The International Journal Of Engineering
And Science (IJES)
||Volume||2 ||Issue|| 2||Pages|| 40-47 ||2013
ISSN: **2319 – 1813** ISBN: **2319 – 1805**

Stokes/Anti Stokes Modes in Co/Copt Magnetic Recording Media

[1]Hadi Arabshahi, [2]Ali Bakhshayeshi, [3]Atefeh Shaabani, [3]Mina Mirzaee and [3]Sara Nobakht

[1]Physics Department, Payame Noor University, Tehran, Iran

[2]Department of Physics, Mashhad branch, Islamic Azad University, Mashhad, Iran

[3]Department of Physics,Khayyam institute of higher education, Mashhad, Iran

Abstract

Here in this paper frequency dependence of Exchange spring Co/CoPt to the external field is being calculated by suggesting a random exchange approach to the exchange bias problem. The film is modeled as a finite series of layers. Each layer has infinite array of dipoles of spin S arranged on a square lattice. The FM/AFM interface is suggested not to be completely perfect due to chemical intermixing and surface disorder at the interface. So, a magnetically disordered interface between F and AF layer is assumed to behave like spin glass system. So spin glass behavior is assumed to occur which incorporates the effect of interface roughness. This model will help us to estimate the strength of the interface exchange field. According to this model, the external magnetic field can influence on the reorientation of the CoPt/Co interface and bulk magnetization and thus the interface energy between the CoPt and Co layer varies with external field. The experimental evidence is recently being observed in anisotropic magneto resistance measurements, lending support to our proposal. The results of calculated spectra for scattering found in exchange-coupled CoPt/Co bilayers compared with the experimental data. Stokes/anti-Stokes frequencies difference and also Stokes/anti-Stokes peak intensity ratio and asymmetry in peak frequency between the Stokes and anti-Stokes spectra is described. There is a reasonable agreement between the theory presented and experimental data.

Key words : *spin glass, magnetic media, perpendicular magnetic recording*

Date of Submission: 28,January, 2013 — Date of Publication: 10, February 2013

I. Introduction

Exchange bias is commonly manifested as the hysteresis-loop shift observed when a FM is in contact with an AFMlayer across their common interface[1].Exchange bias has been studied in a variety of systems including nano particles, layered films and inhomogeneous materials. This effect is considered to be the basis of design and operation of spin valves, magnetic tunnel junctions, spin electronic devices and magnetic recording industry. A comprehensive understanding of exchange bias is a long-standing problem involving fundamental questions of surface and interface Magnetism [2-3]. There have been numerous studies about the magnetic behavior of FM/AFM bi layers [4–11]. One of the key issues that has emerged is the role of disorder and frustration. The results of the magnetization dynamics study could be explained with a model invoking the randomness of the coupling between AF and F layers which originates from the frustration of exchange interactions at the AF/F interface.

II. Model

Models of exchange bias have many properties in common with models of spin glasses and other random magnets[12-17]. Disorder may lead to randomness either in exchange interaction[4]or in anisotropy[17]which implies a strong connection to spin-glass-like behavior[4,5,12]. It is believed that there is enough experimental evidence to consider the interface between the AF/F layers as a disordered state behaving similar to a spin-glass system [12-23].Here in this paper the excitations of the long wavelength in exchange-coupled hard/soft CoPt/Co bilayers using is discussed using magnon scattering mechanism due to the roughness occurs at the interface. Frequency dependence of Exchange spring Co/CoPt to the external field is being calculated by suggesting a random exchange approach to the exchange bias problem. Frequency varies as a function of magnetic field via BLS experiment.The film is modeled as a finite series of layers. Each layer has infinite array of dipoles of spin S arranged on a square lattice. The FM/AFM interface is suggested not to be completely perfect due to chemical intermixing and surface disorder at the interface. So, a magnetically disordered interface between F and AF layer is assumed to behave like spin glass system. So spin glass behavior is assumed to occur which incorporates the effect of interface roughness. This model will help us to estimate the strength of the interface exchange field. According to this model, the external magnetic field can influence on the reorientation of the CoPt/Co interface and bulk magnetization and thus the interface energy between the CoPt and Co layer varies with external field. Interface disordered and magnetic roughness can provide a weak AF interface region. AF layer is assumed to contain two types of AF states: One part has a weak anisotropy and there is a competition among the different interactions between the moments. There is no single configuration of the spins which is uniquely favored by all interactions (frustrated). Another part has a large anisotropy with a collection of spins which remains in a frozen disordered state even at low-temperatures. The spin orientation ruled by the AF spins (frozen). A fraction of the frustrated interfacial spins do rotate almost in phase with the F spins.Spin glass system has partially random interactions. This partial random state will be introduced in our model as a reduced interfacial exchange energy (effective exchange-Jeff) which is the related to the frustrated and rotatable AF spins, SG interface, and some of F spins. The experimental evidence is recently being observed in anisotropic magneto resistance measurements, lending support to our proposal. The results of calculated spectra for scattering found in exchange-coupled CoPt/Co bilayers compared with the experimental data. Stokes/anti-Stokes frequencies difference and also Stokes/anti-Stokes peak intensity ratio and asymmetry in peak frequency between the Stokes and anti-Stokes spectra is described. There is a reasonable agreement between the theory presented and experimental data.

Spin wave excitations can be used as probes in order to determine magnetic properties at surfaces and buriedinterfaces[24]. Additionally, frequencies of long-wavelength spin waves can lie in the microwave region, and magneto static spin waves are of great importance for many high frequency signal processing technologies [25,26]. Most recently, spin wave excitations in confined geometries such as dots and wires [27] and spin wave propagation in non collinear magnetic structures [28-29] have become a focus of attention.Considering only long-wavelength region, S can be treated as a classical vector. Writing the Landau-Lifshitz equations of motion, welinearize these equations for small-amplitude oscillations. The equations can be solved in order to achieve frequency:

$$\mathrm{H} = -\sum_{\prec i,j \succ} J_{ij}\, \vec{S}_i \cdot \vec{S}_j + \mathrm{H}_{rand} - g\mu_B \sum_i H_{in}\left(\frac{S_{iz}}{S}\right)\vec{S}_i \cdot \hat{z}$$
$$- g\mu_B \sum_i (H_{Out} - 4\pi M_S)\left(\frac{S_{iy}}{S}\right)\vec{S}_i \cdot \hat{y} - g\mu_B H \sum_i \vec{S}_i \cdot \hat{z} \qquad (1)$$

Since theinterface is not completely perfect, it has a spin glass-like behavior. So, Site disorder and Rkky interactions can happen at the interface. These features can be replaced by a random set of bonds which satisfy a Gaussian distribution. According to this model there is no change in the randomness of spin sites and only the spin directions can vary. We write the Hamiltonian like this [30]:

$$\mathrm{H}_{rand} = -kT \sum_{S_i^\alpha} \exp\left[\sum_{i,j} \frac{1}{2}\left(\frac{\Delta}{kT} \sum_{\alpha=1}^{n} S_i^\alpha S_j^\alpha\right)^2\right] \qquad (2)$$

Interface random effective field can be written as:

$$\vec{H}_{eff}^{rand} = \frac{1}{N}\left(\frac{-1}{g\mu_B}\right)\frac{\partial \mathrm{H}_{rand}}{\partial S_i} \qquad (3)$$

$$\vec{H}_{eff}^{rand} = \frac{1}{N}\left(\frac{\Delta^2}{kT}\right)\left(\frac{S_i S_j}{g\mu_B}\right)(\vec{S}_j)\sum_{S_i^\alpha} \exp\left[\sum_{i,j} \frac{1}{2}\left(\frac{\Delta}{kT} \sum_{\alpha=1}^{n} S_i^\alpha S_j^\alpha\right)^2\right] \qquad (4)$$

And to the first order we have:

$$\vec{H}_{eff}^{rand} = \frac{1}{N}\left(\frac{\Delta^2}{kT}\right)\left(\frac{S_i S_j}{g\mu_B}\right)(\vec{S}_j)\ , \Delta_{eff} = \left(\frac{\Delta^2}{kT}\right)(S_i S_j) \qquad (5)$$

The effect of exchange can be eliminated by increasing randomness: when a layer is random it has a weaker exchange so the term of exchange in equation can be corrected like this: $\vec{H}_{eff}^{exch} = \vec{H}^{exch} - \vec{H}_{eff}^{rand}$ where

$$\vec{H}_{eff}^{rand} = \frac{1}{N}\left(\frac{\Delta_{eff}}{g\mu_B}\right)(\vec{S}_j) \qquad (6)$$

We calculate the parameter Δ_{eff} in equation (5) for long wave-lengths. The correction to equation (1) cannot be noticeable for the x and y directions: inlong wave-lengths S_x and S_y are small so the correction in equation (5) only effects on z direction:

$$\begin{cases}(S_{ix}S_{iy}=0),(S_{jx}S_{jy}=0)\\ (S_{iz}S_{jz}=S_iS_j)\end{cases} \rightarrow J_{eff-x}=j_x \;, J_{eff-y}=j_y \;, J_{eff-z}=j_z-\Delta_{eff} \qquad (7)$$

Adding this to the effective field inequation (1) we have:

$$\vec{H}_{eff}^{co} = \frac{1}{g\mu_B}\left(J_{co}\vec{S}_{co} + \frac{J_{eff}}{N_{co}}\vec{S}_{copt}\right) + H_{in}^{co}\left(\frac{S_{co-z}}{S_{co}}\right)\hat{z} + (H_{Out}^{co} - 4\pi M_{co})\left(\frac{S_{co-y}}{S_{co}}\right)\hat{y} \qquad (8)$$
$$+ H_{external}\hat{z} - 2\pi k_l d_{co} M_{co} Cos^2\theta\left(\frac{S_{co-x}}{S_{co}}\right)\hat{x} + 2\pi k_l d_{co}\left(\frac{S_{co-y}}{S_{co}}\right)\hat{y}$$

$$\vec{H}_{eff}^{copt} = \frac{1}{g\mu_B}\left(J_{copt}\vec{S}_{copt} + \frac{J_{eff}}{N_{copt}}\vec{S}_{co}\right) + H_{in}^{copt}\left(\frac{S_{copt-z}}{S_{copt}}\right)\hat{z} + (H_{Out}^{copt} - 4\pi M_{copt})\left(\frac{S_{copt-y}}{S_{copt}}\right)\hat{y} \qquad (9)$$
$$+ H_{external}\hat{z} - 2\pi k_l d_{copt} M_{copt} Cos^2\theta_k\left(\frac{S_{copt-x}}{S_{copt}}\right)\hat{x} + 2\pi k_l d_a\left(\frac{S_{copt-y}}{S_{copt}}\right)\hat{y}$$

The applied field polarizes the SG interface layer. Polarization of the FM layer and some of frustrated AF interfacial spins can be added to this polarization. These polarizations have a significant dependence on the applied field: At lower external fields, the effect of average random exchange is important. So, theFM/AFM interface has a spin- glass-like behavior. At higher external fields, magnetic field overcomes the average random exchange of the spin-glass-like interface and the interface moments would be aligned with the external field, and thus, the interface spin-glass behavior disappears. This means that Jeff which is affected by these polarizations, should be dependent to the external fieldso $J_{eff} = f(H_{ext})$. We use the derived effective field in the landau-lifshitz equations of motion as follows:

$$\frac{d\vec{M}}{dt} = \gamma \vec{M} \times \vec{H}_{eff} \quad (10)$$

For time dependent magnetization components in Co/CoPt system we take the magnetization components as:

$$M_x = M_{0x}e^{-i\omega t}$$
$$M_y = M_{0y}e^{-i\omega t} \qquad (11)$$
$$M_z = M_{0z}$$

Solving this equation with respect to the x and y components of magnetization, we will be able to obtain the frequency of magnons which is dependent to the magnetic properties of thin films. The obtained theoretical frequency is being compared with experimental ones.

III. Numericalresults

The material examined is a exchange spring bilayer which consists of 25nm of L10 CoPt with a <111> S out-of-plane and 16.7nm of Co with an HCP <0001> S out-of plane Texture[31]. The parameters are: $d_{Co} = 16.7\times10^{-7}Cm$ ، $d_{CoPt} = 25\times10^{-7}Cm$ ، $S_{CoPt} = 0.784\mu_B$ ، $S_{CoPt-z} = 0.784\mu_B$ ، $S_{Co} = 1.31\mu_B$ ، $S_{Co-z} = 1.31\mu_B$ $M_{CoPt} = 10053\ Oe$ ، $M_{Co} = 17593\ Oe$ ، $H_{in}^{Co} = 7143\ Oe$ ، $H_{Out}^{Co} = -6000\ Oe$ ،

$H_{in}^{CoPt}=106000\ Oe\ H_{Out}^{CoPt}=-38000\ Oe$ ، $\theta=\frac{\pi}{4}$ ، $J_{CoPt}=92.48\times10^{-15}erg$ ، $J_{Co}=45.6\times10^{-15}erg$

$k_l=1.2\times10^5 Cm^{-1}$

The calculations have been made for a SG like interface. The magnitude of exchange parameter at the interface is unknown to the investigatorsdue to the interface conditions but in some papers, the interfacial exchange coupling is assumed to be the average of the exchange coupling in the two bulkmaterials[9].In our model j_x, j_y, j_z can be dependent to the external field [8,9] and also Δ_{eff} :

During spin reversal, the SG interface layer and F spins reverse for the field $H_{ext}=-2505\ [Oe]$ so, two set of parameters used. One set is before spin reversal and the other is after that. We take the dependence of bout Δ and J_0 to be linear to external field:

$$J_0=\begin{cases}A_pH_{external}+B_p\ ,H_{ext}>-2505\ [Oe]\\ A_nH_{external}+B_n\ ,H_{ext}<-2505\ [Oe]\end{cases}\qquad(12)$$

The parameters A, B are chosen in order to have $J_0(H_{ext})$ average in the same order of $10^{-15}erg$ which is in agreement with speculations in[11].So we have: $A_p=4.64\times10^{-18}$ $B_p=3.19\times10^{-14}$ $A_n=1.97\times10^{-18}$ $B_n=-1.5\times10^{-14}$ For the term Δ_{eff} , it is noticeable that in the room temperature $kT=4.14\times10^{-14}erg$,So $\Delta_{eff}=(\frac{\Delta^2}{kT})(S_iS_j)\approx\frac{\Delta^2}{40\times10^{-15}}$ and Δ should be in the order of $10^{-15}erg$ for this model. So Δ and J_0 would be comparable:

$$\Delta=\begin{cases}C_pH_{ext}+D_p\ ,H_{ext}>-2505\ [Oe]\\ C_nH_{ext}+D_n\ ,H_{ext}<-2505\ [Oe]\end{cases}\qquad(13)$$

And we have: $C_p=-0.82\times10^{-18}$ $D_p=1.2\times10^{-14}$ $C_n=-0.62\times10^{-18}$ $D_n=-0.77\times10^{-14}$

Experimentally, the intensities of the peaks on the Stokes and anti-Stokes sides of the spectrum are nonequivalent [32].Relative intensities for the magnon lines contain important information about magnon properties [33-43].There are several physical effects which cause Stokes-anti-Stokes intensity ratio different from one. The main effect is related to the nonreciprocalpropagation behavior of surface magnons[34].For the magnetic field H into the page, the surface wave vector labeled +k, can only be supported for a top surface magnon. The bottom surface can support only -k. The propagation directions reverse for a reversal of the magnetic field. The amplitude of the surface magnon associated with one surface decays exponentially as one moves into the film with a decay length on the order of the in-plane propagation wavelength [35].

For the scattering geometry and the allowed surface magnon propagation directions discussed above, the scattering can only result in the creation of a surface magnon related to the top surface or the destruction of a magnon related to the bottom surface. The S/AS intensity ratio for the above situation will scale with the relative intensity of the top and bottom surface magnons at the top surface [35]. To a good approximation, this ratio is given by:

$$S/AS=\exp(2k_Md)\qquad(14)$$

Where d is the film thickness and k_M is the in-plane propagation wave number. If the field is reversed, the above expression then applies to the anti-Stokes/Stokes ratio (AS/S). Qualitative support for this model has come from the observed inversion of the S/AS ratio for a reversal in the direction of the magnetic field[36, 37].or the in-plane component of the incident light[38].This inversion has become the main test for surface magnons. The Stokes to anti-Stokes peak ratio for the model and experiment are compared in Figure. 1, for the film thickness, $d_{Co-CoPt}=41.7\times10^{-7}Cm$ and $k_M=1\times10^5 Cm^{-1}$.The calculations were found to be in agreement with experimental results.Damon–Eschbach surface modes are localized at one or the other surface of the Co film, depending on the direction of propagation and this is reflected by a frequency difference. The creation of a magnon results in a decrease in the frequencyof the scattered light(Stokes peak) and magnon destruction yields an increase in the frequency of the scattered light(anti-Stokes peak). The experimental frequency difference between the Stokes and anti-Stokes peaks is shown in Figure. 2[7]. The line is calculated from our model. There is a reasonable agreement between the experiment and the model.The dependence of frequency to the layerthickness is shown in Figure2. The results are in agreement with[6,32]. The thickness dependence of frequencies is plotted in figure 3. It is shown that the frequency decreases as thickness increase. It might be due to the omission of some volume modes of frequency when thickness decreases.

IV. Conclusion

On the basis of the experimental results, an approach to the problem of exchange bias is suggested. It relies on interacting magnetic defects at the interface. The roughness at the interface gives rise to a large fluctuating field because the FM magnetization interacts alternatively with one or the other AFM sublattice via atomic exchange coupling. The frequency of excitations of thin FM layer depends on the value of the interface coupling in interface areas of microscopic size. These excitation measurements may bring valuable information about the local value of the interface exchange coupling field and degree of interface roughness. In conclusion, a model has been developed which can calculate light scattering intensities from exchange-spring structures, Stokes/anti-Stokes frequency difference and also Stokes/anti-Stokes peak intensity ratio. The calculations were found to be in agreement with experimental results. The model is an approach to the microscopic understanding of exchange bias and has important implications for future experimental and theoretical work.

V. Acknowledgements

The Authors would like to thank Prof R. L. Stamps, Prof Ulrich Nowak and Prof Florin Radu for helpful discussions.

References

[1] Meiklejohn W.H. et al. (1956). New Magnetic Anisotropy. Phys. Rev. **102**1413. Doi:10.1103/PhysRev.102.1413, http://link.aps.org/doi/10.1103/PhysRev.102.1413
[2] Nogues J. et al. (1999). Exchange bias. JMMM **192** 203–232. Doi:10.1016/S0304-8853(98)00266-2, http://dx.doi.org/10.1016/S0304-8853(98)00266-2
[3] Berkowitz A. et al. (1999). Exchange anisotropy. JMMM **200**552–570. Doi:10.1016/S0304-8853(99)00453-9, http://dx.doi.org/10.1016/S0304-8853(99)00453-9
[4] Malozemoff A.P. et al. (1987). Random-field model of exchange anisotropy at rough ferromagnetic-antiferromagnetic interfaces.Phys. Rev. B **35** 3679 Doi:10.1103/PhysRevB.35.3679, http://link.aps.org/doi/10.1103/PhysRevB.35.3679
[5] Malozemoff A.P. et al. (1988). Heisenberg-to-Ising crossover in a random-field model with uniaxial anisotropy. Phys. Rev. B **37** 7673-7679 Doi:10.1103/PhysRevB.37.7673, http://link.aps.org/doi/10.1103/PhysRevB.37.7673
[6] Stamps R.L. et al. (1997). Influence of exchange-coupled anisotropies on spin-wave frequencies in magnetic layered systems: Application to Co/CoO. Phys. Rev. **54** (1997) 4159 Doi:10.1103/PhysRevB.54.4159, http://link.aps.org/doi/10.1103/PhysRevB.54.4159
[7] Crew D.C. et al. (2005). Light scattering from spin wave excitations in a Co/CoPt exchange spring. JMMM **290-291**530–532 Doi:10.1016/j.jmmm.2004.11.519, http://dx.doi.org/10.1016/j.jmmm.2004.11.519
[8] Almeida J.R.L. et al. (2006). On the field dependence of the interface energy in AF/FM bilayers. JMMM **302** 122–125 Doi:10.1016/j.jmmm.2005.06.033, http://dx.doi.org/10.1016/j.jmmm.2005.06.033
[9] Tang Y. (2006). Cooling field dependence of exchange bias in phase-separated $La_{0.88}Sr_{0.12}CoO_3$ J. Appl. Phys.**100**023914, Doi:10.1063/1.2219698, http://dx.doi.org/10.1063/1.2219698
[10] Keller J. et al (2002). Domain state model for exchange bias. II. Experiments. Physical Rev B **66**014431 Doi:10.1103/PhysRevB.66.014431, http://link.aps.org/doi/10.1103/PhysRevB.66.014431
[11] Livesey K.L. et al. (2006). Spin wave valve in an exchange spring bilayer Phys. Rev. B **73** 184432 Doi: 10.1103/PhysRevB.73.184432, http://link.aps.org/doi/10.1103/PhysRevB.73.184432
[12] Radu, F& Zabel, H. (2008). Magnetic Heterostructures. Springer, Berlin, Vol. 227, p.97
[13] J.I. Hong. et al. (2005). On the perpendicular anisotropy of Co/Pd multilayers. JMMM **285** 539-366 Doi:10.1016/j.jmmm.2004.07.054, http://dx.doi.org/10.1016/j.jmmm.2004.07.054
[14] Stamps R.L. et al. (2000). Mechanisms for exchange bias. J. Phys. D **33** R247 Doi:10.1088/0022-3727/33/23/201,http://dx.doi.org/10.1088/0022-3727/33/23/201

[15] Nowak U. et al. (2002). Domain state model for exchange bias. I. Theory. Phys. Rev. B **66** 014430 Doi: 10.1103/PhysRevB.66.014430, http://link.aps.org/doi/10.1103/PhysRevB.66.014430

[16] Fiorani D. et al. (2006). Glassy dynamics in the exchange bias properties of the iron/iron oxide nanogranular system. Phys. Rev. B**73** 092403 Doi: 10.1103/PhysRevB.73.092403, http://link.aps.org/doi/10.1103/PhysRevB.73.092403

[17] Holand, W & Beall, G. H. (2012). Glass Ceramic Technology. (2rd ed.). Wiley-American Ceramic Society

[18] Usadel K.D. et al. (2009). Exchange bias for a ferromagnetic film coupled to a spin glass Phys. Rev. B **80** 014418 Doi: 10.1103/PhysRevB.80.014418, http://link.aps.org/doi/10.1103/PhysRevB.80.014418

[19] Ohldag H. et al. (2003). Correlation between Exchange Bias and Pinned Interfacial Spins Phys. Rev. Lett**91** 017203 Doi: 10.1103/PhysRevLett.91.017203, http://link.aps.org/doi/10.1103/PhysRevLett.91.017203

[20] Camarero J. et al. (2003). Field dependent exchange coupling in NiO/Co bilayers Phys. Rev. B **67** 020413(R) Doi: 10.1103/PhysRevB.67.020413, http://link.aps.org/doi/10.1103/PhysRevB.67.020413

[21] Gruyters M. et al. (2005). Spin-Glass-Like Behavior in CoO Nanoparticles and the Origin of Exchange Bias in Layered CoO/Ferromagnet Structures Phys. Rev. Lett **95** 077204 Doi: 10.1103/PhysRevLett.95.077204, http://link.aps.org/doi/10.1103/PhysRevLett.95.077204

[22] Wang H. et al. (2004). Surface spin glass and exchange bias in Fe_3O_4 nanoparticles compacted under high pressure Phys. Rev. B **70** 092409 Doi: 10.1103/PhysRevB.70.092409, http://link.aps.org/doi/10.1103/PhysRevB.70.092409

[23] Gibert M. et al. (2012). Exchange bias in $LaNiO_3$–$LaMnO_3$ superlattices. Nature Mater**11** 195-198 Doi:10.1038/nmat3224, http://dx.doi.org/10.1038/nmat3224

[24] Puszkarski H. et al. (1994). Theory of interface magnons in magnetic multilayer films Surf. Sci. Rep. **20** 45 Doi:10.1016/0167-5729(94)90011-6,http://dx.doi.org/10.1016/0167-5729(94)90011-6

[25] Schloemann E. et al. (1988). Epitaxial Fe films on GaAs for hybrid semiconductor-magnetic memories. J. Appl. Phys. **63** (1988) 3140 Doi:10.1063/1.340868, http://dx.doi.org/10.1063/1.340868

[26] Camley R.E. et al. (1997). Theory of microwave propagation in dielectric/magnetic film multilayer structures. J. Appl. Phys. **82** 3058 Doi:10.1063/1.366144, http://dx.doi.org/10.1063/1.366144

[27] Astalos R.J. et al. (1998). Magnetic permeability for exchange-spring magnets: Application to Fe/Sm-Co. Phy. Rev. B **58** 8646 Doi:10.1103/PhysRevB.58.8646, http://link.aps.org/doi/10.1103/PhysRevB.58.8646

[28] Demokritov S.O. et al. (2001). Brillouin light scattering studies of confined spin waves: linear and nonlinear confinement. Phys. Rep**348** 441 Doi:10.1016/S0370-1573(00)00116-2, http://dx.doi.org/10.1016/S0370-1573(00)00116-

[29] Hertel R. et al. (2004). Domain-Wall Induced Phase Shifts in Spin Waves Phys. Rev. Lett. **93** 257202 Doi:10.1103/PhysRevLett.93.257202, http://link.aps.org/doi/10.1103/PhysRevLett.93.257202

[30] Mydosh J.A. (2007). Spin Glasses, Taylor & Francis

[31] Kim J. et al. (2003). $L1_o$-CoPt/Co bilayer ferromagnetic films: interdiffusion, structure and microstructure. Acta Mater. **51** 313. Doi:10.1016/S1359-6454(02)00302-6, http://dx.doi.org/10.1016/S1359-6454(02)00302-6

[32] Grimsditch G. et al. (1999). Exchange-spring systems: Coupling of hard and soft ferromagnets as measured by magnetization and Brillouin light scattering. J. Appl. Phys. **85**, Issue **8** 5901-5904 Doi:10.1063/1.369908, http://dx.doi.org/10.1063/1.369908

[33] Camley R.E. et al. (1981). Theory of light scattering by the spin-wave excitations of thin ferromagnetic films. Phys. Rev. B **23** 1226 Doi:10.1103/PhysRevB.23.1226, http://link.aps.org/doi/10.1103/PhysRevB.23.1226

[34] Damon R.W. et al. (1961). Magnetostatic modes of a ferromagnet slab I. Phys. Chem. Solids. **19** 308 Doi:10.1016/0022-3697(61)90041-5,http://dx.doi.org/10.1016/0022-3697(61)90041-5

[35] Moosmuller H. et al. (1991). Oscillations in the Stokes–anti-Stokes ratio in Brillouin scattering from magnons in thin permalloy films. J. Appl. Phys.**69**5721
Doi:10.1063/1.347898, http://dx.doi.org/10.1063/1.347898

[36] Sandercock J.R. et al. (1979). Light scattering from surface and bulk thermal magnons in iron and nickel. J. Appl. Phys. **50** 7784
Doi:10.1063/1.326763, http://dx.doi.org/10.1063/1.326763

[37] Malozemoff A.P. et al. (1979). Brillouin-scattering studies of polycrystalline and amorphous sputtered films of $Fe_{1-x}B_x$ and $Co_{1-x}B_x$. J. Appl.Phys. **50** 5885
Doi:10.1063/1.326685, http://dx.doi.org/10.1063/1.326685

[38] Grunberg P. et al. (1977). Light Scattering from Bulk and Surface Spin Waves in EuO
Phys. Rev. Latt. **39** 1561
Doi:10.1103/PhysRevLett.39.1561, http://link.aps.org/doi/10.1103/PhysRevLett.39.1561

[39] Cottam M.G. et al. (1972). Theory of dipole-dipole interactions in ferromagnets. III. Application to $GdCl_3$. J. Phys. C: Solid State Phys. **5** 2205.
Doi:10.1088/0022-3719/5/16/022,http://dx.doi.org/10.1088/0022-3719/5/16/022

[40] Marvakov D I. et al. (1985). The self-consistent theory of elementary excitations in systems with many-branch quasiparticle spectra (ferromagnetic semiconductor)
J. Phys. C: Solid State Phys. **18** 2871
Doi:10.1088/0022-3719/18/14/018, http://iopscience.iop.org/0022-3719/18/14/018/

[41] Camley R.E. et al. (1999). Magnetization dynamics in thin films and multilayers. JMMM **200** 583-597
Doi:10.1016/S0304-8853(99)00345-5, http://dx.doi.org/10.1016/S0304-8853(99)00345-5

[42] Camley R.E. et al. (1982). Stokes-anti-Stokes asymmetry in Brillouin scattering from magnons in thin ferromagnetic films. Phy. Rev. B **26**2609
Doi:10.1103/PhysRevB.2 6.2609, http://link.aps.org/doi/10.1103/PhysRevB.26.2609

[43] Cochran J.F. et al. (1988). Calculation of the intensity of light scattered from magnons in thin films. JMMM **73** 299-310
Doi:10.1016/0304-8853(88)90095-9, http://dx.doi.org/10.1016/0304-8853(88)90095-9

Figure Caption

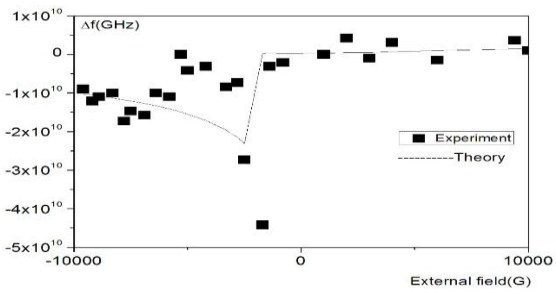

Figure1. Inversion of the S/AS ratio for a reversal in the direction of the magnetic field.
For the magnetic field H into the page, the surface wave vector labeled +k and the bottom
Surface can support only –k. The propagation directions reverse for a reversal of the magnetic field

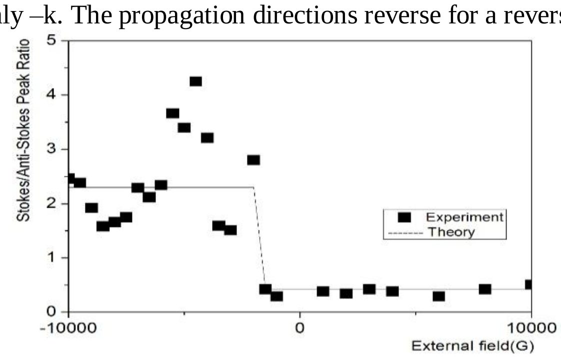

Figure2. Damon–Eschbach surface modes are localized at one or the other surface of the Co film, depending on the direction of propagation and this is reflected by a frequency difference.

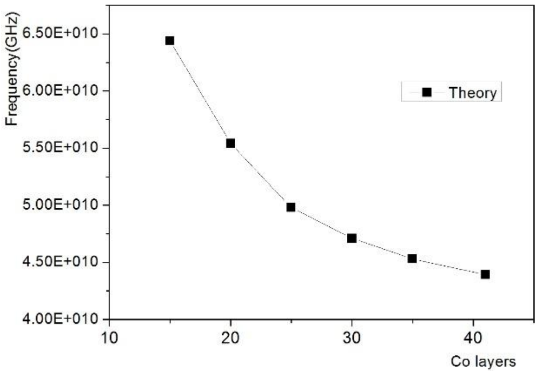

Figure 3. frequency to the layer thickness which is in agreement with [6, 32]