Available online at www.sciencedirect.com
ScienceDirect
Journal of Magnetism and Magnetic Materials 310 (2007) 1903–1904
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

High frequency impedance inverse in MTJ junction

L.C. Hsieh[a], Y.W. Huang[a,*], X.F. Han[b], Z.M. Zeng[b], W.C. Chien[c], T.Y. Peng[c], C.K. Lo[a,d], Y.D. Yao[e]

[a]Electronics and Optoelectronics Research Laboratories, Industrial Technology Research Institute, Hsinchu 310, Taiwan
[b]State Key Laboratory of Magnetism, Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Science, Beijing 100080, China
[c]Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu 300, Taiwan
[d]Nano Technology Research Center, ITRI, Hsinchu 310, Taiwan
[e]Institute of Phys., Academia Sinica, Taipei 115, Taiwan

Available online 27 November 2006

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.

PACS: 85.70.Kh; 85.30.Tv

Keywords: MTJ; Inverse; Impedance

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 magnetoimpedance behavior of MTJ was studied with frequency (*f*) ranged from 100 Hz to 15 MHz. The inverse *MR* has been found in the $Co/SrTiO_3/La_{0.7}Sr_{0.3}MnO_3$ 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/SiO 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 ($Z = R + iX$) 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 (R_1, R_2) and the inductances of the MTJs (L_1, L_2), and the capacitances of the Al_2O_3 Barriers

*Corresponding author. Tel.: +886 3 591 2878; fax: +886 3 591 2936.
E-mail address: yingwenh@itri.org.tw (Y.W. Huang).

0304-8853/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmmm.2006.10.1097

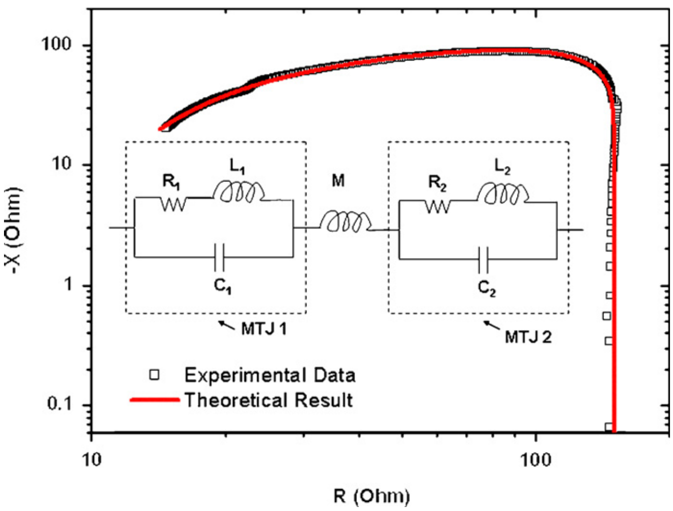

Fig. 1. The Cole-Cole plots of the MTJ sample. The experimental data (open symbols) are very close to the theoretical result (solid curves) which calculated from the equivalent circuit shown in the inserted panel.

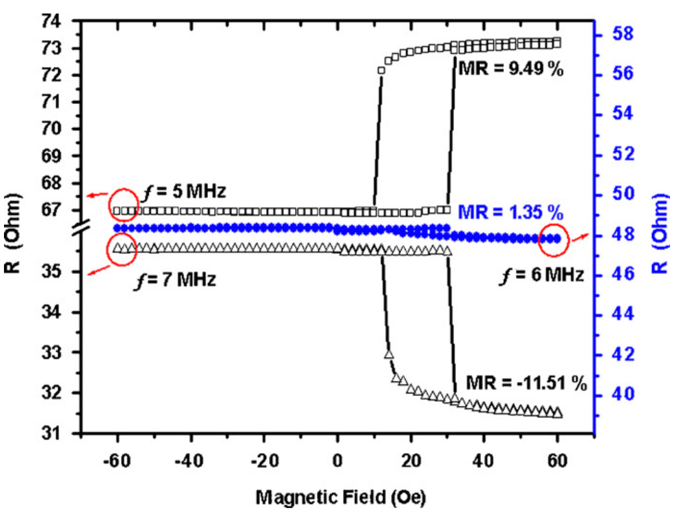

Fig. 2. The *MR* ratio changed from positive to negative at around 6 MHz, which came from the reverse shape of the *MR* loop.

(C_1, C_2). Interestingly, these two MTJs are couple 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 ratio $= 100\%*(R_{AP}-R_P)/R_P$, and MX ratio $= 100\%*(X_{AP}-X_P)/X_P$, 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 $f = 30$ 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 ($f > 6$ 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

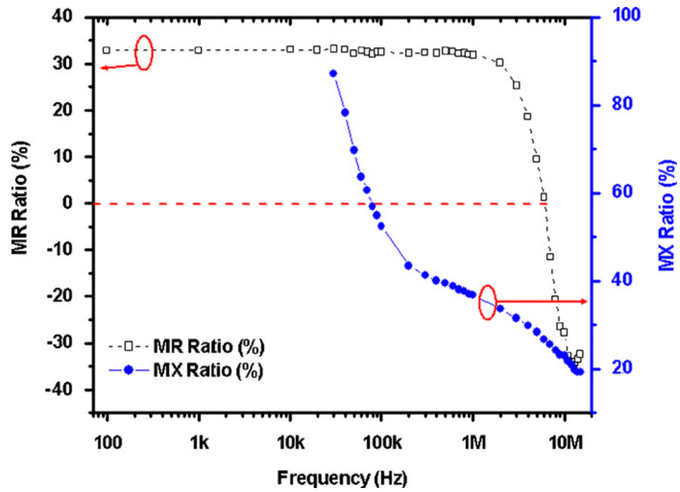

Fig. 3. The *MR* and *MX* ratios as function of frequency.

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 ($f < 6$ MHz), the effective impedance in this model, $Z_{R\text{–}L}$ 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 ($f > 6$ MHz), $Z_{R\text{–}L}$ 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.

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

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 ($f > 6$ 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

[1] S.F. Zhao, J. Zhao, Z.M. Zeng, X.F. Han, A.C.C. Yu, Y. Ando, T. Miyazaki, IEEE Transactions on magnetics 41 (2005) 2636.
[2] J.M. De Teresa, A. Barthélémy, J.P. Contour, A. Fert, Marie Curie Fellowships Annals 1 (2001) 35.
[3] T.Y. Peng, S.Y. Chen, L.C. Hsieh, C.K. Lo, Y.W. Huang, W.C. Chien, Y.D. Yao, J. Appl. Phys 99 (2006) 08H710.
[4] W.C. Chien, T.Y. Peng, L.C. Hsieh, C.K. Lo, Y.D. Yao, IEEE Transactions on magnetics 42 (10) (2006) 2624.