Epitaxial strain effect on ferromagnetic resonance and magnetic anisotropy of $(Ga_{0.8},Fe_{0.2})Sb$ thin films at room temperature

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Magnetic anisotropy plays an important role in determining the magnetization direction of ferromagnetic electrodes in spintronic devices. In Mn-doped III-V ferromagnetic semiconductor (FMS) (Ga,Mn)As, control of the magnetic anisotropy between in-plane and perpendicular magnetization using epitaxial growth and strain effects has been demonstrated [1]. However, due to the low Curie temperature (T_C < 300K), the (Ga,Mn)As is not suitable for room temperature applications. To overcome this problem, recently we have successfully grown Fe-doped FMS (Ga,Fe)Sb, which shows T_C > 300K when the Fe concentration is higher than 23% [2,3]. Therefore, this new material is considered as a good candidate for device applications at room temperature.

In this work, we investigate the magnetic anisotropy of $Ga_{1-x}Fe_xSb$ (x = 0.2, 15nm) grown by low temperature molecular beam epitaxy (LT-MBE) on various different buffer layers: AlSb, GaSb, $(In_{0.5},Ga_{0.5})As$ and GaAs. All of the buffer layers are thick enough (300-500 nm) to be lattice-relaxed on semi-insulating GaAs(001) substrates. All the samples show T_C higher than room temperature. We carried out ferromagnetic resonance (FMR) and magnetization measurements by superconducting quantum interference device (SQUID) at room temperature, and estimated the magnetic anisotropy parameters. Fig. 1 representatively shows the dependence of the resonance field in FMR on the applied magnetic field direction of the (Ga,Fe)Sb/AlSb sample. By fitting to this angle dependence, we obtained the values of the effective magnetization (M_{eff}), and combining with the saturation magnetization (M_s) measured by SQUID, we estimated the uniaxial anisotropy energy (K_u), the shape anisotropy energy (K_{sh}) and the effective anisotropy energy, ($K_{eff} = K_u + K_{sh}$) of the (Ga,Fe)Sb thin films. We performed this study on all the $Ga_{1-x}Fe_xSb$ samples grown on different buffers (AlSb, GaSb, $(In_{0.5},Ga_{0.5})As$ and GaAs). In this work, we define in-plane anisotropy as negative values and perpendicular anisotropy as positive values of K_u and K_{eff}. Fig. 2 a), b) and c) summarizes the K_u, K_{sh} and K_{eff} values *vs* epitaxial strain ε, which is defined by $\varepsilon(\%) = (\alpha_{GaFeSb} - \alpha_{buffer})/(\alpha_{GaFeSb}) \times 100$, where α is the intrinsic lattice constant of each material. In Fig. 2 a), when going from tensile (ε = -1.2%) to compressive (ε = +3.9%) strain, the magnitude of K_u initially decreases dramatically, and changes from large negative (in-plane anisotropy) to small positive (perpendicular anisotropy). However, in Fig.2 b) K_{sh} changes from large negative to small negative, making K_{eff} always negative (in-plane anisotropy) as shown in Fig 2 c). As a result, all the (Ga,Fe)Sb films examined here show an in-plane easy magnetization axis. Interestingly, K_u in the (Ga,Fe)Sb thin film grown on AlSb (tensile strain) shows a large value (-12 kJ/m^3), which is comparable to that of (Ga,Mn)As. These results indicate that unlike (Ga,Mn)As, which shows a perpendicular easy axis in the case of tensile strain and an in-plane easy axis in the case of compressive strain [1], (Ga,Fe)Sb can only show in-plane easy axis even in the case of maximum compressive strain. (Ga,Mn)As has large K_u and small K_{sh}, which makes K_{eff} dependence on K_u, both in tensile and compressive strain, so easy axis can be tuned in perpendicular and in-plane directions more easily. In conclusion, in (Ga,Fe)Sb (except on the AlSb buffer layer), all samples show small magnitude of K_u due to which K_{eff} depends mainly on K_{sh} and thus, the easy magnetization axis always lies in the film plane.

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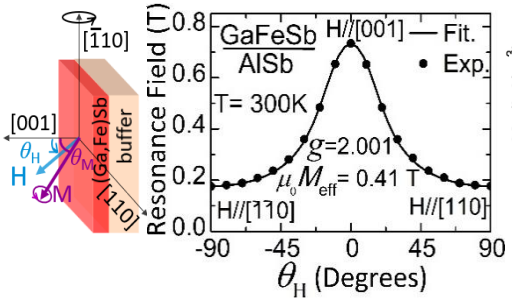

Fig.1. Angular dependence of FMR positions at 300K of a GaFeSb/AlSb sample with various **H** angle directions θ_H (shown in inset).

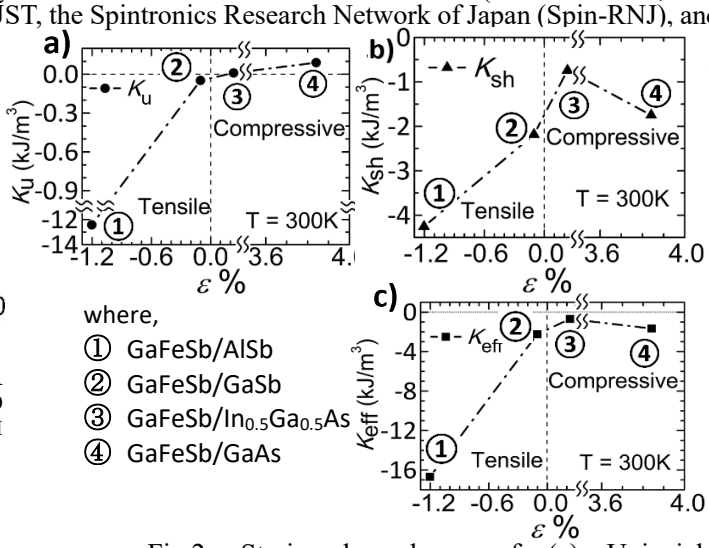

Fig.2. Strain dependence of (a) Uniaxial anisotropy (K_u), (b) shape anisotropy (K_{sh}) and (c) effective anisotropy (K_{eff}) of GaFeSb with different buffer layers.

References:
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