PROXIMITY EFFECTS IN $Fe_{1-x}Co_x/Mn/Fe_{1-x}Co_x$ TRILAYERS

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In the last decade much effort has been dedicated to the study of the magnetic coupling in multilayer systems such as Dy/Y, Fe/Cr, Co/Cu because ultra-thin magnetic films exhibit unusual magnetic configurations and coupling not found in bulk systems. Among these, we can cite magnetic helicoidal ordering in Dy propagating through non magnetic rare-earth (Y, Lu), or oscillating coupling as a function of the spacer layer thickness in transition metal (e.g. Fe/Cr/Fe); the coupling changes from antiferromagnetic to quadratic and ferromagnetic depending on the Cr layer thickness. These structures have found practical applications as magnetic field sensors in magnetic read heads because of the large magneto-resistive effect observed when the relative orientation of the two magnetic layers is changed.

The purpose of this work has been to investigate the structure and magnetism of $Fe_{1-x}Co_x/Mn/Fe_{1-x}Co_x$ trilayers, and especially to study the magnetic structure of δ-Mn (bcc with 2 atoms per cell) which can be stabilised in the form of thin films by molecular beam epitaxy on the (001) surface of bcc $Fe_{1-x}Co_x$ (x = 0-0.75) up to thicknesses of 3 nm.

Very recently, ab initio calculations of the magnetic structure of bcc Mn in the bulk and in $Fe_{1-x}Co_x$ /Mn multilayers have been presented, considering non collinear magnetic order [1]. It is shown that, in the bulk, the (001) anti-ferromagnetic structure can be almost degenerate in energy with a canted anti-ferromagnetic order and that, in $Fe_{1-x}Co_x$ /Mn multilayers. Fe atoms at the interfaces with the Mn layers favour the collinear state whereas Co atoms favour the non-collinear one. Our aim was to study the magnetic structure of the Mn in the $Fe_{1-x}Co_x$ /Mn/$Fe_{1-x}Co_x$ trilayers and to correlate it with its crystallographic structure, the interface morphology and the magnetic coupling. Results on the Fe/Mn/Fe system have been published in [2].

Sample preparation

The $Fe_{1-x}Co_x$/Mn/ $Fe_{1-x}Co_x$ trilayers are deposited in UHV by thermal evaporation onto a GaAs/Fe(1nm)/Ag(150nm) substrate-buffer system. The first layer is deposited at room temperature on Ag. The Mn atoms are deposited epitaxially on the $Fe_{1-x}Co_x$ at a temperature of 360 K. The Mn layer remains monocrystalline for thicknesses up to 3 nm. The figure 1 shows a description of the final system.

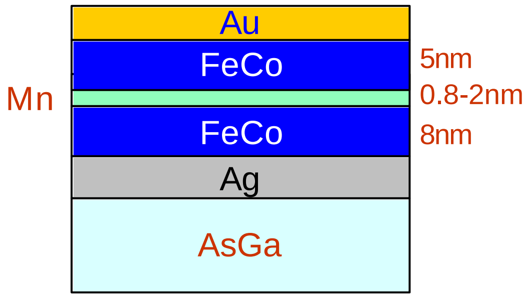

Figure 1. typical trilayer structure.

The structure of the interfaces was investigated using X-ray reflectivity. These measurements show that the interfaces are sharp. They also show that two lateral coherence length coexist in the height-height correlation functions, a long range (400 nm) and a short range one (4 nm). The long-range height-height correlation function evolves in phase from one interface to the other and corresponds to a long range correlated roughness between the layers (of the order of 0.45 nm). The short range correlation length corresponds to a very small roughness of 0.15 nm linked to local atomic disorder.

Magnetic measurements

From magneto-optical Kerr effect (MOKE) measurements, we found non-collinear coupling between the FeCo layers for Mn thicknesses up to 1.3 nm. The easy axis of magnetisation in the $Fe_{1-x}Co_x$ layers is the [110] crystallographic axis (whereas the easy axis in Fe layers is [100]).

The angle between the magnetisation vectors of the FeCo layers at remanence start from about 180° for a Mn layer between 0.5 and 0.85 nm and gradually decreases between 0.85 and 1.3 nm. Above 1.3 nm, perfectly square hysteresis is observed, meaning a ferromagnetic coupling between the FeCo layers. The non ferromagnetic coupling strength shows a maximum around 0.85 nm.

In figure 2, we show polarised neutron reflectometry (PNR) performed on a $Fe_{0.5}Co_{0.5}$/ Mn(0.8nm)/ $Fe_{0.5}Co_{0.5}$ sample on the polarised reflectometer PRISM under a saturating field of 0.5 T.

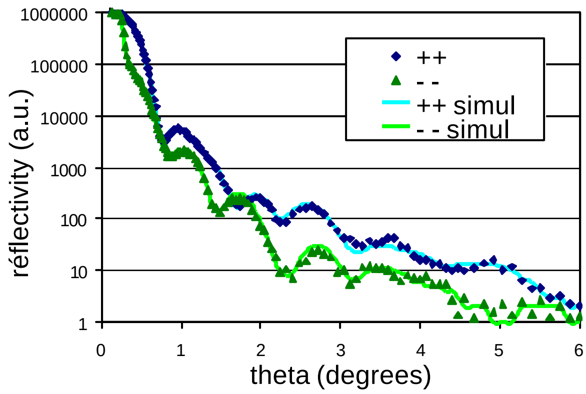

Figure 2. reflectivity of a $Fe_{0.5}Co_{0.5}$ (8nm)/ Mn(0.8nm)/ $Fe_{0.5}Co_{0.5}$(5nm)/ Au(5nm) trilayer in a saturation field of 0.5 T.

From a fit of the non-spin-flip channels (up-up) and (down-down), we obtain a net magnetisation of 0.8 ± 0.3 μ_B/at in the Mn layer. A net magnetisation in Mn has been predicted from ab-initio calculations on (bcc Co_{5ML})/bct Mn_{4ML}) multilayers [1], parallel to the total magnetisation and varying from 0.85 to 0.25μ_B/at when the angle between the net magnetisation of two successive layers is increased from 0 to 180°. Figure 3 shows the reflectivity measured at remanence (1.2 mT). In this case, a large spin-flip signal (yellow) is observed which indicates a strong non colinear magnetic coupling between the FeCo layers.

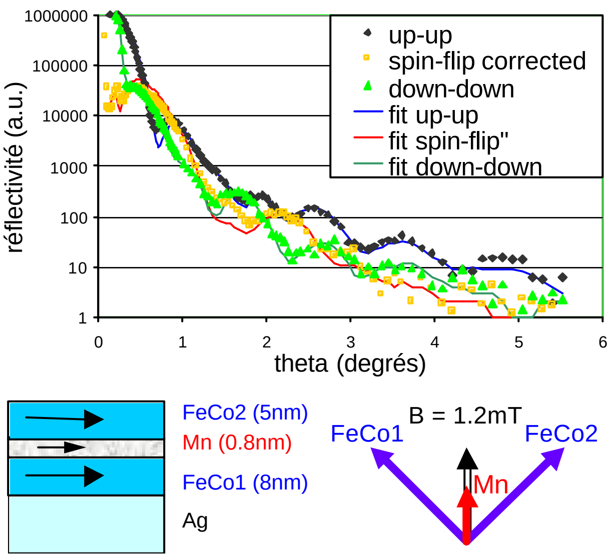

Figure 3. (a) reflectivity of a trilayer system in a low magnetic field (1.2 mT). (b) magnetic configuration deduced from the fit.

For the fit (solid lines), only the three angles of magnetisation have been varied, the other parameters being fixed at their values obtained at saturation (measurement in fig. 2). A good fit is obtained for the Mn magnetisation parallel to the applied field and an angle between the $Fe_{0.5}Co_{0.5}$ layers magnetisations of 90 ± 5°, both being tilted at 45° with respect to the applied field. Another fit was performed letting also the magnetisation inside the Mn layer free to vary. It stayed at the same value as at saturation.

Conclusion

We proved that monocrystalline δ-Mn can be efficiently stabilised on $Fe_{1-x}Co_x$ alloys and that the interfaces are sharp. PNR performed at room temperature indicate a net magnetisation of 0.8 ± 0.3 μ_B/at. to be present in the Mn layers in $Fe_{0.5}Co_{0.5}$/Mn/$Fe_{0.5}Co_{0.5}$ sample but no net magnetisation could be found in the Fe/Mn/Fe trilayers.

[1] C. Cornea and D. Stoeffler, J.M.M.M. **198-199** (1999) 282.
[2] E. Kentzinger, U. Rücker, W. Caliebe et al, Physica B **276-278** (2000) 586.
[3] S. Nerger, E. Kentzinger, U. Rücker et al, Physica B **297** (2001) 185-188.