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Frequency-selective control of ferromagnetic resonance linewidth in magnetic multilayers

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We report on a frequency-specific linewidth broadening of the ferromagnetic resonance (FMR) mode of a NiFe free layer within a magnetic multilayer stack. The FMR studies reveal a significant broadening of the FMR linewidth of the free layer at frequencies where this resonance is degenerate with FMR modes stemming from other layers within the multilayer stack. By pinning part of the magnetic multilayer to an antiferromagnet, we tailor a ferromagnetic linewidth behavior that is anisotropic for a specific frequency. © *2012 American Institute of Physics*. [doi:10.1063/1.3678025]

Magnetization dynamics in thin magnetic multilayers continue to attract considerable scientific interest. This includes work to understand effects like exchange bias[1] as well as a vast number of studies looking into spin-transfer-torque switching[2,3] or spin-torque nano oscillators.[4] Magnetic multilayers and the understanding of their dynamic behavior are already important for devices such as magnetic-recording read heads and will play an ever more critical role with the utilization of spin-transfer torque (STT) for magnetic memory[5] as well as spin-logic[6,7] devices.

In this letter, we report on a frequency-selective ferromagnetic resonance (FMR) linewidth broadening in magnetic multilayer stacks containing an 8 nm thick magnetic $Ni_{90}Fe_{10}$ free layer on top of a synthetic antiferromagnet (SAF),[8] separated by a MgO spacer (see inset Fig. 1). The SAF consists of two layers of $Co_{90}Fe_{10}$ with a 0.8 nm thick Ru interlayer, providing antiferromagnetic coupling within the SAF.[9] In addition, the lower $Co_{90}Fe_{10}$ layer is pinned using an antiferromagnetic IrMn layer. For the data presented here, the lower layer had a thickness of 2.5 nm while the upper layer thickness was varied from 2 to 5 nm for different samples. Similar structures are commonly used in hard-disc read heads. The magnetization dynamics of such a structure is nontrivial due to the interlayer exchange coupling within the SAF as well as the pinning of the bottom SAF layer to the IrMn. The aim of this letter is not to give a complete picture of the magnetization dynamics of this multilayer system, but rather to report on the influence of the SAF resonances on the dynamic response of the free layer.

We studied the magnetization dynamics of the samples using a broadband FMR technique. For these measurements, the magnetic field is applied in the plane of the sample both parallel and antiparallel to the exchange-bias direction. As shown in Fig. 1, three FMR modes can be observed in the parallel orientation, the center one stemming from the free layer and the modes at higher and lower magnetic fields from the SAF. In Fig. 1, data points with right-pointing (left-pointing) triangles are measured with the external magnetic field pointing parallel (antiparallel) to the bias direction. Because the interlayer exchange coupling between the $Co_{90}Fe_{10}$ layers is strong, the modes at high and low field are collective modes of the SAF, referred to as optic and acoustic mode, respectively.[10,11]

These SAF resonances are considerably weaker than the free-layer resonance. This complicates extracting their position when they are close to the strong free-layer resonance, because they merge into the flanks of the stronger signal. Thus, the position of the SAF modes cannot unambiguously be determined in the crossing region with the free layer. The optic mode of the SAF is very weak, making it difficult to determine its position at higher frequencies. In Fig. 1 we included a guide to the eye for the SAF resonances,

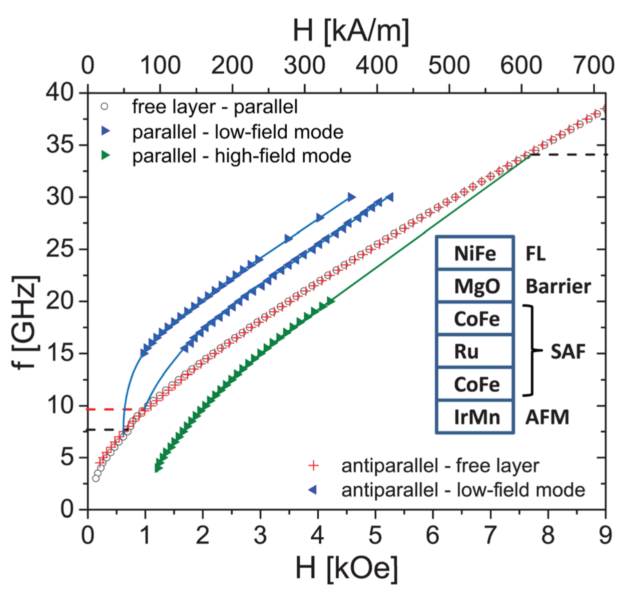

FIG. 1. (Color online) FMR mode positions for various excitation frequencies. The circles (crosses) represent the resonance mode of the free layer for the external field applied parallel (antiparallel) to the exchange-bias direction. The triangles at higher and lower fields show the positions of the optic and acoustic mode of the SAF, respectively. The lines connecting the data points of the SAF modes are a guide to the eye. Inset: Structure of the magnetic multilayer.

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extrapolating their behavior into the crossing region with the free layer.

One important feature of the chosen multilayer structure is the ability to shift the relative position of the FMR modes of the SAF with respect to the free layer by changing the angle of the external magnetic field relative to the pinning direction of the SAF. Moreover, because the free layer is separated from the SAF structure by a 1.4 nm thick MgO layer the free-layer resonance position is not directly influenced by the presence of the IrMn. Magneto-optic Kerr effect (MOKE) measurements as shown in the inset of Fig. 2 indicate a pinning field of about 2 kOe. This bias field is the reason that positions of the SAF resonances in Fig. 1 depend on the in-plane angle between the external magnetic field and the bias direction.

Figure 2 shows the linewidth of the free-layer FMR mode. The right-pointing (left-pointing) triangles depict the data for a parallel (antiparallel) orientation of the external magnetic field and the exchange bias direction for the 2.5 nm thick upper SAF layer. Interestingly, both data sets reveal a prominent peak in the linewidth at low frequency on top of a linear dependence expected for Gilbert damping.[12] These peaks occur at the frequencies where crossings of the low-field SAF mode and the free layer resonance are expected as indicated in Fig. 1.

Here it is important to note that the FMR linewidth not only measures Gilbert-type damping but reflects all available relaxation processes. While two-magnon scattering can contribute significantly to the linewidth in ultra-thin films,[13,14] the relatively thick free layer and the frequency dependence of the linewidth indicate that this is not the origin of the observed nonlinearity in the linewidth data. Another process that leads to a nonlinear contribution to the linewidth are slowly relaxing impurities[15–17] with sufficiently slow relaxation rates. Given the absence of any deliberate impurities and the angular dependence of the linewidth nonlinearity, the slow-relaxer can also be ruled out as the origin of the

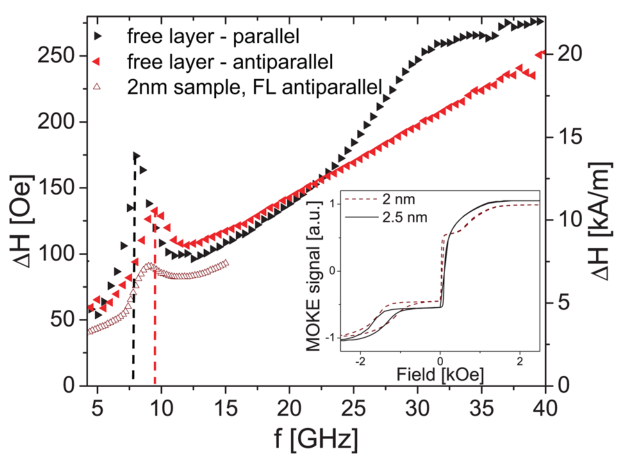

FIG. 2. (Color online) FMR linewidth of the free-layer mode versus excitation frequency for parallel (right-pointing triangles) and antiparallel (left-pointing triangles) orientation of external magnetic field and exchange bias direction for a thickness of the upper SAF layer of 2.5 nm. The up-pointing triangles depict the linewidth for the sample with a 2 nm thick upper layer in the antiparallel orientation. Inset: MOKE reversal loops for the samples with 2 nm (dashed line) and 2.5 nm upper SAF layer thickness (continuous line).

observed behavior. We therefore propose the following model to explain the observed peaks in the linewidth of the free layer in the multilayers under investigation. For microwave frequencies for which the free layer resonance and the resonances of the SAF occur at different applied fields, the relaxation of the free layer is unaffected by the presence of the SAF. However, if the resonance of the free layer is degenerate with a highly damped resonance of the neighboring SAF this opens a new relaxation channel for the free layer, provided there is some form of coupling. For the samples investigated here this coupling is not mediated by spin-pumping between the neighboring layers,[18,19] as the MgO spacer between the free layer and the SAF prevents spin-pumping. Rather the interaction between free layer and SAF is likely due to dynamic dipolar coupling[20] in the films. One expects the dynamic dipolar coupling to be very sensitive to the details of the interface roughness of the films.[20–23] This coupling can cause a significant broadening of the otherwise sharp FL resonance linewidth because the linewidth of the SAF mode is significantly larger, hence having a considerable contribution to the FL relaxation even at moderate or low coupling strength. While a detailed description of the dependence of the dynamic coupling on film roughness is beyond the scope of the current manuscript, we note that the linewidth broadening effect is more pronounced for samples that exhibit a stronger static coupling resulting in a shift of the switching in the quasi-static magnetization reversal, see Fig. 2.

The linewidth for the parallel orientation of magnetic field and exchange bias direction exhibits another broad peak for higher frequencies whereas no such behavior is observed for the antiparallel orientation, consistent with the fact that the high-field SAF mode, crossing the free-layer mode at these frequencies, is only observed for the former orientation. The deviation from the Gilbert-type damping[24] at high frequencies is considerably broader than the clear, peak-like increase observed at the crossing of the low-field SAF resonance with the free-layer mode. This is caused by the broad field range, for which a crossing of the high-field SAF mode and the free-layer mode is observed as is evident from Fig. 1.

As mentioned above, we analyzed the positions of the linewidth broadening for several samples with varying thicknesses of the upper SAF layer. The results are presented in Fig. 3 with right (left) pointing symbols for the parallel (antiparallel) orientation of external magnetic field and exchange-bias direction.

Interestingly, the frequency peak position in the linewidth does only shift slightly for the low-field mode crossing whereas the broad peak at high frequencies and high fields shifts more significantly. As can be seen in Fig. 1, this difference originates in the difference of the crossing of the SAF resonances and the free layer resonance. A small change in frequency quickly lifts the degeneracy of the low-field SAF resonance with the free layer resonance leading to a linewidth peak that is relatively narrow and depends only weakly on the top layer thickness of the SAF. However, for the broad high-field SAF resonance, the mode is degenerate with the free layer resonance over a wide frequency range leading to a broad peak in the linewidth that depends very sensitively

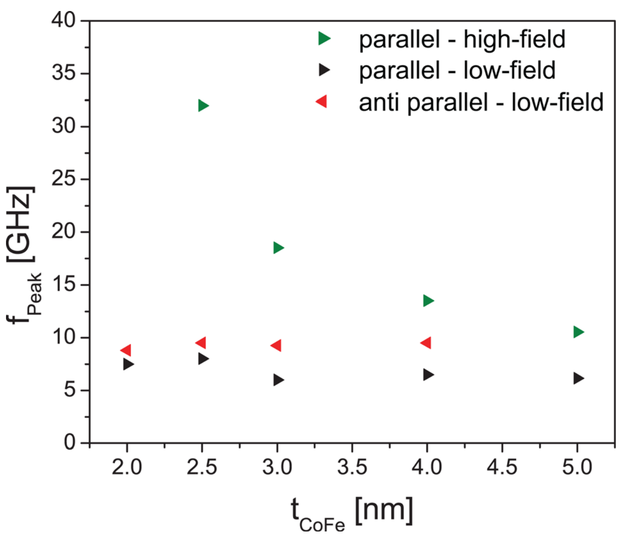

FIG. 3. (Color online) Positions of the free-layer linewidth broadening for different thicknesses of the upper SAF layer. The right-pointing (left-pointing) triangles depict the data for the external magnetic field being parallel (antiparallel) to the exchange bias direction. The frequencies of the linewidth broadening were determined by subtracting the linear background of the linewidth as seen in Fig. 2 and fitting a Lorentzian peak to the remaining, non-linear part of the linewidth.

on the top layer thickness of the SAF, as a small change in the dispersion relation of the SAF will lead to a significant shift of the crossing point with the free layer dispersion.

The experimental results in Fig. 3 illustrate, how the linewidth of a free layer within a magnetic multilayer stack, commonly used to read and store information, can be artificially increased at specific frequencies. By choosing proper material parameters of the multilayer system, this effect can be tailored over a wide frequency range, as well as prepared in an anisotropic matter as is the case for the studies we report on here.

The observed linewidth broadening is interesting beyond the study of dynamic magnetization coupling in magnetic multilayers. Especially the anisotropic nature of this effect in exchange-bias pinned structures offers ways for a technical utilization. The significant difference in linewidth and hence loss at a particular frequency for different orientations might be exploited in the frequency as well as the time regime. An obvious application would be a continuously tunable filter at microwave frequencies which could easily be scaled down to the micrometer scale. In the time domain, the anisotropic linewidth broadening might offer a much-needed handle at tailoring fast switching events in magnetic multilayers.

In conclusion, we investigated a frequency-selective linewidth broadening of the FMR mode of a metallic free layer within a magnetic multilayer stack. This effect is caused by the dynamic dipolar coupling of the free layer to the SAF beneath it. By pinning the SAF with an antiferromagnet, one can tailor a strongly anisotropic behavior of the FMR linewidth for certain frequencies. Further effort to increasing the coupling within the multilayer stack potentially could enhance the effect significantly and thus make it interesting to tailor the relaxation behavior in such multilayers on fast timescales.

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[1]T. Mewes, R. L. Stamps, H. Lee, E. Edwards, M. Bradford, C. K. A. Mewes, Z. Tadisina, and S. Gupta, IEEE Mag. Lett. **1**, 3500204 (2010).
[2]D. Bedau, H. Liu, J. Z. Sun, J. A. Katine, E. E. Fullerton, S. Mangin, and A. D. Kent, Appl. Phys. Lett. **97**, 262502 (2010).
[3]D. E. Nikonov, G. I. Bourianoff, G. Rowlands, and I. N. Krivorotov, J. Appl. Phys. **107**, 113910 (2010).
[4]S. Choi, S.-K. Kim, V. E. Demidov, and S. O. Demokritov, Appl. Phys. Lett. **90**, 083114 (2007).
[5]E. Chen, D. Apalkov, Z. Diao, a. Driskill-Smith, D. Druist, D. Lottis, V. Nikitin, X. Tang, S. Watts, S. Wang *et al.*, IEEE Trans. Magn. **46**, 1873 (2010).
[6]S. A. Wolf, D. D. Awschalom, R. A. Buhrman, J. M. Daughton, S. von Molnár, M. L. Roukes, A. Y. Chtchelkanova, and D. M. Treger, Science (New York, N.Y.) **294**, 1488 (2001).
[7]R. Richter, H. Boeve, L. Bär, J. Bangert, U. Klostermann, J. Wecker, and G. Reiss, J. Magn. Magn. Mater. **240**, 127 (2002).
[8]H. van den Berg, W. Clemens, G. Gieres, G. Rupp, W. Schelter, and M. Vieth, IEEE Trans. Magn. **32**, 4624 (1996).
[9]S. Parkin, Phys. Rev. Lett. **67**, 3598 (1991).
[10]B. Heinrich, S. Purcell, J. Dutcher, K. Urquhart, J. Cochran, and A. Arrott, Phys. Rev. B **38**, 12879 (1988).
[11]A. Layadi and J. O. Artman, J. Magn. Magn. Mater. **92**, 143 (1990).
[12]B. Heinrich, J. F. Cochran, and R. Hasegawa, J. Appl. Phys. **57**, 3690 (1985).
[13]M. J. Hurben and C. E. Patton, J. Appl. Phys. **83**, 4344 (1998).
[14]H. Lee, Y.-H. A. Wang, C. K. A. Mewes, W. H. Butler, T. Mewes, S. Maat, B. York, M. J. Carey, and J. R. Childress, Appl. Phys. Lett. **95**, 082502 (2009).
[15]J. Van Vleck and R. Orbach, Phys. Rev. Lett. **11**, 65 (1963).
[16]G. Woltersdorf, M. Kiessling, G. Meyer, J.-U. Thiele, and C. Back, Phys. Rev. Lett. **102**, 6 (2009).
[17]H. Nembach, T. Silva, J. Shaw, M. Schneider, M. Carey, S. Maat, and J. Childress, Phys. Rev. B **84**, 054424 (2011).
[18]B. Heinrich, Y. Tserkovnyak, G. Woltersdorf, A. Brataas, R. Urban, and G. Bauer, Phys. Rev. Lett. **90**, 7 (2003).
[19]H. Lee, L. Wen, M. Pathak, P. Janssen, P. LeClair, C. Alexander, C. K. A. Mewes, and T. Mewes, J. Phys. D: Appl. Phys. **41**, 215001 (2008).
[20]O. Dmytriiev, T. Meitzler, E. Bankowski, A. Slavin, and V. Tiberkevich, J. Phys: Condens. Matter **22**, 136001 (2010).
[21]L. Néel, Comptes Rendus des Séances de l'Académie des Sciences **255**, 1676 (1962).
[22]D. Altbir, J. Magn. Magn. Mater. **149**, L246 (1995).
[23]Y.-P. Zhao, G. Palasantzas, G.-C. Wang, and J. De Hosson, Phys. Rev. B **60**, 1216 (1999).
[24]T. Gilbert, IEEE Trans. Magn. **40**, 3443 (2004).