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 AlOx 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, AlOx 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, HN, for an MTJ was used as the images of MTJ after optimization and before, respectively. Figs. 3 (a) and (b) show cross-sectional TEM faces, process parameters and materials for each layer were used. To get smooth film interfaces, process parameters and materials for each layer were optimized. 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.

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References
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-\(\text{O}_x\) 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.