltaic cells are still popular due to their efficiency. Currently 21% of efficiency is achieved for the silicon based inorganic photovoltaic cells whereas maximum 10% efficiency is reported for the organic photovoltaic cell. However, the economic aspects of organic photovoltaics and their ease of fabrication have made them strong candidates for solar cell applications. But these organic PSC's still have low efficiency and shorter lifetime. Thus, it is very important to enhance their PCE and stability of the device. To achieve high PCE, extensive research must be carried to reduce band gap and long range of absorption capacity of the polymers. Small organic molecules can be constructed and synthesized through geometrical combinations with D-A units. Further exploration of change in morphology and advanced device concepts may lead to exceed the PCE of solar cells. Lifetime of OPV's can be enhanced by State of art photovoltaic technology. Tuning of energy levels *i.e* HOMO & LUMO was done carefully to minimize the adverse effect. Photovoltaic performance was further improved by developing new electron acceptor as an alternative to PCBM.

However, there is no doubt that polymer based organic solar cells are feasible option but over a time period their degradation should not be a serious concern. Still there are many challenges in this field, including low cost of production, pre-eminent infrastructure, stability of device and awareness. At present the solar energy is regarded as the best alternate source of renewable energy and a promising future for sustainable energy materials that can be used for various applications. The combination of thiophene-based donor-acceptor copolymers and suitable metal electrodes constitutes the key components of OPV devices, with ongoing research aimed at optimizing their properties and performance for commercial viability in renewable energy applications.

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