CALIFORNIA STATE SCIENCE FAIR
2014 PROJECT SUMMARY

Name(s)

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S1802

Project Title

A Kinetic Monte Carlo Study of the Scalability and Variability of the Forming Voltage of Transition Metal Oxide ReRAMs

Abstract

Objectives/Goals

Resistive random access memories (ReRAMs) are currently under intense investigation because they are promising alternatives to flash-based non-volatile memories, which are not expected to scale to dimensions below about 20nm. "Forming" is a relatively high-voltage process that is used just after manufacturing to functionalize the ReRAM device, by creating a conductive filament whose resistance is then modulated to encode "0" or "1" memory states. Since forming is a one-time process and since the underlying physics is stochastic in nature, statistically meaningful experimental characterizations of the forming voltage (V_f) are difficult to perform. I have addressed this problem using a novel simulator that I developed. Even though forming is a one-time process, it is important to characterize it because it determines the overall scalability of this emerging technology.

Methods/Materials

My simulator captures one of the unique aspects of ReRAMs: mixed ionic and electronic transport. I treat the electronic effects--both current flow and temperature rise due to Joule heating--using equivalent resistor networks, and oxygen vacancy generation and ion migration using kMC. The distribution of vacancies determines the linear/nonlinear elements of the resistor network, and the heat generated by electron flow in this network in turn determines the vacancy/ion generation rates that drive kMC. The strong coupling between electronic, thermal and ionic effects allows my simulator to closely reproduce the experimentally observed rapid increases in current at the V_f threshold.

Results

I characterized the forming voltage and its statistical variability as device dimensions and forming conditions were varied: (1) V_f vs thickness, (2) V_f vs. width, (3) V_f vs. maximum allowed current at forming, (4) V_f vs. temperature and (5) V_f vs. voltage ramp rate.

Conclusions/Discussion

I found that the critical voltage at which the filament forms depends linearly on thickness and roughly logarithmically on width. I motivate the thickness dependence using an effective field argument, and then offer a plausible statistical argument to explain the width dependence. I also found that forming at an elevated temperature can both reduce the average V_f, as well as the variability in V_f.

Summary Statement

I developed a novel kinetic Monte Carlo (kMC) simulator that possesses physics-based realism as well as speed, and used it to investigate the forming process in ReRAMs, and project V_f trends in deeply scaled (~10nm) memory cells.

Help Received

I would like to thank my advisors Dr. Dipu Pramanik, Mr. William Abb and Mr. Ronald Nicoletti for their valuable guidance throughout the course of my work.