Numerical Modeling of Resistive Switching in a RRAM Device

D. Niraula[1], V. Karpov[1]

[1]University of Toledo, Toledo, OH, USA

Abstract

A new nonvolatile memory device based on its resistance state has emerged known as resistive random access memory (RRAM). It operates by switching between the high resistance and low resistance states which can be interpreted as logical 0 and 1 variables. Understanding the resistive switching (RS) of RRAM is vital before its industrial manufacturing. In this project, our group has proposed a general phenomenological theory based on thermodynamics of phase transformations to explain the RS in RRAM independent of the underlying microscopic processes like migration of ions and defects. The filamentary RRAM device switches by growth and dissolution of the conducting filament (CF) in an insulating host. Our approach describes RS via phase transitions between 3 phases, namely, insulating, and conducting unstable, and metastable phases. Several analytical solutions describing RRAM features including the current voltage (I-V) characteristics are predicted. Our numerical modeling utilizes the thermodynamic approach as well. However, it leads to more quantitative results based on realistic geometries and material parameters. It describes the peculiar domains of current voltage characteristics corresponding to the RS. . Our computational technique involves calculating of the system free energy and finding the stable phase configuration during RS. The corresponding electric current and voltage are then computed. We utilize the COMSOL Multiphysics® simulation software package to compute the electric field and temperature distributions that are necessary to find the system free energy. A generic cylindrical nanoscale RRAM device is constructed in COMSOL Multiphysics® using the 2D Axisymmetric space dimension. Electric Currents sub module under AC/DC main module is utilized to compute electric field and simultaneously coupled with Heat Transfer in Solid sub module under Heat Transfer main module to compute the temperature distribution due to joule heating. The electric field and temperature distribution is calculated for various filament radius and gap (dissolved filament) size to obtain the system free energy for various source voltage. We utilize MATLAB® package via LiveLink™ to MATLAB® to find the stable phase configurations for various source voltages and to communicate with COMSOL Multiphysics®. Utilizing the known material parameters, our modeling remains approximate as compared to the measured current voltage characteristics; however, it correctly reproduces their non-trivial trends. Further improving our modeling will increase the computational complexity by including various stochastic features and the quantum mechanical tunneling typical of the amorphous phases involved. This work was supported in part by the Semiconductor Research Corporation (SRC) under Contract No. 2016LM-2654.

Figures used in the abstract

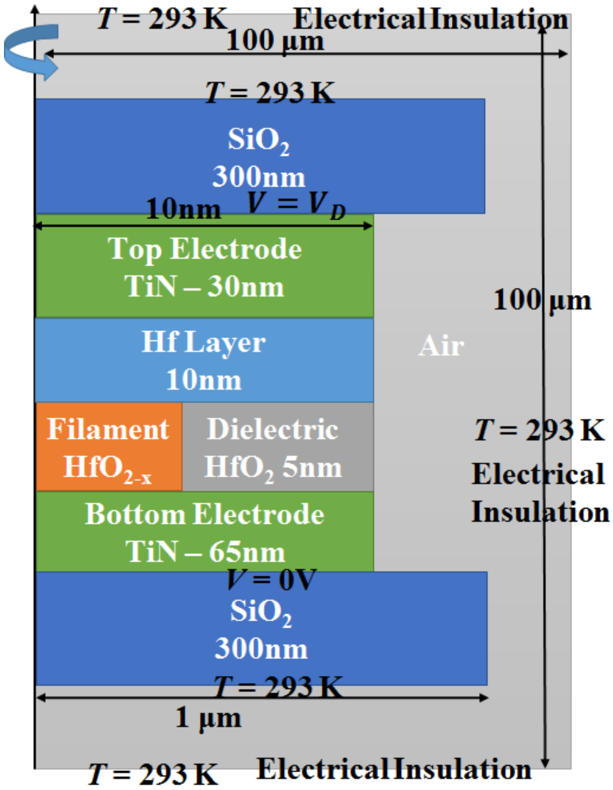

Figure 1: Schematic of half of the cross section of nanoscale cylindrical RRAM device modeled in 2D axisymmetric space dimension of COMSOL Multiphysics® simulation software which depicts the device dimension, domains material name, and required pde boundary conditions. Note: Figure not drawn to scale.