Boolean Logic Gates from a Single Memristor via Low-Level Sequential Logic

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Abstract. By using the memristor's memory to both store a bit and perform an operation with a second input bit, simple Boolean logic gates have been built with a single memristor. The operation makes use of the interaction of current spikes (occasionally called current transients) found in both memristors and other devices. The sequential time-based logic methodology allows two logical input bits to be used on a one-port by sending the bits separated in time. The resulting logic gate is faster than one relying on memristor's state switching, low power and requires only one memristor. We experimentally demonstrate working OR and XOR gates made with a single flexible Titanium dioxide sol-gel memristor.

Keywords: Memristor, sequential logic, ReRAM, OR, XOR, Boolean logic, Time-separated logic.

1 Introduction

The memristor is the recently-discovered [1] fourth fundamental element, joining the set of the resistor, inductor and capacitor. It was predicted to exist based on an expectation of symmetry in electromagnetic phenomena when applied to circuit theory [2], specifically in that it would be passive two-terminal device that would relate the two as-then-unrelated circuit measurables: charge, q, and magnetic flux, φ [1]. From knowledge about its electronic properties, Chua predicted that it would be a non-linear version of a resistor that possesses a memory, hence the name memristor, a contraction of memory-resistor.

Whilst Chua's theoretical contributions were not known to the wider chemical and physics communities, devices highly similar in constitution and operation to Strukov's memristor [1] were created and dubbed ReRAM, for Resistive Random Access Memory, after the use their inventors intended for them. What exactly constitutes a memristor or ReRAM device is a matter of debate, although it

[1] The other measurables being current and voltage, and the other five relationships being the definitions of current and voltage and the constitutive relations of the other three fundamental circuit elements.

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has been suggested that they may be the same thing [3]. Both memristors and ReRAM have suggested uses as computer memory and both are believed to possess the same physical interactions and thus, in this paper, we shall deal with both under the name of memristors, where it is understood that a large part of the results presented here should be tested on ReRAM devices and are expected to work in the same way.

Both memristors [1] and ReRAM [4] have been suggested as possible low-power next-generation computer memory technology, however the field of ReRAM has been around for 20 years and has not yet produced a commercial product and Hewlett-Packard (the company that discovered the Strukov memristor) has been delaying their computer memory offering based on their memristor.

Chua's theoretical model of the memristor has been used to model neuronal synapses (see for example [5–7]) and to update the Hodgkin-Huxley model of neuronal membranes and axonal transport [8, 9]. It has been shown [10] that the experimental memristor spikes in a similar manner to those seen in axonal transport, where it is understood that neurons demonstrate a voltage spike in response to the current influx, and the spikes shown in [10] are current spikes in response to the voltage change. These current spikes have been seen in other memristor systems to ours and are generally ignored or dismissed as current transients. A view which will be tested with our devices in a forthcoming paper. Regardless of how these spikes arise, they are impossible (as far as we know and the literature states) to remove and thus it is our opinion that future uses of memristor technology will have to involve these spikes. Based on the relation to the brain's operation, we consider that memristor networks will be useful for neuromorphic computing, however in this paper we will demonstrate how a single memristor can be used as a Boolean logic gate by making use of the physical property of these current spikes, which can be done if we take an unconventional approach to logic assignation.

This is not the first paper on how to make logic gates with memristors. Strukov et al [11] resorted to using implication logic to design logic gates which required two memrsitors (IMP-FALSE logic is Turing complete, but somewhat unfamiliar to computer scientists). The most notable Boolean logic gates were simulated by Pershin and di Ventra [12] and required a memcapacitor, three or four memristive systems and a resistor. Before the gate was sent the two bits of data, a set of initialization pulses were required to be sent to put the gate into the correct state to give the correct answer. This system, however, is not true Boolean logic because these initialization pulses were different dependent on what the logic to follow would be. Thus the gate can not be considered to be operating only on the two bits of input data and is not a simple Boolean logic gate (it is a Turing machine doing a computation on several bits of data (Boolean input pulses and initialization pulses) which is capable of modeling a Boolean logic gate). Note also that this scheme was tested with memristor emulators, not real devices. There have been other more complex designs for memristor based Boolean logic gates, the simplest of which requires 11 circuit elements [13]. In this paper, we will demonstrate how to perform Boolean logic with a single memristor.