Abstract

Modern display technology requires higher resolution, wide area, mechanical flexibility, optical transparency, and lower cost. Over time enormous size cathode ray tube (CRO) based display has been replaced by an active matrix light-emitting display (AMLED) based display. Active matrix display and Passive matrix display are the two main types of flat panel display technology. Up to the present time, active-matrix flat panel displays (AM-FPDs) have conquered the bigger market, and that has been developed as an active matrix thin film transistor (TFT) since 1995. The flat-panel LED-based display is thin, lightweight and has the ability to produce high-resolution images which are very useful in many application such as television, monitors, smartphones, laptops, and the portable device. TFTs are the backbone of active matrix display technology and works as a driver (switching device) to drive a pixel in display 'on' (light) or 'off' (dark), therefore, development of low-cost TFT is urgently required. Because of their high carrier mobility and easy manufacturing process, metal oxide TFT may be one ideal choice for this application. In 1940, Bell Telephone Laboratories demonstrated the first working example of a transistor while Weimer at RCA Laboratories recognized the first working thin-film transistor (TFT) in 1962. [1-3] Thin-film transistors are basically three-terminal metal oxide field effect transistor devices. In a TFT structure, the dielectric layer is sandwiched between the gate electrode and the semiconductor. The charge flow through the semiconducting layer between the source and drain electrodes can be modulated by the gate bias, which induces polarization in the dielectric layer. Thin-film transistors are constructed using three main components; namely, i) a dielectric layer, ii) a semiconducting material, and iii) metallic electrodes (source (S), drain (D) and gate (G)). Dielectric, active channel layer, and their manufacturing process play a very important role in the performance of thin-film transistors.[4] There are various vacuum-based techniques for making thin-film transistors, e.g.,

sputtering, molecular beam epitaxy (MBE), chemical, and atomic vapor depositions.[5-7] While the use of vacuum-based technology can deposit high quality of thin films, these techniques are cost capital and complex. An alternative approach is solution process techniques, which are very simple, convenient, and cost-saving. Solution-processed MOx dielectric materials have been widely studied due to their high-k values[8-10], excellent optical transparency[11, 12], and chemical/environmental stability.[13, 14] Moreover, their main function as a gate dielectric layer in TFTs, high-k dielectrics also plays a very crucial role in the capacitor and memory devices.[15] In this concern, SiO_2 is the standard gate dielectric because it makes high-quality film without defect (free from the pinhole, impurity) in the form of native oxide with silicon substrates, which is easily deposited through thermally grown.[16] SiO_2, having nearly perfect properties for a gate insulator: high bandgap and electrical resistivity, outstanding Si-SiO_2 interface, least defect density in bulk, and high crystallization temperature. However, one main drawback of this dielectric is its lower dielectric constant (k), and due to this issue, metal oxide thin film transistor requires high operating voltages that limit its application to low power electronics. Relatively, high-k AlO_x [17] dielectric are batter choice for oxide electronics has been prepared by using various aluminum sources such as aluminum nitrate [18, 19] aluminum acetylacetonate[20], aluminum chloride. Zirconium (ZrO_x)[21] and hafnium oxides (HfO_x)[22] constitute another class of most-studied high-k oxide dielectrics those are used for low voltage TFT. Subramanian and co-workers reported high-performance all solution-processed MOx electronics using these high -k dielectrics[23]. Alternatively, Katz[24] and co-workers proposed a novel approach by incorporating ionic dopants into MOx lattices to enhance the k value of host dielectric material dramatically.[25, 26]. However, processing temperature of this ionic dielectric is very high (>800° C) which is required to lower significantly for flexible electronics. Moreover, this ionic dielectric is mostly studied for n-channel

TFT fabrication. Although for common electronics application, we need both n-channel and p-channel TFT. Therefore, development of low voltage p-channel TFT is also required.

Important Finding of the Present Work:

Keeping those requirements in mind, in my thesis work, we have focused on the development of different ion-conducting gate dielectric, which required lower processing temperature and can be suitable for p- and n-channel metal oxide TFT fabrication. The summary of the findings is given below.

1) **Low band gap Ion Conducting Gate Dielectric with lower processing temperature**

   Three new ion-conducting gate dielectrics have been developed by the sol-gel route and have been successfully used as a gate dielectric in metal oxide thin film transistor. These three ion-conducting dielectrics are Li_2ZnO_2, $LiInO_2$, and $LiGaO_2$. In these dielectrics, Li_2ZnO_2 was assumed to possess a hexagonal structure[27], while $LiInO_2$ and $LiGaO_2$ having the tetragonal structure.[28, 29] Owing to this Li+ ion conductivity, a high-capacitive thin film can be produced with these three ion-conducting dielectrics, which is a key factor in the development of low-voltage TFTs. Finally, using these dielectrics, high-performance transistors were fabricated that required ≤ 2.0 V operating voltage with high carrier mobility and good on/off ratio.

2) **Fabrication of ambipolar transistor using ionic gate dielectric**

   Metal oxide semiconductors are commonly n-type in nature. However, SnO_2 can show ambipolar nature, in case its doped in a proper way. In my thesis work, a p-type doping SnO_2 channel semiconductor has been made from the dielectric/semiconductor interface and has been utilized to develop high carrier mobility balanced ambipolar oxide-transistor.

To introduce this interfacial-doping, a bottom-gate top-contact TFTs have been fabricated by using two different ion-conducting oxide dielectrics which contain trivalent atoms like indium (In) and gallium (Ga). These ion-conducting dielectrics are $LiInO_2$ and $LiGaO_2$, respectively, containing mobile Li^+ ion. During SnO_2 thin film fabrication on top of those ionic dielectrics, the trivalent atoms allow p- doping to the dielectric/semiconductor interfacial SnO_2 layer to introduce the hole conduction in the channel of TFT. Our comparative electrical data indicates that TFTs with $LiInO_2$ and $LiGaO_2$ dielectric is ambipolar in nature. Most interestingly, by using $LiInO_2$ dielectric, we are capable to fabricated 1.0 V balanced ambipolar TFT with a high electron and hole mobility values of 7 $cm^2 V^{-1} s^{-1}$and 8 $cm^2 V^{-1} s^{-1}$ respectively with an on/off ratio $>10^2$ for both operations which has been utilized for low-voltage CMOS inverter fabrication.

3) Fabrication of graphene field-effect transistors (GFETs) using ionic gate dielectric

In the last fifteen years, a large number of literature has been published on graphene TFT; those are mostly fabricated through an expensive lithography process. Moreover, it required a very high gate voltage to get the variation channel current, and it’s hard to get a saturation drain current. Because of that limitation, until now, graphene TFT are not used for common electronics. In my thesis work, we have fabricated large channel length (up to 5.7 mm) graphene field-effect transistors (GFETs) through a simple, cost-effective method that required thermally evaporated source-drain electrode deposition, which is less cumbersome from the conventional wet-chemistry based photolithography. The semiconducting nature of graphene has been achieved by utilizing Li^+ ion of Li_5AlO_4 gate dielectric, which shows current saturation at a low operating voltage (~2V). The length scaling of these GFETs has been studied with channel length variation within a range from

0.2 mm to 5.7 mm. It is observed that the GFET of 1.65 mm channel length shows optimum device performance with good current saturation. This particular GFET shows the ‘hole’ mobility of 312 cm^2 V^{-1} s^{-1} with on/off ratio 3. For comparison, GFET has been fabricated in the same geometry by using conventional SiO_2 dielectric that doesn’t show any gate-dependent transport property, which indicates the superior effect of Li^+ of the ionic gate dielectric on current saturation.

4) **Fabrication of GFETs based ammonia sensor using ionic gate dielectric**

For an application as chemical gas sensor, our developed large-area graphene TFT, we have fabricated a GFET with a large channel length of 450 µm. The device characteristics are shown excellent low operation behavior within 2V, which is paving the path for portable TFT based chemical gas sensors. The fabricated device has also been tested for very low concentration ammonia under ambient environment conditions at 25˚C temperature, which shows the enormous potential for ammonia sensing for real-life applications. The average response time and recovery time of this GFET based sensor is ~40 sec and ~120 sec, respectively. A large change in Dirac point variation from 1.4V to 0.7V indicates its high sensitivity in the ammonium atmosphere.

Organization of the topics of the seminar

The seminar topic is divided into VII chapters

Chapter 1 gives the introduction of thin-film transistor (TFT) and solution-processed high-k materials.

Chapter 2 describes the experimental techniques.

Chapter 3 explains the solution-processed low band gap ion-conducting gate dielectric for low voltage metal oxide transistor

Chapter 4 deals with the high mobility 1 V balanced ambipolar oxide transistor and its application as CMOS inverter

Chapter 5 Low operating voltage and large channel length graphene transistor with current saturation by utilizing Li+ of ion-conducting gate dielectric

Chapter 6 deals with large channel length Graphene field-effect Transistor for the detection of ammonia in the presence of an ambient atmosphere

Chapter 7 is about suggestions and future work.