Exchange Magnon in Ferromagnetic Thin Films Exited by a Series of Acoustic Pulses

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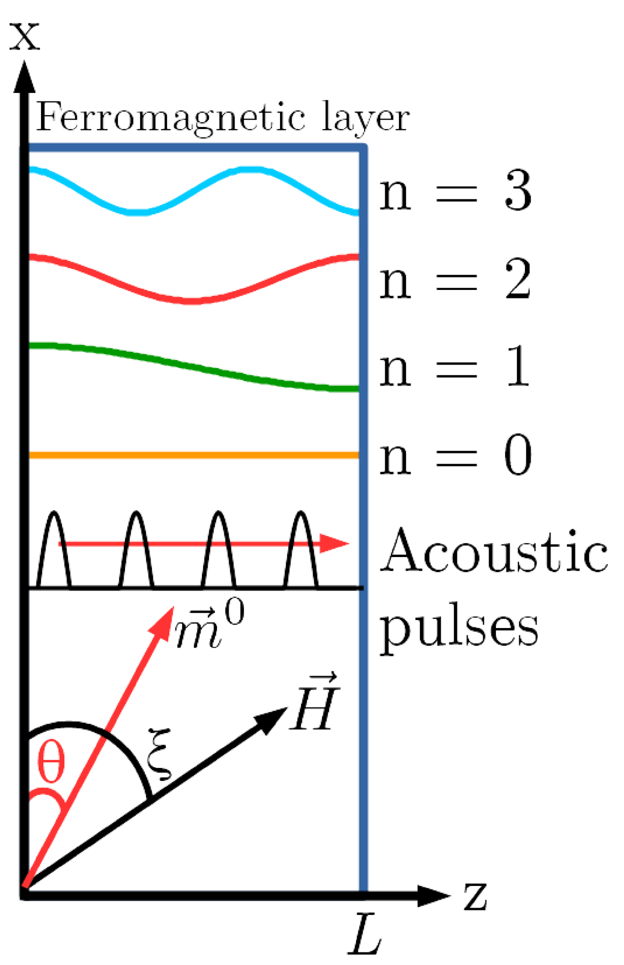
Introduction

Ultrafast demagnetization and precession of the magnetization induced by ultrashort laser pulses are very active topics[1-4] even though their demonstration is quite recent[5]. The idea of data transmission by using the spins rather than electric currents had a large impact. Ultrafast manipulation of the magnetization is a key for further development of spintronics. Magnetization dynamics can be driven by different mechanisms[6]. Since we consider a single ferromagnetic layer, we can limit our consideration just to two mechanisms: laser-induced heating[2,6] and phonon-magnon interaction[7]. Here we only consider the second mechanism. We report a numerical study of the magnetization dynamics in nickel thin films excited by a series of picosecond acoustic pulses. This situation can be realized in an optical pump-probe experiment using a train of laser pump pulses. Absorption of each pump pulse leads to the excitation of an acoustic pulse. Acoustic pulses propagate through a ferromagnetic film and alter the direction of the effective magnetic field thereby driving precessional motion of the magnetization.

Theory

Geometry



Landau-Lifschitz-Gilbert Equation

$$\boxed{\underset{(1)}{\frac{\partial \vec{m}}{\partial t}} = \underset{(2)}{\gamma}\vec{m}(t) \times \underset{(3)}{\vec{H}_{eff}(t)} - \frac{\overset{(4)}{\alpha}}{|\vec{m}(t)|}\vec{m}(t) \times \frac{\partial \vec{m}}{\partial t}}$$

This model includes:
- (1) magnetic moment
- (2) gyromagnetic ratio
- (3) effective magnetic field
- (4) Gilbert damping

(3) includes:
- demagnetization field
- external magnetic field
- exchange field
- inverse magnetostrictive effect

Boundary conditions

$$\left.\frac{\partial \vec{m}}{\partial z}\right|_{z=0,L} = 0$$

Magnetization

$$\vec{m} = \vec{m}^0 + \sum_{n=0}^{N} \vec{m}_n(t)\cos(k_n z)$$

$$k_n = \frac{\pi n}{L}$$

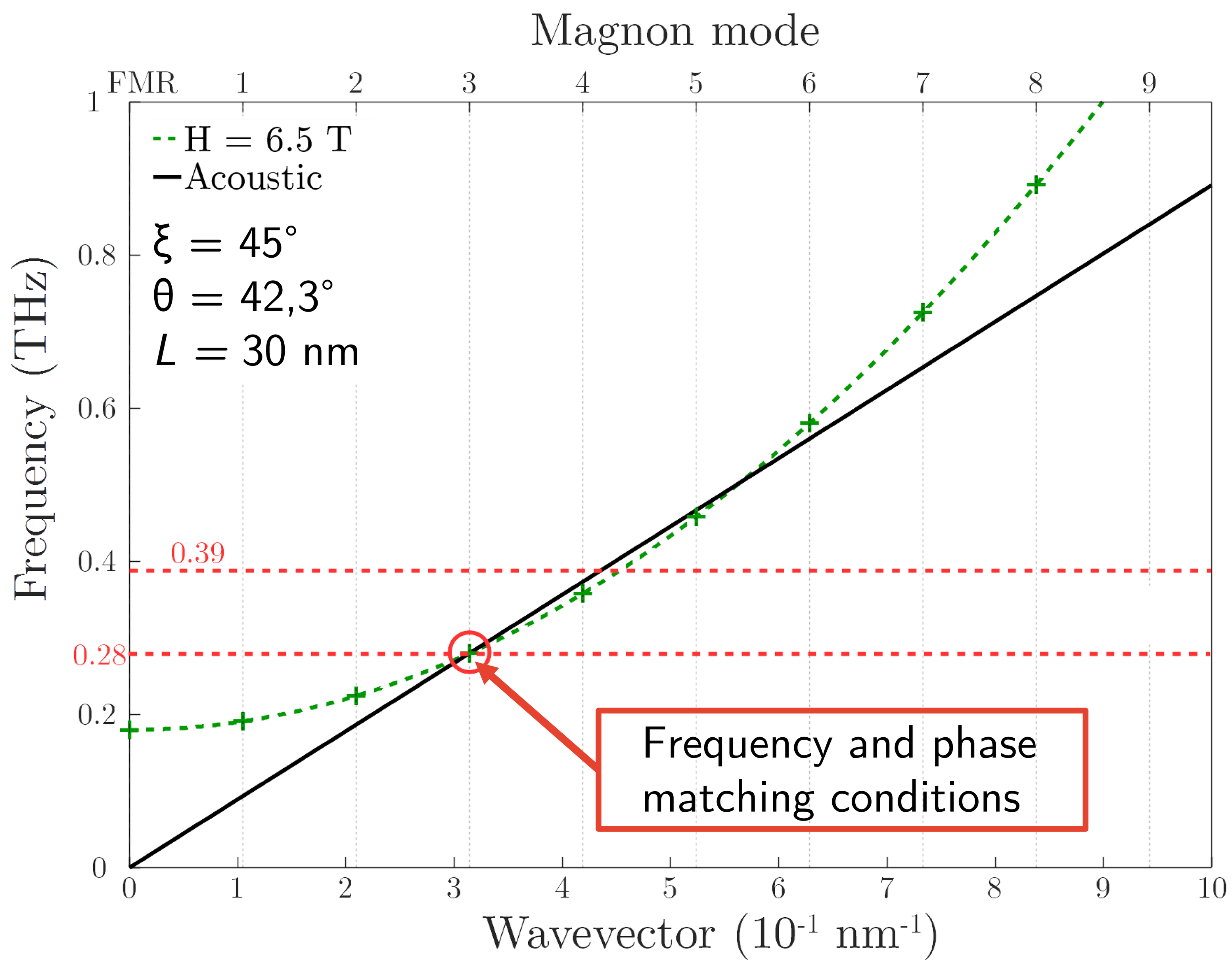
Numerical results and analysis

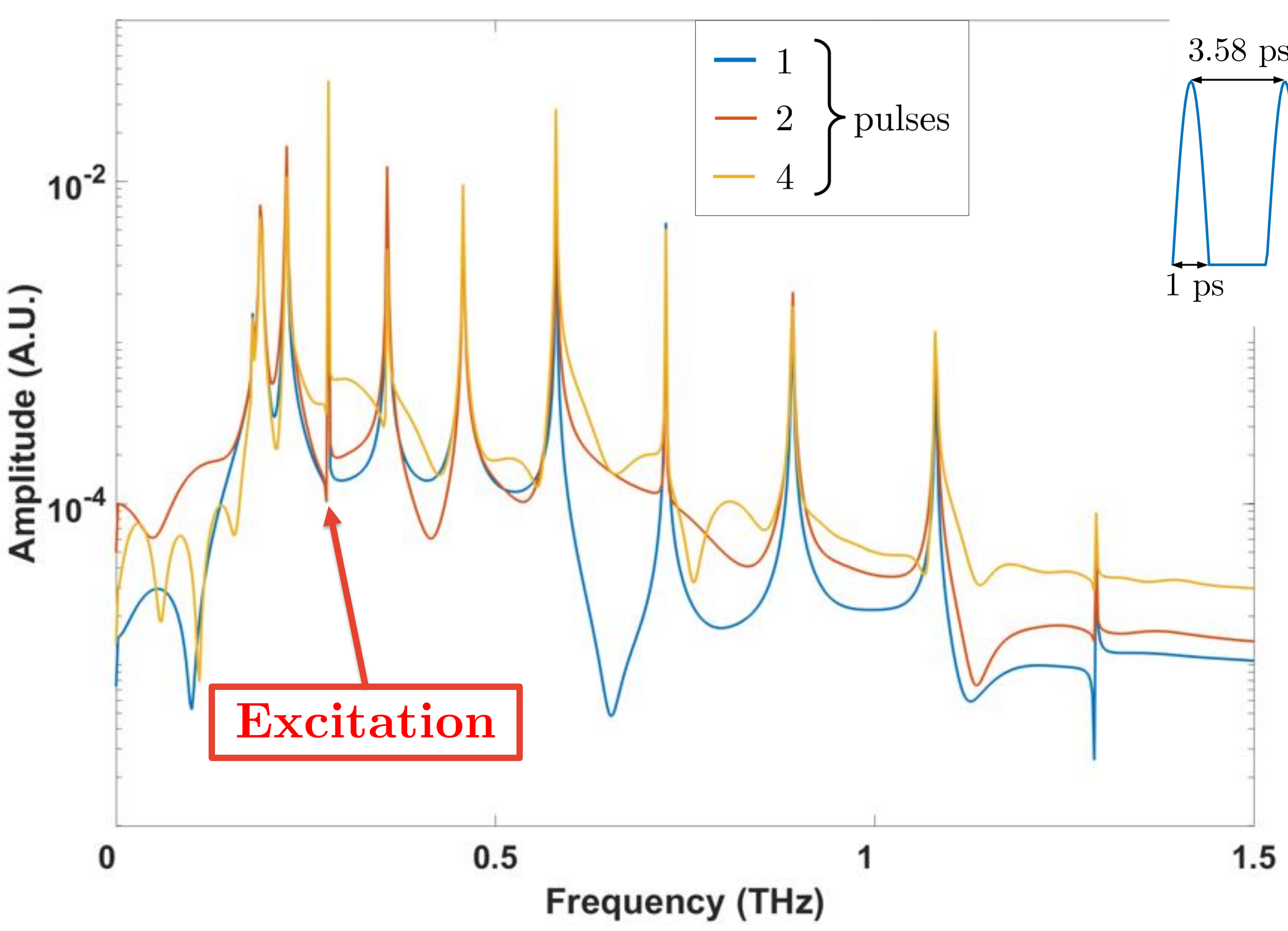
Spinwaves resonant frequencies

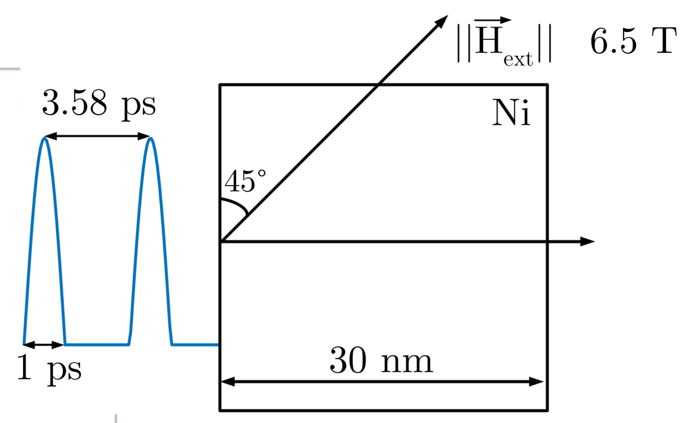
$$\begin{aligned} \omega_n^2 &= (\gamma\mu_0)^2 \Big[\big(H\sin\xi + (Dk_n^2 - M_0)\sin\theta\big)^2 \\ &+ \big(H\cos\xi + (Dk_n^2 + M_0)\cos\theta\big)\big(H\cos\xi + Dk_n^2\cos\theta\big)\Big] \end{aligned}$$

By playing on the magnitude of the external magnetic field it is possible to tune the position of crossing points between the magnonic and the acoustic dispersion curves. So there is different configurations/matching conditions :

- Frequency
- Phase
- Group







With the appropriate matching condition (here frequency and phase) it is possible to amplify one magnon mode (here the third one).
By varying the number of acoustic pulses it is possible to amplify this excitation.

It is possible to drive the magnetization with acoustic pulses by playing on:
- their shapes.
- their number.
- the delay between them.

Frequency and phase matching, together, lead to the highest amplification. Spinwaves could be highly damped.

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