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Time-Resolved Switching Characteristic in Magnetic Tunnel Junction with Spin Transfer Torque Write Scheme

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1. Introduction

Recently, magnetic tunnel junction (MTJ) [1] based spin transfer torque (STT) RAM is extensively investigated for next generation nonvolatile memory. Especially, CoFeB/MgO/CoFeB based MTJ [2] gathers attention because of its good manufacturability and high tunnel magnetoresistance ratio. However, time-resolved switching characteristics of MTJ with STT writing scheme [3] have not been fully analyzed. This time-resolved switching characteristic of MTJ is very important to improve the switching speed and switching probability of STT-RAM.

In this paper, by using the 20GHz sampling measurement technique, we investigate the time-resolved switching characteristics of CoFeB/MgO/CoFeB based MTJ integrated with 4-metal CMOS circuit. In addition, the time-resolved fluctuation of magnetization in write operation is shown.

2. MTJ Structure and its DC Characteristics

The size of the MTJ fabricated on 90 nm CMOS backend process is 100 nm × 200 nm as shown in Fig.1. The MTJ is composed of Ta/Ru/Ta/CoFeB(1.7)/MgO(1.09)/CoFeB(2.4)/Ru/ CoFe/PtMn/Ta. Figure 2 shows the measured DC characteristics of the fabricated MTJ with STT writing scheme. The TMR ratio of this MTJ was 181 % at room temperature.

3. Time-Resolved Switching Characteristics

We developed the measurement system using the 20GHz sampling measurement technique for investigating the time-resolved switching characteristics as shown in Fig.3 [4]. Figure 4 shows the waveform of the time-resolved voltage (V_{MTJ}) measured by oscilloscope (=50Ω × flow current in the MTJ) that shows the time-resolved switching characteristics of the MTJ. By investigating these time-resolved voltage waveforms, we evaluate the time-resolved switching characteristics of the MTJ. When the resistance of the MTJ becomes small, V_{MTJ} increases because of the increase in the current flow in the MTJ.

We investigate the time-resolved switching characteristics of the MTJ as shown in the inset of Fig.4. The focused physical parameters of the time-resolved characteristics are shown in Fig.5. In the measurements, the applied voltage to the MTJ (Vpp) and the rise time of applied voltage waveform are varied from 0.8V to 1.1V and from 2nsec to 12nsec, respectively. Incubation time (t_A) is defined by the time from the pulse rising to the onset of switching. The onset of switching is the point that the signal level begins to change from AP to P state (from P state to AP state in the opposite switching direction). Reversal time (t_B) is defined as the period between the onset of switching and the end of switching. In addition, the ΔV0, ΔV1, and ΔV2 are the voltage fluctuation defined by standard deviation; ΔV0 is observed before the voltage is applied to MTJ, ΔV1 is observed before the onset of switching, and ΔV2 is observed after the end of switching.

Figure 6 and 7 show the incubation time and reversal time of the MTJ in the case when AP→P and P→AP for analyzing the time-resolved switching characteristics of the MTJ, respectively. From these results, in both cases, AP→P and P→AP, as the voltage applied to the MTJ increases, the incubation time (t_A) exponentially decreases. The results regarding to t_A can be understood as the following. It is approximated in this measurement condition that the spin transfer torque generated by a single electron and the total spin torque required for magnetization switching are both constant; thus, the total number (N) of electrons flowing in the MTJ for switching is also constant. Therefore, incubation time (t_A=N/I) exponentially decreases because the flow current (I) exponentially increases as Vpp becomes larger.

On the other hand, the dependence of reversal time (t_B) on V_{pp} was not observed. In addition, reversal time (t_B) was shorter than 2nsec. This can be interpreted as the following: since reversal time is determined by the angular velocity of spin precession, reversal time is about 1nsec that does not depend on Vpp.

Furthermore, time-resolved fluctuations of magnetization in each region of the spin switching operation are analyzed as shown in Fig.8. These time-resolved fluctuations of magnetization are evaluated from standard variations of measured voltage such as ΔV0, ΔV1 and ΔV2 from the designated periods of 10nsec, which are taken from three constant sections before applying the voltage, before the onset of switching and after the end of switching, respectively. It is found that the time-resolved fluctuation of magnetization ΔV1 in the condition before switching (in incubation time) is larger than both ΔV0 in the condition before applying voltage, and ΔV2 in the condition after switching. From this, it is interpreted that this large time-resolved fluctuation of magnetization (ΔV1) is generated by a damping force due to STT effect, and ΔV2 after switching becomes about same as ΔV0 before applying voltage, as damping force after switching is very small.

4. Conclusions

By using the 20GHz sampling measurement technique, the time-resolved switching characteristics of CoFeB/MgO/CoFeB based MTJ are investigated in detail. It is found that in the case of both AP→P and P→AP, as the applied voltage to MTJ increases, the incubation time (t_A) exponentially decreases, while the reversal time (t_B) remains unchanged. In addition, the time-resolved fluctuation of magnetization in write operation is shown. It is found that the time-resolved fluctuation of magnetization ΔV1 in the condition before switching (in

incubation time) is larger than both ΔV0 in the condition before applying voltage, and ΔV2 in the condition after switching. Moreover, it is found that the ΔV2 is about the same as the ΔV0, while STT current still flows in MTJ. Finally, the novel time-resolved switching characteristics mentioned above are explained with the model based on STT phenomena and spin precession manner of MTJs.

Acknowledgements

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References

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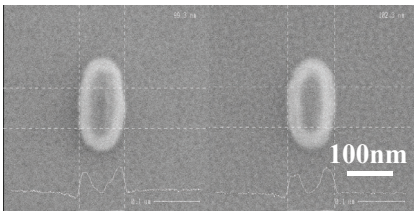

Fig. 1 SEM image of the fabricated MTJ.

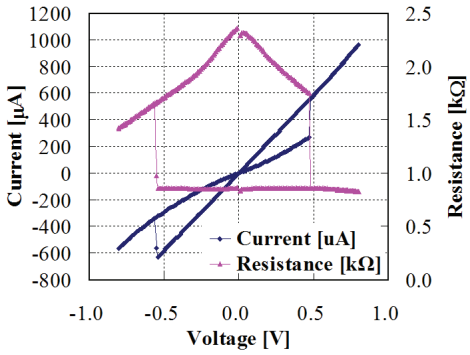

Fig. 2 DC characteristics of the fabricated MTJ with STT scheme.

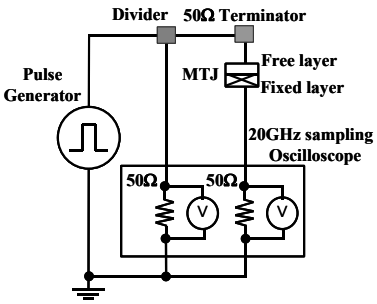

Fig. 3 Measurement setup for time-resolved switching characteristics [4].

Fig. 4 Measured waveforms by 20GHz sampling technique with high resolution. Upper green waveform is applied voltage to MTJ. Lower red waveform shows measured voltage that is flow current times 50Ω.

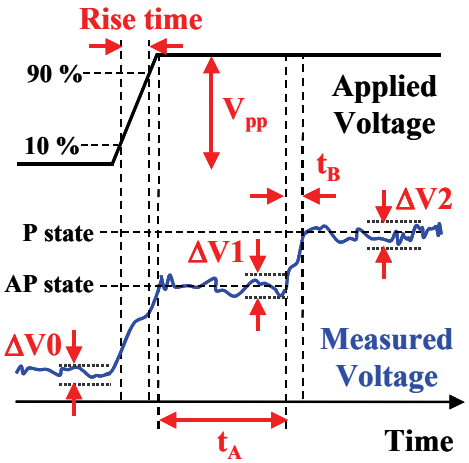

Fig. 5 Timing chart of the measurement and the measured physical quantities.

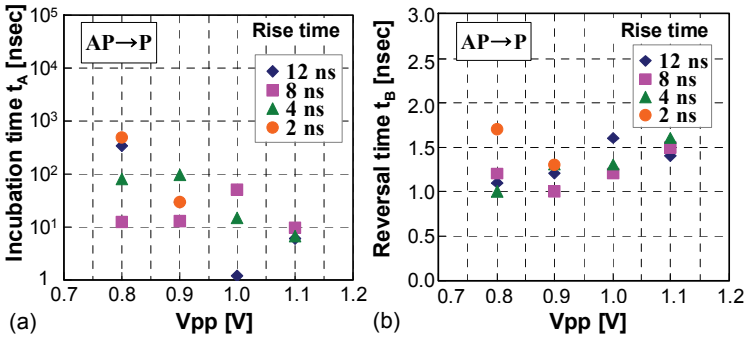

Fig. 6 Measured physical quantities in the case of switching from AP to P.
(a) the dependence of incubation time t_A on the applied voltage.
(b) the dependence of reversal time t_B on the applied voltage.

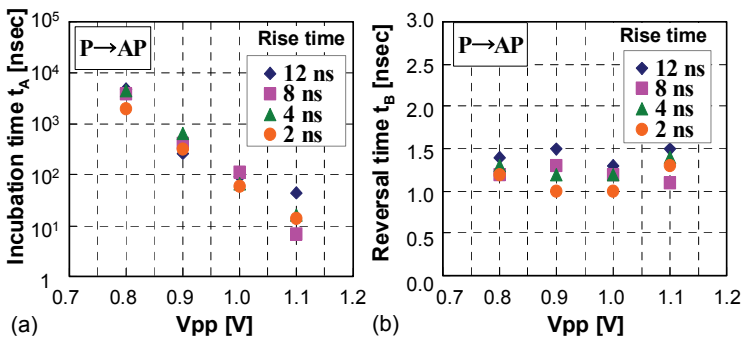

Fig. 7 Measured physical quantities in the case of switching from P to AP.
(a) the dependence of incubation time t_A on the applied voltage.
(b) the dependence of reversal time t_B on the applied voltage.

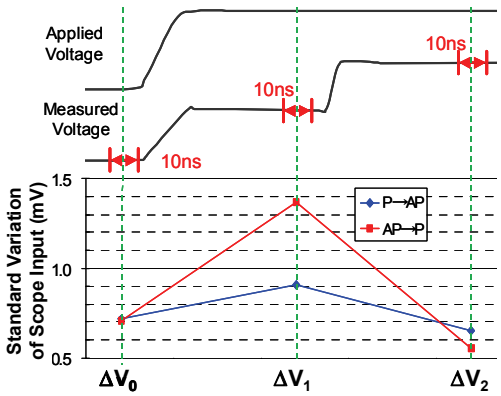

Fig 8 Voltage fluctuation defined by standard deviation.