Background and Motivation

- Neuromorphic systems are novel computing systems that mimic the functionality of biological neural systems
- They consist of a network of synapses and neurons where synapses can be thought of as memory elements while neurons are the processing elements.
- Resistive RAM (ReRAM) devices have been used as synaptic elements, primarily, for there analog programmability wherein Ohm’s Law can be leveraged for the dot product operation
- Neurons on the other hand are still realized using conventional CMOS circuitry which is both area and power consuming
- Insulator Metal Transition (IMT) devices are novel nanoelectronic devices that can be leveraged in realizing neurons.
- This work presents a compact model for IMT devices and proposes the design of an IMT-based neuron

The Neuron Model

- Inputs from the synapse network are accumulated and fed to the neuron’s input
- The neuron then compares the accumulated sum to a threshold value and fires if the value exceeds the threshold.
- This Structure is commonly referred to as Integrate And Fire (IAF) Neuron
- The mathematical model of the neuron can be expressed as follows:
  \[ y = \begin{cases} 
  1, & \sum V_i G_i > \text{Threshold} \\
  0, & \text{Otherwise} 
\end{cases} \]

IMT Compact model

- While the switching mechanism of IMT device and its underlying physics is still subject to further research, Joule heating is believed to play a major role in the phase transition of the IMT device
- Other works in the literature suggest that an Electric field assisted switching is more plausible
- Two models exist in the literature that use the Joule heating as the major driving force instigating device switching
- Those models, however, are not suitable for SPICE simulators.
- We developed a compact SPICE model for IMT devices

  \[
  \begin{align*}
  R_{\text{IMT}} &= LRS + \frac{1}{\text{exp}\left(\frac{(HRS - LRS)}{T}\right)} \\
  C_{\text{th}} \frac{dT}{dt} &= \text{IMT} - \frac{T}{T0} \\
  \end{align*}
  \]

IMT-based Neuron

- The weighted sum through the synaptic elements is represented by a current source feeding into a capacitor
- The core of the neuron is the IMT device that switches from a high resistance state to a low resistance state once the temperature exceeds the critical temperature
- The IMT stays idle for a period of time known as the refractory period before it relaxes back to a high resistance state after the device has cooled down below the critical temperature
- The Buffer and the Spike Generator circuits are used for signal restoration

Simulation Results

- A compact model of IMT devices and an IMT-based IAF neuron were presented in this work.

Conclusion

Acknowledgement

This material is based in part on research sponsored by Air Force Research Laboratory under agreement number FA8650-16-1-0065 and by the Air Force Office of Scientific Research under award number FA9550-16-1-0301. The U.S. Government is authorized to reproduce and distribute reprints for Governmental purposes notwithstanding any copyright notation thereon. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the United States Air Force.