High frequency impedance inverse in MTJ junction


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Abstract

The magnetoimpedance effect of magnetic tunnel junction (MTJ) was investigated at room temperature in the frequency ranged from 100 Hz to 15 MHz. The MR loop with a ratio of 9.49% at 5 MHz switches to −11.51% at 7 MHz, respectively. This indicates the MR loop reverse shape and sign around 6 MHz. This inverse MR effect is explained by the impedance competition among Resistor-Inductor series circuit and Capacitor part.

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Magnetic Tunnel Junction (MTJ) is a good system for investigating the spin-polarized electron coherent tunneling effect; and both theoretical and experimental researches on the MTJ are interesting topics of current research [1]. However, the studies of impedance as a function of magnetic field on MTJ were still rare; this motivated us to study the impedance as a function of magnetic field on MTJ. In this article, the MTJ was fabricated and the magnetooimpedance behavior of MTJ was studied with frequency (f) ranged from 100 Hz to 15 MHz. The inverse MR has been found in the Co/SrTiO3/La0.7Sr0.3MnO3 magnetic tunnel junction (MTJ) structure [2] in DC system, and it is the first time that the inverse MR properties have been observed in AC system.

In this article, the MTJ with the layer structures of Ru (5)/Cu (10)/NiFe (5)/IrMn (12)/CoFe (4)/Ru (0.8)/CoFeB (4)/Al (1.0)-oxide/CoFeB (4)/Al (1)-oxide/Ru (0.8)/CoFe (4)/IrMn (12)/NiFe (5)/Ru (5) were deposited on Si/SiO2 wafer using Magnetron Sputtering System, where all thicknesses are given in nm. The Al–O insulating layer was formed by inductively coupled plasma (ICP) oxidation with an oxidation time of 44 s in a mixture of oxygen and argon at a pressure of 1.0 Pa. The MR ratio of MTJ is 36% in DC system. The AC behavior was determined by using the HP4194 impedance analyzer with the 16047D fixture in the frequency (f) ranged from 100 Hz to 15 MHz, [3,4], and together with an electromagnet which can supply a field up to ±60 Oe.

In AC system, the impedance (Z = R + jX) includes two parts, the resistance (R) and the reactance (X). Fig. 1 shows the Cole-Cole plot, i.e. R versus −X, of the MTJ sample in normalized log-log scale. The equivalent circuit of MTJ was found by analyzing the impedance results as shown in the inserted panel of Fig. 1. In this model the circuit contains two parts, the MTJ1 and the MTJ2, and each MTJ can be regarded as the combination of a resistor (R), an inductor (L) and a capacitor (C). They are basically the resistances of MTJs (R1, R2) and the inductances of the MTJs (L1, L2), and the capacitances of the Al2O3 Barriers.
Interestingly, these two MTJs are coupled by a mutual inductor of \( M \) with negative inductance. The ratios of the component of magnetoimpedance are also defined in the same DC manner, that is, 

\[
MR = \frac{100\% \times (R_{AP} - R_P)}{R_P}, \quad \text{and} \quad MX = \frac{100\% \times (X_{AP} - X_P)}{X_P},
\]

respectively. At low frequency, the behavior could be regarded as dc, and hence the field independences in \( MX \). For instance, at 100 Hz, the \( MR \) and \( MX \) ratios are 32.8% and 0, respectively. Nonzero \( MX \) is observed at the higher frequency as \( f = 30 \text{ kHz} \) and the \( MX \) ratio is 87.1%. Interestingly, the shape of the \( MX \) loop is reverse to the \( MR \) loop at 30 kHz to 5 MHz. The \( MR \) ratio changed from positive to negative at around 6 MHz. For instance, \( MR \) ratios are 9.5% at 5 MHz, and -11.5% at 7 MHz as shown in Fig. 2. This means that at high frequency (\( f > 6 \text{ MHz} \)) the \( R \) part of impedance at magnetic parallel state, \( R_P \), is larger than that at magnetic anti-parallel state, \( R_{AP} \); however, the \( MX \) ratio does not vary too much at these frequencies. Furthermore, the \( MR \) and \( MX \) ratios as function of frequency as shown in Fig. 3.

The inverse in \( MR \) loop around a certain frequency is due to the competition among \( R-L \) and \( C \) in the circuit. At low frequency (\( f < 6 \text{ MHz} \)), the effective impedance in this model, \( Z_{R-L} \) is smaller than \( Z_C \), so the part of \( R-L \) is dominated, and most of current go through \( R-L \) circuit, and the hysteresis properties of \( R \) is similar to the DC properties. On the contrary, at high frequency (\( f > 6 \text{ MHz} \)), \( Z_{R-L} \) is larger than \( Z_C \), so the part of \( C \) is dominated, it cause the reverse \( MR \) loop. It can be explained from Eq. (1) as follows.

\[
Z = \left( \frac{1}{R_1 + i \times 2\pi f \times L_1} + i \times 2\pi f \times C_1 \right)^{-1} \\
+ \left( \frac{1}{R_2 + i \times 2\pi f \times L_2} + i \times 2\pi f \times C_2 \right)^{-1} + i \times 2\pi f \times M
\]  

In summary, the magnetoimpedance effect of MTJ has been investigated at room temperature. It is found that the inverse \( MR \) occurred around 6 MHz, this means that at high frequency (\( f > 6 \text{ MHz} \)) the \( R_P \), is larger than \( R_{AP} \); however, \( X_{AP} \) is always larger than \( X_P \) from 30 kHz to 15 MHz. It is a novel discovery for magnetic store because the memory states can be controlled by frequency. More detail experiments, likes MOKE, VSM, can be practiced to verify that the magnetization reverses at high frequency in the future.

References