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Modeling of Resistive Switching in RRAM Using Monte Carlo Simulations

P325

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Resistive random access memory (RRAM) is a promising candidate for future memory applications [1, 2]. Unfortunately, a proper fundamental understanding of the switching mechanism is still missing, despite the fact that several physical mechanisms have been recently suggested [3, 4]. In this work we present a stochastic model of the resistive switching mechanism.

We associate the resistive switching behavior in RRAM with the formation and rupture of a conductive filament (CF). The CF is formed by localized oxygen vacancies (V_o) or domains of V_o [4]. If the CF is formed, the following events can happen: 1) an electron hops into a V_o from an electrode; 2) an electron hops from a V_o to an electrode; 3) an electron hops between two V_o.

In order to model the dependence of transport on the applied voltage and temperature we choose the hopping rates as [5]:

$$\Gamma_{nm} = \frac{dE}{1-\exp(-dE/T)} \cdot \exp(-R_{nm}/a), \quad (1)$$

Here, dE is the energy difference between the positions of sites n and m, R_{nm} is the hopping distance, a is the localization radius. The hopping rates between an electrode (0 or N+1) and an oxygen vacancy m are described as [9]:

$$\Gamma_m^{iC} = \alpha \cdot \Gamma_{0m}, \Gamma_m^{oC} = \alpha \cdot \Gamma_{m0}, \quad (2)$$

$$\Gamma_m^{iA} = \beta \cdot \Gamma_{(N+1)m}, \Gamma_m^{oA} = \beta \cdot \Gamma_{m(N+1)}, \quad (3)$$

α and β are the coefficients of the boundary conditions on the cathode and anode, respectively, N is the number of sites, A and C stand for cathode and anode, and i and o for hopping on the site and out from the site, respectively.

We have calibrated the model with the results reported in [4], for V=0.4 V to V=1.6 V. All calculations have been performed on a one-dimensional lattice consisting of thirty equivalent, equidistantly positioned hopping sites V_o. When the hopping rate between the electrodes and V_o is larger than the rate between the two V_o (i.e. $\alpha, \beta > 1$), the low occupation region is formed near the anode (unipolar behavior). Fig. 1 shows a case, when the hopping rate between the two V_o is larger than the rate between the electrodes and V_o (i.e. $\alpha, \beta < 1$). In this case a low occupation region is formed near the cathode (bipolar behavior).

After the model was calibrated, the temperature dependence of the occupations in the low occupation region was studied (Fig. 2). Our calculations indicate a high robustness of the low occupation region (the changes amount to less than 10%), when the temperature is elevated from 25° C to 200° C.

In conclusion, a stochastic model of the resistive switching mechanism is presented. Results of our simulations are in excellent agreement with experimental work. Our model demonstrates high robustness of the low occupation region, when the temperature is elevated. This stochastic model can be used for better understanding the resistive switching mechanism in RRAM devices.

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References

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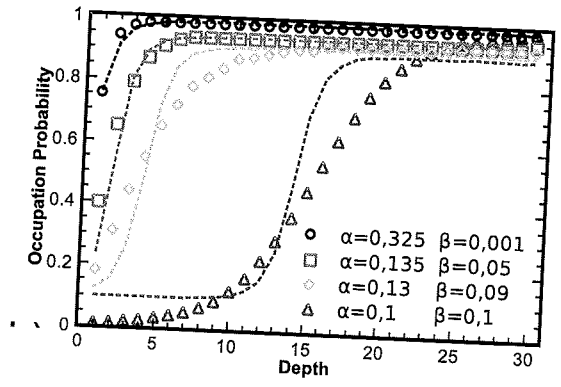

Fig.1. Calculated distribution of electron occupation probabilities under different biasing voltages. Lines are from [4], symbols are obtained from our stochastic model.

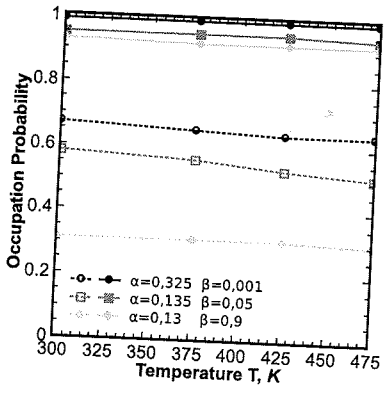

Fig.2. Temperature dependence of electron occupation probability near the anode (line) and the cathode (dotted line).