Chapter-7. Conclusion and Future Work

7.1 CONCLUSION

This thesis, addresses the material issues and electronic behaviour of organic thin film transistors. The main findings of the thesis provide useful insights and highlights role of materials in improving the device performance and reliability of organic thin film transistors (OTFTs). Especially the role of gate dielectric and substrate layers in improving the performance and reliability of the OTFTs is detailed. In addition to the material issues, the thesis presents computationally efficient and numerically accurate solution for calculating the surface potential function when the trap states in the organic semiconductor are modeled using a double exponential function. Further, to facilitate the process of design and optimization of large complexity circuits using OTFTs, an adaptation of the well-established SPICE level-3 model for OTFT and its utility for designing digital and analog circuits is demonstrated.

To begin with, an extensive literature survey has been conducted to identify the trends, application scenario, opportunities and challenges associated with the OTFT technology. As a part of the literature survey, the focus has been primarily on understanding the charge carrier transport in disordered semiconductors, the performance parameters of OTFTs and the factors influencing these performance parameters and the existing computer aided design (CAD) tools support for the OTFT technology. Through this literature survey, it has been identified that: (i) choice of material plays a significant role in defining the performance and reliability of the OTFTs, (ii) The peculiar and unique behaviour of organic semiconductors, necessitate a surface potential based compact model for obtaining the I-V characteristics of the OTFT and (iii) There is a deficit of CAD tools which could be a bottleneck for commercialization of OTFT technology for large scale circuit design.

Gate dielectric plays an important role in determining the performance of an OTFT. The choice of a gate dielectric material can significantly influence the OTFT device parameters like threshold voltage, subthreshold swing, I_{ON}/I_{OFF} ratio and the stability issues related to hysteresis and other bias stress effects. Dielectric constant, breakdown field, surface energy and glass transition temperature are identified as those material parameters which have a significant impact on the device performance. Using well established Multi-Criteria Decision Making (MCDM) techniques: MOOSRA, TOPSIS and VIKOR, the problem of selecting a suitable gate dielectric material has been solved. The outcome of these three techniques, which solve the problem independently and using a different heuristic suggests that the dielectrics, CYTOP is the best possible material followed by BCB and SU-8 are the best possible alternatives among the materials analyzed.

The reliability and stability issues of an OTFT, are largely influenced by the choice of substrate material. It is identified that the thermal stability, thermal dimensional stability, flexibility and ability to conduct heat away from the semiconductor interface are identified to be the critical issues which can impact the stability and reliability of an OTFT. Based on these mechanisms, the material parameters: Young's modulus, coefficient of thermal expansion, thermal conductivity and glass transition temperature are identified as the ones which have a direct ad significant impact on the reliability of the OTFTs. Here, the interval based TOPSIS technique which is an extended version of the TOPSIS MCDM techniques is used to choose a suitable substrate material. Among the materials which are investigated as possible options for the substrate, polyimide (PI) emerges to be the best possible alternative to improve the thermal and mechanical aspects of the OTFTs, thereby improving the reliability of the device.

OTFTs are accumulation mode devices, therefore it is difficult to precisely define the threshold voltage in OTFTs. Hence, a surface potential based physical model would be more suitable for OTFTs. The thesis presents an analytical non-iterative solution for calculating the surface potential near the semiconductor-dielectric interface in an OTFT when the trap states in an organic semiconductor are modeled as double exponential density of states. The single step non-iterative solution is a computationally efficient, highly accurate and provides a path for integrating physics based analytical model into the computer aided design tools.

Behavioral modeling of an OTFT has been captured through a SPICE Level-3 model, which is an empirical model. This model has been used to reproduce the experimental I-V characteristics of an OTFT through parameters like field effect mobility, threshold voltage and interface trap density. Later this model has been used to design and develop an inverter, ring oscillator and a common source amplifier. Through different analysis available in the SPICE simulator the DC, transient and frequency response of the circuits are captured.

7.2 FUTURE WORK

The findings from the thesis, point towards some exciting possibilities which could be both of commercial or academic interest.

1. This work has tried to establish a connection between material parameters and the device performance. In addition to this an efficient framework for choosing a suitable gate dielectric is also presented. Due to a variety of possible approaches that exist in fabricating an OTFT like: spin coating, dip coating, ink jet printing and spray deposition, it is necessary to identify and optimize the process which can improve the yield and performance of OTFT. It would be interesting to study as to what factors (material properties, external parameters during fabrication and process parameters) would determine the yield and hence the economic feasibility of the process for commercial OTFTs.

2. The need for examining the failure mechanism due to mechanical stress in OTFTs is missing in the literature. It is also observed that very limited studies are available on the reliability aspect of the OTFTs when subjected to mechanical and electrical stress. This thesis has proposed an efficient and scalable technique to choose an appropriate substrate material for improving the mechanical reliability related issues. It would be exciting to study this aspect of OTFTs through automated test equipment which can monitor the performance of the OTFT on repeated bending

cycles. The reasons for failures and possible solutions to mitigate or delay the onset of these failure would be of immense value for the commercial success of OTFTs.

3. High frequency and noise analysis of OTFTs could be another interesting avenue for future studies. Realizing high frequency OTFTs and modeling of OTFTs for high frequency regions could be a challenging and exciting task. Since, very few studies have focused on the high frequency performance of OTFTs. Noise is another important aspect which has received very little attention so far from the research community. Since, noise plays an extremely important role in determining the performance of analog circuits, it is necessary to address this issue both from device physics as well as behavioral modeling.

4. A complete computer aided design tool chain which includes layout, process variation simulation, bias stress effects need to be developed. This could boost the industry adaptability of the technology. Moreover, availability of a standardized design tool helps in optimizing the circuit and reducing the design cycle time.

5. Since it is possible to design biodegradable polymer materials, emphasis can be on design and development of biodegradable OTFTs which will be eco-friendly and progress electronics towards sustainability.