Experimental report

26/01/2024

Proposal: **5-54-390** **Council:** 10/2022

Title: Investigation of the spin canting in thin films of Mn2Rh0.6Ir0.4Sn Heusler compound.

Research area: Physics

This proposal is a new proposal

Main proposer: **Rebeca IBARRA**

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Samples: Mn2Rh0.6Ir0.4Sn

Instrument	Requested days	Allocated days	From	To
D10	8	8	06/06/2023	14/06/2023

Abstract:

The study of noncollinear magnets and quantification of their spin canting is crucial for the development and optimization of technological applications, for which thin films are vital for this purpose. In this experiment, we will determine the magnitude and nature (ferro/antiferromagnetic) of the spin canting in the Heusler compound Mn2Rh0.6Ir0.4Sn, grown on MgO(100) substrate. From the magnetic and transport properties of the parent compound Mn2RhSn, we see that the substitution of Rh by Ir, with higher spin-orbit coupling, alters the balance of the Heisenberg and Dzyaloshinskii-Moriya exchange interactions, as well as the magnetic anisotropy, therefore changing the spin canting angle. Preliminary results in Mn2RhSn from single crystal neutron diffraction at ZEBRA (PSI) already show differences with the bulk. Through the examination of a set of (HKL) Bragg peaks in a wide T range, the spin canting angle could be resolved in D10 diffractometer. Our previous experiment in a single 60 nm thin film performed at D10 proved that the proposed methodology is successful for the quantification of spin canting in thin films.

Experimental Report 5-54-390

Investigation of the spin canting in thin films of $Mn_2Rh_{0.6}Ir_{0.4}Sn$ Heusler compound.

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Introduction

The spin canting in the Heusler compounds can be engineered through chemical substitution in addition to the perpendicular magnetic anisotropy (PMA) derived from tetragonal crystal structures. The inverse tetragonal (t) Heusler compound t-Mn_2RhSn was investigated for the first time by neutron powder diffraction (NPD) by Meshcheriakova *et al.*, shedding light on the spin canted state in this material [1]. An antiferromagnetic (AFM) coupling is suggested to exist among the two Mn sublattices of this compound. Yet, other types of magnetic ordering are not decisively excluded in this pioneering work. We propose the study of the Iridium substituted system t-$Mn_2Rh_{0.68}Ir_{0.32}Sn$, where the higher SOC of Iridium is expected to alter the spin canting angle in the system. Until now, no neutron scattering studies in thin single-crystalline films of $Mn_2Rh_{1-x}Ir_xSn$ have been reported, making it an ideal benchmark system for the investigation of noncollinear magnetism.

In this work, we study the magnetic ground state of tetragonal Mn_2RhSn and $Mn_2Rh_{0.68}Ir_{0.32}Sn$ epitaxial thin films (60 nm nominal thickness) grown by magnetron sputtering on MgO (001) single crystalline substrate. The films crystalize in the non-centrosymmetric $I-4m2$ (no. 119) space group, displaying perpendicular magnetic anisotropy and a second order phase transition into a collinear magnetic state at $T_C = 275$ K. A second magnetic transition is identified by SQUID-VSM magnetometry and electrical transport experiments at $T_sr \approx 100$ K. In order to examine the temperature evolution of the magnetic structure, we performed single-crystal neutron diffraction in the D10 four-circle diffractometer at the Institut Laue-Langevin.

Performed Experiment

Thermal neutrons of incident wavelength 2.36 Å were selected employing a vertically focusing pyrolytic graphite (PG) (002) monochromator and collected in a $96 \times 96\,mm^2$ 2D microstrip detector. Given the higher flux of the updated instrument, the triple-axis configuration in elastic mode was not implemented. The measurements were performed in the temperature range of 300 K to 2 K and no magnetic field was applied.

Data Analysis

The crystal structure of the 60 nm $Mn_2Rh_{0.68}Ir_{0.32}Sn$ in the paramagnetic (PM) state was first analyzed at room temperature. The refinement of the nuclear (and subsequently magnetic) structure was performed by the Rietveld method implemented within the FullProf software [2].

A set of 16 Bragg reflections were collected below T_C, first in the collinear magnetic state at $T = 150$ K and afterwards at $T = 2$ K, in the spin-canted state. A detailed T-scan was performed for a selected number of reflections, in the range 2 to 280 K. The increase of intensity of the (110) Bragg reflection below T_C signals the appearance of an additional ferromagnetic contribution to the scattering (Fig. 1(a)). Furthermore, we observe a non-zero intensity of the (002) reflection, originated in the weakly nuclear scattering plus the in-plane component magnetic moment (Fig. 1(b)). The observation of this reflection at $T = 150$ K indicates a transition to a ferrimagnetic (FiM) canted state, rather than a collinear FiM state, as expected.

During the second part of this experiment we examined the magnetic structure of a 60 nm t-Mn_2RhSn thin film. A temperature dependence of a selected number of reflections revealed a strong T-dependence of the (1-10) reflection, with a weakly nuclear and strong collinear (to the c-axis) magnetic contribution (Fig. 1(c)). The emergence of a weakly (002) reflection indicates a transition to a spin canted state, similarly to the observed in the $Mn_2Rh_{0.68}Ir_{0.32}Sn$ films (Fig. 1(d)).

Conclusions

The magnetic structure of Mn_2RhSn and $Mn_2Rh_{0.68}Ir_{0.32}Sn$ epitaxial thin films of 60 nm nominal thickness were investigated in this single-crystal diffraction experiment. By examining the temperature dependence of a selected number of Bragg diffractions, we can preliminary conclude that the $Mn_2Rh_{(1-x)}Ir_{(x)}Sn$ system shows a magnetic transition to a spin-canted ferrimagnetic phase. This conclusion is grounded in the observation of a non-zero (002) magnetic intensity accompanied by the absence of the (004) reflection magnetic reflection. Such reflections evidence a spin-canted ferrimagnetic groundstate along the c-axis, below 150 K.

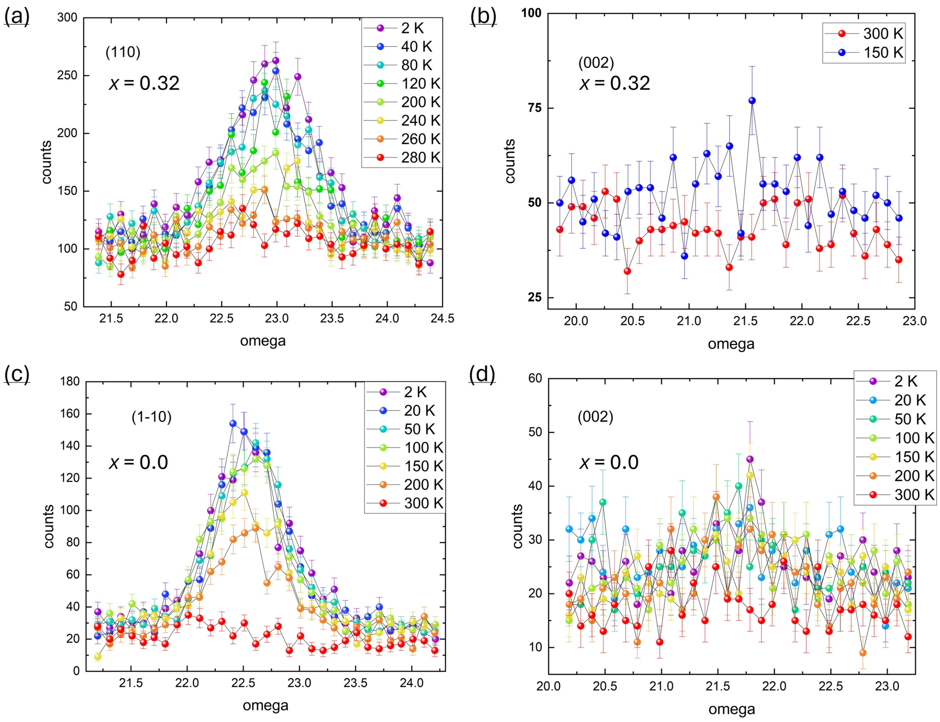

Figure 1: Single-crystal neutron diffraction of 60 nm $Mn_2Rh_{(1-x)}Ir_{(x)}Sn$ epitaxial thin films. $Mn_2Rh_{0.68}Ir_{0.32}Sn$: (a) Temperature dependence of the (110) Bragg reflection, due to the FM component of the magnetic structure. (b) Temperature dependence of the magnetic (002) Bragg reflection, evidencing the emergence of the spin canted state below $T = 150K$. Mn_2RhSn: (c) Temperature dependence of the (1-10) Bragg reflection, due to the FM component of the magnetic structure. (d) Temperature dependence of the magnetic (002) Bragg reflection, evidencing the emergence of the spin canted state below $T = 150K$.

[1] O. Meshcheriakova, S. Chadov, A. Nayak, U. Rößler, J. Kübler, G. André, A. Tsirlin, J. Kiss, S. Hausdorf, A. Kalache, *et al.*, “Large noncollinearity and spin reorientation in the novel mn 2 rhsn heusler magnet,” *Physical review letters*, vol. 113, no. 8, p. 087203, 2014.

[2] J. Rodríguez-Carvajal, “Fullprof,” *CEA/Saclay, France*, vol. 1045, pp. 132–146, 2001.