

Realization and Stability Analysis of Perovskite Oxide-Based Thin Films for Memory Applications

A Thesis submitted by

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Conclusions and Future Work

8.1 Conclusions

In the presented thesis work, the ABO_3 type perovskite oxides were used for the realization of resistive switching devices with different memory behaviour like WORM and RRAM. The observed results confirm the potential of perovskite oxides to be used as a switching layer in memory devices. To address the current requirement of fast, denser and cost-effective NVM memory technique, this thesis work provides a valuable outcome in terms of device optimization. Further, the low-temperature deposition of the switching layer makes these devices compatible with CMOS integration. Various aspects of memory technology including classification, challenges and advantages are discussed in chapter 1. Further in this chapter, we discussed the potential of resistive switching devices as an emerging candidate for NVM technology. The various types of resistive switching behaviour and mechanisms with performance parameters were explained in detail. In the last, we mentioned the state-of-the-art progress of the perovskite oxide-based resistive switching devices.

The material synthesis, characterization and device fabrication tasks involve a large number of equipment and characterization systems. The use of these instruments requires a basic understanding of working principles. Thus, in chapter 2, we explained the all techniques used during the various stages to carry out the presented work. It includes the furnace hydraulic press, RF-sputtering, thermal evaporation, XRD, UV-Vis, Raman, FESEM, AFM and electrical characterization setup. Further, we mentioned a brief introduction to ion irradiation facilities for low energy ions and swift heavy ions established in Inter-university Accelerator Centre (IUAC) New Delhi.

In chapter 3, the material synthesis and sputtering target preparation flow were explained in detail. It includes the material characterization of the synthesized $BaTiO_3$ powder. Further, the optimization of deposition parameters to deposit $BaTiO_3$ for as a switching layer to fabricate the resistive switching devices. The device performance concerning the deposition parameters was analysed. The fabricated devices show the write-once-read-many (WORM) memory behaviour which is widely used as a memory element in RF-id tags. The thickness and the deposition temperature of $BaTiO_3$ thin film significantly alter the WORM properties. We observed a reduction in switching voltage from 1.31 V to 0.49 V as the deposition temperature increased.

Further in chapter 4, we explored the effect of Ar^{+6} ions irradiation on the WORM properties of amorphous $BaTiO_3$ thin film. A varying fluence of ions was exposed to the thin film and respective results were analysed. The results reveal that there is no significant alteration in the WORM properties of the devices upto the irradiation level used in the studies. The stable WORM behaviour irrespective of the irradiation confirms the radiation-hard nature of the $BaTiO_3$ thin film-based WORM devices and their potential to be used in radiation harsh environments.

In chapter 5, the material synthesis and sputtering target preparation flow were explained in detail for $SrTiO_3$. It includes the material characterization of the synthesized $SrTiO_3$ powder. Further, the optimization of deposition parameters to deposit $SrTiO_3$ as a switching layer to fabricate the resistive switching devices. The $SrTiO_3$ thin films show bipolar RRAM behaviour at low switching voltages. Further, the devices were subjected to an irradiation

chamber for Au ion irradiation and the effect of irradiation was explored. The stable performance of the fabricated RRAM devices after irradiation confirms the radiation-hard nature of the SrTiO₃ thin film-based RRAM devices and their potential to be used in radiation harsh environments.

In this sequence to explore the resistive switching properties of perovskite oxides, we optimized the synthesis process of LaFeO₃ powder and prepared the sputtering target mentioned in chapter 6. The deposition parameters were optimized for resistive switching device fabrication. The LaFeO₃ thin film devices show the cF8 bipolar RRAM behaviour. Further the results confirm the increased switching voltage with increased thickness of devices. The devices show a forming free stable RRAM behaviour that makes them suitable for the neuromorphic application. The synaptic behaviour of these devices confirms the potential to be used for neuromorphic memory applications. The reduction of switching voltage with the increased deposition temperature upto 450° shows the potential of these devices as low-voltage operating devices.

Chapter 7 explores the effect of Ar⁺⁶ ions irradiation on the RRAM properties of amorphous LaFeO₃ thin film resistive switching devices. A varying fluence of ions as that with BaTiO₃ thin films was exposed to the thin film and respective results were analysed. The results reveal that the devices were able to maintain the RRAM behaviour but the switching voltage was significantly increased. The retention data shows the stable read state even after the irradiation and hence we can conclude that the LaFeO₃ thin film RRAM devices have the potential to be used in a radiation harsh environment with neuromorphic computing capabilities.

In conclusion of this thesis work, we explored different perovskite oxides as a switching layer for the realization of resistive switching devices. The effect of deposition parameters was analysed to get the optimum performance of the fabricated devices. Further, the exposure to ionic radiation studies reveals the potential of these devices to be used in a radiation harsh environment.

8.2 Future Work

Overall, despite the promising results observed during the presented studies, there is a lot of scopes and dimension that need to be explored in future. The device area plays the important role in the conduction mechanism of these devices and hence there is a huge potential to scale down the feature size upto the nanometric scale level to develop high-density storage. The common bottom electrode configuration has many drawbacks so advanced device structures like crossbar should be explored to achieve further downscaling of the devices and low variability.

The low-temperature deposition of these perovskite oxides offers stable memory performance and has the potential to be used in flexible and wearable electronics as a memory element. However, flexible resistive switching devices have been widely studied with different materials as switching layers but the metal oxides have not been explored so much due to the high-temperature growth of the thin films. The room temperature growth of these switching layers will enable the limitation associated with their application in flexible electronics and it needs to be explored in future.

Further, the in-memory computation should be realized using the LaFeO₃ thin film RRAM devices to address the limitation of current memory technologies. The experimental findings revealed good potentiation and depression behaviour and the complete neuromorphic studies will enable the application of these devices for neuromorphic computing applications.