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A self-resetting phase-change neuron

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ABSTRACT

Neuromorphic, or brain-like, computing applications of phase-change devices have to date concentrated primarily on the implementation of phase-change synapses. However, a phase-change device can also mimic the integrative properties of a biological neuron. Here we demonstrate, using both physical and circuit modelling, that by combining a phase-change memory device with a simple external circuit we can readily deliver a self-resetting spiking phase-change neuron.

Key words: neuromorphic, phase-change neuron, phase change memory

1. INTRODUCTION

Phase-change devices have exciting possible applications that extend far beyond providing simple binary memory, including the provision of novel optoelectronic displays [1], phase-change meta-photonics [2], integrated phase-change photonics [3], arithmetic and logic processing [4] and, the topic of this paper, brain-like or neuromorphic computing [5,6]. To date, most studies of the possible neuromorphic applications of phase-change materials and devices have concentrated on the implementation of synaptic mimics (see e.g. [5,6]), since in biological brains synapses typically outnumber neurons by many orders of magnitude. However, the natural accumulation property exhibited by phase-change materials, i.e. the fact that they can accumulate energy to gradually transform from the amorphous to crystalline phase, can be exploited to also provide a quite effective neuron mimic, as previously pointed out by Ovshinsky and ourselves [4], and as very recently convincingly demonstrated by Tuma et al., [7]. In the neuronal-mimic mode, the excitations provided to the phase-change device are tailored in amplitude and/or duration such that multiple input pulses are needed to induce full crystallisation (rather than a single input pulse as is the case for binary memory applications). After the receipt of a certain number of such tailored input pulses, the resistance of the phase-change cell falls below a pre-determined threshold value and a neuronal output spike is generated, usually by an external circuit. Here we use a simple comparator-type external circuit to generate the neuronal spike. We also feed back to the phase-change device a portion of this output spike so that the phase-change cell is reset, i.e. switched back to the amorphous phase, and the neuronal accumulation of input excitations can begin all over again. We here simulate the operation of such a self-resetting phase-change neuron using both physical and circuit (SPICE) modelling.

2. SIMULATIONS

We consider a phase-change ‘mushroom’ type cell with an active layer of $Ge_2Sb_2Te_5$ (GST), as shown in Fig. 1. The GST region is 75 nm in radius (W in Fig. 1) and 60 nm thick (TH), with the ‘heater’ electrode being 50 nm (HW) in radius. To model the electrically-driven phase-switching of the device, we use a combined electro-thermal simulation tool that simultaneously solves the Laplace and heat-diffusion equation in order to determine the temperature distribution throughout the structure at each simulation time step. This temperature distribution feeds into a Gillespie cellular automata model that solves for the phase [8]. This physical device model feeds into a circuit-level phase-change SPICE model (based on the previous work of Cobley & Wright [9]) that simulates the operation of the external neuronal spike generating circuit etc. This external circuit consists of a low-pass filter and voltage comparator for generating the output spike, along with a feedback path that enables the output spike to also reset the phase-change cell, so providing the self-resetting capability - see Fig. 2.

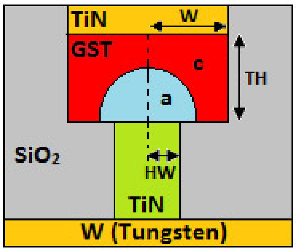


Figure 1: Phase-change device structure

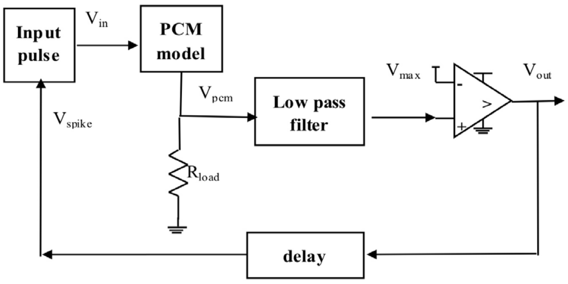
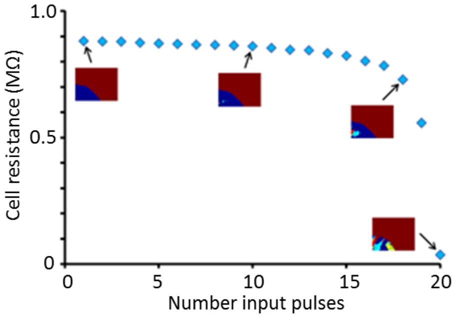


Figure 2: Self-resetting neuron circuit block diagram

3. RESULTS & DISCUSSION

The phase-change memory cell of Fig. 1 was excited with multiple input pulses of 1.025 V amplitude and 70 ns duration. As shown in Fig. 3, some twenty such pulses are required to fully crystallize the cell (after the 20th pulse the resistance was 36 kΩ). Connecting the cell to the circuit shown in Fig. 2 results in periodic ‘spiking’ of the neuron circuit, along with self-resetting, as shown in Fig. 4.



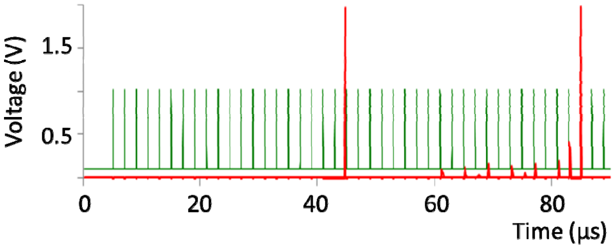


Figure 3: Resistance of PCM cell as a function of number of input pulses

Figure 4: Input spikes (green) and output spikes (red) for the self-resetting neuron circuit of Fig. 2

4. CONCLUSION

We have shown that a spiking phase-change neuron can be implemented using a single nanoscale phase-change memory cell along with a simple external comparator-type electronic circuit.

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