Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp925-926

PS-12-09

Resistance Drift and Degradation of Fe/Spinel $MgAl_2O_4$/Fe(001) Magnetic Tunnel Junctions

Chulmin Choi[1], Hiroaki Sukegawa[2], Seiji Mitani[2] and Yunheub Song[1]

[1]Department of Electronics and Computer Engineering, Hanyang Univ.
Wangsimni-ro 222, Seongdong-gu, Seoul, Korea
Phone: +82-2-2220-4135 E-mail: yhsong2008@hanyang.ac.kr
[2]Research Center for Magnetic and Spintronic Materials
National Institute for Materials Science (NIMS)
1-2-1 Sengen, Tsukuba 305-0047, Japan

Abstract

We fabricated fully epitaxial Fe/$MgAl_2O_4$/Fe(001) magnetic tunnel junctions (MTJs) using plasma oxidation of an Mg/Al bilayer. Lattice mismatches are very small between the $MgAl_2O_4$ (MAO) tunnel barrier and the Fe layers. In the present paper, resistance drift and degradation in an optimally post-oxidized MAO-MTJ with an MAO thickness of t_{MAO} = 1.25 nm and an under post-oxidized MAO-MTJ with t_{MAO} = 2.8 nm are examined at electric fields of 0.5 and 0.6 MV/cm under the R_{AP} (anti-parallel) condition. Breakdown phenomena are also compared.

1. Introduction

Magnetic tunnel junctions (MTJs) consisting two ferromagnetic electrodes and a tunnel barrier between the electrodes have been intensively investigated for applications of read heads of hard disc drives and memory cells of magnetic random access memories (MRAMs) [1][2]. Nowadays, MTJs with a crystalline MgO as tunnel barriers and CoFeB as electrodes were commonly used to obtain high tunnel magnetoresistance (TMR) ratios [3]. Recently, MTJs having a high TMR ratio even at a high bias voltage have been realized using a new tunnel barrier spinel $MgAl_2O_4$ (MAO) due to the achievement of lattice-matched Fe/MAO/Fe(001) MTJ structures [4]. Although the reliability of MgO-based MTJs has been examined extensively, there are no reports on the reliability of MAO-based MTJs. The present study aims to study the reliability on bias application for MAO-based MTJs. Especially we examine the degrees of resistance drift for two different MAO-based MTJs; one is the optimum oxidation with a high TMR ratio and the other is under-oxidation condition with a low TMR ratio [4]. Here, we focus on dependences on bias voltage and bias polarity in the R_{AP} (anti-parallel) magnetic configuration. Especially, to investigate the effect of degree of oxidation of MAO, we compared optimum and under-oxidized MAO barrier cases [4].

2. General Instructions

Device fabrication

We deposited a multilayer stack on a single-crystal MgO (001) substrate using an ultrahigh vacuum magnetron sputtering system with a 5×10^{-7} Pa; the MTJ stack has the following structure: Cr (40)/Fe (30)/Mg (0.45)/$Mg_{19}Al_{81}$ (t_{MgAl} = 0.9 or 2.0)/post-oxidation/Fe (7)/IrMn (12)/Ru (12) (the numbers in parentheses represent thickness in nm), as schematically illustrated in Fig. 1 (a). To obtain MAO barrier, the MgAl layer was post-oxidized using oxygen plasma [3]. Here, we used optimum post-oxidation condition for t_{MgAl} = 0.9 nm and under-oxidation condition for t_{MgAl} = 2.0 nm (the final MAO barrier thicknesses are 1.25 and 2.8 nm, respectively). A TMR ratio of the optimum (under-oxidation) sample was XXX% (XXX%). To measure resistance drift ratios, constant voltage stress (CVS) test was done as shown in Fig. 1 (b) [5]. CVS test is conducted by applying a constant voltage until the MTJ cell is broken down.

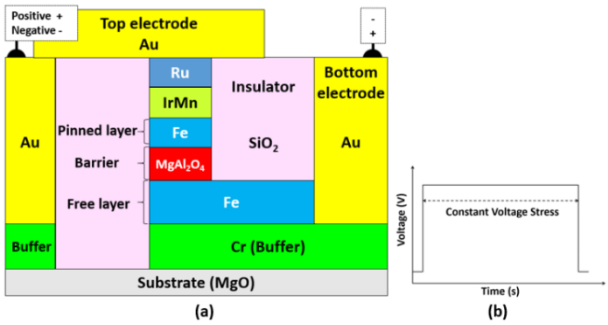

Fig. 1. (a) Cross-sectional schematic of an MTJ device. (b) Timing diagram for the constant voltage stress (CVS) test.

Experimental results and discussion

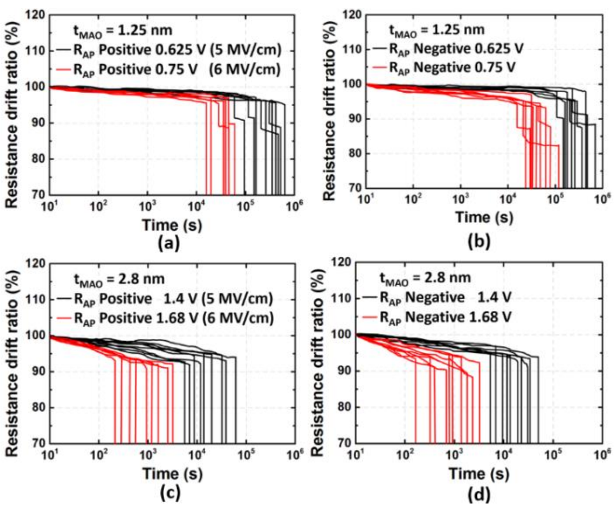

Fig. 2. R_{AP} drift ratios for (a) positive bias and (b) negative bias when t_{MAO} = 1.25 nm, and R_{AP} drift ratios for (c) positive bias and (d) negative bias when t_{MAO} = 2.8 nm.

The observed low TMR ratio and a drastic decrease in the resistance against bias voltage in the under-oxidized MTJ may be due to the lack of oxygen [4]. Fig. 2 shows the times at which the MTJs broke down at different levels of bias polarity and bias voltage in an optimized condition or an under-oxidized condition, respectively.

In Fig. 2 (a) and (b), the MTJs in the optimized condition, where t_{MAO} = 1.25 nm, showed a hard breakdown phenomenon, in which the MTJs were completely broken down, but they also showed a soft breakdown phenomenon in which 80~90% of resistance could be observed in some MTJs at all bias-polarity and bias-voltage levels. The resistance maintained because of this soft breakdown phenomenon could be observed in R_{AP} and the resistance was maintained for several hundred seconds at the minimum and for 10,000 seconds or longer at the maximum. In Fig. 2 (c) and (d), however, the MTJs in the under-oxidized condition, where t_{MAO} = 2.8 nm, showed only the hard breakdown phenomenon; the MTJs were completely broken down, as observed with the Alumina-MTJ and MgO-MTJ studied previously. Also, the resistance drift of under-oxidized MTJs was larger than that of optimized MTJs and the breakdown time was shorter.

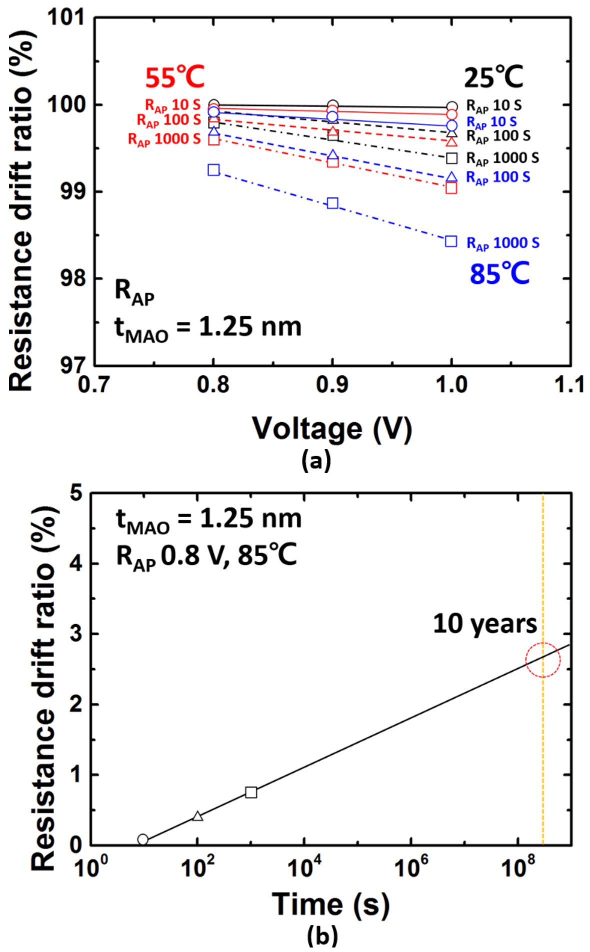

Fig. 3. (a) R_{AP} drift ratios at different temperatures, biases, and stress time when t_{MAO} = 1.25 nm. (b) Predicted R_{AP} resistance drift ratios for 10 years at 0.8 V and 85°C.

Fig. 3 (a) shows the R_{AP} drift ratios at different stress-time duration and bias-voltage sat 55°C, 85°C, and room temperature (RT) for the optimum oxidation condition (t_{MAO} = 1.25 nm). The reason why different temperature conditions were used was to study the self-heating effect [6], in which resistance drift is accelerated by temperature increases as a result of thermal bond-breakage due to the electric field [7]. Fig. 3 (b) shows the resistance drift ratios that are expected to appear in 10 years based on the resistance drift ratios at 10, 100, and 1000 sin the R_{AP}, t_{MAO} = 1.25 nm, 0.8 V, and 85°C condition. The graph shows that the drift of R_{AP} should be approximately 2.6 % even after 10 years, indicating high reliability. When seen collectively, spinel-based MTJs hardly depend on the polarity of bias. Instead, degree of oxidation greatly affects the reliability.

3. Conclusions

We fabricated fully epitaxial Fe/$MgAl_2O_4$/Fe(001) MTJs using plasma oxidation of an Mg/Al bilayer. Thereafter, resistance drift and breakdown phenomena under an optimized post-oxidation condition and an under-oxidation condition were compared through CVS tests. In the tests, in addition to hard breakdown phenomena, soft breakdown phenomena, in which an MTJ was not completely broken but a certain level of resistance was maintained, were observed in the MTJ under the optimized condition. Finally, when the application of 0.8 V at 85°C (considering self-heating) for the optimized oxidation MTJ, small resistance drift of approximately 2.6% for 10 years was predicted. In conclusion, $MgAl_2O_4$ tunnel barriers with small lattice mismatch should be reliable for device applications.

Acknowledgements

This research was supported by the Ministry of Trade, Industry and Energy (10044608) and by a support program of the Korea Semiconductor Research Consortium for the development of future semiconductor devices.

References

[1] M. Durlam *et al*., *Electron Devices Meeting, IEDM ’03 Technical Digest* (2003) 34.6.1.

[2] M. Hosomi *et al*., *Electron Devices Meeting, IEDM ’05 Technical Digest* (2005) 459.

[3] C. Yoshida *et al*., *2009 IEEE International Reliability Physics Symposium* (2009) 139.

[4] H. Sukegawa *et al*., *Applied Physics Letters* **105** (2014) 092403

[5] K. Hosotani *et al*., *2009 IEEE International Reliability Physics Symposium* (2008) 703

[6] K. Hosotani *et al*., *Japanese Journal of Applied Physics*, **49** (2010) 04DD15

[7] A. A. Khan *et al*., *Microelectronics Reliability*, **55** (2015) 894