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INVERSION OF THE SPIN-TORQUE EFFECT IN MTJs VIA RESONANT MAGNON SCATTERING

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Nanoscale magnets are the building blocks of many existing and emergent spintronic applications, e.g. nonvolatile spin torque memory, spin torque oscillators, neuromorphic and probabilistic computing. Controlling magnetic damping in nanomagnets holds the key to improving the performance of future technologies. Here, we experimentally demonstrate and theoretically corroborate that a ferromagnetic nano-particle (free layer of a magnetic tunnel junction (MTJ) nanopillar) can exhibit spin dynamics qualitatively different from those predicted by the harmonic oscillator model. Nonlinear contributions to the damping can be unusually strong, and the effective damping parameter itself can exhibit resonant dependence on field/frequency [1].

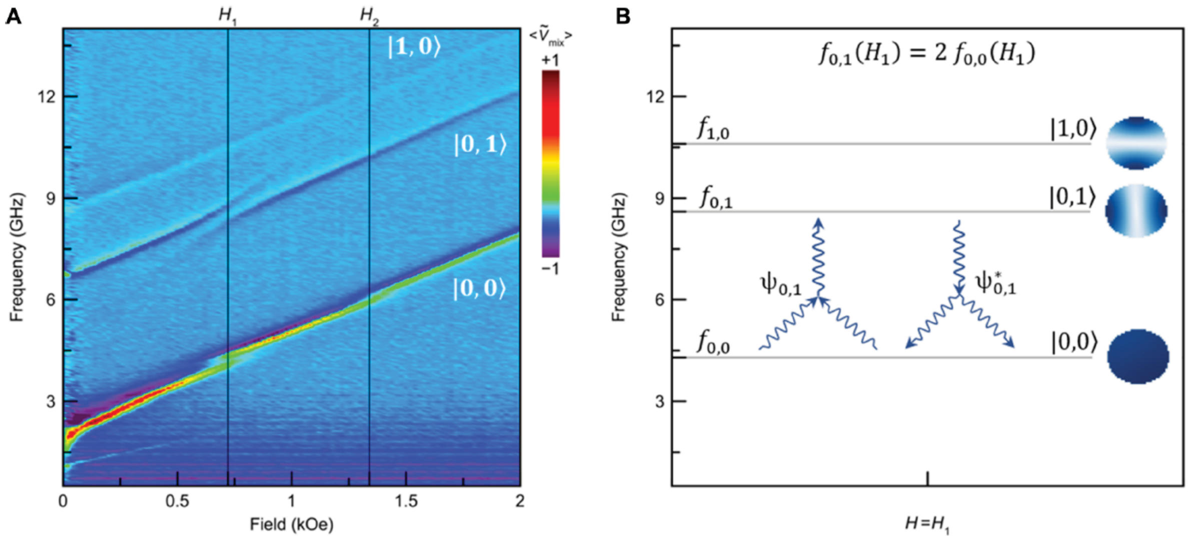

Figure 1: (A) Spin-torque ferromagnetic resonance on a 60 nm MTJ nanopillar with out-of-plane magnetic anisotropy. The spectrum reveals three discrete spin wave modes localized in the nano-size free layer of the MTJ. At the characteristic fields of the three-magnon scattering, the spin wave spectra show anomalies (splitting, broadening, apparent anti-crossing). (B) Sketch of the three-magnon scattering: at the first characteristic field, two quanta (magnons) of the lowest-energy spin wave mode merge into one magnon of the next higher-energy mode. The lateral profile of the spin wave amplitudes is shown. Source: modified from Ref. [1] (see *).

We carry out spin torque ferromagnetic resonance [2] on magnetic tunnel junction nanopillars with in-plane and out-of-plane magnetic anisotropy. We observe a discrete spin-wave spectrum in the geometrical confinement of the MTJ free layer (Fig. 1A). Its analysis uncovers a nonlinearity that has a strong impact on nanomagnet's response even at low excitation levels. The nonlinearity shows a distinct resonant enhancement at characteristic magnetic fields corresponding to the three-magnon scattering (Fig. 1B), where the frequency of the lowest-energy mode is half of that of a higher-energy mode. This process manifests in splitting or broadening (Fig. 2A) of the lowest-energy spin wave mode spectrum and in an apparent anti-crossing signature of the higher-energy modes. We present evidence of processes in which two quanta of the lowest-energy mode merge into one quantum of higher-energy modes.

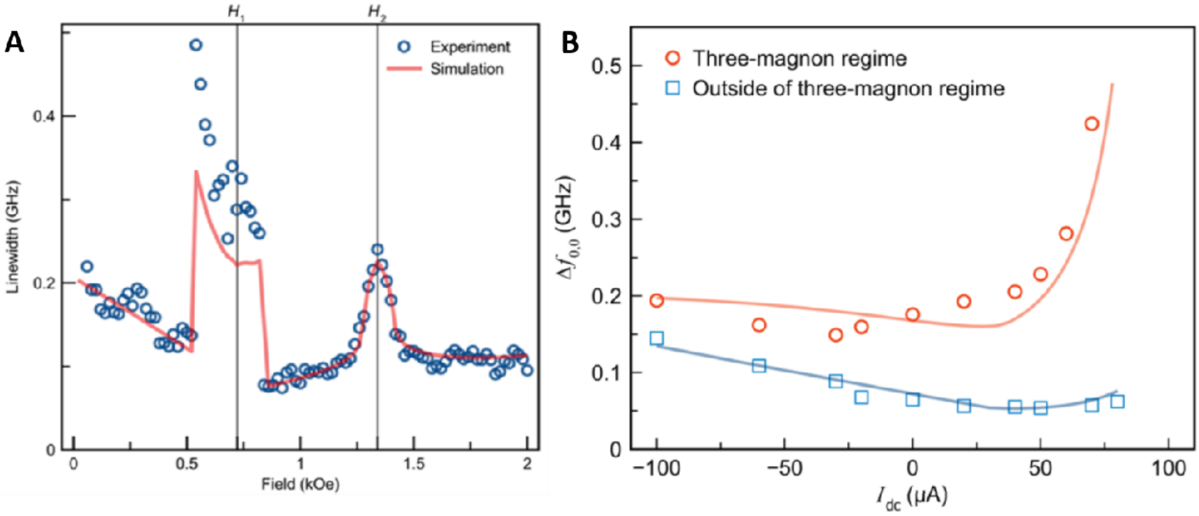

Figure 2: (A) The frequency linewidth of the lowest-energy spin wave mode as a function of the applied magnetic field. At the characteristic fields, the three-magnon scattering leads to spectral broadening. (B) The linewidth of the lowest-energy mode decreases linearly with increasing the DC bias current supplied to the MTJ, when the applied magnetic field is far away from the characteristic field. However, near the characteristic field (i.e. in the three-magnon regime), the linewidth changes its behavior. The effective damping of the lowest-energy mode begins to rise with an increasing anti-damping spin torque. Source: modified from Ref. [1] (see *).

Our work demonstrates that nonlinear damping in nanomagnets is qualitatively different from that in extended systems [1,3]. The observed resonant magnon scattering drastically alters the magnetization dynamics of a nanomagnet driven by spin torques. We find that it reverses the effect of the spin torque on magnetic damping and turns an anti-damping torque into a dissipation-enhancing torque. As shown in Fig. 2B, the linewidth (corresponding to the effective damping) of the lowest-energy mode decreases, as expected, linearly with electric current bias supplied to the MTJ, when outside of the three-magnon regime. However, at the characteristic magnetic fields corresponding to the three-magnon regime, the linewidth of the lowest-energy mode diverges near the expected critical current. The discovery of this counter-intuitive effect advances our understanding of spin dynamics in nanoscale magnetic systems and has far-reaching implications for spin torque oscillators, spin torque memory, and other emergent spintronic technologies.

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