A Macromodel of Memristor using Symbolically Defined Devices*

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***Abstract* - A macromodel of the prototype of memristor is described which is developed in Advance Design System software (ADS) using symbolically defined devices (SDDs). It can fast simulate the electrical behavior of a memristor. It is shown that the presented macromodel meets the requirements for simulations of application circuits.**

Index Terms – Memristor, macromodel, simulation.

I. Introduction

The first memristor was manufactured by a research group in Hewlett-Packard laboratories [1]. Numerous potential applications of memristors have been discussed in areas ranging from non-volatile RAM (NVRAM) to artificial neural networks [1–3]. [4] Broadband electromagnetic radiation modulated by dual memristors. Although mathematical models can be constructed easily, they are not supported by the circuit simulation tool. Thus, a macromodel is desirable to simulate a circuit that includes memristors. It is useful to have a circuit model of the memristor as a tool for speeding-up the analysis of the behavior and developing applications of this interesting circuit element via simulation experiments.

Some modeling methods charactering nonlinear and hysteretic behavior of memristors have been developed recently. A PieceWise Linear (PWL) model of the memristor is proposed in [5]. A SPICE macromodel which allows for fast simulation of circuits that include memristors is described in [6]. A SPICE Model of memristor with Nonlinear Dopant Drift is described in [7]. A methodology of SPICE modeling of general memristive, memcapacitative, and meminductive systems is proposed in [8]. But these proposed models are only used for transient or SPICE simulation, which can't suit the multi-level circuit simulations, such as co-simulation with microwave transmission line.

The purpose of this paper is to develop a macromodel which can be used for the multi-level circuit simulations. The paper structures are as follows: Section II summarizes the physical and mathematical property of the memristor, already published in [1] and [6]. Section III introduces the ADS macromodel of the memristor, which starts from the mathematical property in Section II. Section IV is the demonstrations of transient simulation that are based on the proposed macromodel.

II. Mathematical Equations of Memristor

According to [8], the total resistance of the memristor, RMEM, is a sum of the resistances of the doped and undoped regions as presented in [9]:

$$R_{MEM}(x) = R_{ON}x + R_{OFF}(1-x) \quad (1)$$

$$\text{where} \quad x = \frac{w}{D} \in (0,1) \quad (2)$$

is the width of the doped region, referenced to the total length D of the TiO_2 layer, and R_{OFF} and R_{ON} are the values of the memristor resistance for $w = 0$ and $w = D$.

The equation for the voltage across a memristor within the boundaries is

$$v(t) = R_{MEM}(w)i(t) \quad (3)$$

The speed of the movement of the boundary between the doped and undoped regions is

$$\frac{dx}{dt} = ki(t)f(x), \; k = \frac{\mu_v R_{on}}{D^2} \quad (4)$$

where $\mu_v \approx 10^{-14}\,\mathrm{m^2 s^{-1} V^{-1}}$ is the so-called dopant mobility. The window function is presented in [5] and given as follows

$$f(x) = 1-(2x-1)^{2p} \quad (5)$$

III. ADS Macromodel

The proposed macromodel is shown in Fig.1, which is constructed by symbolically defined devices (SDDs), differentiator, initial condition, and current-controlled voltage

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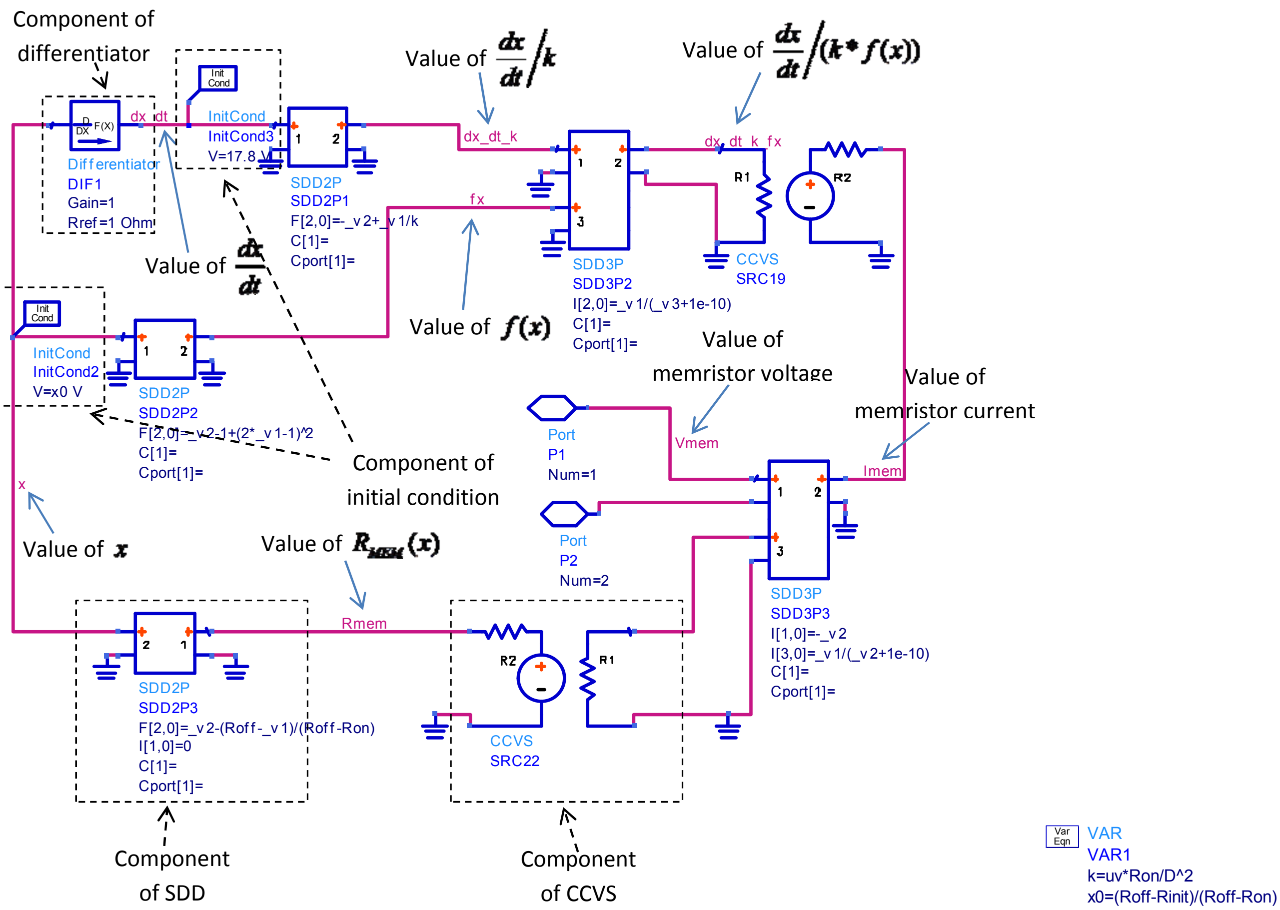

Fig. 1 The macromodel of the memristor using the SDDs.

sources (CCVSs). These ADS in-built components are used for describing mathematical equations of the memristor electrical properties. The SDD enables us to create equation based, user-defined, nonlinear components. It is a multi-port device which is defined by specifying algebraic relationships that relate the port voltages, currents, and their derivatives, plus currents from certain other devices.

In order to help to understand the modeling process, some nodes are named in the topology shown in Fig. 1, whose voltage values represent the function values in (1)-(5). Two components of initial condition are used to ensure that the diffraction equation can be solved correctly by a transient solver with a fit initial condition of 1th and 2th order.

The constitutive relationships of the components SDD3P2 and SDD3P3 are specified in explicit representations with current output items, which are different from these of the components SDD2P1, SDD2P2, and SDD2P3, while they are specified in implicit representations with voltage output items. But the current output items of SDD3P2 and SDD3P3 are followed with the CCVSs to change to the voltage items. The reason why SDD3P2 and SDD3P3 don't use voltage output items in implicit representations directly is to improve convergence in the transient simulation with the SDDs.

IV. Simulation and Results

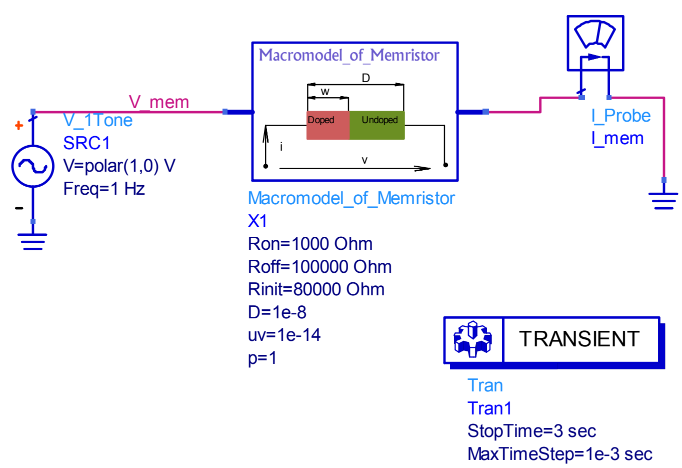

Fig. 2 The macromodel simulation in ADS.

Driven by a voltage source, the macromodel packaged from Section III is simulated by the transient solver, shown in Fig. 2. The device parameters R_{OFF}, R_{ON}, R_{init}, D, uv (μ_v), and p can be defined by the user according to the physical property of it. The parameter k is calculated by R_{ON}, D, and uv according to (4). The parameter x0 (The initial state of the normalized width of the doped layer, x_0) is calculated by R_{OFF}, R_{ON}, and R_{init} according to (1) with replacing R_{MEM} by R_{init}.

The typical waveforms, voltage across the memristor vs the current passing through the memristor are given in Fig. 3 and 4, respectively. The width of the doped region of the memristor in time domain is given in Fig. 5. The simulation results in Fig. 3 and 4 agree well with the graphs published in [1], [6], [7], and [8]. The models in these literatures all are SPICE model, which can be only used in SPICE time domain simulation. However, our ADS macromodel can be used in the multi-level simulations including such as envelope simulation, harmonic balance simulation, or co-simulation with S parameters solver. By using the multi-level technology, we can discover many good potential applications of the memritors before the experiments.

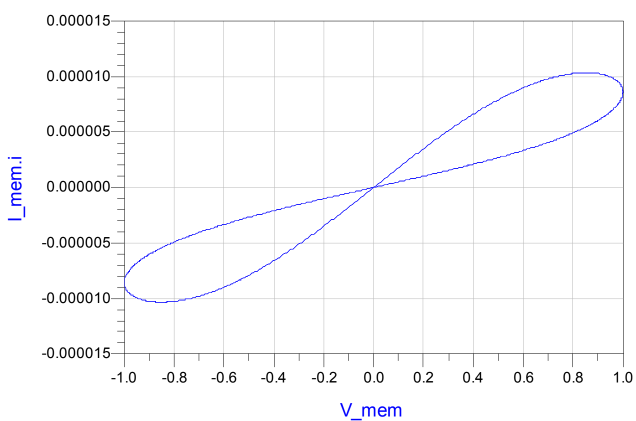

Fig. 3 Voltage VS current of the memristor.

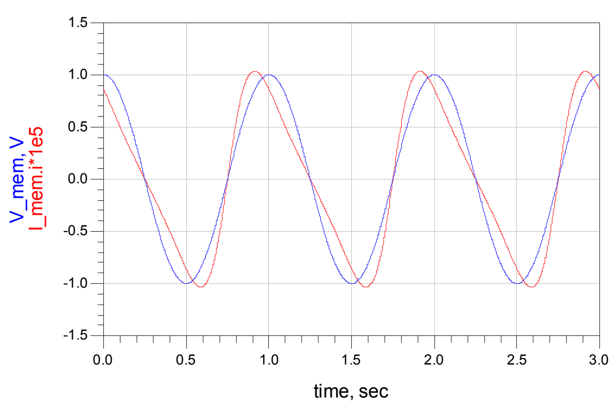

Fig. 4 Voltage and current of the memristor in time domain.

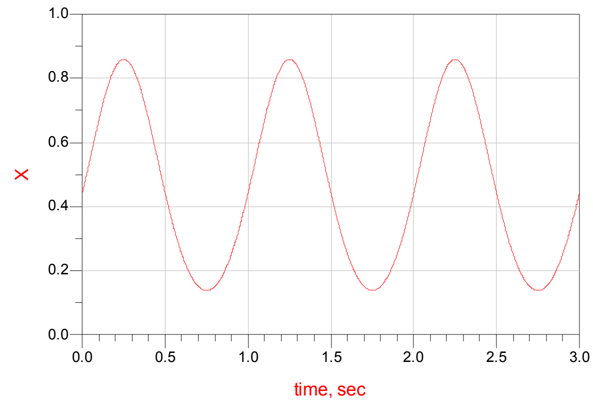

Fig. 5 x of the memristor in time domain.

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