MATERIALS ENGINEERING SEMINAR

"Nanostructural Designs in Oxides for Enhanced Resistive Switching Properties Towards Neuromorphic Computing"

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ABSTRACT

Neuromorphic computing is a brain-inspired computing paradigm that integrates processing and memory units into a single device, offering advantages for artificial intelligence applications. Resistive switching devices, known as memristors or RRAM, are promising for neuromorphic hardware due to their resemblance to biological systems. These devices serve as artificial neurons and synapses, replicating key neural functionalities. However, resistive switching devices face challenges hindering their applications, including variability issues and trade-offs in endurance and retention. To address these challenges, research has focused on defect engineering methods and structural designs including utilizing extended defects, multilayer stack, nanoparticle embedding, and electrode patterning.

In this dissertation, various engineering methods have been explored to enhance the resistive switching properties of several oxide and oxide nanocomposite systems. Simple binary oxides with demonstrated CMOS compatibility are chosen as the switching materials. Firstly, the impact of extended defects, including phase boundaries and grain boundaries, on resistive switching has been investigated. Self-assembled HfO_2:CeO_2 vertically aligned nanocomposite and pure CeO_2 films are examined, demonstrating the influence of these defects on resistive switching behavior. The successful demonstration of a self-assembled vertically aligned nanocomposite, specifically HfO_2:CeO_2, showcases the role of phase boundaries as sites for oxygen vacancies and pathways for their transport. The presence of phase boundaries leads to enhanced conductivity and electroforming-free behavior. Secondly, the investigation of different morphologies of grain boundaries in CeO_2 reveals the favorable properties of the "columnar scaffold" morphology, including a high On/Off ratio, low switching voltage, and low cycle-to-cycle variability. Thirdly, the use of self-assembled Au nanoelectrodes in a $BaTiO_3$-Au vertically aligned nanocomposite has been explored to control the electric field distribution in the HfO_2 switching layer. These results include improved threshold switching performance, including reduced voltage requirements, enhanced switching uniformity, and increased stability. These devices serve effectively as artificial neurons, enabling stable and low-power leaky integrate-and-fire functionality. Lastly, highly uniform resistive switching with controllable retention is demonstrated in an oxidized TiN system forming a unique TiO_2/TiN stack for the resistive switching devices. The resistive switching and synaptic behaviors of the system are investigated, showcasing the effectiveness of simple engineering methods in improving the overall resistive switching properties. Overall these findings contribute to our understanding of resistive switching in various materials systems and offer insights into the development of more efficient and tunable resistive switching devices for practical applications.

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