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Study about the Process Damage Mechanism of the Patterned Interface Perpendicular Magnetic Tunnel Juncotions (MTJs) by Hydrogen Ion Treatments

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Abstract

In order to identify the degradation mechanism of patterned CoFeB/MgO based interface perpendicular MTJs for two types of hydrogen gas treatments which are the hydrogen plasma condition (HPC) and the hydrogen etching condition (HEC), the MR and RA trend for various damaged layer (DL) conditions were evaluated and compared to experimental results by the HPC and the HEC treatment. As a result, for the HPC treatment, hydrogen just reacted with the damaged layer at the edge of patterned MTJs and there were no magnetic damages in the middle area of patterned cell. However, for the HEC treatment, there were magnetic degradations even in the middle area of MTJs as well as in the DL. It was because the HEC treatment can accelerate the activity of hydrogen plasma ions by applying the bias voltage and penetrate into the interface between MgO and CoFeB. This study validate it can be classified which types of degradations are generated by various patterning gases using the evaluation method suggested in this study.

1. Introduction

For recently, spintronic devices has been studied very actively as various advanced semiconductor applications such as magnetic random access memory (MRAM), embedded MRAM (e-MRAM) and non-volatile logic devices because of its low energy consumption by non-volatility, the high speed read/write operation, the semiconductor-friendly manufacturing process and cost benefits.[1, 2] However, for the successful development of spintronic devices, we should overcome several technical bottle-necks such as the high tunneling magneto-resistance (TMR), the high switching efficiency and the damage-less magnetic tunnel junctions (MTJs) patterning method. Especially, the development of the damage-less MTJs patterning process using the conventional semiconductor etching sources is the most critical key factor for the efficient commercialization of spintronic devices. Essentially, MTJs are easy to be damaged by halogen gases used generally in semiconductor patterning process because they are composed of well corroded materials such as cobalt (Co) and iron (Fe).[3] Therefore, we have used hydrogen gas at the MTJs patterning process to avoid the MTJs corrosion.[4] However, it was found that even hydrogen gas can make damage to MTJs by the hydration of MgO and the reaction with damaged metal layers at the edge of patterned MTJs.[5]

In this study, we study about the damaged mechanism of the patterned interface perpendicular magneto-anisotropy (i-PMA) MTJs by several hydrogen conditions. Especially, by compared the evaluated trend and measured trend for MTJs degradation as several MTJs size, it is speculated how the degradation of MTJs is generated.

2. Experimental Procedure

Stacks of Ru (5 nm)/CoPt (2 nm)/Ru (4 nm)/CoFeB (1.5 nm)/MgO (1 nm)/CoFeB (1.2 nm)/Ta (2nm)/Ru (2 nm) were deposited using an ANELVA C-7100 ultra-high vacuum sputtering system. They were patterned as three types of sizes, $30x60nm^2$, $45x70nm^2$, $60x80nm^2$ using the minimum damaging patterning process which is composed of the RIE Etching and multi-step ion beam etching (IBE) treatment.[5] At these patterned samples, additional hydrogen gases were applied with two types of gas flowing methods which are the hydrogen plasma condition (HPC) applying no bias voltage and the hydrogen etching condition (HEC) applying the bias voltage. After the full integration process, the MR and RA for all of samples were measured and compared to the calculated MR and RA trend.

3. Results and Discussions

In order to study about the damaged mechanism of the patterned MTJs by the HPC and the HEC treatment, the change of the MR and RA for patterned samples was evaluated as various electric and magnetic conditions of the damaged layer (DL) with several assumptions. Firstly, it was assumed that the patterned MTJs were composed of the damaged area and the middle area as shown at figure 1-(a). Secondly, it was also assumed that the damaged area was distributed uniformly at the edge of the patterned sample and a current flowed in parallel to total area of MTJs as shown at figure 1-(b). Finally, we assumed that there were no magnetic damages in the middle area and the resistance of the DL was higher than the resistance of the middle area. With these assumptions, we calculated the change of the MR and RA for the patterned MTJs using equation (1) ~ (3) and compared this result to the experimental result by the HPC and the HEC treatment.

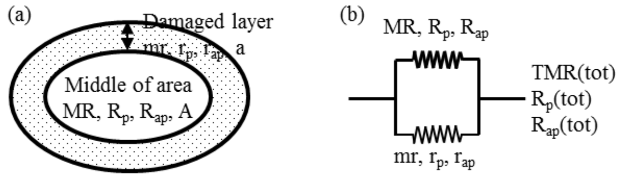

Fig. 1 (a) Schematic diagram of the patterned MTJs and (b) circuit diagram of the damaged layer and the middle of cell.

$$R_p = \frac{RA}{A},\ r_p = \frac{ra}{a},\ R_{ap} = R_p\left(1+\frac{MR}{100}\right),\ r_{ap} = r_p\left(1+\frac{mr}{100}\right) \quad (1)$$

$$R_p(tot) = \frac{R_p r_p}{R_p + r_p},\ R_{ap}(tot) = \frac{R_{ap} r_{ap}}{R_{ap} + r_{ap}} \quad (2)$$

$$TMR(tot) = \frac{R_{ap}(tot) - R_p(tot)}{R_p(tot)} \times 100 \quad (3)$$

Figure 2 shows the calculated MR and RA trend when it is assumed that the RA of the DL was twice of the middle area, the MR of the DL was 10% and 40% respectively and the damaged layer width (DLW) is 3nm. The assumed DLW is verified by the measured DLW by TEM, 2.89nm, of the patterned MTJs by the HPC treatment. As shown at figure 2, when the MR of the DL is 10%, the calculated MR and RA trends at various MTJs sizes are almost same with the trend of the HPC treated MTJs sample at the similar DLW. This result shows the HPC treatment doesn't make the magnetic damage in the middle area of patterned cells as assumed before. Because the HPC doesn't apply the bias voltage can activate hydrogen plasma ions, hydrogen ions just react with the damaged layer at the edge of the patterned MTJs, not the middle area of MTJs.

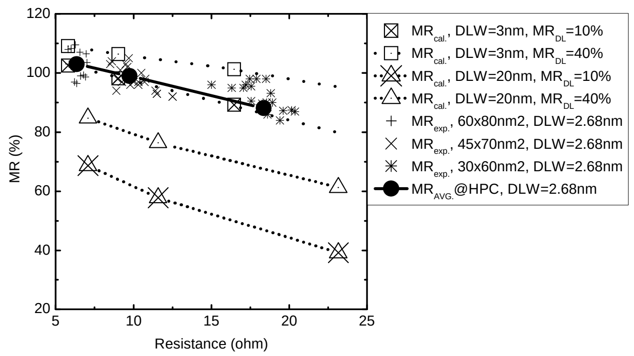

Fig. 2 MR and R trend by the HPC treatment and the comparison to the calculated MR and RA trend with various DL sizes.

However, unlike the HPC treatment, the MR and RA trends by the HEC treatment are totally different from the calculated result at the similar DLW as shown at figure 3. The MR by the HEC treatment is decreased more severely with all of MTJs sizes compared to the calculated MR trend. By this result, it can be inferred there are additional magnetic damages in the middle area of MTJs as well as the DL. At the HEC treatment, the properties of i-PMA MTJs might be degraded more severely than at the HPC treatment because hydrogen ions can penetrate into the interface between MgO and CoFeB not just reacting with damaged layers. Hydrogen plasma ions generated by the HEC are activated sufficiently to penetrate into the interface of i-PMA MTJs because the bias voltage can accelerate the activity of hydrogen plasma ions is applied which is like the etching process.

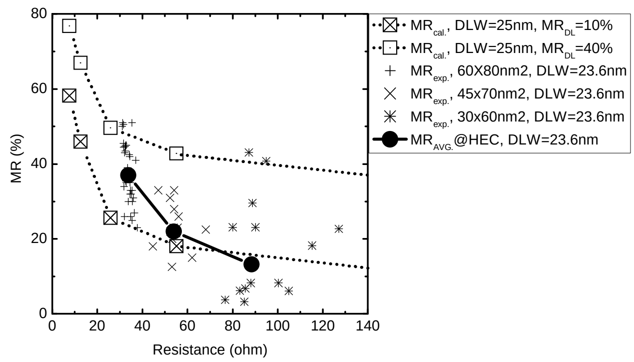

Fig. 3 MR and R trend by the HEC treatment and the comparison to the calculated MR and RA trend at the similar DL size.

4. Conclusions

With all of these studies, it was found that the HPC treatment make less DL and magnetic degradations than the HEC treatment. In addition, after the MTJs patterning process, because the edge of patterned MTJs is easy to be reacted by the patterning damage, activated hydrogen ions by the HEC treatment can make damage more easily by penetration into the interface between MgO and CoFeB.

Finally, using our evaluation method in this study, it could be classified which types of degradations were generated by various hydrogen treatment conditions. This evaluation method can be utilized as the extrapolation for the magnetic degradation after the MTJs patterning process.

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