Report : Strain dependence on exchange interaction February 22, 2018

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1 Introduction

In this report we discuss the strain dependence of the exchange interaction. We present the theory that describe the energy and the field of the exchange interaction (see section 2). We introduce the strain dependence on these equations and we predict some results.

We conclude by a proposition of the new tasks regarding this specific interaction.

2 Theory

The energy of the exchange interaction in a ferromagnet can be represented by [1]

$$U_{\text{ex}} = U_{\text{ex},0} + U_{\text{ex,NU}} \tag{1}$$

where $U_{\text{ex},0}$ is the exchange energy when the magnetization is uniform and $U_{\text{ex,NU}}$ is responsible for the change of the exchange energy when the magnetization is non-uniform. The first term of Eq. (1) can be written

$$U_{\text{ex},0} = \frac{1}{2}\mathbf{M}\overleftrightarrow{\Lambda}\mathbf{M} \tag{2}$$

with the magnetization $\mathbf{M}$ and the exchange tensor $\overleftrightarrow{\Lambda}$.

The second term of Eq. (1) can be written

$$U_{\text{ex,NU}} = \frac{1}{2}\sum_{p=1}^{3}\sum_{s=1}^{3} q_{ps}\frac{\partial \mathbf{M}}{\partial x_p}\frac{\partial \mathbf{M}}{\partial x_s} \tag{3}$$

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where q_{ps} are the components of a tensor $\overleftrightarrow{q}$.

The effective field is a functional derivative (or variational derivative) of the energy by the magnetization vector

$$H_{\mathbf{eff}} = -\frac{\delta U}{\delta \mathbf{M}} = -\frac{\partial U}{\partial \mathbf{M}} + \sum_{p=1}^{3} \frac{\partial}{\partial x_p} \left[\frac{\partial U}{\partial \left(\partial \mathbf{M} / \partial x_p \right)} \right] \tag{4}$$

with the total free energy U. Using Eqs. (3) and (4) we obtain the contribution of the exchange interaction to the effective field

$$\mathbf{H}_{\text{ex}} = \mathbf{H}_{\text{ex},0} + \mathbf{H}_{\text{ex,NU}} \equiv \overleftrightarrow{\Lambda} \mathbf{M} + \sum_{p=1}^{3} \sum_{s=1}^{3} q_{ps} \frac{\partial^2 \mathbf{M}}{\partial x_p \partial x_s} \tag{5}$$

So now, let's consider the case of an isotropic ferromagnet, it implies that Λ and q are scalars. We write $q = D$. We also consider the equation only for the x-direction. The Eq. (5) becomes

$$\mathbf{H}_{\text{ex}} = \Lambda \mathbf{M} + D \frac{\partial^2 \mathbf{M}}{\partial x^2}. \tag{6}$$

We write the magnetization vector as a Fourier series

$$\mathbf{M} = \mathbf{M}_0 + \sum_{n=0}^{N} \mathbf{M}_n \left(t \right) \cos \left(k_n x \right) \tag{7}$$

where $\mathbf{M}_0$ is the steady states of the magnetization vector, $\mathbf{M}_n$ is the n-th order of the magnetization vector and k_n is the wavevector of the n-th magnetic order. It is obvious that $\mathbf{M}_n \ll \mathbf{M}_0$. Substitutes Eq. (7) into the non-uniform part of Eq. (6) we obtain

$$\mathbf{H}_{\text{ex,NU}} = D \frac{\partial^2 \mathbf{M}}{\partial x} = -D \sum_{n=0}^{N} k_n^2 \mathbf{M}_n^2 \cos \left(k_n x \right). \tag{8}$$

The lossless Landau-Lifshitz-Gilbert equation is defined by

$$\frac{\partial \mathbf{M}}{\partial t} = -\gamma \mathbf{M} \times \mathbf{H}_{\text{eff}} \tag{9}$$

with γ is the gyromagnetic ratio. We consider only the contribution of the exchange interaction when the magnetization is non-uniform. Adding Eq. (8) into Eq. 9 we obtain

$$\frac{\partial \mathbf{M}}{\partial t} = -\gamma D \mathbf{M} \times \frac{\partial^2 \mathbf{M}}{\partial x^2} \tag{10}$$

Let's consider that $\mathbf{M} \sim \exp \left(i \omega t \right)$ and that the exchange constant D is modified by the propagation of a strain. It is easy to imagine that since the distance between two atoms change when a strain is propagating that the exchange interaction. It implies that $D(t,x)$.

3 Conclusion

List of abbreviations

Landau-Lifschitz-Gilbert	$\Longrightarrow$	LLG
Ferromagnetic resonance	$\Longrightarrow$	FMR

References

[1] A. G. Gurevich and G. A. Melkov, *Magnetization oscillations and waves*. CRC press, 1996.