Magnon-dynamics Studies in Ferromagnets including Effects of Secondary Signal

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Motivation

Excitation of ferromagnets by a microwave signal can lead to interesting non-linear effects. Such phenomena have garnered considerable research interest recently in both the physics as well as the engineering communities. Proper understanding of such processes is needed before magnetic-materials could be used for applications such as microwave-signal-processing and novel computation paradigms like magnonic and spintronics. Applications ranging from mobile phones and state-of-the-art satellite systems to critical defense-related systems like RADARs would benefit immensely from the non-linear magnetics based technology.

The advantages of magnetics-based nonlinear devices include: lower energy consumption, better accuracy, and simpler implementation when compared with all-electrical implementations currently in use. However, not sufficient physical understanding exists as of now for the development of design rules that are necessary for practical devices.

The main goals of this study are: to develop powerful computational tools and techniques for studying magnetic non-linear processes, and use these tools to provide essential predictive capability towards the design of magnetic-material-based devices.

Physical Principles and Methodology

**Magnetic-sample and -fields**

Magnetic sample with field configurations

**Equation of motion**

Landaau-Lifshitz-Gilbert equation (LLG)

**Micromagnetic Solver**

Landaau-Lifshitz-Gilbert Micromagnetic solver is based on CUDA (parallel programming language) and relies on modern GPUs for computing magnetization dynamics under RF excitation.

Most important parameters are: effective magnetic-field ($H_{eff}$) and magnetization ($\mathbf{M}$).

Effective magnetic field comprises of:

(a) Neighbor independent fields: Applied (DC and RF), thermal fields. These allow for a high degree of parallelism.
(b) Neighbor dependent fields: Exchange, demagnetization fields.

**Demonstration of 3-magnon Scattering Process**

Three magnon scattering is an energy ($\omega$) and momentum ($\mathbf{k}$) conserving nonlinear process intrinsic to the magnetic material.

**Nonlinearity control using secondary signal**

A novel method that allows in-situ control of the non-linearity has been developed.

Conventionally, non-linearity control is achieved by changing the thickness of the sample, however, this has the obvious disadvantage of having to physically replace the magnetic sample.

This has limited the use of magnetic-materials for various applications that require control of non-linearity e.g. noise reduction in communication systems.

**Experimental Conformity**

Parameters

- Saturation magnetization: \(145 \text{emu/cm}^3\)
- Intrinsic damping: \(3 \times 10^{-5}\)
- Hf film thickness: \(5.1 \mu\text{m}\)

- Agreement with experiment to within 2 dbm (agreements within 5 dbm are considered reasonable).
- Points to the suitability of Micromagnetics for such nonlinear studies.
- Justifies the newly developed reduced 2D-simulation paradigm as well as magnon-based approach to analysis.

**Magnetization near $h_{th}$**

(a) Demonstrated magnon pair creation and subsequent pair interactions that lead to increased importance of 4-magnon scattering in device physics. (Ask to Cooper-pairs in superconductors.)

(b) Demonstrated direct excitation of $\mathbf{k} = 0$ magnons.

Conclusions

a) Developed an accurate, efficient, and fast computational tool that can capture essential physics of parallel RF-excitation of ferromagnets. This is useful in the design of near-future RF devices, and futuristic magnonic/spintronics devices.

b) Demonstrated computationally the abstract intrinsic processes of the three - magnon scattering.

c) Demonstrated in-situ control of the non-linear nature of the material using an additional secondary signal of MHz frequency.

d) Demonstrated exceptional agreement with experimental data with regard to RF threshold fields.

e) Investigated interesting features of magnon dynamics close to RF threshold field. Four-magnon interactions ignored in device level physics are found to have increased role in determining device behavior.

Future Work

a) Demonstration and study of non-linear damping effects e.g. negative damping.

b) Studies involving two GHz radio-frequencies to look at absorption and intermodulation products.

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