

Spin-pumping in Pt/Py heterostructures: The role of Al spacer layers

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The magnetic damping of spin-pumping heterostructures consisting of Pt and Ni₈₀Fe₂₀ (Permalloy, Py) thin films is studied via temperature- and frequency-dependent ferromagnetic resonance (FMR). Additional magnetic and structural characterization is done by transmission electron microscopy (TEM), x-ray absorption spectroscopy, and x-ray magnetic circular dichroism (XMCD). The frequency-dependence of the FMR linewidth allows to extract the Gilbert damping parameter α as a function of temperature. Py in direct contact with Pt exhibits a strong enhancement of $\alpha(T)$, and the dependence on the thickness of the Py layer suggests this to be an interfacial effect. The enhanced $\alpha(T)$ is accompanied by an induced magnetic polarization of the Pt as evidenced by XMCD, while the other magnetic properties of Py as measured with FMR and static magnetometry remain virtually unchanged. The increase of $\alpha(T)$ can be efficiently suppressed by the insertion of an Al-spacer layer between Pt and Py as thin as 1 nm, which coincides with the loss of the magnetic polarization of Pt.

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I. INTRODUCTION

Ferromagnetic resonance (FMR) is an established tool to study magnetic relaxation processes of excited magnetic states of ferromagnets (FM) [1]. In thin films, these are intrinsically associated with spin-lattice relaxations and with the dissipation into spin-wave states of the ferromagnetic layer itself [2]. The magnetic damping is usually described by the phenomenological Gilbert damping parameter α [3], which gives rise to a linear increase of the FMR linewidth ΔH with microwave frequency f ; however, other processes like two-magnon scattering (TMS) can give rise to a nonlinear $\Delta H(f)$, see, e.g., [4]. In general, for magnetic damping the generation (and detection) of spin currents, which represent the flow of angular momentum, plays an important role. One possibility to generate nonequilibrium spin currents is the spin-pumping effect, where the flow of angular momentum is generated by a precessing magnetization of a FM layer at FMR, as described by the Landau-Lifshitz-Gilbert equation [3,5], with the consecutive injection of a spin current into an adjacent normal metal (NM) layer. Typically, the NM is a strongly paramagnetic material, like Pd or Pt, where the presence of spin pumping gives rise to an increase of the Gilbert damping parameter $\Delta\alpha$ [6]. The $\Delta\alpha = \alpha_{\text{Pt/Py}} - \alpha_{\text{Py}}$ of the prototypical

Pt/Py spin-pumping system has been extensively studied in the past. For example, in an early work using X-band FMR, the Py thickness dependence demonstrates an interfacial character of the spin-pumping effect, and Pt has the strongest increase in FMR linewidth compared to other NM materials [7]. Later, it was found by others that the insertion of a spacer layer between FM and NM layers can reduce $\Delta\alpha$. In [8] it was reported that the insertion of a Cu spacer layer in Py/Pt heterostructures reduces the increase in α . This was associated with the loss of the induced magnetic polarization in Py/Pt multilayers upon insertion of 1 nm of Cu as evidenced by element-selective x-ray magnetic circular dichroism (XMCD) at the Pt L₃ edge which was taken as evidence for additional spin-flip processes at the interface [8]. Other studies, in particular low-Z materials with small spin-orbit coupling, for the spacer layer are however sparse, e.g., Al was studied as spacer layer in CoFeB/Pt heterostructures leading to a reduction of α [9].

Here, we report a systematic investigation of the influence of an Al-spacer layer inserted between Pt and Py forming a prototypical Py/Pt spin-pumping heterostructure. As expected, Py in direct contact with Pt exhibits a clearly increased Gilbert damping parameter α at all studied temperatures from 10 K to 295 K, while other magnetic parameters remain virtually unchanged, compared to a Al/Py/Al reference sample from [10] of identical Py thickness. Varying the Py thickness, this increase of α is shown to be an interfacial effect. The increase in $\alpha(T)$ coexists with an induced magnetic polarization of Pt as evidenced by element-selective XMCD at the Pt L₃ edge. Inserting an Al spacer causes the induced polarization to vanish for spacer layers as thin as 1 nm. At the same time, the increased α is clearly reduced for a 1 nm Al-spacer

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layer and it further reduces toward values of the Al/Py/Al reference sample with increasing Al-spacer thickness. These findings suggest that the increase of α is not only caused by spin pumping but the induced polarization of Pt should be considered as an additional source of increased damping.

II. EXPERIMENTAL DETAILS

We have grown two series of Pt/Py spin-pumping heterostructures by magnetron sputtering on as-received, epitaxially *c*-plane sapphire [Al₂O₃ (0001)] substrates, which were covered by a 2 nm Al buffer layer, which optimizes the magnetic damping of Py [10]. The Pt thickness has been set to 5 nm, which assures that the increase of the Gilbert damping parameter α with Pt thickness has saturated, see, e.g., [8,11]. All depositions are done at ambient temperature in an ultrahigh vacuum system with a base pressure of 2×10^{-9} mbar. The working pressure for Al, Pt, and Py was 4×10^{-3} mbar using 10 sccm Ar and a sputter power of 7 W for Pt and 20 W for Al and Py, respectively. The respective growth rates of typically 5.3 ± 0.2 nm/min were monitored using a quartz-crystal microbalance. For the first series, an Al-spacer layer was inserted between Py (fixed thickness of 14.7 nm) and Pt with a thickness from 0 nm (no Al buffer, i.e., direct contact between Pt and Py) up to 3 nm. For the second sample series, Pt and Py were in direct contact and the thickness of the Py layer was varied from 4.7 nm to 37.1 nm. The thickness of all layers was determined by x-ray reflectivity (XRR) with a parallel beam of Cu K_α radiation and partially crosschecked using transmission electron microscopy (TEM), as done before [10,12]. In addition, standard magnetic characterization was carried out using a superconducting quantum interference device (SQUID) magnetometer. The external magnetic field was applied in the film plane to record the easy-axis $M(H)$ curves of Py at room temperature to determine the saturation magnetization M_s as described elsewhere [12].

Temperature-dependent broadband FMR measurements were carried out using the NanOsc Cryo-FMR40 setup with a microwave frequency f in the range of 2–40 GHz at temperatures between 10 K and 295 K. The sample was placed flip chip on a coplanar waveguide assembly with a fixed polar angle of $\theta_H = 90^\circ$ (in plane) and the transmitted microwave power was detected by a diode. The FMR spectra were recorded at a fixed microwave frequency as a function of the external field, which was modulated by a pair of Helmholtz coils for lock-in detection. The individual FMR spectra were fitted with a Lorentzian derivative, which allows to extract the resonance field H_{res} as well as the FMR linewidth ΔH . Additional angle-dependent broadband vector network analyzer FMR measurements (VNA-FMR) were conducted at ambient temperature at a fixed microwave frequency of 14 GHz without any field modulation. The sample was placed flip chip on a coplanar waveguide and the complex transmission parameter S_{21} was directly measured by the VNA. The polar (θ_H) and azimuthal (ϕ_H) angular dependence of the resonance field H_{res} and linewidth $\Delta H_{\text{pp}} = \Delta H/\sqrt{3}$ together with the broadband in-plane FMR were fitted using a single parameter set. These fits allow to extract the following parameters: from the Kittel fit the g -factor, the effective magnetization M_{eff} , and the in-plane uniaxial anisotropy $K_{2||}$; from the fits of the FMR

linewidths the Gilbert damping parameter α and a virtually frequency-independent broadening due to a small mosaicity in M_{eff} ; see [10] for further details. Note, that all M_s determined by SQUID agree within experimental accuracy with the M_{eff} from FMR so that one can consider a negligible effective out-of plane anisotropy $K_{2\perp}$, as expected for Py.

High-resolution TEM investigations were done in cross-sectional geometry using an image-C_s-corrected Titan 80–300 microscope (FEI) operated at an accelerating voltage of 300 kV. High-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM) imaging and spectrum imaging analysis based on energy-dispersive x-ray spectroscopy (EDXS) were performed at 200 kV with a Talos F200X microscope equipped with a Super-X EDX detector system (FEI). Line-by-line intensities of the EDXS element distribution maps were computed to obtain element intensity profiles across the sample stack, as described in greater detail in [10]. Cross-sectional TEM specimen preparation was done by *in situ* lift out using a focused ion beam (FIB) device. To protect the sample surface, a carbon cap layer was deposited beginning with electron-beam assisted and subsequently followed by Ga-FIB assisted precursor decomposition. Afterwards, the TEM lamella was prepared using a 30 keV Ga-FIB with adapted currents. To minimize sidewall damage, Ga ions with only 5 keV energy were used for final thinning of the TEM lamella to electron transparency. Prior to (S)TEM analysis, the specimen mounted in a high-visibility low-background double-tilt holder was placed for 10 s into a plasma cleaner to remove potential contamination.

X-ray absorption near edge spectra (XANES) at the Pt L₃ edge were taken at the ID12 beamline of the ESRF [13] in total fluorescence yield in backscattering geometry using a silicon photo diode (PD) under grazing incidence (15°) and an external field of 1 T [14]. Additionally, background- and diffraction-peak-free XANES were taken using an energy-resolved silicon drift detector (SDD) to only record the characteristic Pt fluorescence. Further, the SDD was covered with a 12 micron thick Kapton foil to reduce the dominant Al K_α emission from the sapphire substrate. The XMCD measurements were taken as the direct difference of the XANES spectra recorded with right and left circular polarized light. In addition, the external field was switched between ± 1 T to minimize artifacts. For the XMCD spectra recorded with the PD, the third harmonic of the HU52 HELIOS-II undulator in elliptical mode was used as source, which results in a degree of circular polarization p_c of 0.7; thus, the XMCD spectra were corrected to $p_c = 1.0$. For the XMCD recorded with the SSD, the second harmonic of the HU-38 APPLE-II undulator in pure helical mode was preferred, which provides a p_c of 1.0.

III. EXPERIMENTAL RESULTS

Figure 1 summarizes the FMR characterization at ambient temperatures for three different samples: the Pt/Py/Al/sapphire spin-pumping heterostructure (black squares), the Pt/Al/Py/Al/sapphire heterostructure with 2 nm Al spacer (red circles), and—for comparison—the Al/Py/Al/sapphire reference structure of identical Py thickness, which was reported before [10]. The frequency

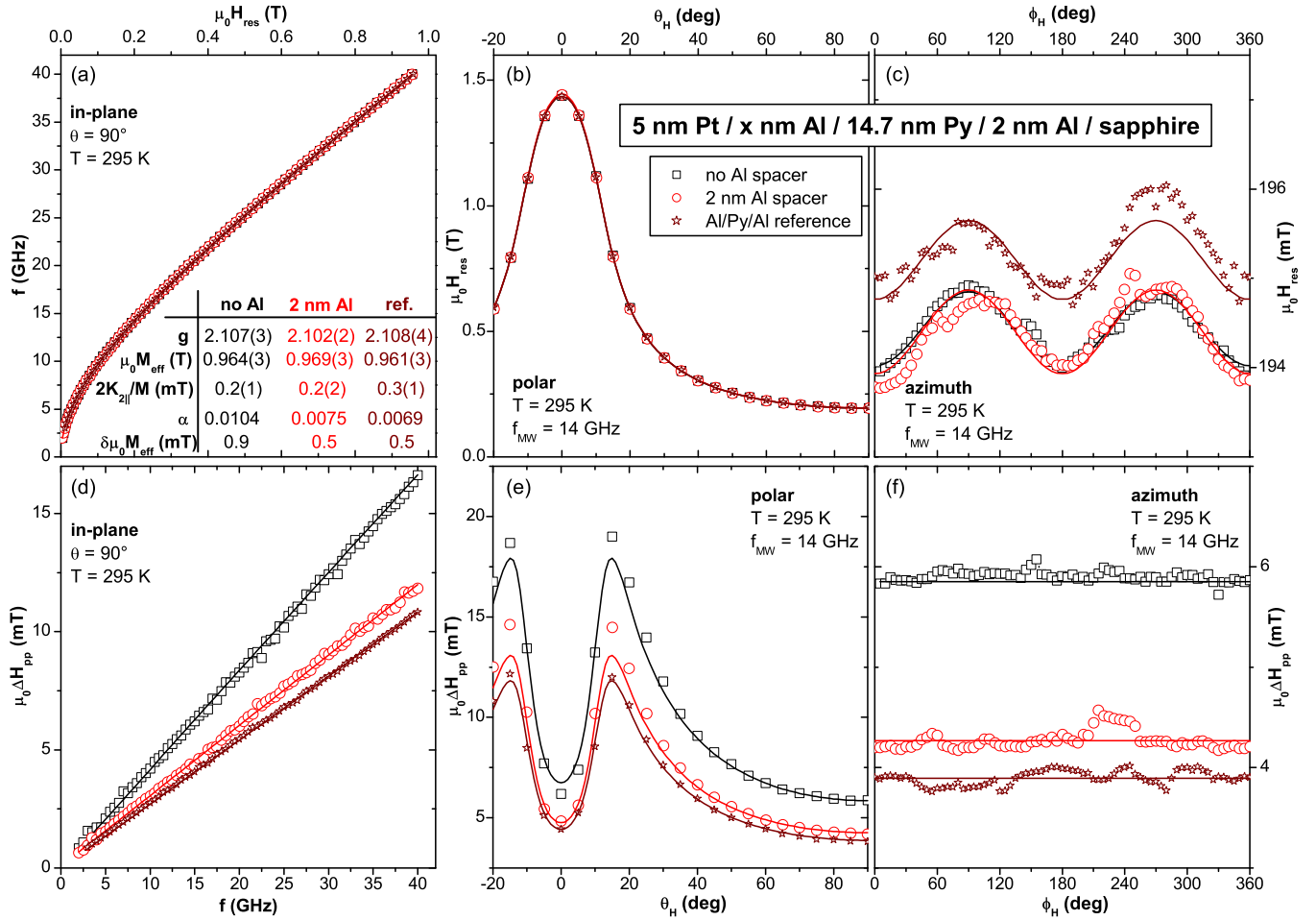


FIG. 1. FMR characterization of the Pt/Py spin-pumping heterostructure without (black squares) and with 2 nm Al spacer layer (red circles) measured at 295 K in comparison with an Al/Py/Al reference sample (wine stars). The $f(H)$ measurement for in-plane geometry is shown in (a), while FMR at a fixed frequency of 14 GHz is shown for the polar (b) and (c) azimuthal angular dependence. The corresponding FMR linewidths are displayed in (d)–(f), respectively. Solid lines are fits with a single set of parameters as given in the table in (a) for each sample, respectively.

dependence of resonance field (a) and FMR linewidth (d) reveal that the magnetic parameters derived from the Kittel fit are virtually identical for all three samples, whereas the Gilbert damping parameter α extracted from the frequency dependence of the FMR linewidth is significantly larger for Pt/Py compared to the Pt/Al/Py sample for which α is almost as small as for the Al/Py/Al reference sample. This analysis can be refined by the polar and azimuthal angular dependencies of the resonance field in (b) and (c), and FMR linewidths in (e) and (f), respectively. It can be seen that the polar and azimuthal angular dependencies of the resonance field in (b) and (c) indeed reveal no significant changes in the relevant magnetic parameters, which agree well within the experimental uncertainties. The samples typically show a very weak uniaxial in-plane anisotropy of less than 0.5 mT. The resonance field of these azimuthal angular dependencies themselves are slightly different due to a small difference in the respective M_{eff} . Nonetheless, the size of the in-plane uniaxial anisotropy is not increased for Py in direct contact with Pt. In contrast, the FMR linewidth is significantly increased for Pt/Py in comparison to the Al/Py/Al reference sample, both in the polar as well as in the azimuthal angular

dependency in (e) and (f), corroborating the findings from the in-plane frequency dependence of the FMR linewidth in (c). The angular dependencies from the VNA-FMR measurements do not indicate any significant changes in the static magnetic parameters. Therefore, we will exclusively use the in-plane frequency dependence of the resonance field and FMR linewidth as in (a) and (d), respectively. These are measured by Cryo-FMR as a function of temperature, mainly focusing on $\alpha(T)$ for the different sample series.

Figure 2 summarizes the findings for the temperature dependence of the Gilbert damping parameter $\alpha(T)$ for the two sample series. In Fig. 2(a), the $\alpha(T)$ dependence of the Al-spacer thickness series with a fixed Py thickness of 14.7 nm is compared to the Al/Py/Al reference sample (wine stars). It can be seen that α for the Pt/Py sample (black squares) is clearly increased over the entire temperature range by almost a factor of two, i.e., $\Delta\alpha$ ranges from 0.0036 at 295 K to 0.0045 at 10 K. Note that the data for α at 295 K are directly derived from the analysis of Fig. 1(d). This increase of α is commonly associated with the presence of spin pumping from the precessing magnetization of Py into the adjacent Pt as suggested by theory, and this additional damping contribution

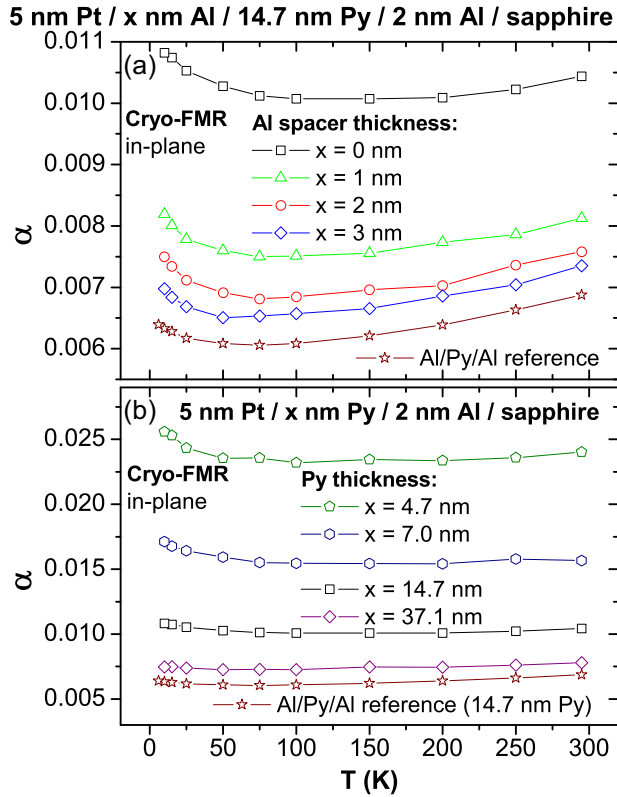


FIG. 2. (a) Summary of the Gilbert damping parameters α as a function of temperature for the Pt/Py spin-pumping heterostructure (black squares) in comparison to the heterostructures with varying Al-spacer thicknesses from 1 nm (green triangles), 2 nm (red circles), and 3 nm (blue diamonds). In addition, the Al/Py/Al reference sample is shown (wine stars). (b) The temperature dependence of α for Pt/Py with different Py-layer thicknesses from 4.7 nm up to 37.1 nm (see text).

can also be converted into the spin-mixing conductance [6]. However, in the present study there is a different focus: here, it is of interest, how this increased damping is altered, when the Pt is separated from the Py by a thin Al-spacer layer, i.e., by a low-Z metal with long spin coherence lengths [15]. It can be clearly seen that already the insertion of 1 nm Al spacer between Pt and Py (green triangles) strongly reduces the enhancement of α by about a factor of two at all temperatures, i.e., $\Delta\alpha$ ranges from 0.0013 at 295 K to 0.0019 at 10 K. This is further reduced for 2 nm (red circles) with $\Delta\alpha$ from 0.0007 at 295 K to 0.0012 at 10 K and 3 nm (blue diamonds) Al-spacer layers, where $\Delta\alpha$ is only around 0.0005 and thus close to being experimentally significant. Nonetheless, it appears that there is still some small enhancement of $\alpha(T)$ compared to the Al/Py/Al reference sample. This may be due to the presence of weak spin pumping, which still can pass through the 3 nm Al spacer. However, larger Al-spacer thicknesses, which could verify or disprove this hypothesis, are not possible due to the onset of a rough growth of Al above 3 nm leading to potentially altered magnetic damping of Py due to the onset of TMS processes [10].

Figure 2(b) shows the dependence of $\alpha(T)$ for Py in direct contact with Pt as a function of the Py layer thickness. For the thinnest Py thickness of 4.7 nm (olive pentagons),

α is increased by almost a factor of five compared to the Al/Py/Al reference. Note, that thinner Py layers are difficult to be studied because of the large FMR linewidth (up to 6.7 mT at 40 GHz and 295 K); the signal-to-noise ratio is close to the detection limit of the Cryo-FMR setup for 4.7 nm of Py. This strong increase of $\alpha(T)$ quickly reduces with the Py thickness and for 37.1 nm Py it is already close to the Al/Py/Al reference sample. The linear dependence of α , if plotted versus inverse Py thickness, illustrates that the increase of α for Py in direct contact with Pt is an interface effect, as reported before [6]. In addition, one can derive bulk and interface contributions from the inverse thickness dependence of α , as done before in [12,16]. Since only four thicknesses have been studied here and the α of the thinnest Py sample slightly deviates from the linear dependence in the $\alpha(1/d)$ plot, the accuracy of the extrapolated bulk value is somewhat limited. The bulk contribution of α^{bulk} for all temperatures is in the range of 0.0053(3) – 0.0057(4) for the present sample series (not shown) which compares well with the one for the Al/Py/Al reference series having an extrapolated α^{bulk} in the range of 0.0054(2) – 0.0061(2); see [12]. Also, the extrapolated bulk value for M_s from the SQUID measurements of 767(10) kA/m (not shown) agrees within experimental accuracy with the reference series having 782(18) kA/m [12]. The pronounced increase of $\alpha(T)$ for Py in direct contact with Pt can solely be attributed to a strongly increased interfacial damping $\alpha^{\text{interface}}$ of 0.11(4) nm compared to 0.014(3) nm for the Al/Py/Al reference [12]. This interfacial character of the increased α due to spin pumping is consistent with the reports in literature. On the other hand, the strong reduction of $\alpha(T)$ upon insertion of a thin Al-spacer layer has likely not been reported so far for Py/Pt, but qualitatively, these findings are consistent with reports for Al spacers in CoFeB/Pt in [9] and Cu spacers in Py/Pt in [8].

At first sight, it may be tempting to assign the strong increase of $\alpha(T)$ to some finite amount of intermixing at the Pt/Py interface due to the rather kinetic sputtering process. However, as already seen in Fig. 1, the basic magnetic parameters such as g -factor, M_{eff} , and anisotropy are virtually unaltered no matter whether Py is in direct contact with Pt or Al. To further shed light on the structural properties, additional TEM investigations are shown in Fig. 3 for the Pt/Py samples (a) without Al and (b) with 2 nm Al spacer. Due to the polycrystalline growth of the Py layer, the interface to the Pt cap layer is slightly wavy and the Al spacer layer in (b) can hardly be seen, neither in the HAADF-STEM, nor in the high-resolution TEM images. However, in the element distribution maps, it is visible that the transition between Py and Pt is rather abrupt in (a) for the sample without Al spacer, and for the sample with 2 nm Al spacer in (b), one can see that Pt and Py are separated by Al. In the line-by-line intensity profiles, the Al spacer layer can be seen as a peak right at the position where the Py and Pt intensities cross. One can therefore conclude that the Al spacer layer leads to a separation of Py and Pt without obvious intermixing. Note that the small signal of all other elements across the Pt layer visible in the line intensity profiles can be explained by fluorescence radiation caused by the high-energy characteristic Pt x-rays.

In a last step, the role of the Al-spacer layer shall be investigated by probing the element-selective magnetic properties

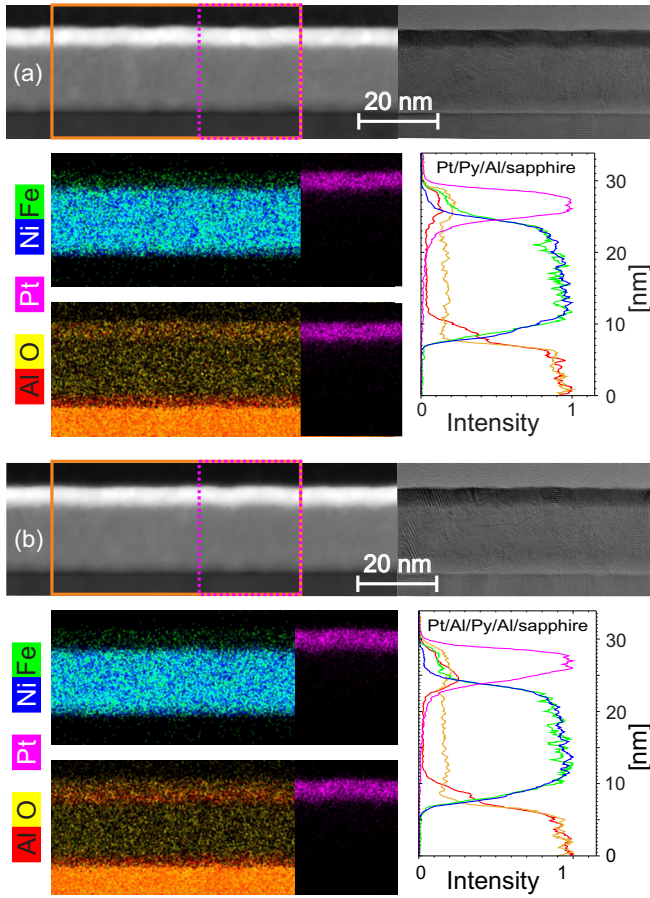


FIG. 3. HAADF-STEM images, high-resolution TEM images, and element distribution maps with corresponding line-by-line intensity profiles of the Pt/Py heterostructures having (a) no Al spacer and (b) a 2 nm Al spacer. The regions of the element analyses are marked by boxes, and the overlay of the combined element distribution maps of Fe/Ni and Al/O from the orange box are shown next to the Pt element distribution map from the purple box.

of the adjacent Pt layer as done before for Cu spacer layers in [8]; however, this time the identical pieces of samples were studied for the FMR and XMCD investigations. Figure 4(a) shows the background-free normalized XANES spectra at the Pt L_3 edge for the Py layer in direct contact with Pt (black) in comparison with the samples with an Al-spacer layer of 1 nm (green), 2 nm (red), and 3 nm (blue). It can be seen that the XANES changes upon introducing the Al-spacer layer. With increasing Al thickness, the main absorption peak becomes lower and broader developing a shoulder around 11.58 keV. In addition, the XANES is slightly shifting to higher photon energies. Both observations imply that the electronic structure of the Pt $5d$ -states is slightly altered when being in contact with either Py or Al. More importantly, Fig. 4(b) shows the resulting magnetic properties by means of XMCD at the Pt L_3 edge. For Pt in direct contact with Py, a clear XMCD signal of 1.5% and thus a finite induced polarization of Pt can be seen (black) with identical spectral shape and amplitude, no matter if recorded with the PD (thick line) or the SDD (thin line). However, due to the smaller signal-to-noise ratio in spectra recorded with SDD, which is mainly saturated by the elastic

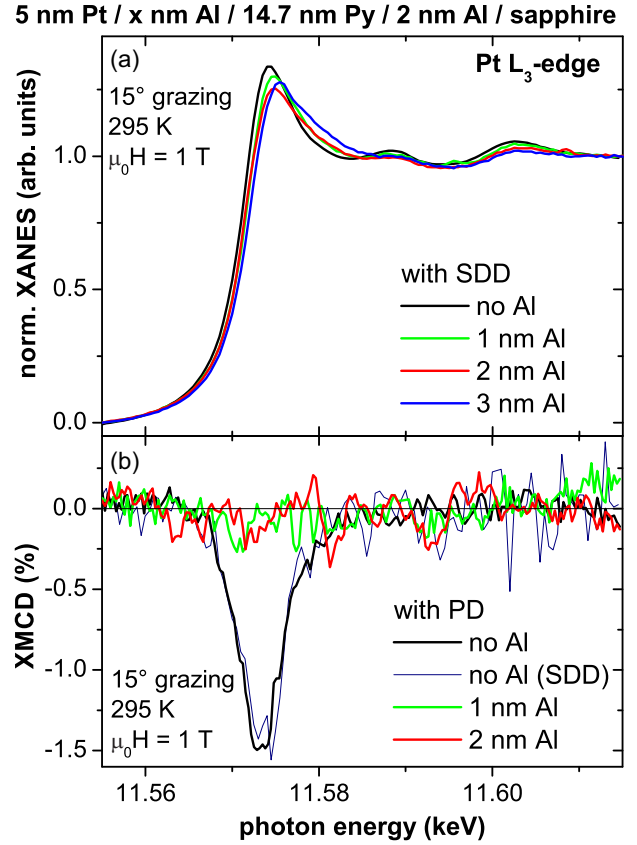


FIG. 4. (a) XANES measurements at the Pt L_3 edge recorded under 15° grazing incidence at 295 K and in an external field of 1 T for different thicknesses of the Al spacer using an energy resolved silicon drift detector (SDD). (b) Corresponding XMCD spectra of the Pt L_3 edge recorded using a conventional silicon photo diode (PD); for the Pt/Py heterostructure, the corresponding XMCD spectrum recorded with the SDD is shown for comparison (thin dark blue line).

peak, the XMCD is slightly noisier despite an increased number of averaged, individual XANES. Therefore, the XMCD spectra for the samples with 1 nm (green) and 2 nm (red) Al-spacer layers were only recorded using the PD to obtain better statistics and higher signal-to-noise ratios. Nonetheless, no XMCD signal could be detected, which demonstrates that already a 1 nm Al spacer is able to suppress the induced polarization of Pt. Furthermore, the size of the XMCD of our Pt/Py is consistent with the previous findings in [8] where a 1 nm thick Pt in a Pt/Py multilayer (two Pt/Py interfaces per Pt layer, fully polarized) showed an XMCD signal of 6% which compares well with an XMCD signal of 1.5% for a 5 nm thick single Pt layer (one Pt/Py interface), if one considers, that the induced polarization is limited to the interfacial region and does not extend over the entire 5 nm of the Pt film. In agreement with the findings for Cu spacer layers in [8], this implies that the presence of a strong increase of $\alpha(T)$ seen in Figs. 1(d) and 2(a) is associated with a clear induced magnetic polarization of Pt and the strong reduction of the increase of $\alpha(T)$ upon insertion of an Al-spacer layer is accompanied by a loss of the induced magnetic polarization of the Pt. These findings may corroborate theoretical predictions based on nonadiabatic modeling of FMR damping, which suggest that

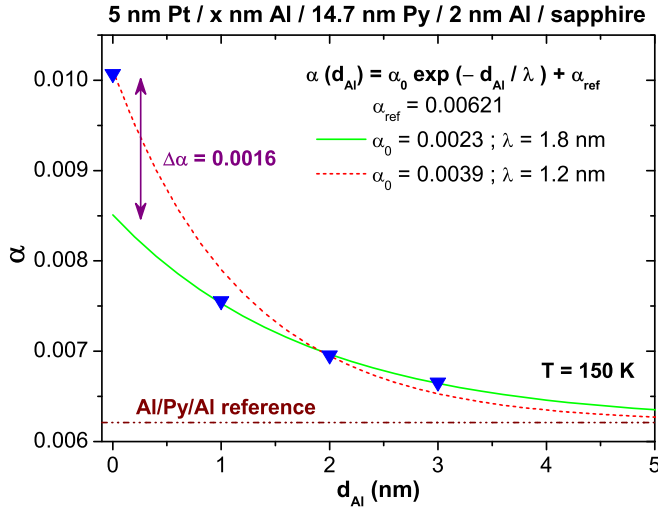


FIG. 5. Gilbert damping parameter α at 150 K as a function of Al spacer thickness d_{Al} for the Pt/Py spin-pumping heterostructures in comparison to the Al/Py/Al reference sample (wine dashed line). The lines are two different fitted exponential decays (see text).

“Stoner enhancement in materials like Pt and Pd also plays an important role in the determination of FMR frequencies and damping rates.” [17]. Note, that in [8] a similar effect of Cu spacers has also been reported for Pd/Py. Following that line of argumentation, one can take the changes in the Pt L_3 edge as an indication of a more narrow $5d$ band of the Pt induced by direct contact with Py, i.e., hybridization with the Ni/Fe $3d$ band, which gives rise to the induced magnetic polarization. This scenario may also better explain why already 1 nm of Al spacer is sufficient to suppress both induced polarization and enhancement of $\alpha(T)$ by simply suppressing the hybridization between the spin-split bands of the ferromagnet Py and the Stoner-enhanced paramagnet Pt.

All experimental findings suggest that the enhanced $\alpha(T)$ is composed of two contributions: (i) increased damping due to the Stoner enhancement of Pt evidenced by the induced polarization and (ii) spin pumping, which persists over a certain thickness of the Al-spacer layer as evidenced by the gradual reduction of $\alpha(T)$ with increasing Al-spacer thickness. To get an idea of the relative size of the respective contributions, the data of α in Fig. 2(a) have been plotted against the thickness of the Al spacer. Figure 5 exemplarily shows the $\alpha(d_{\text{Al}})$ data at 150 K. An exponential decay has been fitted to the data, once including the Pt/Py sample without Al spacer (dashed red line) and once without (solid green line); α_{ref} has been set to the value of the Al/Py/Al reference sample. It is obvious, that the entire data set cannot be fitted well with a single exponential decay, while only the Pt/Py spin-pumping heterostructures with Al spacer layers can be fitted surprisingly well. This model implies a characteristic decay length λ of a pumped

spin current through the Al spacer, which however disregards possible separate effects of different spin transmission coefficients at the Py/Pt versus Py/Al/Pt interfaces. Nonetheless, such a fit allows to estimate the effect on α in the limit of vanishing Al spacer layers; this α_0 of about 0.0023 can be considered to be the additional damping contribution of spin pumping in the absence of an induced Pt polarization. In turn, the remaining $\Delta\alpha$ of about 0.0016 (indicated by the arrow in Fig. 5) can be regarded as additional magnetic damping due to the induced magnetic polarization of the Pt. Admittedly, a fit to a set of only three data points does not allow to draw very significant quantitative conclusions, but a similar analysis like in Fig. 5 for the other temperatures consistently shows that around 40%, i.e., a quite substantial fraction, of the increase of α compared to the Al/Py/Al reference sample can be attributed to the induced magnetic polarization of Pt.

IV. SUMMARY

The magnetic damping in Pt/Py and Pt/Al/Py spin-pumping heterostructures has been studied and it has been shown that Pt in direct contact with Py exhibits the expected increase of the FMR linewidth due to an interfacial increase of damping commonly assigned to spin pumping. However, this goes hand-in-hand with an induced magnetic polarization of the Pt evidenced by XMCD. Separating Pt and Py by the insertion of a thin Al spacer layer, the increase in FMR linewidth is gradually reduced, and for 3 nm spacer thickness, α is already close to the value of an Al/Py/Al reference sample. Already starting from 1 nm of Al spacer layer thickness, the induced magnetic polarization of Pt vanishes, which indicates that the strong increase of α has to have more than one microscopic origin, and one has to at least consider induced magnetic polarization and spin pumping as separate contributions to the increased Gilbert damping $\Delta\alpha$ in Pt/Py spin-pumping heterostructures.

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DATA AVAILABILITY

There are no publicly available research data or software supporting this manuscript. Requests for further information or data should be sent to the authors.

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