Tunneling spectroscopy of magnetic tunnel junctions: Comparison between CoFeB/MgO/CoFeB and CoFeB/Al-O/CoFeB

著者	水口　将輝
journal or publication title	Journal of Applied Physics
volume	99
number	8
page range	08T309-1-08T309-3
year	2006
URL	http://hdl.handle.net/10097/47382

doi: 10.1063/1.2171961

JOURNAL OF APPLIED PHYSICS **99**, 08T309 (2006)

Tunneling spectroscopy of magnetic tunnel junctions: Comparison between CoFeB/MgO/CoFeB and CoFeB/Al–O/CoFeB

M. Mizuguchi[a)]
Department of Materials Engineering Science, Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka 560-8531, Japan, and Core Research for Evolutional Science and Technology (CREST), Japan Science and Technology Agency, Kawaguchi, Saitama 332-0012, Japan

Y. Hamada, R. Matsumoto, and S. Nishioka
Department of Materials Engineering Science, Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka 560-8531, Japan

H. Maehara, K. Tsunekawa, D. D. Djayaprawira, and N. Watanabe
Electron Device Equipment Division, Canon ANELVA Corporation, Fuchu, Tokyo 183-8508, Japan

T. Nagahama, A. Fukushima, H. Kubota, and S. Yuasa
NanoElectronics Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8568, Japan, and Core Research for Evolutional Science and Technology (CREST), Japan Science and Technology Agency, Kawaguchi, Saitama 332-0012, Japan

M. Shiraishi and Y. Suzuki
Department of Materials Engineering Science, Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka 560-8531, Japan, and Core Research for Evolutional Science and Technology (CREST), Japan Science and Technology Agency, Kawaguchi, Saitama 332-0012, Japan

(Presented on 3 November 2005; published online 24 April 2006)

Tunneling spectroscopy measurements of magnetic tunneling junctions including two different barrier layers were performed. Intense dips at bias voltages of ±0.3 V were observed in second derivative conductance spectra only for a magnetic tunneling junction with a MgO barrier. It was concluded that the electronic structure of the MgO barrier has significant influence on the tunneling process of electrons through magnetic tunnel junctions. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2171961]

I. INTRODUCTION

Magnetic tunneling junctions (MTJs) are attracting much attention due to its application to magnetoresistive random access memory and coming read heads for ultrahigh density hard disk drives.[1–3] Recently, MTJs showing a large tunnel magnetoresistance (TMR) effect at room temperature with MgO tunnel barriers have been reported.[4–7] In particular, it is surprising that a very high TMR ratio of 230% was observed even for MTJs with a highly oriented MgO barrier sandwiched by amorphous CoFeB electrodes.[7,8] Thus, to make clear the detailed mechanism of the huge TMR effect become a very important topic.

Tunneling spectroscopy can extract information on detailed spin-dependent tunneling processes of electrons that are directly linked to the density of states of constituting materials. Several studies have been reported on investigating the electronic structure of MTJs by tunneling spectroscopy measurements.[9,10] In this study, we performed tunneling spectroscopy of MTJ with a MgO barrier (CoFeB/MgO/FeCoB) which shows a very high TMR ratio at room temperature. For a reference, tunneling spectroscopy of MTJ with an Al–O barrier (CoFeB/Al–O/FeCoB), which shows the largest MR ratio among MTJs using Al–O barriers, was also performed.

II. EXPERIMENTS

Two spin-valve type MTJs were fabricated by a magnetron sputtering (Canon ANELVA C-7100) and subsequent photolithography processes. Structures of MTJs are as follows: Ru(7 nm)/Ta(10 nm)/$Co_{60}Fe_{20}B_{20}$(3 nm)/*barrier layer*/$Co_{60}Fe_{20}B_{20}$(3 nm)/Ru(0.85 nm)/$Co_{70}Fe_{30}$(2.5 nm)/PtMn(15 nm)/Ta(10 nm)/thermally oxidized Si(001) substrate. We employed two sorts of barrier layers, MgO(1.8 nm) and Al–O(1.2 nm).[11] We use abbreviations of “MgO-MTJ” and “Al–O-MTJ” for each MTJs hereafter. The MgO barrier layer was deposited by a rf sputtering, whereas the Al–O layer was formed by a radical oxidation of metallic Al layer (0.87 nm). Other layers were deposited by a dc sputtering. Then, both samples were annealed in a high vacuum applying a magnetic field of 8 000 Oe, at 360 °C for 2 h (for MgO-MTJ) and at 270 °C for 5 h (for Al–O-MTJ). Junctions with a size of 1 $\mu m \times 1$ μm were fabricated by photolithography and Ar ion-milling.

Tunneling spectroscopy studies were performed using a cryostat equipped with superconducting solenoids (OXFORD MagLab System^{2000}). First, MR curves were measured by a dc two-probe method at liquid helium temperature to investigate the magnetic hysteresis of the MTJs. Then, we measured the second derivative conductance (d^2I/dV^2) with an energy resolution down to 1 mV by conventional lock-in detection technique applying an ac-modulated voltage at 4.3 K. Bias voltages between −1.0 and +1.0 V were applied.

[a)] Author to whom correspondence should be addressed; electronic mail: mizuguchi@mp.es.osaka-u.ac.jp

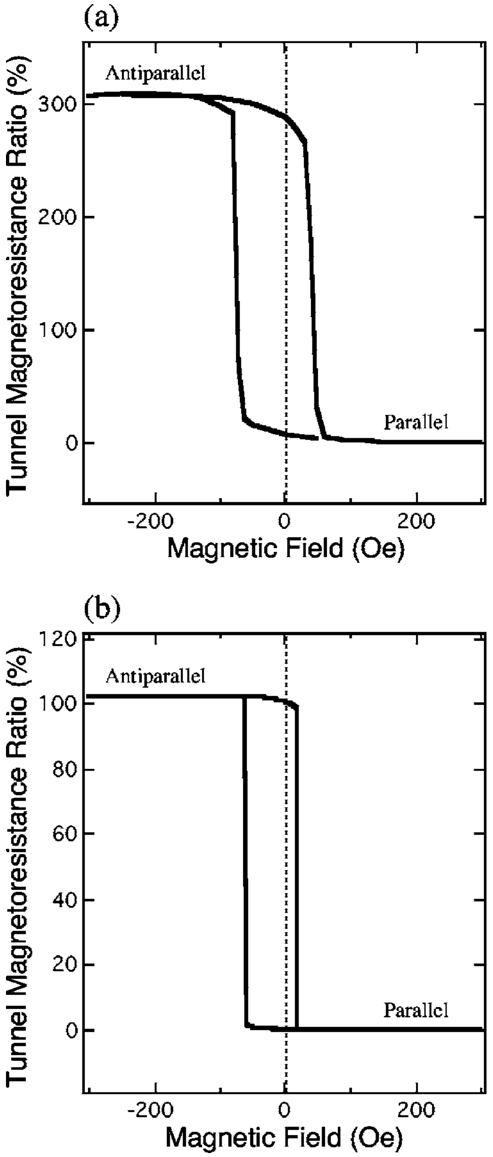

FIG. 1. MR curves of (a) MgO-MTJ taken at 4.3 K and (b) Al–O-MTJ taken at 4.7 K.

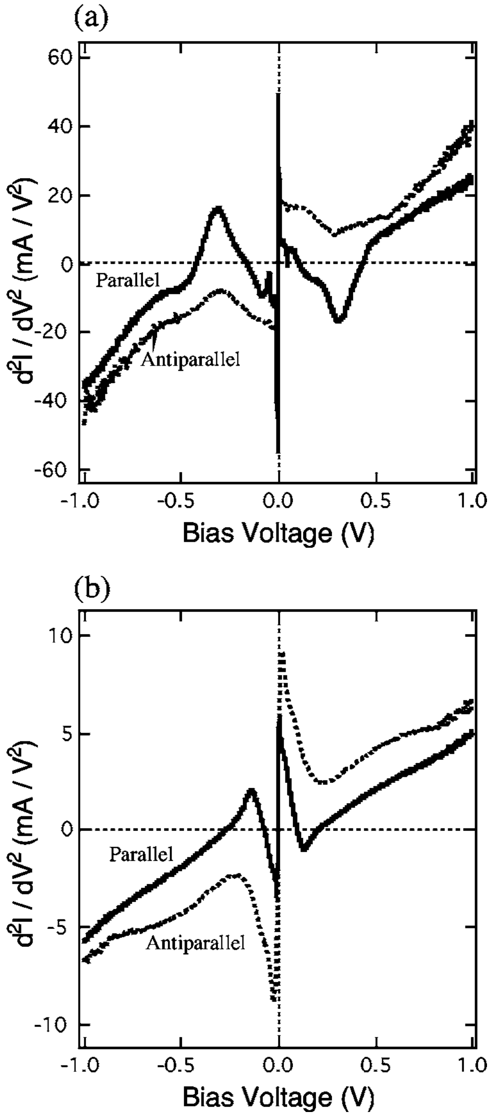

FIG. 2. d^2I/dV^2 spectra of (a) MgO-MTJ and (b) Al–O-MTJ, taken at 4.3 K.

Signals were taken for two magnetization configurations of ferromagnetic layers of CoFeB, parallel configuration and antiparallel configuration, by applying adequate external magnetic fields for both MTJs. More details of measurements are denoted in our previous paper.[12]

III. RESULTS AND DISCUSSION

The MR curve of MgO-MTJ is shown in Fig. 1(a). The resistance in the parallel configuration was 36 Ω, and the MR ratio was 307% at 4.3 K. In contrast, the resistance of Al–O-MTJ in the parallel configuration was 248 Ω, and the MR ratio was 102% at 4.7 K. Large MR ratios obtained for both samples tell the high quality of these MTJs.

Figure 2(a) shows the d^2I/dV^2 spectra of MgO-MTJ that were measured at 4.3 K by applying magnetic fields of 220 and −220 Oe for parallel and antiparallel configurations, respectively. Strong peaks around zero bias voltage were observed for both configurations. These peaks are often called "zero-bias anomaly." One possible origin for these peaks is magnetic impurity scattering, which should become conspicuous with decreasing measurement temperature. Broad and large dips, particularly noticeable for the parallel configuration, were observed at ±0.3 V, which reflects the reduction of conduction. Speculation for the origin of the dips is discussed later. Besides, sharp and tiny anomalies, were found at around ±0.05 V only for parallel configuration in the case of Fig. 2(a). It has been already clarified in our previous study[12] that the anomalies strongly depend on the configuration of ferromagnetic layers, which implies that they can be attributed to magnon excitations.

On the other hand, the d^2I/dV^2 spectra of Al–O-MTJ showed completely different characteristics [Fig. 2(b)]. They were taken at 4.3 K by applying magnetic fields of 100 and −150 Oe, respectively. Intense zero-bias anomaly peaks were observed also for Al–O-MTJ. The peaks, however, were much broader than that of MgO-MTJ. Other distinct features were not identified within the bias voltage of ±1.0 V. Fundamental structures of the both configurations were very similar to each other.

A comparison of the d^2I/dV^2 spectra of two MTJs in the

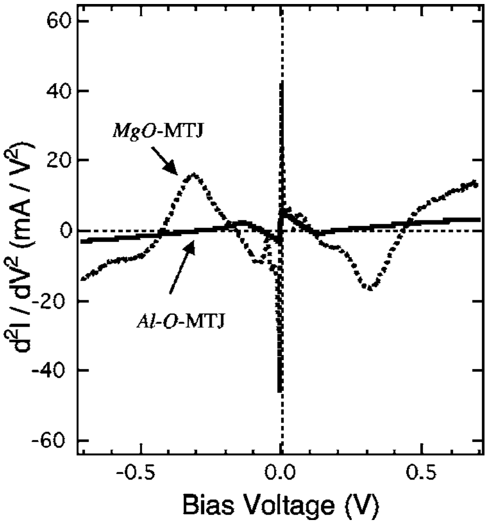

FIG. 3. d^2I/dV^2 spectra of MgO-MTJ and Al–O-MTJ in the parallel configuration taken at 4.3 K.

parallel configurations is shown in Fig. 3. One can see intense dips obviously only for the spectrum of MgO-MTJ. In contrast, the spectrum of Al–O-MTJ is featureless without any intense peaks or dips. We conclude that these dips are brought from the change of tunneling probability through the MgO(001) barrier depending on the bias voltage, and the density of states of the MgO barrier has significant influence on the tunneling process. However, inelastic tunneling electron spectra of a single-crystal Fe(001)/MgO(001)/Fe(001)-MTJ (Ref. 13) are thoroughly different from those of CoFeB/MgO/CoFeB-MTJ in the present study. Thus, it was proved that the reduction of conductance at around ±0.3 V is peculiar to MTJs including a MgO(001) epitaxial barrier and amorphous CoFeB electrodes. This fact implies that not only the electronic structure of the MgO barrier but also those of electrodes and interfacial states have relation to the giant MR ratios. The origin of disappearance of the dips for Al–O-MTJ is unclear at the present stage.

IV. CONCLUSION

We performed d^2I/dV^2 measurements of MTJs including two different barrier layers. The figures of spectra were completely different between a MTJ with a MgO barrier and a MTJ with an Al–O barrier. Intense dips at bias voltages of ±0.3 V were observed only for the spectra of the MTJ with the MgO barrier, which means that the electronic structure of the MgO barrier has significant influence on the tunneling process.

ACKNOWLEDGMENTS

We are grateful to M. Yamamoto of AIST for assisting with the experiments. This work was partly supported by The 21st Century COE Program (G18) of the Japan Society for the Promotion of Science.

[1] J. S. Moodera, L. R. Kinder, T. M. Wong, and R. Meservey, Phys. Rev. Lett. **74**, 3273 (1995).
[2] T. Miyazaki and N. Tezuka, J. Magn. Magn. Mater. **139**, L231 (1995).
[3] S. A. Wolf, D. D. Awschalom, R. A. Buhrman, J. M. Daughton, S. von Molnár, M. L. Roukes, A. Y. Chtchelkanova, and D. M. Treger, Science **294**, 1488 (2001).
[4] S. Yuasa, A. Fukushima, T. Nagahama, K. Ando, and Y. Suzuki, Jpn. J. Appl. Phys., Part 2 **43**, L588 (2004).
[5] S. S. P. Parkin, C. Kaiser, A. Panchula, P. M. Rice, B. Hughes, M. Samant, and S. H. Yang, Nat. Mater. **3**, 862 (2004).
[6] S. Yuasa, T. Nagahama, A. Fukushima, Y. Suzuki, and K. Ando, Nat. Mater. **3**, 868 (2004).
[7] D. D. Djayaprawira, *et al.* Appl. Phys. Lett. **86**, 092502 (2005).
[8] MR ratio is defined as $(R_{\mathrm{ap}}\text{-}R_P)/R_P$, where R_{ap} and R_P are the tunneling resistances when magnetizations of two electrodes are aligned in antiparallel (AP) and parallel (P), respectively.
[9] J. S. Moodera, J. Nowak, and R. J. M. van de Veerdonk, Phys. Rev. Lett. **80**, 2941 (1998).
[10] J. Murai, Y. Ando, M. Kamijo, H. Kubota, and T. Miyazaki, Jpn. J. Appl. Phys., Part 2 **38**, L1106 (1999).
[11] The designed thicknesses of the two barriers were different because the optimum TMR was obtained for different thicknesses in each case.
[12] R. Matsumoto, *et al.* Solid State Commun. **136**, 611 (2005).
[13] Y. Ando, T. Miyakoshi, M. Oogane, T. Miyazaki, H. Kubota, K. Ando, and S. Yuasa, Appl. Phys. Lett. **87**, 142502 (2005).