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STUDY OF THE ELECTRON SPIN DYNAMICS IN MgB_2 SUPERCONDUCTOR BY MAGNETIC RESONANCE METHODS

PhD thesis

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BUTE
2005

Research Antecedents

The discovery of superconductivity in MgB_2 [Nagamatsu *et al.*, 2001] opens new fields for research. The observable isotop-effect [Hinks *et al.*, 2001] is a strong indication that the superconductivity is phonon-mediated. The high critical temperature and normal state (room temperature, ambient pressure) properties forecast the possibility of daily-using in research (e. g. superconducting magnet construction). The two-gap model described superconductivity in MgB_2, the exotic Fermi-surface [Choi *et al.*, 2002] give a whole new range of phenomena. The extension of BCS theory for two-gap superconductors has already arisen [Suhl *et al.*, 1959], the MgB_2 is the first material where it is observable.

The first suggestion of direct detection of spin-lattice relaxation time (T_1) was published in 1960 by Herve *et al.* [Herve *at al.*, 1960], through difficulties of realization there are just a few papers about it [Atsarkin *et al.*, 1995]. The spin-lattice relaxation time of MgB_2 is in the range of 4-20 ns, it is not directly measurable by other known and current magnetic resonance methods (e. g. spin-echo, ***E****lectron-****N****uclear* ***Do****uble* ***R****esonance*: ENDOR).

Objectives

During my PhD work I studied the temperature and magnetic field dependence of density of states in MgB_2 by **E**lectron **S**pin **R**esonance method. The electronic spin susceptibility was measured by 3.8, 9.4 and 35 GHz microwave excitation. The measurements confirm that a large part of the density of states is restored at low temperatures at fields below 1 T. The goal of spin susceptibility measurements was the study and comparison of theoretical results [Choi *et al.*, 2002] to experimental datas.

The developed new method (LOD-ESR) [Murányi *et al.*, 2004] is suitable to detect spin-lattice relaxation times in the range of 2-80 ns contrary to current magnetic resonance methods. The spin-lattice relaxation time of MgB_2 in its superconducting state is inside this range, we were able to detect the relaxation time.

Methods

During my PhD work I applied Electron Spin Resonance method to study the electronic spin susceptibility in MgB_2. To detect the spin-lattice relaxation time I developed a new, less current method called Longitudinally Detected ESR.

New scientific results

I. I have developed a Longitudinally Detected Electron Spin Resonance (LOD-ESR) spectrometer operating at 9 and 35 GHz microwave excitation. The spectrometer is suitable to direct detection of electron spin-lattice relaxation time in the range of 2-80 ns, between 2 and 300 K. The probe-heads allow to run ESR and LOD-ESR measurements. I tested the spectrometer by Rb_1C_{60} fulleride which has a known spin-lattice relaxation time.

[1] Murányi, F., F. Simon, F. Fülöp, A. Jánossy, J. Magn. Res. **167**, 221 (2004)
[2] Simon, F., F. Murányi, *cond-mat/0409051* (2004)

II. I applied a novel method to study the MgB_2 superconductor which is unused in the investigation of superconducting materials. ESR experiments were done on MgB_2 superconductor in the range of 3-300 K at different magnetic fields from 0.14 T up to 8.1 T at the corresponding microwave frequencies from 3.8 GHz up to 225 GHz both in the normal and in the superconducting state. The magnetic field and the temperature dependence of the linewidth, the resonance field and the intensity of the resonance confirm that the resonance arises from the spins of conductive electrons.

[3] Simon, F., A. Jánossy, T. Fehér, F. Murányi, S. Garaj, L. Forró, C. Petrovic, S. L. Bud'ko, G. Lapertot, V. G. Kogan, P. C. Canfield, Phys. Rev. Lett. **87**, 047002 (2001)
[4] Simon, F., A. Jánossy, T. Fehér, F. Murányi, S. Garaj, L. Forró, C. Petrovic, S. Bud'ko, R. A. Ribeiro, P. C. Canfield, *cond-mat/0302620* (2003)

III. The results of conducting electron spin resonance experiments confirm that the upper critical field (H_{c2}) in MgB_2 is strongly anisotropic and lies between ~2.5 T and at least 13 T depending on the magnetic field orientation.

[3] Simon, F., A. Jánossy, T. Fehér, F. Murányi, S. Garaj, L. Forró, C. Petrovic, S. L. Bud'ko, G. Lapertot, V. G. Kogan, P. C. Canfield, Phys. Rev. Lett. **87**, 047002 (2001)

IV. According to the magnetic field dependence of the intensity of conduction electron spin resonance the two-gap model interprets the observed behavior only qualitatively. The magnetic field dependent behavior of the density of states demands a more sophisticated model which takes into account the magnetic field.

[4] Simon, F., A. Jánossy, T. Fehér, F. Murányi, S. Garaj, L. Forró, C. Petrovic, S. Bud'ko, R. A. Ribeiro, P. C. Canfield, *cond-mat/0302620* (2003)

V. I applied successfully the realized new method (LOD-ESR) in the measurement of the spin-lattice relaxation time in MgB_2 both in the normal and the superconducting state. On the grounds of spin-lattice relaxation time measurements the upper critical field on the "π" Fermi surface sheets is $H_{c2}^{\pi} \leq 0.34$ T. Below T_c the electron spin-lattice relaxation time is longer than in the normal state. This result can not be interpreted by simple, qualitative theories like vortices are normal metal.

Publications related to my Ph. D. work:

[1] Murányi, F., F. Simon, F. Fülöp, A. Jánossy: *A longitudinally detected high-.eld ESR spectrometerfor the measurement of spin –lattice relaxation times,* J. Magn. Res. **167**, 221 (2004)

[2] Simon, F., F. Murányi: *ESR spectrometer with a loop-gap resonator for cw and time resolved studies in a superconducting magnet, cond-mat/0409051* (2004)

[3] Simon, F., A. Jánossy, T. Fehér, F. Murányi, S. Garaj, L. Forró, C. Petrovic, S. L. Bud'ko, G. Lapertot, V. G. Kogan, P. C. Canfield: *Anisotropy of Superconducting MgB_2 as Seen in Electron Spin Resonance and Magnetization Data,* Phys. Rev. Lett. **87**, 047002 (2001)

[4] Simon, F., A. Jánossy, T. Fehér, F. Murányi, S. Garaj, L. Forró, C. Petrovic, S. Bud'ko, R. A. Ribeiro, P. C. Canfield: *Magnetic Field Induced Density of States in MgB2: Spin Susceptibility Measured by Conduction Electron Spin Resonance*, *cond-mat/0302620* (2003)

Presentations related to my Ph. D. work:

[1] F. Murányi, F. Simon, F. Fülöp, A. Jánossy :**Development of a longitudinally detected high-field ESR spectrometer for the measurement of spin-lattice relaxation times** AMPERE 2002, 31st Congress Ampere Magnetic Resonance and Related Phenomena, Adam Mickiewicz University, Poznan, Poland, 14-19 July 2002

[2] F. Murányi, F. Simon, F. Fülöp, A. Jánossy: **Longitudinally detected high-field ESR spectrometer for the measurement of spin-lattice relaxation times, application to Rb_1C_{60} and MgB_2** EPR and NMR at High Field: Applications to Magnetic Systems and Superconductors, Satellite Conference of the ICM 2003: Pisa, Italy, 23-25 July 2003

[3] F. Murányi, F. Simon, F. Fülöp, A. Jánossy: **Spin relaxation in the superconductor, MgB_2** Electron Paramagnetic Resonance at High Field and High Frequency: Technology and Applications, Leiden, Lorentz Center, 10-12 May 2004

[4] F. Murányi, F. Simon, F. Fülöp, A. Jánossy: **Spin-lattice relaxation time, T1, in the superconductor, MgB_2** Study of non-common metals of practical interest: ESR investigations, Workshop, EPF Lausanne, 10-11 June 2004

[5] F. Murányi, F. Simon, F. Fülöp, A. Jánossy: **Spin relaxation in the superconductor, MgB_2** LEES 2004, Kloster Banz, Germany, 18-23 July 2004

[6] F. Murányi, F. Simon, A. Jánossy: **Spin susceptibility (χ_S) and spin-lattice relaxation time (T_1) in the superconductor, MgB_2** "Electron-Electron Interactions in Solids" Seminar 2004, Ráckeve, Hungary, 29 August-2 September 2004

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[1] F. Simon, A. Jánossy, F. Murányi, T. Fehér: *Magnetic resonance in the antiferromagnetic and normal state of $NH_3K_3C_{60}$*, Phys. Rev. B **61**, 3826 (2000)

[2] F. Fülöp, T. Fehér, F. Simon, F. Murányi, A. Kiss, G. Oszlányi, S. Pekker, A. Jánossy, L. korecz, A. Rockenbauer: *High frequency electron spin resonance spectroscopy* Research News, Technical University of Budapest **2**, 27 (1999)

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