Artificial Neuron using Ag/2D-MoS_2/Au Threshold Switching Memristor

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ABSTRACT

- Neuromorphic computing comprises of systems that are based on the human brain or artificial neural networks, with the promise of creating a brain inspired ability to learn and adapt.
- Technical challenges, such as developing an accurate neuroscience model of the functionality of the brain to building devices to support these models, are significantly hindering the progress of neuromorphic systems.
- We are fabricating a Ag/MoS_2/Au threshold switching memristor (TSM), to emulate four critical behaviors of neurons - all-or-nothing spiking, threshold-driven firing, post firing refractory period and stimulus strength based frequency response
- Continuing to emulate biological neurons using memristors can help solve many optimization and machine learning problems, which in turn, can make electronics as energy-efficient as our brain.

INTRODUCTION

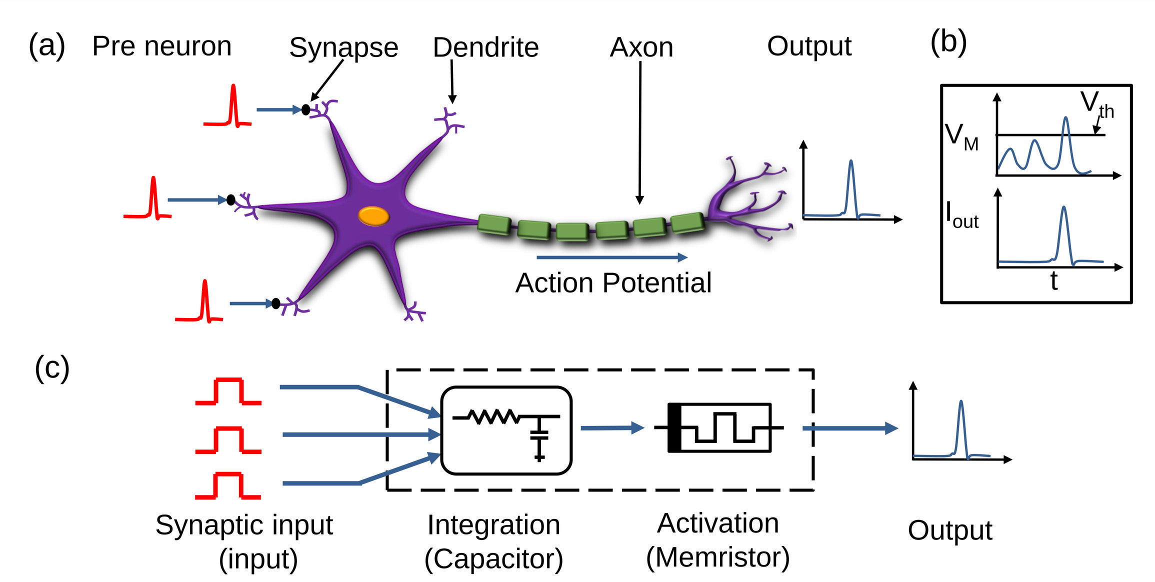


Figure 1: (a) Representation of biological neuron. (b) Output spiking from neuron. (c) Representation of memristor based artificial neuron [4].

- Neuromorphic systems encompass implementations that are based on biologically-inspired or artificial networks and are notable for being highly parallel and requiring low power, thus having the potential to perform complex calculations faster and more efficient compared to Von Neumann architectures [3].
- The limitations of current von Neumann architecture have paved the way for artificial neural networks (ANN) to meet these criteria. The memristor has become an emerging candidate to realize ANN through emulating biological synapse and neuron behavior [2-4].
- An integrate-and-fire neuron mimics the crucial behavior of a biological neuron. The capacitor integrates the charge and when the voltage across the capacitor is past the threshold value of the TSM, the neuron fires and an output spike is produced [4].

DEVICE FABRICATION

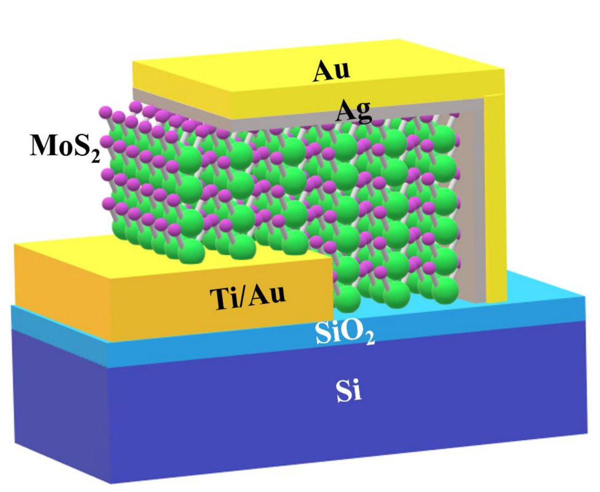


Figure 2: Ag/MoS_2/Au memristor device schematic

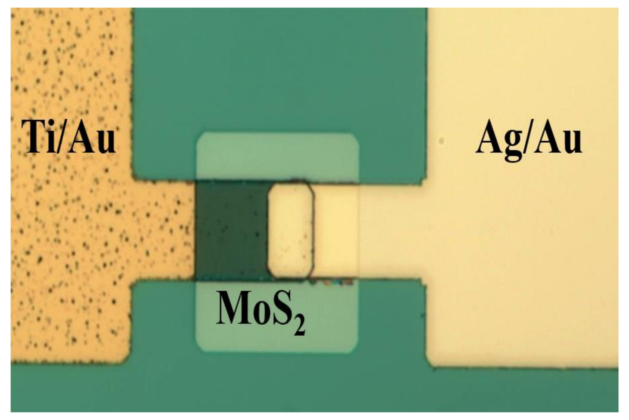


Figure 3: Optical image of Ag/MoS_2/Au memristor.

- On a Si/SiO_2 substrate, Ti/Au (5/100 nm) bottom electrodes are patterned and deposited by e-beam evaporation. 10 nm Mo is patterned and deposited on the bottom electrodes, followed by sulfurization of the Mo to MoS_2 by chemical vapor deposition (CVD). 15 nm Ag is deposited as top electrode, and capped with 40 nm of Au.

DC CHARACTERISTICS

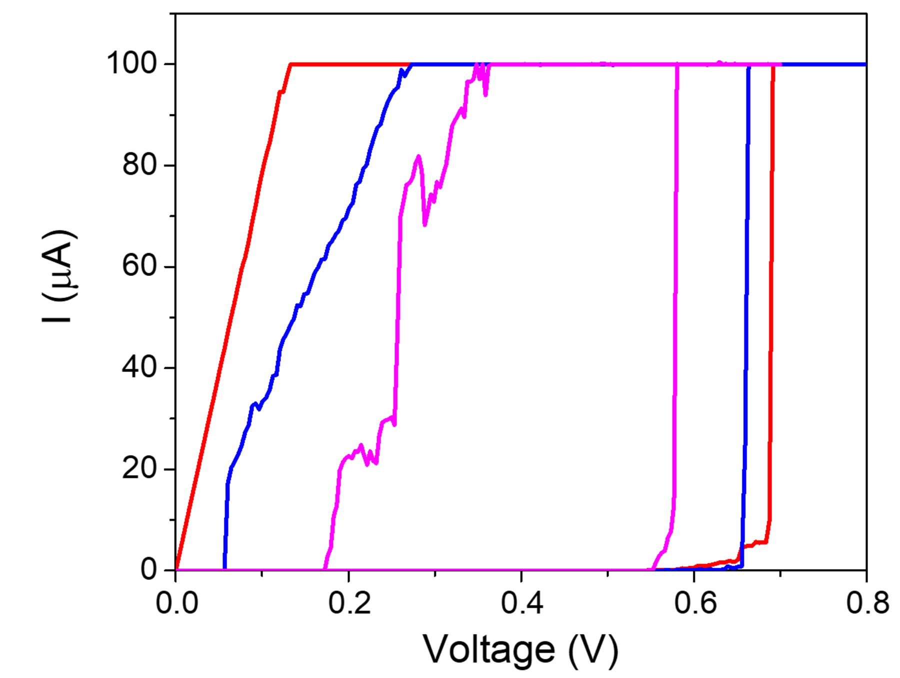


Figure 4: Ag/MoS_2 memristor showing stochastic volatile behavior

ARTIFICAL NEURON SPIKING

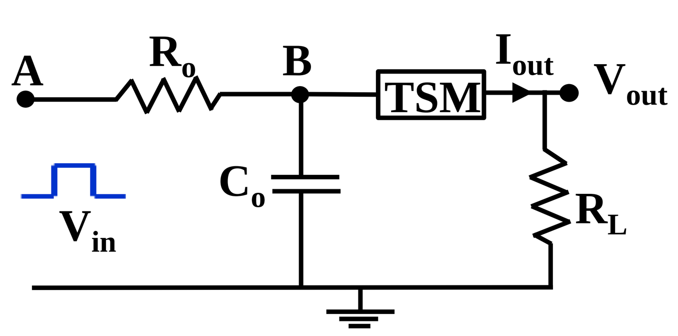


Figure 5: RC circuit for integration & firing (R_0= 10 kΩ, C_0= 100 nF, R_L=1 kΩ)

- TSM device is series connected with an RC circuit shown in Figure 5.
- Long continious train of pulses of 100 µs width are fed to the input terminal A.
- Increased spiking was observed in MoS_2 with increase in voltage pulse amplitude.

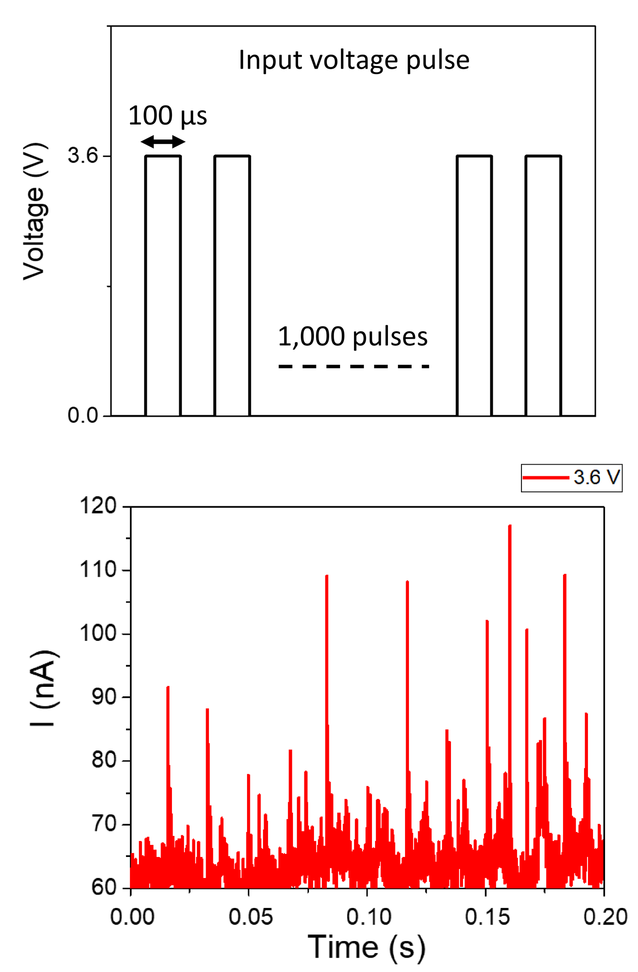


Figure 6: Artificial neuron spiking at 3.6 V

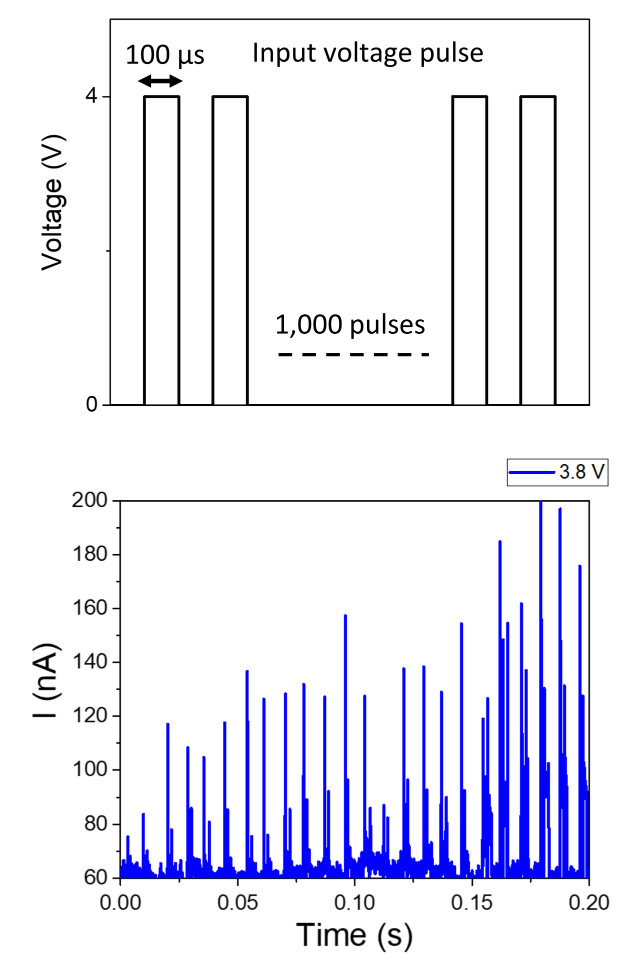


Figure 7: Artificial neuron spiking at 3.8 V

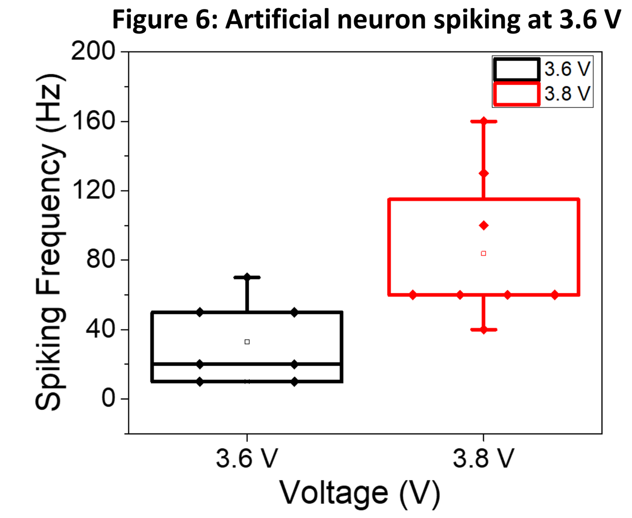


Figure 8: Relationship between spiking frequency and input voltage

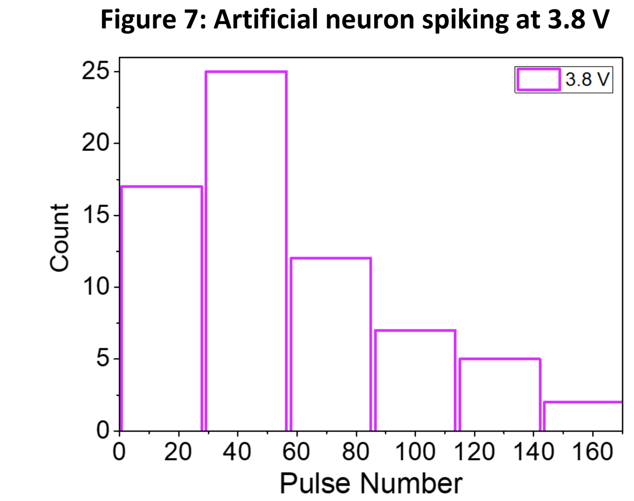
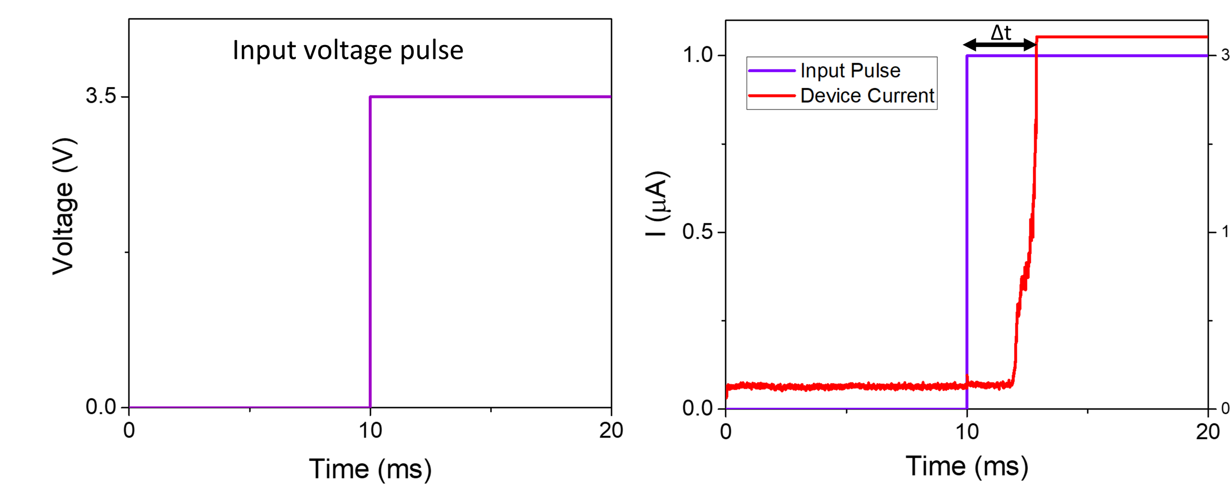


Figure 9: Histogram of inter-spike interval as a function of pulse number

STOCHASTIC MEASUREMENTS

Pulse Scheme



- If current reached >1 µA within the voltage pulse, the wait time was found.
- Delay time (Δt) is the time it takes for the device to set within the voltage pulse.

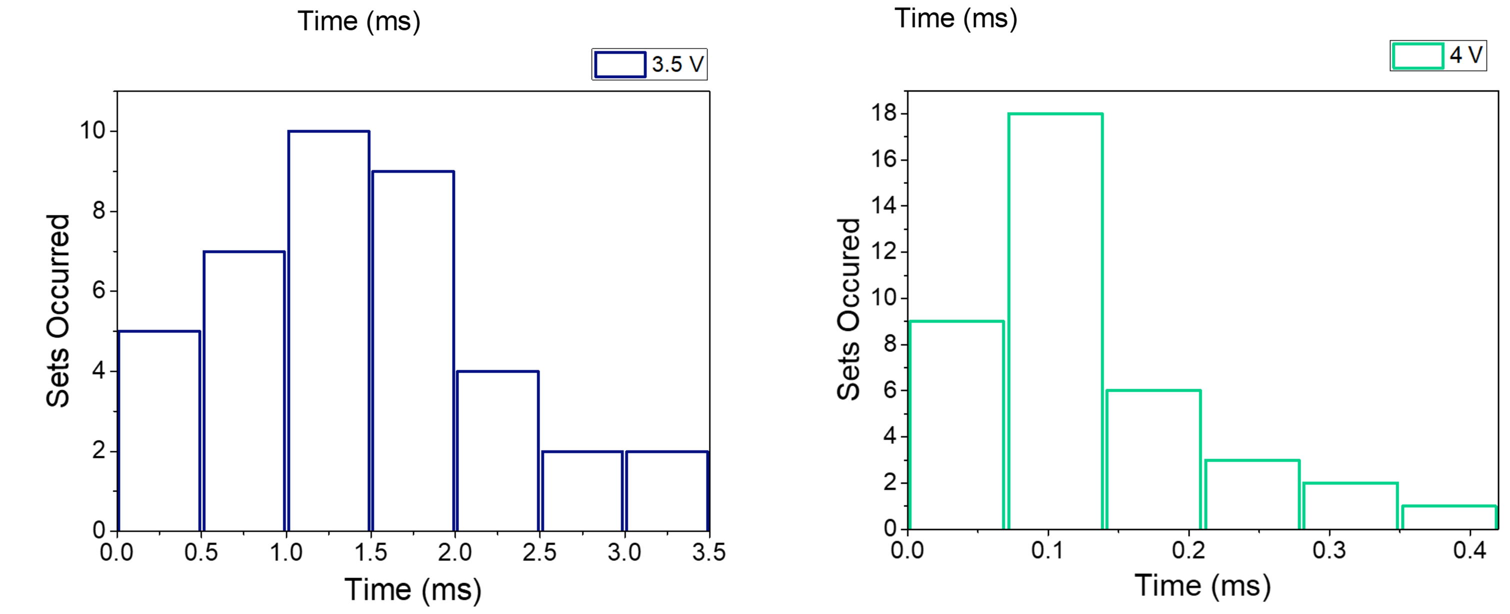


Figure 10: Distribution of switching time at 3.5 V and 4 V

Constant Voltage

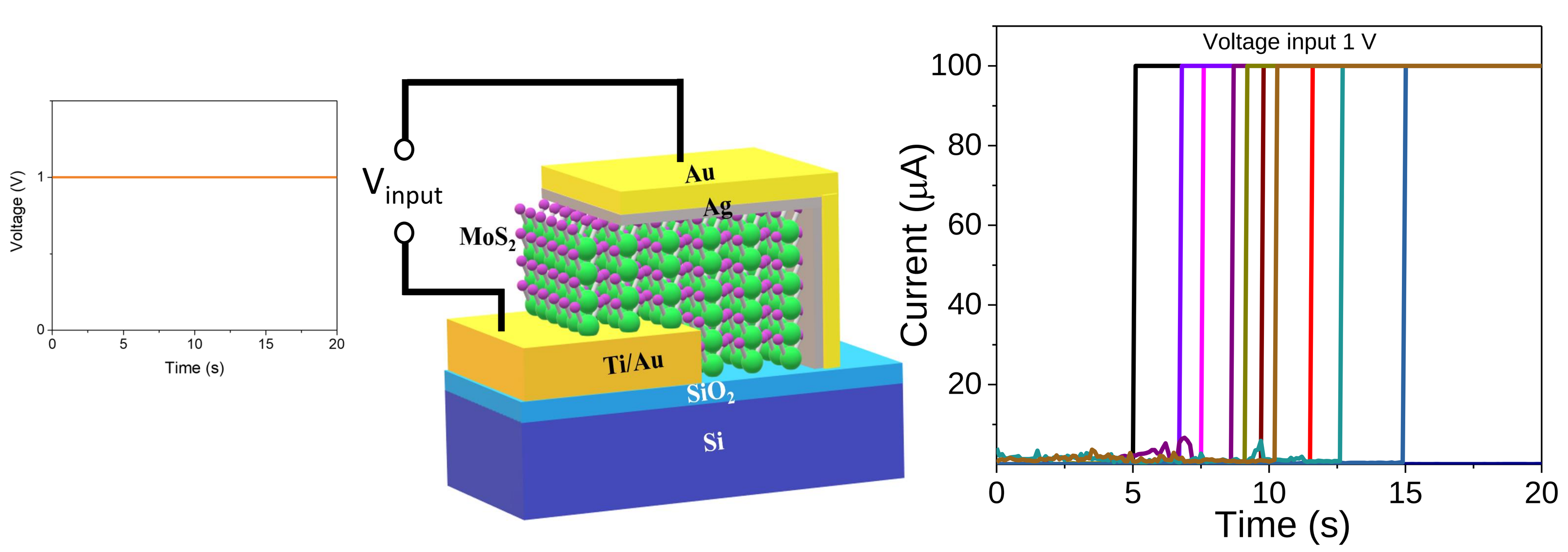


Figure 11: Time it takes device to switch when applying a constant voltage of 1 V

CONCLUSION

- It can be observed that increasing the input voltage leads to an increase in spiking in the devices.
- The time it takes to set the device also decreases with a higher input voltage.
- We have demonstrated a Ag/MoS_2/Au threshold switching memristor based artificial neuron that emulates all four critical behaviors of a biological neuron - all-or-nothing spiking, threshold-driven firing, post firing refractory period and stimulus strength based frequency response. The ability of emulating a biological neuron makes this threshold switching memristor a potential candidate for future neuromorphic computing.

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