Nonlinear magnetization dynamics in magnetic insulator / normal metal hybrids

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The equation of motion of magnetization is strongly nonlinear, yielding a series of interesting phenomena. For instance it is well known that in ferromagnetic resonance of extended films, where one uses a microwave field to pump the spin system at a particular frequency, spin-wave (SW) instabilities quickly develop as the excitation power is increased, preventing to achieve large angle of uniform precession. Due to its unmatched low damping, yttrium iron garnet (YIG) has been for long the material of choice to investigate the deeply nonlinear regime. In this talk, I will discuss two different experiments, allowed by the recent development of ultra-thin (< 20 nm) YIG films of high dynamical quality [1].

In the first one, nonlinear ferromagnetic resonance is monitored by magnetic resonance force microscopy in the out-of-plane configuration of individual YIG nanodiscs with diameters below 1 μm. Due to the geometric confinement, SW modes are highly quantized [2], and the SW instabilities described above are far less effective. As a result, a very large foldover of the main resonance line can be observed: for relatively weak microwave excitation fields, in the mT range, the nonlinear field shifts are as large as 0.18 T, corresponding to a reduction of the longitudinal magnetization M_z by up to 90%. Strikingly, the reduction of M_z is not constantly growing as the power is increased, but instead presents plateaus, pointing towards nonlinear energy dissipation to quantized SW modes [3].

In the second one, SWs are generated by spin-orbit torque in YIG/Pt hybrid structures. Above a threshold current injected into the Pt (typically, a few 10^{11} A/m^2), the transfer of angular momentum across the YIG/Pt interface is sufficient to destabilize SWs in YIG. It is observed that the threshold current is increased by the presence of quasi-degenerate SW modes, whose density is reduced by the confinement. The spectral width of the auto-oscillation peak grows with the supercritical current, and the corresponding electrical signal vanishes, which is attributed to the nonlinear flow of energy from the most uniform mode towards non-uniform modes that are poorly coupled to the inductive detection scheme [4]. To support this interpretation, micro-focus Brillouin light scattering is used to directly image the dynamic modes excited by spin-orbit torque in YIG/Pt hybrids. The dynamic magnetization exhibits strong spatial localization at the onset of the auto-oscillations. However, just above the onset, the amplitude of the auto-oscillations rapidly saturates and the excited mode experiences a spatial broadening [5]. These behaviors are ascribed to the efficient nonlinear mode coupling, which prevents the growth of the amplitudes of the dynamic magnetization to the level necessary for the onset of nonlinear self-localization and formation of the bullet mode.

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