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Characterization of Magnetic Properties of 3D CoFeB Nano-Pyramids

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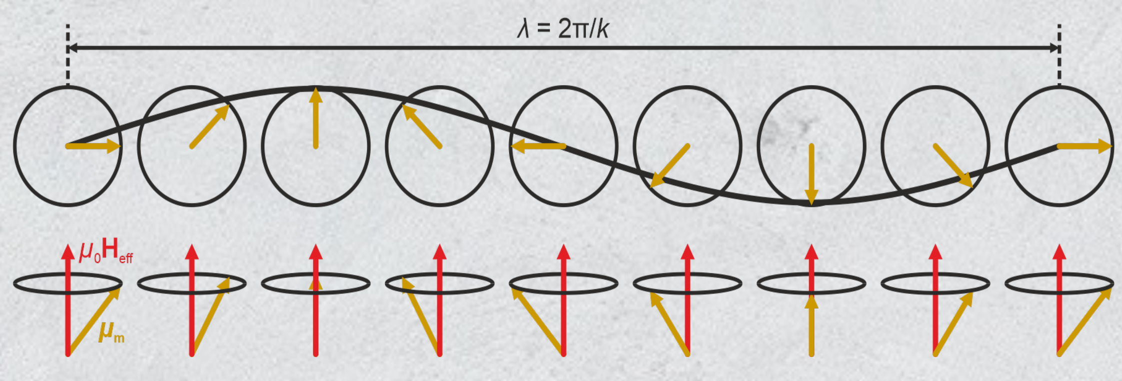
Introduction

What are Spin Waves ?

The magnetism of ferromagnetic materials is made of many local magnetic moments called spins. When excited by microwaves, the spins start precessing and we talk about **spin waves** (SW), also known as **magnons**.



Their motion of precession is determined by the **Landau-Lifschitz-Gilbert** (LLG) equation:

$$\frac{dM}{dt} = -\frac{\gamma\mu_0}{1+\alpha}\left[(M \times H_{eff}) + \frac{\alpha}{M_s} M \times (M \times H_{eff})\right]$$

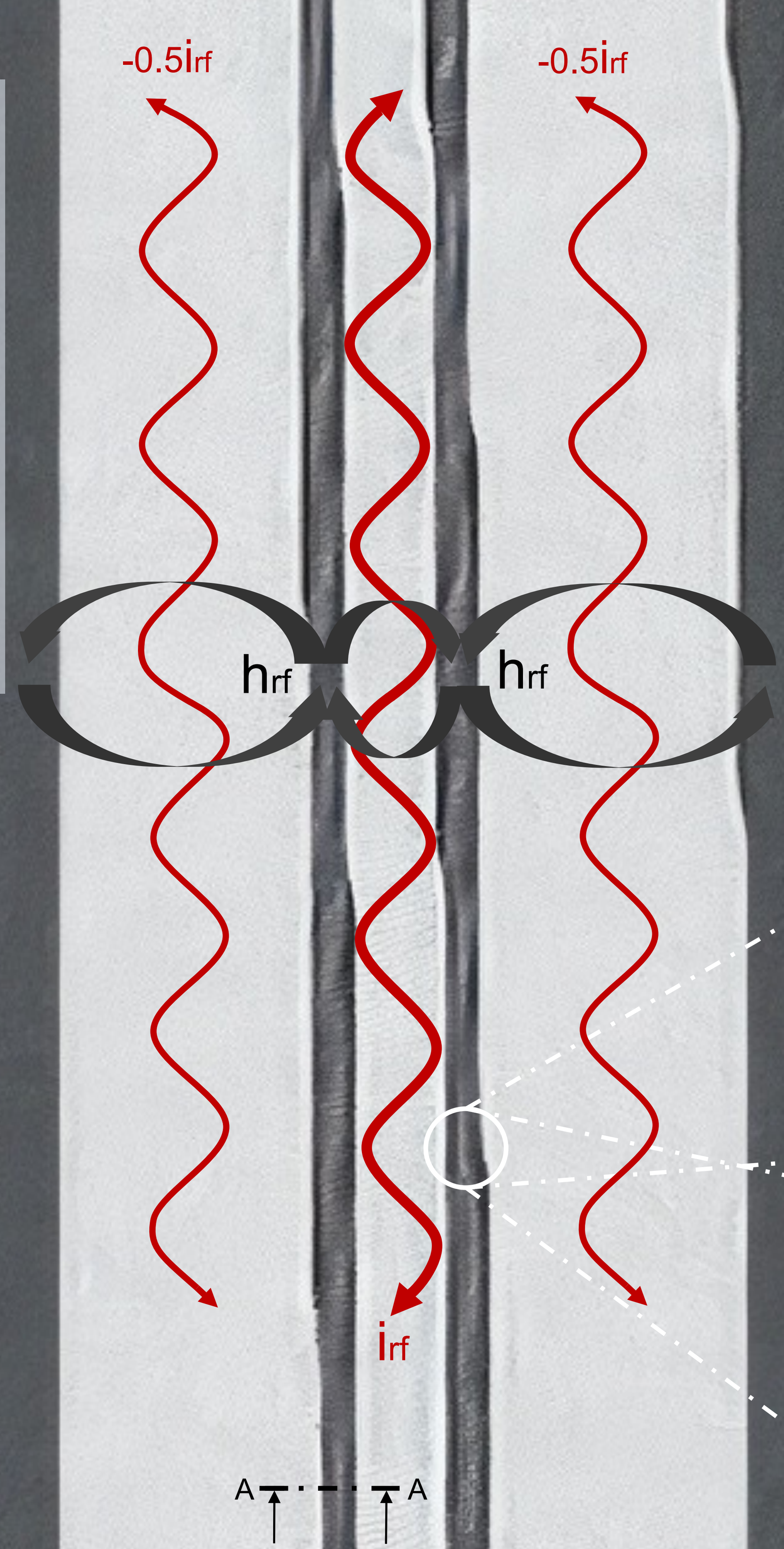
$H_{eff} = H_{ext} + H_{demag} + \ldots$

Why Spin Waves ?

- Short wavelength (nm)
- High processing speed
- Less heating
- Miniaturization
- Operate in GHz range of modern technologies 1 - 300 GHz
- Signal processing and computing applications

Research Aim

The aim of this research is to study the **magnetic response** of inverted 3D **CoFeB nanopyramids** when excited with spin waves using **broadband ferromagnetic resonance**.



Results & Discussions

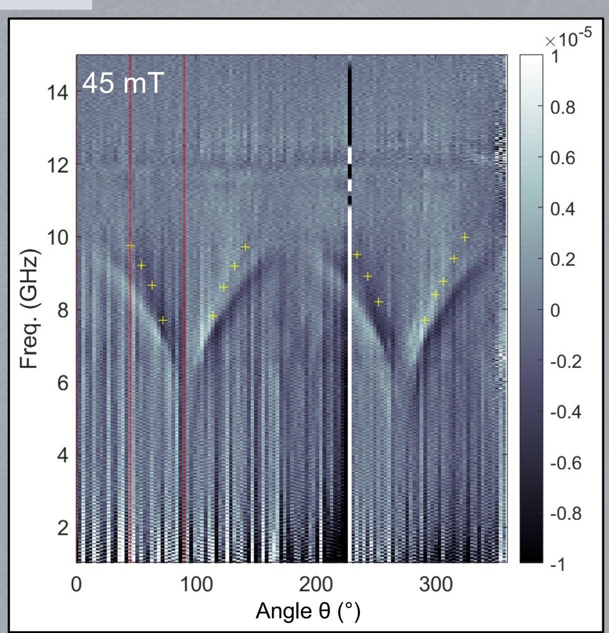
Angle sweeps

Two-fold symmetry around 180° axis

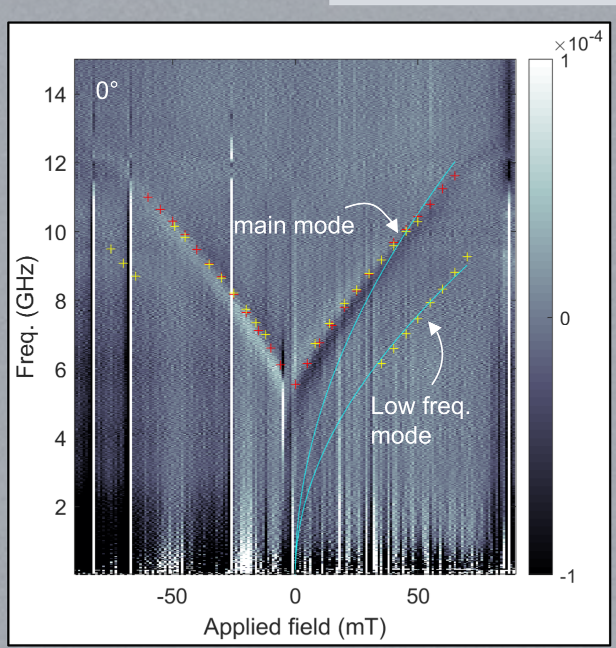
Interesting points

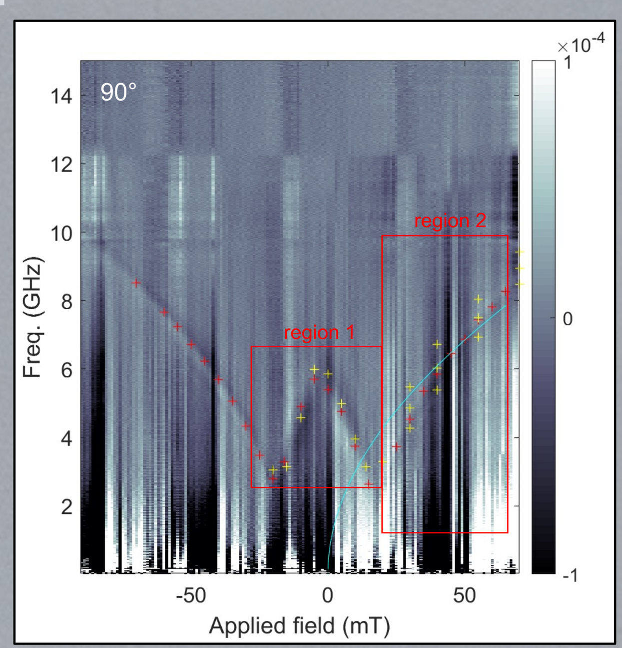
- 0° ➜ H_{ext} field oriented along pyramid edges
- 45° ➜ H_{ext} field oriented along pyramid diagonals
- 90° ➜ Lowest frequency orientation

Secondary mode branches



Field sweeps





Chip 1 absorption spectra

- + Chip 1 plot
- + Chip 2 plot
- Kittel fit

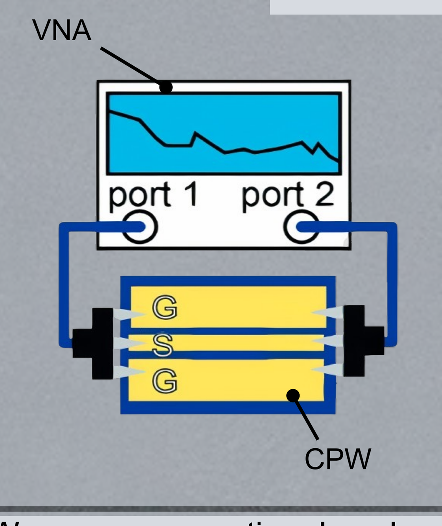
Kittel formula for a thin film:

$$f_{res} = \frac{\gamma\mu_0}{2\pi}\sqrt{H_0(H_0 + M_s)}$$

(FMR frequency)

Materials & Methods

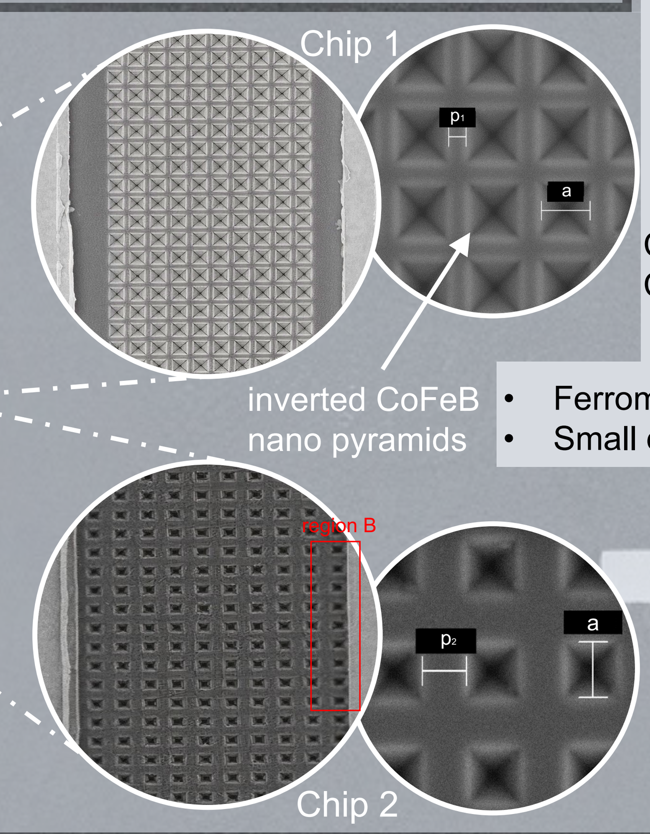
FMR Spectroscopy



We test our sample by **broadband ferromagnetic resonance** (FMR) spectroscopy using a **Vector Network Analyzer** (VNA) that sends microwave signals ranging from **10 MHz – 15 GHz** to our sample and measures the transmission of the signal.
This measurement is performed while applying an **external field H_{ext}** and doing a **field resolved sweep** from **-90 mT to 90 mT** or an **angle resolved sweep** from **0° to 360°** to observe the magnetic behavior of our sample.

We use a conventional coplanar waveguide embedded with inverted nanopyramids engineered by Ferdinand Posva. There are two different chips with different spacings between the pyramids.

Integrated Nano-Pyramids



Pyramids

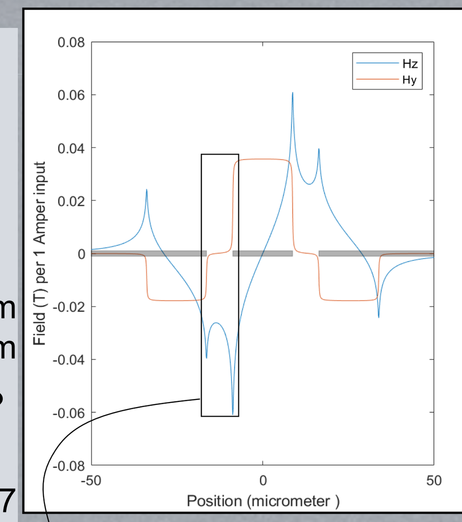
10 rows
x
1100 columns

a = 400nm

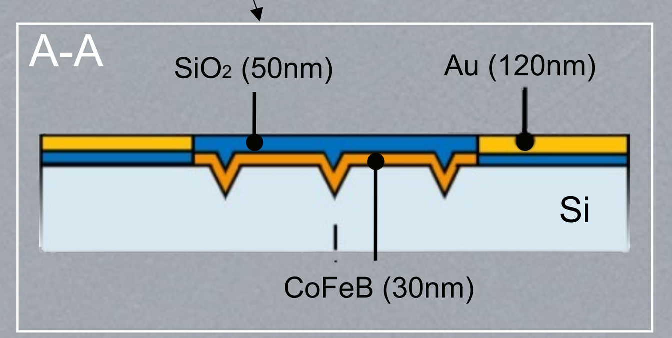
Chip 1: p_1 = 150nm
Chip 2: p_2 = 375nm

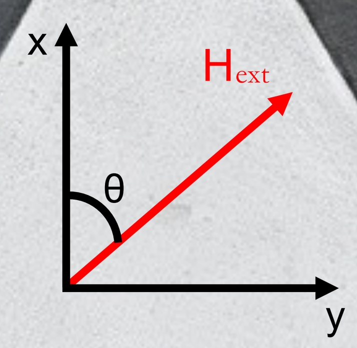
Why CoFeB ?

- Ferromagnetic
- Small damping α ≈ 0.007



CPW h_{rf} field distribution





coplanar waveguide
(CPW)

Analysis

Non-Kittel-like modes

➜ We observe one **main mode** and multiple **lower frequency modes**.

The modes do not have a null frequency at 0 mT meaning that they are not regular thin film modes but **originate from the geometry of our system**. We compared them to different models such as Kittel and Kalinikos Slavin but did not get any match.
One aspect which leads to non-Kittel-like modes is confinement. We think that the modes in region 2 at 90° come from SW confined in the thin film stripes in region B near the signal line where the h_z and h_y components are significantly bigger.

0° spectra ≠ 90° spectra

➜ **0°** and **90°** spectra are **different** despite the symmetry of our pyramids.

This is very interesting and could come from the **inhomogeneous H field** distribution over our CPW, particularly from the **h_y component** near the signal lines.

Chip 1 spectra ≠ Chip 2 spectra

➜ **Chip 1** and **Chip 2** spectra are **different.**

Chip 2 always displays at least one more lower frequency mode than Chip 1 at 0° and 45°. In the 90° configuration region 1 is identical for both Chips but region 2 is one strong mode for Chip 1 and three weak modes for Chip 2.

This shows that the **period p** between the pyramids dictates their magnetic behavior.

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Conclusion

- The inversed nanopyramids pattern gives rise to unexpected **spin wave modes confined** within the **nanopyramids geometry**.
- The magnetic response of CoFeB inversed square nanopyramids can be tuned by adjusting its parameters: side length, period, tilt angle.
- Due to a multitude of variables altering simultaneously, more tests are needed to take everything into account and determine the exact origins and implications of these phenomena.

This research shows a promising lead towards understanding and optimizing spin waves behavior in 3D structures for future **magnonic devices applications**.
The next steps would be to explore **propagating spin waves** excitations that travel across our structure and investigate the dynamic response of the system.