From artificial neurons and synapses to standards for resistance and time – rational design of memristive functionalities

Ilia Valov[1,2]

[1]Research Centre Juelich, PGI-7, Juelich, Germany
[2]Institute of Electrochemistry and Energy Systems, BAS, Sofia, Bulgaria

Tuning the electric characteristics of nanoscale devices by reversible insertion or removal of ions has proven to be a reliable and effective way to achieve spectacular functionalities. The process of ion incorporation can be considered as electrochemically driven doping, where the inserted species play the role of either donors or acceptors, and the resulting electron band structure and conductivity are a direct function of the chemical state and physicochemical properties of the mobile dopants' concentration. Ideal example for the nanoionic-enhanced devices are memristors, considered the next generation building units of the future, brain-inspired hardware, going beyond the von Neumann architecture. Memrsitive devices exhibit a broad spectrum of functionalities, being used for volatile and non-volatile memories, selectors, sensors, field-programmable gate arrays and for in-memory computing. Sharing same electrochemical fundamentals with their biological counterparts, they are especially appropriate to be used as artificial neurons and synapses for neuromorphic applications. However, challenges for this technology remain variability and still unresolved puzzle on precise tuning and control of the different functionalities. To overcome these problems, in-depth understanding of the fundamentals of material related properties and details on nanoscale processes is urgently required.
In this contribution, essential but mostly overlooked fundamental factors, that strongly influence memristive properties will be discussed, that are of key importance for establishing a materials-based, rational design roadmap. It will be showcased that the level of intrinsic impurities in both oxide and metal components determine the performance. Stack composition and even the thickness ratios of individual layers within the stack should be properly adjusted. The importance of the interplay between the Schottky and electrochemical redox barriers, and the resulting demand on rational interface engineering will be highlighted. New areas of application are identified, using memristors as standards for resistance and time in the light of the revised SI system of units. Finally, results from a newly developed, unique synchrotron-based technique for nm-resolved structural and chemical analysis will be shown, demonstrating the prospective for revealing new fundamental knowledge, further expanding the fields of application for memristive devices.