Influence of the strain effect on magnetocrystalline anisotropy in $Co_2Fe_{0.4}Mn_{0.6}Si$ Heusler alloys*

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Abstract

The perpendicular magnetocrystalline anisotropy, magnetoelastic properties as well as the Gilbert damping factor in $Co_2Fe_{0.4}Mn_{0.6}Si$ (CFMS) thin films were found to depend on a magnetic layer thickness, and they can be also tuned by the application of additional Ag buffer layer. The tetragonal distortion of a magnetic layer was found to increase with decreasing thickness, and after the application of an additional Ag buffer layer, the character of this distortion was changed from tensile to compressive in the plane of a film. A correlation between the tetragonal distortion and perpendicular magnetocrystalline anisotropy was found. However, the magnitude of the observed tetragonal distortion for most samples seems to be too small to explain alone the experimentally found large magnitude of the perpendicular magnetocrystalline anisotropy. For these samples, other mechanisms including both surface and volume effects must be taken into account.

Samples:

The ultrahigh-vacuum-compatible magnetron sputter-deposition
MgO (100)/Cr(20nm)/CFMS(15nm, 30nm, 50nm)/Au(5nm)
MgO (100)/Cr(20nm)/Ag(20nm)/CFMS(30nm, 50nm)/Au(5nm)

Tetragonal distortion – increases with decreasing thickness of CFMS and after application of Ag buffer changes from tensile to compressive

Layer thickness	Lattice constant in plane	Lattice constant perpendicular	$\varepsilon_{11}=\varepsilon_{22}$	ε_{33}
15 nm	5.6878 Å	5.6258 Å	5.1×10^{-3}	-5.9×10^{-3}
30 nm	5.6696 Å	5.6503 Å	1.6×10^{-3}	-1.8×10^{-3}
50 nm	5.6610 Å	5.6555 Å	4.5×10^{-4}	-5.2×10^{-4}
30 nm/Ag	5.6457 Å	5.6685 Å	-1.9×10^{-3}	2.2×10^{-3}
50 nm/Ag	5.6450 Å	5.6750 Å	-2.5×10^{-3}	2.9×10^{-3}

Strain modulated ferromagnetic resonance (SMFMR) and **ferromagnetic resonace** (FMR) were used to determine the magnetoelastic properties and the magnetocrystalline anisotropy .

Magnetoelastic Constants: b_1 and b_2 are anisotropic ($b_1 \neq b_2$).
Magnetoelastic energy (cubic):

$$E_{me} = b_1(\alpha_1^2\varepsilon_{11} + \alpha_2^2\varepsilon_{22} + \alpha_3^2\varepsilon_{33}) + 2b_2(\alpha_1\alpha_2\varepsilon_{12} + \alpha_2\alpha_3\varepsilon_{23} + \alpha_1\alpha_3\varepsilon_{13})$$

sample	b_1 (erg/cm^3)	b_2 (erg/cm^3)
15 nm	-1.24×10^7	-2.84×10^7
30 nm	-1.91×10^7	-2.79×10^7
50 nm	-2.28×10^7	-2.94×10^7
30 nm/Ag	-1.71×10^7	-2.90×10^7
50 nm/Ag	-1.68×10^7	-2.49×10^7

Gilbert damping factor, α, increases with increasing thickness, δ, but it is much higher than estimated form the eddy current model: $\alpha^{eddy} = \frac{C}{16}\frac{\gamma\mu_0^2 M_s\delta^2}{\rho}$

sample	α	α^{eddy}
15 nm	1.0×10^{-3}	2.3×10^{-6}
30 nm	1.9×10^{-3}	9.0×10^{-6}
50 nm	4.5×10^{-3}	2.5×10^{-5}
30 nm/Ag	2.6×10^{-3}	9.0×10^{-6}
50 nm/Ag	3.9×10^{-3}	2.5×10^{-5}

The induced by the tetragonal distortion **strain induced magnetocrystaline anisotropy**: $K_{si} = b_1(\varepsilon_{11} - \varepsilon_{33})$ for most samples is lower than the perpendicular magnetocrystalline anisotropy K_p

sample	K_p (erg/cm^3)	K_{si} (erg/cm^3)
15 nm	-1.0×10^6	-1.4×10^5
30 nm	-6.2×10^5	-0.6×10^5
50 nm	-5.3×10^5	-0.2×10^5
30 nm/Ag	-6.2×10^5	0.7×10^5
50 nm/Ag	1.0×10^5	0.9×10^5

Conclusions

- The tetragonal distortion of the epitaxially grown $Co_2Fe_{0.4}Mn_{0.6}Si$ Heusler thin film, the magnetocrystalline anisotropy, anisotropic magnetoelastic properties as well as Gilbert damping all depend on both the thickness of the magnetic layer and the type of buffer layer
- The changes of perpendicular magnetocrystalline anisotropy qualitatively correlate with the changes of the in-plane tetragonal distortion. For most samples, however, is too small to explain the very large magnitudes of the perpendicular magnetocrystalline anisotropy
-Eddy current mechanism does not explain the changes of the Gilbert factor with the changes of magnetic layer thickness

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