Verification of Simulation Time Improvement for SPICE Simulator using Built-in MTJ Model

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INTRODUCTION

In order to introduce spintronics devices into general CMOS LSI design, a high-speed and accurate circuit simulator is highly required. There has been reported an MTJ macro model for SPICE simulator [1]. On the other hand, we have proposed a high-speed SPICE simulator incorporating the model parameters, which describe MTJ's behavior [2]. In this paper, the simulation times are compared for both the developed SPICE simulator, which is a "built-in MTJ model" type, and conventional MTJ simulator, which uses an "MTJ macro model".

SIMULATORS UNDER EVALUATION

We take a 2-terminal MTJ, shown in Fig.1, for consideration. Our SPICE simulator with built-in MTJ model can describe DC R-V and switching characteristics of MTJ. An example of MTJ characteristics is shown in Fig. 2. Its model parameters are categorized into 3 levels. Each level supports the following characteristics.

Level 1: only DC R-V.
Level 2: Level 1
+ Switching in Thermal Activation Region.
Level 3: Level 2
+ Switching in Precession Region.

The MTJ characteristics in Fig. 2 are described using level 3 model parameters.

Meanwhile, a simple MTJ macro model was created for evaluation. Figure 3 shows the macro model circuit. It can describe only 2-state resistance switching between Rp (parallel) and Rap (anti-parallel) without the bias dependency of the MTJ resistances, as shown in Fig. 4. In order to support the detailed characteristics like the above-mentioned level 1 to 3, a complicated macro circuit including several tens of components is needed, resulting in obviously requiring much more simulation time than that of the macro circuit composed of only 4 components in Fig. 3.

SIMULATION AND DISCUSSION

Simulations were carried out to compare the simulation time between the SPICE simulator with built-in MTJ model [2] and that with the simple MTJ macro model in Fig. 3. The circuit used in the simulation is shown in Fig. 5. It can perform switching operations of 100 ~ 50000 MTJs using an ideal driver. Simulation time was measured for both two simulators.

Figure 6 shows the simulation result. It can be seen that the simulation time for our built-in MTJ model simulator is below the time for the conventional simulator with the simplest circuit in all cases, even for the highest modelling level 3. This is mainly because the increased internal nodes by the macro model circuit increase the matrix calculation time in the SPICE simulation. Thus the result means that the SPICE simulator with built-in MTJ model has an essential advantage in simulation speed and accuracy, compared to that with the MTJ macro model.

CONCLUSION

The SPICE simulator with built-in MTJ model is advantageous in simulation time and accuracy compared to the simulator with MTJ macro model.

ACKNOWLEDGEMENT

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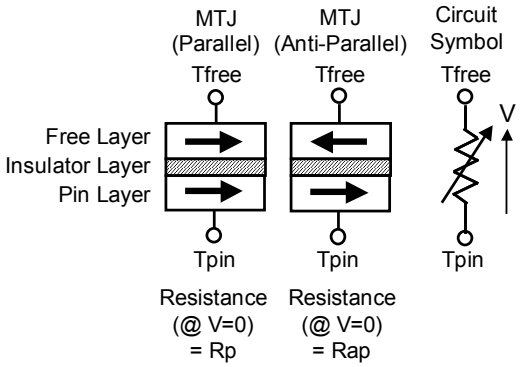

Fig. 1. 2-terminal MTJ device. An MTJ is composed of Free/Insulator/Pin layers. If the magnetization directions for Free and Pin layers are parallel, the resistance is Rp. If they are anti-parallel, then the resistance is Rap (Rap>Rp).

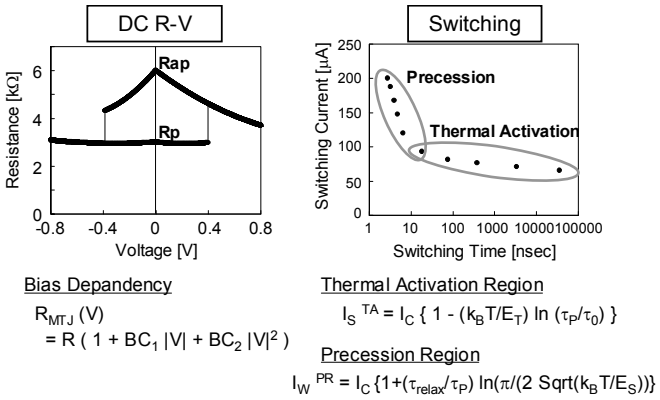

Fig. 2. MTJ characteristics supported by the developed SPICE simulator with "built-in MTJ model" [2]. The switching model equations for both thermal activation and precession region are reported in reference [3].

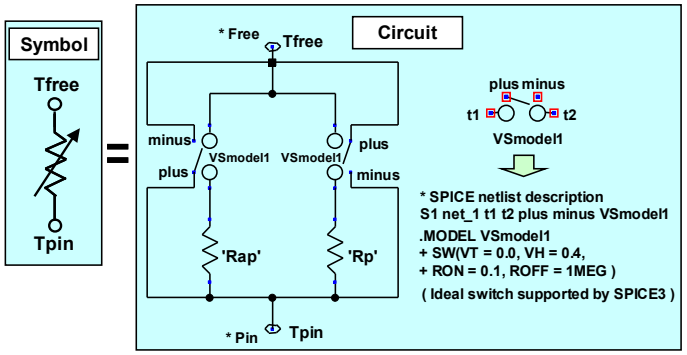

Fig. 3. Simple MTJ macro model circuit. It uses 2 linear resistors and 2 ideal switches supported by SPICE3. Simple 2-state switching can be described by this circuit.

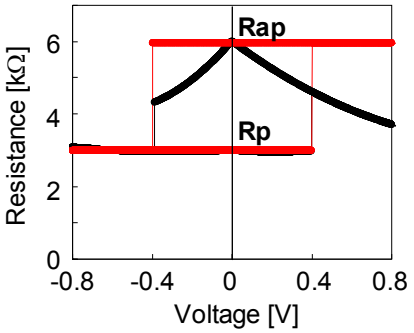

Fig. 4. DC R-V characteristics simulated using the SPICE with built-in model (black line) and the SPICE with macro model (red line).

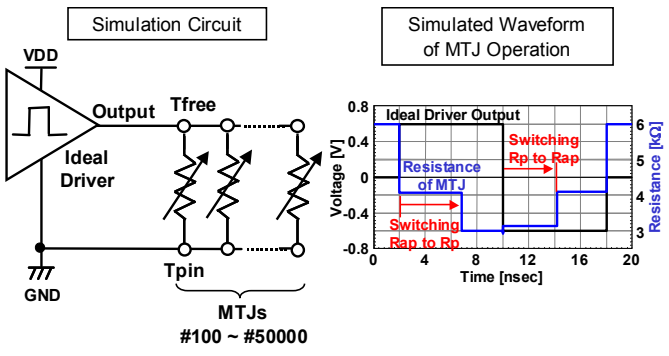

Fig. 5. Simulation circuit and its typical simulated waveforms, which show Rap to Rp switching followed by Rp to Rap switching.

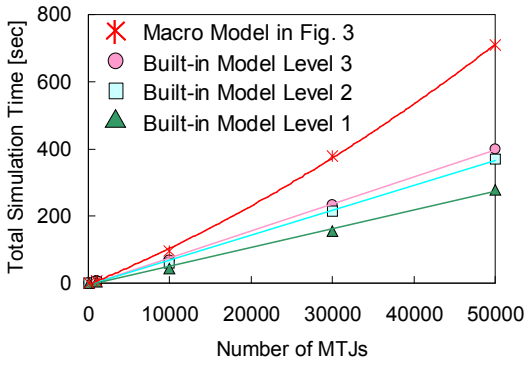

Fig. 6. Simulation result. In case of 30000 MTJs, for example, about 38% simulation time reduction is achieved by our built-in model simulator, although our built-in MTJ model simulator uses level 3 model and macro model simulator uses the simplest model as shown in Fig.3.