Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.1042-1043

H-9-2

A Novel MTJ Shape with Large Write Operation Margin for High Density MRAM

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Abstract

We propose a novel MTJ shape, "Sandglass", to have an excellent asteroid curve. A unique switching mechanism of the MTJ is confirmed by LLG simulation and experiment. The "Sandglass" MTJ improves not only the write disturbance issue but also a memory cell size to be a complete $8F^2$. This has the potential to realize high density MRAM.

Introduction

Magnetoresistive Random Access Memory (MRAM) is one of the candidates for the low power SoC memory. This is because of not only non-volatility that makes electricity consumption low in the stand-by mode but its high capacity, high speed operation, unlimited read / write endurance, and CMOS process compatibility. The factors to achieve high density MRAM are to realize wide write operation margin to widen "0" and "1" separation and eliminate the disturbance of half-selected cells during programming. Savtchenko switching mode was reported as an epoch-making invention to improve the write margin [1]. However, the large switching current [2] and its complicated write procedure is pointed out. On the other hand, a conventional switching mode with a designed magnetic tunnel junction (MTJ) shape, which is considered the magnetization to have an ideal asteroid, is effective to resolves the write disturbance issue, additionally including relatively low switching current and high thermal stability [3]. In this paper, we propose a novel MTJ shape that has an excellent asteroid curve and that forms an $8F^2$ unit memory cell.

Concept of New MTJ Shape

Our proposed MTJ shape is like a "Sandglass". Fig.1 shows the shape of the 200nm x 200nm "Sandglass" MTJ and its magnetization configurations that are simulated by the Landau-Lifshitz-Gilbert (LLG) simulator. When magnetic field is applied from only a bit line in Fig.1 (c), the magnetization of the half-selected cells generates two C-state configurations in the upper and lower sides, respectively, in Fig.1 (a). In this case, the write disturbance of half-selected cells is improved greatly, because it is very hard to switch the magnetic orientation of the C-state free-layer. The non-selected cell also forms the same configuration of the half-selected cell. Meanwhile, magnetic field is applied from both a bit line and a write-word line, the magnetization of the selected cell changes into one continuous S-state configuration in Fig.1 (b). In general, the switching field of the S-state is lower than that of the C-state, the switching field of the selected cell, therefore, reduces drastically. Fig2 shows the schematic of the write operation margin in the asteroid characteristic. This type of the write operation margin is mainly determined by difference between the S-state curve and C-state one. Consequently, the larger difference of both curves generates the wider write operation margin. Thus the switching mechanism is unique and different from switching mode proposed by Toshiba [3] or Cypress [4]. Fig.3 shows that the calculated asteroid curves are little dependent on the both sides of the dent shape, as shown in Fig.4. It indicates that the large yield of memory cells is expected. Additionally, these memory cell arrays are designed as a complete minimum $8F^2$ par unit cell as shown in Fig.5. This is because the aspect ratio of the "Sandglass" MTJ is unity, though that of conventional MTJ shapes is twice or more.

Experiment results

We fabricated "Sandglass" MTJs. The MTJ stack consisted of Bottom-electrode/PtMn/CoFe/Ru/CoFe/AlOx/NiFe/CoFe/Top -electrode. Fig.6 shows the cross-sectional view of TEM image. Measured asteroid curves of both "Sandglass" MTJ of 260nm x 400nm and the conventional elliptic MTJ of 200nm x 400nm are shown in Fig.7. The excellent asteroid of the "Sandglass" MTJ is confirmed that the write operation margin is much larger and the switching field is lower than that of the elliptic one. Fig.8 shows the R-H curve of the "Sandglass" MTJ. It is different from that of the conventional MTJ shape but the typical behavior to change the magnetization of between C-state and S-state distinctly.

Conclusion

We proposed a novel MTJ shape, the "Sandglass", to improve both the write disturbance issue using with a new switching concept and to have a potential to design a complete minimum $8F^2$. An excellent asteroid with the large write operation margin was confirmed by LLG simulation and experiment. We found that the "Sandglass" MTJ was the most appropriate for high density MRAM.

Acknowledgement

The authors would like to thank Y. Yamazaki, T. Nagata, H. Noshiro, S. Umehara and M. Sato for their support of this work.

References

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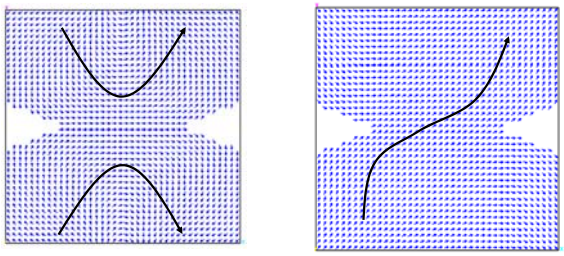
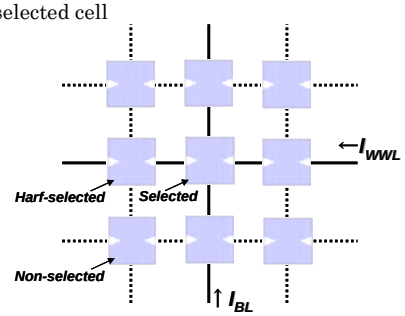
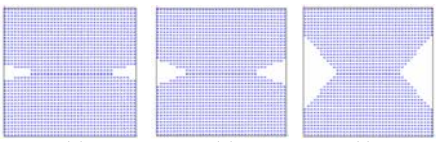


(a) Half-selected or non-selected cell (b) Selected cell



(c) Memory cell arrays

Fig.1 Switching mechanism of "Sandglass" MTJ shape. Magnetization configurations of (a) half-selected cell by only bit line or non-selected cell, and (b) selected cell by bit line and write-word line. (c) Schematic drawing of memory cell arrays.



(a) (b) (c)

Fig.4 "Sandglass" MTJ shapes of (a) narrow dents, (b) middle dents, and (c) wide dents.

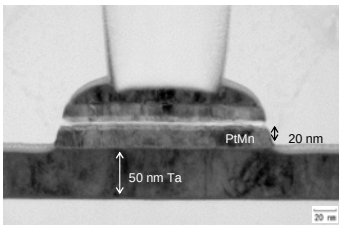


Fig.6 Cross-sectional TEM image of MTJ film.

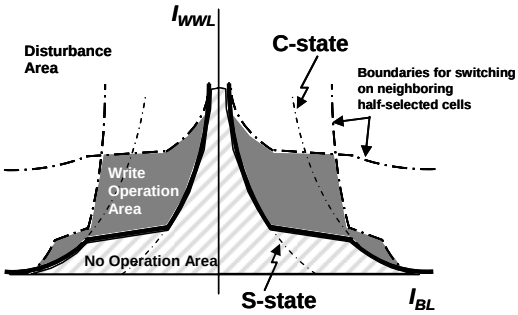


Fig.2 Write operation margin in the asteroid characteristic of the MTJ with magnetization changing between C-state and S-state.

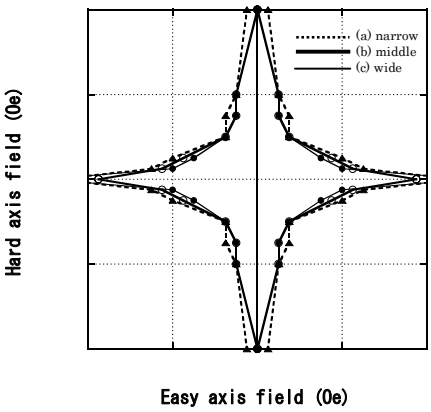


Fig.3 Calculated asteroid curves of the "Sandglass" MTJs that are different from the shapes of both dents, as shown in Fig.4.

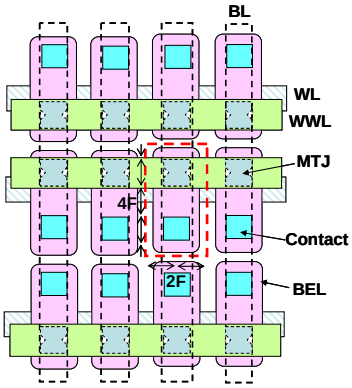
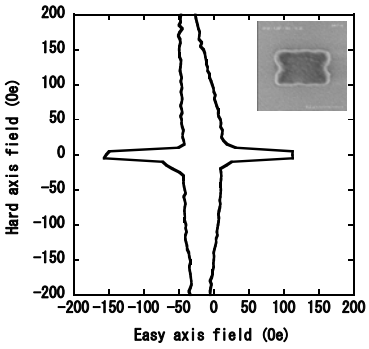
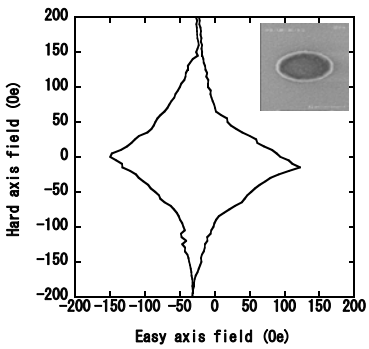


Fig.5 A complete $8F^2$ memory cell layout with $1F^2$ "Sandglass" MTJs.



(a)



(b)

Fig.7 Measured asteroid curves of (a) 260x400 nm² "Sandglass" MTJ and (b) 200x400 nm² conventional elliptic MTJ.

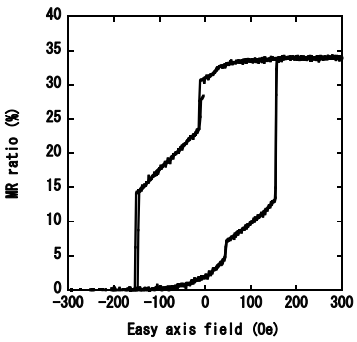


Fig.8 R-H curve of "Sandglass" MTJ.