CHAPTER 1

Introduction

Presently, we are living in a scenario where electronic devices are frequently discarded in order to switch to new generation devices equipped with smarter applications despite the fact that the old device is functioning normally. Slowly but surely we are moving towards ‘use-and-throw’ electronic appliances. Consequently, it will generate a lot of electronic waste which poses a brutal threat to the environment. As far as stability and the longevity of the device is concerned, conventional inorganic materials are much better than organic/polymeric devices. In our opinion, the organic materials should not be portrayed as substitute or competitor for inorganic electronic devices but as an additional club of materials fitting into present scenario where electronic devices are often discarded quickly. In this context the cost of production and ease of manufacturing is preferred over stability and longevity. Therefore, organic and polymeric devices are receiving lot of attention recently around the world due to simplicity of manufacturing with low cost. In addition, the dumping of organic electronic waste significantly reduces the threat to environment as they are easily degradable when disposed off. The main focus of flexible polymeric devices is on wearable and disposable electronics which finds application in toys, games, sensors, body media, medical devices, outer space and high speed communication [1-7].

Organic electronics is a novel branch of electronics in which organic materials instead of conventional inorganic materials are used for manufacturing electronic devices. Moreover, it is significant to understand the history of organic electronics and how it has transformed our lives. Flexible and printed electronics are being developed to do better for advanced products and packages. During the last 30 years, many organic materials and applications have been investigated. Basically the development of
organic devices was started with the discovery of organic semiconductors. Traditionally the organic materials were considered as the poor conductor in electronics and extensively used as insulators. In 1953, Mette *et al.* described the conducting properties of anthracene crystal [8]. A comparatively good conductivity of perylene- bromide complex has been investigated by Akamatu *et al.* in 1954 [9]. In 1977, a big step was forwarded in the field of organic electronics when A. Heeger, H. Shirakawa and A. MacDiarmid discovered that the conduction is not restricted to aromatic compounds alone. They demonstrated that chemical doping of polyacetylene enhanced the electrical conductance of the polymer dramatically [10, 11]. It may be of the order of electrical conductivity of the metals. Their finding was resulted in a new class of materials offering novel applications for electronics. In the mid of 1980s, C. W. Tang and S. van Slyke demonstrated a low voltage and efficient thin film light emitting diode at Kodak [12]. It consisted of a single layer of polymer cast from solution sandwiched between two metal electrodes of different work functions. However, this first demonstration of this diode was not so efficient that it can replace the conventional technologies. It nevertheless opened the door to the possibility of using organic thin films as a foundation for a new generation of optoelectronic devices.

Recently, various types of electronic and optoelectronic devices based on organic and polymeric materials such as organic light-emitting diodes (OLEDs) [12-13], organic field-effect transistors (OFETs) [14-18], organic photovoltaic cells (OPVs) [19-48], and organic memory devices [49] have attracted considerable attention due to their low manufacturing cost, light weight, flexibility and ease of production. We may not be very far from a scenario where solar cells, charge storage devices, switching devices and organic light emitting diodes can be painted on walls, curved surfaces, car bonnet and even clothing. This has spurred the attention of researchers worldwide leading to globally enhanced research activities in the field of organic electronic devices. As organic semiconductor is the heart of organic electronic devices, we begin with the brief introduction of organic semiconductors.
1.1 Organic Semiconductors

In the last two decades, researchers have investigated the physical properties of organic semiconductors as these materials show various characteristics regards a number of applications as mentioned above in optoelectronic devices. Organic semiconductors are a key different from their inorganic counterparts.

Our daily basis life is surrounded by organic materials. From the smallest virus to the tallest giant tree, from basic amino acids to the complex human brain, from the simplest plastic foil to the highly efficient and flexible display, all these things are made up of organic compounds. Organic materials basically consist of carbon atom which has the tendency to bond to other carbon atoms leading to the organization of hexagonal and pentagonal molecules. The organic semiconductors are just the small group of an array of organic compounds. Their peculiar semiconducting behavior is attributed to the formation of so called $\pi$-orbitals, which are spatially extended, and leading to the delocalization of electrons. According to their chemical structure, organic semiconductors can generally be classified into two categories [50] as shown in figure 1.1.

![Figure 1.1: Schematic diagram of classification of organic semiconductors.](image)

Oligomers are the molecules which are formed by only a few chemical units, the monomer units. While the polymer is a macromolecule composed of many monomer units. In the reference of organic semiconductors, many means 100 repeated monomer units. Both have in common a conjugated $\pi$-electron system. Conjugated systems,
consists of alternate single and double bonds, are formed by sp\(^2\) hybridized C atoms in the molecules [51]. Every single bond contains a localized sigma (\(\sigma\)) bond and double bond contains localized pi (\(\pi\))-bond together with sigma bond. \(\pi\) bonds in the molecules are significantly weaker as compared to that of \(\sigma\) bonding. Electrons in the \(\pi\) bonds are loosely bound to the carbon nuclei. Thus they require small energy to excite across energy gap between the valence band and conduction band. Therefore, the lowest electronic excitations of conjugated molecules are the \(\pi-\pi^*\) transitions with an energy gap typically lies between 1.5 and 3eV leads to the absorption or emission of light in the visible region of spectrum [51].

Although these materials can differ significantly in chemical structure and especially in molecule size [52-53]. A major difference between the materials of these two classes lies in the way how they are processed to prepare thin films. As conjugated polymers are processed by spin coating or printing techniques (wet processes) and the small molecules are usually deposited from the gas phase by sublimation or evaporations. Moreover, the chemical and physical properties of these materials can be oriented by molecular level engineering. Since organic semiconductors have a vast range of chemical structures (size, shape), morphology, functionality, crystallinity, impurities and disorder. The physical properties of organic semiconductors show a wide variety of behavior, and often not as simple as in the case of inorganic semiconductors. Hence, in terms of materials and physical properties, these systems are quite complex and several parameters govern physical phenomena and device performances.

1.2. Energy Band gap in Conjugated Polymers

Well ordered pure materials exhibit well defined energy band structures having forbidden energy gaps and delocalized Bloch wave function states. In the conventional semiconductors, conduction band lies above on the valence band and the gap between these two energy bands is known as forbidden energy gap. We have disordered materials such as conjugated materials. Although there are some arguments about the pertinence of the band theory of conjugated polymers. The
arguments come from the fact that conjugated polymers are in general non-crystalline and flexible. Contrary to that, conjugated polymers have the electronic properties that appear to be similar to those of inorganic semiconductors.

The origin of band gap in conjugated polymers can be understood in terms of the bonding and anti-bonding of carbon-carbon double bonds. The $\pi$-bond is formed when overlapping of p-orbital occurs in adjacent $sp^2$ hybridization. The $\sigma$ and $\pi$ molecular orbital forms bonding ($\sigma$, $\pi$) if the p-atomic orbital overlaps in phase and anti-bonding ($\sigma^*$, $\pi^*$) takes place if the p-atomic orbital overlaps out of phase [54]. In these materials, electrons are delocalized from their parent atoms and form two molecular orbitals of different energies, as a highest occupied molecular orbital (HOMO, “valence band”) and a lowest unoccupied molecular orbital (LUMO , “conduction band”). The anti-bonding orbital placed higher in energy ($\pi^*$) construct the conduction band while bonding orbital lying in lower energy form the valence band [55]. These bands are separated by a gap which is known as band gap. The two energy bands have been characterized by two very important energy levels: electron affinity and ionization potential. The electron affinity of a semiconducting polymer corresponds to LUMO and the ionization potential refers to HOMO. Figure 1.2 shows the formation of molecule orbital and their energy levels for ethylene.
Figure 1.2: Ethylene molecule with σ and π bonds. Molecular bonding leads to bonding and anti-bonding states, both corresponding to σ and π bonding orbitals. In solid form, the resulting HUMO and LUMO states take a form of bands, analogous to crystalline semiconductors but the bandwidths are significantly smaller [This figure is taken from D. Gupta, Organic electronics II, In Reach Symposium, 111 (2007)].

When the molecule forms an aggregate, the closeness of the orbitals of the different molecules induces a splitting of the HOMO and LUMO energy levels. This splitting produces vibrational sublevels with their own energy, slightly different from one another. Increasing the number of molecules creates more available molecular orbital energy levels and decreases the energy difference between them. When a large number of molecules interact each other (e.g. in an aggregate), the induced molecular orbitals are large enough to be perceived as a continuum rather than discrete levels. We no longer consider it as energy levels, but energy bands.
Figure 1.3: a) Formation of the valance band and conduction band as a result of overcrowded orbital energy levels. b) Collection of molecular orbitals forming band separated by energy band gap.
The energy difference between the HOMO (valence band) and the LUMO (conduction band) depend on the effective chain length or even better: effective conjugation length. The energy band gap of an organic solid is presented in figure 1.3.

Conjugated polymers have van-der Walls bonding indicates weaker intermolecular bonding comparatively covalently bonded semiconductors. The consequences have been seen in mechanical and thermodynamic properties such as reduced hardness or lower melting point, but even more significantly in a much weaker delocalization of electronic wave functions among neighboring molecules, which results in directly related to the optical properties and charge carrier transport [56-58]. The chemical structure of some conducting polymers is shown in figure 1.4 [59]. We have used polythiophenes and poly (para-phenylene-vinylene) in the present thesis.

Figure 1.4: Chemical structure of some conducting polymers [This figure is taken from A. J. Heeger, Chem. Soc. Rev. 39, 2354 (2010)].

1.3 Bulk Hetero-junction P3HT: PCBM Organic Photovoltaic Cell

At present, inorganic materials based photovoltaic (PV) devices dominate the application. However, manufacturing cost limits its wide applications. Intensive research has been conducted towards the development of low cost PV technologies, of which organic photovoltaic (OPV) devices are promising.
A hetero-junction device consists of two dissimilar materials with different electron affinities and ionization potentials. In 1948, Bardeen and Brattain discovered the first hetero-junction transistor at Bell laboratories [60]. On the basis of pioneering work, Schokley developed a p- n junction transistor in 1949 [61]. Thereafter the development of hetero-junction electronic devices has grown rapidly. In hetero-junction device, the exciton dissociation mainly effective at the donor and acceptor interface. Planer hetero-junction cells must be thin to enable successful charge transport towards the electrodes. However, it absorb small fraction of light due to its thinness. The optimized film thickness for OPV cell is around 100 nm to absorb efficient light. On the other hand, thicker cell absorb large amount of light, but a small proportion of exciton dissociate and reach the interface. The performance of OPV cell can be improved by using the concept of Bulk Heterojunction (BHJ) in order to increase the interfacial area between donor acceptor at which the charge separation takes place. A bulk hetero-junction is that in which multiple hetero-junctions are formed between donor and acceptor to dissociate large number of excitons. G. Yu et al designed the first bulk hetero-junction solar cell in 1995 [62]. This was fabricated by using solution processing technique to interm the donor and acceptor material [63-64]. The photoactive layer in BHJ solar cell, composed of bicontinuous interpenetrating network [55, 66] of donor (conducting polymer) and acceptor (fullerene derivative), sandwiched between two electrodes with different work function [67]. Poly (3-hexylthiophene-2, 5diyl) (P3HT) and [6, 6]-phenyl C_{61} butyric acid methyl ester (PCBM) are two conducting polymers which are often used as donor and acceptor materials in OPV, where the primary objective is to fabricate BHJ device. In the last decades research has been grown tremendously in development of BHJ OPV performance.

Great improvement has been built up in enhancing the performance of solution processed devices throughout the last 10 years. In 2001, Shaheen et al demonstrated OPV devices of 2.5% power conversion efficiency [68]. To date the devices with efficiency of greater than 10% have been reported in laboratory [69-72]. On the other hand, perovskite solar cells have been demonstrated around 2012 with efficiency of 9% and till now this efficiency has been reached up to > 20%. But these efficiencies
are not enough to make them available for practical applications [73]. Therefore the efficiency of these organic devices must be enhanced by processing conditions and post fabrication treatments [74]. In these devices, performance and endurance developments are basic aspects to explore the use of different advanced materials with new device architectures [75]. The performance of BHJ solar cells is closely related to the morphology of the active material, the phase separation between the donor and acceptor domains, crystallinity, crystal orientation, surface area of the solar cell and vertical distribution of the respective domains [76-78]. As a consequence, tremendous efforts have been done to understand the effect of processing circumstances on the donor-acceptor blend ratio [79], thermal or solvent vapor annealing [80-82], solvent [83] and use of solvent additives [84]. We highlight the strategies to control the morphology of the blend thin films in the following section. Today we have a set of several donor-acceptor polymers but here we mainly focus our attention on P3HT and PCBM which are most widely used donor-acceptor pairs used in the literature so far [85].

1.3.1 Effect of Thermal annealing

There are several studies attributed to optimizing thermal annealing to influence the morphology of blend film and hence significant improvement in performance of P3HT: PCBM BHJ devices. It is known that the annealing results in phase separation of polymers in active material. Annealing influences structural properties which are correlated to electrical properties of the optoelectronic devices. At first the thermal annealing is found to be quite significant in P3HT. Vanlaeke et al studied the effect of thermal annealing on P3HT: PCBM thin film and observed the improvement in photon absorption efficiency, BHJ morphology, and hole mobility cause of stacking of P3HT in planar conjugated section [86]. Chen et al have demonstrated the effect of annealing conditions on the final morphology using small angle neutron scattering and Transmission Electron Microscopy (TEM) [87]. Good segregation of the P3HT and PCBM can be determined by PCBM diffusion and crystallization of P3HT during thermal annealing of P3HT: PCBM BHJ film [88]. Degree of crystallinity is increased in P3HT after annealing which is significant parameter for electrical transport towards
electrodes. Thermal annealing induces the phase segregation of PCBM in P3HT:PCBM blend layer. It is complex to explain both the crystallization and aggregation in P3HT:PCBM film [89]. Thermal annealing can be performed on blend films before (pre annealing) and after (post annealing) electrode deposition. Post annealing process is better than pre-annealing as the interfacial area between active layer and Al electrode has been increased in this process. Therefore it provides the ease of more efficient charge collection at electrodes. Following the previous studies, Yang et al have observed significant change in absorption of post annealed devices can be measured [90]. They have found that thermal treatment of BHJ thin films improve the crystallinity of the large amorphous films. If the substance already has crystalline nature, the thermal annealing doesn’t affect that substance [91]. Erb et al have used X-Ray Diffraction (XRD) technique to study the structural and optical properties of P3HT:PCBM blend film. They observed that annealing influences the orientation of P3HT [92]. As shown in figure 1.5, P3HT main chains are oriented in parallel and the side chains perpendicular to the substrate in the polymer crystallites. PCBM crystallites have found to be excluded from the polymer films. Moreover, the PCBM concentration at interfaces has been found lower in pre annealed films than the post annealed films. These distinct properties have been assumed to be responsible for the device performance. Oklobia et al have studied the effect of thermal annealing on transport properties of blend material P3HT:PCBM in hole only and electron only devices and concluded that the trap assisted recombination is comparatively more dominant [93]. Bagui et al have also studied the hole only devices and observed the significant enhancement in hole mobility of P3HT thin films upon annealing under electric field during the solvent drying process [94]. Therefore, thermal annealing can improve crystallinity, morphology and charge transport in P3HT films. This has also the potential for various other low band gap donor polymers.
Choice of Host Solvent

Choice of solvent is one of the most important parameters to affect the blend morphology and device performance. Solvent not only affects the domain size and shape but also determine the degree of crystallinity and vertical distribution of materials in blend layer [95]. W. Wang et al have investigated the morphology of P3HT: PCBM active material with different solvents (chlorobenzene, toluene, xylene and dichlorobenzene) using various experimental techniques such as atomic force microscopy, optical microscopy, grazing incidence small and wide angle x ray scattering and absorption measurements [96]. Then, concluded that PCBM crystallization induced by solvent is the main key for device degradation. The devices, which are fabricated using toluene, chlorobenzene (CB) and xylene as a solvent,
presented the PCBM enriched top layer that is good for device performance. On the other hand, film prepared using chloroform (CF) shows a P3HT-enriched top layer. As CF has good solvent capability, it can be significant solvent for polymer solar cell synthesisation in some cases [97, 98]. Using various experimental tools such as X-Ray Reflectivity (XRR), Grazing Incidence Small Angle X-Ray Scattering (GISAXS), Atomic Force Microscopy (AFM) and Grazing Incidence Wide Angle X-Ray Scattering (GIWAXS), Ruderer et al have studied the effect of solvents on the bulk morphology of P3HT: PC\textsubscript{61}BM films [83]. They have investigated that the different solvents influence the vertical material composition distribution and the lateral phase separation. Morphology of the blend film can be improved by using the high boiling point solvent such as dichlorobenzene (DCB) and CB. A blend film prepared with DCB or CB performs a better structure and crystallinity as compared to the film prepared using a low boiling point solvent [99]. We have used 1, 2 DCB as a solvent in the present thesis.

1.3.3 Use of Solvent Additives

A new strategy to control the morphology of blend films is to introduce solvent additives to the donor acceptor solution. Solvent additives were used first in Poly [2,6-(4,4-bis-(2-ethylhexyl)-4H-cyclopenta [2,1-b;3,4-b']dithiophene)-alt-4,7(2,1,3-benzothiadiazole)] (PCPDTBT): PCBM system. An additive can be effective if it interacts with the blend solution during thin film formation. Thus the boiling point of the additives should be higher than that of the used solvents causes good intermixing and avoid the large domains of PCBM which is attributed to the efficient charge transport [93]. Commonly used high boiling point solvent DCB can also be preferred as additive [101]. Use of 1, 6-hexanedithiol (HDT) or 1, 8-octanidithiol (ODT) additives in P3HT: PCBM produce phase segregation with optimize domain size. Blend films with additives provide a thorough interaction between additives and fullerene which is investigated by Grazing Incidence X-Ray Diffraction (GIXRD) and Scanning Transmission X-Ray Microscope (STXM) [102]. The effect of varying amount of crystallizable solvent 1, 3, 5 trichlorobenzene (TCB), with CB, on morphology of P3HT: PCBM solar cells have been studied by Keawprajak et al [103].
The films casted using TCB shows the better crystallinity, morphology and optical absorption than the film without TCB and hence the performance of the solar cell has been improved. Liao et al investigated several additives which cause high performance systems in his recently published review [104].

### 1.3.4 Solvent Annealing

As the solvent influences the properties of BHJ system mentioned above like domain size, crystallinity and vertical distribution of BHJ components, the choice of solvent is thus dependent not only on the solubility of materials but also on the evaporation process and its influence on the blend morphology. Solvent annealing is the process in which the spin cast films are in contact with solvents and solvents vapors in closed container. These studies focus on the solvent drying time, type of solvent, phase evolution and crystallinity [105-107]. Hedge et al have studied the exposure of CS₂ vapor on P3HT: PCBM films during solvent annealing [108]. They have observed that the PCBM diffuses out of P3HT domains resulted in increased crystallinity of P3HT and therefore improve phase separation between domains. As X ray scattering is known as an effective tool to study the morphology of the polymeric thin films. Verploegen et al have studied the morphology of P3HT: PCBM thin films with different solvents using grazing incidence X-Ray scattering technique [109]. They found perpendicular P3HT lamellae for the film cast using CB while in case of film preparation using CF, parallel P3HT lamellae were observed. Hence a high boiling point solvent CB has proven to be more significant than CF for blend film preparation Structural and optical properties of active layer (P3HT: PCBM) fabricated using spin coating can be improved by monitoring the speed at which the solvent is removed at the time of deposition. [110].

### 1.3.5 Charge Transport

Charge transport in organic materials occurs via hopping process, in which charge carriers are localized at finite number of locations within the whole density of states. To achieve highly efficient OPV, high mobility of the charge carrier is needed to reduce recombination and produce free electrons and holes in blend layer. Charge
transport in P3HT: PCBM blend strongly depends on the work function of metal electrodes. When an ohmic contact is formed between metal and blends film, Schottky thermal emission current plays a dominant role on the charge transport in the devices with Au or Al electrodes. On the contrary, in the case of non ohmic contact SCLC mechanism takes place [111]. Otalora et al have used impedance spectroscopy to investigate the electrical transport properties of thin layers used in OSC. P3HT layer is found to be strongly influenced by air exposure which affected the mobility of charge carriers. They have also studied the impact of solvent and rate at which the solvent evaporate on the carrier’s mobility. It has been observed that the devices using mesitylene show high mobility than the devices prepared with CB. The carrier mobility is also influenced by the rotating speed at which the solvent evaporates and the electrical properties of P3HT: PCBM thin films can be improved by removing the solvent slowly [112]. Khelifi et al have used TEM to reveal the change in blend morphology of P3HT: PCBM with phase segregation on long illumination [113]. They have investigated the photo-degradation mechanisms in P3HT: PCBM solar cells using various electrical characterizations and device modeling. Device performance has been improved by incorporating the Ag nano particles and Si-PCPDTBT in blend solution of P3HT: PCBM. Paci et al have used Time Resolved High Spatial Resolution X-Ray (TRHRXD) technique to investigate the effect of incorporation of Ag nano particles in the OPV devices. Authors have observed how structural and interface modifications occurs at nanoscale using this technique [114]. Koppe et al have used the ternary BHJ system instead of most frequently used binary BHJ [115]. They introduced low bandgap polymer Si-PCPDTBT in P3HT: PCBM and observed the phase separation without the perturbation of the crystallization of the P3HT: PCBM matrix. This ternary blend involves the transfer of photo generated positive polarons from Si-PCPDTBT to P3HT within few hundreds of picoseconds which can enhance the device efficiency. Proctor et al published a review on geminate and non geminate recombination in OSCs [116]. Charge carrier recombination plays a crucial role in the action of OSC.

Yoo et al theoretically studied and developed different models approaches for blend layer [117]. They have studied the effect of variation of molecular structure on Poly
(3-Alkylthiophene) (P3AT): PCBM blend layer. It has been observed that the P3HT: PCBM layer is more reliable for OPV due to its well-organized structure in each of the donor and acceptor phases and large interfacial area between P3HT and PCBM.

Device degradation is still a big challenge to the researchers. Many research papers have been published in this context. Yu et al. have described thin film encapsulation (TFE) technology in order to increase the life time of flexible organic devices which is most influential in preventing water vapor and oxygen permeation and also provide potential barrier performance [118]. Snaith et al. have elucidated that the perovskite semiconductors are the promising material in this era cause of their unique and optimized properties [119]. They are to be the most promising material meet to the high power conversion efficiency approach.

1.4 Aim of the Thesis

In this thesis, our aim was to relate the current transport with the internal morphology of P3HT/PCBM composite. A great deal of work had already been done of photovoltaic properties of this combination of polymers. The desired morphology of BHJ OSC is bicontinuous interpenetrating network of donor and accepter material with a domain size of 10-20 nm for efficient charge separation and their unhindered transportation to respective electrodes. However the systematic investigation relating internal morphology with the current transport is far from being understood.

Very recently there has been a paradigm shift in the understanding of the morphology of P3HT-PCBM system where the separate crystalline phase of P3HT and PCBM coexist with the miscible phase of the two components, which is a significant deviation from bicontinuous morphology concept [76, 120-121]. It is well known that the morphology of P3HT and PCBM system also results in isolated grains and crystallites of the polymeric materials quite often. Such kind of morphology is undesirable for photovoltaic applications which do not serve as an active medium since it is not usually conducive for efficient charge transport. The control on internal morphology of the mixed polymers is very crucial for device applications and that depends on several parameters such as, solvent used, temperature of preparation,
molecular weight and regioregularity of polymer, degree of confinement may lead to varied morphologies [95, 122-129].

Therefore matching of exact condition becomes extremely difficult for different batches of the samples even in the same laboratory. This has led to conflicting results from different laboratories around the world [120-121]. There is an enough room for the possibility that only a fraction of composite medium of P3HT and PCBM serves as ‘true active medium’, while rest of the fraction is ‘dead’ for charge transport due to isolated network structure. Perhaps this is the reason that the samples prepared in the same batch may show different electronic transport properties. Even some of the samples do not show any photovoltaic conversion. Such samples are usually discarded since they do not fit into the objective of solar material.

Our study is carried out from a different perspective, that is, to relate internal morphology with electrical transport, particularly for samples which do not show photovoltaic effect. It will be useful in two ways. First it will help us understand the pitfalls to be avoided for preparing solar device. Secondly but more importantly it will lead to the understanding of role of nanoscale morphology of the composite in controlling the electrical transport in the system. Nanoscale morphology of composite medium with different size of crystallites, degree of crystallization, and varied nature of amorphous phase provides a playground for several kinds of electronic structure and energy landscapes which could hinder as well as augment the charge transport depending on their arrangement at different length scale [130]. The morphological richness of a composite medium of donor and acceptor polymer needs to be explored for different kind of applications going beyond photovoltaic applications for their wider utility.

We prepared devices using P3HT and PCBM which demonstrate their potential beyond photovoltaic applications. In these devices we did not observed photovoltaic effects mainly because we prepared the sample with active area of 510 mm² which is much larger as compared to the reported devices (5-15mm²) where photovoltaic effect is observed [131]. It is important to note that large area devices showing systematic repeatable behavior suggests that the quality of the devices over the large area was
quite good. Usually it is the practice the most researchers deposit electrodes as small dots (1 mm x 1mm) to obtain the consistent results. The present thesis is a successful attempt at showing that a donor-acceptor combination of organic or polymeric materials such as P3HT and PCBM holds an unbound potential for organic electronic devices in addition to its conventional application in organic photovoltaic. In one of the study we have shown that isolated grains in the three phase network results in charge blockade leading to high dielectric constant which observes switching as a function of applied electric field. In another case study we have shown that nanoscale three-phase morphology results in negative differential resistance (NDR) –the phenomenon which has a wide implication in logic circuit and feedback circuits [132].
References


Introduction


