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Energy eigenstates for magnetostatic oscillations in thin-film ferrrite disks

E.O. Kamenetskii*, R. Shavit, M. Sigalov

Department of Electrical and Computer Engineering, Ben Gurion University of the Negev, Beer Sheva 84105, Israel

Abstract

The confined effects for magnetostatic (MS) oscillations in normally magnetized thin-film ferrite-disk resonators demonstrate unique properties. The atomic-like character of the experimental MS spectra in such particles shows that the energy of a source of a DC bias magnetic field is absorbing ''by portions''. In this paper we give the energy spectrum calculations for MS oscillations in a ferrite disk. The oscillating system can be described as a collective motion of quasi-particles—the ''light magnons'' (lm). Discrete energy levels of ''lm'' are shown. Effective masses of ''lm'' are analyzed.

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Keywords: Magnetic oscillations; Confined phenomena; Discrete energy spectrum

1. Introduction

The confinement phenomena affect the dynamic properties of magnetic oscillations to a large extent. Recently, new results of strongly spatially localized spin wave modes have been shown (see, e.g., Ref. [1]). These results, however, do not demonstrate any energy spectrum properties of a whole ferrite-particle system. In a series of well-known experiments the confined effects for magnetostatic (MS) oscillations in normally magnetized thin-film ferrite disks demonstrate very unique properties. The δ-functional (atomic-like) character of the multi-resonance MS spectra, one can observe experimentally in such resonators, leads to a clear conclusion that the energy of a source of a DC bias magnetic field is absorbing ''by portions'' or discretely, in other words. Evidently, there should be a certain inner mechanism of quantization of the DC energy absorbed by a small disk-form ferrite sample. It was shown recently [2] that MS oscillations in a normally magnetized ferrite-disk resonator are described by the Schrödinger-like equation for MS-potential wave function and absorption peaks can be characterized by a discrete spectrum of energy levels. In this paper we give the results of energy spectrum calculations for MS oscillations in a ferrite-disk resonator. Because of discrete energy eigenstates resulting from structural confinement, one can describe the oscillating system as a collective motion of quasiparticles—the ''light magnons'' (lm).

2. Energy spectral problem for MS oscillations

MS oscillations are described by scalar wave function ψ. For MS waves propagating along z-axis in an axially magnetized ferrite rod one has [3]

$$a^{(1)}(z)\frac{\partial^2\psi(z,t)}{\partial z^2}+a^{(2)}(z)\psi(z,t)=\frac{\partial\psi(z,t)}{\partial t}. \qquad (1)$$

This is the Schrödinger-like equation. Coefficients $a^{(1)}$ and $a^{(2)}$ are imaginary quantities. In a normally magnetized ferrite-disk resonator with a small thickness–to–diameter ratio, the monochromatic MS-wave potential function ψ is represented as [2]

$$\psi=\sum_{p,q}A_{pq}\tilde{\xi}_{pq}(z)\tilde{\varphi}_q(\rho,\alpha), \qquad (2)$$

*Corresponding author. Tel.: +972-8-6472407; fax: +972-8-6472949.

E-mail address: kmntsk@ee.bgu.ac.il (E.O. Kamenetskii).

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where A_{pq} is an MS mode amplitude, $\tilde{\xi}_{pq}(z)$ and $\tilde{\varphi}_q(\rho,\alpha)$ are dimensionless functions describing, respectively, "thickness" (z coordinate) and "in-plane", or "flat" (radial ρ and azimuth α coordinates) MS modes. For MS "flat" functions $\tilde{\varphi}$ in a ferrite-disk resonator one can formulate the energy eigenvaue problem [2]

$$\hat{F}_\perp \tilde{\varphi}_q = E_q \tilde{\varphi}_q, \tag{3}$$

where $\hat{F}_q$ is a two-dimensional, "in-plane", differential operator. The normalized energy of MS mode q is expressed as

$$E_q = \tfrac{1}{2} g\mu_0 (\beta_q)^2, \tag{4}$$

where g is unit dimensional coefficient.

In our description of MS oscillations we neglect the exchange interaction and the "magnetic stiffness" is characterized by the "weak" dipole–dipole interaction. Because of discrete energy eigenstates of MS-wave oscillations one can describe the oscillating system as a collective motion of quasi-particles—the "lm". An effective mass of the "lm" can be obtained based on juxtaposition of Eq. (1) with the Schrödinger equation for a free particle. For a monochromatic MS-wave mode, the "lm" effective mass is expressed as [3]

$$(m_{\text{eff}}^{(\text{lm})})_q = \frac{\hbar}{2}\frac{\beta^2}{\omega}. \tag{5}$$

This expression looks very similar to an effective mass of the ("real", "heavy") magnon for spin waves with the quadratic character of dispersion.

3. Calculation

To find the normalized average MS energy one should find the MS-wave propagation constants β_q. Since in an open ferrite disk with a small thickness/diameter ratio one can use separation of variables [2], the propagation constants are defined as solutions of a system of two equations characterizing MS mode propagation in a normally magnetized ferrite slab and in an axially magnetized ferrite rod. The graphical solutions of these equations are illustrated in Fig. 1. The solutions were obtained for the main "thickness mode" and different "in-plane (flat) modes" calculated for Bessel functions of orders $v = 1, 2, 3$ and with a number of radial variations (q numbers). Figs. 2 demonstrate the positions of quantities $E_q^{(\text{lm})}$—the normalized energies of the "lm" collection—corresponding to different "flat modes".

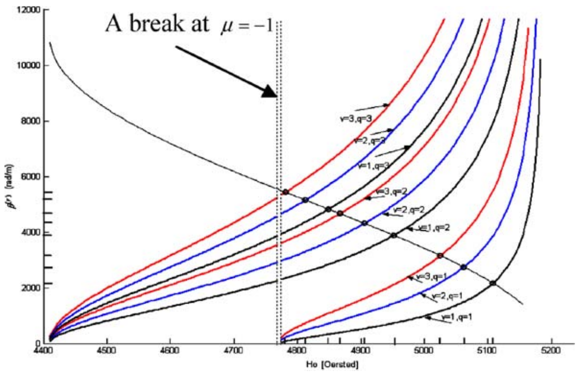

Fig. 1. The graphical solutions for the main "thickness" and different "flat" modes.

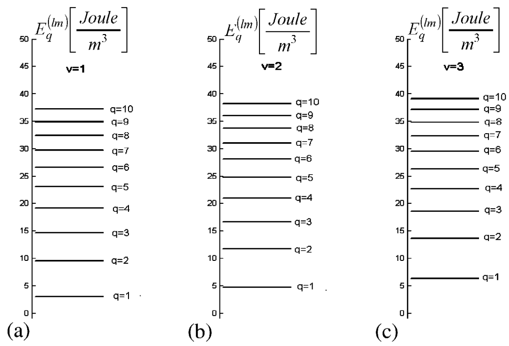

Fig. 2. The energy levels for different-type "lm" collections: (a) the energy levels for the dipole-type "lm" collection ($v = 1$), (b) the energy levels for the quadrupole-type "lm" collection ($v = 2$), and (c) the energy levels for the hexapole-type "lm" collection ($v = 3$).

4. Conclusion

Our analysis shows that a normally magnetized ferrite disk with MS-wave oscillating spectra can be considered as a macroscopically quantized system. Such "artificial magnetic atoms" can find a broad application for artificial materials and quantum computation.

References

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