Pis'ma v ZhETF, vol. 104, iss. 2, pp. 114 – 115

Magnetization of the $Mn_{1-x}Fe_xSi$ in high magnetic field up to 50 T: possible evidence of a field-induced Griffiths phase[1)]

S. V. Demishev [a,b 2)], A. N. Samarin[a,c], J. Huang[d], V. V. Glushkov[a,c], I. I. Lobanova[a,c], N. E. Sluchanko[a,c], N. M. Chubova[e], V. A. Dyadkin[e,f], S. V. Grigoriev[e,g], M. Yu. Kagan[b,h], J. Vanacken[d], V. V. Moshchalkov[d]

[a]Prokhorov General Physics Institute of Russian Academy of Sciences, 119991 Moscow, Russia

[b]National Research University Higher School of Economics, 101000 Moscow, Russia

[c]Moscow Institute of Physics and Technology, 141700 Dolgoprudny, Russia

[d]KU Leuven, Department of Physics and Astronomy, B-3001 Leuven, Belgium

[e]Petersburg Nuclear Physics Institute, 188300 Gatchina, Russia

[f]Swiss-Norwegian Beamlines at the European Synchrotron Radiation Facility, 38000 Grenoble, France

[g]Saint-Petersburg State University, 198504 St. Petersburg, Russia

[h]Kapitza Institute for Physical Problems of RAS, 119334 Moscow, Russia

Submitted 18 May 2016
Resubmitted 6 June 2016

DOI: 10.7868/S0370274X16140095

The essential fundamental questions concerning the nature of magnetism MnSi, FeSi and MnSi based solids remain unsolved. It was taken for granted during decades that magnetic properties of these materials may be adequately described with the help of an itinerant model, which assumes a crucial role of spin fluctuations together with distributed spin density in the unit cell [1]. In the case of $Mn_{1-x}Fe_xSi$ solid solutions this point of view contradicts to recent electron spin resonance (ESR) experiments and to observation of the Yosida-type magnetic scattering demonstrating localized character of magnetic moments in $Mn_{1-x}Fe_xSi$ [2–5]. However, for resolving the paradigm of the $Mn_{1-x}Fe_xSi$ magnetism based on localized magnetic moments (LMM), it is necessary to explain the reduced value of saturated magnetization (less than Bohr magneton μ_B per Mn ion) and to suggest consistent explanation of ESR and magnetic scattering experiments [3–5] together with specific features of the field and temperature dependences of magnetization $M(B,T)$ [6]. For this purpose, spin polaron phenomenological model was developed, where spin polaron represents a nanometer size quasi-bound state of itinerant electrons in the vicinity of manganese localized magnetic moments [3, 5, 6]. In order to make the right choice between the competing models of magnetism of $Mn_{1-x}Fe_xSi$, it is instructive to study magnetic properties in high magnetic fields. Indeed magnetic field may affect both spin fluctuations and spins alignment in spin polaron, so that analysis of the field and temperature dependences of magnetization $M(B,T)$ data may shed more light on the origin of the magnetism in this system.

To the best of our knowledge, the magnetization of substitutional solid solutions $Mn_{1-x}Fe_xSi$ has never been examined in a strong magnetic field. In the present work, we undertake the investigation of the magnetization in the paramagnetic phase of $Mn_{1-x}Fe_xSi$ with $x < 0.2$ in magnetic fields up to 50 T. Single crystals of $Mn_{1-x}Fe_xSi$ with $x < 0.2$ investigated in the present work were identical to those studied in [7]. Experiments in high magnetic field were carried out at KU Leuven pulsed field facility [8].

Field dependences of the magnetization are shown in Fig. 1. It is found [9] that in a weak magnetic field the magnetization follows Curie–Weiss law $M(B) = C \cdot B/(T-\theta)$. In a high magnetic field the power asymptotic $M(B) \sim B^\alpha$ is observed (Fig. 1b). In order to describe field-induced transformation of the Curie–Weiss linear dependence $M(B) \sim B$ into the power law $M(B) \sim B^\alpha$ the interpolating formula may be used

$$M(B) = \frac{C}{T-\theta}\frac{B}{[B/B_c(T)+1]^{1-\alpha}}$$

(see solid lines in Fig. 1a), where $B_c(T)$ denotes the crossover field, which may lie in the limits 1.5–7 T (arrows in Fig. 1a). In the considered case, the average value is $\langle\alpha\rangle = 0.38 \pm 0.04$.

The power asymptotics $M(B) \sim B^\alpha$, which are observed instead of saturated magnetization, are very

[1)]See Supplemental material for this paper on JETP Letters suit: www.jetpletters.ac.ru.

[2)]e-mail: demis@lt.gpi.ru

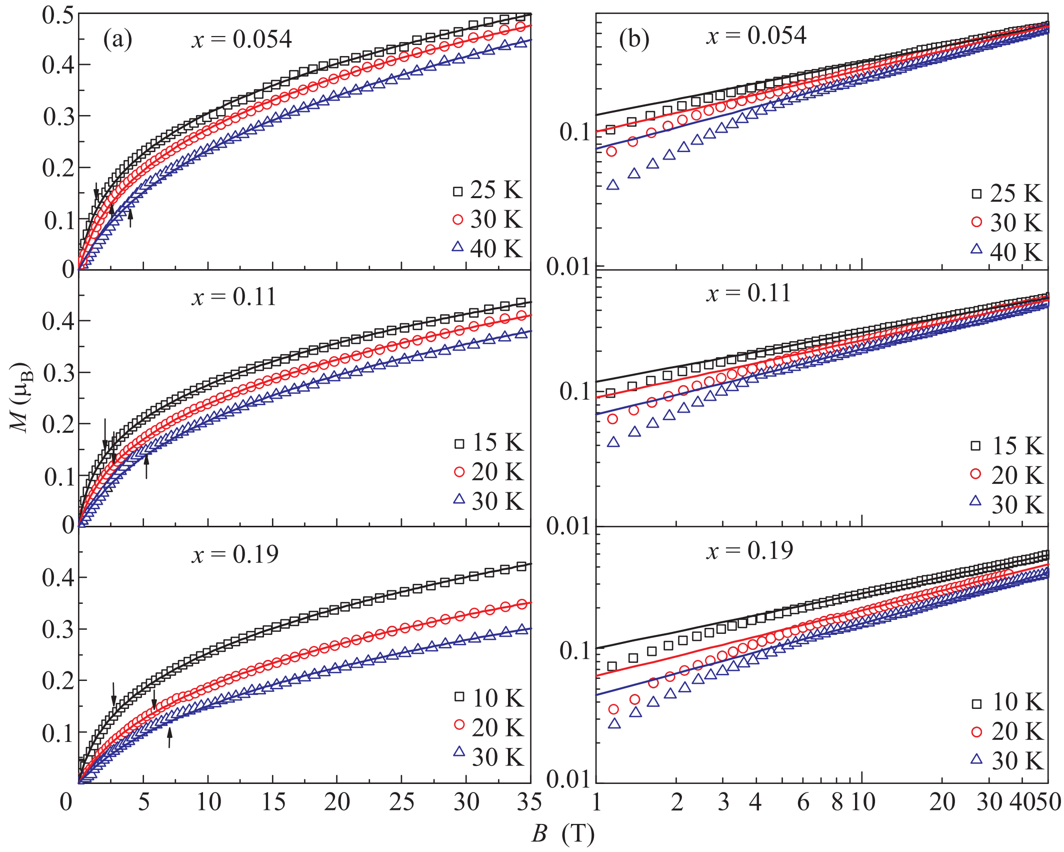

Fig. 1. (Color online) Magnetization field dependences for $Mn_{1-x}Fe_xSi$ in the units of Bohr magneton per Mn ion. Points in the panels (a, b) – experiment, lines in the panel (b) – best fit by the power law $M(B) \sim B^{\alpha}$, lines in the panel (a) – best fit with the help of interpolating formula. Arrows in the panel (a) denote crossover fields B_c

unusual. Existing theories predict the power law for magnetization when the system ground state is a Griffiths phase [10, 11]. This behavior may be expected in magnetically disordered spin-chain systems in the case $k_BT \ll \mu^*B$ with either ferromagnetic [11], or antiferromagnetic [10] interactions (here μ^* denotes the effective magnetic moment). The calculated values of the exponent α lie within limits $0.2 \leq \alpha \leq 0.6$ [10] or $1/3 \leq \alpha \leq 1/2$ [11] in agreement with the experimental data. However, in the studied case the asymptotic $M(B) \sim B^{\alpha}$ behavior is observed in three-dimensional case rather than in one-dimensional spin chain system. Nevertheless our theoretical analysis supports interpretation based on the possible formation of a field-induced Griffiths phase presumably caused by spin-polaron effects in LMM paradigm [9].

The authors are grateful to D.I. Khomskii for helpful discussions. This work was supported by programmes of Russian Academy of Sciences "Electron spin resonance, spin-dependent electronic effects and spin technologies", "Electron correlations in strongly interacting systems". The work at KU Leuven was supported by the Methusalem Funding by the Flemish Government. M. Yu. K. thanks the Program of Basic Research of the National Research University Higher School of Economics for support.

1. T. Moriya, *Spin Fluctuations in Itinerant Electron Magnetism*, Springer-Verlag, N.Y., Tokyo (1985).
2. S. V. Demishev et al., Pis'ma v ZhETF **103**, 365 (2016).
3. S. V. Demishev et al., JETP Lett. **93**, 213 (2011).
4. S. V. Demishev et al., JETP Lett. **100**, 28 (2014).
5. S. V. Demishev et al., Phys. Rev. B **85**, 045131 (2012).
6. S. V. Demishev, T. V. Ishchenko, and A. N. Samarin, Low Temperature Physics **41**, 1243 (2015).
7. S. V. Demishev et al., JETP Lett. **98**, 829 (2013).
8. J. Vanacken, T. Peng, J. A. A. J. Perenboom, F. Herlach, and V. V. Moshchalkov, J. Low. Temp. Phys. **170**, 553 (2013).
9. S. V. Demishev et al., arXiv:1605.05519.
10. C. Dasgupta and S. Ma, Phys. Rev. B **22**, 1305 (1985).
11. D. S. Fisher, Phys. Rev. B **51**, 6411 (1995).

Full text of the paper is published in JETF Letters, v. 104-1.

DOI: 10.1134/S0021364016140022