Potential Application of time dependent Threshold Switching in Neuromorphic Computing

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***Abstract*— In 1955 Stan Ovshinsky proposed a model of the cognitive behavior of neurons. This led directly to his development of chalcogenide memory and threshold switching devices in 1963. Now five years after his death, 3DXPoint memory is a commercial reality and cognitive models are used in a variety of computing applications. Practical cognitive computers use arrays of graphics processors to model the synaptic weights and thresholds of neurons. This paper describes additional characteristics of neurons that chalcogenide switching devices can emulate, potentially applicable to making more powerful neuromorphic computers.**

Keywords—chalcogenide switching, neuromorphic computing, threshold switch, spiking neural network

I. INTRODUCTION

Chalcogenide alloy switching devices have many properties that make them good candidates for artificial neural networks. Most obvious are the ability to program the device to a wide range of resistances, simulating synaptic weights, and threshold switching simulating neuron firing. But there are other properties of these devices that could mimic other behavior in neurons that has recently been recognized as valuable for machine learning [1,2].

Neuron cognition models have always shown that pulse repetition in neurons diminishes their ability to fire, so the pulsing rate plays some role in cognition. In 1955 Ovshinsky studied the behavior of epileptic disorders and noted that the pulsing rate weakens the most used pathways, allowing other neural pathways to influence the cognitive process [3]. To show this, he spent the next 8 years exhaustively studying the switching properties of materials, culminating in the development of chalcogenide alloy memory and threshold switches [4].

Device measurements presented in this paper will show some properties of these switches that could be useful in cognitive computer systems.

II. EXPERIMENTAL SETUP

It is difficult to make accurate measurements on switching devices due to the capacitance of the measurement system. Any capacitance in parallel with the switch affects its switching properties and must be minimized. A Hewlett Packard 8110a dual channel pulse generator was used to provide pulses to the circuit with a 50 Ohm terminated coaxial cable. A 250 to 20K Ohm load resistor limits the current applied. A Tektronix TDS694C oscilloscope with active probes monitors the voltage of the device and the pulse with sub-Pico Farad loading on the circuit. Care must be taken to minimize lead lengths to the device contact. Figure 1a shows the equivalent circuit for this test apparatus.

Devices are fabricated on silicon wafers with a one-micron thermal oxide-insulating surface. A thin layer of TiN, a thin layer of carbon and a SiO2 layer are deposited. E-beam lithography patterns small vias in the top oxide forming small contacts to the underlying carbon. Next a chalcogenide alloy is deposited, with a thin carbon barrier and aluminum top contact. This top stack is patterned and etched into 30-micron pads. Figure 1b shows a cross sectional representation of this device. The top contact pad contributes ~1pF of capacitance in parallel with the device.

The combination of the circuitry and the device pad has a total capacitance of ~2pF. This capacitance has a strong effect on how the device turns off.

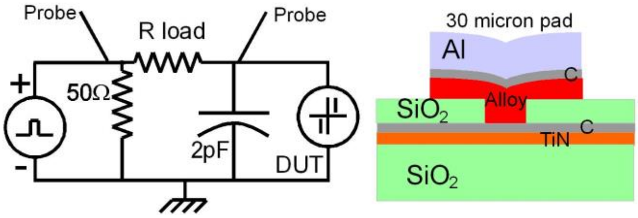

Fig.1: a) Circuit of the measurement; b) Device cross section

III. MEASUREMENTS

The following graph shows the current density and electric field characteristic of the threshold switching of a chalcogenide device. The pre-switching IV was taken with a parametric tester and the same device was measured with 30ns pulses to plot higher current points. The highest current applied to the device was a 30ns pulse with a current density of 60 million Amps per square centimeter. This pulse was then repetitively applied at a 1 MHZ rate for 3 hours with no change in the device's behavior. The low duty cycle of this repetitive pulse and the short pulse width of the signal are necessary to ensure that the power dissipation of the device doesn't alter its behavior. The 2pF parallel capacitance of the device causes the on state device to turn off at a current density of around 1e7 amp/cm2, however in VLSI implementations this capacitance will be substantially smaller, permitting stable turn off at much lower current densities [5].

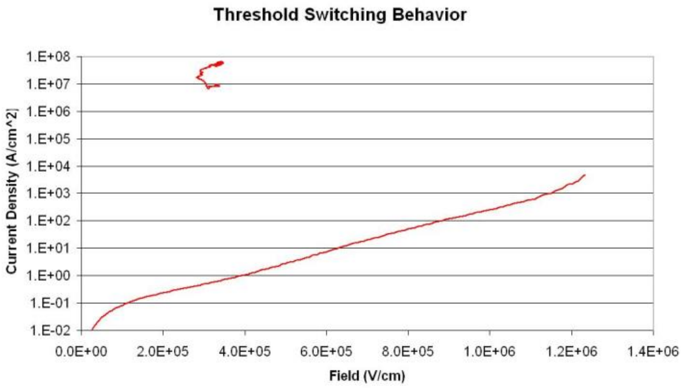

Fig. 2: The behavior is plotted using electric field and current density. Device area can be increased to allow greater currents and device thickness can be used to tailor the threshold voltage.

Two pulses in rapid succession with a varying time interval between the pulses were used to measure threshold voltage recovery time.

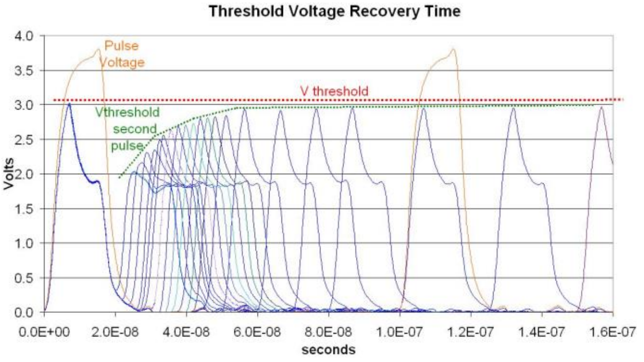

Fig. 3: Double pulse experiment with variable pulse spacing shows the dependence of threshold Voltage on the interval between pulses.

IV. DISCUSSION

The recovery time of threshold voltage exhibited by chalcogenide alloy switches, shown in Figure 3 above shows a strong dependence on the pulse rate for times less than 50 nanoseconds. This is roughly the clocking speed used in semiconductor memories. The speed of pulsing a cognitive array of these could exploit the threshold voltage recovery to mimic the threshold behavior of neurons. Namely, the reduced threshold immediately after switching and its gradual recovery simulate the actual behavior of brain neurons as mentioned in the introduction, thus making these switches candidates for creating true, brain-like neural networks.

Modeling has shown that thermal cooling of these devices happens in nanoseconds so the reason for this threshold voltage recovery is clearly electronic in nature [6].

The mechanism of drift in the reset state of chalcogenide alloy memory devices is possibly the same as that shown in this threshold voltage recovery [7]. It is observed that the resistance of a threshold switch drops after a switching event and complete recovery of the initial resistance state can take many months. In the reset state, a phase change memory device behaves the same as a threshold switch.

The high current densities achievable in these chalcogenide alloy switches, shown in Figure 2, can make current drivers that could go beyond the limitations of conventional MOS circuitry. New technologies typically rely on an underlying CMOS planar substrate. Threshold switches can implement logic without MOS transistors and three terminal switching devices have been demonstrated that simplify logic circuitry [8].

V. CONCLUSION

The switching behavior of chalcogenide alloy threshold devices exhibits a pulse timing dependence that could be useful in neuromorphic computers to change the threshold voltage of frequently used pathways in a neural network. This is an essential property of spiking neural networks. The pulse repetition rate for such an effect to work has been shown to be in the 20ns to 50ns range, which is in line with the signal speeds possible on a VLSI neural network implementation. Furthermore, the high current density capability of these devices could assist with signal driving in large networks.

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