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Nuclear magnetic relaxation in impure magnetic materials

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1. Introduction

The strong hyperfine interactions and magnetic ordering in electron spin system cause main features of NMR in magnetic materials [1]. As a result, the NMR frequency depends on the valent state of ion to which resonance nucleus belongs. The heterovalent impurities can change the valency of lattice ions and the NMR frequency can be changed too. Let us consider a situation, when the ion of changed valency migrates from one lattice position to another. For a fixed position this means the NMR frequency depends on a time. It is known that stochastic modulation of resonance frequency gives a contribution into transverse relaxation time [1]. Such relaxation mechanism has been observed experimentally in magnetic materials (see f.e. [2]).

On the other hand, the dipole and Suhl-Nakamura interactions are sensitive to the resonance frequency. As a result, the changing valency can modulate nuclear interactions. We analyze here the influence of changing valency on nuclear magnetic relaxation in magnetic materials with low concentration of impure ions.

2. Theory

Let us consider the system of two spins $I$and S. The Hamiltonian of system can be divided into main Hamiltonian $H_0$and interaction Hamiltonian H_d:

$$H_0 = -\omega_I I_Z - \Delta(t) S_Z \quad . \tag{1}$$

$$H_d = 2d(2I_Z S_Z - I_X S_X - S_Y I_Y) \tag{2}$$

Here $\omega_I$is the NMR frequencies of nucleus I, d- dipolar interaction constant. The resonance frequency$\Delta(t)$ of nucleus$S$ is the stochastic function of a time and can be equals to ω_S (ion of changed valency) or ω_I(ion of "normal" valency). The low concentration of impurities means here the time-independent resonance frequency of spin I.

Using the standard procedure [1] we have obtained the following expressions for spin-lattice (T_1^{-1}) and spin-spin (T_2^{-1}) relaxation rates

$$T_1^{-1} = \frac{\Omega}{\omega_I^2 + \Omega^2} d^2, \tag{3}$$

$$T_2^{-1} = \frac{\omega_I}{\omega_I^2 + \Omega^2} d^2. \tag{4}$$

Where $\Omega = ((\omega_I - \omega_S)/2)^2 \tau_c$ and τ_c is the correlation time for resonance frequency fluctuation of spin S.

3. Discussion

As it follows from (3), (4), the proposed model describes the contribution of changing valency effects into both transverse and longitudinal nuclear relaxation. Really, if the ion to which nucleus Sbelongs has a "normal" valency, interaction Hamiltonian H_d commutate with Hamiltonian H_0. If this ion changes valency (i.e. $\Delta = \omega_S$), only $I_z S_z$member of H_d commutates with H_0. So, the changing valency modulates both secular and non-secular interactions.

For a case of Suhl-Nakamura interactions the Hamiltonian depends on a time

$$H_{SN} - V(t)(I_X S_X + S_Y I_Y). \tag{5}$$

Where $V(t) = V$, if $\Delta(t) = \omega_I$ and $V(t) = 0$, if $\Delta(t) = \omega_S$. The changing valency modulates secular interaction and can give a contribution into transverse nuclear relaxation only.

4. Conclusion

The proposed model can be applied to the NMR relaxation in YIG films, where both transverse and longitudinal relaxation rates depend on concentration of magnetic nuclei [3]. The un-controled technological impurities which appears during film grows is a source of changing valency. On the other hand, longitudinal relaxation rate depends on nuclear interaction constant. As a result, the increase of magnetic nuclear concentration results in the increasing of longitudinal relaxation rate (3) such well as the increasing of transverse relaxation rate (4).

References

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