Experimental report

28/06/2019

Proposal: **5-54-245** **Council:** 4/2017

Title: Direct measure of proximity effectin SF superlattices by PNR

Research area: Materials

This proposal is a new proposal

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Yury KHAYDUKOV

Local contacts: Alexei VOROBIEV

Samples: [Gd(3,4,6nm)/Nb(25nm)]12//Al2O3

Instrument	Requested days	Allocated days	From	To
SUPERADAM	13	7	26/06/2018	03/07/2018

Abstract:

A new method for the direct measure of proximity effect in S/F superlattices is proposed. Method is based on measure of flux expulsion which will be significantly different in case of coupled and decoupled superconducting layers

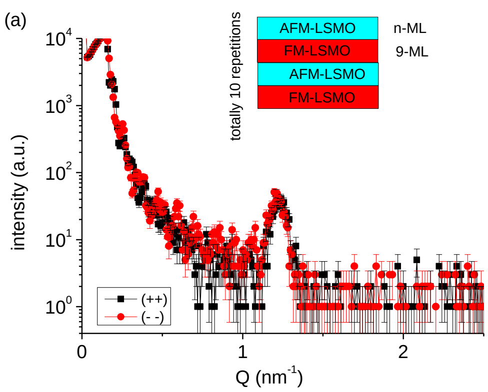
Report on experiment 5-54-245 „Direct measure of proximity effect in SF superlattices by PNR“

Experiment time: 06/06/2018-03/07/2018

Experimental team: Yury Khadukov (MPI Stuttgart), Gideok Kim (MPI Stuttgart), Alexei Vorobiev (local contact, Uppsala University).

Originally the proposal was aimed on a study of proximity effects in Gd/Nb superlattices of ferromagnetic/antiferromagnetic type. However in the time between acceptance of proposal and allocated time at SuperADAM we completed the project on other machines. In this experiment we aimed on the next step of our proximity effects project, study of proximity effect in ferromagnet/antiferromagnet oxide heterostructures. For the experiment heterostructures with the nominal composition: 10x[9x$La_{0.6}Sr_{0.4}MnO_3$+**n**x$La_{0.2}Sr_{0.8}MnO_3$] (see sketch in the inset of Fig.1) have been grown at the molecular beam epitaxy facility of MPI-FKF of Stuttgart. Samples were grown on a LSAT substrate of dimensions 5x10 mm^2. The LSMO(x=0.4) shows ferromagnetic ordering with Curie temperature ~ 260 K and LSMO(x=0.8) shows antiferromagnetic ordering in bulk. In the PNR experiment we used continuous flow cryostat and full polarization setup with magnetic field applied in-plane of the structure and normal to the scattering plane.

We started experiment with the sample D2#1080 (n=4). The sample was cooled down to 5K in a magnetic field of H=6.1kOe (PFC protocol). After this we measured reflectivity curves in non-spin-flip channels at the saturated state (Fig. 1a). Despite of having marginal nuclear contrast we were able to measure a Bragg peak originating from magnetic contrast between FM and AFM layers. Fitting of these curves will allow us to restore magnetic depth profile and get information about proximity effect in the structure. On the next step we measured reflectivities in four spin channels in magnetic fields of H=25-1000G. Fig 1b shows the PNR curves measured at H=160 Oe. We have observed quite strong spin-flip scattering in the vicinity of critical edge Q_{crit}. We have observed a dQ ~$2x10^{-3}$ nm^{-1} shift of resonance peaks in (+-) and (-+) channels. The origin of the splitting has to be understood. One of explanation can be a Zeeman splitting of the resonances in the presence of strong out of plane stray field [1]. On the next step we heated up the sample to room temperature and cooled it down in magnetic field of H=11kOe to 5K (NFC protocol). After this we performed experiments first rising magnetic field from 50Oe to 5kOe and then decreasing again.



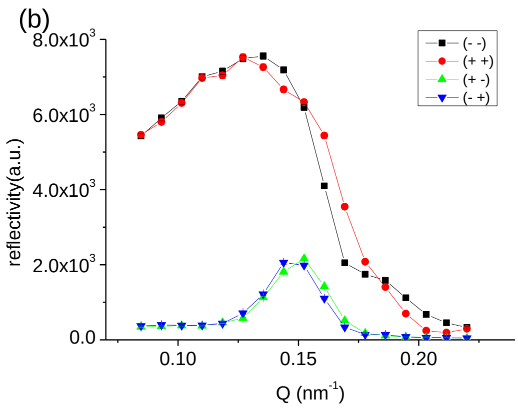


Fig. 1 (a) Reflectivity curves measured at T=5K on the sample D2#1080 in magnetic field H=6.1 kOe (a) and H=160G (b). Inset in (a) shows the sketch of the structure.

Fig. 2 shows combined results of PFC and NFC experiments. The H-dependence of averaged in the vicinity of Q_{crit} spin asymmetry is shown in Fig. 2a. Following [2] we present the NFC with H and <S> multiplied by -1 which allows to construct a neutron hysteresis loop. From Fig. 2a one can see that reversal fields for PFC Hc=375 Oe and NFC H=-617 Oe are significantly different which speaks about exchange bias effect. Fig. 2b shows the H-dependence of integrated spin-flip scattering which is also significantly different for PFC and NFC regimes. Analysis of such a difference is following.

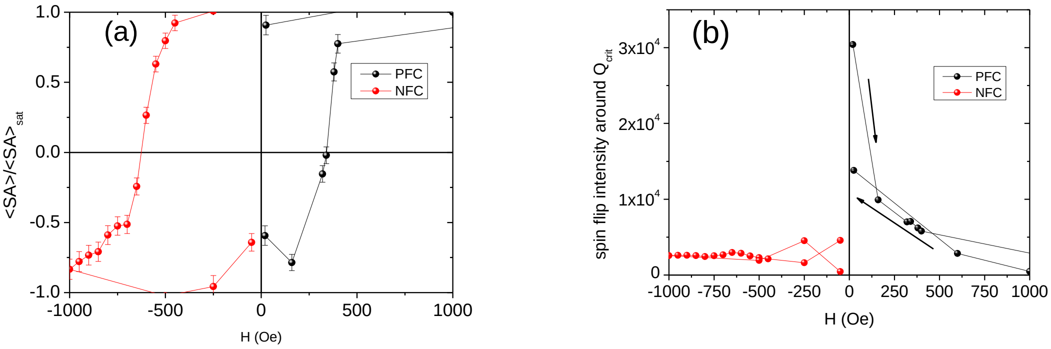


Fig.2. Field dependence of spin asymmetry (a) and spin-flip (b) measured in the vicinity of Q_{crit} in PFC and NFC protocols.

On the next step we changed the sample to **D2#1078 (n=2ML)** and applied PFC protocol. After this we performed series of H-scans in the vicinity of Q_{crit} and study influence of training effect. Unfortunately due to depolarization we were able to measure only at magnetic fields above 60Oe. Next step, the NFC protocol was used and H-dependencies were measured. Similar to above mentioned effects were also observed on this sample, quantitative analysis is following.

On the last 2 days of experiment we changed sample to D2#1079 (n=3ML) and measured H-scans and saturation curve in NFC protocol.

Concluding, main results of the experiment are following. We performed PNR experiment on $10x[9xLa_{0.6}Sr_{0.4}MnO_3+\mathbf{n}xLa_{0.2}Sr_{0.8}MnO_3]$ superlattices with n=2,3 and 4 spacer of nominally antiferromagnetic manganite spacer. Experiments were performed at T=5K after cooling experiment in positive and negative magnetic field of H~ 10kOe strength. In the experiment we measured:

(a) reflectivity curves at the saturated state in a wide range of momentum transfers up to Q~ 3-5 nm^{-1}. Fit of these curves will allow us to make a conclusion about presence of proximity effect between ferromagnetic and antiferromagnetic manganite;

(b) reflectivity curves in four spin state in the vicinity of critical edge in a wide range of magnetic field. These measurements evidences complex non-collinear or even non-complanar state of the samples in the presence of exchange bias effect.

References:
1. F. Radu et al Physica B 335, 63-67 (2003)
2. F. Radu et al Appl. Phys. A 74 (2002)