A VALIDATED MATHEMATICAL MODEL FOR SEMICONDUCTOR MEMRISTOR DEVICES

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ABSTRACT: Memristors and memristive devices have attracted interest in recent years as circuit elements that will enable new technologies. For this reason, it is important to determine the characteristics of the devices and to specify their associated parameters in the analysis of their behavior. At this point, various mathematical models such as linear model, non-linear model, Threshold Adaptive Memristor Model and Simmons tunnel barrier model are presented for the theoretical analyzes in the literature. The most widely used nonlinear modeling is mainly based on the use of window functions. In this model, some basic criteria such as boundary lock, boundary effect, linkage linear and non-linear model, flexibility and scalability are considered in evaluating window functions.

In this study, firstly a window function is created which can be used as a new mathematical model, which satisfies the aforementioned basic criteria. The proposed function is derived from the Gaussian function and re-equipped with various parameters. These parameters change the form by giving flexibility and scalability to the window function. The modified function has three parameters to change the form and amplitude of the window. Furthermore, the function is associated with the current of the memristor with the current parameter added to the function.

In this study, secondly the applicability of this new model has been investigated through the characterization of a ZnO memristor produced in the laboratory environment. Thus, it has been shown that our window model provides the desired conditions and can be used for simulation in a real memristor.

Keywords: memristor; non-linear modeling; mathematical modeling; window function; ZnO;

1. INTRODUCTION

The memristor is a new circuit element whose mathematical theory was introduced by Chua in 1971 and physically produced by a group of researchers in HP labs in 2008 [1,2]. It is seen as a device that can lead to new technologies due to its different features. Therefore, it is studied intensively about the memristor and memristive systems in recent years. Various mathematical models have been developed to find the properties of this new circuit element and to use it in different circuit applications. One of these models is the nonlinear drift model.

2. NONLINEAR DRIFT MODELING

The nonlinear drift mechanism is expressed by equation (1), where x is the state variable as shown in Fig. 1.

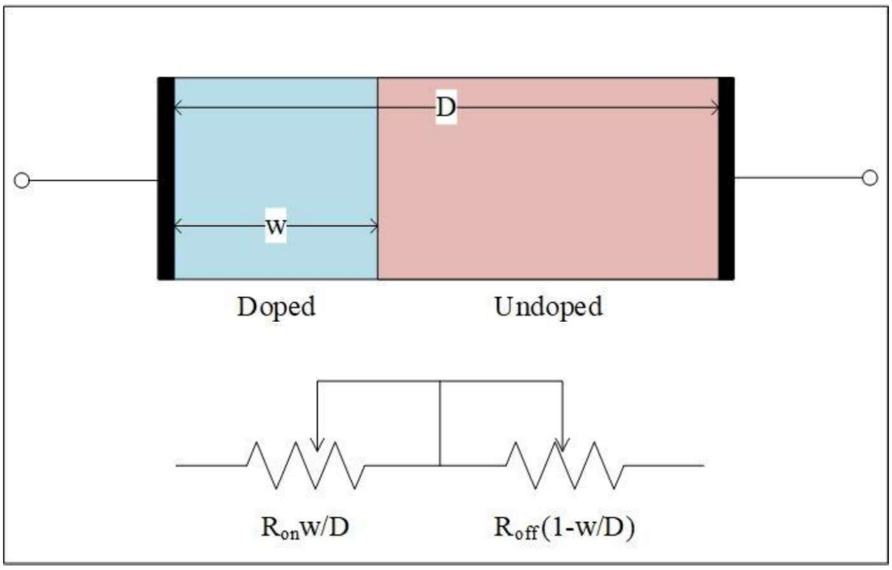

Figure 1: HP memristor structure.

$$\frac{dx(t)}{dt} = \mu_v \frac{R_{on}}{D^2} i(t) f(x(t)) \tag{1}$$

$$x(t) = \frac{w(t)}{D} \tag{2}$$

where µv is the average dopant mobility, Ron is the value of the resistance for w = D, D is total thickness of the memristor, w is the width of the doped layer, f(x) is the window function [3]. The relationship between current and voltage for a memristor can be expressed as follows

$$v(t) = M(t) \times i(t) \tag{3}$$

$$M(t) = R_{on} x(t) + R_{off}(1 - x(t)) \tag{4}$$

where M is the memristance of memristor, Roff is the value of resistance for w=0 [2].

3. WINDOW FUNCTION

The nonlinear drift model is updated case by adding a window function parameter to provide a nonlinear relationship to linear drift model. Several different window functions have been proposed in the literature [3-6]. Some criteria are taken into account when evaluating window functions in nonlinear modeling. In [6], comparison of window functions according to these criteria is given in detail.

4. PROPOSED MODEL

In this study, it has been proposed a new window model which meets the desired criteria. Proposed new model can be expressed by the following equations

$$f(x) = j \times \left(e^{-\left(\frac{x - stp(-i)}{c}\right)^{2p}} - f_{\min}\left(stp(-i)\right) \right) \tag{5}$$

$$stp(i) = \begin{cases} 1, & i \geq 0 \\ 0, & i < 0 \end{cases} \tag{6}$$

$$f_{\min}(index) = \min\left(e^{-\left(\frac{x - index}{c}\right)^{2p}} \right), \qquad x = 0 \ldots 1 \tag{7}$$

where j is a scaling parameter and positive real number, p is a positive integer number, c is a positive real number, i is the memristor current.

The change of the window function for a fixed j and c value with the p parameter is shown in Fig. 2. As shown in Fig. 2, the p parameter plays an important role in the linearity of the proposed window function. For this reason, the selection of the p is very important to achieve the appropriate result.

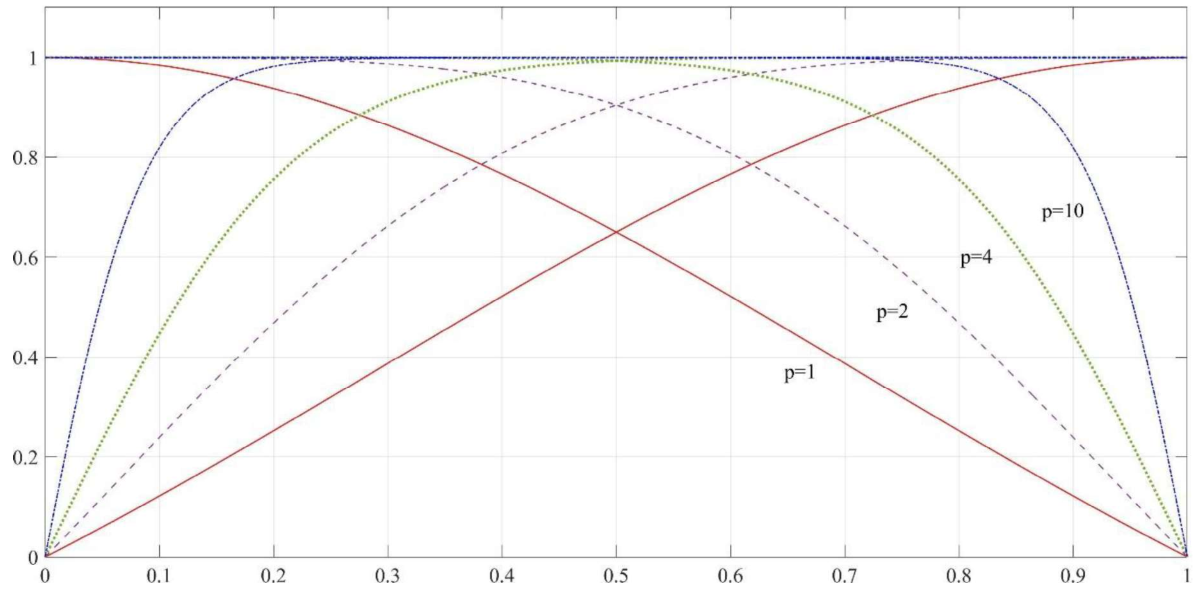

Figure 2: Change of the proposed window function with x for j = 1.58, c = 1 and different p values.

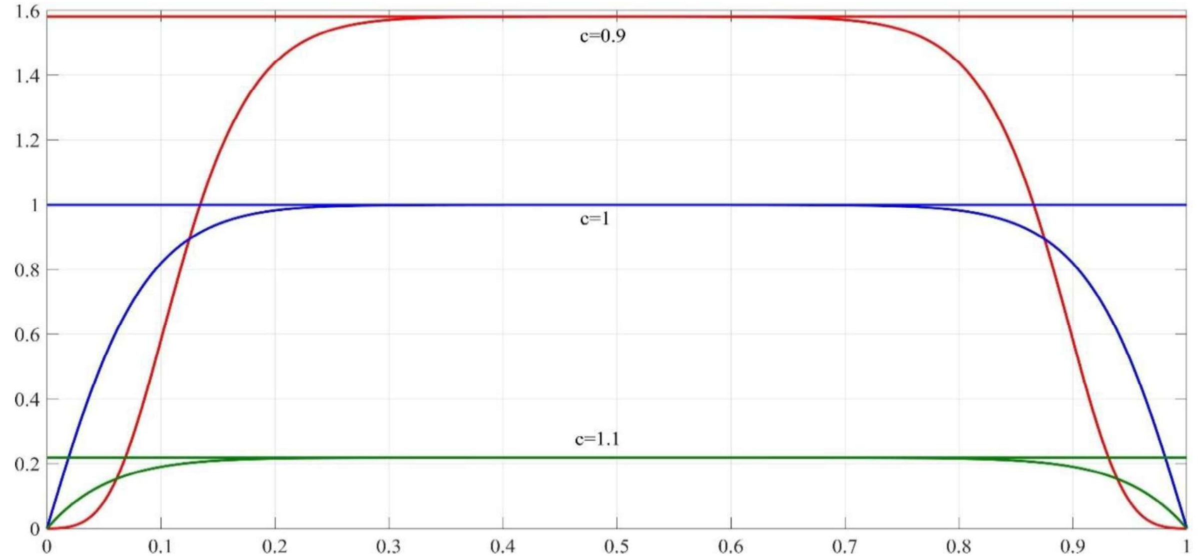

Figure 3: Change of the proposed window function with x for j = 1.58, p = 10 and different c values.

The change of the window function for a fixed j and p value with the c parameter is shown in Fig. 3. The parameter c causes changes both in amplitude and in the form of the window. The parameter c will be useful for using the appropriate window form for different memristor constructions.

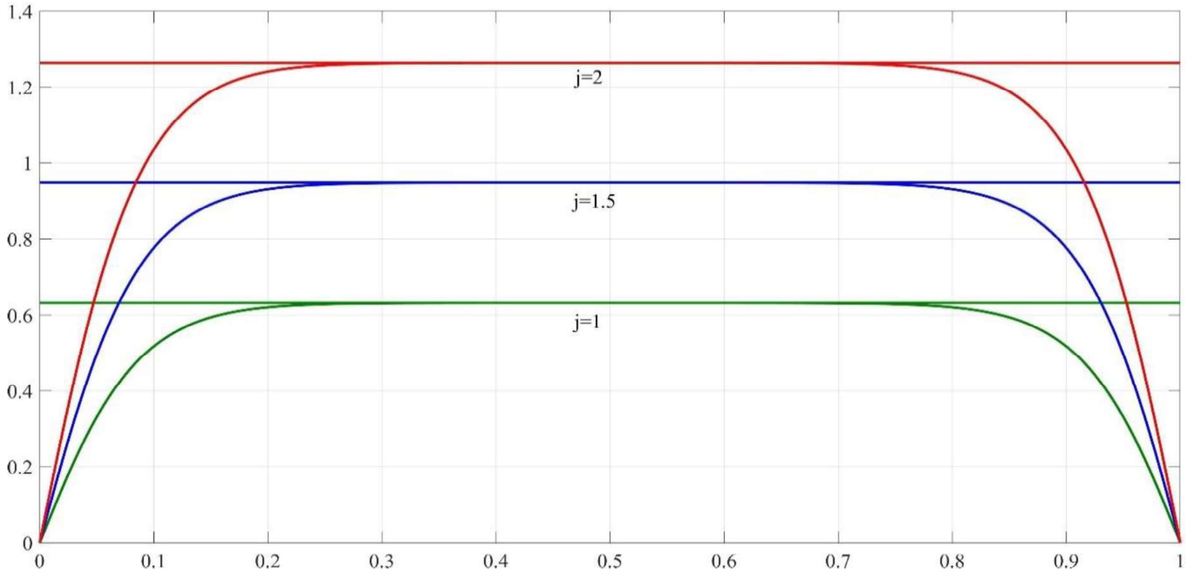

Figure 4: Change of the proposed window function with x for c = 1, p = 10 and different j values.

The change of the window function for a fixed c and p value with the j parameter is shown in Fig 4. As you can see, the j parameter is a scaling parameter that only affects the amplitude of the function.

5. RESULTS AND DISCUSSION

In Fig. 5, I-V graphs are shown for two different p values. For this figure, j=1.58, c=1, V_o=1V, f =1 Hz, V(t) =V_o sin(2πft), R_{on}=100Ω, R_{off}=16kΩ, R_{init}=11kΩ, D=10nm, $\mu_v=10^{-14}$ $m^2V^{-1}S^{-1}$.

In Fig. 6, I-V graphs are shown for three different frequency values. For this figure, j=1.58, c=1, p=10, V_o=1V, V(t)=V_o sin(2πft), R_{on}=100Ω, R_{off}=16kΩ, R_{init}=11kΩ, D=10nm, $\mu_v=10^{-14}$ $m^2V^{-1}S^{-1}$.

In Fig. 7, for a ZnO memristor prepared in the laboratory environment, the I-V graph is shown comparatively with the proposed model. Here, j=1, c=1.45, p=5, V(t)=V_o sin(2πft), V_o=1.38V, f =0.25 Hz, R_{on}=400Ω, R_{off} = 5 kΩ, R_{init}=700Ω, D=30nm, $\mu_v=10^{-14}$ $m^2V^{-1}S^{-1}$ have been taken.

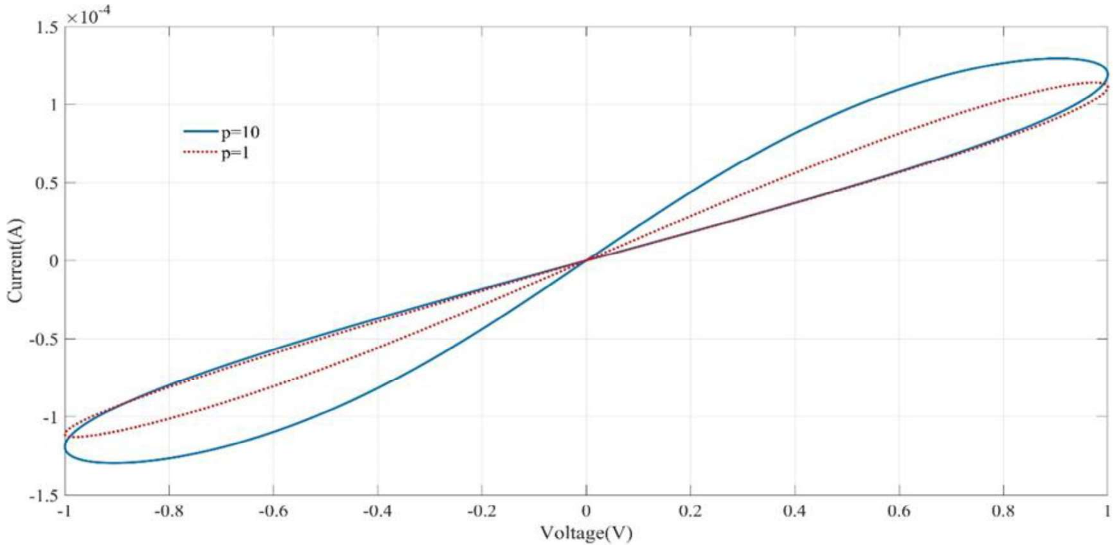

Figure 5: I-V curves with proposed window function for p=1 and p=10.

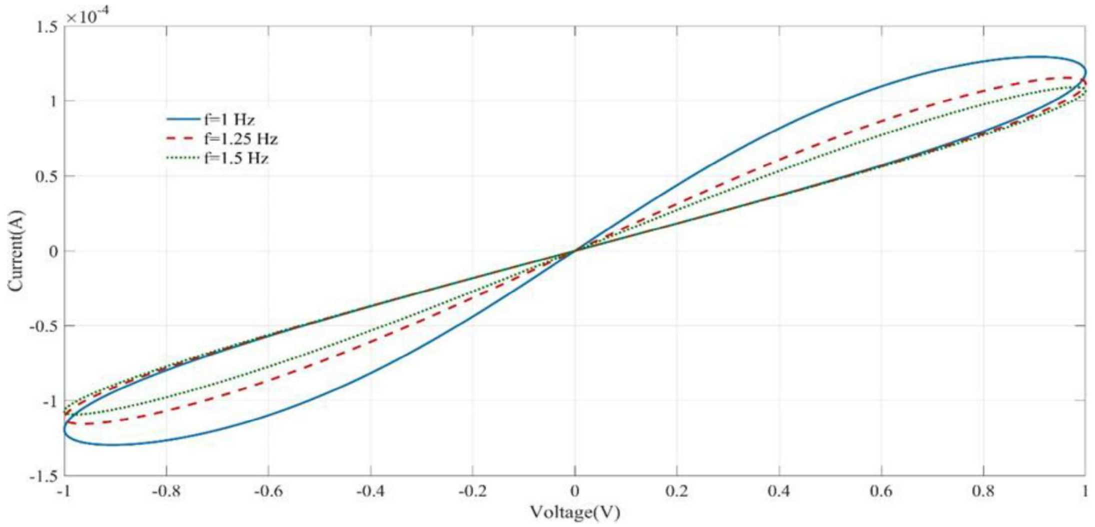

Figure 6: I-V curves with proposed window function for different frequency values.

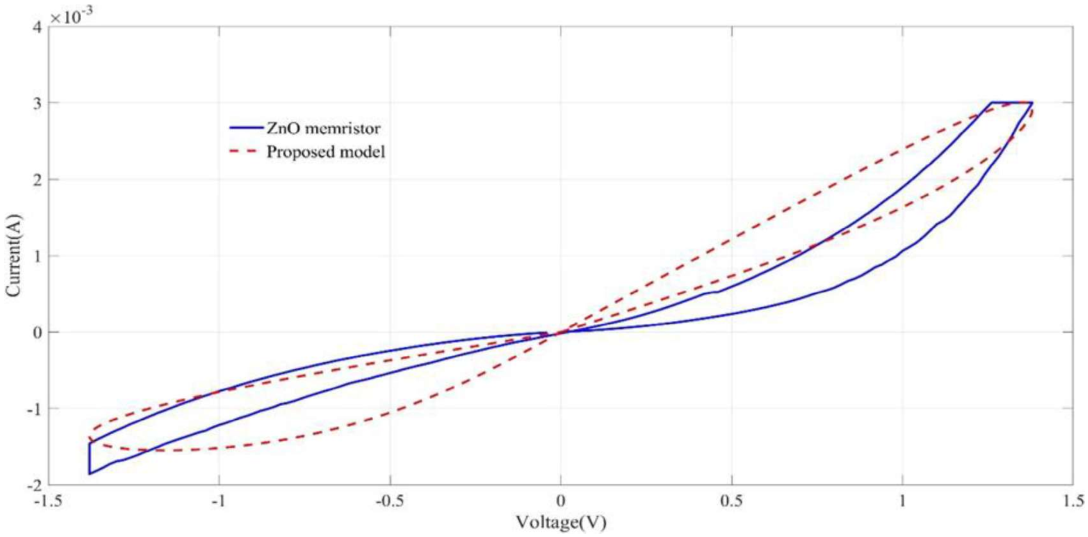

Figure 7: I-V curves for ZnO memristor and proposed model

6. CONCLUSIONS

Memristor is a basic circuit element that includes the relationship between magnetic flux and charge. Numerous studies have been carried out on the mathematical modeling of memristors. In this study, a window function is proposed as a new contribution to the nonlinear drift model. In the proposed model, three different parameters and the current of the memristor have been used. The study of modeling for different situations has been shown. Finally, the I-V curve obtained for a ZnO memristor has been simulated with the proposed model. When the given results are examined, it is seen that modeling carried out with the new window function produces appropriate simulations. Appropriate results can be obtained for various memristor structures by giving appropriate values to different parameters that the proposed model has.

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