Experimental report

10/10/2023

Proposal: 5-54-386 **Council:** 10/2022

Title: Magnetic proximity in a superconductor-ferromagnetic-superconductor epitaxial system

Research area: Materials

This proposal is a new proposal

Main proposer: Kim LEFMANN

Experimental team: Kamaldeep DALAL

Local contacts: Thomas SAERBECK
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Samples: InAs(Sub)-Pb(40)-EuS(4)-Pb(40)-Al2O3(2)
InAs(Sub)-Pb(20)-EuS(2.5)-Pb(20)-Al2O3(2)
InAs(Sub)-Pb(20)-EuS(1.5)-Pb(20)-Al2O3(2)
InAs(Sub)-Pb(20)-EuS(4)-Pb(20)-Al2O3(2)

Instrument	Requested days	Allocated days	From	To
D17	6	3	09/09/2023	13/09/2023

Abstract:

The superconductor-ferromagnetic insulator-superconductor(SU-FMI-SU) junctions where the superconducting order parameter exhibits a phase difference across the FMI layer, are opening new avenues in the field of topological quantum computation. Our motive is to estimate the correlation in between the structural characteristics of FMI layer and the interfacial magnetic coupling at SU-FMI interface. We have already measured the PNR data of Pb-EuS-Pb junctions on POLREF(ISIS) and, we have observed the signatures of magnetic proximity effect across superconducting transition temperature in the reflectivity and spin-asymmetry profiles. However, to be conclusive, we need to exclude the effect of other temperature dependent magnetic phenomenon which could also give rise to similar changes in PNR profiles. With this proposal, we aim to de-entangle these effects from the exclusive signatures of magnetic proximity effect in superconducting Pb layer or at the Pb/EuS interface by recording PNR data in presence of different applied magnetic field and in different cooling schemes. These measurements will help us to make conclusive estimation of the long-range proximity effect in these systems.

Experimental report: 5-55-386

Title: Magnetic proximity in a superconductor-ferromagnetic-superconductor epitaxial system

Proposers: Kamaldeep Dalal, Dr. Malvika Tripathi, Dr. Yu Liu, Dr. Thomas Saerbeck, Dr. Nina J. Steinke, Prof. Kim Lefmann

Experimentors: Kamaldeep Dalal, Dr. Thomas Saerbeck, Dr. Nina J. Steinke

Date of experiment: 8th - 13th September, 2023

ILL instrument: D17

Scientific background: The superconductor-ferromagnetic insulator-superconductor(SU-FMI-SU) junctions where the superconducting order parameter exhibits a phase difference across the FMI layer, are opening new avenues in the field of topological quantum computation. Our motive is to estimate the correlation in between the structural characteristics of FMI layer and the interfacial magnetic coupling at SU-FMI interface. We have already measured the PNR data of Pb-EuS-Pb junctions on POLREF(ISIS) and, we have observed the signatures of magnetic proximity effect across superconducting transition temperature in the reflectivity and spin-asymmetry profiles. However, to be conclusive, we need to exclude the effect of other temperature dependent magnetic phenomenon which could also give rise to similar changes in PNR profiles. With this proposal, we aim to de-entangle these effects from the exclusive signatures of magnetic proximity effect in superconducting Pb layer or at the Pb/EuS interface by recording PNR data in presence of different applied magnetic field and in different cooling schemes. These measurements will help us to make conclusive estimation of the long-range proximity effect in these systems.

Preliminary results and discussion:

List of samples measured at D17 instrument during the beamtime –

1. Qdev1238 - InAs (Substrate)/ Pb (20nm)/ EuS(1.5nm)/ Pb (20nm)/AlOx(2nm)
2. Qdev1295 - InAs (Substrate)/ Pb (20nm)/ EuS(4nm)/ Pb (20nm)/AlOx(2nm)
3. Qdev1307 - InAs (Substrate)/ Pb (40nm)/AlOx(4nm), reference sample for Pb
4. Qdev1303 - InAs (Substrate)/ EuS(10nm)/ AlOx(6nm), reference sample for EuS

We have measured these samples at different temperatures covering both superconducting and ferromagnetic ordering temperature range. PNR measurements were recorded in time of flight mode with a wavelength range from 4 to 20Å. Firstly**,** the samples were cooled in zero magnetic field to a temperature well below both superconducting (~7.5K) and ferromagnetic (~17.5K) transitions. For acquiring the structural information, a reference measurement was performed, for all the samples, by warming to 100K (a temperature well above both transitions). For these samples, each measurement took around 6hrs.

Sample Q1238 –

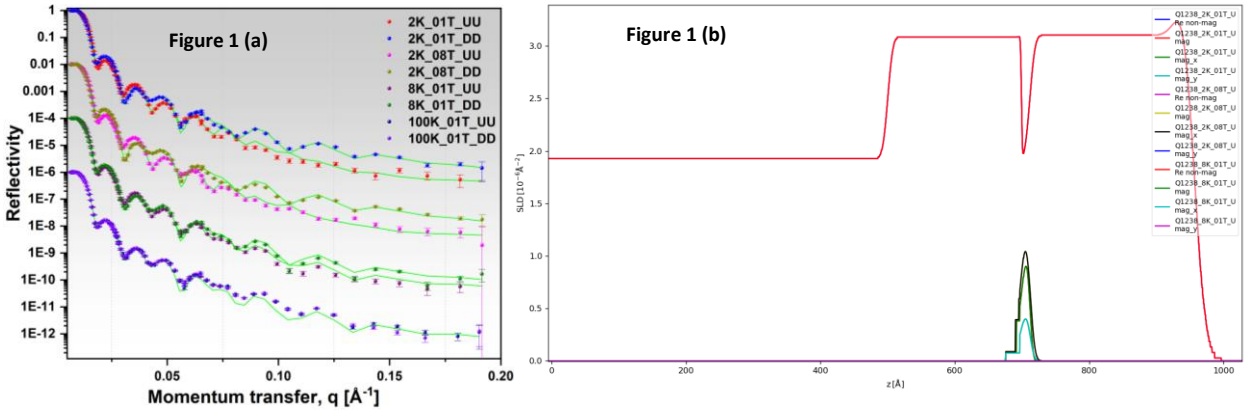

Figure 1: (a) Recorded PNR data along with preliminary fits for three temperatures (b) SLD v/s depth profile for the sample. The nuclear SLD for all temperatures overlaps and shown in red. The magnetic SLD is shown in shorter peaks near z =700 Å.

Firstly, we measured this sample in presence of 0.1T at 2K, a temperature well below both magnetic and superconducting transition. In order to decouple the magnetic effects due to the presence of superconductivity and ferromagnetism, we tried to destroy the superconducting at 2K by applying a higher magnetic field of 0.8T (a field higher than the critical field for Q1238). We have observed an increment in the magnetism in EuS layer and the origin is the mixture of application of stronger external magnetic field and suppression of superconductivity. The field dependency data is shown in figure 1 (a). Then, we heated the sample to 8K (@3T), a temperature just above the superconducting transition, to see the changes in interfacial magnetism. The recorded data along with preliminary fits is shown in figure 1 (a). We have tried to fit the data with simple model with no interfaces. The fitted nuclear SLDs [figure 1 (b)] for the layers are in good agreement with the literature values.

Sample Q1295

We recorded the PNR data for three temperatures in presence of 0.1T covering both superconducting and ferromagnetic ordering temperatures [Figure 2 (a)]. The fit to the data improves when we add a magnetic interface on both sides of EuS layer. The fitted SLDs [figure 2 (b)] are in good agreement with the literature values.

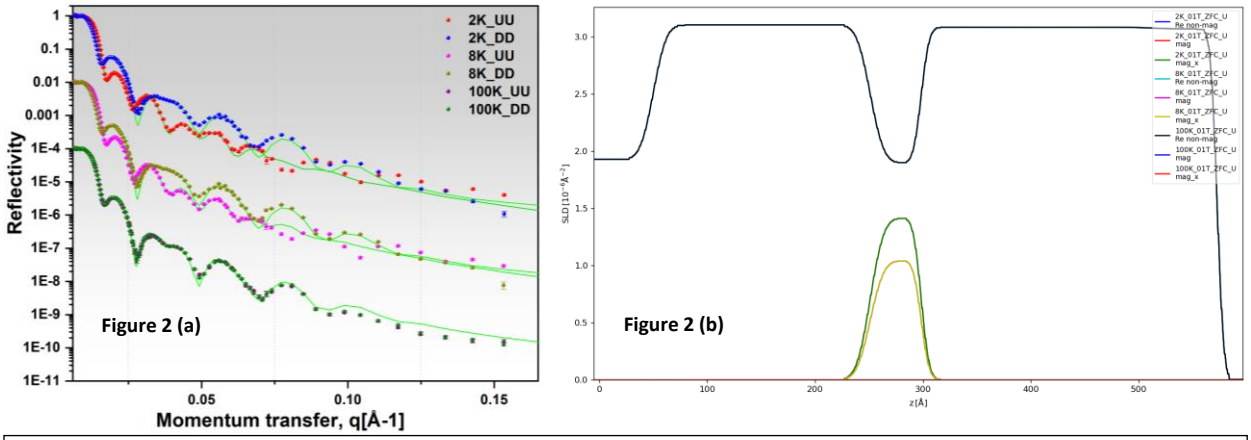

Figure 2: (a) Recorded PNR data along with preliminary fits for three temperatures at 0.1T (b) SLD v/s depth profile showing structure and distribution of magnetism. The nuclear SLD, material specific, for all temperatures overlaps and shown in black. The magnetic SLD is shown in shorter peaks near z =280 Å.

Sample Q1307

PNR data was recorded at three temperatures at a constant in-plane magnetic field of 0.1T is shown in figure 3. The choice of the magnetic field is consistent with measurements for the heterostructure. The preliminary fits to the data suggest no magnetism in lead layers at any temperature below and above superconducting transition. Also, the fitted SLD for lead layer matches with the literature value.

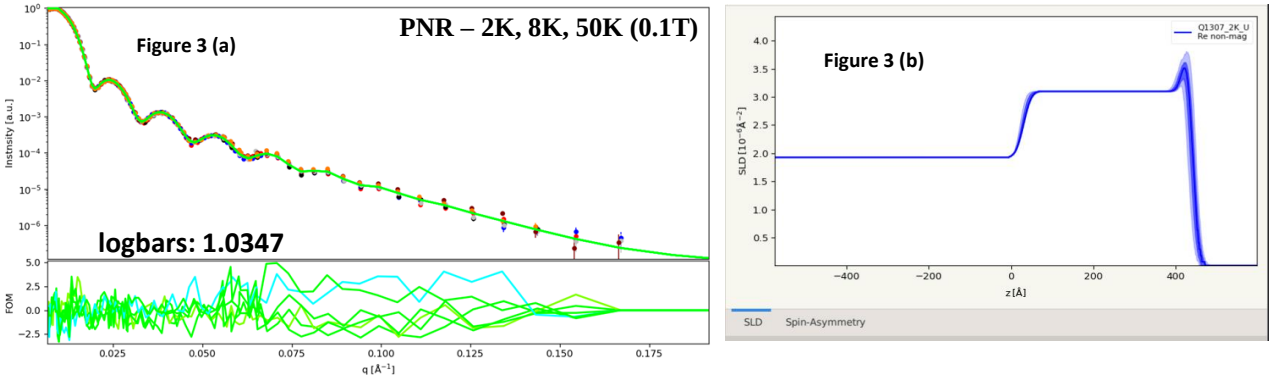

Figure 3: (a) Recorded PNR data along with preliminary fits for three temperatures at 0.1T (b) SLD v/s depth profile. The broad region around the main curve represents the uncertainty profile for this fit.

To explore the evolution of magnetism in EuS with temperature, we studied a reference sample with 10nm thick EuS layer on InAs substrate. We performed PNR measurements at four temperatures in presence of 3T and the data is shown in figure 4. We observed a magnetic signal at 100K and 300K, which is well above the transition temperature of EuS (T_C ~ 17.5K). We are still investigating the origin of this magnetic signal. We need to study how it will get translated to lower thicknesses of EuS in our heterostructures which are currently being studied for interfacial magnetism.

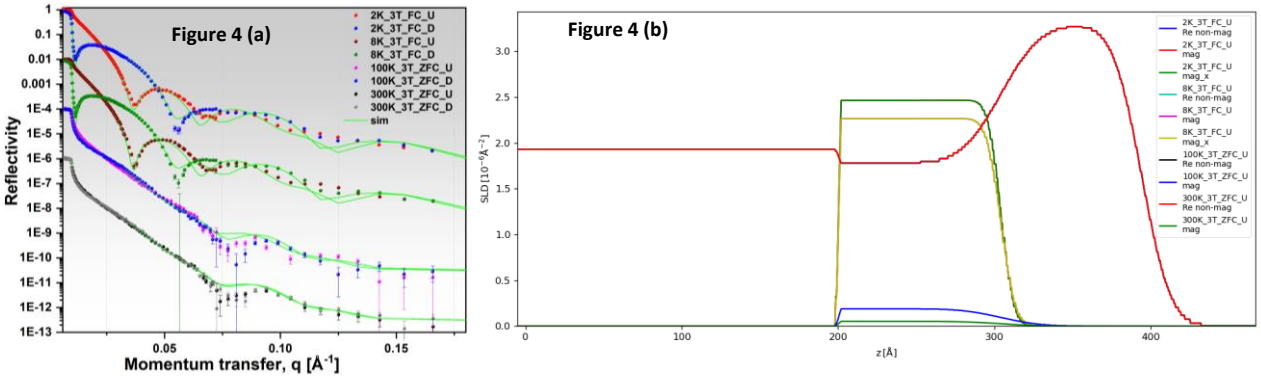

Figure 4: (a) Recorded PNR data along with preliminary fits at four temperatures in presence of 3T (b) SLD v/s depth profile. The nuclear SLD, material specific, for all temperatures overlaps and shown in red. The magnetic SLD is shown in shorter peaks from z = 200 Å to z = 320 Å.

We are currently fitting our PNR profiles with appropriate structural and magnetic models which would lead to further conclusive results.