Collective spin pumping beyond the single-interface limit: The role of interlayer exchange coupling

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Understanding of how interlayer exchange coupling (IEC) reshapes collective magnetization dynamics is essential for controlling spin transport and damping in nanoscale magnetic systems. When two ferromagnetic (FM) layers are indirectly coupled through a nonmagnetic (NM) spacer, their magnetizations no longer precess independently — instead, the balance between bilinear (J_1) and biquadratic (J_2) exchange interactions, magnetic anisotropy of individual sublayers, and interfacial spin–orbit effects defines a new dynamic state governed by an effective magnetic anisotropy field (H_{eff}). In this talk, I will explore how this balance manifests experimentally in Fe/Si/Fe and Co/Re/Co trilayers using time-resolved magneto-optical Kerr effect measurements, which will be supported by analytical modeling and numerical solutions of coupled Landau–Lifshitz–Gilbert equations [1, 2]. In both systems, coexistence of J_1 and J_2 leads to noncollinear magnetization ordering and hybridization of precession modes into acoustic and optical branches [3]. The strength of IEC directly modifies the frequency field dependencies $f(H)$, reshaping H_{eff} and determining whether the modes remain well separated, cross, or soften. At the same time, collective precession activates mutual spin pumping across FM/NM interfaces. As a result, intrinsic Gilbert damping and effective spin-mixing conductance ($g_{\uparrow\downarrow}^{\text{eff}}$) become strongly dependent on coupling strength and magnetic configuration. The two material systems, however, reveal distinct physical regimes. In Fe/Si/Fe multilayers, systematic tuning of spacer thickness drives the transition between ferromagnetic and antiferromagnetic bilinear coupling with a significant biquadratic contribution. This enables observation of mode-crossing phenomena and optical-mode softening near the critical condition $|J_1| \approx 2 \cdot J_2$, providing direct insight into the interplay between exchange and anisotropy fields. In Co/Re/Co heterostructures, strong antiferromagnetic IEC combined with mixed magnetic anisotropies of asymmetric Co layers produces pronounced noncollinearity and exceptionally strong mutual spin pumping. In this case a marked enhancement of intrinsic damping and a giant increase of $g_{\uparrow\downarrow}^{\text{eff}}$ compared to uncoupled single Co layers is observed, demonstrating a direct correlation between IEC magnitude, anisotropy imbalance, and dynamic spin transport efficiency. For comparison, Co/Pt/Co trilayers [3] — despite thickness-driven magnetic reorientation transitions — exhibit only a single precession mode, indicating absence of resolvable dynamic hybridization and highlighting the decisive role of IEC in shaping collective dynamics.

These results establish interlayer exchange coupling as a decisive control parameter for tailoring effective magnetic fields, collective mode formation, intrinsic damping, and spin-pumping efficiency in nanoscale magnetic heterostructures, opening pathways toward IEC-engineered high-frequency spintronic devices.

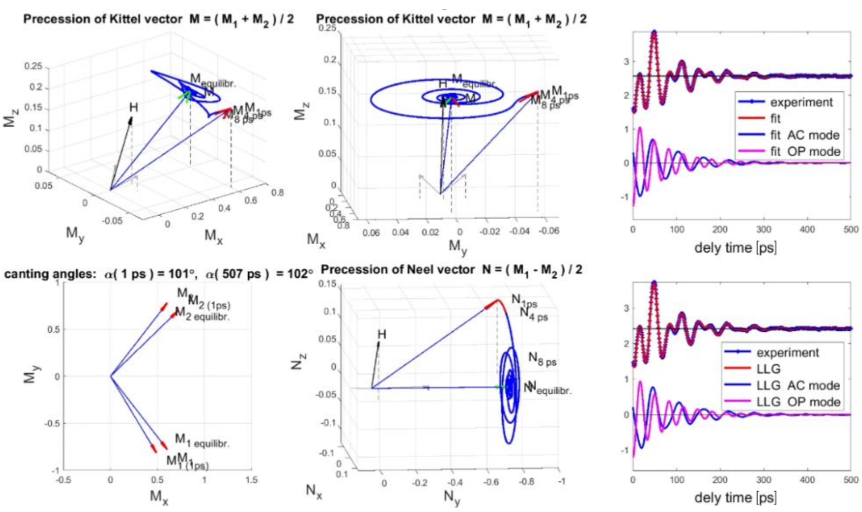

Fig. 1. The illustration shows the example of spatial evolution over delay time (left panels column) during the magnetization precession of M_1 and M_2 vectors, as well as Néel and Kittel vectors (middle panels column), together with the fitting of the experimental signal decomposed into two modes and the comparison with LLG-based simulations (right panels column).

References:

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