Experimental report: MA-5662

Title: Magnetic proximity effect in superconductor-ferromagnetic insulator – superconductor junctions

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

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

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ESRF beamline: ID-12

Scientific background and aim: EuS/Pb and EuS/InAs interfaces form building blocks of a device structure which has been proposed to hold topologically protected surface states, called Majorana bound states (MBS). There exist a few proposals on how one can manipulate these states to store the information with longer coherence time. The material's choice is very limited by certain parameters that need to be fulfilled such as lattice matching, large spin-orbit splitting, high electron mobility, metallic superconductivity, etc. Using MBE, we fabricated Pb-EuS-Pb trilayers on InAs substrates with variable Pb and EuS thicknesses. The existence of proximity effects at these interfaces are crucial for the aforementioned states to appear in the proposed device structure. However, since, the difference in transition temperature of ferromagnetic (T_C) and superconducting (T_S) materials is very small, changes in the global magnetization can also correspond to the thermal evolution of the ferromagnetic moment of EuS. With this proposal, we were aiming to dis-entangle these effects from the exclusive signatures of magnetic proximity effect in superconducting Pb layer or at the Pb/EuS interface. The plan was to measure the XANES and XMCD spectra at Eu L_3 and Pb M_5-edges for all the samples in three magnetic states - (i) when both Pb and EuS are below their transition temperature, (ii) in the close vicinity of T_S and (ii) above the magnetic transition of EuS (T_C).

Results and discussion: We measured four samples during the five days beamtime at ID12 beamline. The samples were mounted on a copper sample holder, with grazing incidence angle of 10°. The samples were cooled to 3K in zero applied magnetic field (Zero Field Cooling, ZFC). Then, we applied a magnetic field of 3T for performing the energy scans around the Eu L_3-edge and measured the absorption spectra in the energy range 6955-7025 eV. XANES and XMCD results from the four samples are shown in Figure 1(a) and (b).

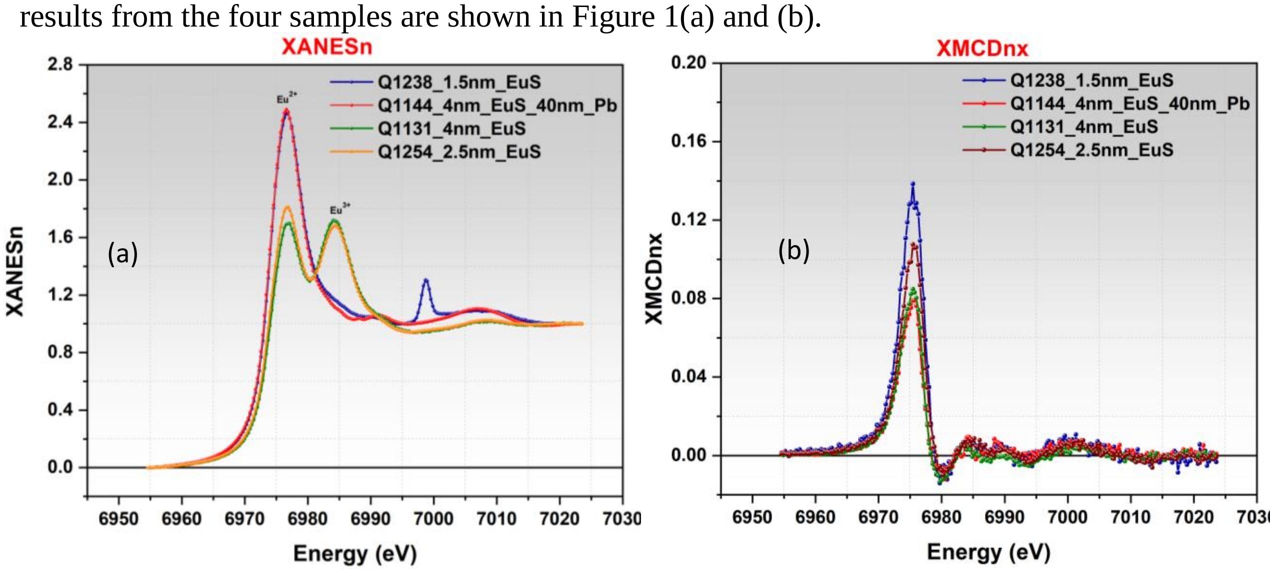

Figure 1: (a) Normalized XANES spectra for all the four samples measured at 3K @3T (b) Normalized XMCD signals from all four samples observed at 3K @3T.

List of samples measured:
Q1238 - Substrate/Pb(20nm)/EuS(1.5nm)/Pb(20nm)/cap
Q1254 - Substrate/Pb(20nm)/EuS(2.5nm)/Pb(20nm)/cap
Q1131 - Substrate/Pb(20nm)/EuS(4nm)/Pb(20nm)/cap
Q1144 - Substrate/Pb(40nm)/EuS(4nm)/Pb(40nm)/cap

XANES spectra of two out of four samples show the presence of Eu^{3+} oxidation states, which generally are not expected to contribute to ferromagnetism. This trivalent oxidation state could originate from defects or during the growth. The normalized XMCD signal from all the samples is compared in figure 1 (b). A higher XMCD is observed from the thinner layers which was unexpected. However, this may be a result of a degradation of the EuS layer with time as the thicker samples were older than the thinner samples by around 6 months.
XMCD at the Eu L_3 edge was measured while performing the temperature scans (from 3 to 33 K) at a constant magnetic field of 3T, 0.3T and 0.1T (figure 2) after field cooling (FC) in the corresponding field. The measurements were taken after stabilizing at each temperature step. The possible reason for broad transition at 3T could be the field polarization in EuS layer.
At 0.3T and 0.1T an onset of a magnetic XMCD is observed around 15K, except from one sample Q1144 which is believed to be magnetically dead (confirmed by other magnetometry measurements later). The amount of magnetic signal observed varies strongly between the different EuS thicknesses, and may indicate a balance between inherent defects of thin layers or introduced by growing films of larger thickness. However, the age of the sample must be taken into account and the reason for the varying signal strength is currently under investigation.

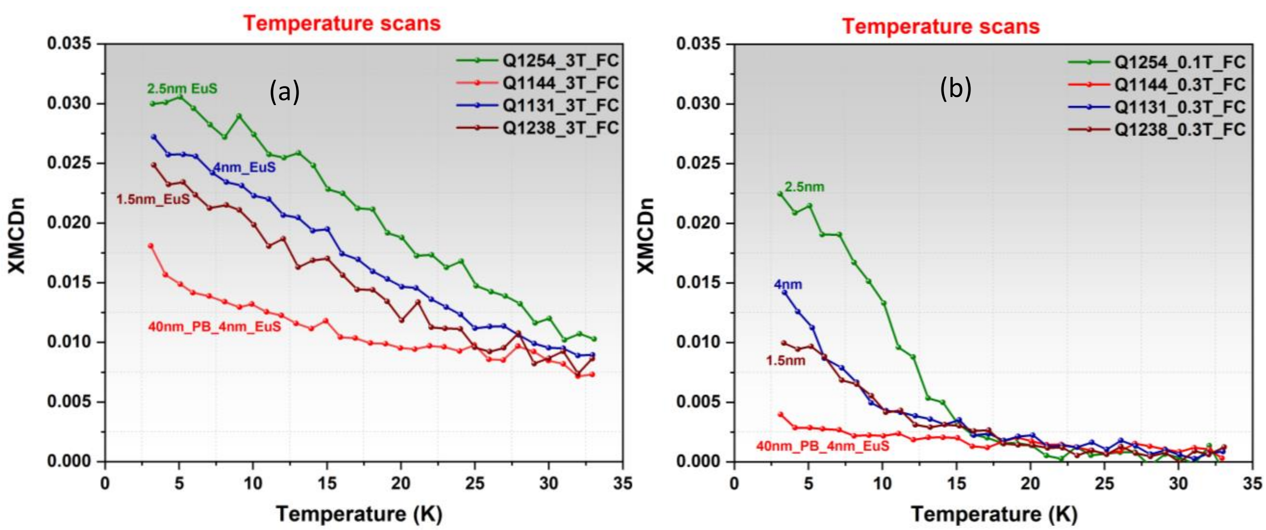

Figure 2: (a) Temperature scans at 3T for field cooled samples (b) Temperature scans at 0.1 and 0.3 T for field cooled samples.

Field scans at the Eu L_3 edge were performed in the range ±7T at a constant temperature well below both the superconducting and magnetic transition (figure 3(a)). For Q1144 (red), the signal is almost linear in the range of ±3T and starts to saturate at ±6T, which is not the case for other samples where the magnetization reaches the saturation faster.

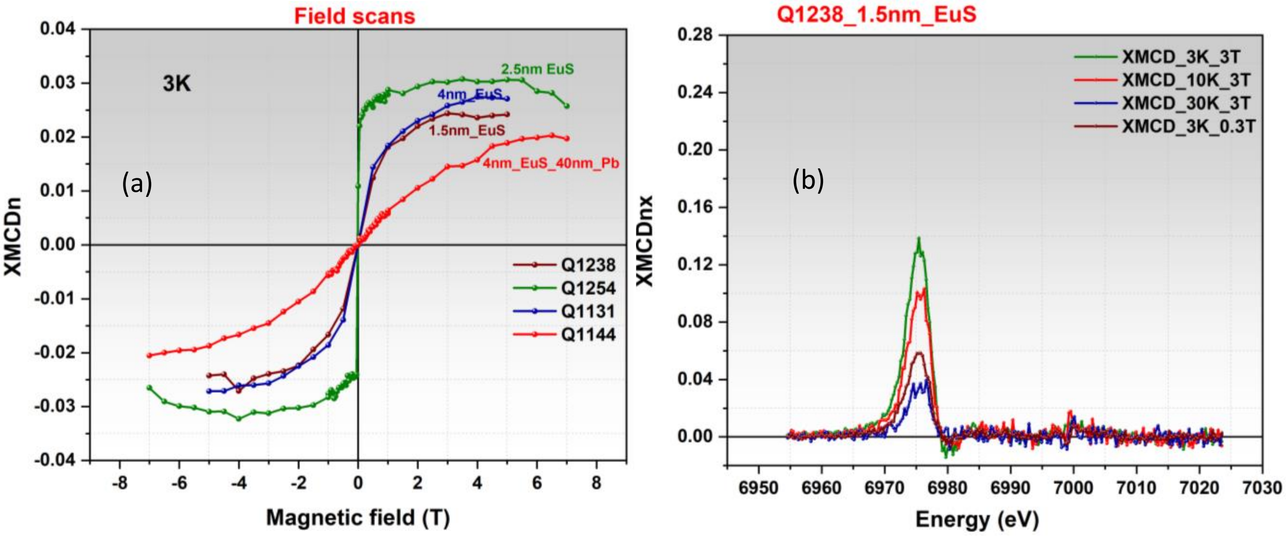

Figure 3: (a) Field scans for all the samples at 3K and Eu L_3-edge (b) Normalized XMCD signal for the sample Q1238 at two magnetic fields and three different temperatures.

Finally, in order to explore the temperature variation of XMCD signal at constant field, we performed four measurements on sample Q1238. These measurements are shown in figure 3(b). The initial plan was to study both edges – Eu L_3 and Pb M_5, but, the Pb M_5 edge was close to the other edge, whose signal was causing immense background and saturating the detector before we could observe anything at the Pb edge. So, we need to plan another beamtime to study the Pb edge in order to verify the effects in question.