Chapter 6

6.1 Conclusions

The basic objective of the present thesis is to fabricate the cost-effective ion conducting dielectric based high-performance, low voltage thin film transistor. Their coherent interface formation with solution-processed oxide semiconductors lead to considerable improvements in TFT performance and make it possible to all solution processed TFT fabrication. To fill the gap of reported data and requirement of practical application, there are two primary goals for this thesis. First, to synthesize the ion conducting dielectric via low-cost solution processed technique at lower processing temperature. Second, fabricate high mobility metal oxide TFT with this ion conducting dielectric that can operate with a much lower voltage (~1.0 V) of the earlier report. Also, the improvement of the TFT performance using the combination of ionic dielectric with the bilayer.

In this context, we have synthesized the new ion conducting Li_5AlO_4 dielectric through sol-gel route and successfully utilized this dielectric as a gate dielectric for the first time in thin film transistors. The crystal structure of Li_5AlO_4 dielectric revealed by the X-ray measurements crystal structure preferred because of higher dielectric constant. The surface roughness of dielectric represents the compatibility of dielectric with semiconductor roughness values were extracted from the AFM measurement. To ensure the optical properties of this material, the thin films of Li_5AlO_4 have been fabricated on quartz and p^+-Si substrate at different annealing temperature. The film is highly transparent in the visible region due to less scattering at the interface and it shows high electrical insulating nature indicating Li_5AlO_4 as a suitable gate dielectric for TFT application. This sol-gel derived

Li_5AlO_4 shows different phases like a-Li_5AlO_4, α- Li_5AlO_4 and β-Li_5AlO_4 at different annealing temperature 350 ^oC, 500 ^oC and 700 ^oC respectively. To achieve the applicability of these three different types of Li_5AlO_4 dielectric thin films, solution processed IZO (Indium Zinc Oxide) TFT were fabricated. Among all the devices, TFT made of α- Li_5AlO_4 dielectric required the least voltage to saturate the drain current in I_D-V_D plot and showed the highest mobility too, suggesting the best candidate for low voltage TFT application. This device showed effective electron mobility 21.9 $cm^2V^{-1}s^{-1}$ with an ON/OFF ratio of 5x 10^4. This value is much better than that of the TFT device fabricated with sodium beta-alumina (SBA) dielectric on p^{++}-Si substrate reported previously. The higher concentration of a mobile ion in Li_5AlO_4 film compared to SBA is responsible for this improved performance of the TFT device. Besides, the Li_5AlO_4 film required 500 ^oC processing temperature to attain the crystalline phase of the dielectric which is ~300 ^oC lower than the temperature needed for SBA, indicating the significant improvement of ion conducting dielectric film fabrication for TFT applications. Finally, metal oxide/quantum dot heterojunction phototransistor has been fabricated by coating IZO TFT with colloidal PbS QDs. The responsivity and the response time of the devices are measured as 4.5 X 10^{-4}A/W and 2.2 sec respectively.

The second target of this thesis work was to achieve a high-performance transistor marinating the lower processing temperature for removing the substrate limitation for future application. In this goal, $LiAlO_2$, a new ion conducting dielectric, has been developed via convenient and simple solution processed technique which has annealing temperature lower than other two ion-conducting dielectrics. The α-phase of $LiAlO_2$ (α-$LiAlO_2$) synthesized by a sol-gel method requires only 350 ^oC annealing temperature is a much better option to use it as a gate insulator of metal oxide TFT. We observed that this α-$LiAlO_2$ remained stable up to 500 ^{o}C. The other thermodynamically stable γ-phase (γ-$LiAlO_2$) was developed by direct annealing of precursor film at 700 ^{o}C. A various number of characterization technique were used for the physical properties of the spin-coated $LiAlO_2$ dielectric thin film. This dielectric film annealed at different temperature exhibited nice transparency, smooth surface and high band gap. FTIR measurement exposed that the film is free from organic impurity, which is beneficial for high-performance TFT. All phases of $LiAlO_2$ displayed the moderate leakage current because of its high bandgap and due to the impurity-free film. To realize the applicability of these two different crystalline phases on TFT performance, three different devices were fabricated $LiAlO_2$ dielectrics with the IZO semiconductor at three different processing temperatures (350 ^{o}C, 500 ^{o}C and 700 ^{o}C). We found that all three devices exhibited high mobility, high on/ off ratio as well as low operating voltage (≤2 V). The γ-$LiAlO_2$ dielectric TFT demonstrated the highest carrier mobility 25 $cm^2V^{-1}s^{-1}$ and high on/off ratio (>10^5) with a low subthreshold swing (~150 mV/decade). Such kind of low subthreshold swing is not commonly achieved in solution-processed metal oxide TFT. However, the most appealing result of this work is to develop 1.0-volt operation voltage TFT low processing temperature α-$LiAlO_2$ dielectric which became achievable because of existing high concentration Li^+ with higher ion mobility inside gate insulator and low surface roughness. On the other hand, this device also shows high carrier mobility (13.5 $cm^2V^{-1}s^{-1}$), high on/off ratio (10^4) with low subthreshold voltage swing (~150 mV/decade) at 1.0-volt operating voltage. This is a considerable accomplishment towards the development of high performance 1.0 V TFT. The other innovation of this work is to achieve the least processing temperature (350 ^oC) of ICMO dielectric, which is now compatible for display application.

To develop a much better performance of 1.0 V TFT, a new design concept has been introduced. It is observed that in place of single layer dielectric, a high permittivity gate interface is capable of reducing operating voltage further with the improvement of carrier mobility and on/off ratio. Specifically, by using electron donating TiO_2 gate interface, high-performance solution-processed one-volt indium zinc oxide thin film transistor (TFT) has been fabricated onto sol-gel derived ion-conduction gate dielectric with improved subthreshold swing and lower interface states. Through detail and comparative investigation of two different TFTs with TiO_2, Al_2O_3 gate interface realize that n-type TiO_2 works as an electron donor to the semiconductor/dielectric interface trap state that essentially reduces the interface state and subthreshold swing of the device. Moreover, gate leakage current extensively reduced by the depletion layer of p^{++}-Si (111)/TiO_2 interface that helps to improve the on/off ratio of the device. Leakage current density should be minimum not only for higher on/off ratio but also for lower power consumption for portable electronics. Specifically, the dielectric film achieved a high capacitance by inserting a high-k TiO_2 layer between the ion conducting Li_5AlO_4 gate dielectric and the gate electrode, that also provide saturation current at lower gate bias. In this chapter, comparing four TFTs with Al_2O_3, Li_5AlO_4, Li_5AlO_4/Al_2O_3 and Li_5AlO_4/TiO_2 dielectric layer combination, device with Li_5AlO_4/TiO_2 dielectric exhibited the best performance with electron mobility of 32 $cm^2/V.s$, on/off ratio of 5×10^5, and sub-threshold swing of 110 mV/dec. This investigation suggests a new direction for the development of high-performance, low voltage TFT fabrication by selecting proper material combinations for gate dielectrics.

6.2 Scope for future work

The present work has been reported the synthesis of ion conducting dielectric materials, thin film deposition via spin coating, characterization and effectively utilized as a gate dielectric in thin film transistor. These materials have been explored as a gate dielectric for high-performance, low voltage transistor on a silicon substrate (p^{++}-Si) in this thesis. However, many possible research directions can be extended in the near future work. Some important of them are given below:

Low voltage transparent transistor: In this work, we observed that these dielectric thin films are transparent in the visible region. We can fabricate the fully transparent transistor using the transparent substrate and electrode.

Low voltage ambipolar transistor: We have developed only the n-type transistor in this thesis. In order to realize complementary logic circuits, both p- and n-channel OTFTs are required. Therefore this can be elaborate with the p-type transistor fabrication. This will be beneficial for the integrated logic circuit.

Low voltage ferroelectric memory transistor: A memory element based on the ferroelectric thin film transistor (FeTFT) is one interesting device because of its non-volatile data retention. Therefore, by using Li-ion containing ferroelectric gate dielectric, it is possible to fabricate low-voltage operation and short programming time memory.

Low voltage phototransistor: We can develop the low voltage metal oxide phototransistor using this ion conducting dielectric based TFT for the detection purpose.

Low voltage light emitting transistor: This fabricated transistor can be explored for the development of the low voltage light-emitting transistor in the application of flat panel display.

Low voltage sensors: Thin film transistors (TFTs) based sensors have attracted great interest due to the high selectivity, repeatable response and low-cost production. We can extend different sensor like a gas sensor, biosensor, pressure sensor use different sensing materials with this low voltage transistor.

6.3 Contribution of Author

The author developed the ion-conducting dielectric materials through sol-gel route. Fabrication, characterizations of the low voltage metal oxide thin film transistor and calculations of the device parameters like, mobility, on-off ratio and subthreshold swing etc is done by student himself. All design of experiments and its execution is done by the author under the guidance of supervisor.