Underlayer-dependent perpendicular magnetic anisotropy of $Co_2Fe_{0.4}Mn_{0.6}Si$ Heuslar alloy ultra-thin films

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Introduction

Spin transfer torque magnetoresistive random access memory (STT-MRAM) is being developed as a candidate for the next generation non-volatile memories. For the development of giga-bit-class STT-MRAM, perpendicularly magnetized films with high spin polarization are required [1]. Some Co-based Heusler alloys, such as Co_2FeAl, $Co_2(Fe\text{-}Mn)Si$, are known as half-metallic compounds and their ultra-thin films with perpendicular magnetic anisotropy (PMA) have been investigated [2-4]. Our group has been studying PMA in $Co_2Fe_{0.4}Mn_{0.6}Si$ (CFMS) ultra-thin films with a Pd underlayer [3, 4], showing perpendicular magnetization. However, the underlayer dependence of PMA in CFMS ultra-thin films is unclear. In this work, we have systematically investigated PMA in CFMS ultra-thin films with different kinds of underlayers.

Experimental methods

The stacking structure of samples was as follows: MgO (100) substrate / underlayer(s) / CFMS (t_{CFMS}) / MgO (2 nm) / Ta (5 nm), in which the CFMS layer thickness, t_{CFMS} was changed in the range from 0.6 to 1.4 nm. Pd, Ru and Cr were chosen as underlayers. For Pd and Ru underlayers, Cr was first deposited on the substrate as a buffer layer in order to get a smooth surface. The metallic layers were deposited using an ultrahigh-vacuum sputtering system with a base pressure less than 2×10^{-7} Pa, and the MgO layer was deposited using electron beam evaporation system. *In-situ* post-annealing process was done after the deposition of Cr buffer at 700ºC for 1 hour. The deposition temperature for the Pd layer was 350ºC, and other layers were deposited at an ambient temperature. After the deposition of all layers, the samples were annealed in a vacuum furnace. The annealing temperatures (T_{anneal}) were 200ºC, 300ºC, 400ºC and 500ºC. Hysteresis loops of all samples were measured by superconducting quantum interference device-vibrating sample magnetometer (SQUID-VSM) at 300 K. The maximum applied magnetic field was 30 kOe.

Results

Perpendicularly magnetized films were achieved in the samples with t_{CMFS} = 0.6 and 0.8 nm using the Pd underlayers and T_{anneal} = 400ºC. However, all films exhibited in-plane magnetization in the samples using the Ru and Cr underlayers, regardless of the annealing temperatures. The maximum value of PMA energy (K_u) were 1.7×10^7 (t_{CFMS} = 0.6 nm), 7.3×10^6 (t_{CFMS} = 1.0 nm) and 7.1×10^6 (t_{CFMS} = 0.8 nm) erg/cm^3 for Pd, Ru and Cr underlayers, respectively. T_{anneal} for the optimum condition was 400ºC for all. The maximum value of interface anisotropy energy (K_s) were 1.2, 0.3 and 0.2 erg/cm^2 for the Pd, Ru and Cr underlayers, respectively at the optimum T_{anneal}. It is suggested that the differences in the dead layer thickness and the amount of the interdiffusion possibly result the underlayer dependence of the PMA in CFMS ultra-thin films.

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References

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