Activation of resistive switching in TaOx on the nanoscale

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Memristive and nanoionic devices have recently emerged as leading candidates for neuromorphic computing architectures. The promise of the technology is to create a brain-like ability to learn and adapt, but the technical challenges are significant, starting with an accurate neuroscience model of how the brain works, to finding materials and engineering breakthroughs to build devices to support these models, to creating a programming framework so the systems can learn, to creating applications with brain-like capabilities. Resistive switching in thin films phenomena have by now been widely reported throughout an enormous range of material classes, almost making them a generic property of field-induced material response. However, the mechanisms behind resistive switching have been persistently difficult to control, not in a small part due to its non-equilibrium nature. Moreover, from a practical side, the need for "controlled breakdown" to initiate resistive switching, is undesired due to significant power dissipation, stochasticity as well as dramatic restructuring of the material. Such structural changes is the major reason why the structure-function paradigm for resistive switching materials is difficult to develop.

In present work we have shown two an alternative pathways to induce resistive switching of prototypical TaOx –(1) via direct biasing with a nanoscale AFM probe in oxygen free environment and (2) via He-ion patterning. Both approaches were carried out with fine control over the net amount of dissipated energy during activation. With direct AFM probe activation in oxygen free environment, we were able to switch conducting properties of the material in poorly controlled conditions. This is a similar pathway to electroforming, albeit combined with microscopy, which revealed directly the changes induced in the film during field-induced insulator-metal transition. Filamentary regions down to 20 nm in dimension could be routinely achieved by reducing the peak current during the activation cycle. Nevertheless, the process remains extremely stochastic. In contrast, by use of He ion irradiation pristine insulating state can be easily converted to conducting and resistively switching state without any breakdown, but the transition itself is a smooth function of ion-irradiation dose. These findings revealed numerous intermediate states of TaOx can be created by controlled ion-irradiation. Remarkably, this effect is directly compatible with device architectures, potentially allowing for a high-degree of on-demand tunning of neuromorphic circuitry and materials. By combining AFM and SEM-CL we were able to determine dependence of the ion dose/materials damage correlated with the chemical, structural and compositional tunability of thin TaOx films which offers significant opportunities to neuromorphic nanoelectronic materials in comparison with more mature technologies based on traditional bulk electronic materials.

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