Chapter 7

Conclusion and Scope for Future Work.

7.1 Conclusion

The key finding of this thesis is to develop a reliable route to fabricate solution processed low-voltage thin-film transistors using different perovskite oxide as a dielectric. Besides, I have also developed a new ion-conducting gate dielectric for the same purpose. Their coherent interface with solution-processed oxide semiconductors improved TFT performance significantly and made solution-processed TFT fabrication viable. Organization of Ph.D. works in final shape becomes possible due to the development of two distinguished steps. An initial step was to find out a reliable route for developing a solution-processed oxide perovskite and ion-conducting oxide thin film fabrication and their characterization. The second step was the fabrication of TFT by using those perovskites and ion-conducting dielectric. I have explored different possibilities to fabricate those devices with optimum performance.

My first effort was to find out a reliable technique to synthesize $Pb_{0.8}Ba_{0.2}ZrO_3$ (PBZ) thin film deposition and its characterization. From that study, it was observed that PBZ thin film was polycrystalline and optically very transparent with low electrical conductivity and high breakdown voltage. Besides, the positive side of PBZ thin film is its capability to form a high capacitive thin film which is an essential requirement for developing low operating voltage TFT. The AFM study was performed to identify the roughness of PBZ thin film indicating its low roughness which is required for the high-quality dielectric/semiconductor interface. Solution-processed Indium Zinc Oxide (IZO) TFTs were fabricated by using PBZ dielectric. After optimization of device performance, it was possible to fabricate TFT with carrier mobility of 4.5 $cm^2 V^{-1} s^{-1}$ with an on/off ratio of 5×10^3.

The second effort of my thesis work was to develop a lead (Pb) free perovskite dielectric through a sol-gel approach and use it as a gate dielectric of a TFT. For this development, particularly, I have focused on solution-based strontium titanate ($SrTiO_3$) thin-film fabrication because of its vast popularity as Pb-free oxide perovskite. After the systematic study, it was possible to fabricate smooth morphology of $SrTiO_3$ thin film which is polycrystalline. The arial capacitance of this film was ~ 730 nF cm^{-2} at a frequency below 50 Hz and was quite constant up to 10 kHz. Besides, the insulating nature and high breakdown voltage of this thin film makes it possible to fabricate a solution-processed tin oxide TFT that shows electron mobility of 0.23 cm^2 V^{-1} s^{-1} with $>10^4$ on/off ratio under 2 V operating voltage. To the best of my knowledge, this is the 1st demonstration of solution-processed TFT by using sol-gel derived $SrTiO_3$ thin film gate dielectric. In a similar route I have developed $BaTiO_3$ thin film and successfully fabricated SnO_2 TFT which shows carrier mobility of 0.028 cm^2 $V^{-1}s^{-1}$, on/off ratio is 25, and subthreshold swing is 2.2 V/decade. As a solution-processed TFT, the performance of this TFT is not up to the mark at this stage. However, in this work, I have demonstrated the possibility to use $BaTiO_3$ thin film as a gate dielectric of a TFT.

Apart from these perovskite dielectrics (PBZ, $SrTiO_3$, and $BaTiO_3$), I have also given some effort to develop a novel ion-conducting Li_2SnO_3 thin film for the same purpose. Although Li_2SnO_3 thin film is well known as a solid-state electrolyte and has been explored for the development of Li-ion batteries. However, the possibility to use this material as a gate dielectric of a TFT is not reported so far. In my thesis work, Li_2SnO_3 thin film was synthesized and successfully employed as a gate dielectric in SnO_2 thin-film transistors. The performance of this TFT was improved further by adding a TiO_2 thin film in between the gate electrode and Li_2SnO_3 thin film. For comparison, two TFTs with Li_2SnO_3 and TiO_2/Li_2SnO_3 bilayer dielectric combinations were studied extensively. This study reveals that the device with TiO_2/Li_2SnO_3 bilayer dielectric had comparatively better performance, with electron mobility of 3.47 $cm^2\ V^{-1}s^{-1}$, on/off ratio of 50, and sub-threshold swing of 1.23 V/decade.

7.2 Scope for future work

The synthesis of perovskite and ion-conducting dielectric materials, thin film deposition through spin coating, successful use as a gate dielectric in thin-film transistors, and different characterization are all covered in this paper. In this research, these materials were investigated as gate dielectric for high-performance, low-voltage transistors that are fabricated onto a silicon substrate (p^{++}-Si). Earlier, in most of the cases, these solution-processed dielectric thin films were not explored as a gate dielectric of metal oxide TFT. Therefore, there is enough room to develop further of these materials for better performance of TFTs in the future. Some of those possibilities are listed below:

Solution-processed all perovskite thin-film transistor

In my thesis work, I have used perovskite oxide as a gate dielectric of thin-film transistors. Although, there is a possibility to use perovskite oxide semiconductors with this combination to develop a solution-processed all perovskite TFT. One promising perovskite metal oxide semiconductor is $ZnSnO_3$ which can be used in combination with $SrTiO_3$ or $BaTiO_3$ gate dielectric in the future.

Low operating voltage transparent transistor

These dielectric thin films are transparent in the visible range, but all of these TFTs were fabricated on top of the p^{++}-Si substrate. By using a transparent conducting substrate like ITO, FTO it is possible to fabricate transparent TFT.

Low voltage ferroelectric field-effect transistor-

Because of the ferroelectric nature of different perovskite oxides, it is possible to fabricate high-performance low operating voltage ferroelectric thin-film transistors (FeTFT) which can show a long retention time for non-volatile memory application.

Low voltage phototransistor and light-emitting transistor

We may use these optically transparent perovskite oxides and ion-conducting dielectric-based TFTs to construct a low voltage metal oxide phototransistor and light-emitting transistor.

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List of Publications

1. **Acharya, V.,** Sharma, A., Chourasia, N. K., & Pal, B. N. (2020). Solution-processed Pb0. 8Ba0. 2ZrO3 as a gate dielectric for low-voltage metal-oxide thin-film transistor. ***Emergent Materials, 3*(1), 57-62.**

2. **Acharya, V.,** Pal, N., Sharma, A., Pandey, U., Biring,S,.& Pal, B. N. (2022) Solution-processed low operating voltage SnO_2 thin film transistor by using Li_2SnO_3 gate dielectric. **(Under Revision)**

3. Sharma, A., Chourasia, N. K., **Acharya, V.,** Pal, N., Biring, S., Liu, S. W., & Pal, B. N. (2020). Ultra-low voltage metal oxide thin film transistor by low-temperature annealed solution processed LiAlO2 gate dielectric. ***Electronic Materials Letters, 16*(1), 22-34.**

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5. Pal, N., Sharma, A., **Acharya, V.**, Chourasia, N. K., Biring, S., & Pal, B. N. (2019). Gate interface engineering for subvolt metal oxide transistor fabrication by using ion-conducting dielectric with Mn2O3 gate interface. ***ACS Applied Electronic Materials, 2*(1), 25-34.**