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Demonstration of Enhanced Tunneling Magneto Resistance Ratio for a Magnetic Tunnel Junction Connected in Parallel with a Tunnel Diode

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1. Introduction

Memory that features non-volatile, high-density and high-speed random access capability is indispensable for ubiquitous networks. Magnetic random access memory (MRAM) is a promising candidate for such nonvolatile high-performance memory[1-3]. Although the tunneling magneto-resistance (TMR) ratio of magneto-tunneling junctions (MTJs) reported to date is typically 30–40%, it should be larger for realizing a future high-performance memory system.

In this paper, we propose a novel MRAM cell consisting of a MTJ connected in parallel with a tunnel diode (TD) to enhance the TMR ratio. The negative differential resistance (NDR) characteristics of the TD can increase the TMR ratio of the MTJ.

2. MTJ/TD Cell Structure

Figure 1(a) and 1(b) show a proposed MRAM cell consisting of a MTJ and a TD connected in parallel, and its expected *I-V* characteristics with two different TMR values, R_P and R_{AP}, depending on the magnetization directions of the MTJ. The peak current of the circuit is given by

$$I_{P(AP)}=I_{P0}+V_{P0}/R_{P(AP)} \quad (1)$$

where I_{P0} and V_{P0} are the peak current and peak voltage of the TD, I_P and I_{AP} are the peak currents at parallel state and anti-parallel state, respectively. When the bias current, I_{bias}, of which value being between I_P and I_{AP}, is applied, the voltage ratio between the two states is expected to become large, resulting in the large TMR ratio. It should be noted that the addition of the TD has almost no area penalty if both devices can be stacked each other.

3. Experiment and Results

In order to demonstrate the MTJ/TD circuit, we fabricated CoFe-based double barrier MTJs and GaAs-based Esaki tunnel diodes, respectively. The MTJ consists of a 50-nm CoFe lower electrode, a 1.5-nm AlOx, a 3.0-nm CoFe, a 1.5-nm AlOx, and a 50-nm CoFe upper electrode. The TMR ratio and *RS* value was 11% and $7.2\times10^5\ \Omega\mu m^2$. The TD consists of a 500-nm n^+-GaAs ($n=1\times10^{19}$ cm^{-3}) and a 200-nm p^+-GaAs ($p=5\times10^{19}$ cm^{-3}). The peak current density and peak-to-valley current ratio (PVR) of the TD was 6.3 A/cm^2 and 15. To confirm the basic operation, we combined both devices, and measured the *I-V* characteristics and resistance under the magnetic field at room temperature.

Figure 2(a) shows the *I-V* characteristics of the MTJ/TD circuit at different magnetic field. The solid and dashed curves indicate the parallel and anti-parallel states. The sizes of the MTJ and TD are 20×20 μm^2, and 50 μmϕ, respectively. When the bias current is between 0.221 and 0.235 mA, the ratio of the sensing voltage becomes large. Figure 2(b) shows an effective TMR as a function of magnetic field at the bias current of 0.226 mA. The magnetic field is increased from 0 to 170 Oe in steps of 17 Oe and then decreased from 170 to 0 Oe in the same steps. Two clearly distinguished TMR values with their ratios of as high as 103% were obtained. Since the bare TMR ratio of the MTJ is only 11%, almost 10 times larger TMR ratio was obtained by using the TD.

4. Discussion

The peak current difference gives the operating margin of the bias current. When the operating margin is defined as $(I_P-I_{AP})/(I_P+I_{AP})/2$, it becomes 6.0% in this experiment. Figure 3 shows the SPICE simulation results of the operating margin and effective TMR ratio as a function of the peak current of the TD. Changing the peak current corresponds to changing the device size and/or current density. There is a trade-off relation between the operating margin and the effective TMR ratio. As the current density increases, the operating margin decreases, while the effective TMR ratio increases. Although the maximum operating margin is 8% in this system, it would be further increased by using the MTJ with larger bare TMR ratios.

5. Conclusion

We proposed a novel MRAM cell consisting of the MTJ/TD structure. The TD can increase the TMR ratio of the MTJ due to the nonlinear characteristics of the NDR devices. The basic concept was confirmed by both experiment and simulation. The fabricated device showed that the TMR ratio could be enhanced from original value of 11% to 103%.

References

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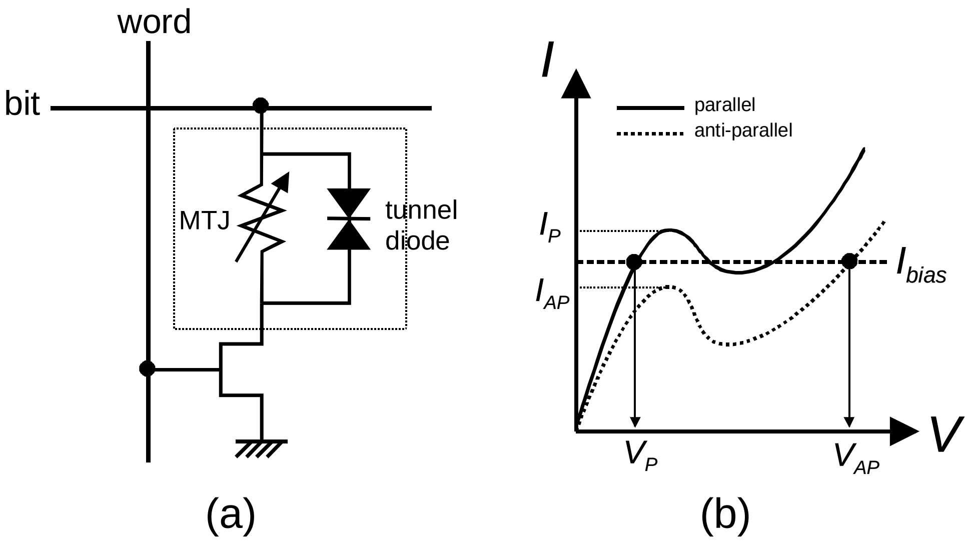

Fig. 1 (a) Schematic representation for the proposed cell structure consisting of a magnetic tunnel junction (MTJ) connected in parallel with a tunnel diode (TD). (b) Expected *I*-*V* characteristics. When I_{bias} is applied, either the V_P or V_{AP} is sensed, depending on the magnetization states of the MTJ.

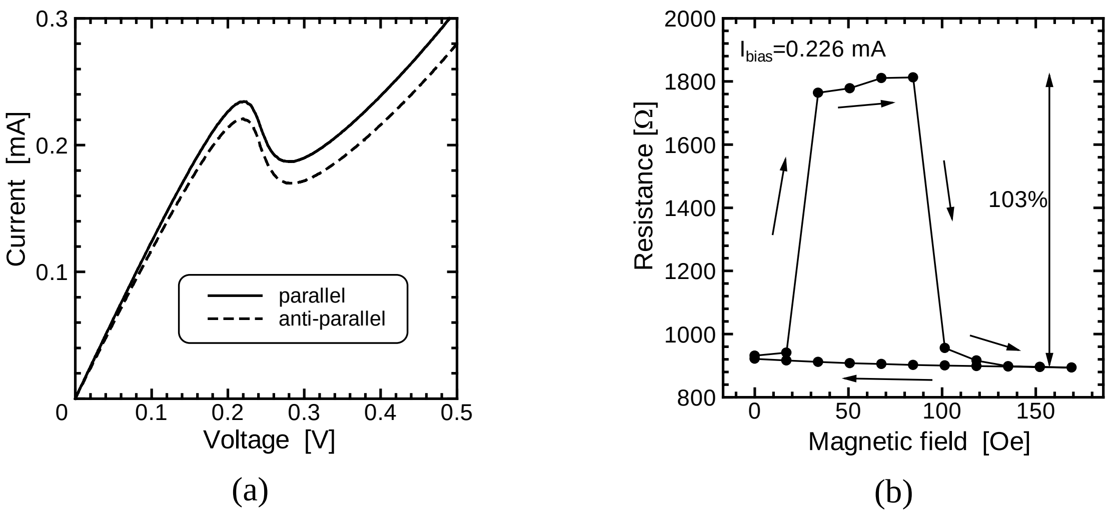

Fig.2 (a) Measured *I*-*V* characteristics of the MTJ/TD hybrid circuit. (b) Measured effective TMR of the MTJ/TD hybrid circuit as a function of the magnetic field. Effective TMR ratio was enhanced.

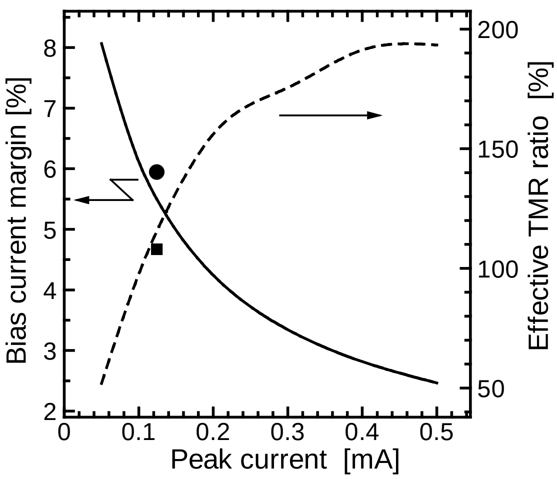

Fig. 3 Simulated operating margin and effective TMR ratio of the MTJ/TD circuit as a function of the peak current of TD. For simulation the bare TMR ratio of 11%, which was obtained experimentally, was assumed. ● and ■ represent the experimental data.