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 ($T_C < 300$K), 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 $T_C > 300$K when the Fe concentration is higher than 29% [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$_x$Sb ($x = 0.2$, 15nm) grown by low temperature molecular beam epitaxy (LT-MBE) on various different buffer layers: AlSb, GaSb, (In$_{0.5}$Ga$_{0.5}$)Sb 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 represents an example showing 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 magnetic anisotropy energy ($K_{\text{eff}}$) and the saturation magnetization ($M_s$) measured by SQUID, we estimated the uniaxial anisotropy energy ($K_u$), the shape anisotropy energy ($K_s$) and the effective anisotropy energy, ($K_{\text{eff}} = K_u + K_s$) of the (Ga,Fe)Sb thin films. We performed this study on all the Ga$_{1-x}$Fe$_x$Sb samples grown on different buffers (AlSb, GaSb, (In$_{0.5}$Ga$_{0.5}$)Sb and GaAs). In this work, we define in-plane anisotropy as negative values and perpendicular anisotropy as positive values of $K_u$ and $K_{\text{eff}}$. Fig. 2 a), b) and c) summarizes the $K_u$, $K_s$ and $K_{\text{eff}}$ values vs epitaxial strain $\varepsilon$, which is defined by $\varepsilon(\%) = (a_{\text{GaFeSb}} - a_{\text{buffer}})/(a_{\text{GaFeSb}} \times 100$, where $a$ is the intrinsic lattice constant of each material. In Fig. 2 a), when going from tensile ($\varepsilon = -1.2\%$) to compressive ($\varepsilon = +3.9\%$) 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) $K_s$ changes from large negative to small negative, making $K_{\text{eff}}$ 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 K/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 $K_s$, which makes $K_{\text{eff}}$ 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 $K_{\text{eff}}$ depends mainly on $K_s$, and thus, the easy magnetization axis always lies in the film plane.

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References:

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

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