Large magnetocapacitance effect at room temperature in magnetic tunnel junctions

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Magnetocapacitance (MC) effect in spintronic devices has attracted much interest due to their fascinating spin phenomena, such as frequency-dependent spin transport and spin capacitance, and applications to high-speed storage devices and high-frequency elements. The MC effect has been observed in magnetic tunnel junctions (MTJs) [1, 2], molecular spin valve devices [3], magnetic nanogranular films [4], and magnetic single electron transistors [5]. The MC in MTJs is called a tunneling magnetocapacitance (TMC), in which the capacitance is high for the parallel (P) configuration of the magnetization vectors in both ferromagnetic layers adjacent to the barrier and it is low for the antiparallel (AP) configuration. Although this phenomenon has been explained by the spin-injection accumulation model, the TMC is as small as ~50%, which is much smaller than the expected value. Also, it is not enough to fully understand the mechanism on the frequency dependence of TMC. In this study, we propose a new model for TMC in MTJs and investigate the frequency dependence of TMC theoretically and experimentally [6].

Our model for TMC is based on the Debye-Fröhlich model combined with Julliere formula. According to our calculation, the TMC ratio strongly depends on frequency with a maximum peak at a specific frequency, and the maximum TMC ratio is larger than the TMR ratio. To verify the model, we investigate experimentally the frequency dependence of TMC in MgO-based MTJs with a key structure of $Co_{40}Fe_{40}B_{20}$(3 nm)/MgO(2 nm)/$Co_{40}Fe_{40}B_{20}$(3 nm)/IrMn(15 nm). Fig. 1 shows the frequency dependence of TMC and TMR. It is evident that the calculation results of TMC and TMR are in good agreement with experimental data. Also, the TMC ratio is 155% at 200 Hz, which is larger than the TMR ratio of 108%. The TMC curve is shown in Fig. 2. Furthermore, the calculation predicts that the TMC ratio can reach 1000% in MTJs with a corresponding TMR ratio of 623%, which is within the realm of high performance MgO-based MTJs, as shown in Fig. 3. Our theoretical and experimental findings provide a deeper understanding on AC spin-dependent transport in MTJs and will open up wider opportunities for device applications, such as highly sensitive magnetic sensors and impedance-tunable devices. This research was supported by JSPS KAKENHI Grant No. 15H03981, Nanoelectronics Research Initiative through the INDEX program, and NSF Grant No. DMR-1307056.

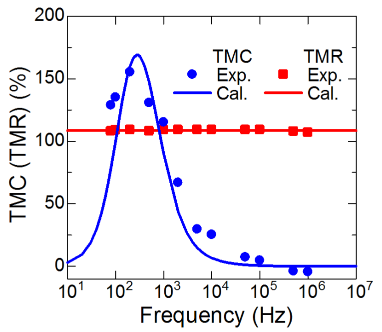

Fig. 1 Frequency dependence of TMC and TMR.

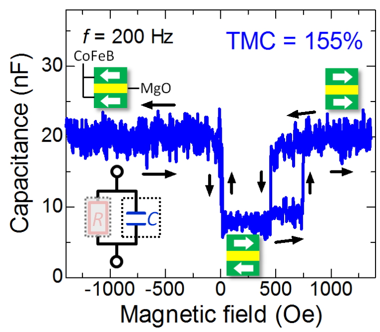

Fig. 2 TMC effect in MgO-based MTJs with a TMR ratio of 108%.

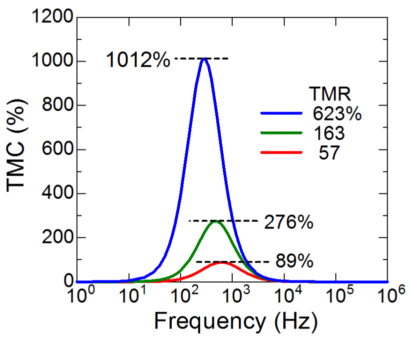

Fig. 3 Calculated results on the frequency dependence of TMC.

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