Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp929-930

PS-12-11

Research on the failure cell screen method of MgO based MTJ

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Abstract

Time Dependent Dielectric Breakdown (TDDB) of Magnetic Tunneling Junction (MTJ) is dependent on thickness of tunnel barrier and bias voltage. Figuring out the changing tendency of TDDB due to these conditions, we predict the TDDB under the increasing temperature caused by self-heating phenomenon and propose the standard which can screen the potential reliability failure MTJ cell. Moreover, we suggest Constant Voltage Stress (CVS) which is a general method of TDDB test and Constant Current Stress (CCS) that improves the disadvantage of long test time using CVS.

1. Introduction

Spin-Transfer-Torque Magneto-resistive Random Access Memory (STT-MRAM) is the most promising next generation memory to replace Dynamic Random Access Memory (DRAM) due to its unique features, such as non-volatility, excellent reliability, low power consumption and high speed operation [1]. Amorphous Aluminum oxide layer has been used as Tunnel barrier of Magnetic Tunneling Junction (MTJ) that is an important component of MRAM. However, crystalline MgO barrier is used to replace Aluminum oxide layer recently, because Tunnel Magneto Resistance (TMR) effect of Aluminum oxide is very low (< 60 %) when compared to MgO barrier. MgO barrier can improve the reliability of the device a lot, because MgO barrier has high TMR and lower trap generation rate that according to improved roughness between tunnel barrier and electrode material [2]-[4]. By inserting Mg layer between MgO tunnel barrier and CoFe / CoFeB electrode, trap is reduced more because roughness between the two layers is improved even more [5]. In this letter, we investigate on TDDB of MgO based MTJ with Mg layer inserted with changing tunnel barrier thickness and voltage using CVS test method, and suggest CCS test method which improves the disadvantage of long test time using CVS test method.

2. Sample Fabrication and Experiment

Sample fabrication

In order to reduce trap, MTJs consisted of multilayers with Mg layer inserted under MgO tunnel barrier were prepared on SiO_2 substrates using ultrahigh vacuum magnetron sputtering system with a base pressure of 4×10^{-7} Pa. The MTJ stack is consisted of SiO_2-Si substrate/ Ta/ Ru/ Ta/ NiFe (5)/ IrMn (11)/ CoFe (2.5)/ Ru (0.85)/ CoFeB (2)/ CoFe (1)/ Mg/ MgO (1)/ CoFe (0.4)/ CoFeB (2)/ Ta (2)/ Ru (8) (the numbers in parentheses represent thickness in nm) as schematically illustrated in Fig. 1, where the numbers in brackets represent thickness in nm. Since the Mg layer is combined with oxide and generates MgO during the process, the MgO barrier becomes thicker than deposited MgO tunnel barrier. Therefore, using this effect, MgO tunnel barrier thickness can be controlled (t_{MgO} = 1.1, 1.2 nm) by changing the thickness of Mg layer. After deposition, we annealed the MTJ for 1 h at 360 ℃ under a magnetic field of 5 kOe to get larger MR ratio and better magnetic hysteresis. Size of MTJ Pillar is 200 × 100 nm^2, which is made through E-beam lithography process.

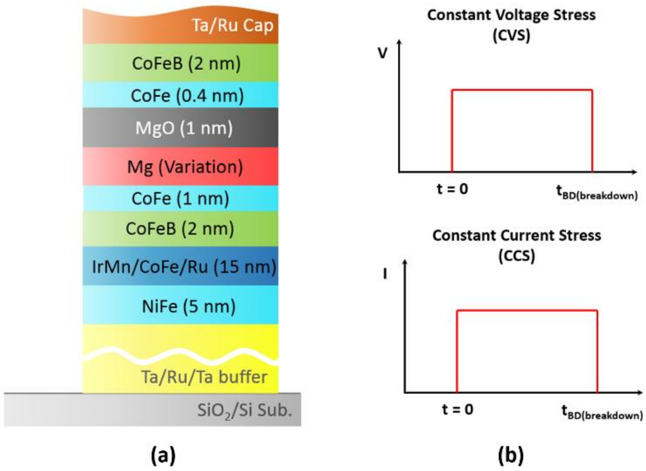

Fig. 1 (a) Schematic of stacking structure of MgO based MTJ. (b) Timing diagrams of the constant voltage stress (CVS) test and constant current stress (CCS) test.

Condition and method of experiment

For the experiment, we used CVS and CCS method to screen the potential reliability failure MTJ cell to measure TDDB. Using measured TDDB, we assumed the temperature rise according to heat generated due to self-heating inside the MTJ to 100 ℃ [6]. In order to realize STT for in reality, low Resistance-area (RA) is required. Therefore, to achieve low RA and predict MTJ with 1.0 nm MgO tunnel barrier, we fabricated MTJ that thickness of MgO tunnel barrier is 1.1 nm and 1.2 nm. During the CVS and CCS test, voltage and a current were applied by using sourcemeter

(Keithley 2614B). Voltage range from 0.9 V and 1.3 V was applied, and current condition will be explained in detail in next section.

The result of CVS test experiment

Fig. 2 shows measured TDDB when voltage from 0.9 V to 1.3 V is applied when thickness of MgO tunnel barrier are 1.1 nm and 1.2 nm. We measured TDDB of the twenty samples for each MTJ condition, and then indicated TDDB when samples of 63 % are broken in Fig. 2. As shown in Fig. 2, we confirmed that constant TDDB variation is observed as thickness gets thinner. From the result, we indicated the predicted result of when thickness of tunnel barrier is 1.0 nm in Fig. 2. Voltage range from 0.5 V to 0.7 V in Fig. 2 are predictive value when by assuming the operating voltage of MRAM when commercialized. When MgO tunnel barrier thickness is 1.0 nm, TDDB is expected to maintain the value of about 10^7 second at 0.7 V and 120 ℃ condition, and over 10^{10} second at 0.5 V. Though reliability over 10 years is achieved for commercialization, CVS test has fatal disadvantage of long test time up to 10^5 second when MgO thickness is 1.2 nm. We have set the current condition as Fig. 3(a) to perform proposed CCS test method which compensate the disadvantage of CVS test.

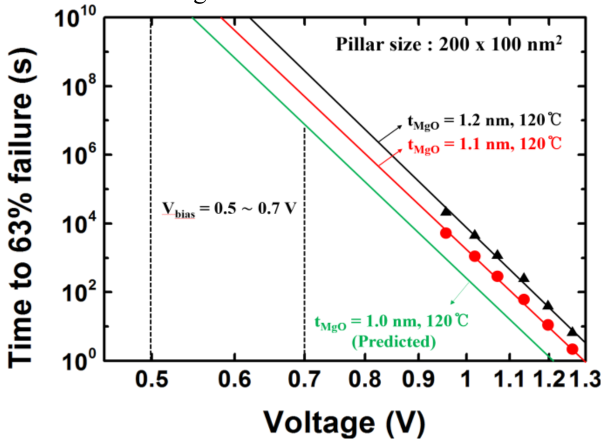

Fig. 2 TDDB measured by CVS method.

The result of CCS test experiment

I_{BD} is breakdown current at CVS test and I_0 is initial current value in Fig. 3(a). When $I_{BD} - I_0$ is 100 %, CCS test is performed by fixed current of 25 %, 50 % and 75 %. The experiment was conducted with a current value set in Fig. 3(a). The result of TDDB is indicated in Fig. 3(b). When 25 % current is applied, much time is spent rather than CVS test method. When current of 50 % (75 %) is applied, TDDB is shorten in the order of about $10^{0.5}$ (10^1) compared to CVS test. It is also confirmed that TDDB slope is maintained with current under 75 %. However, we could also confirm that the sample is broken in few seconds when current 80 % is applied to shorten much time. Based on these, we obtained a new fact that it is most efficient for time saving when the current variation of 75 % is regularly applied.

3. Conclusions

In this letter, we predict TDDB of MTJ for commercialization through CVS method with changing thickness of

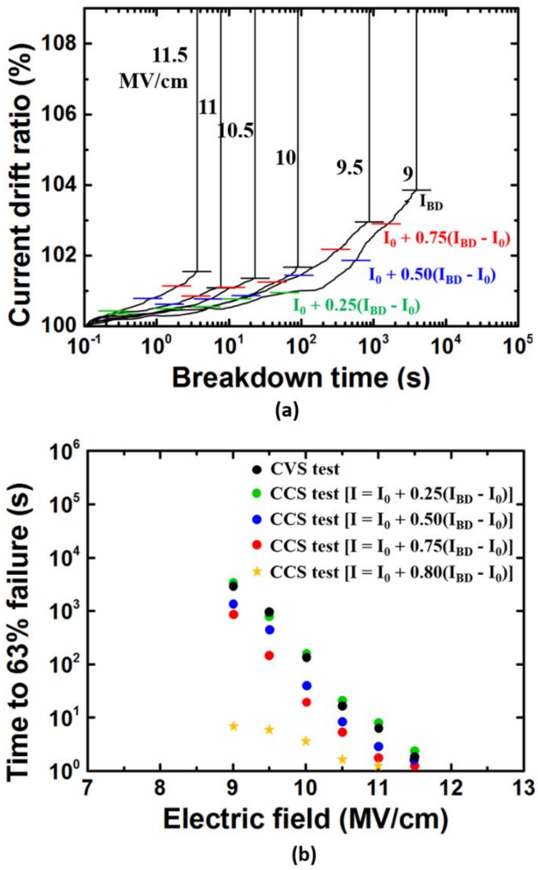

Fig. 3 (a) Current of CCS test setting through CVS test (b) TDDB measured by CCS method when MgO tunnel barrier is 1.1 nm.

MgO tunnel barrier and voltage. Moreover, we suggest CCS test can compensate the long test time of CVS method. TDDB of 1.1 nm MgO tunnel barrier is measured by CCS method and the results are presented in this letter. Also TDDB according to changing thickness is measured. Generation of CCS method will contribute on predicting potential failure MTJ cell screen method when MRAM is commercialized.

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.

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