Experimental Report

22/03/2014

Proposal: **5-54-134** **Council:** 10/2012

Title: Magnetization reversal in ferromagnetic III-Mn-V semiconductors prepared by ion implantation and pulsed laser melting

This proposal is a new proposal

Research Area: Physics

Main proposer: **PEREIRA Lino**

Experimental Team: HOUBEN Kelly
PEREIRA Lino

Local Contact: WILDES Andrew

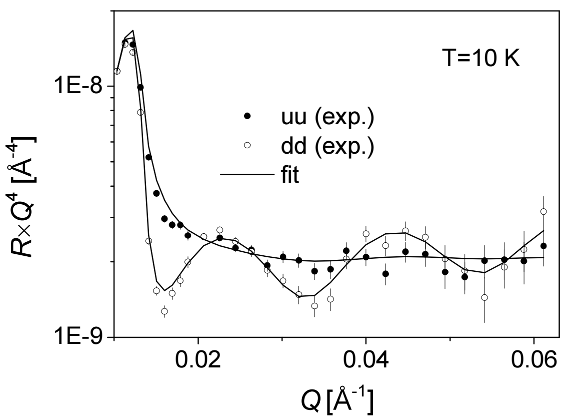
Samples: Ga_0.94Mn_0.06As film (150 nm) on GaAs substrate

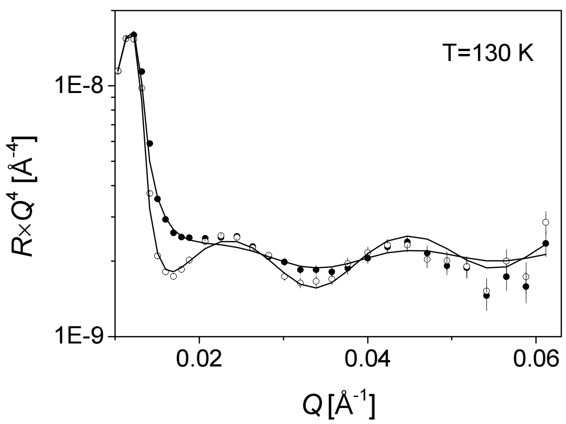
Instrument	Req. Days	All. Days	From	To
D17	4	4	31/05/2013	04/06/2013

Abstract:

Mn-doped III-V semiconductors such as (Ga,Mn)As and (In,Mn)As have become the model materials in which to study phenomena of interest for semiconductor spintronics. In alternative to molecular beam epitaxy (MBE), a more versatile method for the synthesis of such alloys has been developed: ion implantation followed by pulsed laser melting (II-PLM). Using polarized neutron reflectivity, we propose to investigate the magnetization reversal mechansisms in several III-Mn-V alloys prepared by II-PLM. This will allow us to compare, at a very fundamental level, II-PLM (Ga,Mn)As to the better understood MBE-grown counterpart, and to advance our understanding of the correlation between magnetic anisotropy and magnetization reversal for different III-Mn-V alloys.

The goal of this experiment was to investigate the reversal mechanisms in III-Mn-V dilute magnetic semiconductors prepared by ion implantation followed by pulsed laser melting (II-PLM), by (i) comparing II-PLM $Ga_{1-x}Mn_xAs$ to the counterpart grown by molecular beam epitaxy (MBE), and (ii) comparing II-PLM $Ga_{1-x}Mn_xAs$ and $In_{1-x}Mn_xAs$. These experiments consist of the following. A specular reflectivity scan is first performed under a saturation field. Based on this reflectivity scan, a given wave vector Q value is selected as a compromise between intensity and splitting ratio. Subsequently, the spin-flip and the non-spin-flip signals (i.e. using neutron spin analysis) are recorded at the selected Q value, as a function of the applied magnetic field from above to below the coercive field (H_c) previously determined by magnetometry measurements. From the spin-flip and non-spin-flip components of such field scan measurements, one can infer on the reversal mechanisms, for example: 180° domain-wall nucleation and propagation, which is expected for a $Ga_{1-x}Mn_xAs$ film with uniaxial anisotropy; 90° domain-wall nucleation and propagation for a $Ga_{1-x}Mn_xAs$ film with biaxial anisotropy [1]. However, after several attempts it became clear that we were unable to properly reverse the magnetization in these samples. After some additional tests we realized that the unfortunate combination of (i) the magnetic behavior of III-Mn-V materials (soft magnetic materials, with weak anisotropy) and (ii) the particular field geometry (guide field and applied field) implemented in the instrument resulted in a coherent rotation of the magnetization, with the neutron moment always parallel to the applied field and magnetization above and below H_c (irrespective of the intrinsic reversal mechanism of each sample). Since these unexpected circumstances render the proposed experiment unfeasible, the remainder of the beam time was devoted to alternative experiments aimed to probe how the T_C of MBE-grown $Ga_{1-x}Mn_xAs$ thin films layers varies as a function of depth. By comparing the magnetization profiles at different temperatures (from 10 K to close to T_C) the goal was to elucidate if T_C is uniform across the layer or decreases near the surface or interface. Understanding such effects is crucial when exploiting the surface and interfacial properties of III-Mn-V dilute magnetic semiconductors in functional heterostructures. The figure below shows specular reflectivity measurements of a $Ga_{0.92}Mn_{0.08}As$ film (25 nm) grown by MBE, in the remanent state (at zero applied field, after saturation at 0.1 T along the [100] easy axis). Measurements are shown for two different temperatures, 10 K and 130 K (close to the T_c of 145 K determined by magnetometry measurements). The analysis of the data shows that from 10 K to 130 K, in addition to a decrease in magnetization (as expected for a ferromagnet as the temperature approaches T_c, and consistent with magnetometry data), an apparent *thinning* of the ferromagnetic layer (by a few nm) is also observed.





This indicates that regions of the $Ga_{0.92}Mn_{0.08}As$ film near surface or interface are paramagnetic at 130 K while the rest of the film remains ferromagnetic. With the limited temperature steps and statistics which we were able to accumulate in this alternative second part of the beam time, although promising, these experiments are not yet conclusive. Therefore, we are currently considering a future proposal aimed to investigate how the T_C of $Ga_{1-x}Mn_xAs$ varies as a function of depth. In parallel, the same samples would be characterized in terms of (i) chemical depth profiling, using secondary ion mass spectroscopy (SIMS), and (ii) defect depth profiling, using Rutherford backscattering-channeling spectrometry (RBS/C). This combined magnetic/chemical/defect profiling would allow us to advance the understanding of how the ferromagnetic properties and its influencing factors vary as a function of depth in III-Mn-V DMS, which is crucial for the development of these materials towards integration in functional heterostructures.

[1] J. L. Primus *et al., J. Appl. Phys.* **97**, 123909 (2005).