Experimental report

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Title: Quantum fluctuations of the spin spiral in Fe-doped MnGe

Research area: Physics

This proposal is a new proposal

Main proposer: Sergey GRIGORYEV

Experimental team: Sergey GRIGORYEV
Evgeniy ALTYNBAEV
Alexander SUKHANOV
Vadim DIADKIN
Sven-Arne SIEGFRIED

Local contacts: Dirk HONECKER

Samples: MnFeGe

Instrument	Requested days	Allocated days	From	To
D11	5	4	22/10/2015	26/10/2015

Abstract:

MnSi and other transition monosilicides, the cubic helimagnets with Dzyaloshinskii-Moriya
interaction (DMI) have attracted significant attention during the last time. The magnetic chirality in these systems is determined by the signs of the DM interaction. The helix direction is fixed along the <111> direction by the anisotropic exchange interaction. For MnSi a quantum phase transition (QPT) exhibit under a pressure pc or a critical amount of Mn-atoms substituted by Fe-atoms into the MnSi. The pure MnGe and FeGe are helically ordered but show very different properties. The aim of this proposal is to determine the temperature and magnetic-field evolutions of the magnetic spiral structure for samples Mn1−xFexGe compounds with a Fe-doping around x = 0.4. We plan to study the nature of the spiral fluctuations observed earlier at low (T < 80 K) and high (T > 80 K) temperature ranges. We will also investigate the effect of magnetic field on their size, shape and stability in the magnetic fields (up to 5T).

Quantum fluctuations of the spin spiral in Fe-doped MnGe.

S. V. Grigoriev,[1,2] E. Altynbaev,[1,2] D. Chernyshov,[3] V. Diadkin,[3] D. Menzel,[4] and S.-A. Siegfried[5]

[1] *Petersburg Nuclear Physics Institute, Gatchina, St-Petersburg, 188300, Russia*
[2] *Saint-Petersburg State University, Ulyanovskaya 1, Saint-Petersburg, 198504, Russia*
[3] *Swiss-Norwegian Beamlines at the ESRF, Grenoble, 38000 France*
[4] *Technische Universität Braunschweig, 38106 Braunschweig, Germany*
[5] *Helmholtz Zentrum Geesthacht, Geesthacht, 21502, Germany*

I. INTRODUCTION

The cubic B20-type compounds (MnSi, etc) are well known for the incommensurate magnetic structures with a very long period appeared due to noncentrosymmetric arrangement of magnetic atoms. It is widely recognized that the helix spin structure is built on the hierarchy of interactions: ferromagnetic exchange interaction, antisymmetric Dzyaloshinskii-Moryia (DM) interaction, and the anisotropic exchange interaction [1, 2].

The polycrystalline samples of another B20 compound, $Mn_{1-x}Fe_xGe$, have been synthesized by high pressure method at the Institute for High Pressure Physics, Troitsk, Moscow, Russia. As it can be only synthesized under high pressure, the sample have a polycrystalline powder form with a crystallite size not less than a $10-100$ microns (see [3] for details). The X-ray powder diffraction confirmed the B20 structure of the samples used in experiments [4].

Since the magnetic system of $Mn_{1-x}Fe_xGe$ is ordered in a spiral spin structure in the whole concentration range of $x \in [0 \div 1]$ [5], we use the small angle neutron scattering (SANS) technique to investigate the evolution of the magnetic structure with x and temperature.

II. PERFORMED EXPERIMENT

The SANS measurements were carried out with neutrons with a mean wavelength of $\lambda = 0.6$ nm. The Sample-Detector distance of 2 m was set to cover the scattering vector range Q from 0.7 nm^{-1} to 2.7 nm^{-1} with the resolution equal to 0.1 nm^{-1}. The scattering intensity is measured upon zero field cooling from $T = 300$ K to the $T = 5$ K.

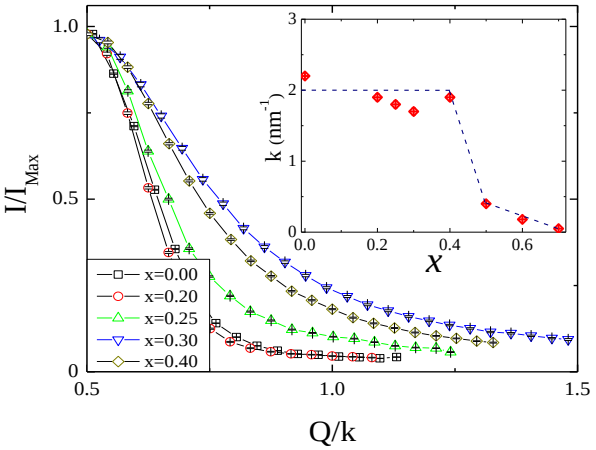

FIG. 1: (color online). Momentum transfer dependence of the scattering intensity at $T = 10$ K for different $Mn_{1-x}Fe_xGe$ compounds. The inset represents the x-dependence of the wave vector value k of the helical magnetic structure of $Mn_{1-x}Fe_xGe$ compounds with $x < 0.7$. Lines are the guide for the eyes.

III. RESULTS

The scattering intensity $I(\mathbf{Q})$ was radially averaged and plotted in Fig.1. For better comparison the intensity was normalized to its maximum I/I_{Max} and plotted in dependence on the scattering vector normalized to the helix wave vector value Q/k for all studied samples. The helical wave vector values k are presented in the inset in Fig.1 for $Mn_{1-x}Fe_xGe$ with $x < 0.7$. The helical structure with $k \sim 2$ nm^{-1} can be found in the concentration range $x < 0.4$. With further increase of Fe concentration, $x > 0.4$, the wave vector of the helix, k, decrease dramatically. That fact allows one to consider the critical concentration $x_{c2} = 0.40$ as a point where the helical structure based on effective RKKY exchange interaction is turning into the helimagnet based on DM interaction.

The scattering function (Bragg peak) of the

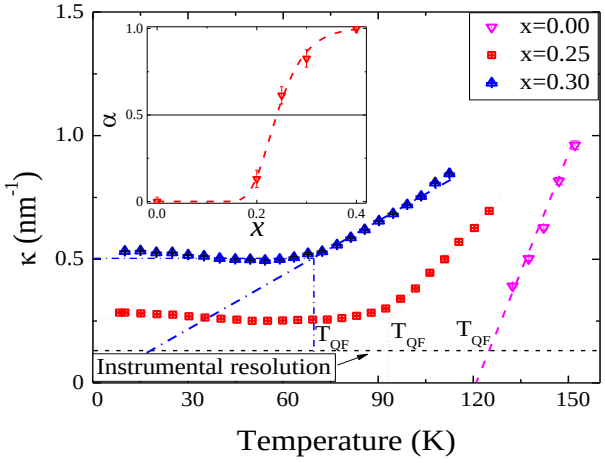

FIG. 2: (color online). Temperature dependence of the inverse correlation length of helical fluctuations, $\kappa = 1/\xi$, for $Mn_{1-x}Fe_xGe$ with $x = 0.0$, 0.25 and 0.3. The inset represents the x-dependence of the Lorensian α fraction in the scattering peak, which is associated to the fluctuated helical phase in $Mn_{1-x}Fe_xGe$ compound. The contribution of the stable helical phase into the scattering is equal to $(1-\alpha)$. Lines are the guide for the eyes.

MnGe can be well approximated by Gaussian (Fig. 1). The shape of the scattering function changes upon Mn replacement with Fe and can only be described by the pseudo-Voigt function with four different parameters: the scaling factor I_{Max}, the Lorentz fraction α, the peak position k and the width of both, Gaussian and Lorentzian functions κ. The fact that Bragg reflection is well described by the sum of Lorentzian and Gaussian functions with same width and peak position allows one to separate the fractions of helical fluctuations and stable helices in the compound [6]. The x-dependence of the Lorentz fraction α is presented in the inset in Fig. 2.

The fraction of SRO dominates over the fraction of the LRO at $x > 0.25$ (inset in Fig. 2) showing that the LRO of the stable helix disappears and is replaced by the SRO at low temperatures. We assume that the LRO of the helix structure is build on the main effective RKKY interaction and small DMI constant. The RKKY interaction decreases and DMI increases with x that leads to the quantum phase transition to SRO of the helix fluctuations at $x_c \approx 0.25$.

Another evidence of the competition between different interactions that built helical order is the evolution of the correlation length of the structure. The inverse correlation length κ is constant in the wide range of low temperatures for all studied compounds and then increases with temperature. The existence of two different temperature regimes implies the different states of the magnetic system: the thermal spin helix fluctuations, which change with temperature and different T-independent type of the SRO at low temperatures. We notify the crossover temperature of these two regimes as T_{QF}. The examples of such determination of the crossover temperatures T_{QF} are presented in Fig. 2 for $Mn_{1-x}Fe_xGe$ compounds with $x = 0.0$, 0.25 and 0.3. The helical fluctuations at temperatures far below T_N was observed even for the pure MnGe compound [6].

In summary, the results of this study allows one to assume the RKKY as the fundamental interaction for helical structure in MnGe. It could be concluded that there is a quantum order-disorder phase transition with x at $x_C = 0.25$. The DMI can be considered as an instrument for destabilization of the ordered helical structure with x or T, despite the fact that all $Mn_{1-x}Fe_xGe$ compounds crystallizes in B20 type structure.

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