Metal Oxide Thin Film Transistor with Nano Inorganic Gate Dielectric : Material Chemistry, Nanoscience, Solution Processing and Electronics

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Abstract: *Indium Lead Oxide (ILO) based Metal Oxide Thin Film Transistor (MOTFT) is fabricated with Lead Barium Zirconate (PBZ) gate dielectric. PBZ is formed over doped silicon substrate by cheap sol-gel process. Thin film PBZ is analysed with X-ray Diffraction (XRD), Ultra-Violet Visible Spectra (UV-Vis) and Atomic Force Microscope (AFM). IZO is used as bottom gate to contact Thin Film Transistor (TFT). This device needs only 5V as operating voltage, and so is good for lower electronics <40V. It shows excellent e-mobility 4.5cm^2/V/s, with on/off ratio 5x10^5 and sub-threshold swing 0.35V/decade.*

Keywords: Perovskite, PBZ, ILO, MOTFT, sol-gel, electronics, nanofilm, dielectric, transistor

1. Introduction

Metal Oxide Thin Film Transistors (MOTFT) are a distinct class of metal-oxide-semiconductor field-effect transistors (MOSFET) fabricated by coating a layer of an active semiconductor layer, metallic contacts, and the dielectric layer over an insulating substrate. And, Printed Thin Film Transistors (TFT) are a major application of printed electronics [1-20]. Solution processed inorganic oxide gate dielectric is key element for low voltage MOTFT. It is a high performance device [1-8]. It is used in optoelectronics as next generation display, light emitting transistor, phototransistor, etc.

TFT is made by sol-gel process (or so-called solution processing), pulsed laser deposition, atomic layer deposition, radiofrequency magnetron sputtering, etc. Solution processing is cheap and easily mass produced [2,3,8]. Popular ferroelectric MOSFET's are Lead Zinc Titanate (PZT), Lead Barium Zirconate (PBZ), Indium Zinc Oxide (IZO) and Barium Zinc Niobate (BZN) [4,5,7]. These oxides are used in random access memory (RAM) and display [1,2,5,6]. This review article poses solution processing and electronic worthiness of an inorganic oxide gate dielectric, embedded in mixed metal oxide thin film transistor. **Figures 1-3** shows the electronic set up for electronic worth analysis of these materials. Nanofilm PBZ dielectric with material chemistry $Pb_{0.8}Ba_{0.2}ZrO_3$ and perovskite structure is taken for scientific analysis (In **Figure 1**, Red ball – Oxide ion, Blue ball – Zirconium ion, Centre Ash ball – Lead ion / Barium ion).

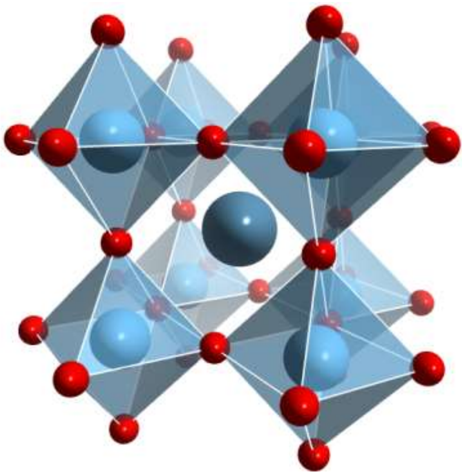

Figure 1. Perovskite Unit Cell

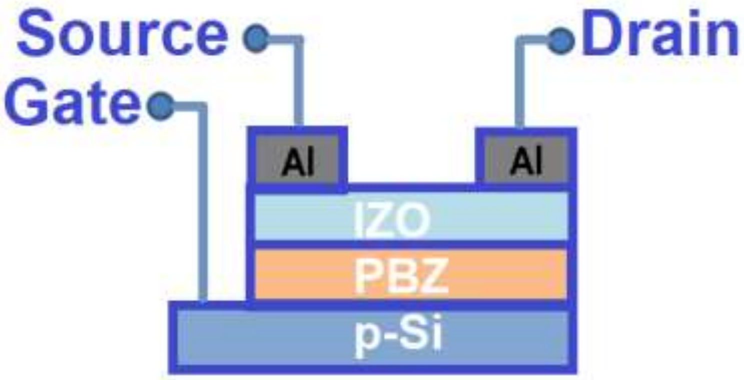

Figure 2. Scematic of MOTFT

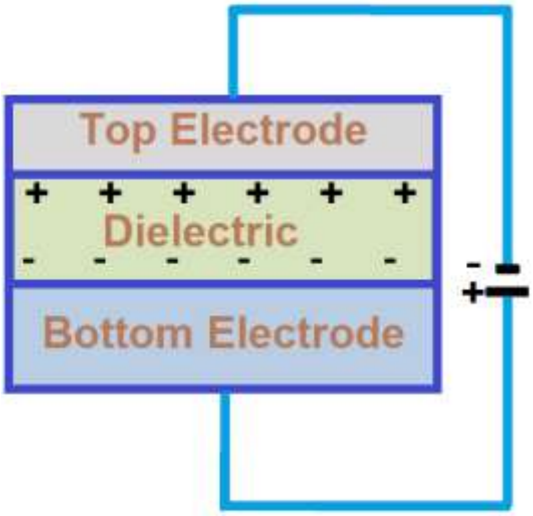

Figure 3. Polarisation in PBZ

2. Materials & Methods

2.1. Making of PBZ material

The gate dielectric material PBZ (with chemistry $Pb_{0.8}Ba_{0.2}ZrO_3$) is made by mixing aqueous solutions of lead acetate of chemical formula $Pb(OAc)_2$, barium nitrate of chemical formula $Ba(NO_3)_2$ and zirconyl nitrate of chemical formula $ZrO(NO_3)_2$ in organic solvent 2-Methoxy Ethanol in a glass beaker. After 2hours of stirring using glass rod or with the help of magnetic stirrer, oxide formed is filtered and dried to be used as dielectric.

2.2. Making of IZO material

Indium Zirconium Oxide (IZO) is made from aqueous solutions of indium chloride of chemical formula $InCl_3$ and zinc acetate of chemical formula $Zn(OAc)_2$ in organic solveny 2-Methoxy Ethanol, stirring for 2hours using glass rod or with the help of magnetic stirrer.

2.3. Making of MOTFT device

PBZ is deposited over doped silicon (Si) substrate by spin coating method, followed by solvent evaporation technique. Annealing at 800ºC cystallises PBZ. IZO (with chemistry $InZnO_3$) is also deposited by spin coat, over PBZ followed by solvent evaporation and annealing to crystal formation. Aluminium (Al) electrode is deposited over IZO for electricity passage and is done by thermal evaporation method. So, the device contains Si-PBZ-IZO-Al layers.

2.3. Testing of PBZ coating

PBZ is analysed by thermogravimetric analyser (TGA), differential thermal analyser (DTA), differential scanning calorimeter (DSC) and X-ray diffractometer (XRD) to obtain solution processing (sol-gel process) effectiveness and to identify % crystallinity. Optical Transmittance Spectra (OTS) or UV-Vis Spectra, AFM and Scanning Electron Microscope (SEM) are used to analyse film transparency and interface smoothness.

2.4. Dielectric worth by MIM

Metal-Insulator-Metal (MIM) set up is made to analyze dielectric performance. Current-voltage characteristics (I-V), frequency-dependent capacitance (C-f), saturation drain current-saturation drain voltage (I_D-V_D) and saturation drain current-gate voltage (I_D-V_G) plots are generated to obtain electronic worthiness of the ILOTFT

3. Results & Discussion

3.1. Characterisation of PBZ dielectric

TGA, DTA and DSC analyses show an abrupt weight loss at 410ºC vide moisture loss and solvent evaporation. Again, exothermic peaks at 550ºC and 850ºC. So, it is annealed at 550ºC and 850ºC to form dense pure polycrystalline thin film (**Figure 4**). Again, from **Figure 5**, PBZ contains cubic crystal as observed through the peaks (111) and (200).

OTS or UV-Vis spectra by 94% transmittance in visible light region, shows the dielectric PBZ is free from defect and impurity (**Figure 6**). This film is good for TFT. AFM and SEM images show surface roughness 4.6nm and so good for making smooth dielectric/semiconductor interface for TFT (**Figures 7 & 8**)

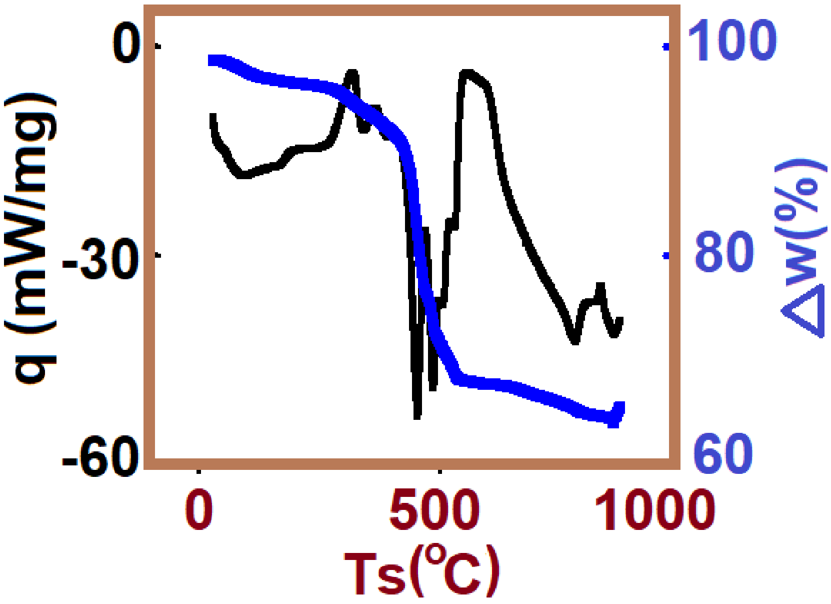

Figure 4. Thermal Analysis

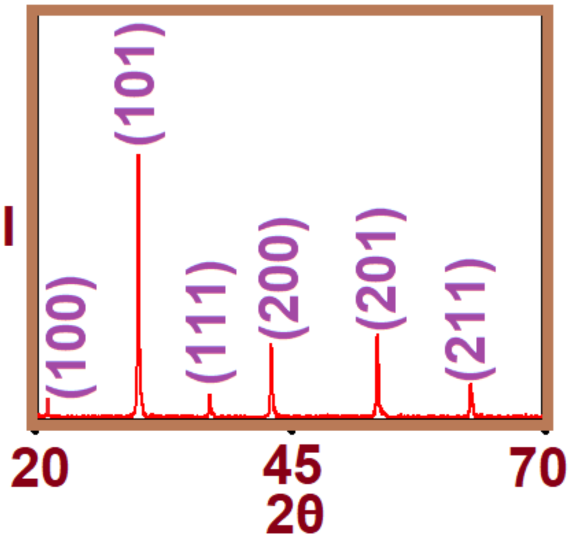

Figure 5. XRD Analysis

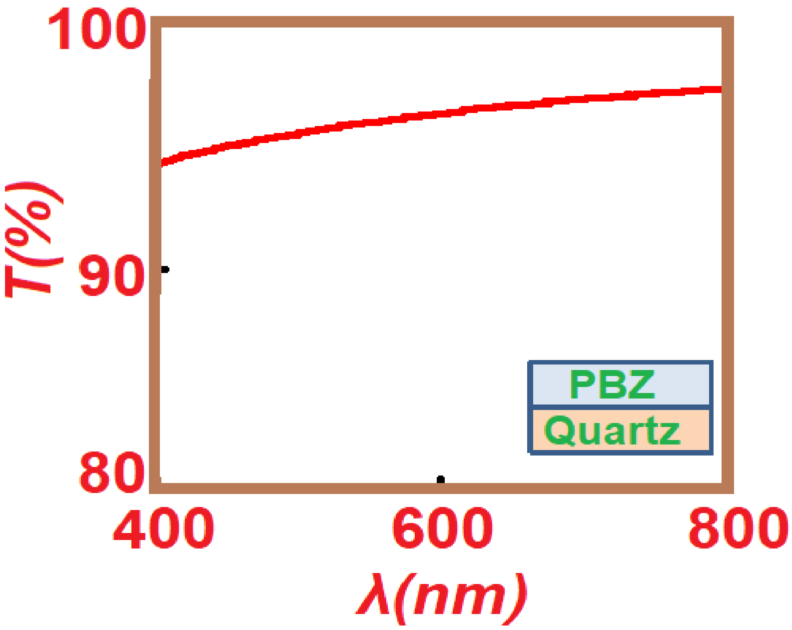

Figure 6. UV-Vis Spectra

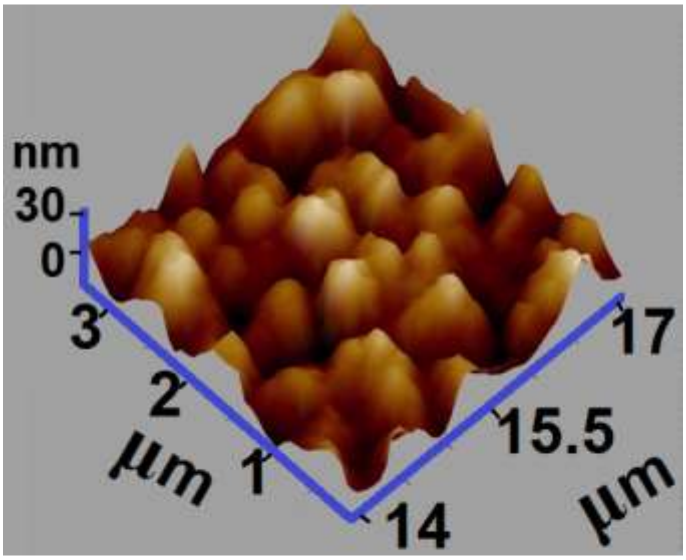

Figure 7. AFM image-PBZ layer

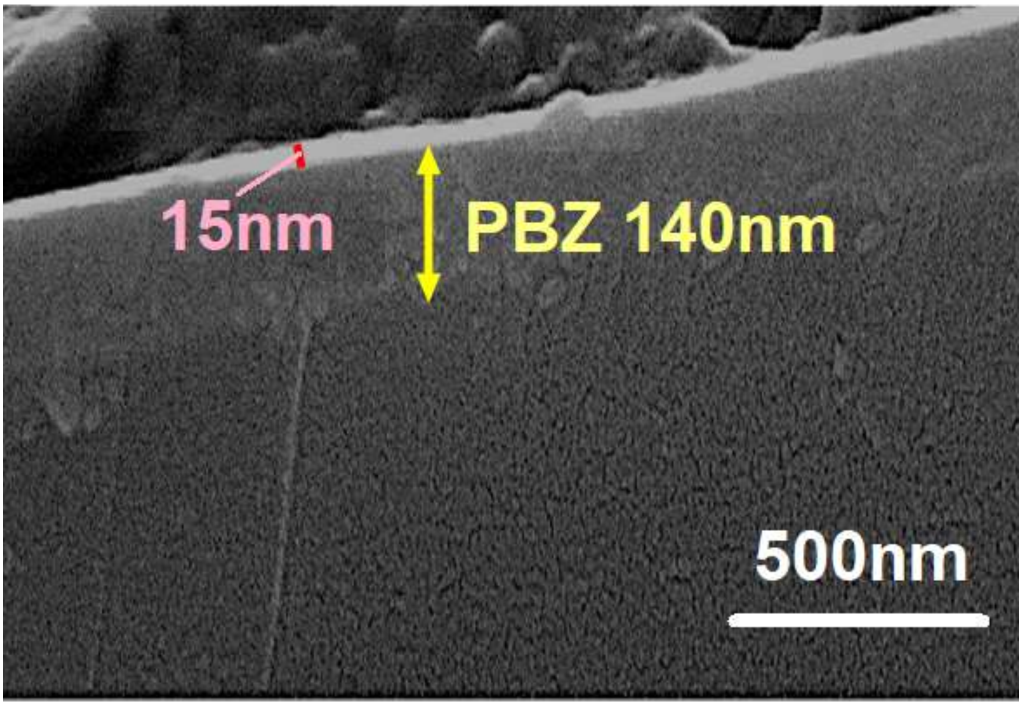

Figure 8. SEM image-PBZ layer

3.2. MIM-based electronic characterisation

MIM based analysis proves better leakage property and polarization response respectively via I-V and C-f plots (**Figures 9&10**). Hysteresis is very small in both the cases. Thin film PBZ capacitance is 65nF/cm^2, layer thickness 140nm and dielectric constant 12. From **Figures 11-13**, further analysis of electronic worthiness gives operating voltage 5V and break-down voltage 25V. Saturation current is achieved <3V. These data is suitable to make this PBZ as gate dielectric for TFT in low power electronics applications.

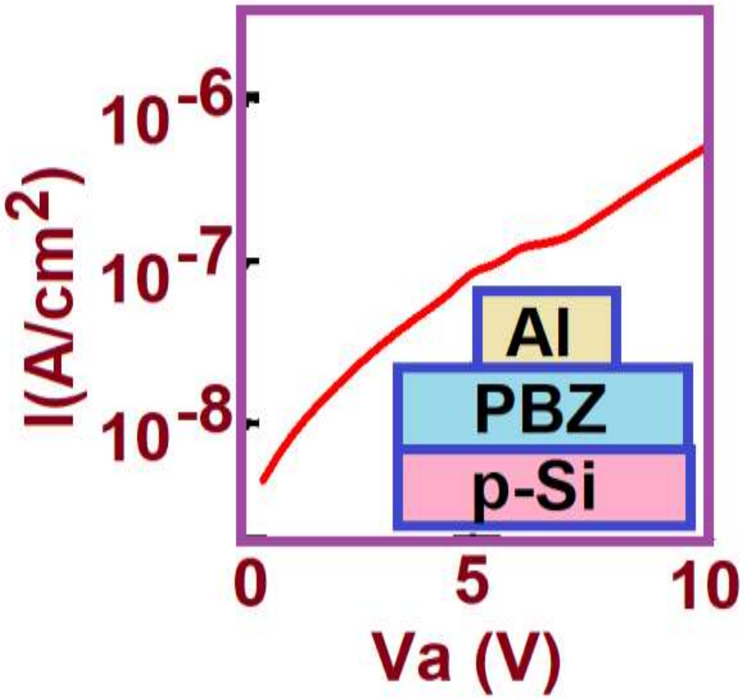

Figure 9. Current-Voltage plot

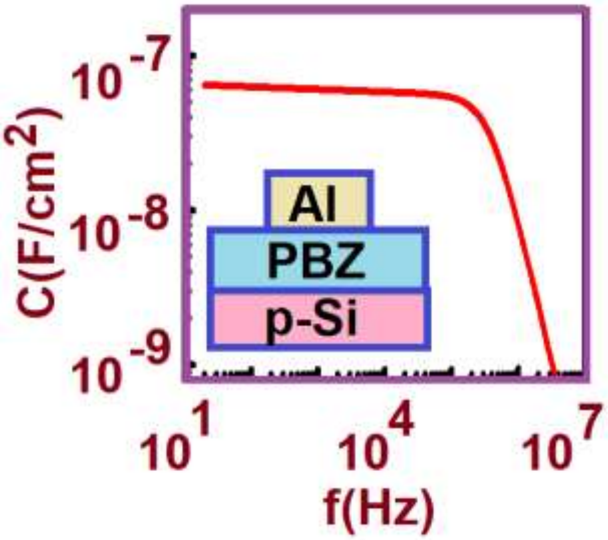

Figure 10. Capacitance-Frequency plots

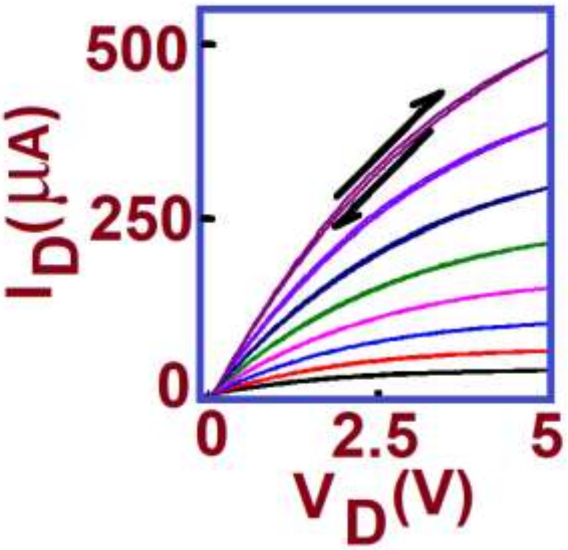

Figure 11. Output (I_D-V_D)

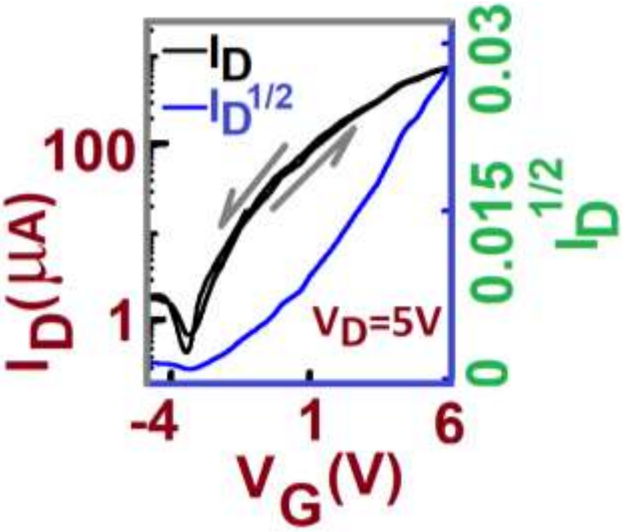

Figure 12. Transfer (I_D-V_G)

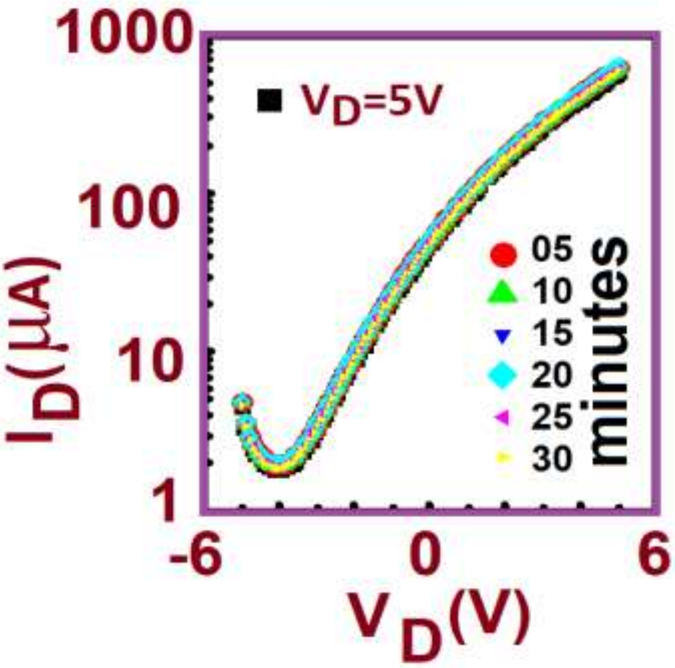

Figure 13. Operational Suitability

Effective carrier mobility (μ) in terms of saturation drain current (I_D) and sub-threshold voltage (Vss) of TFT are calculated with the help of Equations given in **Table 1**

Table 1. Equations for MOTFT electronic worth calculation

Effective Carrier Mobility	Sub-Threshold Voltage
$_D = \mu C \frac{W}{2L}(V_G - V_T)^2$	$V_{SS} = \left(\frac{d(\log I_D)}{dV_G}\right)^{-1}$
I_D - saturation drain current, μ - effective carrier mobility, C - capacitance per unit area, W - width (24mm), L - length (0.2mm), V_G - gate voltage, V_T - threshold voltage, Vss - sub threshold voltage	

4. Conclusions

PBZ made by sol-gel process is used as gate dielectric in solution processed IZOTFT. Device so made is operated with 5V, and can be used in low power electronics. Solution processed PBZ is annealed at 800°C to crystallize. PBZ is formed over quartz and doped Si. It is a nanofilm, transparent and insulator. IZOTFT with PBZ gate is good with e-mobility 4.5cm^2/V/s and on/off ratio 5x10^5. It can be used in microelectronics in future.

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