CHAPTER 6

Conclusion and Future Scope

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6.1 Summary

This thesis explored water induced LiO_x as the gate dielectric for low voltage operable OFETs. Furthermore, bilayer LiO_x/AlO_x dielectrics for performance improvement of ultra-low voltage operable OFETs has also been investigated. The W-FTM film of DPP-DTT transferred from the surface of the water has been investigated for enhanced sensing performance in NO_2 sensing applications and in Near-infrared phototransistors. The present work integrates the benefits of water-induced synthesis of dielectrics and the large area transfer advantage of FTM with the added benefits of eco-friendly transfer from the surface of the water. Following is the chapter-wise summary of the obtained experimental results:

Chapter 1 briefly describes the progress in the field of OFETs followed by an extensive literature review of solution processed dielectrics, some OFET based NO_2 sensor, and near Infrared phototransistors. This chapter also covers a brief introduction to floating film transfer method, steps of fabrication, some basic theory, working principle, and parameters of OFETs.

Chapter 2 investigates the synthesis of water-induced LiO_x as the dielectric for its application in the OFETs for the first time. This work combines the advantages of cost effective, large area suitable W-FTM film (OSC) transferred from the water surface and water-induced processing of LiO_x dielectric. For SAM treatment we used the HMDS vapor method which is suitable for large-area SAM treatment. The electrical characterization of the fabricated LiO_x/DPP-DTT

OFETs was encouraging. The device showed typical p-type characteristics with nice saturation and linear region under -2 V operation. We obtained an average saturation mobility (μ_{avg}) of 0.14 (±0.035) $cm^2\ V^{-1}\ sec^{-1}$, maximum mobility (μ_{max}) of 0.184 $cm^2\ V^{-1}\ sec^{-1}$ of ON/OFF ratio of ~ $10^{4,}$ and subthreshold swing of 186 (±15) mV/decade. The current bias stress carried out at $V_{DS} = V_{GS} = -2$ V for 1 hour, showed almost 20 % decay in drain current which has been fitted with the stretched exponential function. Over all this work integrated the water induced dielectric synthesis with large area transferred FTM film from the water surface instead of commonly used toxic organic solvents like ethylene glycol and glycerol.

Chapter 3 studies bilayer dielectric based OFET by employing an additional layer of water-induced AlO_x over the LiO_x surface. AlO_x was chosen because of its large bandgap and low leakage and fewer trap states (owing to its covalent character). The processing of the OSC layer (DPP-DTT) was done using the FTM approach from the water surface. The Device showed ultra-low voltage operation under -1 V. The LiO_x/AlO_x bilayer-based device showed a subthreshold swing of 90 mV /decade which is very close to the theoretical limit. ON/OFF ratio of 10^5 and average mobility of 0.24 $cm^2\ V^{-1}\ sec^{-1}$ and maximum mobility of 0.34 $cm^2\ V^{-1}\ sec^{-1}$ was obtained. A drastic reduction in surface trap density was achieved by the insertion of the AlO_x layer. Furthermore, the normalized current bias stress showed just ~ 10 % decay in one hour. The fitted stretched exponential function shows a trapping time of ~ 10^8 sec and β (trapping time constant) of ~ 0.28. This large trapping time is comparable to Si-H TFTs signifying the high electrical stability of OFETs. Positive bias stress and negative bias stress were also carried out which further showed very stable performance of OFETs with negligible shift in threshold voltage. This enhanced performance is attributed to the smoother surface of the AlO_x layer and the hydrophobic nature of ODPA treatment.

Chapter 4 explores to the development of ultra-sensitive and low voltage operable OFET-based ppb level NO_2 sensor. The AlO_x dielectric layer was processed using DI water and the ultrathin DPP-DTT OSC layer was transferred from the surface of the water. Since OFETs are the preferred choice for gas sensors because of multiparametric variation, variation of sensor response, mobility, threshold voltage shift, subthreshold swing, and trap density were extracted. The device exhibited excellent multiparameter sensing response upon exposure to 1.4 ppm of NO_2, including a remarkable response (R) of ~ 8445%, a significant % mobility change of ~ 1210, a % threshold voltage changes of ~ 121.92, and an impressive ~ 66.90% reduction in the subthreshold swing. Furthermore, the device showed a quick response recovery time of 34 s and 174 s. Such excellent response is attributed to an extremely thin film of DPP-DTT layer (~ few monolayer thicknesses), superior sensing properties of FTM transferred film, and significant dipole moment of donor-acceptor polymer. A selectivity study was also performed to establish that the fabricated device is selective to NO_2. Moreover, the effect of humidity on sensing response shows a slight increase in the sensing performance. Owing to its suitability for large area processing and no requirement of complex equipment in FTM, this result can be employed to fabricate low voltage operable, low cost, highly sensitive ppb level NO_2 sensor based on OFET for multiparametric variation along with eco-friendly processing advantage.

Chapter 5 demonstrates an ultra-low voltage NIR OPT with PVA dielectric layer and FTM transferred DPP-DTT OSC film. The device showed a Responsivity of 7.72 A/W, Photosensitivity of 456 EQE of ~1183.84 %, and detectivity of 1.097×10^{12} Jones all under -1 V operation. The logarithmic and linear fit of the drain current in on-state and off-state with the experimental data respectively confirm the photovoltaic and photoconductive modes of operation of the device. Such high performance of NIR OPT can be explained with the help of the charge trapping effect due to the presence of hydroxyl ions on the PVA dielectric surface which results in a very low dark current and reduced hole injection barrier due to electron trapping by hydroxyl ions on illumination. This has been further confirmed by fabricating another device in which charge traps on the PVA layer have been passivated by thermal crosslinking and using HMDS treatment. The thermally crosslinked and HMDS-treated device shows a very small change in the current on illumination. The maximum processing temperature of 100℃ for both the dielectric layer and OSC and FTM transfer method adapted for OSC makes this device suitable for future applications in flexible and large-area electronics. Furthermore, since this report utilizes Water as an FTM substrate for OSC layer transfer and PVA dielectric processing, makes it an eco-friendly suitable processing of NIR OPTs.

6.2 Future Scope

The main objective of the present work was to fabricate the device with enhanced performance using water processed LiO_x as dielectric and large area transfer advantages of FTM transferred film from the surface of water. In the due course of time, we also explored the application of FTM transferred DPP-DTT (from the surface of the water) film in the area of gas sensing and NIR phototransistor. Though all the objectives have largely been achieved still there are many areas that needs further exploration. With limited duration, we skipped various investigations which could further enhance the performance.

1. A study can be further designed to investigate the effect of Various other kinds of SAM treatments on lithium oxide (LiO_x) based dielectric by utilizing commonly used SAMs

like OTS etc.

2. Many a times, mobility of organic semiconductors is dependent on the organic solvent used. Therefore, a study to investigate the effect of different solvents or a combination of them can be carried out.
3. A combination of different inorganic dielectric or organic dielectrics can be tried to investigate its effect on the performance parameters of the device and electrical stability.
4. With the limited resources we could not pattern the FTM transferred organic semiconductor film. Further study needs to be carried out to find a suitable method to pattern the FTM transferred film which may further improve the ON/OFF ratio of developed OFETs along with large area processing advantage.
5. Further bias stability of devices can be improved by using a suitable encapsulation layer to shield the active area of the device from common environmental interferants.
6. Organic inorganic nanocomposites have been commonly used to improve gas sensing performance because of their superior charge transfer properties. Regarding the application of FTM-transferred film for NO_2 sensing a study to investigate various inorganic organic-based nanocomposites for further enhancement in response time can be carried out.
7. A further advanced study can be carried out by introducing suitable organic/inorganic-based nanocomposites/blends for increasing the detection range of NIR OPTs to make them broadband phototransistors.

Publications related to this Work

1. **Prashant Kumar**, V. N. Mishra, and R. Prakash, "Low Voltage Operable Eco-Friendly Water-Induced LiO_x Dielectric Based Organic Field Effect Transistor," ***IEEE Electron Device Lett.*, vol. 44, no. 4, pp. 638–641, 2023, DOI: 10.1109/LED.2023.3250821.**
2. **Prashant Kumar**, V. N. Mishra, and R. Prakash, "Ultralow-Voltage Eco-Friendly Water-Induced LiOx/AlOx Bilayer Dielectric-Based OFET," ***IEEE Trans. Electron Devices*, vol. 70, no. 8, pp. 1–6, 2023, DOI: 10.1109/ted.2023.3285172.**
3. **Prashant Kumar**, V. N. Mishra, and R. Prakash, "Highly Sensitive and Selective Room Temperature-Operated NO_2 Sensor Based on Eco-Friendly Water Processed Low Voltage Operable OFET," ***IEEE Sens. J.*, vol. 23, no. 12, pp. 12544–12551, 2023, DOI: 10.1109/JSEN.2023.3271598.**
4. **Prashant Kumar**, V. N. Mishra, and R. Prakash, "Ultra-Low Voltage FTM transferred DPP-DTT Based Near Infra-Red Phototransistor" **(under revision IEEE *Trans. Electron Devices*)**.