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ScienceDirect
Journal of Magnetism and Magnetic Materials 310 (2007) 1599–1601
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Field-induced reorientation of helix in MnSi near T_C

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Available online 13 November 2006

Abstract

The spiral structure of the single crystal MnSi has been studied by SANS near $T_C = 29$K in the magnetic field. When the field ($H > 20$ mT) is applied along one of the $\langle 1\,1\,1 \rangle$ axes, it produces a single domain sample with the helix wave vector along the field. The 90°-reorientation of the spin spiral from the [1 1 1] axis to [1 −1 0] axis is observed in the field range from 130 to 180 mT in close vicinity to T_C. Further increase of the field above $H = 180$ mT, restores the original orientation of the helix and leads to the induced ferromagnetic state at $H = 350$ mT. The SANS experiments demonstrate that not a new phase, but helix reorientation occurs in the narrow domain of the H–T phase diagram near T_C.

PACS: 61.12.Ex; 75.40.−S

Keywords: Helix spin structures; Dzyaloshinskii–Moriya interaction

1. Introduction

The itinerant cubic helimagnet MnSi with the space group $P2_13$ and the lattice constant $a = 0.4558$ nm is ordered below $T_C = 29$K in a left-handed spiral with a propagation vector $\mathbf{k} = (2\pi/a)$ (ζ, ζ, ζ), where $\zeta = 0.017$ [1–3]. Its helicity is a result of antisymmetric Dzyaloshinskii–Moriya (DM) exchange interaction caused by the lack of a center of symmetry in Mn-atomic arrangement. This DM interaction is isotropic itself, but another weak anisotropic exchange (AE) interaction fixes a direction of the magnetic spiral along one of the cube diagonals [4]. At present the critical behavior of the helix structure at finite temperatures is of interest in relation to the discovery of a quantum phase transition in MnSi under applied pressure at $T = 0$ [5]. The critical properties were recently studied by polarized SANS in zero field [6]. When the magnetic field is applied, a new, so-called, A-phase was found at $H_A \sim 200$ mT and slightly below T_C, by measuring the magnetization and magneto-resistance [7]. The neutron scattering experiments had shown that the intensity of the helical Bragg reflection decreased strongly in the narrow range of $H \sim H_A$ near T_C [7]. This was interpreted as a new paramagnetic phase just below T_C provoked by the field. The AC susceptibility measurements under applied pressure have confirmed the presence of the A-phase [8]. Our study is aimed to demonstrate that not a new phase found by other techniques, but the helix reorientation takes place in the corresponding domain of the H–T phase diagram of MnSi.

2. Experimental

The single-crystal MnSi was chosen for the study. The crystallographic mosaicity is of order of 0.25°. The polarized SANS experiments were carried out at the SANS-2 scattering facility of the FRG-1 research reactor in Geesthacht (Germany). In the case of the scattering from helix with a long period, SANS geometry allows one to observe diffraction peaks in a range of small-angle scattering, provided that the Bragg condition is fulfilled.

Our goal was to study possible reorientation of the helix vector, k in magnetic field applied along the [1 1 1] direction. It is important to note that if the field is applied

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doi:10.1016/j.jmmm.2006.10.626

parallel to the [1 1 1] axis, then the three other ⟨1 1 1⟩ axes as well as three ⟨1 0 0⟩ axes are equivalent with respect to the field. On contrary, the axes [1 1 0], [1 0 1] and [0 1 1], which are inclined at about 35° to the field direction, are not equivalent to axes [1 −1 0], [1 0 −1] and [0 1 −1], which are perpendicular to the field. Therefore, different orientations of the crystal are needed to complete a picture of the reorientation process of the spin helix under applied field. For this purpose, we used two configurations with the neutron wave vector $\mathbf{k}_0$ directed along the [−1 1 0] axis (i) and along the [1 1 −2] axis (ii) of the MnSi single crystal. In these two cases, we can study different Bragg reflections, which lay in two different scattering planes perpendicular to the beam. In the first (i) case Bragg reflections with k parallel to [1 1 1], [1 −1 1], [1 1 0], and [0 0 1] may be observed. The second (ii) configuration allows one to detect reflections along [1 1 1] and [1 −1 0] axes.

3. Measurements

The magnetic structure of the MnSi is the left-handed helices, oriented along four ⟨1 1 1⟩ axes. Thus, four different domains coexist. The magnetic field dependence of the scattering intensity is shown in Fig. 1 for **k** along the [1 1 1] and [1 1 −1] axes (configuration (i)) and in Fig. 2 for **k** along the [1 1 1] and [1 −1 0] axes (configuration (ii)), at $T = T_C - 0.2 = 28.5$K. The intensity of the [1 1 1] reflex increases with the field, while the reflection at [1 1 −1] disappears at $H < H_{C1}$. Thus, we observe the reorientation of all helical domains toward the only [1 1 1] axis, which is parallel to the applied field. The intensity of the [1 1 1] reflection increases smoothly at $H > H_{C1}$, but it has a drastic feature at $H \sim 150$ mT, showing a "collapse" of the spiral structure along the [1 1 1] axis (Fig. 1). Instead, the

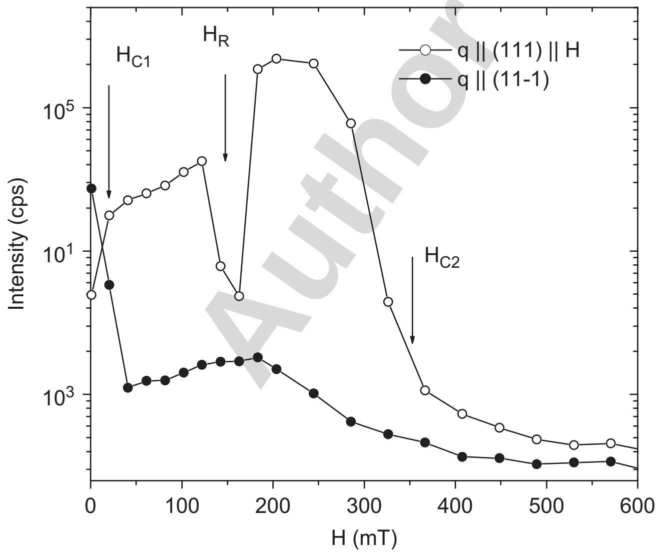

Fig. 1. Magnetic-field dependence of the Bragg intensity for $\mathbf{q} \| (1\,1\,1) \| \mathbf{H}$ and $\mathbf{q} \| (1\,1\,{-1})$ at $T = 28.5$K.

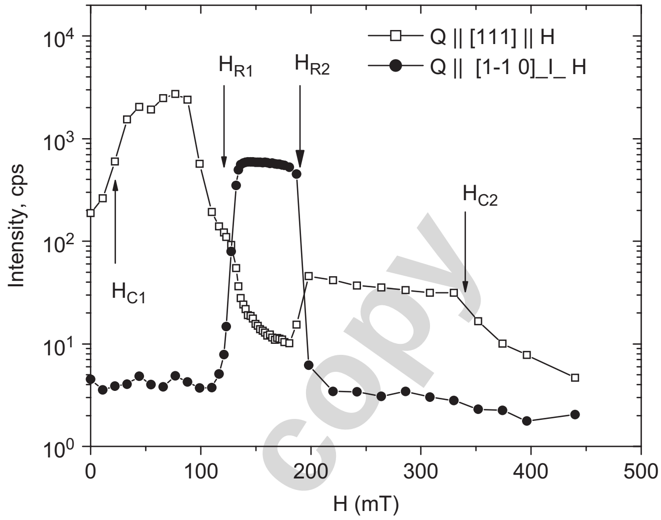

Fig. 2. Magnetic-field dependence of the Bragg intensity for $\mathbf{q} \| (1\,1\,1) \| \mathbf{H}$ and $\mathbf{q} \| (1\,{-1}\,0)$ at $T = 28.5$K.

Bragg reflection (1 −1 0) arises and remains constant within the range $130 < H < 180$ mT (Fig. 2).

Therefore, the "collapse" of the helix structure along [1 1 1] axis may be explained by the rotation of the helix wave vector, **k** from the direction parallel to the field $\mathbf{k} \| [1\,1\,1] \| \mathbf{H}$ to the direction perpendicular to the field $\mathbf{k} \| [1\,{-1}\,0] \perp \mathbf{H}$. No real "collapse" takes place and no real new phase, a so-called A-phase, occurs. With further increase of the field, the spiral structure reappears in the [1 1 1] direction and dissolves in the [1 −1 0] direction. At $H = H_{C2} \approx 350$ mT, the intensity of the Bragg reflections decreases to the background level. This implies transformation from the helical to the ferromagnetic structure. As to the [1 1 −1] axis (Fig. 1), a weak critical-like scattering is still observed at the place of the former Bragg peak. The intensity of this scattering is maximal at $H \sim 150$ mT.

4. Conclusion

Thus, we observe the 90°-reorientation of the spin helix from the [1 1 1] axis to the [1 −1 0] axis under magnetic field $H \sim 150$ mT applied along [1 1 1] in the close vicinity to T_C. In the previous studies [7,8], this was wrongly interpreted as appearance of a new phase. Our results show that not a new phase but helix reorientation occurs in this domain of the phase diagram.

Acknowledgments

The work was partly supported by the joint Russian–Japanese project RFBR 05-02-19889 and 04-02-16342.

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