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Thermally Stable Magnetic Tunnel Junctions for High Density MRAM

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1. Introduction

A magnetoresistive random access memory (MRAM), which features non-volatility and unlimited writing endurance, has been actively researched [1-4]. Fig. 1 depicts an MRAM cell containing 1 magnetic tunnel junction (MTJ) and 1 transistor. In the integration of LSI, high temperature processes of over 300 °C, such as deposition of interlayer dielectrics and Cu interconnections, are indispensable. Thus, thermally stable MTJs should be realized for the production of MRAM. In this paper, we focus on thermal endurance of the tunnel barrier and report improvement in both the thermal stability and the readout performance.

2. Thermally Stable MTJ

The tunnel barrier of AlO_x is usually formed by oxidation of Al. As is known well, oxidation occurs via grain boundaries at the initial stage and later proceeds to grain interiors [5,6]. There is a tendency for metallic Al to remain in the interior of the grain of more than 1 nm-thick Al film because of the kinetics of Al oxidation [5-7]. We found that the remaining Al caused a serious change in the junction resistance during the high temperature processes. On the other hand, the roughness is thought to induce non-uniformity in barrier thickness and the thin portion of barrier dominates the electrical conduction. Then, if a rougher MTJ film is used, a thicker Al has to be used to get a required junction resistance. These points are illustrated in Fig. 2. Thus, MTJ having smooth film interfaces is strongly required for obtaining thermally stable MRAM.

In this work, bottom-pin type MTJs, which were composed of under layers (UL), PtMn pinning layers, synthetic antiferromagnetic (SAF) pinned layers, AlO_x tunnel barriers and free layers, were used. To get smooth film interfaces, process parameters and materials for each layer were optimized. Figs. 3 (a) and (b) show cross-sectional TEM images of MTJ after optimization and before, respectively. Néel coupling field, H_N, for an MTJ film was used as the measure of roughness. H_N of the sample in Fig. 3 (a) is 3 Oe, which is much smaller than that in Fig. 3 (b) (16 Oe).

Fig. 4 shows annealing temperature dependence of resistance-area (RA) product of the patterned MTJ. For the MTJ using 1 nm-thick Al [Fig. 4 (a)], the RA product and MR ratio (inset) did not change at over 300 °C. In the case of 1.4 nm-thick Al on rougher pinned layer [Fig. 4 (b)], RA increases drastically after annealing above 225 °C, especially in the smaller MTJ. This suggests that high resistance area expands from the circumference of patterned MTJ, which may be due to the oxidation of remaining Al from the circumference during annealing. Actually we observed metallic Al remained in the middle of AlO_x barrier in the case of thicker Al, as shown in Fig. 5.

3. Readout Performance

Typical magnetoresistance characteristic is shown in Fig. 6. A variation of junction resistance across a wafer was measured for over 200 MTJs with the size of 240×480 nm^2. We found a clear correlation between the variation and H_N, as shown in Fig. 7. The smoother MTJs give uniform junction resistances, which may be due to the good thermal stability of the resistance. The bias voltage dependence of MR ratio was improved after improvement of the smoothness, as shown in Fig. 8. The readout margin is expressed by the resistance difference between "0" and "1" divided by the standard deviation of resistance, $\Delta R/\sigma(R)$. As a consequence of the large ΔR and the small $\sigma(R)$, sufficient readout margin was obtained after improvement of smoothness: $\Delta R/\sigma(R)=25$ for the 2kbit array.

Using the optimized MTJs and a 0.13 μm CMOS technology, a high-speed cross-point MRAM (1Mb) having the hierarchical bit line architecture was fabricated (Fig. 9) [8]. The access time of 250 nsec at 1.5 V was successfully obtained as a result of the wide readout margin [8], which is the fastest among the reports for the cross-point type [9].

4. Conclusions

The MTJ having smooth interface was developed and incorporated in high density MRAM. The integrated MTJ showed higher thermal stability at over 300 °C. The MRAM proved to have excellent readout performance. Characterization of tunnel barrier indicated that uniform oxidation of the smooth barrier was the key point.

Acknowledgements

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References

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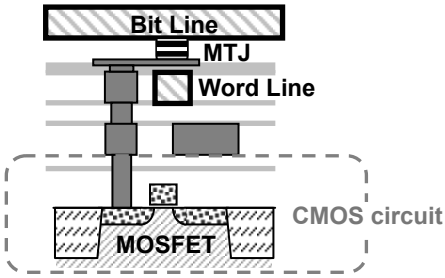

Figure 1. Cross sectional drawing of MRAM cell.

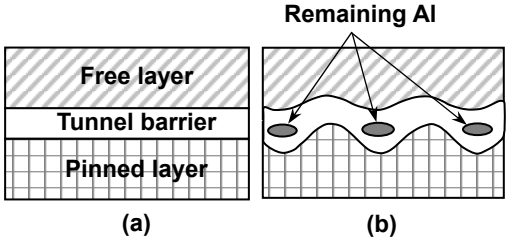

Figure 2. Schematic illustrations of tunnel barrier: (a) on smooth pinned layer, (b) thick Al on rough pinned layer.

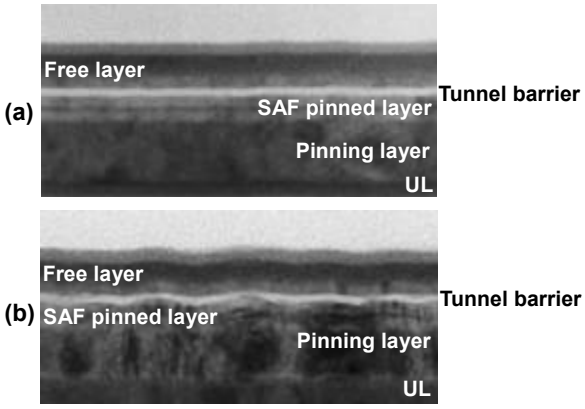

Figure 3. Cross-sectional TEM image of MTJ film: (a) smooth interface and (b) rough interface.

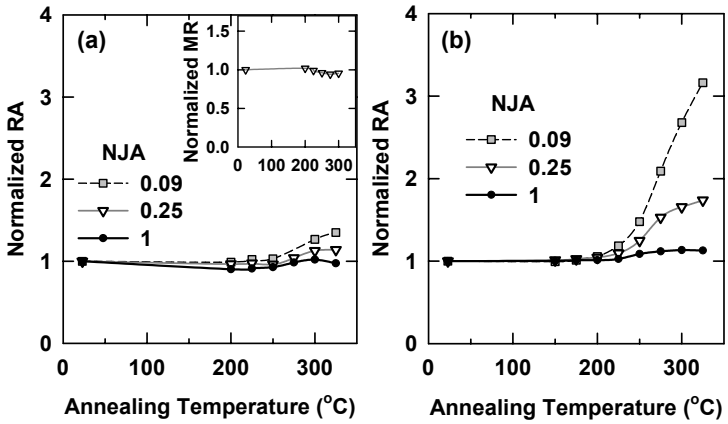

Figure 4. Annealing temperature dependence of RA product: (a) 1 nm-thick Al, (b) 1.4 nm-thick Al. NJA stands for normalized junction area.

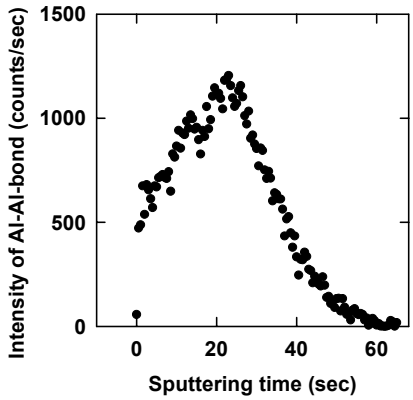

Figure 5. Depth profile of XPS intensity for the Al-O_x film in the case of thicker Al.

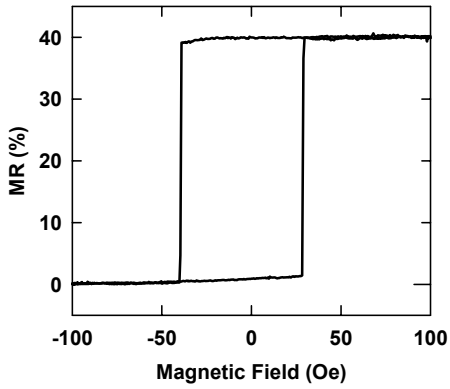

Figure 6. Typical tunnel magnetoresistance characteristic for a 240×480 nm^2 MTJ.

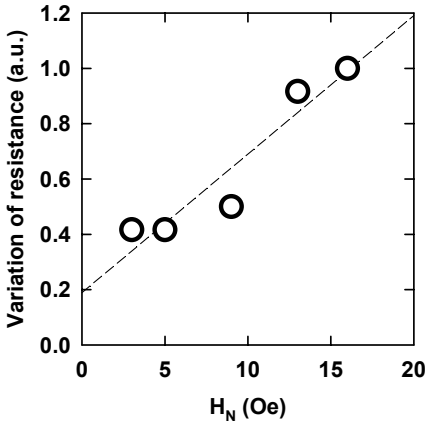

Figure 7. Correlation between the variation of resistance and Néel coupling field.

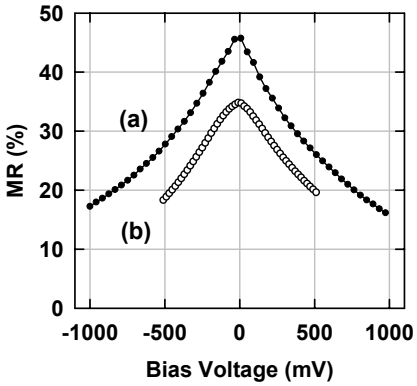

Figure 8. MR curves vs. bias voltage: (a) on smooth pinned layer, (b) on rough pinned layer.

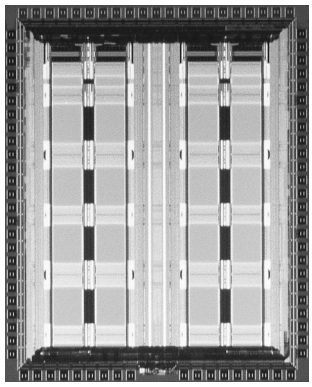

Figure 9. Photograph of 1 Mbit cross-point MRAM chip.