CALIFORNIA SCIENCE & ENGINEERING FAIR
2019 PROJECT SUMMARY

Name(s)

Akhilesh Balasingam

Project Number

S1004

Project Title

Brain-Inspired Circuitry for the Future of AI: Optimizing the Analog Response of RRAMs Under Pulsing for Synaptic Use

Abstract

Objectives

On tasks such as pattern recognition, the human brain, which consumes 20W of power and takes up 1.5L of space, substantially outperforms artificial intelligence (AI) algorithms running on large clusters of von Neumann (vN) computers. To close this glaring gap, intense research is underway on brain-inspired alternatives to vN. Like the brain, these alternatives capture the computationally-intensive parts of AI algorithms in massively parallel circuitry, interweaving low-power computing and analog memory (synapse) elements.

My research optimizes the analog response of resistive random access memories (RRAMs), to permit their use as synaptic elements in brain-inspired architectures for AI-centric computing. I chose to study non-filamentary (nf) RRAMs, because their conductance can be adjusted in a continuous, or analog, fashion with voltage pulses applied between their 2 terminals.

Methods

Key steps of my research: (a) Write a Kinetic Monte Carlo simulator (KMC), capturing mixed ionic-electronic conduction central to nf-RRAM operation. Model conductance using nonlinear resistor network--apply Kirchhoff's Laws and Newton's Method. (b) Use KMC to study nf-RRAM response under different pulsing schemes. (c) Find pulsing schemes that yield the best synaptic response. (d) Benchmark the system-level accuracy of my synaptic designs in NeuroSim, a neural network simulator.

Results

My contributions: (a) Developed physics-based KMC simulator in Python. (b) Validated KMC by comparing its predictions with published experimental data. (c) Using KMC characterized the synaptic behavior of nf-RRAMs under several pulsing schemes: standard, stepping, hybrid. (d) Standard pulsing yielded the poorest synaptic behavior. (e) Hybrid scheme yielded the most linear/symmetrical synaptic response. (f) Analyzed the system-level behavior of my synapses in NeuroSim and showed that my hybrid scheme yields nearly-ideal learning accuracy.

Conclusions

I studied and optimized the synaptic behavior of nf-RRAMs, using a KMC simulator I developed. Using my simulator, I identified a pulsing scheme that yields synaptic behavior with the desired analog properties of linearity and symmetry, and at the system-level I showed that this scheme yields 90% accuracy, which is very close to the 93% rate achieved by the ideal synapse.

Summary Statement

I developed a hybrid pulsing scheme that allows nf-RRAMs to be used as synapses in massively parallel brain-inspired architectures, which can enable AI to be performed on small IoT (Internet of Things) devices.

Help Received

I developed and performed the simulations and analysis on my own. I would like to thank my mentor for guiding me through the current literature. I would like to thank my school math teacher for helpful discussions and encouragement.