CCIT Report #804 January 2012

TEAM: ThrEshold Adaptive Memristor Model

Shahar Kvatinsky, Eby G. Friedman, *Fellow*, *IEEE*, Avinoam Kolodny, *Senior Member*, *IEEE*, and Uri C. Weiser, *Fellow*, *IEEE*

***Abstract*—Memristive devices are novel devices, which can be used in applications such as memory, logic, and neuromorphic systems. A memristive device offers several advantages to existing applications: nonvolatility, good scalability, effectively no leakage current, and compatibility with CMOS technology, both electrically and in terms of manufacturing. Several models for memristive devices have been developed and are discussed in this paper. Digital applications such as memory and logic require a model that is highly nonlinear, simple for calculations, and sufficiently accurate. In this paper, a new memristive device model is presented – TEAM, ThrEshold Adaptive Memristor model. This model is flexible and can be fit to any practical memristive device. Previously published models are compared in this paper to the proposed TEAM model. It is shown that the proposed model is reasonably accurate and computationally efficient, and is more appropriate for circuit simulation than previously published models.**

***Index Terms*—Memristive systems, memristor, SPICE, window function.**

I. Introduction

Memristors are passive two-port elements with variable resistance (also known as a memristance) [1]. Changes in the memristance depend upon the history of the device (*e.g.*, the memristance may depend on the total charge passed through the device, or alternatively, on the integral over time of the applied voltage between the ports of the device).

Formally, a current-controlled time-invariant memristive system [2] is represented by

$$\frac{dw}{dt} = f(w,i), \tag{1}$$

$$v(t) = R(w,i)\cdot i(t), \tag{2}$$

where w is an internal state variable, i(t) is the memristive device current, $v(t)$ is the memristive device voltage, $R(w, i)$ is the memristance, and t is time. The terms memristor and memristive systems are often used interchangeably to describe memristive systems [2]. While there are discussions in the literature about specific definitions [29, 30], in this paper we use the term "memristive device" to describe all devices within these categories.

Manuscript received January 17th , 2012, revised April 8th, 2012. This work was partially supported by Hasso Plattner Institute, by the Advanced Circuit Research Center at the Technion, and by Intel grant no. 864-737-13.

S. Kvatinsky, A. Kolodny, and U. C. Weiser are with the Department of Electrical Engineering, Technion – Israel Institute of Technology, Haifa 32000, Israel. (S. Kvatinsky corresponding author phone: 972-4829-4662; fax: 972-4829-5757; e-mail: skva@tx.technion.ac.il).

E. G. Friedman is with the Department of Electrical Engineering and Computer Engineering, University of Rochester, Rochester, NY 14627, USA.

Since Hewlett-Packard announced the fabrication of a working memristive device in 2008 [3], there has been an increasing interest in memristors and memristive systems. New devices exhibiting memristive behavior have been announced [4], [5], and existing devices such as spin-transfer torque magnetoresistive random access memory (STT-MRAM) have been redescribed in terms of memristive systems [6].

Memristive devices can be used for a variety of applications such as memory [7], neuromorphic systems [8], analog circuits (*e.g.* see [9]), and logic design [10], [27]. Different characteristics are important for the effective use of memristive devices in each of these applications, and an appropriate designer friendly physical model of a memristive device is therefore required.

In this paper, the characteristics of memristive devices are described in Section II. Previously published memristive device models are reviewed in Section III. TEAM - a new model that is preferable in terms of the aforementioned characteristics is proposed in Section IV. In section V, a comparison between these models is presented. The paper is summarized in Section VI.

II. Requirements for Memristive device Characteristics

Different applications require different characteristics from the building blocks. Logic and memory applications, for example, require elements for computation and control, as well as the ability to store data after computation. These elements require sufficiently fast read and write times. The read mechanism needs to be nondestructive, *i.e.*, the reading mechanism should not change the stored data while reading. To store a known digital state and maintain low sensitivity to variations in parameters and operating conditions, it is crucial that the stored data be distinct, *i.e.*, the difference between different data must be sufficiently large. The transient power consumption while reading and writing, as well as static power consumption, are also critical issues.

Although the definition of a memristive system is quite broad, all memristive systems exhibit a variable resistance, which is related to an internal state variable. Memristive devices employed in practice exhibit a nonvolatile behavior. To provide a nondestructive read mechanism, the internal state variable needs to exhibit a nonlinear dependence on charge, *i.e.*, changes in the state variable due to high currents should be significant, while changes due to low currents should be negligible. Other mechanisms where the state variables return to the original position after completing the read process may also require the nondestructive read mechanism. For certain