Heisenberg Exchange and Dzyaloshinskii–Moriya Interaction in Ultrathin Pt(W)/CoFeB Single and Multilayers

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We present results of the analysis of Brillouin light-scattering (BLS) measurements of spin waves performed on ultrathin single and multirepeat CoFeB layers with adjacent heavy metal layers. From a detailed study of the spin-wave dispersion relation, we independently extract the Heisenberg exchange interaction (also referred to as symmetric exchange interaction), the Dzyaloshinskii–Moriya interaction (DMI, also referred to as antisymmetric exchange interaction), and the anisotropy field. We find a large DMI in CoFeB thin films adjacent to a Pt layer and nearly vanishing DMI for CoFeB films adjacent to a W layer. Furthermore, the influence of the dipolar interaction on the dispersion relation and on the evaluation of the Heisenberg exchange parameter is demonstrated. Eventually, an experimental analysis of the impact of the DMI on the spin-wave lifetime is presented.

Index Terms—Brillouin light-scattering (BLS), Dzyaloshinskii-Moriya interaction (DMI), Heisenberg exchange, magnetic films, spin waves.

I. INTRODUCTION

MAGNETIC objects such as skyrmions and spin waves are envisaged to form the basis of a new generation of information storage and processing devices [1]–[3]. For the stabilization of skyrmions, the presence of an antisymmetric exchange contribution favoring a chiral alignment of spins is a crucial requirement [4]. As predicted by Dzyaloshinskii [5] and Moriya [6], low-symmetry systems can exhibit such a contribution to the exchange interaction. Hence, it can be especially pronounced in ultrathin magnetic films adjacent to a layer of a heavy metal. In this case, it is referred to as interfacial Dzyaloshinskii–Moriya interaction (DMI) (iDMI) [7] and can be measured using asymmetric domain expansion [8], asymmetric switching of triangles [9], or stripe domain annihilation [10], [11]. However, such methods require an additional determination or estimation of the symmetric exchange interaction since the strength of the iDMI cannot be determined independently of this parameter. In contrast, an investigation of spin waves allows for an independent determination of symmetric as well as the antisymmetric exchange interaction since they possess a spatial chirality making them sensitive to the presence of DMI. DMI and other material parameters can be traced by the characterization of the thermally populated spin-wave dispersion relation using Brillouin light-scattering (BLS) spectroscopy [12], [13].

At the same time, spin waves and their corresponding quasi-particles, magnons [14], have been employed in many prototype devices such as a magnon transistor [15], spin-wave majority gates [16], [17], and many others [18]–[21]. In this context, nonreciprocal spin-wave propagation as a consequence of DMI might constitute an interesting tool to boost the capabilities of spin-wave logic devices [22].

CoFeB (in various compositions) plays an important role in many spintronic applications such as MRAM [23] and devices based on the propagation of spin waves [24]. Its properties can be widely tuned by annealing [25], and it is easy to handle using sputtering techniques, rendering this alloy important for many applications. Heavy metals like Pt and W show a large spin-orbit coupling which, for example, leads to a large spin Hall angle [26] which is desirable for devices involving spin orbit torques [27].

In this work, we present measurements of the DMI strength in single-repeat and multirepeat systems of both Pt/CoFeB/MgO and W/CoFeB/MgO stacks using BLS spectroscopy. In particular, we employ wave vector-resolved BLS spectroscopy resulting in a direct measurement of the spin-wave dispersion relation. Considering the role of the symmetric and antisymmetric exchange interaction on the dispersion relation [28], [29], BLS spectroscopy allows for an independent determination of both exchange contributions. We find a pronounced iDMI in the Pt-based stack and nearly vanishing iDMI in the W-based system even though the symmetric exchange of both systems is found to be identical within the measurement errors.

II. SAMPLES

The investigated single-repeat samples consist of an underlayer (UL) of either Pt or W sputter-deposited onto a thermally oxidized Si substrate using a Singulus Rotaris deposition system. The full single-repeat stack is UL(5 nm)/
Co$_{20}$Fe$_{60}$B$_{20}$(0.6 nm)/MgO(2 nm)/Ta(5 nm) and it has been investigated as deposited. The corresponding multirepeat samples investigated in this work consist of 10 repetitions of UL(5 nm)/Co$_{20}$Fe$_{60}$B$_{20}$(0.6 nm)/MgO(2 nm), deposited onto a thermally oxidized Si substrate and finally capped with a 5 nm Ta layer using the same sputtering system.

The value of the saturation magnetization used in all calculations has been obtained by vibrating sample magnetometry (VSM) from a W(5 nm)/Co$_{20}$Fe$_{60}$B$_{20}$(0.6 nm)/MgO(2 nm)/Ta(5 nm) stack on an oxidized Si substrate. From this, we obtain $M_S = 1388$ kA/m. Concerning the $M_S$ value used here, we would like to point out that for CoFeB a maximum of $M_S = 1380$ kA/m has been found and, in particular, no dead layer could be identified both for annealed and as-deposited samples [30]. Thus, we do not expect to drastically underestimate the actual $M_S$ of the material by taking the above-mentioned value for the following calculations.

III. EXTRACTION OF EXCHANGE CONSTANS FROM THE SPIN-WAVE DISPERSION RELATION

For spin waves propagating perpendicular to the magnetization in in-plane saturated ultrathin films, the corresponding influence of the inDMI on the dispersion relation [28] can be described by a frequency shift linear in the spin-wave wave vector $\mathbf{k}$ [29], [31]. Hence, the frequency shift between spin waves with opposite wave vector is used to extract the DMI constant $D$

$$f(k)_{\text{asymp}} = \frac{|f(-k) - f(k)|}{2} = \frac{\gamma}{\pi M_S} D k.$$  

Here, $\gamma$ denotes the gyromagnetic ratio for which we take $\gamma = 176$ rad T$^{-1}$ s$^{-1}$. In case the DMI is of purely interfacial origin, the DMI constant $D$ can be related to the film thickness $t$ resulting in an interfacial DMI constant [13]

$$D_S = D t.$$  

It is noted in this context that the above expression for the frequency shift neglects any inhomogeneity of the magnetic parameters over the film thickness such as an inhomogeneous saturation magnetization or different surface anisotropies on the upper and lower surface which, principally, could also lead to a frequency non-reciprocity [33], [34]. However, as will be shown later, these effects are very small in the present case because of the ultrathin film thickness.

On the other hand, the average of the spin-wave frequencies for positive and negative wave vector leads to the symmetrized dispersion relation which can be employed to more precisely extract other sample properties

$$f(k)_{\text{sym}} = \frac{|f(-k) + f(k)|}{2} = \frac{\gamma \mu_0}{2\pi} \left[H_{\text{ext}} + \lambda_{\text{ex}} k^2 + M_S g(kt)\right]$$

$$\cdot \left(H_{\text{ext}} - H_U + \lambda_{\text{ex}} k^2 + M_S - M_S g(kt)\right)^{1/2}$$  

with the permeability of vacuum $\mu_0$, the film thickness $t$, and the uniaxial anisotropy field $H_U$ connected to the anisotropy constant $K_U$ via $\mu_0 H_U = 2K_U/M_S$. The influence of the symmetric exchange interaction is included in the exchange stiffness $\lambda_{\text{ex}} = 2A/(\mu_0 M_S^2)$ with the exchange constant $A$ and the dipole–dipole interaction is represented by the function

$$g(x) = 1 - \left[1 - \exp(-|x|)/|x| \right]$$  

with $x = k t$ a dimensionless parameter.

For the measurement of the spin-wave dispersion relation, BLS spectroscopy is employed, which is based on the inelastic scattering of photons with magnons. For this process, momentum as well as energy conservation laws hold [32]

$$\hbar k_{\text{out}} = \hbar k_{\text{in}} \pm \hbar k_{\text{sw}}$$

$$\hbar \omega_{\text{out}} = \hbar \omega_{\text{in}} \pm \hbar \omega_{\text{sw}}.$$  

Here, (in) and (out) describe the wave vector and frequency of the incident and scattered photon, respectively, and the label (SW) relates to the spin-wave wave vector and frequency, respectively. A positive sign in the above equations holds for the case of an anti-Stokes process in which a magnon is annihilated, whereas the negative sign holds for the case of a Stokes process in which a magnon is created. By operating the setup in the backscattering geometry [32], wave vector-resolved probing of spin waves and, with that, a direct measurement of the spin-wave dispersion relation is possible.

For the probing laser, $\lambda = 532$ nm, and the spin-wave wave vector ($k = 4\pi \sin(\varphi)/\lambda$) can be probed by varying the angle of incidence $\varphi$. The probing laser beam is incident perpendicular to the applied field which lies in the sample plane. Thus, in case the film is saturated, magnetostatic surface spin waves are probed ($k \perp \vec{M}$).

IV. RESULTS

A. Pt/CoFeB/MgO

From measurements performed at an applied field of $\mu_0 H_{\text{ext}} = \pm 200$ mT, the center frequency of the Stokes and anti-Stokes signal are extracted by fitting a Lorentzian peak function to the respective signals in the recorded BLS spectra.

The full dispersion relation is shown by the black squares in Fig. 1(a). Clearly, it features a pronounced asymmetry with respect to wave-vector inversion as a consequence of the DMI. Furthermore, we would like to point out that the group velocity, which is the derivative of the dispersion relation with respect to the wave vector, is positive in the entire probed wave vector range. Consequently, the group velocity, or, in other words, the magnon energy flow, is unidirectional for all spin-wave wave vectors probed in the experiment. This effect, which is due to a comparably strong inDMI might provide interesting opportunities for the application of such layer systems in spin-wave logic devices [1], [35].

The black line in Fig. 1(a) shows the full dispersion relation including the DMI contribution. For the plot, the external field ($\mu_0 H_{\text{ext}} = 200$ mT), the magnetic film thickness ($t = 0.6$ nm), as well as the saturation magnetization ($M_S = 1388$ kA/m) have been used. The symmetric exchange constant has been taken as $A = 17.6$ pJ/m and the DMI constant is $D = 1.33$ mJ/m$^2$.

The symmetrized spin-wave frequency is shown in Fig. 1(b) by the black squares. Fitting the symmetrized dispersion relation as in (3) to the data results in a symmetric exchange
constant of $A = (17.60 \pm 3.14) \text{ pJ/m}$. At this point, we would like to underline the fact that, even though the magnetic film thickness is only 0.6 nm, neglecting the dipolar interaction significantly falsifies this analysis. The blue curve in Fig. 1(b) represents a pure exchange model, i.e., $f_{\text{SW}} = f_{\text{FMR}} + \lambda_{\text{ex}} k^2$ leading to $A = (30.26 \pm 3.93) \text{ pJ/m}$ which drastically overestimates the actual value of the symmetric exchange constant. However, this pure exchange model with $A = 17.60 \text{ pJ/m}$ (dotted red curve) is equally insufficient for a thorough description but the dipolar contribution has to be taken into account for an adequate analysis of the results. It is separately illustrated by the red dashed line in Fig. 1(b). This curve is a plot of the dispersion relation with the parameters obtained from the fit of the full dispersion relation but with the symmetric exchange constant $A$ set to zero. The dipolar contribution is linear in the spin-wave wave vector to very good approximation and is definitely of importance despite the very small film thickness. Please note in this context, that the full dispersion relation is not the sum of the dipolar and exchange contribution but it is more complex as visible from (3).

Eventually, we would like to point out once more that the dipolar contribution to the dispersion relation is not the result of a fitting procedure but that this part is inherently present in the analytical model for the dispersion relation (3) using the saturation magnetization $M_S$ of the material.

The antisymmetric exchange interaction, i.e., the DMI, is extracted according to (1). The red squares in Fig. 2 show the frequency difference of the Stokes signal under reversal of the sign of the wave vector which linearly increases with the absolute value of the wave vector. With the above-mentioned value for $M_S$ and with the film thickness of $t = 0.6$ nm, the values for the DMI constant obtained from the Stokes data and the anti-Stokes data agree very well within their respective error bars. We obtain

$$D = +(1.33 \pm 0.09) \text{ mJ/m}^2$$
$$D_S = +(0.80 \pm 0.06) \text{ pJ/m}.$$

Ma et al. [37] found a DMI constant of $|D_S| = 0.97 \text{ pJ/m}$ using BLS for a CoFeB/Pt interface with the same CoFeB composition as for the samples under investigation in this work. This result is in reasonable agreement with our findings.

Additionally, we find $\mu_0 H_U = (1.198 \pm 0.038) \text{T}$ which is smaller than $\mu_0 M_S = 1.744 \text{ T}$ confirming the in-plane anisotropy of the film under investigation.

Following the description in [34] for the calculation of the anisotropy-induced frequency nonreciprocity, we take

![](image1.png)

**Fig. 1.** (a) Measured spin-wave frequency (black dots) and analytical model of the full dispersion relation. For the model, $A = 17.60 \text{ pJ/m}$ and $D = 1.33 \text{ mJ/m}^2$ have been used. (b) Symmetrized spin-wave dispersion relation (black dots) and a fit only including symmetric exchange interaction (blue curve). The red solid line is a fit of (3) resulting in $A = (17.60 \pm 3.14) \text{ pJ/m}$. The red dashed line is the dipolar contribution and red dotted line is the (symmetric) exchange contribution to the dispersion, respectively. Error bars in frequency are fit errors of the Lorentzian fit to the signal peaks. Their vector dependence results from the increasing group velocity in conjunction with the viscous character of Gilbert damping [36] and, with that, the steeper dispersion relation toward larger wave vectors leads to a larger signal linewidth. Error bars in the spin-wave wave vector vary as a consequence of the relation between probed wave vector and the angle of incidence, see Section III.

![](image2.png)

**Fig. 2.** Difference in the peak position of the Stokes peak under reversal of the spin-wave wave vector for a single CoFeB layer on Pt (red squares) and on W (black dots), respectively. The measured values clearly exhibit a linear dependence which is in accordance with the DMI-induced frequency shift to the dispersion relation being linearly dependent on the wave vector.
For the fit, we again use \( M \) in the corresponding fit curve depicted by the solid black line, between symmetric exchange, the dipolar interaction, and the It's remarkable flatness is a consequence of the interplay between PMA, symmetric exchange, and dipolar interaction.

The black solid line is a fit of the dispersion relation according to (3). From the fit we obtain \( A = (15.00 \pm 2.82) \) pJ/m. The flat character in the wave-vector range covered is consequence of the interplay between PMA, symmetric exchange, and dipolar interaction.

\[ A = 17.6 \text{ pJ/m}, \ M_S = 1388 \text{ kA/m}, \ t = 0.6 \text{ nm}, \] and assume the total anisotropy of the film to originate from one interface (Surface anisotropy constant \( K_S = K_U \cdot \tau = 0.5 \text{ J/m}^2 \)). Thus, for a spin-wave wave vector of \( k = 20 \text{ rad/\mu m} \), we obtain a nonreciprocity of \( f_{\text{asym}} = 0.82 \text{ MHz} \) which is clearly below the observed frequency nonreciprocity.

### B. W/CoFeB/MgO

Similar measurements as for the Pt/CoFeB/MgO film have been performed for the W/CoFeB/MgO film. From a field-sweep BLS measurement (not shown) in which a softening can be observed [38], it is found that this film features a perpendicular magnetic anisotropy (PMA). Measurements are performed at an applied field strength of \( |\mu_0 H_{\text{ext}}| = 400 \text{ mT} \) such that the film is saturated in its plane.

The symmetrized dispersion relation is shown in Fig. 3. Its remarkable flatness is a consequence of the interplay between symmetric exchange, the dipolar interaction, and the PMA causing a backward curvature which is clearly visible in the corresponding fit curve depicted by the solid black line in Fig. 3. For the fit, we again use \( M_S = 1388 \text{ kA/m} \). The film thickness is \( t = 0.6 \) nm and the applied magnetic field is \( \mu_0 H_{\text{ext}} = 400 \text{ mT} \). With that, we obtain \( A = (15.00 \pm 2.82) \) pJ/m for the symmetric exchange constant. For the uniaxial anisotropy field, we find \( \mu_0 H_U = (2.047 \pm 0.001) \) T. The value \( \mu_0 H_{\text{sat}} = \mu_0 H_U - \mu_0 M_S = 302 \text{ mT} \) corresponds well to the value of the applied field at which the maximum softening has been observed in the field-sweep measurement (not shown). Hence, a remarkable difference to the Pt/CoFeB/MgO sample is the presence of a significantly larger PMA in the W-based stack.

The frequency shift \( f_{\text{asym}} \) of the Stokes signal is shown in Fig. 2 (black dots) together with a linear fit used to evaluate the DMI constant. Both the values for the DMI constant obtained from the Stokes and anti-Stokes data, respectively, agree very well and the obtained values are

\[ D = +(0.06 \pm 0.03) \text{ J/m}^2 \]

\[ D_S = +(0.04 \pm 0.02) \text{ pJ/m} \]

which are much lower than in the Pt-based stack even though both Pt and W are elements with a large spin-orbit coupling and could, hence, be expected to induce a pronounced iDMI in the adjacent magnetic layers. However, this seems not to be the case for the W-based stack investigated in our experiments. While the DMI in magnetic films has been found to change with the phase of the adjacent W layer, nearly-vanishing DMI has not been observed for any of the W phases in [39]. We discuss this in more detail below in the context of the corresponding multilayer sample.

#### 1) Multirepeat Samples: Besides single layers, also magnetic multilayers are of large interest, in particular, since they improve the stability of skyrmions [4].

We note that in the multirepeat samples under investigation, we observe a significantly weaker BLS signal as compared to the single layer resulting in a larger uncertainty of the obtained sample properties. We choose an externally applied magnetic field of \( \mu_0 H_{\text{ext}} = \pm 350 \text{ mT} \) for the Pt/CoFeB-based multilayer and \( \mu_0 H_{\text{ext}} = \pm 400 \text{ mT} \) for the W/CoFeB-based multilayer to perform wave-vector resolved measurements according to the same procedure as described above for the investigation of the single layers. From an analysis of the Stokes signal similar to the single repeats, we obtain the results depicted in Fig. 4.

Again, we find a linear increase in the difference between the peak positions under a reversal of the field with an increase of the spin-wave wave vector. Fitting (1) to the data obtained from the Pt/CoFeB-based multilayer, we find a DMI constant of

\[ D = +(1.15 \pm 0.57) \text{ J/m}^2 \]

which is in agreement with the DMI strength found for a single stack of Pt/CoFeB/MgO within the error bars. This result is in
accordance with the assumption that the individual magnetic layers of the multirepeat stack are exchange decoupled and have the same properties as the magnetic layer in the single stack samples.

The same is true for the multirepeat stack based on W/CoFeB. In this case, we find a DMI constant of

\[ D = +(0.03 \pm 0.08) \text{ mJ/m}^2 \]

which again is in agreement with the findings for the single repeat sample. In XRD measurements performed with the W/CoFeB multirepeat sample the \( \alpha\)-W was identified. In [39], maximal DMI has been found in CoFeB with the adjacent W layer in the \( \alpha\)-W phase. This deviation suggests that, while the phase of W obviously plays a role, it is not the only factor governing the DMI strength. Furthermore, interfacial intermixing might play a very important role since we expect it to be rather low in our as-deposited films in contrast to annealed films. Since the transition of W into the \( \alpha\)-W phase is a thermally activated process [40], we also do not expect any phase change due to heating effects from the probing BLS laser. Regarding the discussion of \( M_S \) in Section II, we would like to mention that even a generous error of 30% will not lead to a \( D \) in excess of 0.1 mJ/m\(^2\) for the single-layer or multilayer W-based sample.

Also for the case of multilayer samples we can consider the anisotropy-induced spin-wave nonreciprocity. In order to do so, we calculate the frequency nonreciprocity for a \( t = 6 \) nm thick magnetic layer corresponding to the total magnetic material thickness of the magnetic material in the multilayer. With \( A = 17.6 \text{ pJ/m}, M_S = 1388 \text{ kA/m}, \) and \( K_S = 0.5 \text{ mJ/m}^2\) this results in \( f_{\text{ex,ani}} = 66 \text{ MHz} \) for \( k = 20 \text{ rad/\mu m}. \) Hence, also in this case, the DMI is the main origin of the measured frequency nonreciprocity and can be considered as conserved when comparing the multilayer samples to the single-layer stacks.

This finding is of particular interest since the enhanced dipolar interaction due to the increased effective magnetic layer thickness in multilayer samples supports the stabilization of skyrmions [4], [42] but also a conservation of the DMI is necessary to make use of this favorable effect.

2) Spin-Wave Lifetime: A parameter which can give further insight into the material properties such as the damping is the lifetime \( \tau \) of a spin-wave mode with wave vector \( k \), which in the case of thin films is significantly influenced by the heavy metal layer due to spin pumping [43] and two-magnon scattering at interface imperfections and, in addition, has been reported to depend on DMI [44]. In concrete terms, DMI is expected to cause a difference of the linewidth between the Stokes and the anti-Stokes signal.

Via the phenomenological loss theory [45], the lifetime can be connected to the spin-wave dispersion relation [28]. As given in the work of Brächer et al. [35], in the absence of DMI and for thin films with spin waves propagating perpendicularly to the magnetization direction, the lifetime can be expressed as

\[ \tau_0 = \frac{1}{2\pi \alpha} \left[ \frac{\gamma \mu_0}{2\pi} \left( H_{\text{ext}} + k^2 - \frac{H_U}{2} + \frac{M_S}{2} \right) \right]^{-1} \]  

(7)

with the effective Gilbert damping parameter \( \alpha \). In the BLS measurements, provided the signal linewidth is large compared to the frequency resolution of the setup (~100 MHz), the spin-wave lifetime is directly linked to the signal linewidth \( \delta f \) via the relation

\[ \delta f = \frac{1}{4\pi \tau}. \]  

(8)

The presence of dDMI leads to a modification of the spin-wave lifetime. With the DMI-induced frequency difference \( f_{\text{ asym}} \) [see (1)] between Stokes and anti-Stokes signals, the lifetime of the respective counterpropagating waves (plus and minus sign, respectively) is found to be

\[ \tau_{\pm} = \frac{\tau_0}{1 \pm \frac{f_{\text{ asym}}}{f_{\text{ sym}}}} \]  

(9)

with the frequencies \( f_{\text{ asym}} \) and \( f_{\text{ sym}} \) as defined in (1) and (3).

The signal linewidth of Stokes and anti-Stokes signal for the Pt/CoFeB/MgO single stack sample are shown in Fig. 5 for positive applied field (\( \mu_0 H_{\text{ext}} = 200 \) mT). The model curves are the calculated linewidths according to (7) and (9) with an effective Gilbert damping parameter of \( \alpha = 0.33 \) and \( D = 1.33 \text{ mJ/m}^2\). This value for the Gilbert damping parameter is reasonable given the fact that the film under investigation is ultrathin and that an adjacent Pt layer is known to significantly enhance the Gilbert damping due to spin pumping effects [46], [47]. To quantitify this effect, we estimate the contribution of spin pumping to the total Gilbert damping. It can be expressed as [48]

\[ \alpha_{\text{sp}} = \frac{\gamma h}{4\pi M_S \tau_{\text{eff}}^\perp} \]  

(10)

with \( h = h/(2\pi) \) where \( h \) is Planck’s constant, and the spin mixing conductance \( g_{\text{eff}}^\perp \). For the spin mixing conductance, a value of \( 4 \times 10^{-19} \text{ m}^2/\text{V} \) is being reported for a Co/Pt interface [49] as well as for a Co\(_{20}\)Fe\(_{80}\)/B\(_{20}\)/Pt interface [47]. With this, we can estimate the spin pumping damping enhancement.
to be $\alpha_{\text{SP}} = 0.23$. Accordingly, the damping of the CoFeB layer, which is not caused by spin pumping effects is about $\alpha_{\text{int}} = 0.10$. Thus, although we can only estimate the different contributions, we can state that spin pumping is likely the dominating contribution to the overall damping.

Concerning the influence of the DMI on the linewidth, we can state that, as expected, the asymmetry of the linewidths of the Stokes and the anti-Stokes peaks inverts under field, i.e., wave-vector reversal. Furthermore, an increase of the linewidth toward higher spin-wave wave vectors is visible. Thus, the systematic wave-vector-dependent influence of the DMI on the spin-wave linewidth can be clearly observed and is well in line with results found elsewhere [50], [51].

V. Conclusion

In summary, from measurements of the thermal spin-wave spectrum, we independently determined the DMI constant and the symmetric exchange constant in ultrathin CoFeB layers deposited on Pt and W, respectively. We find a strong DMI induced by the adjacent Pt layer, whereas the W-based stack exhibits a surprisingly small interfacial DMI constant. In addition, we show that the contribution of the dipolar interaction to the dispersion relation cannot be neglected, especially in the context of an accurate extraction of the symmetric exchange constant.

The parameters found for the multirepeat stacks are in good agreement with the ones found for the single repeat samples underlining the assumption of exchange-decoupled magnetic layers in the multilayer samples.

The influence of DMI on the spin-wave properties can be also traced by an analysis of the spin-wave lifetime.

Acknowledgment

This work was supported in part by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) by TRR 173—268565370 (“Spin Forschungsgemeinschaft (DFG, German Research Foundation)” project A01 and Project 403512431 and Project 403502522.

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