Thermally stable features in double CoFeB/MgO frame for perpendicular magnetic tunnel junctions

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1. Introduction

Recent studies for perpendicular magnetic tunnel junctions (*p*-MTJs) has a great attention due to various advantages, such as current switching efficiency and high thermal stability factor (Δ=KeffV/k_BT, where Keff,V, k_B, and T refer to the magnetic anisotropy energy density, volume of the free layer, Boltzmann constant and T, respectively).[1-3] Most of all, *p*-MTJs based on CoFeB/MgO frames has exhibited high tunneling magnetoresistance ratio (TMR ratio)[4], while several issues, such as thermal stability for memory retention and tolerance to annealing process for back-end-of-line (BEOL) processing still remain challenges. In order to get over these issues, double-interface structure inserted by proper metal layer was employed to maintain high thermal stability.[5] In this study, we investigated the MgO/CoFeB/metal X/CoFeB/MgO double-interface frame showing higher thermal stability factor than well-known criterion for high performance 1Gb memory device (Δ=60)[3] at a device size below 20 nm. Clear PMA features was achieved at even higher annealing temperature over than 400 °C. In addition, the interlayer exchange coupling phenomenon between two CoFeB layers was observed by changing the inserted metal thickness.

2. Experimental Details

Buffer layer (5)/MgO (1.2)/$Co_{20}Fe_{60}B_{20}$ (t_{CFB1})/metal X (t_X)/$Co_{20}Fe_{60}B_{20}$ (t_{CFB2})/MgO (1.2)/Capping layer (5) stacks were prepared on thermally oxidized Si substrates at room temperature by dual DC & RF magnetron sputtering, where the numbers in parenthesis refer to nominal layer thickness in nanometers. Two additional single interface structures were prepared for comparison: Buffer layer (5)/MgO (1.2)/$Co_{20}Fe_{60}B_{20}$ (t_{CFB1})/Capping layer (5) and Buffer layer (5)/$Co_{20}Fe_{60}B_{20}$ (t_{CFB2})/MgO (1.2)/ Capping layer (5). All the stack were post-annealed at 350 °C, 400 °C, and 425 °C for 1 hour under vacuum conditions of pressure below ~1 x 10^{-6} Torr under a 3 T magnetic field normal to sample plane. Vibrating sample magnetometer (VSM) was used to analyze the in-plane and out-of-plane magnetic hysteresis loops.

3. Results and Discussion

Novel metal layer thickness was varied with the range of 0.25 to 3.0 nm. Increasing an insertion layer thickness leads to weak ferromagnetic coupling strength between two CoFeB layers have weakened, resulting in transition to antiferromagnetic coupling region at a metal X thickness over 1.15 nm. Strong ferromagnetic coupling was observed at t_X =0.55 nm, representing the achievement of highest thermal stability of more than 60 even at higher annealing temperature. This strong ferromagnetic coupling phenomenon permits the two ferromagnetic layer to act like a single layer in switching process. Thereby, the enhanced thermal stability factor Δ could be acquired with expanded volume V of the CoFeB free layer, which has an anisotropic field value H_K up to about 10 kOe. Magnetic dead layer (MDL; t_d) of 1.3 nm was estimated in this work, possibly providing a small critical switching current density J_C with a lower saturation magnetization value M_S. In addition, the possibility of annealing process up to 400 °C would satisfy the industrial requirement for BEOL process.

4. Conclusion

In conclusion, thermally stable free layer frames based on double-interface scheme inserted by novel metal X were developed, where basic MgO/CoFeB/metal X/CoFeB/MgO frame was evaluated at various annealing temperatures. M-H magnetic hysteresis loops analysis indicated that strong ferromagnetic interlayer coupling phenomenon was achieved at a thin insertion layer, confirming high thermal stability factor. Moreover, clear PMA features were kept even at high annealing process over 400 C, that would be suitable for future BEOL process.

5. References

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