Experiment title: Investigation of spin-phonon coupling in ultrathin EuO films by low-temperature nuclear inelastic scattering on ^{151}Eu		Experiment number: MA 3468
Beamline: ID18	**Date of experiment**: From 26/01/17 to 13/02/17	**Date of report**: 24/02/18
Shifts: 18	Local contact(s) Aleksandr Chumakov	

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The aim of this experiment was to systematically investigate by temperature-dependent nuclear inelastic scattering on ^{151}Eu how the recently discovered giant spin-phonon coupling in bulk EuO evolves in ultrathin EuO films of various thicknesses down to a single monolayer

Report

Epitaxial EuO films with thickness of 8.0, 4.0 and 2.0 nm, in the following referred to as S1, S2 and S3, were grown by molecular beam epitaxy on the $YAlO_3$(110) substrate. The samples were prepared and characterized in the UHV system at ID18 [1]. The analysis of the RHEED images shown in Fig. 1, confirmed the formation of high quality epitaxial films. The samples were covered with a 5nm thick Nb layer to protect the sensitive EuO from further oxidation. The nuclear inelastic experiment was performed at 295 K and 30 K using a helium flow cryostat equipped with kapton foil windows for the X-ray beam. In all measurements the X-ray beam was oriented along the EuO[100] direction that revealed the giant spin-phonon interaction in bulk EuO [2].

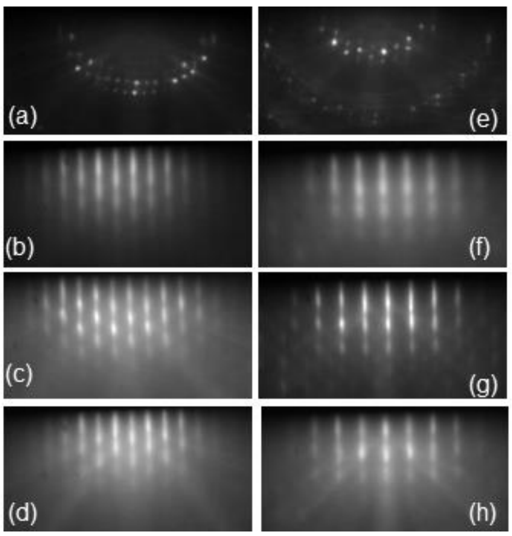

Fig. 1 RHEED images obtained with 28keV energy electrons of the substrate (a,e) and samples S1 (b,f), S2 (c,g) and S3 (d,h) along the [110] (left column) and [100] (right column) azimuths.

Figure 2 shows the obtained Eu-partial phonon density of states (PDOS) of the investigated samples at the indicated temperatures. For comparison, the *ab initio* calculated PDOS of the bulk EuO convoluted with the dumped harmonic oscillator function with quality factor Q=8 is depicted with solid line. This figure reveals that the PDOS of sample S1 exhibits bulk-like features, as expected for this thickness. Reduction of the EuO film thickness leads to drastic modifications of the PDOS.

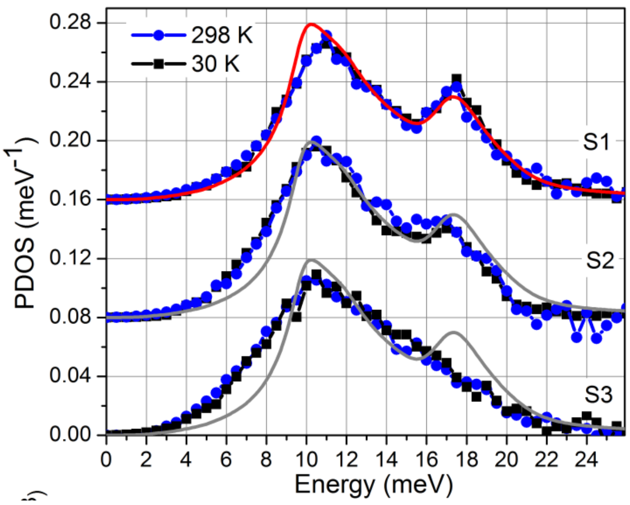

Fig. 2 Eu-partial PDOS of the investigated samples obtained from the nuclear inelastic scattering experiment performed at the indicated temperatures. The solid line marks the ab initio calculated PDOS of bulk EuO convoluted with the DHO function with quality factor Q=8.

Furthermore, Fig. 2 clearly demonstrates that, within the experimental errors, the PDOS curves obtained at 30 K coincide with the ones derived at 298 K. Thus, unlike the experiment reported in ref. [2], additional broadening of the PDOS features at low temperature has not been observed. The investigated EuO films were deposited on the $YAlO_3$(111) substrate, that is known to induce tensile stress on the EuO film amounting to about 2.5% [3]. Most likely the strain-induced broadening of the phonon peaks hinders the broadening due to the spin-phonon interaction observed in a strain-free EuO(001) film deposited on YSZ(001) [2].

During this beamtime we have also investigated the lattice dynamics of Eu_2O_3 films as a function of the film thickness. This experiment was motivated because of the interest in the RE_2O_3 films due to their high dielectric constants that made them very attractive materials for ultrathin dielectric films in the current nanoelectronics. Polycrystalline Eu_2O_3 films with thicknesses of 20.0, 2.0 and 1.0 nm were prepared by deposition of Eu metal on the YSZ(001) substrate in an oxygen atmosphere, followed by annealing for 1 hour. Figure 3 shows the Eu-partial PDOS obtained from the nuclear inelastic scattering experiment performed at room temperature along with the results from first-principles theory. The PDOS of the 20 nm films shows the main features that are predicted by the theory. The reduction of the film thickness to 2.0 and 1.0 nm leads to drastic modifications of the PDOS. Namely, an enhancement of the low-energy states and broadening and suppression of the phonon peaks.

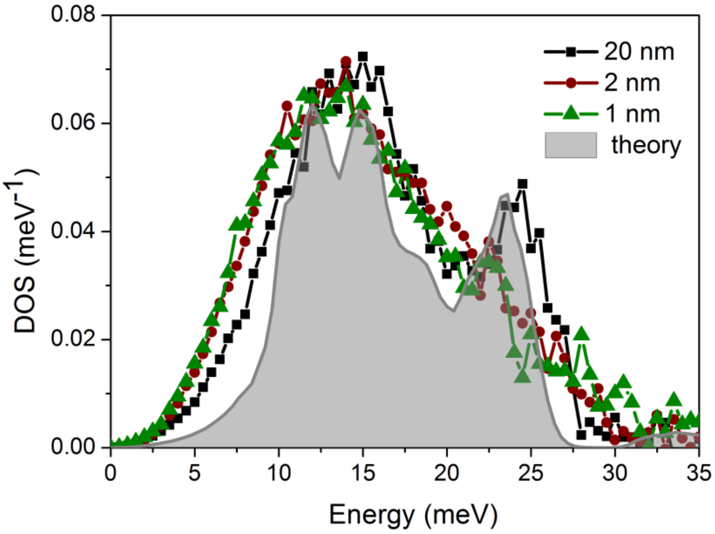

Fig. 3 Eu-partial PDOS of the Eu_2O_3 films obtained from the nuclear inelastic scattering experiment performed at room temperature. For comparison, the ab initio calculated PDOS of bulk crystal is shown.

The obtained within this beamtime results are in an advanced form of preparation for publication and will be submitted soon.

References

[1] S. Stankov et al., Rev. Sci. Instr. **79**, 045108 (2008)
[2] R. Pradip et al., Phys. Rev. Lett. **116**, 185501 (2016)
[3] R. W. Ulbricht et al., Appl. Phys. Lett. **93**, 102105 (2018)