Chapter 7

CONCLUSION

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7.1 Summary and Conclusion

The major limitation of the Organic Field Effect Transistors (OFETs) is their inferior field-effect mobility which confines their use for high speed applications. So, in this research work our aim was to improve the OFET mobility along with other important performance parameters in order to improve the overall performance of an organic transistor.

In this thesis, OFETs were fabricated by using P3HT as the host active channel semiconductor material that was synthesized in the laboratory at ambient condition. It is well known that the performance of an OFET greatly depends on its active channel material, thin-film morphology and orientation of the molecules in the channel film. Therefore, in this study we tried to improve the performance of P3HT FETs by changing the morphology of P3HT as P3HT-nanofibers and P3HT-naocomposites, and also by doping of P3HT with a very good electron acceptor TCNQ. The formation of P3HT-nanofibers was confirmed by measuring UV-visible absorption spectra and AFM, and nanofibers suspension concentration used for OFET fabrication was estimated by using UV-absorption spectra and its value was found to be about 0.1 wt%. P3HT-nanofibers based thin-film show superb electrical conductivity due to end to end charge carrier transfer. Spin coated nanofibers thin-film showed some degree of fiber orientation due to centrifugal force acting on the substrate during coating. These oriented nanofibers may provide “direct lanes” between the source and drain electrodes for fast carrier movement which significantly enhances the electrical characteristics of the fibers film. Thus, the fabricated P3HT-nanofibres based OFETs showed improved electrical properties with

improved mobility, ON/OFF ratio and other key performance parameters. After comparison with the performance of P3HT-solution based FETs, it was found that the mobility of nanofibers based transistors was about 45-folds higher, and ON/OFF current ratio was improved by about one order. It was also concluded that the use of P3HT-nanofibers for OFET fabrication is advantageous for providing high performance devices and less material consumption compared to P3HT-solution.

Further, the morphology of P3HT active channel film was changed by another way in which little amount of graphene flakes were incorporated into the P3HT channel film. It was assumed that the graphene flakes added into the organic semiconducting thin-film would provide "fast tracks" or work as Conduction Bridge for the charge carriers. So, the electrical conductivity of the P3HT/Graphene nanocomposite thin-film enhanced significantly. As a result, the carrier mobility of P3HT/graphene based FETs got enhanced drastically compared to the mobility of only P3HT based FETs; however, the I_{ON}/I_{OFF} current ratio of P3HT/Graphene nanocomposite transistors decreased owing to the aggregation of the graphene flakes as well as the absence of forbidden energy gap in graphene which could not turn-off the OFET effectively. The carrier field-effect mobility of hybrid nanocomposite transistors (in which P3HT active channel was incorporated with 0.2 mg/ml graphene flakes) was around 223-folds higher compared to the mobility of only P3HT based OFETs. Therefore, it was observed that the performance of a transistor was very much influenced by the concentration of graphene flakes in a polymer matrix coated at the OFET channel. Hence, it can be concluded that incorporation of graphene into some organic semiconductor matrix is a straightforward, inexpensive, and new direction to obtain high mobility organic transistors.

OFET performance was further improved by doping technique. Here, the active channel thin-film was doped with a very strong electron acceptor TCNQ in order to boost the

transistor performance. A range of doping concentration (0 to 20%) in the P3HT channel film was used in order to see the effect of doping concentration on the performance of OFETs. The field-effect mobility of the doped OFETs was observed to be enhanced with the function of TCNQ due to a number of reasons. Doping resulted in the formation of the charge transfer complexes which boosted the electrical conductivity of the doped film. A lot of mobile holes in the doped P3HT channel film were also generated; therefore, free charge carriers density in the active channel film was increased. High doping level of TCNQ in P3HT promoted the formation of a few nanofibers which were clearly observed in the AFM measurement of the highly doped films. Due to increase in the electric-field strength at the interface of the source, drain electrodes and organic semiconductor with the function of the doping concentration which decreased the ohmic contact (Au/doped P3HT) resistance by decreasing the image force. The gap among the transport level and Fermi level was also decreased by raising the doping concentration. Therefore, the rate of carrier injections from the electrodes to the channel was increased which raised conductivity as well as mobility of the TCNQ doped P3HT FET. The threshold voltage of the transistor was shifted towards more positive direction with increasing TCNQ concentration in the channel. It was due to the filling of the trap states present at the interface of SiO_2/doped P3HT as well as in the bulk of SiO_2 by the dopant induced free charge carriers which resulted in decrease of the number of trap states. Therefore, by following the trap and released model, it can be concluded that increasing doping concentrations decreases the number of trap states and shifts the threshold voltage towards more positive values.

However, it was also observed that the “ON current” was also decreasing. This was because, Al thin-film coated at the channel is a strong electron donator which tries to decrease the holes present in the conduction channel film as active carriers are decreased

due to the electron-hole recombination and thus decreasing the ON current. But, only a small decrement in the "ON" current was observed due very few electron-hole recombination in the channel compared to the generation of huge number of dopant-induced holes in the TCNQ doped P3HT channel film. Therefore, thin Al coating at the highly doped conducting channel film resulted in a little decrement in the "ON" current and a large decrement in the "OFF" current. Hence, the ON/OFF current ratio of such transistor was greatly improved.

Initially, for some devices, it was observed that the thin-Al-coating reduced both the "OFF" current and "ON current" significantly. Though the decrement in "OFF" current is advantageous, the decrement in "ON" current is a drawback. This problem occurred owing to the deep penetration of depletion layer in the conducting channel film which reduced the effective channel height that supported the flow of current through the channel. To overcome this problem, conduction channel film thickness was increased such that even after the formation of a wide depletion layer, a sufficient effective channel depth remained to support high current flow through the channel.

Thus, the doping and the formation of deletion layer both were contributing to improve the OFET performance. The doping enhanced the "ON-state" performance while the deletion improved the "OFF-state" performance of the highly doped transistors. The mobility was improved by about two orders and the ON/OFF ratio was enhanced by about three orders higher than the undoped device.

As a result, through this research work it was concluded that from all the fabricated OFETs, the best performance was achieved for the highly TCNQ doped P3HT FETs along with a thin-Al coating on top of their channels. Here, the field-effect mobility was improved approximately by 93-folds, and the ON/OFF current ratio was enhanced by about three orders higher than the P3HT based OFETs.

7.2 Suggested Direction for the Future Works

An important issue in this thesis is to make the alignment of the nanofibers in the OFET channel. Here, the nanofibers prepared in the lab were coated on the device channel by simple spin coating technique. Unfortunately, these nanofibers were dispersed randomly on the channel. So, the current conducting carriers were moved in several directions by following the direction of the nanofibers which reduced the electrical property of the nanofiber films. Therefore, if somehow, nanofibers could be made to get aligned successfully in the OFET channel, then they can provide "direct path" to the conducting carriers for the swift movement from the source to drain. This may result in a very good improvement in the electrical conductivity of the channel film. Therefore, a drastic enhancement in the drain current, field-effect mobility as well as others performance parameters of the OFET may result. Hence, the alignment of the nanofibers in the OFET channel is a significant issue. So, it can be the next important objective for future research work in order to get OFETS with much better performance.

Another important issue in the progress of OFET is the poor electron mobility of the organic semiconductors which reduces the usefulness of n-type OFETs; however, nowadays modern electronics circuits require both n-type as well as p-type transistors, so, the growth of n-type OFETs with efficient performance is also an important area for future research.

Development of a number of new organic semiconductors, device architectures, and advanced thin-film deposition techniques are other important areas of research to enhance the OFET performance.

Further, the development of such OFETs in which not only the channel is an organic material, but also all the parts (substrate, insulator, channel and metal electrodes) of the

transistors, if consist of organic materials then the fabrication cost will reduce and flexibility will increase drastically.