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Properties of perpendicular-anisotropy magnetic tunnel junctions prepared by different MTJ etching process

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Abstract

We investigated perpendicular-anisotropy magnetic tunnel junctions (p-MTJ) with two types of MTJ structures prepared by etching. In MTJs with a base electrode which consisted of a tunnel barrier, a synthetic antiferromagnetic reference layer and a seed layer, the coercive force of a perpendicular-anisotropy free layer decreased with decreasing the MTJs sizes. This is assumed to be due to a partial damage of an upper synthetic antiferromagnetic layer which caused a parallel magnetic field on the free layer. In MTJs with a base electrode which consisted of the seed layer, the coercive force of the perpendicular-anisotropy free layer increased gradually with decreasing the MTJ size.

1. Introduction

Applications that use magnetic tunnel junctions (MTJs) such as spin transfer torque random access memory (STT-RAM) and nonvolatile logic-in-memory architecture have been attracting much interest [1-3]. To achieve such practical applications, MTJs need to satisfy high tunnel magnetoresistance (TMR) ratio, low switching current and high thermal stability factor.

We have successfully demonstrated that CoFeB/MgO based MTJs with a perpendicular anisotropy has potential to satisfy these requirements at the same time [4]. Moreover, shrinkage of the MTJ size is beneficial in reducing the switching current. To shrink the MTJ size, we investigated perpendicular-anisotropy MTJs (p-MTJs) with two types of MTJ structures prepared by MTJ etching. One is MTJs with a base electrode which consisted of a tunnel barrier, a synthetic antiferromagnetic reference layer and a seed layer. The other is MTJs with a base electrode which consisted of a seed layer. In this paper, we report the magnetic and electrical properties of these structures.

2. Experimental

Figure 1 shows a schematic process flow for forming an MTJ structure. An MTJ stack including a metal hard mask was deposited on the copper wired substrate (1(b)). A metal hard mask was formed with an insulating hard mask. Using the metal hard mask, an MTJ free layer was etched to an MgO tunnel barrier (1(c)). We named the MTJ etching a barrier stop etching. Next bottom electrode was formed using the insulating hard mask. The bottom electrode consisted of the MgO tunnel barrier, a synthetic antiferromagnetic reference layer and a seed layer. After ILD deposition, planarization process was performed (1(d)). The insulating film on top of MTJs was etched-back, stopping the top metal hard mask. This process opened the top contact of the junction for upper electrode. Finally, the upper electrode was formed (1(e)). The size of the MTJs ranged from 80 nm to 300 nm.

The MTJs with a CoFeB free layer and a MgO tunnel barrier showed the perpendicular anisotropy with magnetoresistance ratio of 80~100% at 80 nm diameter. Circles and dot lines in Fig. 2 exhibit coercive force (H_C) dependence on MTJ size for MTJs with the barrier stop etching. Average H_C value was deduced from 9 MTJs located in the center 9 chips of the 300 mm wafer. H_C of a perpendicular-anisotropy free layer (p-free layer) decreased with decreasing the MTJ size. In the barrier stop etching process shown in Fig. 1(c), etching ions can cause the damage on the synthetic antiferromagnetic reference layer which constituted the bottom electrode, as shown in Fig. 3(a). We simulated s parallel magnetic field H_X in the center line of an MTJ, as shown in Fig. 3(b). Figure 3(c) shows the H_X

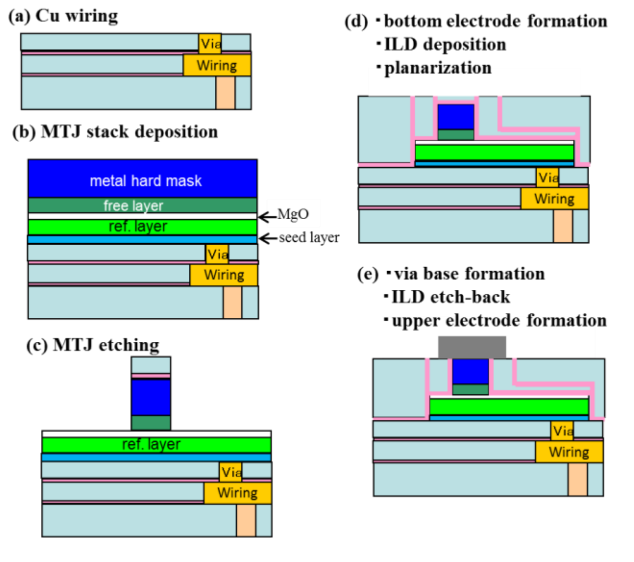

Fig. 1 Process flow for forming an MTJ structure

values as a function of the distance X from one edge of the MTJ. Disappearance of perpendicular anisotropy of the upper synthetic antiferromagnetic reference layer caused a parallel magnetic field on the free layer. Especially, the large parallel magnetic field was generated near the edge of the free layer.

To minimize the parallel magnetic field, the MTJ etching process was modified. MTJ was etched through the magnetic free layer, the MgO tunnel barrier and the synthetic antiferromagnetic reference layer to the seed layer, as

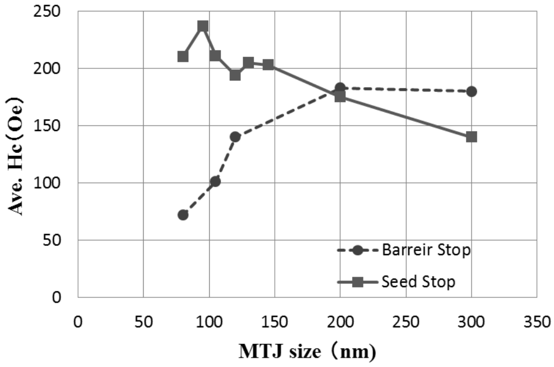

Fig. 2 Dependence of the average H_C value on the MTJ size. Circles and dot lines show the relation of MTJs with the barrier stop etching. Squares and solid lines exhibit the relation of MTJs with the seed stop etching.

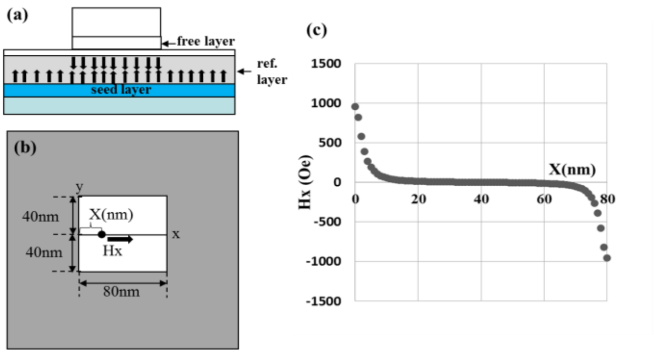

Fig. 3 (a) A cross-sectional schematic of a barrier stop etching MTJ. Arrows indicate the magnetic moment of the reference layer, (b) a schematic plane view of a barrier stop etching MTJ. The outer grey region denotes the base electrode and (c) a simulated parallel magnetic field H_X as a function of the distance from one edge of the MTJ.

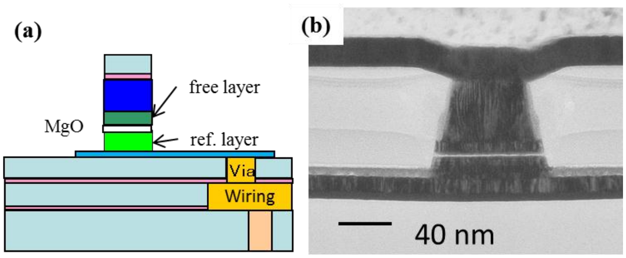

Fig. 4 (a) A cross-sectional schematic of the MTJ structure after a seed stop etching and (b) a cross-sectional TEM image of the fabricated MTJ with a seed stop etching.

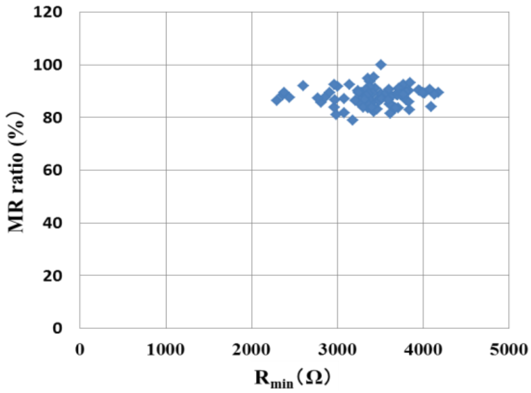

Fig. 5 R_{min} values versus MR ratios for 80 nm MTJs with a seed stop etching. Each measured MTJ was located in the each chip in a 300 mm wafer.

shown in Fig.4 (a). We named the MTJ etching a seed stop etching. Figure 4(b) exhibits the cross-sectional TEM image of the MTJ using the seed stop etching process.

Squares and solid lines in Fig. 2 show dependence of H_C value on MTJ size for the MTJs with the seed stop etching. H_C values of the p-free layer increased gradually with decreasing the MTJ size. This increase suggests that the magnetic switching changed from domain wall motion in large MTJs to single domain switching in small MTJs.

Figure 5 exhibits MR ratios as function of $R_{min.}$ values for 80 nm MTJs with the seed stop etching. Each measured MTJ was located in each chip in a whole 300 mm wafer. There were no MTJs whose tunnel barriers shorted due to redeposition or breakdown. MR ratios were between 80 to 100%. R_{min} values ranged from 2 kΩ to 4 kΩ in a whole 300 mm wafer. The variation of R_{min} values were thought to be due to the inhomogeneous MgO thickness in the whole 300 mm wafer.

3. Conclusions

We investigated perpendicular-anisotropy magnetic tunnel junctions with two types of MTJ structures prepared by etching. In MTJs with a base electrode which consisted of a tunnel barrier, a synthetic antiferromagnetic reference layer and a seed layer, H_C values of a perpendicular-anisotropy free layer decreased with decreasing the MTJs sizes. On the other hand, in MTJs with a base electrode which consisted of the seed layer, H_C values of the perpendicular-anisotropy free layer increased gradually with decreasing the MTJ size.

Acknowledgements

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