Review Article

Review on Optical and Electrical Properties of Conducting Polymers

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We reviewed optical and electrical properties of conjugated polymers. The charge transport models to describe the hole and electron transport mechanism are also included in the electrical properties of conjugated polymers. The effect of optical and electrical properties after doping is also indexed in this paper.

1. Introduction

It is well known that conjugated polymers (CPs) are the most promising candidate among the organic semiconductor world due to their easy processing, color tenability, and so forth. The devices based on structure CPs are composed of very simple structure, that is, an emissive polymer sandwiched between low work function cathode and high work function anode. Since most of CPs shows trap-limited electron transport, polymer LED device is hole dominated system, hence causing the polymer diode degrades. So to fabricate a highly efficient polymer based LED device, it is necessary to achieve balanced electron as well as hole transport. To achieve a balanced electron and hole transport we have incorporated the concept of doping. The concept of doping has been first developed for organic small molecules [1, 2]. Thin films of these small molecules are deposited by thermal evaporation. A dopant molecule is then coevaporated with the host from another source. In this way, a homogeneous distribution of the doping in the host is achieved. However, conjugated polymers (CPs) are deposited from solution method [3]. Adding a dopant to the solution easily leads to charge transfer and aggregation already in the solution, making processing of thin films from such a solution

impossible. Hence in this paper we have reviewed the optical as well as electronic properties of conducting polymers and it is also shown how the optical and electronic properties have been changed via charge transfer occurred from doping.

2. Optical Properties of Conjugated Polymers

2.1. Optical Absorption: Formation of Excited States. In small molecule containing an isolated double bond, a pi electron can be promoted from the lower energy state to the highest energy state by the absorption of photon with energy greater than the energy gap (Eg) between the two orbitals. However, a similar molecule containing conjugated double bonds will have a highest occupied molecular orbital (HOMO) higher in energy and a lowest unoccupied molecular orbital (LUMO) lower in energy. Since the orbital interactions resulted in a decreased energy gap, a lower energy photon can promote a pi electron from HOMO to LUMO; therefore, in conjugated polymers, the energy gap Eg can be even smaller.

2.2. Optical Emission: Relaxation of Excited States. When a sufficiently energetic photon ($h\nu$) is absorbed by a semiconducting polymer, an electron can be promoted from HOMO to LUMO and produces an electrostatically bounded
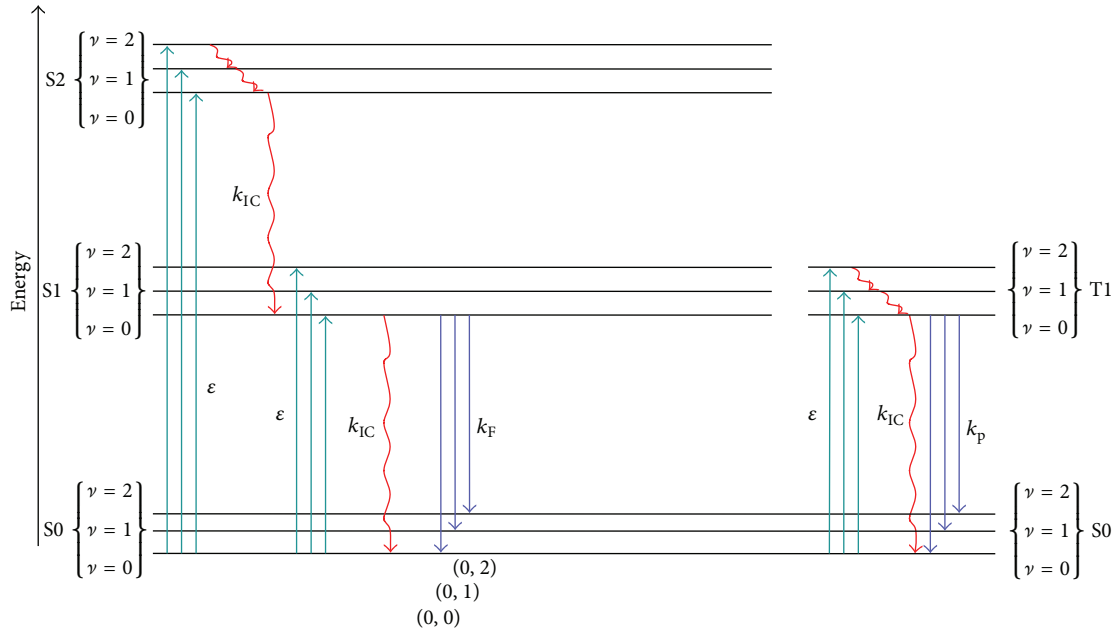
FIGURE 1: State energy diagram of some possible photophysical process in a typical fluorescent molecule.

electron-hole pair, called exciton [4, 5]. This excited state species can migrate from one location to another until it relaxes by some deactivation process. One of the most useful deactivation processes in conjugated polymers is lumines-cence (light emission). Luminescence is classified into two categories: fluorescence and phosphorescence, depending upon the spins of the electron involved in radiative transitions and shown in Figure 1.

If the electrons in the excited states have the same spin with electron in the corresponding ground state orbital, the emission of light is called phosphorescence. If the excited electron has the opposite spin as the electron in the corre-sponding ground orbital, the emission is called fluorescence. Phosphorescence involves an electronic transition from a triplet excited state with unpaired electron spin to a singlet ground state with paired electron spin. This transition is formally forbidden by quantum mechanical selection rule; it occurs at a much slower rate than fluorescence which involves an allowed transition between a singlet excited state to a singlet ground state [5]. There are many other photophysical processes that occur in electronic excited states and these can be illustrated in a state energy diagram or Jablonski diagram as shown in Figure 1. The singlet ground states are defined as S0 and first and second excited states are denoted as S1 and S2, respectively. The first triplet excited state is denoted as T1. Each of these electronic energy levels contains its own vibrational energy; $v = 0, 1, 2$, and so forth. Absorption of an energetic photon typically excites an electron from S0 to S1 or S2. Usually, excited electronic rapid relax by internal conversion to the lowest vibration level of S1. At this excited state (S1, $v = 0, 1, 2$, etc.), the singlet exciton exists long enough to migrate over significant distances in a conjugated polymer. Eventually, the excited electron returns to its ground state followed by fluorescence. Fluorescence

involves electronic transitions from the lowest vibrational level ($v = 0$) of S1 to the vibrational level ($v = 0, 1, 2$) of the electronic ground state (S0) and these radiative transitions are denoted as $(0, 0)$, $(0, 1)$, $(0, 2)$, and so forth.

3. Electrical Properties of Conjugated Polymers

The concept of band conduction by free electrons or holes is no more applied to describe the transport processes in conjugated polymers, as these are strongly disordered system. In order to make participation in transport, charge carriers need to hop from site to site in broad energy landscape. The hopping probability between occupied i to unoccupied j states depends upon energy difference Δ_{ij} between the two states i and j and relative distance between corresponding two states R_{ij}. The probability of hopping transition is given by [5]

$$\nu_{\text{hop}} \alpha \exp\left\{-2\gamma a \frac{R_{ij}}{a}\right\}. \tag{1}$$

This makes it possible by electric field term. Now the temperature dependence of mobility is given by [6]

$$\mu = \mu_0 \exp\left\{-\left(\frac{T_0}{T}\right)^\gamma\right\}. \tag{2}$$

γ represents the field enhancement factor which reflects the fact that upon increasing temperature conductivity arises with increase in available states.

3.1. Hole Transport in Conjugated Polymers. In order to investigate the hole mobility the device consists of a single-polymer layer sandwiched between two electrodes (one hole

injecting contact and one electron blocking contact). In this study Au is used as electron blocking contact. Generally current in polymer based hole only (HO) diodes is space charge limited (SCL) and current density is characterized by Child's law [7, 8]:

$$J = \frac{9}{8} \mu_p \varepsilon_r \varepsilon_0 \frac{V^2}{L^3}, \qquad (3)$$

where $\varepsilon_0 \varepsilon_r$ is the permittivity of the material, L is the film thickness, and μ_p is zero-field hole mobility which obeys the following temperature and field dependence, the thing that will be discussed in the next section.

3.2. Charge Transport Models to Describe Hole Transport in Conjugated Polymers. Conjugated polymeric systems are not perfect systems because of chemical defects, kinks, twists, and finally conjugation breaks. Hence, band-to-band transport is not valid so far and charge transport is governed by hopping process. It is difficult to reveal the charge transport in inorganic semiconductors. Up till now there is no uniform way, and many models have been designed to describe the mobility. In most of the models the mobility is found to be dependent on charge carrier density, electric field, and temperature. Few of the models related to our work are described below.

3.2.1. Field and Temperature Dependence of Hole Mobility. Initially at lower fields, hole transport in conjugated polymers is well described by SCL currents. However, at higher fields, current density normally shows an unusual behavior due to an increase in hole mobility. This suggests that carrier mobility increases with electric field and this behavior has been explained accurately within a space charge limited conduction (SCLC) model taking into account a stretched exponential field dependence of mobility [9]:

$$J = q\mu_p(0,T)\, p(x)\, E(x),$$

$$p(x) = \frac{\varepsilon \varepsilon_0}{q} \frac{dE(x)}{dx},$$

$$\mu_p(E,T) = \mu_p(0,T) \exp\left(\gamma \sqrt{E}\right), \qquad (4)$$

$$\text{where } \mu_p(0,T) = \mu_{P0} \exp\left(-\frac{\Delta_0}{K_B T}\right),$$

where μ_{P0} is the electric field and temperature independent hole mobility, Δ_0 is the zero-field activation energy, K_B is Boltzmann's constant, T is the temperature of the sample, and γ is field enhancement factor. Equation (4) is used to describe the charge transport in a variety of semiconducting polymers [10]; however it lacks theoretical justification.

3.2.2. The Gaussian Disorder Model and the Correlated Disorder Model. Bässler proposed that the energy level (LUMO and HOMO) of the polymer can be approximated using a

Gaussian distribution [11]. Under this Gaussian distribution approximation, the density of states (DOS) is given by

$$\text{DOS}_{\text{Gaussian}} = \frac{N}{\sqrt{2\pi}\sigma_{\text{DOS}}} \exp\left(-\frac{E^2}{2\sigma_{\text{DOS}}{}^2}\right), \qquad (5)$$

where N is the total density of states, σ_{DOS} is the width of the Gaussian density of states, and E is measured relative to the center of the DOS.

The GDM model describes the carrier transport as a biased random walk among the hopping sites with Gaussian distributed random site energies. GDM predicted T and F dependence of charge carrier mobility to be [12]

$$\mu(F,T) = \mu_0 \exp\left[-\left(\frac{2\sigma}{3k_B T}\right)^2\right]$$
$$\cdot \exp\left[C_0 \left\{\left(\frac{\sigma}{k_B T}\right)^2 - \Sigma^2\right\} \sqrt{E}\right], \qquad (6)$$

where σ and Σ are energetic disorder and positional disorder, respectively, and C_0 is the constant. However GDM model reproduced the PF-like field dependence of mobility over only a relatively narrow range of electric field strengths. This has led to believing that UGDM did not model disorder behavior in disorder molecular organic system completely. Recent calculations and simulations demonstrated that the presence of long range energy correlation gives rise to Poole Frenkel- (PF-) like mobility over a much broader field range. Gartstein and Conwell resolved this discrepancy of field dependence between GDM and the experimental results by introducing a correlation between the energies of spatially close sites with an empirical relation [13]. This spatial correlation of energies included in correlated Gaussian disorder model (CGDM) can be justified to arise from long range energy correlation from the charge dipole interaction or correlation in thermal fluctuation in molecular geometries [12]:

$$\mu(F,T) = \mu_0 \exp\left[-\left(\frac{3\sigma}{5k_B T}\right)^2\right]$$
$$\cdot \exp\left[C_0 \left\{\left(\frac{\sigma}{k_B T}\right)^{3/2} - \Gamma^2\right\} \sqrt{\frac{eaE}{\sigma}}\right], \qquad (7)$$

where C_0 and Γ are the parameters of the model, Γ characterizes the geometrical disorder, and a is the intersite hopping distance. Poplavskyy and Nelson explained the hole transport in the organic small molecule material 2,2′,7,7′-tetrakis-(N,N-di-4-methoxyphenylamino)-9,9′-spirobifluorene(methoxy-spiro) [14] using GDM. In the recent study, Redecker et al. also described the hole transport behavior using GDM in blue and white polymers [15].

3.2.3. Pasveer's Model. Further, researchers have realized that one another important factor is overestimated which also affected the carrier mobility which is carrier density. If we ignore carrier density dependence, it will lead to an underestimation of the hopping distance and the width of

the density of states in these polymers. Therefore, Pasveer et al. proposed a density dependent mobility model in combination with electric field and temperature in the form of the extended Gaussian disorder model (EGDM) [16]. In this model, they approached mobility dependence on electric field and charge carrier density that are factored in field and density enhancement functions:

$$\mu_p(T, p) = \mu_0 \exp\left[\frac{1}{2}\left(\hat{\sigma}^2 - \hat{\sigma}\right)\left(2pa^3\right)^\delta\right],$$

$$\text{where } \mu_0 = \frac{a^2\nu_0 e}{\sigma},$$

$$\mu_p(T, p, E) \approx \mu_p(T, p) f(T, E),$$

$$\delta = 2\frac{\ln\left(\hat{\sigma}^2 - \hat{\sigma}\right) - \ln\left(\ln 4\right)}{\hat{\sigma}^2}, \qquad (8)$$

$$f(T, E) = \exp\left\{0.44\left(\hat{\sigma}^{3/2} - 0.22\right)\right.$$

$$\left.\cdot\left[\sqrt{1 + 0.8\left(\frac{Eea}{\sigma}\right)^2} - 1\right]\right\},$$

where $\hat{\sigma} = \sigma/K_BT$.

The attractiveness of EGDM is that it includes both the density and field dependence of the mobility. Additionally it requires only three (temperature independent) parameters, greatly facilitating the fitting of experimental data. Several reports are available to describe the charge transport in such type of materials using this model [17–20]. Zhang et al. described the hole transport in poly[(9,9-di-n-octylfluorenyl-2,7-diyl)-alt-(benzo[2, 1, 3]thiadiazol-4,8-diyl)] (F8BT) by making an Ohmic hole contact on F8BT by using the high work function anode MoO$_3$ as hole injection contact [20].

4. Electron Transport in Conjugated Polymers

In the previous section, an overview on hole transport in conducting polymers has been discussed. However, electron transports are investigated by characterizing an electron only (EO) diode consisting of a polymer layer sandwiched between two low work function electrodes. In most of the PPV derivatives, Malevich observed that the electron current shows a strong field and thickness dependence and also the electron current is small compared to hole current that it is characterized by a stronger voltage and thickness dependence [7]. This is the characteristic of trap-limited conduction, where charge carriers are trapped in localized states within the band gap. An analytical description for the trap-limited conduction in the presence of a discrete trap level was obtained by Lampert and Mark [9]. They proposed a trap-limited conduction model where the current density has the same dependence as the trap-free SCL current, only increased

by a factor θ, and the density of trapped electrons is larger than the density of free electrons:

$$J_{\text{TLC}} = \frac{9}{8}\theta\varepsilon_r\varepsilon\mu\frac{V^2}{L^3}, \quad \text{where, } \theta = \frac{N_c}{N_t}\exp\left[-\frac{E_t}{k_BT}\right], \qquad (9)$$

where N_c is the effective density of states in the LUMO, N_t is the trap density, and E_t is the trap depth. This model is only valid only if the traps are not fully filled. But, in most of the organic semiconductors, the trap states are generally assumed to be exponentially distributed within the forbidden band gap, as obtained by Mark and Helfrich. The exponential distribution by traps is given by the distribution [21]

$$N_t(E) = \frac{N_t}{kT_t}\exp\left[\frac{E - E_c}{kT_t}\right], \qquad (10)$$

where N_t is traps density of states at energy E, E_c is energy of LUMO band, $N_t(E)$ is total density of traps, kT_t is energy characterized, and $E - E_c$ is energy below the LUMO level of the polymer. The trap distribution implies J-V characteristics in trap filled limit [22]:

$$J = q^{1-l}\mu N_\nu\left(\frac{2l + 1}{l + 1}\right)^{l+1}\left(\frac{l}{l + 1}\frac{\varepsilon_r\varepsilon_0}{H_b}\right)^l\frac{V^{l+1}}{L^{2l+1}}, \qquad (11)$$

where J is the current density, V is the applied voltage, q is the elementary charge, and L is the thickness of the material films. μ is the mobility of the material, and $F(x)$ is the electric field, N_ν is the effective density of states, H_b is the total trap density, and $\varepsilon_r\varepsilon_0$ is the permittivity of the material. In case of SCLC and $l = T_c/T$ in case of TCLC, T_c is the characteristic temperature of traps. J-V characteristics follow square law ($J\alpha V^2$) at lower bias but as the bias increases, the slope of $l + 1$ in log-log plot of J versus V curve increases from $l = 2$. Blom and Vissenberg explained the transport of electrons in a poly(dialkoxy-p-phenylene vinylene) (PPV) derivative (MEH-PPV) [10]. The experimental result was supported by trap-limited electron transport with the energy of the trapping sites described by an exponential distribution. Further, their group demonstrated that Gaussian density of states (GDOS) is the characteristic of disordered semiconductors for the mobile carriers. It reduces the temperature dependence of the trap-limited charge transport. The reduction was governed by the width of the GDOS and originates from the equilibrium concentrations of the mobile and trapped carriers [12].

4.1. The Doping Concept. It has been realized that the one important factor that affects the carrier mobility is the carrier density and it is also confirmed from the previous literatures that carrier mobility of such class of materials is very low [9, 10, 12–21]. Hence, to improve the carrier mobility, we have to increase the carrier density via doping. Doping in polymers provides the free charge carriers that leads to an enhancement of optical as well as electrical properties. The doping can be done as p-type or n-type. p-type dopant removes an electron from HOMO of polymer and increases the hole carrier density in the matrix whereas n-type doping
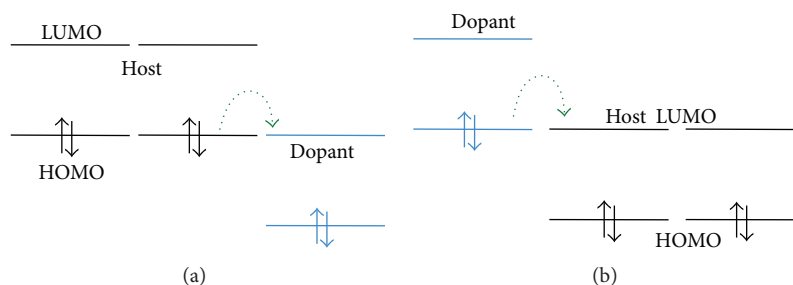
FIGURE 2: (a) Schematic representation of p-type doping mechanism. The molecular dopant acts as acceptor in p-type dopant. The energetic overlap of matrix and dopant energy levels is important. (b) Schematic drawing of n-type doping mechanism. The molecular dopant acts as donor in n-type doping. The energetic overlap of matrix and dopant energy levels is necessary.

provides electrons to the LUMO of the polymer, which leads to increase its electron carrier density [11, 23–25] and finally improves the hole and electron mobility of the concerned material. These free charge carriers are increased by the application of electric field. Thus the carrier mobility is found to be electric field and density dependent.

Concept of doping in conjugated polymer is different from that of inorganic semiconductor in which elements with efficient and deficient electrons are introduced. In polymer, doping process involves both oxidation and reduction processes [25–27]. The first method involves exposing a polymer to an oxidant such as iodine or bromine or a reluctant such as alkali metals. The second is electrochemical doping in which a polymer-coated electrode is suspended in an electrolyte solution. The polymer is insoluble in the solution that contains separate counter and reference electrodes. By applying an electric potential difference between the electrodes, counter ion from the electrolyte diffuses into the polymer in the form of electron addition (n doping) or removal (p doping), as shown in Figure 2. We have done doping in polymers followed by second method.

4.1.1. p-Type Doping. For p-type doping, it is necessary that LUMO of the dopant must match HOMO of the host to increase free carrier concentration of holes (Figure 2(a)). Organic materials like F_4-TCNQ, TCNQ, DDQ, and C60 are possible candidates for p-type doping, depending on the host material.

4.1.2. n-Type Doping. Up till now n-type doping is still a challenge. For n-type doping, the HOMO of the dopant must be adjacent to the LUMO of the host to provide more and more electrons (Figure 2(b)).

Alkali metals, organic molecules which have a high-lying HOMO, and cationic salts are best n-type dopants.

5. Review on Doping in Conjugated Polymers

The doping of p-type materials into conjugated polymers has been realized in terms of enhanced hole injection into matrix followed by the modification of the interfaces. Nollau et al. reported a case study of doping of a p-type dopant, tetrafluorotetracyanoquinodimethane (F_4-TCNQ) with conjugated

polymers of wide range of the HOMO levels [28]. They have shown that the bulk conductivity and hole current increase by several orders of magnitude with reduced turn-on voltage by the result of doping.

Zhang et al. (University of Groningen, Netherlands) addressed another approach to understand the effect of doping in organic semiconductor [29]. Since conductivity of any material is the product of carrier mobility and number of charge carriers and if we dope the materials, conductivity rise will result in a simultaneous increase of carrier concentration and carrier mobility. Generally, the carrier transport in semiconducting materials takes place via hopping between the GDOS. Consequently, if we ignore carrier density dependence, it will lead to an underestimation of the hopping distance and the width of the density of states in these polymers. Therefore, they proposed a density dependent mobility model in combination with electric field and temperature dependence.

They have discussed different cases of controlled p-type and n-type doping of poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene] (MEH-PPV) deposited from solution, with tetrafluorotetracyanoquinodimethane (F_4-TCNQ) and bis(pentamethylcyclopentadienyl)cobalt(II) (DMC) as p- and n-type dopants, respectively [29]. They have demonstrated that by choosing suitable dopant solvents and adjusting the polarity of the solution, aggregation can be prevented and doped films can be deposited with a controlled carrier density.

As the electron transport in conducting polymers is characterized by exponential distribution of traps and resultantly hole current is no longer equal to electron current, it is found that the electron transport in MEH-PPV becomes similar to hole transport by deactivation of traps. In this study, MEH-PPV was doped with the n-type dopant DMC. They have found a trap-free space-charge limited electron current in MEH-PPV, by filling the traps with electrons from the DMC donor. For p-type and n-type, doping greatly improved charge transport and Zhang et al. showed that in MEH-PPV the free-electron mobility is equal to the hole mobility [29].

The doping induced electrical properties have been reported by Zhang and Blom [20]. They have investigated the electron and hole transport in F8BT. They have first studied hole transport by resolving the injection barrier by the use of MoO_3 as a hole injection contact. Further, they have

studied the electron transport in F8BT that was found to be trap limited and these traps were then deactivated by n-type doping of DMC.

Recently, electron transport studies of cesium carbonate (Cs_2CO_3) doped tris(8-hydroxyquinolinato)aluminum (Alq3) are reported [30]. They form ohmic contact with Alq3 by the use of an electron injection layer Cs_2CO_3. Further they have studied the effect of doping of Cs_2CO_3; this leads to increase in conductivity as well as mobility.

6. Effect of Doping on Optical and Electrical Properties

As discussed in Section 6, some of the generated free charge carriers upon doping affect optical as well as electrical properties. In the following subsections a short description of effects of doping on the optical as well as electronic properties will be discussed.

7. Doping Induced Optical Properties: Exciton Quenching by Charge Transfer Centers

Arkhipov and his group proposed a theory of quenching of exciton in doped disordered semiconductors. They proposed that an exciton can dissociate into a geminate pair of charge carriers if a deep trap (usually for electrons) is located next to a molecule or segment visited by the exciton in the course of its energy relaxation. Since the spatial distribution of traps is random and does not correlate with energies of the host molecules, the probability for an exciton to encounter a charge transfer center is fully determined by the number of sites visited by this exciton. They supposed that the possibility of thermally assisted jumps of excitons to sites of higher energies is disregarded, implying that the time scale of energy relaxation is longer than the exciton lifetime unless most excitons were generated within the deep tail of EDOS [31].

After every intermolecular jump, an exciton can find itself in a molecule that has a deep (electron) trap in its close neighborhood. They supposed that the density of deep electron traps N_a and the concentration of quenchers depends upon the molecular configuration. They have considered in the analysis the exciton quenching, in which excitons are delocalized within conjugated molecular segments in the polymer. Most probably the deep traps are distributed homogeneously and the probability w_q of occupation for an exciton quencher to a deep trap has been determined by the Poisson distribution as [31]

$$w_q = 1 - \exp\left(-\pi r_q^2 l N_a\right), \tag{12}$$

where l is the conjugation length and r_q is the maximum distance between a segment and a deep trap which still allows for quenching. They have also supposed that the exciton which is already occupied by a quencher will still avoid further quenching. The probability to be certainly quenched at a quencher, W_q, is given by [31]

$$W_q = \frac{\tau_j}{\tau_q + \tau_j}, \tag{13}$$

where τ_q and τ_j are the quenching and jump times, respectively. To contribute to the photoluminescence, an exciton must avoid quenching during its entire lifetime. Estimating the exciton jump time as $\tau_j = \tau/n$ and using the Poisson distribution of probabilities yield the following expression for the probability η that an exciton is not quenched and eventually decayed radiatively [31]:

$$\eta = 1 - Q\left(\infty\right) = \left\{ \frac{n\tau_q + \tau \exp\left(-\pi r_q^2 l N_a\right)}{n\tau_q + \tau} \right\}^{n+1}. \tag{14}$$

They have shown that the radiative yield η depends upon the concentration of deep traps N_a by using (14) together with experimental data obtained on an alkoxy-substituted polyphenylenevinylene (PhPPV) doped by trinitrofluorene (TNF) [32].

7.1. Doping Induced Electrical Properties. Doping affects the electrical properties like carrier mobility, drift velocity, and so forth of the organic semiconductors. If we do p-type doping, the electron transfers directly from the host level to the dopant molecule without the intermediate step through the shallow level. Similar to the case of p doping, with n doping the electrons in the donor level can drop into the electron traps (empty defect levels) and make them inactive. Hence, hole and electron carrier density are increased upon doping and mobility ratio is also changed accordingly [20, 28, 29, 33].

The mechanism behind the enhancement of hole current upon doping can be understood in Figure 3.

As we know, in most of conducting polymers, the hole transport is governed by SCL. Upon addition of p-type doping, free holes are introduced into the polymer. At low voltages these additional free holes, often termed as background density, p_0, will largely outnumber the charges that are injected from the contacts, which are responsible for the SCLC as observed in undoped polymer. Since the positive charge of this background density p_0 is compensated by the negative charge of the corresponding acceptors and therefore does not contribute to the built-up of space charge, an Ohmic-like current will flow at low voltages [29].

It is also described in previous section that electron transport in CPs is trap-limited. When n-type doping is done into the polymer, most of the traps are deactivated and SCL current is obtained as shown in Figure 4 [33]. As it is already discussed that for n-type doping HOMO of the dopant must be adjacent to the LUMO of the host, hence the electron current is initially trap-limited. As dopant material is doped into polymer matrix, some of the trap states present in the polymer start filling approaching $E_{tc} \approx 0$ eV; it means most of the traps are filled by electron provided by donor and hence SCL current is achieved [29]. A further increase in the dopant concentration does not further enhance the electron current since the HOMO of dopant is not sufficient to add more and more free electrons to the LUMO of polymer.

8. Conclusions

In this paper, we have presented a review on the optical and electronic properties of CPs. We have reviewed the effect
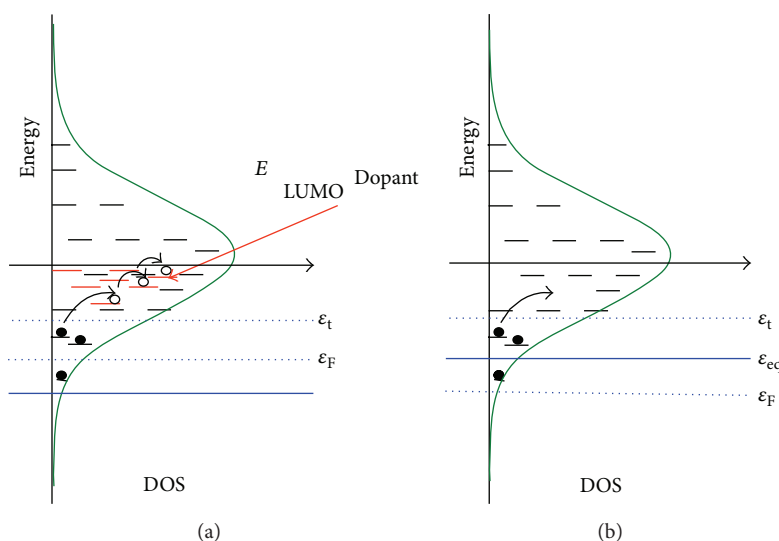
FIGURE 3: Schematic representation of the density of states and the position of Fermi levels (a) in pristine polymer and (b) polymer doped with p-type dopant. The red dashed line represents the LUMO level of dopant.
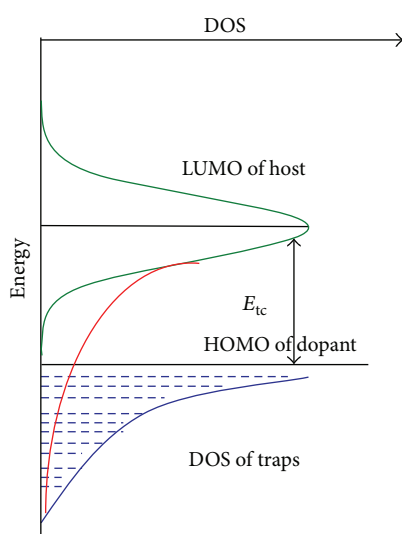

FIGURE 4: Schematic presentation of energy level alignment of Gaussian DOS LUMO.

of dopant on the optical as well as electronic properties of CPs. In essence this paper throws an adequate light on the optoelectronic properties of conducting polymers to enable us to use it with a better understanding for the development of polymer based polymer light emitting diode (PLED).

Competing Interests

The authors declare that they have no competing interests.

Acknowledgments

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