Standard Project

Experimental Report

Proposal title: **Thin film orthoferrites for spintronics and ultrafast magnetization reversal**		**Proposal number:** HC-4300
Beamline: ID 18	**Date(s) of experiment:** from: February 17, 2021 to: 23 February 23, 2021 from: March 30, 2021 to: April 06, 2021	**Date of report:** February 28, 2021 October 30, 2021
Shifts: 18 18	**Local contact(s)** Dr. Aleksandr Chumakov	**Date of submission:** February 28, 2021 October 30, 2021

Objective & expected results (less than 10 lines)

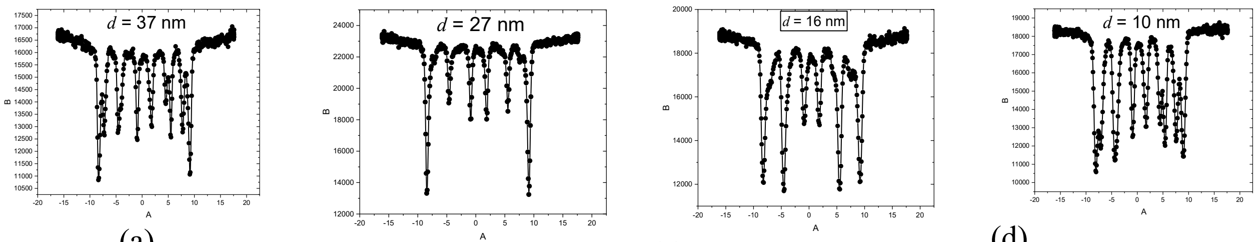
The goal of our experiment was to study the evolution of magnetic properties of ultrathin (2.5-40 nm) antiferromagnetic $YFeO_3$ wedged films on *r*-Al_2O_3 substrates in the 3.5 - 800 K temperature range. including the Neel temperature of $YFeO_3$, and under the action of the external magnetic field by X-ray reflectivity and Mössbauer reflectivity spectra. Mossbauer technique is known to be the best probe for local magnetization, providing information about hyperfine magnetic fields and its orientation [1].

Results and the conclusions of the study (main part)

Wedge-shaped $YFeO_3$ films with 95% Fe^{57} enrichment on the *r*-Al_2O_3 substrates with thickness 40-23 nm, 23-8 nm, 11-6 nm, 7-3 nm, and 4.1-2.5 nm were prepared by magnetron sputtering and *ex-situ* postannealing in air at 800C for 3h.

Low temperature (3.5 – 300 K) synchrotron Mössbauer and reflectivity investigations were carried out for the angles of incidence of synchrotron beam in the range of 0.12-0.20 deg., and in applied magnetic field of up to 3.6 Tesla.

Many unexpected results were obtained. First measurements showed rather complicated thickness dependences of the Mössbauer reflectivity spectra, see Fig.1.



(a) (b) (c) (d)

Fig.1. Mössbauer spectra for several $YFeO_3$ films with thickness *d* indicated recorded at the temperature of 3.5K in zero magnetic field. Angle of incidence of the primary beam 0.12 deg.

The observed unexpected result is the two sextets (with the hyperfine fields of ~54 T and ~45 T) in Fig.1 (a) and (d), while the bulk $YFeO_3$ material is characterized by the sole hyperfine field [1]. That clearly points to the presence of the secondary phase of unknown nature in our films.

Mössbauer reflectivity spectra demonstrate different behavior upon variation of the applied magnetic field and temperature (Fig.2 (a) and (b)). For thicker film, the application of magnetic field increases the splitting for higher hyperfine field, but deceases it for smaller sextet (Fig.2 (a)). For thinner film temperature rise results in complete collapse of splitting only for one sextet (Fig.2 (b)). In addition, the external magnetic field resulted in reorientation of vector of weak ferromagnetism from the normal to the film plane. Such reorientation is more pronounced for thicker films.

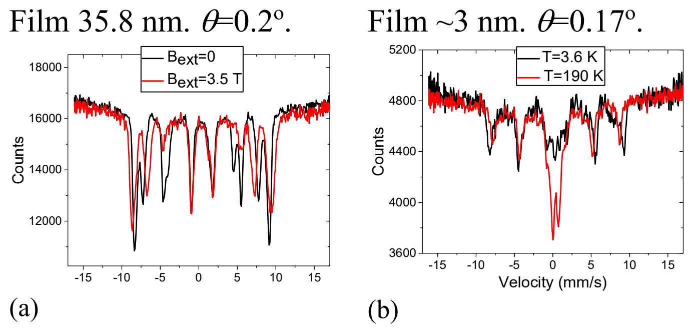


Fig.2. Mössbauer spectra for $YFeO_3$ thin films recorded at two applied fields at T = 3.5 K (a) and at two temperatures in zero magnetic field (b).

High temperature studies carried out in the 300 - 800 K temperature range. including the Neel temperature of $YFeO_3$, revealed even more complicated features. Typical example is shown in Fig.3. Upon approach to the Neel temperature additional doublet appears in the spectra alongside with the basic sextet. The physical nature of this doublet is unclear at present. By analogy with the known Mössbauer spectra for low dimensional antiferromagnetic systems (nanoparticles) [2] the appearance of doublet can be ascribed to antiferromagnetically ordered inhomogeneities. Additional experiment and theoretical investigations are required.

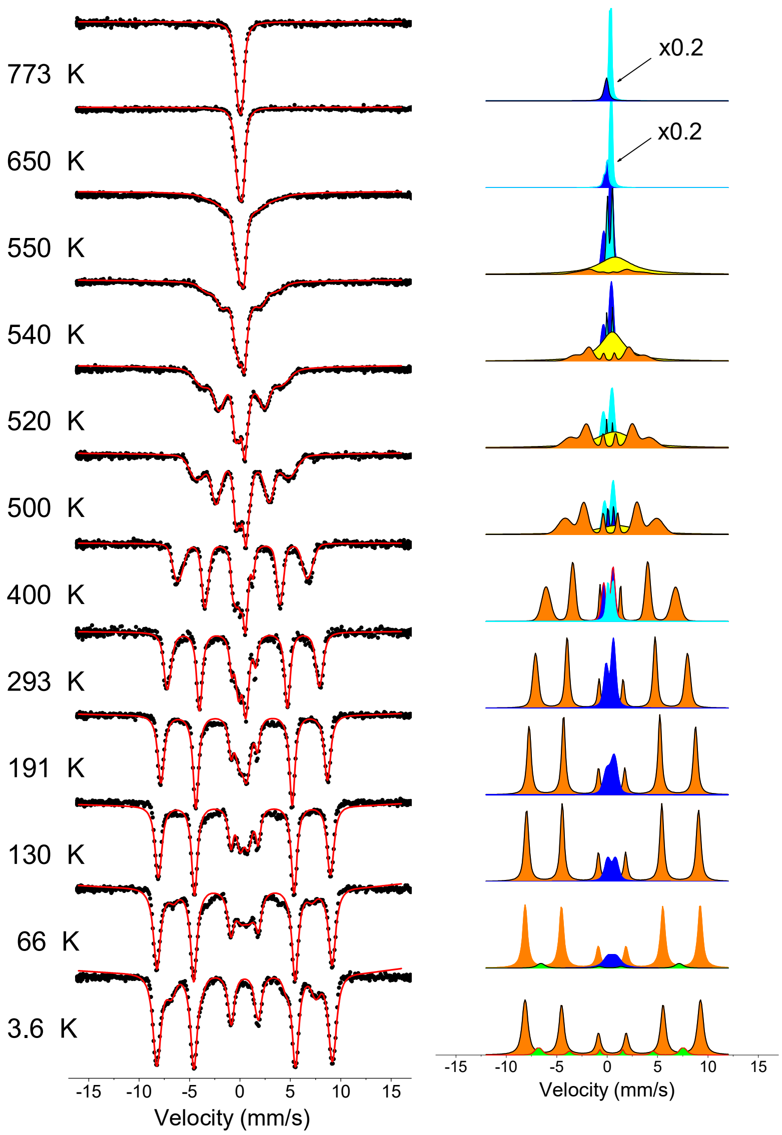


Fig.3. Mössbauer spectra for the 7.2 nm $YFeO_3$ thin film recorded at various temperatures.

Several important questions related to the explanation of the unexpected results remain. The most important one is the nature of the second hyperfine field: it is either the second phase, or the strained layers at the interface, or nanosized inhomogeneities in the thinnest films. Does yttrium give any magnetic contribution? Additional structural and Mössbauer investigations are required. Depth resolved Mössbauer reflectivity investigations at ID18 might clarify the evolution of magnetic properties with temperature and magnetic field.

Justification and comments about the use of beam time:

During the beam time, we have measured over 100 Mössbauer reflectivity spectra revealing a complicated variation of magnetization as a function of the film thickness, temperature, and experimental parameters (angle of incidence of synchrotron beam, temperature, magnetic field). Measurements of Mössbauer reflectivity spectra in wider angular range ae needed for the depth selection of the existing phases in our films in order to clarify the role of the film stress on the magnetic and structural parameters of our $YFeO_3$ orthoferrite.

These measurements provided high-quality data for quantitative analysis of Mössbauer and reflectivity spectra to get the principal physical parameters as a function of angle of incidence, film thickness, temperature, and magnetic field. Anyhow additional detailed Mössbauer, structural, and magnetic measurements will provide a better understanding and accuracy of the quantitative results.

These experiments are original in the antiferromagnetic community and give important outputs for understanding evolution of magnetic properties of ultrathin films the development of advanced devices for antiferromagnetic spintronics.

Publication(s)

A more complete publications dedicated to Mössbauer results will be submitted when all the results will be analyzed.

References

1. G.W.Durbin, C.E.Johnson and M.F.Thomas. J. Phys. C: Solid State Phys. 1975. v.8. p.3051- 3057.
2. M.A.Chuev. Excitation Spectrum and Magnetic Dynamics of Antiferromagnetic Nanoparticles in Mossbauer Spectroscopy. JETP Lett. 2014. V.99. No.5. p. 278-282.