High-momentum nonlinear magnons under parametric pumping detected by Mie-enhanced Brillouin Light Scattering

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Spin waves (SWs) carry information with minimal energy loss and allow for novel computational paradigms using wave-based computing. However, efficient excitation and detection of SWs at the nanoscale is essential for applications. Parametric pumping enables excitation of nanoscale SWs using a spatially unconstrained antenna by exciting two counter-propagating SWs at half the pumping frequency ($\frac{1}{2}f_{\mathrm{p}}$) [1]. As a threshold process, it requires a dynamic magnetic field of sufficient amplitude, which may promote additional nonlinear processes, such as three- or four-magnon scattering. These nonlinearities facilitate unconventional SW interactions, relevant for neuromorphic computing [2].

Experimental study of nanoscale parametrically pumped SWs in the non-adiabatic regime (using a finite-width excitation antenna) can't be done using pump-probe techniques, e.g. Scanning Transmission X-ray Microscopy, because the SW frequencies deviate from exactly $\frac{1}{2}f_{\mathrm{p}}$ [1]. Hence, we employed a Mie-resonance-enhanced microfocused Brillouin Light Scattering (Mie-enhanced µ-BLS) microscopy, which allows for broadband frequency detection of nanoscale SWs [3].

In our experiments, we detected parametrically pumped SWs in a thin NiFe film at frequencies up to 4 GHz, corresponding to a wavelength of ∼100 nm. Moreover, we observed SW signals at $\frac{3}{4}f_{\mathrm{p}}$ and $\frac{5}{4}f_{\mathrm{p}}$, detected only in Mie-enhanced µ-BLS experiments and absent in conventional µ-BLS measurements. This indicates that these modes are associated with high-momentum (nanoscale) SWs, and we attribute their emergence to a four-magnon scattering. Using MuMax3 we modeled our system and obtained results equivalent to the experiment. Further analysis revealed that the SWs at $\frac{3}{4}f_{\mathrm{p}}$ and $\frac{5}{4}f_{\mathrm{p}}$ are predominantly generated in a wavevector range of 40-50 rad/µm. Our results demonstrate the feasibility of experimentally studying nonlinear nanoscale SW dynamics using relatively simple instrumentation.

References:

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