Experimental report

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Proposal: **5-54-366**

Council: 10/2020

Title: Noncollinear magnetic structure inmetallic PtMnGa

Research area: Physics

This proposal is a new proposal

Main proposer: **Rebeca IBARRA**

Experimental team: Rebeca IBARRA

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Samples: PtMnGa

Instrument	Requested days	Allocated days	From	To
D10	4	4	21/05/2021	28/05/2021

Abstract:

Complex noncollinear and noncoplanar magnetic structures attract attention due to various emergent phenomena such as the skyrmion lattice, a noncollinear magnetic structure of topologically protected spin vortices. The different noncollinear magnetic phases of polycrystalline PtMnGa have been recently reported. At the moment, there are no reported studies of the magnetic properties of this compound in thin single-crystalline films. We aim to refine the magnetic structure of a 100 nm thin film of PtMnGa at low temperatures by means of single-crystal neutron diffraction. Preliminary neutron diffraction measurements on our thin-film samples confirmed the feasibility of magnetic structure determination. In this experiment we intend to extend the measurements beyond the first (001) magnetic Bragg peak covered before. To unambiguously refine the noncollinear magnetic structure of the thin films of PtMnGa, we will measure the intensity of all Bragg peaks that can be reached at the D10 diffractometer comparing with high temperature measurements in the paramagnetic state to identify the magnetic Bragg peaks.

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"Noncollinear magnetic structure in metallic PtMnGa"

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Introduction

Magnetic systems exhibiting spin-canted states have garnered much attention lately and promise rich exotic properties driven by their real space spin-textures and competing magnetic orders. In this work, we study the magnetic ground state of a hexagonal h-MnPtGa epitaxial thin films (60 nm thickness) grown by magnetron sputtering on $Al_2O_3(0001)$ single crystalline substrate. The MnPtGa film crystalizes in the centrosymmetric $P6_3/mmc$ (No. 194) space group, showing perpendicular magnetic anisotropy and a second order phase transition at the Curie point (T_C = 263 K). In order to examine the temperature evolution of the magnetic structure, we performed single-crystal neutron diffraction at the D10 four-circle diffractometer in 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 combined with a focusing PG analyzer, and collected in a $96 \times 96\ mm^2$ 2D microstrip detector. The measurements were performed in the temperature range of 300 K to 2 K. The triple-axis configuration in elastic mode was used in order to reduce the background and increase the signal-to-background ratio. No magnetic field was applied.

Data Analysis

The crystal structure of the 60 nm h-MnPtGa in the paramagnetic (PM) state was analyzed through the collection of 17 Bragg peaks at 300 K, leading to 8 unique independent reflections. The refinement of the nuclear and magnetic structures were performed by the Rietveld method implemented within the FullProf software [1]. The refinement of the nuclear structure in the PM phase is shown in Fig. 1(a).

We have collected the same set of Bragg reflections below T_C in the collinear FM state at $T = 200K$. At this temperature an increase in the intensity of the (100) Bragg reflection is observed, which signals the appearance of an additional ferromagnetic contribution to the scattering (see Fig. 1(b)). Accordingly, the nuclear and magnetic structures were refined, including a FM component that leads to a reliability factor $R_B = 8.5\%$, as shown in Fig. 1(c). The magnetic moment is found to be 2.8(7) μ_B per Mn atom along the c-axis.

As we reduce the temperature to 2 K, well below the spin reorientation temperature T_{sr}, we observe that the intensity of the (100) Bragg reflection has further increased, accompanied by the onset of a sizeable (001) Bragg reflection (see Fig. 1(d)). The observation of the structurally forbidden (001) Bragg reflection for the $P6_3/mmc$ space group, of therefore purely magnetic origin, is a signature of the existence of a component of the magnetic moment in the basal plane. The magnetic order in the spin canted state (SC) is found to be commensurate with the lattice, and characterized by a propagation vector $\boldsymbol{k}$ = (0,0,0). This type of magnetic ordering is also found in bulk polycrystalline h-MnPtGa [2].

Accordingly, the refinement of the nuclear and magnetic structures at 2 K were performed including both a FM coupling in the basal plane, with the moment along the c-axis, and an AFM in-plane component (staggered in the out-of-plane direction). The comparison between the calculated and observed squared structure factors at 2 K is shown in Fig. 1(e), yielding a reliability factor $R_B = 9\%$. The components of the magnetic moment of the Mn atoms are obtained from the refined data at 2 K, with values $\mu_z = 4.2(4)\mu_B$ and $\mu_x = 1.5(3)\mu_B$, leading to a total magnetic moment per Mn atoms of 4.5(5) μ_B at 2 K. From our analysis, we find a canting angle of $(20 \pm 0.9)^\circ$ away from the c-axis at 2 K.

Conclusions

Hexagonal MnPtGa thin film undergoes a spin reorientation transition at $T_{sr} = 160K$. We investigate the magnetic groundstate and find the emergence of the (00l) purely magnetic Bragg reflection below T_{sr}. This structurally forbidden reflection evidences the emergence of a spin-canted state, where the magnetic moments align ferromagnetically in the basal plane and a non-zero in-plane component exhibits an antiferromagnetic ordering along the c-axis.

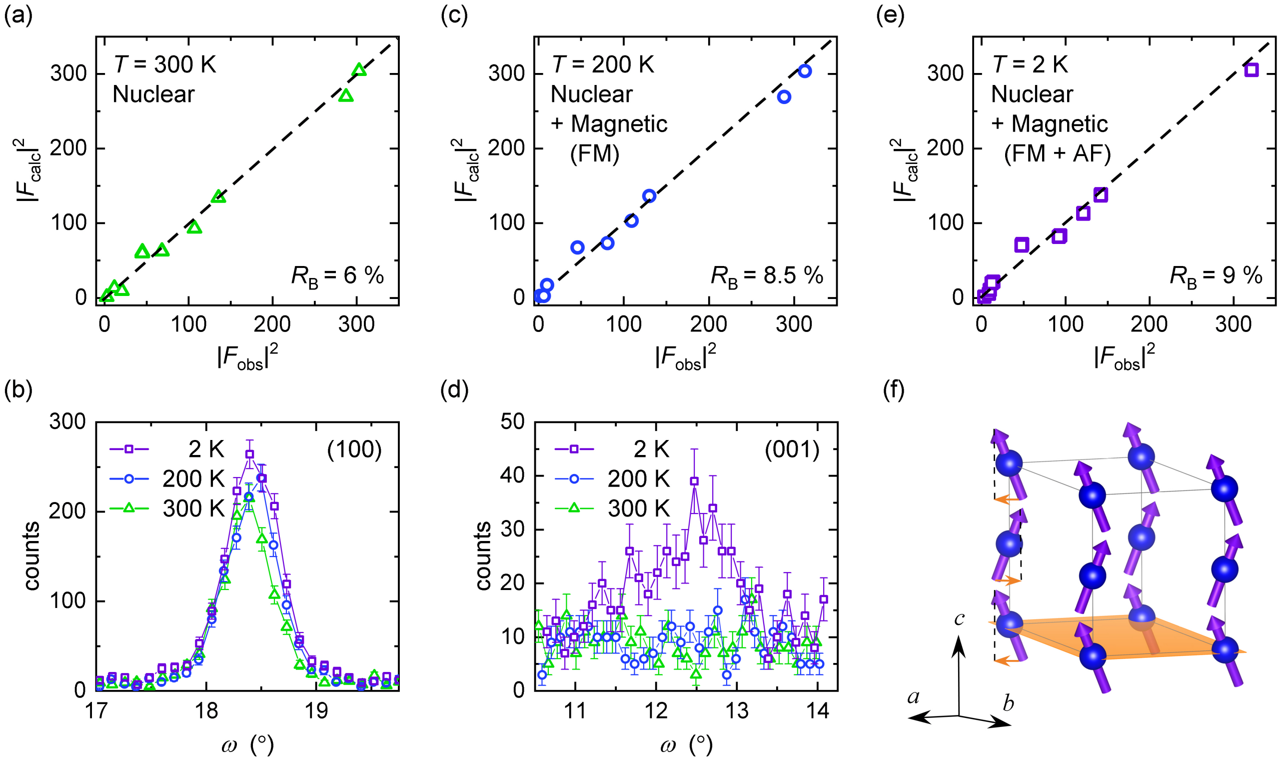

Figure 1: Single-crystal neutron diffraction of h-MnPtGa epitaxial thin film. (a) Rietveld refinement of the nuclear structure in the paramagnetic phase at 300 K. (b,d) Temperature dependence of (b) the (100) Bragg reflection, and (d) the purely magnetic (001) Bragg reflection, in the paramagnetic (300 K), ferromagnetic (200 K) and spin-canted (2 K) states. (c) Rietveld refinement of the nuclear and magnetic structure in the ferromagnetic state at 200 K. (e) Rietveld refinement of the nuclear and magnetic structure in the spin-canted state at 2 K, where we include both the FM and in-plane AFM staggered contributions along the c-axis. (f) Noncollinear magnetic groundstate structure at 2 K, where the Mn moments are depicted with a canting angle of 20° away from the c-axis.

[1] J. Rodríguez-Carvajal, "Fullprof," *CEA/Saclay, France*, 2001.

[2] J. A. Cooley, J. D. Bocarsly, E. C. Schueller, E. E. Levin, E. E. Rodriguez, A. Huq, S. H. Lapidus, S. D. Wilson, and R. Seshadri, "Evolution of noncollinear magnetism in magnetocaloric mnptga," *Physical Review Materials*, vol. 4, no. 4, p. 044405, 2020.