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Nonlinear spin-wave excitations at low magnetic bias fields

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We investigate experimentally and theoretically the nonlinear magnetization dynamics in magnetic films at low magnetic bias fields. Nonlinear magnetization dynamics is essential for the operation of numerous spintronic devices ranging from magnetic memory to spin torque microwave generators. Examples are microwave-assisted switching of magnetic structures and the generation of spin currents at low bias fields by high-amplitude ferromagnetic resonance. In the experiments we use X-ray magnetic circular dichroism to determine the number density of excited magnons in magnetically soft $Ni_{80}Fe_{20}$ thin films. Our data show that the common Suhl instability model of nonlinear ferromagnetic resonance is not adequate for the description of the nonlinear behavior in the low magnetic field limit. Here we derive a model of parametric spin-wave excitation, which correctly predicts nonlinear threshold amplitudes and decay rates at high and at low magnetic bias fields. In fact, a series of critical spin-wave modes with fast oscillations of the amplitude and phase is found, generalizing the theory of parametric spin-wave excitation to large modulation amplitudes. For these modes, we also find pronounced frequency locking effects that may be used for synchronization purposes in magnonic devices. By using this effect, effective spin-wave sources based on parametric spin-wave excitation may be realized. Our results also show that it is not required to invoke a wave vector-dependent damping parameter in the interpretation of nonlinear magnetic resonance experiments performed at low bias fields.